NATIONAL REPORT OF BRAZIL

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Brazil

General Information

Electricity Supply

At the end of 1998 the total capacity of generating plant installed in Brazil was 61554.98 MWe (56121.12 MWe hydro; 4774.53 MWe thermal; 657 MWe nuclear; and 2.33 MWe wind). Nuclear power is responsible for 1.07 % of the installed capacity.

The electricity production in 1998 amounted to 287.39 TWh (264.97 TWh hydro; 6.64 TWh coal; 9.35 TWh fuel oil; 3.28 TWh diesel oil; 3.14 TWh nuclear; and 0.01 TWh wind). Nuclear power was responsible for 1.09 % of the total electricity production.

At this moment a total of 11122.8 MWe in power capacity is being built (8431.4 MWe hydro; 1290.0 MWe thermal; 1309.0 MWe nuclear; and 92.4 MWe wind). The nuclear power unit (1309 MWe) is going to be ready at the beginning of next year increasing the nuclear share on the installed capacity to almost 3%.

The expected electricity demand growth for the next ten years will lead to an increase of thermal power share to the installed capacity. In this context, a nuclear power plant may meet part of this capacity demand.

Nuclear Programme Organization

The actual government began in 1995 to introduce privatization into the energy sector that has been dominated by state enterprises. Nevertheless the nuclear sector remains excluded from this privatization process. The direction of nuclear policy rests in the hands of the president of the republic. The Ministry of Mine and Energy and the Extraordinary Minister for Special Project Office are responsible for the implementation of the nuclear policy.

In August 1997 responsibility for the operation of Angra 1 nuclear power plant and the design and construction of Angra 2 and Angra 3 nuclear power plants was entrusted to a new wholly-owned subsidiary of Eletrobrás (Centrais Elétricas Brasileiras S.A – publicly owned holding company for generation and transmission of electricity) called Eletronuclear (Eletrobras Termonuclear S.A). This new company combined the nuclear sections of the utility Furnas (Furnas Centrais Elétricas S.A) an Eletrobrás subsidiary, and another subsidiary, the archtect engineer Nuclen (Nuclen Engenharia e Serviços S.A). Siemens (Germany) sold its partial holding in Nuclen to Eletrobrás when Eletronuclear was formed.

Research and development, the fuel cycle and regulation are still under the responsibility of CNEN (Comissão Nacional de Energia Nuclear – Brazilian Nuclear Commission). CNEN has two main directorates (DPD and DRS) and two wholly-owned subsidiaries (INB, Nuclep).

DPD (Diretoria de Pesquisa e Desenvolvimento – Research and Development Directorate) is responsible for the fuel cycle, reactor technology, production and utilization of radioisotopes, and nuclear physics and chemistry. Three research institutes report to DPD: IPEN (Instituto de Pesquisas Energéticas e Nucleares – Institute for Energy and Nuclear Research) in São Paulo; IEN (Instituto de Engenharia Nuclear – Institute for Nuclear Engineering) in Rio de Janeiro; and CDTN (Centro de Desenvolvimento de Tecnologia Nuclear – Center for Nuclear Technology Development) in Belo Horizonte.

DRS (Diretoria de Radioproteção Segurança e Licenciamento – Radiation Protection Safety and Licensing Directorate) is responsible for radiation protection, safety, control and licensing of nuclear power plants and other nuclear installations. One researc institute reports to DRS: IRD (Instituto de Radioproteção e Dosimetria – Institute for Radiation Protection and Dosimetry) in Rio de Janeiro.

The subsidiary INB (Industrias Nucleares Brasileiras S.A) is responsible for fuel cycle activities, including uranium mining. Its fuel fabrication factory (FEC) produces PWR fuel assemblies for Angra 1 and Angra 2. INB headquarters is in Rio de Janeiro and FEC is located in Resende, 200 Km south from Rio de Janeiro.

The subsidiary Nuclep (Nuclebrás Equipamentos Pesados S.A) has a facility for the fabrication of heavy equipment for the nuclear program. Nuclep is located at Itaguaí, southwest border of Rio de Janeiro.

Nuclear Power Plants

There is one nuclear power plant in operation (Angra 1), one nuclear power plant in construction (Angra 2), and one nuclear power plant in design (Angra 3). These units are located at the same site on the coast, in the county of Angra dos Reis, 150 Km southwest of Rio de Janeiro. Some data are:

Angra 1 – Westinghouse PWR, 657 MWe, 2 loops, 121 fuel assemblies, fuel assembly 16X16-21; 8 inconel spacer grids, 12 ft active length. It was a turn-key contract with Westinghouse and entered commercial operation in January 1985. Now is in its 8th cycle of operation;

Angra 2 – Siemens-KWU PWR, 1309 MWe, 4 loops, 193 fuel assemblies, fuel assembly 16x16-20, 2 inconel spacer grids and 7 zircaloy spacer grids, 390 cm active length. This was the first unit of Brazil-Germany Agreement (1975). The unit is being commissioned, and commercial operation is planned for the next year (2000);

Angra 3 – Same characteristics as Angra 2. Partial design and engineering work has been done and the main components have been imported. It is waiting the government decision to be built.

Fuel Fabrication

INB (Industrias Nucleares do Brasil S.A) is the company in charge in organizing all activities connected with uranium exploration, i.e. from uranium ore mining and milling up to final production of the fuel assemblies to the nuclear power plants.

Activities of INB in the mineral resources area include uranium, mineral sands and rare-earth production. INB estimates the country's uranium reserve at 309,000 tons. INB's production units are located in Catité, State of Bahia (uranium mine and mill), in São Francisco de Itabapoana, State of Rio de Janeiro (mineral sands exploration), and in Caldas, State of Minas Gerais (rare-earth production).

All conversion services are done abroad. Technology for a conversion plant has been demonstrated by IPEN conversion pilot plant, but industrial-scale plant would not be commercially viable due to the size of the Brazilian nuclear programme.

Enrichment services are currently performed abroad. Work on jet-nozzle process, done by INB, was stopped. IPEN together with CTMSP (Navy Technological Center in São Paulo) developed isotopic enrichment laboratories using ultracentrifuge process. CTMSP is now co-operating with INB in the transfer of this technology to a full-scale industrial plant that would meet the needs of Angra 1 and partial needs of Angra 2. To reduce costs the planned plant would make use of installations at the plant originally intended for jet-nozzle process (FEC in Resende).

INB produces the fuel assemblies at its fuel fabrication units – FEC (Fuel Element Factory) Unit I and Unit II – located in Resende, State of Rio de Janeiro. The components and parts of the fuel assemblies as well as the final assembly are carried out at Unit I. In Unit II is performed the UO_2 powder and pellet fabrication. FEC Unit II make also use of installations built for the jet-nozzle enrichment plant.

The facility for the production of UO_2 powder uses the AUC route. Design, supply and installation of the facility is been done by Siemens. The facility will start commissioning next month and commercial operation is planned for September. The overall annual capacity of this Unit is 140 ton of UO_2 powder.

The pellet production facility started commercial operation this year. Design, supply and installation was done also by Siemens. The annual capacity of this facility is 120 ton of UO_2 pellets. It is now producing part of the pellet loading of Angra 2 first core. The UO_2 powder has been imported meanwhile the powder production facility does not start up.

The FEC Unit I has been operating since 1985 and was refurbished recently. New fuel rod filling stations and welding machines were bought and are in operation now. New equipment to the fuel assemblies components workshop and quality control were also bought giving higher degree of automation, performance and quality to the fuel assembly fabrication process. This Unit I was designed by Siemens who supplied some of the production equipment, and the technology for the mechanical design and fabrication of PWR fuel assemblies for both designs: Angra 1 and Angra 2.

FEC Unit I produced reloads for Angra 1 core and now is producing the first core of Angra 2. Basic materials used in fuel assemblies as zircaloy tubes, bars and strips, inconel strips, and stainless steel plates and tubes have been imported. The fuel pellets are still being imported but will be gradually substituted by FEC Unit II production.

Due to the failures occurred with fuel assemblies during operation in cycles 4 and 6 of Angra 1, INB is implementing a contract of technological transfer with Westinghouse in order to produce original Angra 1 fuel assemblies. New reloads of Angra 1 will use this fuel assembly fabricated by FEC with Westinghouse design.

Fuel Performance

Fuel Failures

Angra 1 is the only nuclear power plant operating in Brazil, but has a large history of fuel failure. The plant is now on its 8^{th} cycle. Failures were identified in cycles 2,3,4,6, and 7. The details presented below are based on reports of Mr. J.L.C.Chapot from Eletronuclear.[1,2,3]

The first core (fuel assemblies batches A,B and C) was supplied by Westinghouse. Since the first reload, cycle 2, the fuel assemblies have been provided by INB with design and technology from Siemens-KWU (fuel assemblies batches D,E,F,G,H,J,L).

During the first three cycles fuel performance at Angra 1 was good. One failed fuel assembly (one fuel rod) in cycle 2 at batch C, and one failed fuel assembly (one fuel rod) in cycle 3, also in batch C were identified. The mechanism and the root cause of these failures were not determined.

In cycle 4, the reactor was loaded with 120 fuel assemblies fabricated by INB (batches D,E,F) and one assembly that remained from the initial core (batch C). During this 4^{th} cycle fuel failures led to increasing activities levels in the reactor cooling system and the reactor was prematurely shutdown on 5 March 1993. In-mast sipping test identified 18 leaking fuel assemblies, 15 from batch D, 2 from batch E and 1 from batch F. Ultrasonic testing performed during outage found 62 leaking fuel rods in 16 fuel assemblies identified as leaking by in-mast sipping test. The test also determined two failed assemblies in batch D and three in batch E that had not been identified by in-mast sipping test. Visual inspection showed seventy-six loose and / or fretted fuel rods in 13 fuel assemblies of batch D. It was identified grid-to-rod-fretting as the main mechanism of the leaking assemblies. One fuel assembly had the hold-down spring deformed. There were secondary damage in fuel rods of one assembly – a crack in the weld area of the upper end cap and a hydride blister. Many fuel rods had slipped down onto the lower end fitting in 10 batch D fuel assemblies. No damaged fuel assemblies were identified by visual inspection in batch E. One grid corner of the assembly of bath F, identified as leaking assembly, was damaged possibly due to improper handling when it was loaded in cycle 4. The average discharge burnup in this cycle were 26 MWd/kgU for batch D, 16 MWd/kgU for batch E, and 5 MWd/kgU for batch F.

Siemens issued a report evaluating the root-cause of the failures. According to Siemens they were caused by grid spring force losses occurred when the fuel rods were inserted in the skeleton, possibly in combination with the loads sustained during transport to the site. Siemens developed then a new spring design with a new shape and higher initial fuel rod fixing force. Neither flow experiments in hydraulic loops nor any change in the grid mixing vanes were done, this means, the exciting force in fuel rods coming from the water flow through the fuel assembly was not evaluated or changed by the designer.

The cycle 5 core loading was an unusual core. It was constituted by 40 fuel assemblies, batch G, manufactured by INB using the new design of the grid spring done by Siemens; 36 fuel assemblies from batch F of cycle 4; and 45 Westinghouse fuel assemblies from the first core (36 from batch A, 8 from batch B and 1 from batch C). Cycle 5 had the burnup limited to the average burnup of 18,5 MWd/kgU on batch F, because this would be the threshold burnup for fuel failure as noticed in cycle 4. No fuel failure was detected during operation in cycle 5.

In cycle 6 Angra 1 core was loaded with 121 INB fuel assemblies. 40 fuel assemblies from batch G used in cycle 5, 40 new fuel assemblies of 3.2% enrichment named batch H and 41 new fuel assemblies of 1.9% enrichment named batch J. Batch J was purchased to be used exclusively in cycle 6 due to the fuel failures in cycle 4. Batches H and J had the same mechanical design as batch G. It was noticed high activities levels in the reactor cooling system water during this cycle, but the values of ^{131}I dose-equivalent was below the technical specification limit and it was not necessary to shutdown the reactor before the schedule burnup. In-mast sipping, visual inspection and sipping-can were performed to identify leaking assemblies. 8 fuel assemblies of batch G and 1 from batch H were determined as failed. At least 5 "loose" fuel rods (rod movement) were observed in batch G (2 rods on east face and 3 corner rods). Ro-to-grid fretting wear were observed in two fuel assemblies of batch G. Hydride blister were observed in two fuel assemblies with no apparent primary failure location. All eight leaking fuel assemblies appeared to maintain good structural integrity with no degradation except the "loose" rods. The failed fuel assembly from batch H showed severe damage on one fuel rod at face north, below grid 2. Also debris mark, on the same rod, below grid 8 was verified and a metallic debris found at face north above grid 8. It was concluded that the batch H fuel failure was due to debris. A common observation on all fuel assemblies visually analyzed (batch G,H and J) was fretting wear on spacer grids side strips. This fretting was limited to west and east faces only, and no wear was noticed on south and north faces of any grid. Most severe fretting was observed on grids 4 and 5 (fuel assembly middle grids) and less in grids 3 and 6. This fretting pattern indicated that flow induced vibration would be the root cause of failure on both cycle 4 and 6.

Recently, INB asked Siemens to perform flow experiments in a hydraulic loop with the batch G fuel assembly design. It was verified that the fuel assembly vibrates perpendicular to the spacer grid mixing vane direction in a sharp resonance in the range of 25-27 Hz for beginning of life mechanical condition. This resonance was not observed for end of life mechanical condition. It was concluded that the spacer grid mixing vane pattern design was responsible for the excitation mechanism.

Cycle 7 core loading came from four sources: 40 new fuel assemblies, batch L, manufactured by INB using the same design as batches G,H and J; 36 fuel assemblies from batch H used in cycle 6; 41 assemblies from batch J used in cycle 6 and 4 fuel assemblies from batch F used in cycles 4 and 5. Again this cycle had an unusual core pattern and the schedule burnup was for a shorter period of time (217 EFPD). Activity of the reactor coolant system water indicated that might be failed fuels again. In-mast sipping and sipping-can tests were performed. Two fuel assemblies were identified as leaking, one from batch H and one from batch F. The mechanism of the failure was not identified but it could be expected, due to the range of burnup achieved in the fuel assemblies, the same kind of mechanism (rod-to-grid fretting) as observed in cycle 4 and 6.

A complete new core was bought from Westinghouse to operate in cycle 8. The fuel assemblies were similar to the ones of the first cycle (batches A,B, and C). It's important to mention that the spacer grid design (spring and mixing vane) of this fuel assembly is different from the INB/Siemens spacer grid design used in fuel assemblies for the reloads of Angra 1. Up to now no water activity related to fuel leaking has been noticed at the reactor coolant system in this 8th cycle.

Burnup Experience

The planned cycles of Angra 1 lead the fuel assemblies to average discharge (equilibrium cycle) of 33 MWd/kgU burnup. The maximum discharge burnup attained was 34 MWd/kgU for batch C. Due to the fuel failures shown before other equilibrium batches have average discharge burnup less than 30 MWd/kgU. Some of the batches, like E and F, had average discharge burnup less than 20 MWd/kgU. Eletronuclear and INB are studying the possibility of the reconstitution of these low burnup fuel assemblies for using then in future cycles. Eletronuclear has no plans for extended burnup fuel cycle, for Angra 1, in near future.

Angra 2 will begin commercial operation next year. It's fuel assembly is the Siemens design FOCUS. For the first cycle is planned 460 EFPD of operation and 370 EFPD for the equilibrium cycle. The average discharge burnup in equilibrium is planned to be 45 to 50 MWd/kgU. Eletronuclear has no plans, in near future, to increase this discharge burnup value.

Fuel Research Programme

The R&D programme at CNEN's research centers has been directed to the study of basic aspects of fuel performance and technology. INB, the fuel supplier, do not have a specific R&D programme on fuel technology. INB has a technical contract with Siemens for technological transfer in this area. Brazil has jointed in 1998 the Halden Project in order to be in touch and to have access to information on actual nuclear fuel R&D programmes.

References

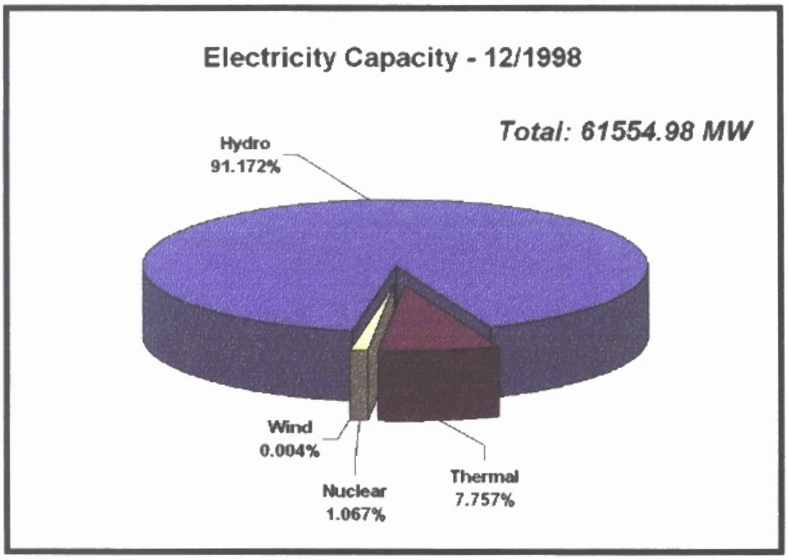
1 – Chapot, J.L.C; Freire, J.S. Tracing Fuel Failures at Angra 1. **Nuclear Engineering International**, p. 32-34, September 1994

2 - Chapot, J.L.C; Freire, J.S., Souza, U.C.S. Fuel Failure in the Sixth Cycle of Angra 1. **1998 Exchange Information Meeting on Recent Events in NPP and Annual Meeting of IRS National Coordinators, OECD/NEA**, Paris, 25-29 May 1998.

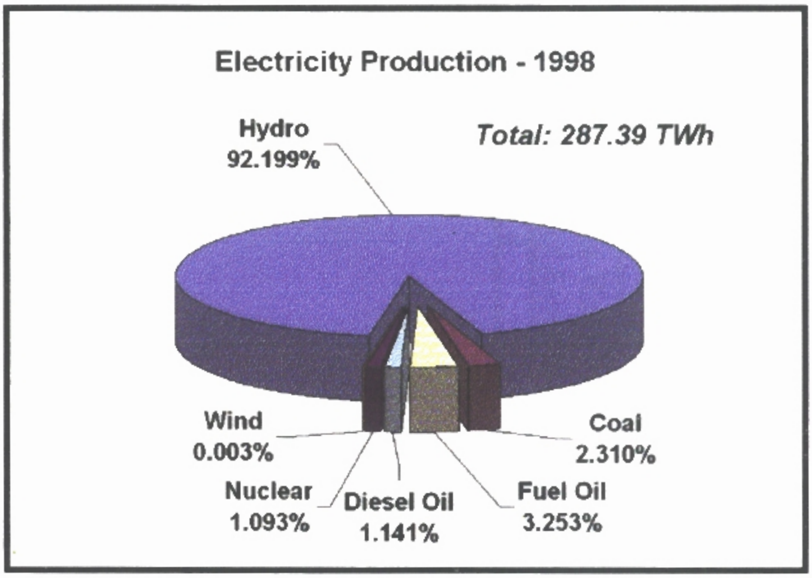
3 – Personal Information.

ELECTRICITY SUPLY

CAPACITY



PRODUCTION



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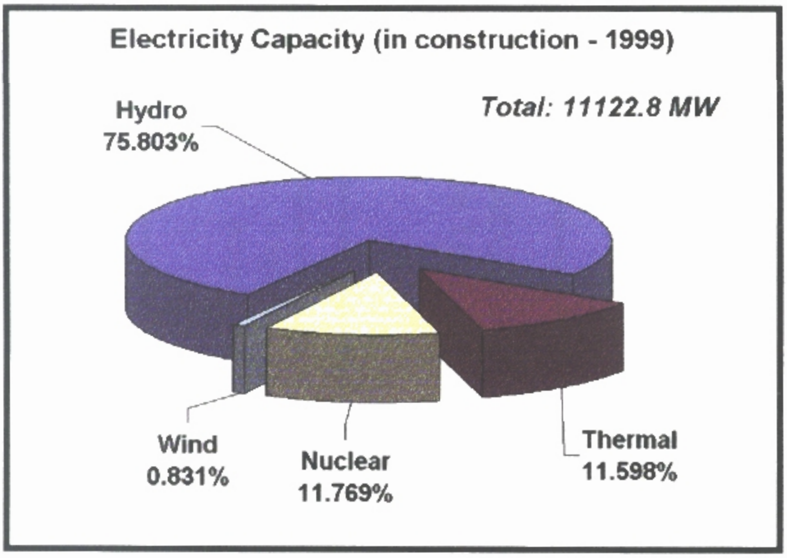
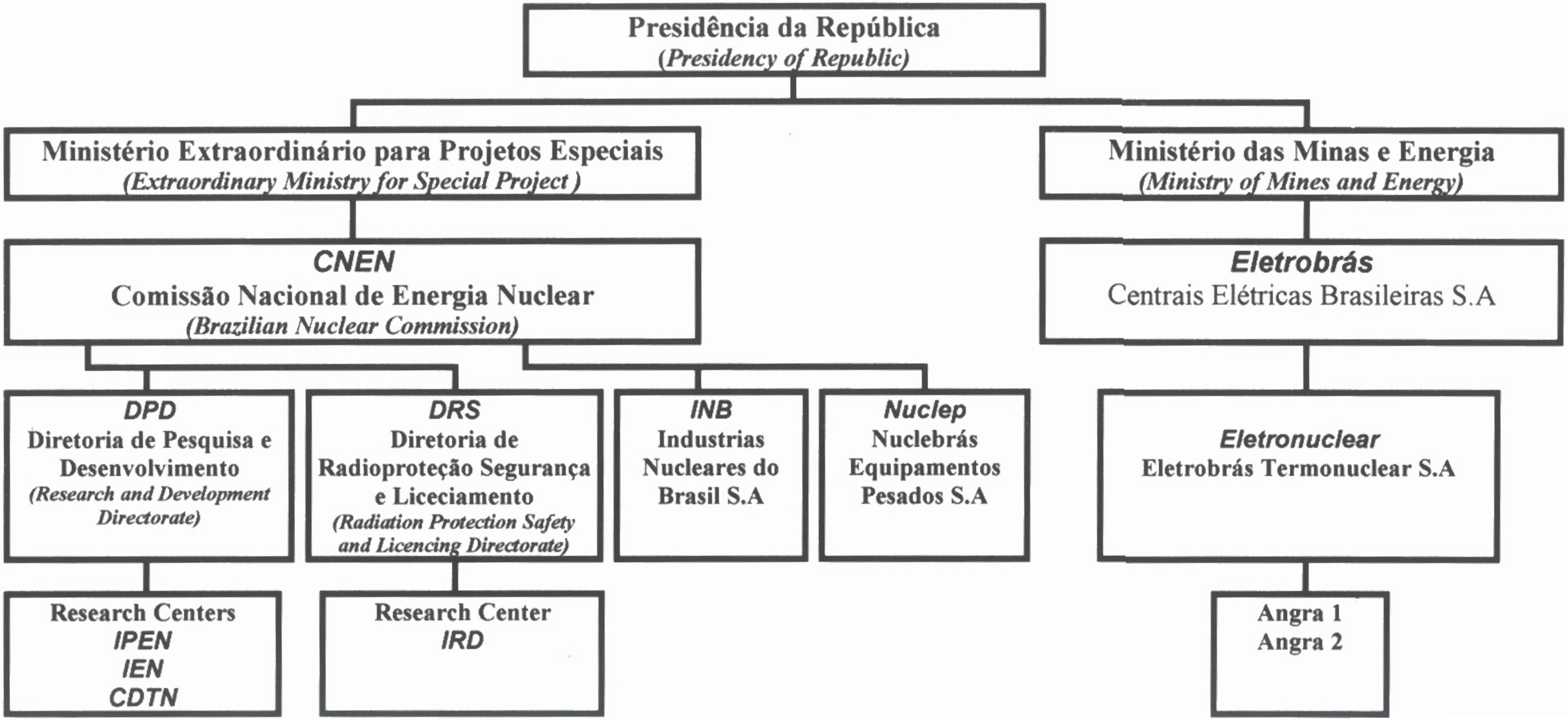
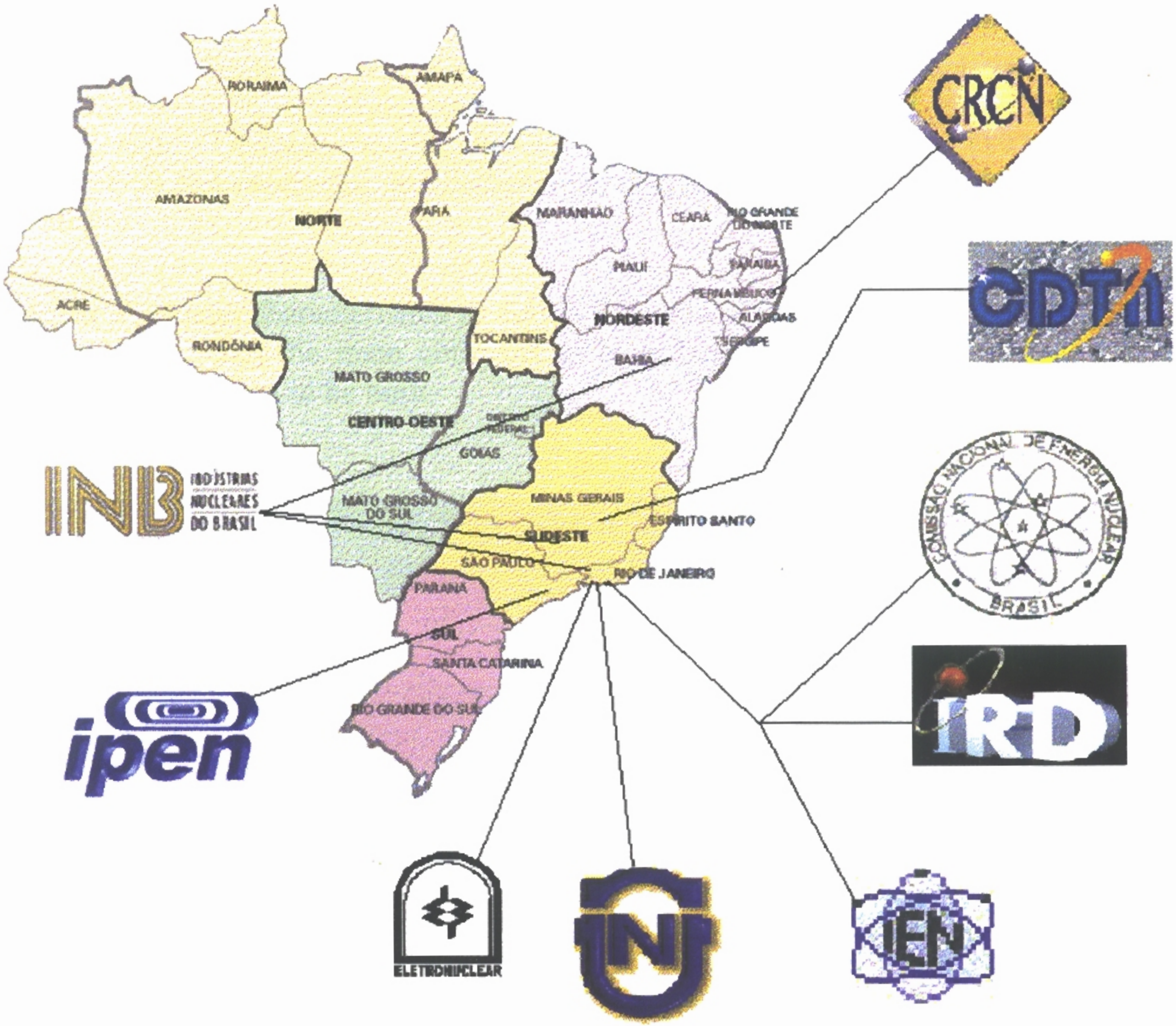


NUCLEAR PROGRAMME ORGANIZATION (simplified)



NUCLEAR PROGRAMME ORGANIZATION



Angra 1 - Westinghouse PWR, 657 MWe, 2 loops, 121 fuel assemblies (16X16-21; 8 inconel spacer grids, 12 ft active length). Turn-key contract. Commercial operation startup in January 1985. Now is in its 8th cycle of operation.

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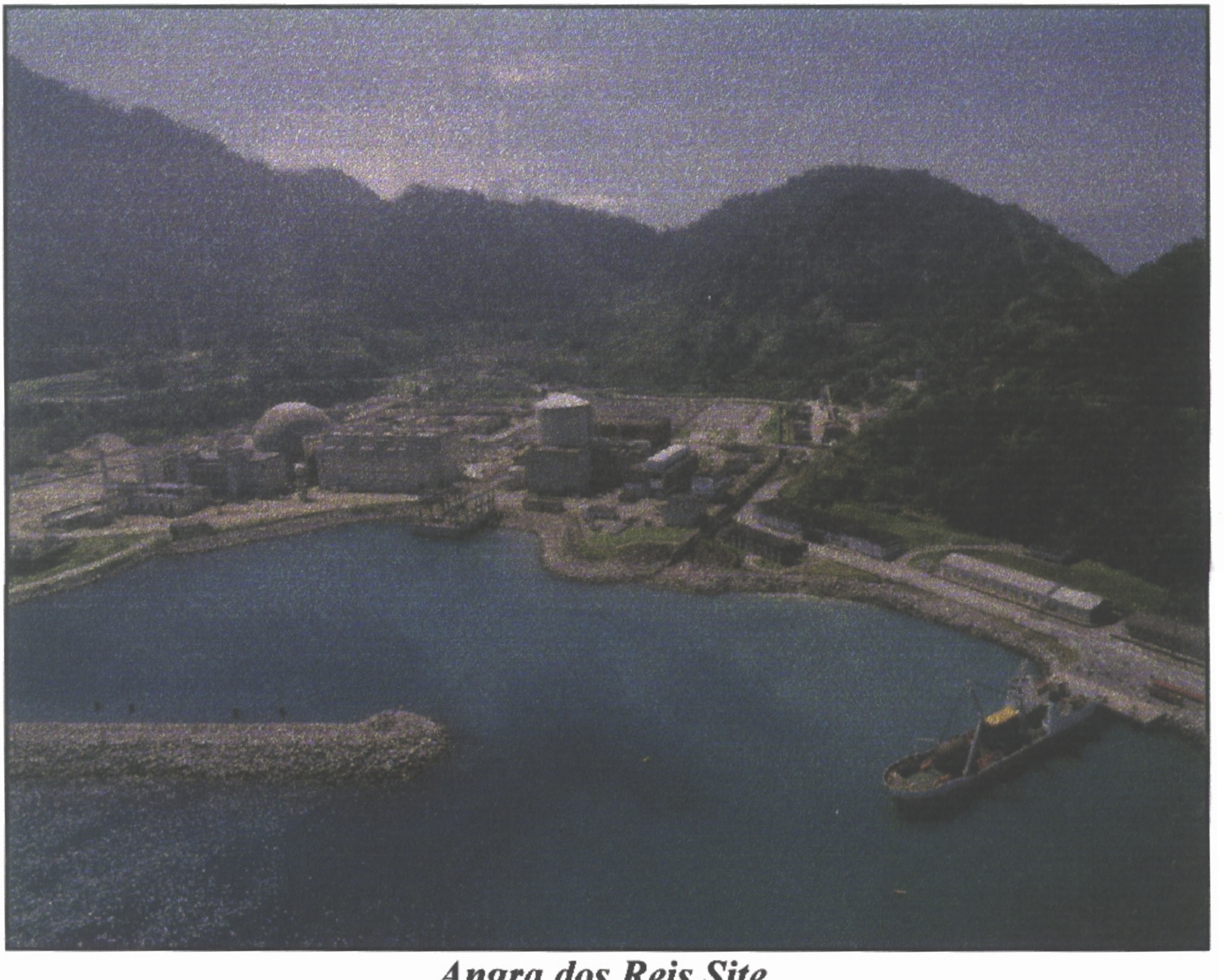


Angra dos Reis Site

INB ACTIVITIES

- ***Mine and Mill*** – Catité Unit, State of Bahia. (Brazil has estimated reserves of 309,000 tons of U).

- ***Conversion*** – Imported. No plant foreseen in near future.

- ***Enrichment*** – Imported now. Industrial plant foreseen in near future using Brazilian technology on ultracentrifuge process. (FEC, in Resende)

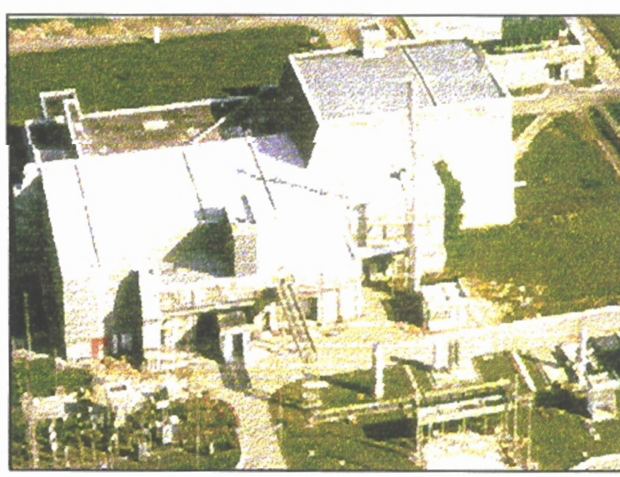
- ***UO_2 Powder*** – Imported now. Industrial plant in comissioning. Commercial operation by September. AUC route ,140 ton/year capacity. Siemens technology. (FEC Unit II, in Resende)

- ***UO_2 Pellet*** – Partially imported now. Industrial plant in operation since the beginning 1999. 120 ton/year capacity. Siemens technology. (FEC Unit II, in Resende)

- ***Fuel Assembly*** – Plant in operation since 1985. Refurbished in 1998/1999. Siemens technology. (FEC Unit I, in Resende)

  - Angra 1 reload F.A (past) – Siemens design
  - Angra 1 reload F.A (future) – Westinghouse design.
  - Angra 2 F.A – Siemens design.

FEC Unit I



FEC Unit II

ANGRA 1 FUEL FAILURES

Cycle	Period	Fuel Assemblies				F.A Leaking Indication	Inspection Tests	Coments
		Batch	Vendor/ Design	Enrich. (wt %)	Number of F.A			
1	01/85 to 01/86	A B C	W/W W/W W/W	2.1 2.6 3.1	41 36 44	No No No	-	No failures in cycle 1.
2	10/86 to 10/89	A B C D	INB/KWU	3.3	1 36 44 40	No No 1 No	Sipping can	One failed fuel (estimation of 1 fuel rod). Mechanism and root cause not determined.
3	01/90 to 08/91	C D E	INB/KWU	3.4	41 40 40	1 No No	Sipping can	One failed fuel (estimation of 1 fuel rod). Mechanism and root cause not determined.
4	05/92 to 03/93	C D E F	INB/KWU	3.4	1 40 40 40	No 17 4 1	In-mast sipping; Visual; Ultrasonic test.	Main mechanism rod-to-grid fretting; secondary damage; loose fuel rods; some fuel rods slipped down onto end fitting. Batch F was handling damaged.
5	12/94 to 03/96	A B C F G	INB/KWU	3.4	36 8 1 36 40	No No No No No		Batch G has a new design for the spacer grid spring: higher fixing fuel rod force. (No flow test was performed and no design change was done to the spacer grid mixing vanes).
6	06/96 to 09/97	G H J	 INB/KWU INB/KWU	 3.2 1.9	40 40 41	8 1 No	In-mast sipping; Visual; Sipping can	Debris failure in batch H. Loose fuel rods in batch G, rod-to grid fretting wear in batch G. Secondary damage observed. Grid-to-grid fretting (west and east faces, higher in F.A middle position) for all F.A.
7	12/97 to 10/98	F H J L	INB/KWU	3.3	4 36 41 40	1 1 No No	In-mast sipping; sipping can	Failure mechanism was not determined. May be the same as cycle 4 and 6.
8	12/98 to now	M N P	W/W W/W W/W	1.9 2.6 3.245	41 40 40	No No No		In operation.

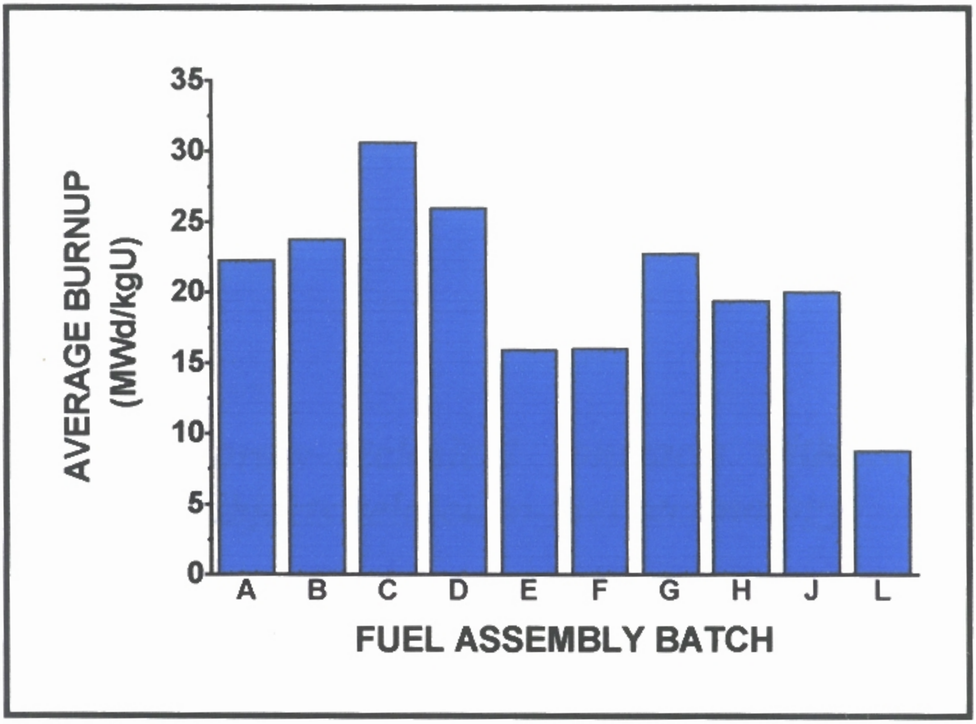
COMPARISONS BETWEEN CYCLE 4 AND CYCLE 6

	CYCLE 4 (BATCH D)	CYCLE 6 (BATCH G)
FRETTING MARKS ON THE FUEL RODS	MANY	6
SLIPPED FUEL RODS DOWN ONTO THE FUEL ASSEMBLY LOWER END FITTING	MANY	NONE
"LOOSE" RODS IN THE GRID CELLS	MANY (grids #1 to #8)	5 (mid-grids/corner rods)
GRID SIDE-STRIP FRETTING WEAR	RARE	MANY (mid-grids/east-west direction)
AVERAGE DISCHARGE BURNUP (MWD/kgU)	26	22.8
SECONDARY DAMAGE (HYDRIDE BLISTERS)	YES	YES

ACTIONS PERFORMED

- **AFTER CYCLE 4** – Spacer grid spring design changed.
- **AFTER CYCLE 6** – Return to original Westinghouse F.A. design.
- *Laboratory flow test* showed INB/Siemens spacer grid mixing vane design caused excessive flow induced vibration.

ANGRA 1 BURNUP EXPERIENCE



PERSPECTIVES

- *ANGRA 1*
  - NO PLANS FOR EXTENDED BURNUP.
  - STUDIES FOR RECONSTITUTION OF BATCHES E AND F.
- *ANGRA 2*
  - MAXIMUM BURNUP PLANNED 45-50 MWd/kgU.

FUEL RESEARCH PROGRAMME

- *CNEN Research Centers do basic studies on fuel performance and technology.*

- *INB performs technical contracts with Siemens for specific subjects related to fuel technology.*

- *Brazil is one of the participants of the HALDEN PROJECT.*