BRAZILIAN NUCLEAR RENAISSANCE IN A SUSTAINABLE DEVELOPMENT SCENARIO

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ABSTRACT

Brazil generated 326 TWh of hydroelectric power in 2005, accounting for ~81% of the electricity production for that year. The 2005 to 2030 projections for the Brazilian development indicate growths from 2,020 kWh to 4,380 kWh in the per capita electricity consumption and from US$4,300 to US$8,950 in the per capita GDP (in market exchange rate and 2005 US$). The consumption of electricity is to grow from 375 TWh in 2005 to 1,030 TWh in 2030. In simple view and without considerations of aspects related with energy efficiency, this growth means 1.8 times the generation capacity of the 20th century should be built along of 25 years of the 21st century. The Brazilian electricity generation will demand all primary sources to meet the foreseen growth of the electricity consumption. As economical, safe and clean primary energy source for electricity generation, the nuclear energy is one option capable of large-scale and short-term deployment in the Brazilian growth of the electricity consumption. The contribution of nuclear generation in the electricity consumption should evolve from the current 2.6% for amounts over 5% in 2030. The perspective of the Brazilian nuclear sector is evolving to be resumed and present an opportunity for pooling and rationalizing the available skills – technical, cultural and human. The role of business opportunities and the future demands in the value chain of nuclear activities are summarized in this document. Institutions of R&D and Brazilian universities play an important role for the formation of new demanded knowledge and human resources

Key Words: Brazil, electricity consumption, nuclear energy, nuclear fuel cycle, uranium resources

1. INTRODUCTION

After 20 years of nuclear moratorium, the renaissance of nuclear energy as a primary source for generating electric energy brings important developments for all organizations involved in the Brazilian nuclear sector with different business opportunities throughout the nuclear fuel cycle and nuclear power generation [1]. In Brazil the uranium is found in association with other elements of great commercial value as, for instance, the phosphate (agribusiness) and columbite-tantalite (computer/communication). The efficiency of the processing and extraction of the elements is associated with the adaptation of technological processes to the genesis of the Brazilian ore.

The 2005 to 2030 projections for development of Brazil indicate growths from 2,020 kWh to 4,380 kWh in the per capita electricity consumption and from US$4,300 to US$8,950 in the per capita GDP. The consumption of electricity is to grow from 375 TWh in 2005 to 1,030 TWh in 2030 [2]. In simple view and without considerations of aspects related with energy efficiency, the generation capacity of the 20th century should be triplicate along the first quarter of the 21st century. The Brazilian electricity generation will demand all primary sources to meet the foreseen growth of the electricity consumption.

2. BRAZILLIAN FACTS AND PROJECTIONS

The electricity shortage in 2001 indicated vulnerability in the Brazilian electricity generation system. The total electricity installed capacity was 76.2 GW in 2001 and reached 100.4 GW in 2007. Besides the shortage risks, the demand for electricity to support the economic growth renewed the interest in energy-generation projects in Brazil. Policy options under consideration include expansion of natural gas exploitation, biomass, hydropower generation in the Amazonas and nuclear power plants [2]. The gross electricity generation by primary sources in 2008 is given in Fig. 1. Brazilians generation system is 87% based on renewable sources and 82% based on hydropower as primary source. This basically renewable generation matrix has risks associated with the current certainties of the climate changes. Consequently, in order to confer reliability to the Brazilian electric system is vital the migration towards a portfolio of different primary energy sources, which increases the reservation capacity and mitigates the external dependence. The nuclear source is certainly one of the options

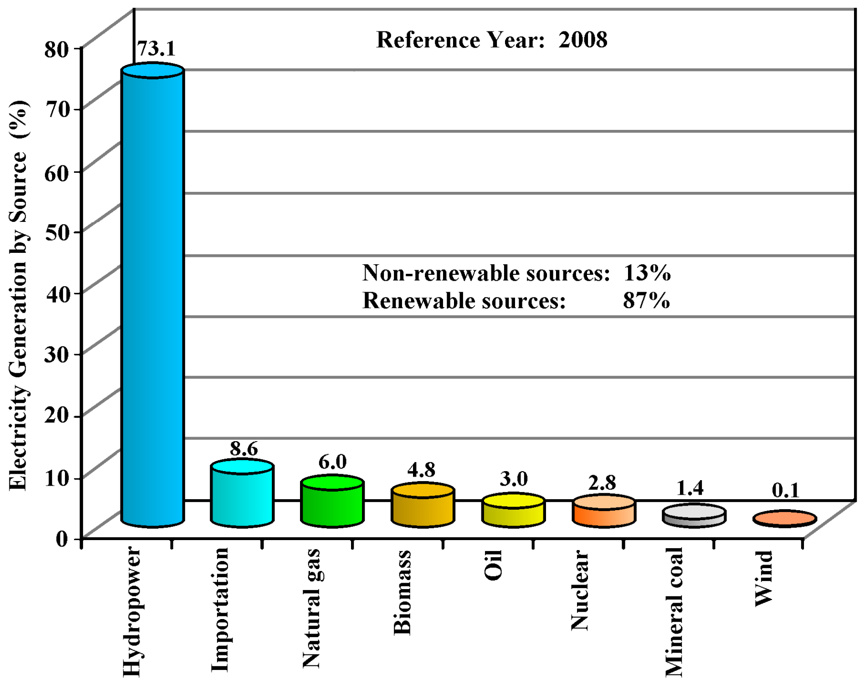


Figure 1. Brazilian electricity gross generation by source in 2008 [3].

The electricity generation depends on the natural cycles for its renewal. Presently, those cycles are successions of non-regular dry and rainy periods. Brazil generated 375 TWh of net electricity energy in 2005 and 430 TWh in 2008, a growth rate over 4%/year in the period [3]. The renewable sources accounted for ~87% of the net electricity generation. The losses of the Brazilian electricity system reach around 15% of the gross electricity generation and are partially resulting from the long transmission grid: 90,316 km in 2008. The Brazilian integrated transmission and distribution by the National Interconnected System (SIN) is singular in the world and allows the north-south-west-east connections in supplement or complement of regional blackout, shortage or special demand of electrical energy.

Brazil's heavy reliance on hydroelectricity has caused problems in the past, mainly during years of below-average rainfall. In the Southeast region there is a difference of 700 to 800 meters from sea level to the plateaus. Great water reservoirs have been built using the valleys existent due this uneven. In the Amazonas on the contrary the topography is flat. Even increasing the flooded area there is no significant increasing in the water capacity reservation that in conjunction with the natural dry and rainy cycles can amplify the risk of eventual water shortages [1]. Hydroelectric distribution and potential in Brazil are presented in Fig.2. It should be noted that only about 30% of the national hydroelectric potential is exploited, much smaller proportion than that observed in industrialized countries. About of 105 GW (42%) in the total 251 GW are to be better evaluated and exploited in the Amazonas region. The major available hydropower potentials are toward the northwest of the country including the Amazonas region. The frontier for expansion of hydropower generation toward the Amazonas increase the vulnerability of the Brazilian electric system, in view of the topographic conditions of Amazonas being quite different from the Southeast region, where are located the big dams for hydroelectric generation and, of course, with major capacity of water reservation. Many of new Brazilian hydropower generating facilities is to be located far away from the main demand centers, resulting in higher transmission losses.

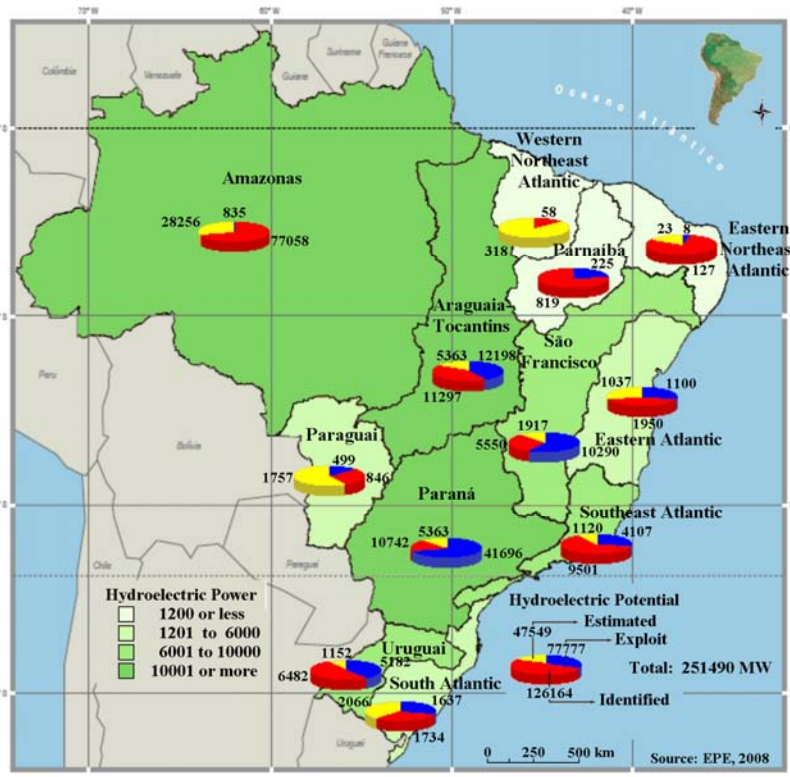


Figure 2. Distribution of the hydroelectric use and potential [4].

The Fig. 3 emphasizes the stagnation of the water storage capacity after 1980 as result of growth in the electricity consumption and despite the significant growth of hydroelectric installed capacity. The start operation of Itaipu in the beginning of 80's supported the electricity demands in this decade and delayed the start operation of Angra 1 (1981) and Angra 2 (2000). However, Angra 1 and 2 Nuclear Power Plants played a key role to support the electricity demand and mitigate the impact of the electricity shortage in 2001. Both NPP´s operated continuously at full power along the shortage period

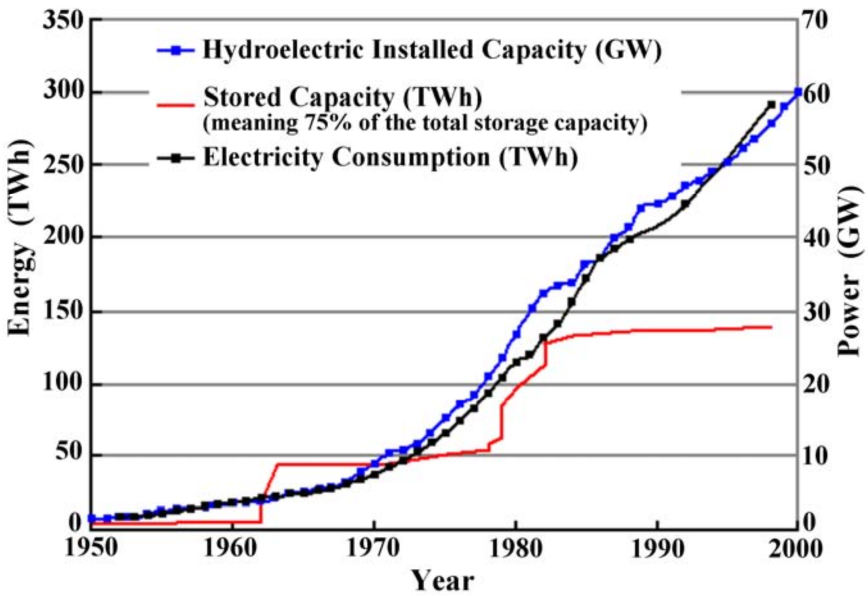


Figure 3. Growths of the hydroelectric generation and consumption [5]**.**

The Brazilian demographic distribution with 80% of the population living in urban areas is other key factor to be accounted in the energy planning. The demographic distribution is concentrated in a band of 1,000 km from the coast, as it is depicted in Fig. 4. Brazil held in 2003 the 10th position in the rank of electricity generation but only the 90th position in terms of per capita consumption. Distributed sources of electric generation such as wind, solar and biomass cannot cope alone with the concentrated demand of the urban areas. Even with the increase of these sources the great concentrated blocks of hydroelectric and thermoelectric power will be still necessary. The portfolio of concentrated and distributed blocks of electricity generation shall be setting up to respond to the great challenges in the growth of electricity demand. The sustainable exploitation and preservation of the Amazonas are also concerns of the Brazilian people. The permanent preservation areas and legal reserves in the Amazonas are depicted in Fig. 5. The Permanent Preservation Areas and Legal Reserves in Amazonas require the exploitation of the hydroelectric potential mainly without construction of water dam.

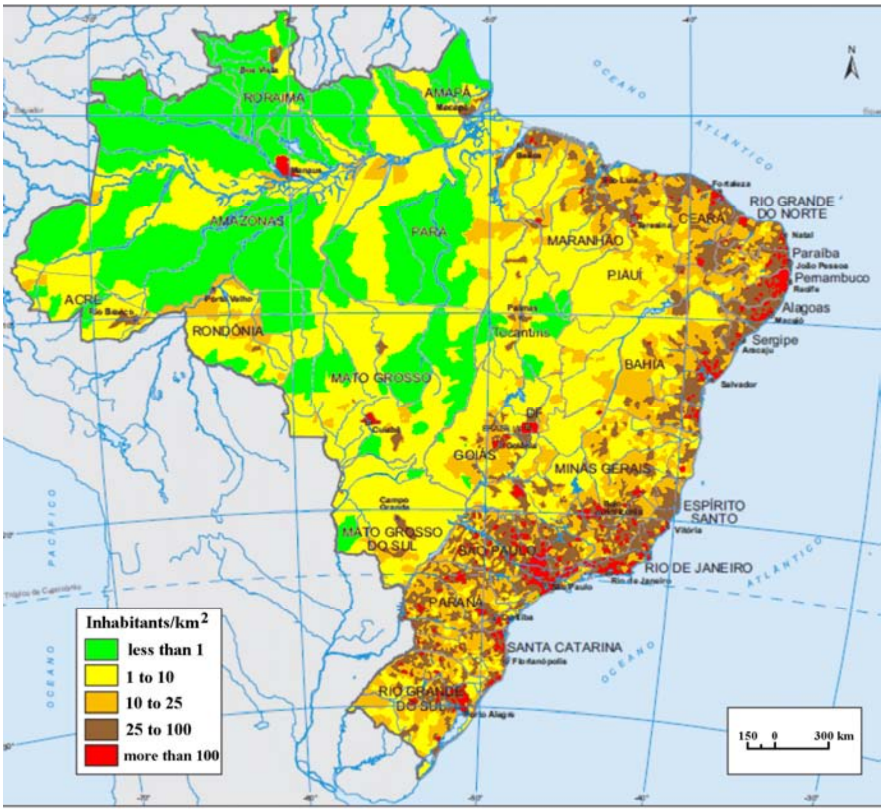


Figure 4. Population Density [6].

The challenges associated with the growth of 180% in the electricity consumption are analyzed in the National Energy Plan 2030, issued by the Energy Research Company of the Brazilian Ministry of Mines and Energy [2]. In order to meet this consumption growth it is projected an increase of 128% of the installed hydropower capacity, 135% of increase in installed thermoelectric capacity, including the nuclear source, and approximately 1300% of increase in installed capacity from alternative sources. In this scenario the country cannot discard any source of energy, including nuclear, that will growth 235% of installed capacity, from 2,000 MW in 2005 to 7,300 MW in 2030. The current prices associated with the electricity generation in Brazil are depicted in Fig. 6. Without the risks of the climate changes, the electricity generation from nuclear energy source is already competitive in relation to the remaining thermal sources and can be built near to the consumption centers with lower transmission losses.

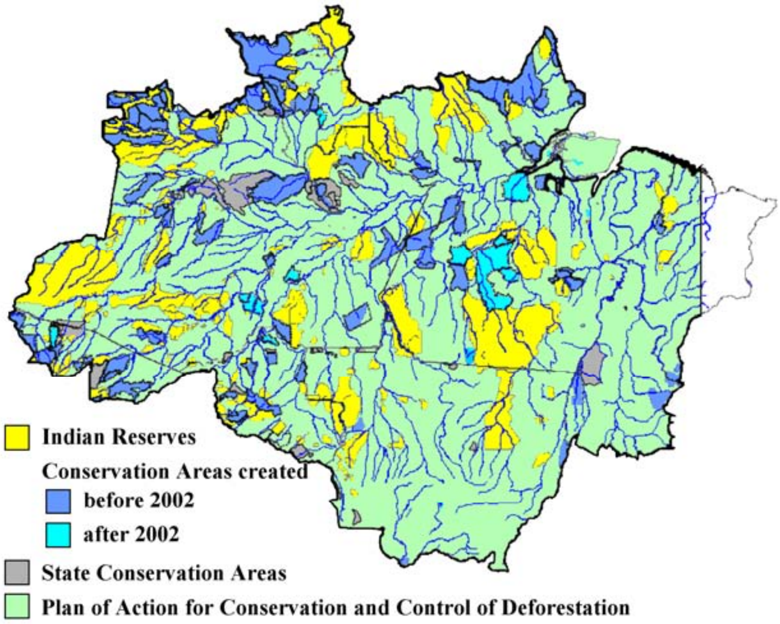


Figure 5. Preservation areas in Amazonas [2]**.**

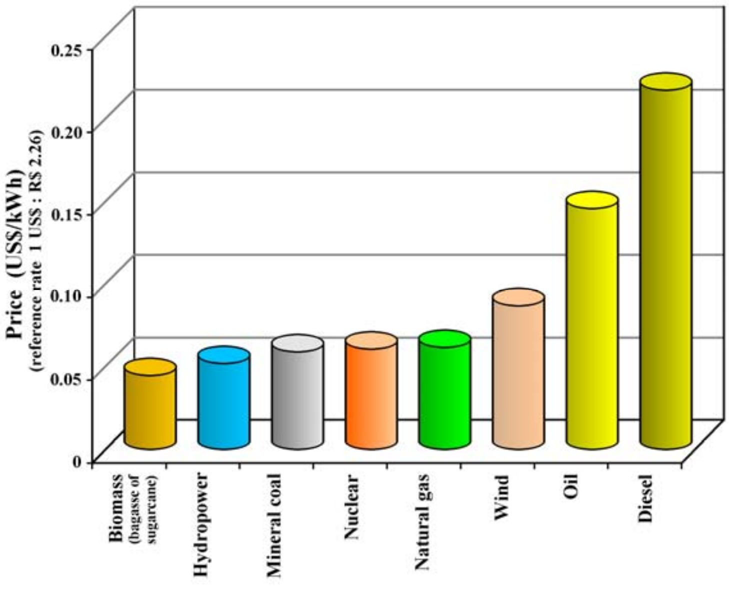


Figure 6. Price of the electricity generation [4].

3. BRAZILLIAN NUCLEAR SCENARIO

In the nuclear scene Brazil, USA and Russia are the countries having the three strategic aspects of the nuclear energy: assured uranium resources, technological domain of the LWR's fuel cycle and use of the nuclear power for electricity generation. The Brazilian uranium resources are given in Table I in terms of categories: identified (assured+inferred), prognosticated and speculative [7]. By considering 13.3 GW of nuclear power (Angra 1 to 3 and new 10 GW) the total reserve of 220,000 metric ton of U_3O_8 is conservatively evaluated to sustain this nuclear power along of 60 years useful life for each NPP [8].

Table I. Uranium Resources in Brazil [7]

CATEGORY	**Metric ton of U_3O_8** (<US$ 130/kgU)
Identified	309,200
Prognosticated	350,000
Speculative	450,000
TOTAL	1,109,200

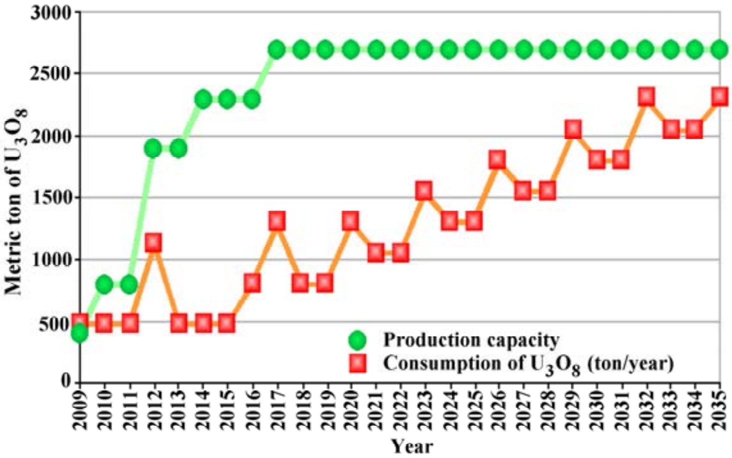
The growth of the nuclear generation between 4 to 8 GW, including the construction of new 1 GW NPPs after completion of the NPP Angra III, is projected in according to the 2030 Energy National Plan. The contribution of nuclear generation in the electricity consumption should evolve from the current 2.6% for amounts over 5% in 2030. To face this growth of the nuclear application in the electricity generation the capacities for each phase of the fuel cycle are to be boosted as it is shown in Fig. 7. After 2018 the fuel element fabrication for the Brazilian needs will require 300 metric ton of enriched UO_2. The uranium mining, UF_6 conversion, uranium isotopic enrichment and others steps in the fuel cycle will require financial investments to increase the production capacities as well as investments in the formation of specialized human resources.

3.1. Fuel Element Design and Fabrication

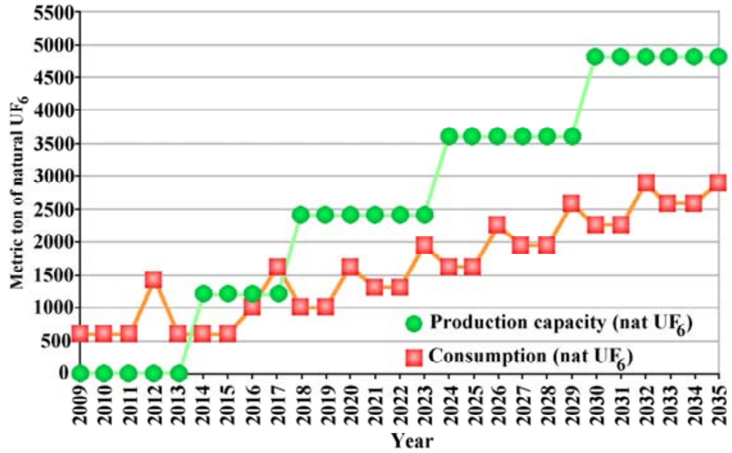
In design of fuel elements Brazil has the domain of the current state of art with limited autonomy for developing its own design. These competences include domain of theoretical knowledge and tools (codes, laboratories) and competence to run and manage tests of qualification.

Brazil has capacity in manufacturing the fuel element and partial autonomy for tests, qualification of suppliers and new processes, and licensing. Further investments in infrastructure and cooperation agreements with universities and technological institutes are being made in order to improve the insertion of Indústrias Nucleares do Brasil (INB) in the fuel market.

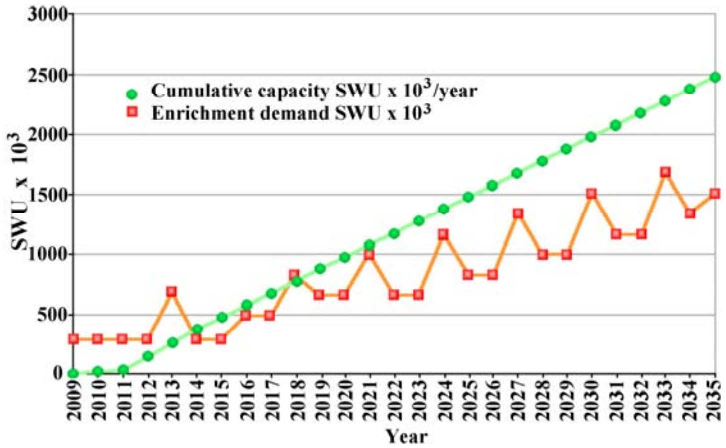
As support to the industrial sector and under financial support of the Financiadora de Estudos e Projetos (FINEP/MCT) the Brazilian nuclear organizations are conducting joint efforts for the management of existing staff and infrastructure towards the nuclear fuel elements for high performance and extended burnup. The role of the Nuclear Technology Development Centre (CDTN) in this effort is promoting the update of the fuel rod design codes to ensure they are fit and appropriate to design purposes and to evaluations of the fuel rod performance in accordance with current and near future insertion conditions [9]. Comprehensive models of thermal properties and in-pile behavior of the fuel are in development by the CDTN's expert staff, insertion into performance codes and validation against a representative database as the International Fuel Performance Experiments (IFPE/NEA/OECD) and the Coordinated Research Project on “Fuel Modeling at Extended Burnup – FUMEX III” (IAEA/NEA).



(a) Uranium mining



(b) Conversion of nat UF_6



(c) Separative work requirement

Figure 7. Requirements in the fuel cycle [7.

In the neutronic field the computational tools NJOY99, MCNP5-1.4, ORIGEN2.1 and MONTEBURNS [10] are been applied in the study and the formation of new experts. The modeling by use of the CFD computational tools [11] and the refurbishment of CDTN's experimental infrastructure are currently applied on the evaluation of the thermal-hydraulic performance of the new nuclear fuel elements. The experimental researches on corrosion of the new cladding and structural alloys are also conducted in the laboratories of the CDTN.

4. CONCLUSIONS

Brazil belongs to the group of countries where the production of electricity is massively from hydropower plants. These plants account for 87% of installed capacity in the country and generated in 2005, 93% of the electricity required by the National Interconnected System (SIN). It should be noted that only about 30% of the national hydroelectric potential has been exploited, a proportion much smaller than that observed in industrialized countries. The 2005 to 2030 projections for the Brazilian development indicate growths from 2,020 kWh to 4,380 kWh in the per capita electricity consumption and from US$4,300 to US$8,950 in the per capita GDP (in market exchange rate and 2005 US$). The consumption of electricity is to grow from 375 TWh in 2005 to 1,030 TWh in 2030. This Brazilian effort shall bring up to 2030 the electricity consumption and per capita GDP indicators closer to the mean world values.

By taking into accounts an enlarged hydropower system towards the Amazonas and to prevent lack of electric energy in the Brazilian supply, the thermoelectric support is important to confer diversification and reliability to the electricity generation system. The Brazilian electricity generation will demand all primary sources to meet the foreseen growth of the electricity consumption.

As economical, safe and clean primary energy source for electricity generation, the nuclear energy is one option capable of large-scale and short-term deployment in the Brazilian growth of the electricity consumption. The contribution of nuclear generation in the electricity consumption should evolve from the current 2.6% for amounts over 5% in 2030. The construction of NPP's near to the consumers can mitigate the transmission losses. The external independence of this kind of primary source is granted by means of assured uranium resources and technological domain of the LWR's fuel cycle.

The accesses to the international databases completed the opportunity for pooling and rationalizing the available skills – technical, cultural and human. The recovery activities and validation of design codes for the fuel rod are to be boosted and completed in the next two years. Parametric and research studies on the new trends of fuel and reactors are important to keep the staff updated and also to advise the decision makers about the suitable options and technological paths for Brazil in considering the evolution of the internal and external scenarios. In spite of the importance to have this information available this activity does not belong to the core business of the industrial sector. The industrial staff is involved on the improvement of its day-to-day processes and there is no space to embrace this kind of study. Here the Research Centers of CNEN and the Brazilian Universities can also give contributions using the expertise of they staff as well as the infrastructures under recover and updating.

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