INTERNATIONAL WORKING GROUP ON
WATER REACTOR FUEL PERFORMANCE AND TECHNOLOGY

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COUNTRY REPORT - BRAZIL

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General Information

Electricity Supply

At the end of 2000 the total capacity of electricity installed in Brazil was 68533 MWe (60183 MWe hydro; 6367 MWe thermal; 1966 MWe nuclear (two units); and 17 MWe other). Nuclear power is responsible for 2.9 % of the installed capacity. The nuclear power unit (1309 MWe – Angra 2) started operation last year (criticality - July, 14th,2000).

The electricity production in 2000 amounted to 305 TWh. Nuclear was responsible for 1.98% (3.42 TWh - Angra 1, and 2.62 TWh - Angra 2) of the total electricity production.

The electricity needs for the next ten years will lead to an increase of thermal power share to the installed capacity. At this moment a total of 37400 MWe in electric power capacity is being planned up to the year 2009 (18700 MWe hydro and 18700 MWe thermal). Nuclear is not considered in these numbers and natural gas will be the main source for thermal plants.

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 Ministry of Science and Technology are responsible for the implementation of the nuclear policy.

Responsibility for the operation of Angra 1 and Angra 2 nuclear power plants is entrusted to the 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).

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 R&D in nuclear technology and utilization. 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 control and licensing of nuclear power plants and other nuclear installations. One research 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 for the nuclear power plants. 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 are two nuclear power plants in operation (Angra 1 and Angra 2), and one nuclear power plant in design (Angra 3). These units are located at the same site by 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 started commercial operation in January 1985. Now is starting its 10th 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 first unit of Brazil-Germany Agreement (1975). The unit started commercial operation in July 2000 and is in its 1st cycle now;

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 Caetité, 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 Sao 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 is planned up to 2008. To reduce costs the planned plant would make use of installations at the plant originally intended for jet-nozzle process (FEC in Resende). The first stage is planned to operate in June 2002.

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 activities for components and parts of the fuel assemblies fabrication, as well as the final assembling, are carried out at Unit I. In Unit II UO_2 powder and pellet are manufactured.

The facility for the production of UO_2 powder uses the AUC route. Design, supply and installation of the facility was done by Siemens and started operation in 1999. The overall annual capacity of this Unit is 140 ton of UO_2 powder. Powder for the fuel assemblies of the 10th Angra 1 cycle was already done by this new plant.

The pellet production facility started commercial operation in 1999. Design, equipment supply and installation was done also by Siemens. The annual capacity of this facility is 120 ton of UO_2 pellets. The plant produced part of the pellet loading for Angra 2 first core and the pellet loading for the fuel assemblies of the 10th Angra 1 cycle.

The FEC Unit I has been operating since 1985 and was refurbished in 1999. This Unit I was designed by Siemens who supplied some of the production equipment and the technology for PWR fuel assemblies manufacture.

FEC Unit I produced the reload cores for Angra 1 and 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.

Due to the failures occurred with fuel assemblies during operation in cycles 4, 6 and 7 of Angra 1, INB has implemented a contract of technological transfer with Westinghouse in order to produce original Angra 1 fuel assemblies. New reloads of Angra 1 (started with the 10^{th} cycle) use this fuel assembly fabricated by FEC with Westinghouse design.

Fuel Performance

Angra 1 Fuel Failures

Angra 1 has just finished its 9^{th} cycle but has a large history of fuel failure. Failures were identified in cycles 2,3,4,6, and 7. Details of these failures were reported at the 15^{th} IWGFPT Plenary Meeting.[1]

The main cause of fuel failure in cycles 4,6 and 7 was related to rod to grid fretting due to fuel rod and fuel assembly vibration. Cycle 4 (batch D) fuel failure showed a pattern related to fuel rod vibration. Rod fretting wear were located at spacer grids where the highest dislocation amplitude of the first mode of rod vibration would appear. Cycle 6 (batch G) showed a pattern related to fuel assembly vibration. Grid wear (east-west side), due to fretting between adjacent fuel assemblies, were located at fuel assembly position where the highest dislocation amplitude of higher ($7^{th}/8^{th}$) modes of fuel assembly vibration would appear. Visual inspection of batch L (cycle 7, but 1^{st} time in core) showed the same pattern as batch G.

After cycle 4 failure, the fuel designer issued a report evaluating the root-cause of the failures. According to it the failures 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. The designer developed then a new grid spring design with a new shape and higher initial fuel rod fixing force (batch G fuel assembly). 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.

After cycle 6 failure, INB asked the designer 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.

INB received from the designer an alternative fuel assembly design that uses split mixing vanes at the spacers grids. Four fuel assemblies (batch Q) were manufactured by INB with this new design and used (in an experimental basis) in cycle 9. Inspections will be carried out on these fuel after each reactor cycle in order to verify their performance.

Laboratory flow tests with batch G fuel assembly design showed that the use of dampers would lower the amplitude of vibration observed at the resonance. The use of dampers (dummy burnable poison inside guide thimbles) will be adopted to the batch L, low burnup fuel assembly. Assuming the previous experience of cycle 4,6,and 7, rod to grid fretting may occur after 20 MWD/kgU. Twelve fuel assemblies of batch L will be used (with dampers) in cycle 10 with a maximum planned discharge burnup of 25 MWD/kgU.

Cycle 8 and 9 , using original fuel assembly design from Westinghouse, had performed well and no failure was detected in both cycles.

It has to be pointed out, in the case of Angra 1, the importance of the NDT performed on fuel assemblies (in mast sipping, sipping can, visual examination) in order to address the cause of failure. As vibration was known the main cause of failure the expected behavior observed in laboratory tests could be confirmed by the visual details observed in failed fuels.

Burnup Experience

The planned cycles of Angra 1 lead the fuel assemblies to average discharge burnup (equilibrium cycle) of 33 MWD/kgU. 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. As mentioned before, Eletronuclear decided to use batch L, with dampers, up to 25 MWD/kgU. Reconstitution of the low burned fuel assemblies are not forseen in near future. Actual fuel assemblies are expected to discharge at the equilibrium cycle burnup.

Eletronuclear and INB are planning to upgrade the fuel assembly for Angra 1. Advanced fuel assemblies for 18 months cycle will be analyzed for future use.

Angra 2 will began commercial operation last 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.

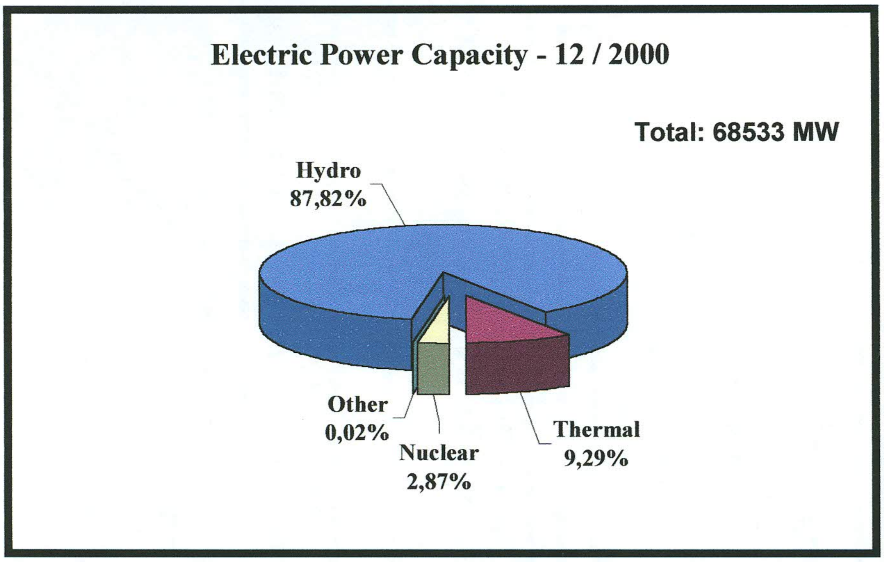
Fuel Research Programme

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 technical contracts with fuel designers and vendors for technological transfer in this area. Participation at the Halden Project initiated in 1998 and is foreseen to continue in 2001.

References

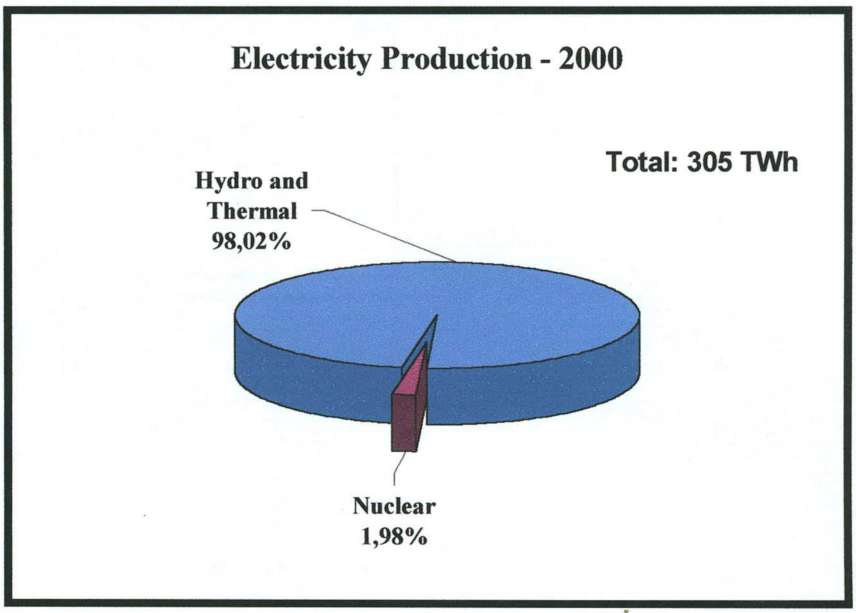
1 –Perrotta, J.A – National Report of Brazil – IWGFPT 15th Plenary Meeting, Vienna, 27-29 April 1999 (IWGFPT/49).

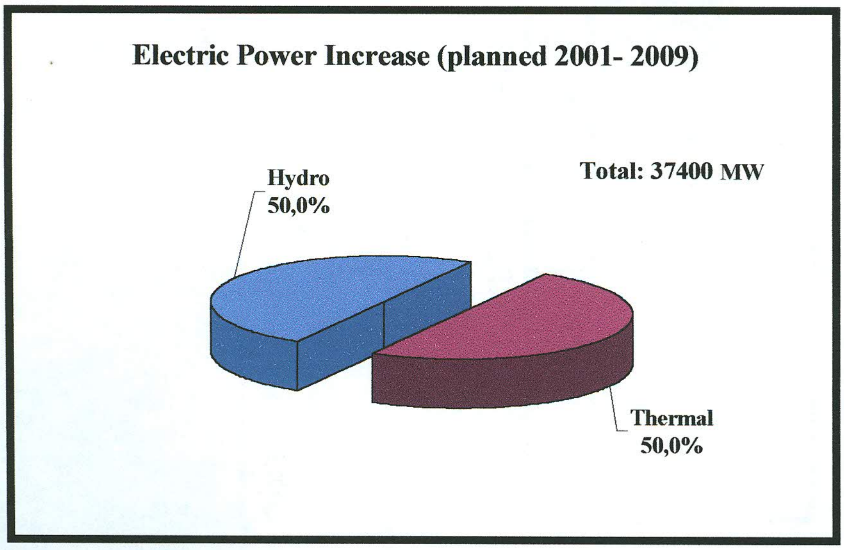
ELECTRICITY SUPLY



CAPACITY

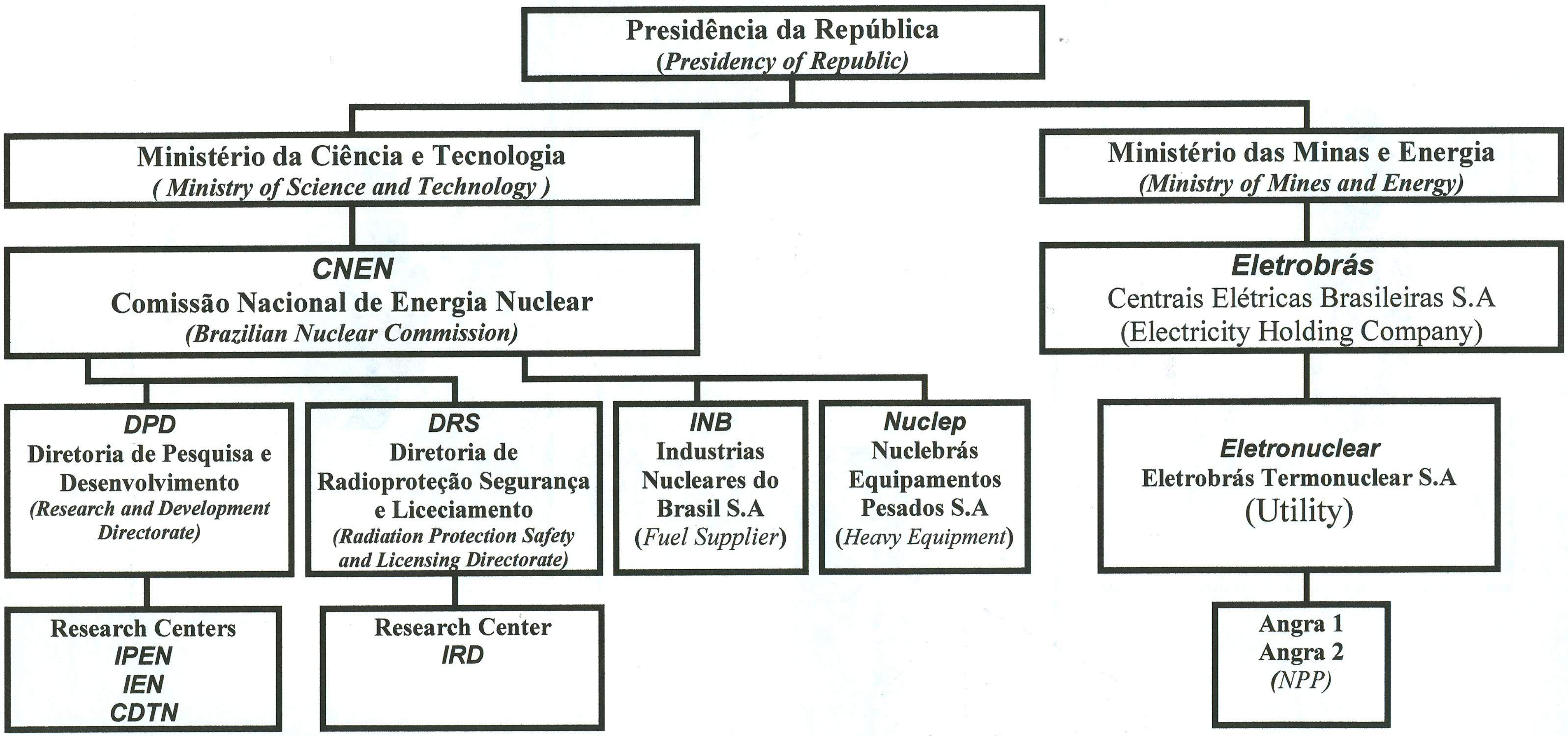
PRODUCTION



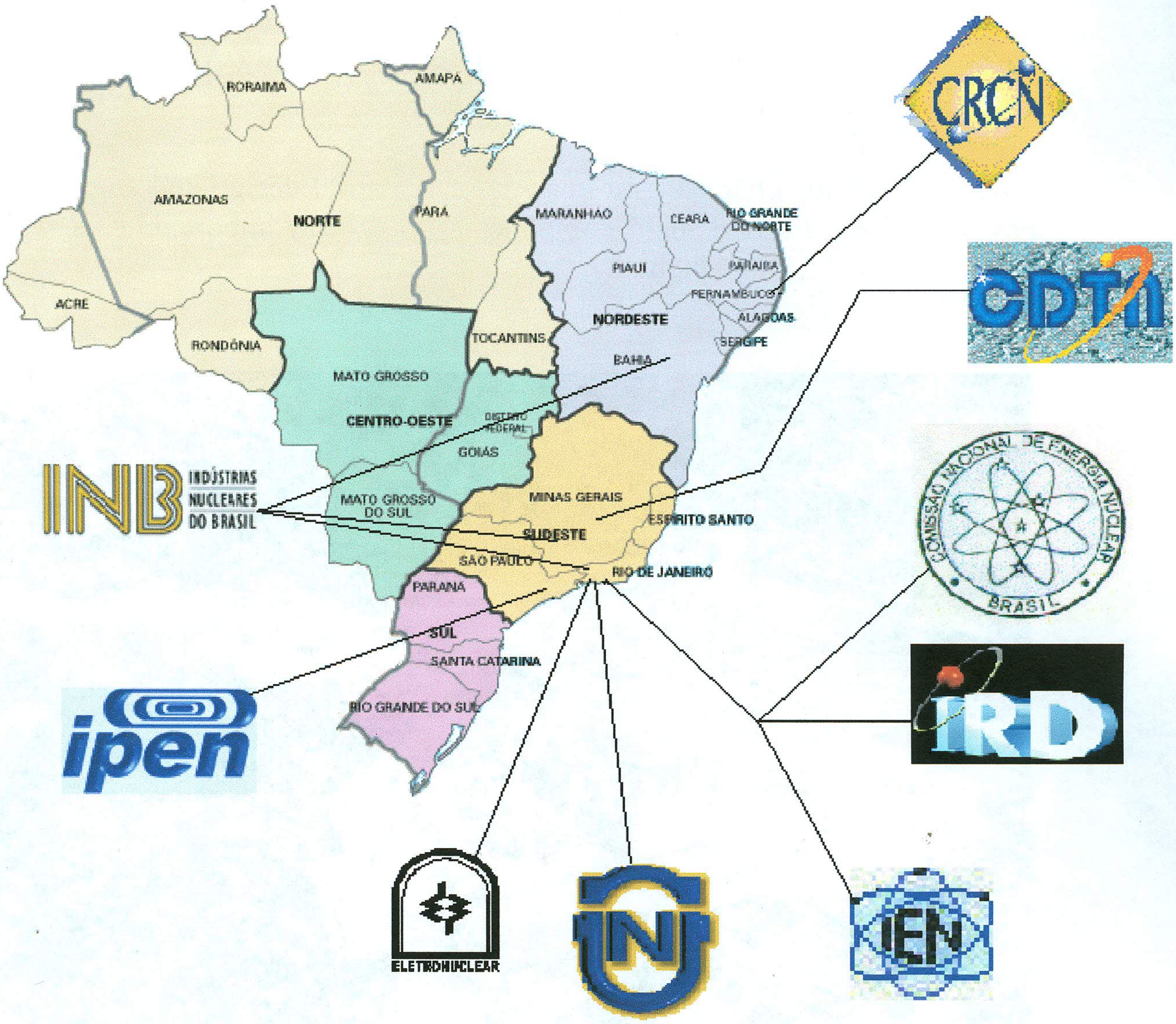


PLANNED

NUCLEAR PROGRAMME ORGANIZATION (simplified)



NUCLEAR PROGRAMME ORGANIZATION



NUCLEAR POWER PLANTS

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 starting its 10^{th} cycle of operation.

Angra 2 **-** Siemens-KWU PWR, 1309 MWe, 4 loops, 193 fuel assemblies (FOCUS 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 had its first criticality on July 14^{th} , 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.

Angra dos Reis Site

INB ACTIVITIES

- ***Mine and Mill*** – Caetité Unit, State of Bahia, 400 ton/year. (Brazil has estimated reserves of 309,000 tons of U).

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

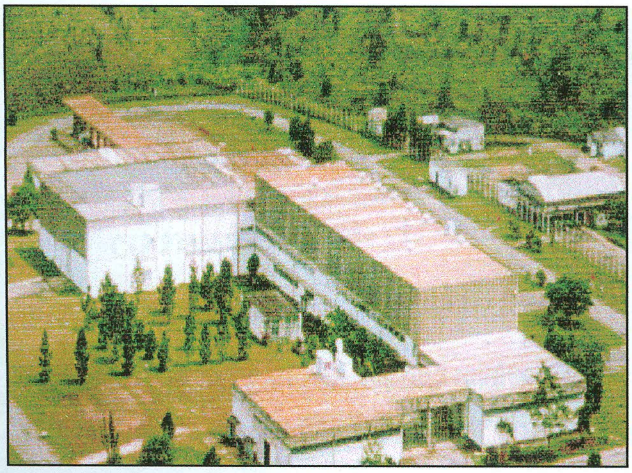
- ***Enrichment*** – Imported now. Industrial plant for the needs of Angra 1 and partial needs of Angra 2 is foreseen in near future (2008) using Brazilian technology on ultracentrifuge process. The first stage is planned to June 2002. (FEC, in Resende)

- ***UO_2 Powder*** – Industrial plant in operation since September 1999. AUC route ,140 ton/year capacity. Siemens technology. (FEC Unit II, in Resende)

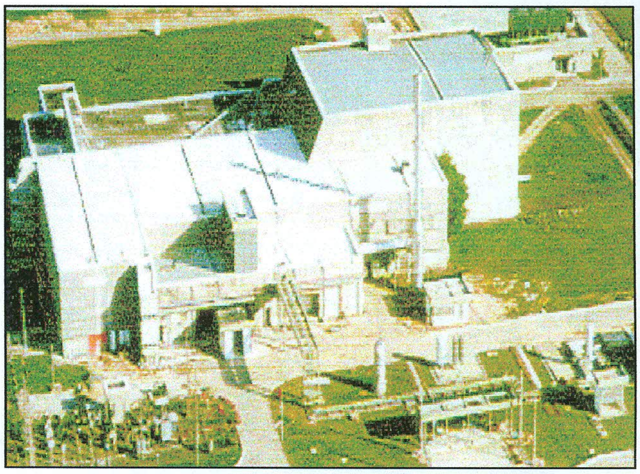
- ***UO_2 Pellet*** – Industrial plant in operation since the beginning of 1999. 120 ton/year capacity. Siemens technology. (FEC Unit II, in Resende)

- ***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 (present) – 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	Comments
		Batch	Vendor/ Design	Enrich. (wt %)	Number of F.A			
1	01/85 to 01/86	A	W/W	2.1	41	No	-	No indication of fuel failure.
		B	W/W	2.6	36	No		
		C	W/W	3.1	44	No		
2	10/86 to 10/89	A			1	No	Sipping can	One failed fuel (estimation of 1 fuel rod). Mechanism and root cause not determined.
		B			36	No		
		C			44	1		
		D	INB/KWU	3.3	40	No		
3	01/90 to 08/91	C			41	1	Sipping can	One failed fuel (estimation of 1 fuel rod). Mechanism and root cause not determined.
		D			40	No		
		E	INB/KWU	3.4	40	No		
4	05/92 to 03/93	C			1	No	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.
		D			40	17		
		E			40	4		
		F	INB/KWU	3.4	40	1		
5	12/94 to 03/96	A			36	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).
		B			8	No		
		C			1	No		
		F			36	No		
		G	INB/KWU	3.4	40	No		
6	06/96 to 09/97	G			40	8	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.
		H	INB/KWU	3.2	40	1		
		J	INB/KWU	1.9	41	No		
7	12/97 to 10/98	F			4	1	In-mast sipping; sipping can	Failure mechanism was not determined. May be the same as cycle 4 and 6.
		H			36	1		
		J			41	No		
		L	INB/KWU	3.3	40	No		
8	12/98 to 03/00	M	W/W	2.1	41	No	In-mast sipping	No indication of fuel failure.
		N	W/W	2.6	40	No		
		P	W/W	3.3	40	No		
9	03/00 to 04/01	M	W/W	2.1	21	No		No indication of fuel failure.
		N	W/W	2.6	40	No		
		P	W/W	3.3	40	No		
		Q(*1)	INB/S(*1)	3.4	4	No		
		R	W/W	3.4	16	No		
10	12/98 to now	M	W/W	2.1	1			Starting operation.
		N	W/W	2.6	8			
		P	W/W	3.3	40			
		Q(*1)	INB/S	3.4	4			
		R	W/W	3.4	16			
		L(*2)	INB/KWU	3.3	12			
		S(*3)	INB/W	3.4	40			

(*1) – New Siemens F.A design with split mixing vanes in the spacer-grids, manufactured by INB.
(*2) – F.A with dampers inside the guide-thimbles.
(*3) – Westinghouse design, manufactured by INB.

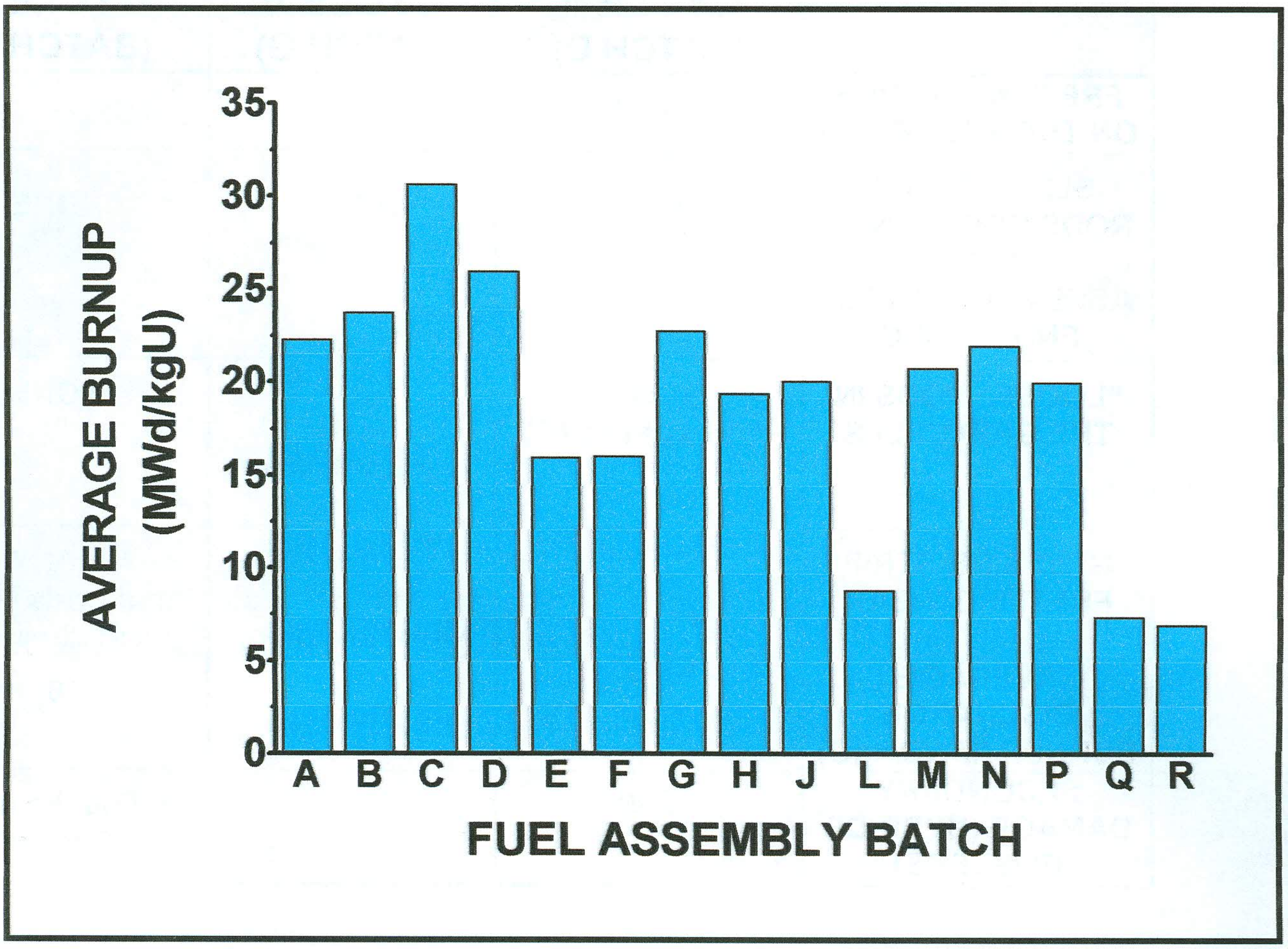
COMPARISONS BETWEEN CYCLE 4, CYCLE 6 and CYCLE 7

	CYCLE 4 (BATCH D)	CYCLE 6 (BATCH G)	CYCLE 7 (BATCH L)
FRETTING MARKS ON THE FUEL RODS	MANY	6	1
SLIPPED FUEL RODS DOWN ONTO THE FUEL ASSEMBLY LOWER END FITTING	MANY	NONE	NONE
"LOOSE" RODS IN THE GRID CELLS	MANY (grids #1 to #8)	5 (mid-grids/corner rods)	NONE
GRID SIDE-STRIP FRETTING WEAR	RARE	MANY (mid-grids / east-west direction)	MANY (mid-grids / east-west direction)
AVERAGE DISCHARGE BURNUP (MWD/kgU)	26	22	8
SECONDARY DAMAGE (HYDRIDE BLISTERS)	YES	YES	No Fuel Failure of Batch L

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.
- New Siemens F.A. design with split mixing vanes in the spacer-grids. Four F.A. manufactured by INB are under irradiation in Angra 1 (started at cycle 9).
- Utilization of F.A. batch L with dampers inside the guide-thimbles, up to 25 MWD/kgU (starting at cycle 10)

ANGRA 1 BURNUP EXPERIENCE



PERSPECTIVES

- *ANGRA 1*
  - STUDIES FOR ADVANCED F.A UTILIZATION AND EXTENDED BURNUP.
  - UTILIZATION OF BATCH L WITH DAMPERS (UP TO 25 MWD/kgU)

- *ANGRA 2*
  - MAXIMUM BURNUP PLANNED 45-50 MWD/kgU.

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

- *INB performs technical contracts with Fuel Vendors/Designers for specific subjects related to fuel technology.*

- *Eletronuclear and INB intend to change Angra 1 F.A (improved design, materials, higher burnup discharge).*

- *Participation of the HALDEN PROJECT.*