THE DRIVERS OF THE NUCLEAR RENAISSANCE

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Abstract. *The renaissance of the nuclear option for generating electric energy is stimulated by its economic competitiveness and its social and environmental benefits. Presently, nuclear energy is a key component to the rapid expansion of world electricity consumption. Drivers of the nuclear renaissance are (a) the growth of public acceptance as result of the historic demonstration of safety, (b) the economic competitiveness in the costs of generation, (c) the incorporation of innovations and technological advances with impacts on main barriers like the reducing of the capital investments and technological solutions for destination of the radioactive wastes. The nuclear retaken already affects the international Uranium market with records of negotiated volumes and a rise of prices. Brazil as detainer of some of the biggest reserves of Uranium in the world has much to profit with this retaken.*

Keywords: *nuclear energy, electricity generation, environmental impact, safety, cost, waste disposal*

1. INTRODUCTION

Since 2004, specialized publications in the area of energy notably the annual editions of the International Energy Outlook (IEO) consolidate the retaken of the nuclear option in the global energy scene. The retaken were considered unlikely until the year 2000. Initially, they were predominantly strategic evaluations related with the search of several countries to reduce external dependence and vulnerability related to fossil fuels. However, up-to-date revisions of the projections for electricity demands indicate that the generation capacity installed during the XX century is to be doubled in the first 25 years of the XXI century. This fact in addition to the climate changes requires the sustainability as a component of the energy options (EIA/DOE 2006a, Dias, Mattos, Jordão, Vasconcelos 2006a and 2006b).

The nuclear renaissance must be examined by evaluating the environmental impacts of the electricity generation, the histories of the operational confidence and safety levels, trends of the generation competitiveness, the solutions for the radioactive wastes and for the non-proliferation issues and, ultimately, for the fuel costs.

2. ENVIRONMENTAL IMPACT

The projections of the International Energy Outlook 2007 (EIA/DOE, 2007a) is summarized in Table 1 and indicate that global energy consumption will growth of 64.8% from 2003 to 2030. The consumptions of fossil fuels with growth rate above 70% sustain the energy consumptions in sectors of transport, industrial, commercial and residential.

Table 1. EIA/DOE 2007 projections from 2003 until 2030 to global energy consumptions and CO_2 emissions.

Fuel	Units	2003	2010	2020	2030	Rates 2003-2030(%)	
						annual	**total**
Oil	million barrels per day	79.8	90.7	103.7	117.6	1.4	47.4
Natural Gas	trillion m^3	2.72	3.28	4.00	4.62	2.0	70.0
Coal	billion metric tons	4.74	6.12	7.50	8.93	2.4	88.5
Nuclear	trillion kWh	2.52	2.72	3.26	3.62	1.4	43.7
Renewables	10^{18} J	33.87	42.63	49.06	56.45	1.9	66.7
Total	**10^{18} J**	**449**	**539**	**640**	**740**	1.9	64.8
Electricity	billion kWh	14781	19554	24959	30364	2.7	105.4
Emission of CO_2	billion metric tons	25.5	30.8	36.8	42.9	1.9	68.1
Liquid	(%)	41.1	38.4	36.9	36.0		
Natural Gas	(%)	20.6	20.6	21.0	21.0		
Coal	(%)	38.4	41.0	42.1	43.1		

The generation of electricity demands about 41% of the global energy consumption and in 2003 its distribution by primary sources was 66% from fossil fuels, 16% nuclear and 18% renewable sources (hydroelectric and others). The CO_2 emission with growth rate of 68.1% over the period 2003 to 2030 follows the growth rate of global energy consumption and is a world concern associated with the climate changes. The effects of these changes have no borders and cause damages in a global way. As low emitter source of greenhouse gases, the nuclear generation returned to the agenda of the energy matrix of various countries. Not only due to the environmental aspect, but also by the considering the economic and strategic aspects, the nuclear renaissance still contains (a) the growth of public acceptance as result of the historic demonstration of safety, (b) the economic competitiveness in the costs of generation, (c) the incorporation of innovations and technological advances with impacts on main barriers like the reducing of the capital investments and technological solutions for destination of the radioactive wastes. The most visible face of this renaissance is demonstrated by the international market with accentuated increases of the cost and volume of traded uranium oxide.

From the environmental point of view, projected growth rates to the CO_2 emissions in Table 1 are very worrying. In the IEO 2007 evaluation by the EIA/DOE, the rates of China and USA accounted for 38% of CO_2 emissions in 2003 and will respond for 44.8% of the emission in 2030. Under the pressure of growing costs of oil and natural gas, the growths of the energy matrixes of both countries foresee a strong component based on coal. The relative reduction in the use of natural gas to the electricity generation in the USA will be compensated in large part by an increasing the coal contribution. In terms of the coal consumption, China, USA and India will be responsible by 65.8%, 12.6% and 8.2% of the worldwide increase, respectively. That is, 3 countries are to account for 86.6% of the projected increase in the coal consumption until 2030. Evidently, China and U.S. should not ratify the Kyoto protocol.

In accordance with John Ritch (2004), despite of much rhetoric and diplomacy the overall rate of CO_2 emissions continue to increase, and in 2003 reached 25 billion tons/year (t/y) or 793 tons/second (t/s). In 2030 the CO_2 emission will reach 42.9 billion metric tons or 1,360 t/s. Over 400,000 years of Earth history, the levels of CO_2 in the atmosphere fluctuated between 200 and 300 parts per million (ppm), maintaining an almost perfect correlation with oscillations of the global average temperature around of 15 ^oC. From measurements of the air bubbles retained in glaciers, the concentration of CO_2 in the atmosphere remained unchanged since the beginning of the century XI until the end of the XIX century. This concentration increased with the industrialization at the end of the XIX century and the emission projections indicate values between 540 and 960 ppm of CO_2 at the end of the XXI century (IAEA, 2006a). Accord with James Lovelock (2004), the father of the Gaia theory, the global warming becomes irreversible for a concentration limit between 450 to 550 ppm of CO_2. In 2006 this concentration reached a value around of 380 ppm of CO_2 (IAEA 2006a). According to the analysis of the 2007 IPCC, the climate changes are going to be definitively irreversible as well as the Kyoto Protocol is going to fail.

In 2003 the world electricity production presented the source contributions as 66% from fossil fuels 16% form the nuclear energy. The impact of this distribution on the emission of greenhouse gases can be evaluated from the consumption and emissions for the 1 MWe plant along one year as summarized in the Table 2.

Table 2. Consumptions and emissions in the generation of 1 MWe along one year.

Source: (Barros, 2006)

Fuel	Wastes
2.500 tons of coal	5000 tons of CO_2, SO_2, ash and heavy metals released into the air
1.500 tons of oil	4800 tons of CO_2, SO_2 and other
700 tons of natural gas	2400 tons of CO_2
25 kg enriched uranium	23 kg of radioactive waste (only 1 kg of high activity)

Conventional thermal sources of energy launch tons of pollutants into the air. In this sense, the nuclear generation without atmospheric emissions is considered a clean energy. As a result of the decomposition from the organic material into the reservoirs, the hydroelectric generation also contributes with the emission of methane gas, a powerful greenhouse gas (GHG). The wastes from the nuclear industry are completely enclosed and sealed as well are in terms of volume extremely minor than the waste from the fossil fuels. The 443 nuclear plants operating in the world can generate 370,000 MWe (IAEA, 2006b) and 2,518 billion kWh generated in 2003 represent a significant relief for the burden of greenhouse gases that, otherwise, would be launched by equal thermal generation from other sources. The major advantage of nuclear energy is the energy density, since the combustion of 1 kg of coal or oil results in the 3-4 kWh of electricity and 1 kg of uranium can produce 50,000 kWh and with reprocessing until 3,500,000 kWh (IAEA 1997).

Figure 1 shows the evolution of global energy consumption in terms of 10^{18} Joules (EJ). From the total energy consumption, 41% is directed to the generation of the electricity as showed by the fuel distributions in this Figure. The useful generated electricity indicated by the dotted line represents only 31% of the total energy consumed in the generation. In accordance with the IEO 2006 evaluation, the utilization efficiency for the electricity generation (useful electricity/primary energy consumption) grows from 31% to 34.5% between 2003 and 2030. By considering the consumption in Table 1 for the year 2030, the 3.5% rise of the utilization efficiency represents 1.06 billion kWh of useful energy, that is, about 3 times the consumption in Brazil in 2003.

Electricity generation from nuclear power is projected to increase from 2.52 billion kWh in 2003 to 3.62 billion kWh in 2030 (+43.7%) (EIA/DOE, 2007a).The world’s installed nuclear capacity grows from 362 GW in 2003 to 437 GW in 2025 (+20.7%). In accordance with the EIA/DOE, the high prices of fossil fuels and concerns about the electricity supply are factors contributing to the projected growth of the nuclear energy (EIA/DOE, 2006a).

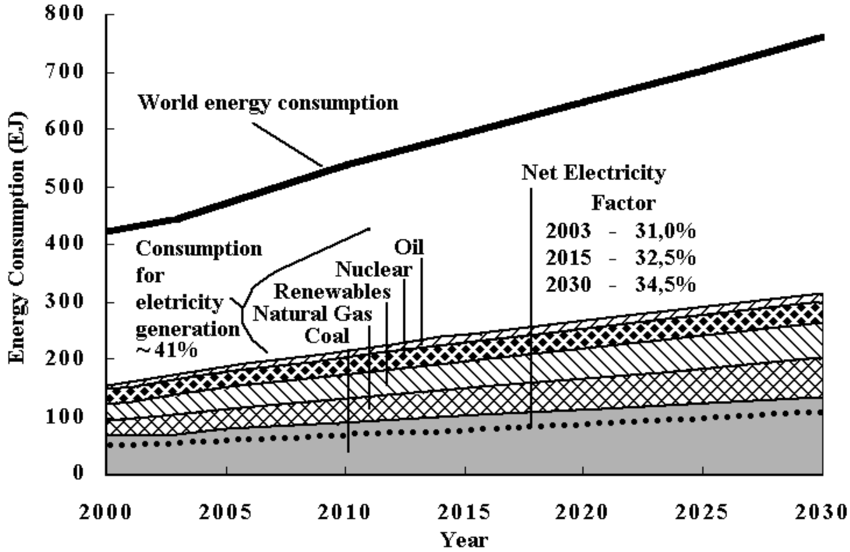

Figure 1. Evolution and distribution of the world energy consumption to electricity generation (EIA/DOE, 2006a).

3. RELIABILITY AND SAFETY

In 2006, the nuclear power reactors have accumulated 12,000 reactors-year of operating experience and two serious nuclear accidents throughout its history: Three Mile Island and Chernobyl. The 1st accident in 1979 resulted in the melting of the reactor core at Three Mile Island plant in Pennsylvania. In accordance with Patrick Moore (2006), co-founder of Greenpeace, "*which nobody noticed at the time, though, was that Three Mile Island was in fact a success story: the concrete containment structure did just what it was designed to do – prevent radiation from escaping into the environment. And although the reactor itself was crippled, there was no injury or death among nuclear workers or nearby residents.*" The Soviet reactor at Chernobyl involved in the 2nd accident in 1986 didn't have the containment vessel, was a project of the 2nd generation and the operators literally caused its explosion. Unlike the reactor at Chernobyl, the western reactors are of the 3rd generation and have in the containment vessel the 5th and 6th physical barriers to prevent the escape of radioactivity to the outside.

The number of industrial accidents (non-nuclear) in each 1 million man-hours worked in the Figure 2 emphasizes the evolution of the operational safety of nuclear power plants. It is also remarkable the world availability factor for nuclear power plants which evolved from 73% in 1990 to 83% in 2004.

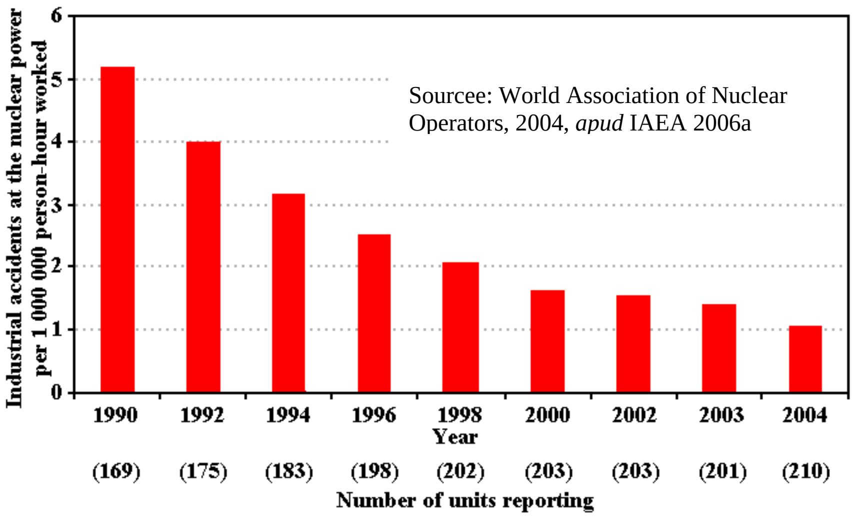

Figure 2: Safety and reliability in the nuclear industry.

4. COMPETITIVENESS AND COSTS OF NUCLEAR GENERATION

Nuclear and coal as primary sources remain as cheapest prices to the USA's electricity generators (EIA/DOE 2007b) - Figure 3. According to the "Annual Energy Outlook – 2006" (EIA / DOE 2006c), most of the USA's nuclear plants will apply for and receive plus 20-years license renewals. In that case, the capital investments have already been paid and the costs of generation became highly competitive. Since the 80's, the installed capacity in the USA is around of

100 GW. The capacity factor was 56% in 1980 and should reach the level of 91% in 2010, that is, a gain of 35 GW in the same period. The USA installed capacity should grow from the current 99.6 GW to 112.6 GW (+11.3%) while the generation grows from 780 billion kWh in 2005 to 896 billion kWh in 2030 (+15%) (EIA/DOE 2007b).

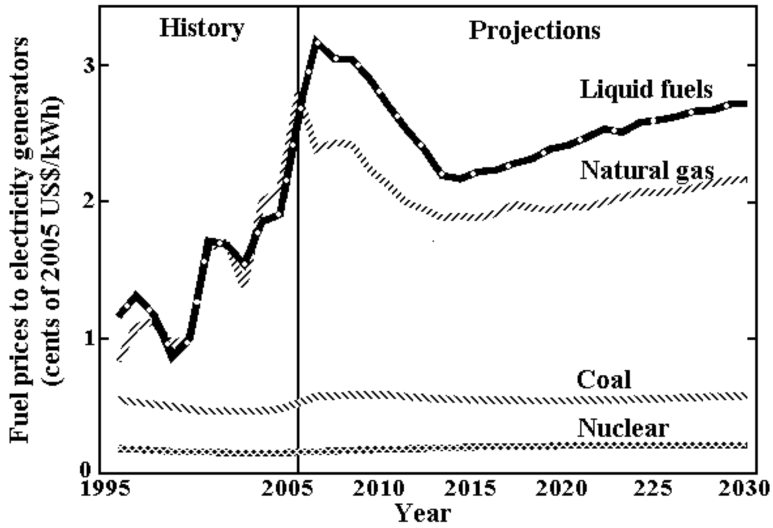

Figure 3: Fuel prices to the USA electricity generators (IEA/DOE, 2007b).

For some countries like Finland, a new nuclear plant is already competitive when compared with other thermal sources. Electricity prices in Finland present an ascending evolution and the nuclear generation was the Finland's option to mitigate the rising costs of electricity. (Tarjanne, 2005, IAEA, 2006b).

5. RADIOACTIVE WASTES AND NON-PROLIFERATION

An important contribution for the retaken of the nuclear energy is associated with the reprocessing of the spent nuclear fuel, in order to achieve the goals of (a) reduce the amount and radiotoxicity of the nuclear wastes that are destinated for the geological disposal, (b) extend the effective use and reduce the cost of the geological disposal, (c) reduce the inventories of plutonium and finally, (d) recover the useful energy still present in the spent fuel from the commercial nuclear power plants (Stillman 2005, Meyer 2004). Basically, these goals will be achieved with the recovering of elements from the actinide group (plutonium, americium, and curium) which are present in the spent fuel from the commercial nuclear power plants. As showed in the Figure 4 (NE/DOE, 2006), the radiotoxicity of the spent fuel without actinides will reach the values of the uranium mining ore after a period of 300 years. In similar way, it also is reduced the heat load which comes mainly from the radioactive decay of the long-life actinides.

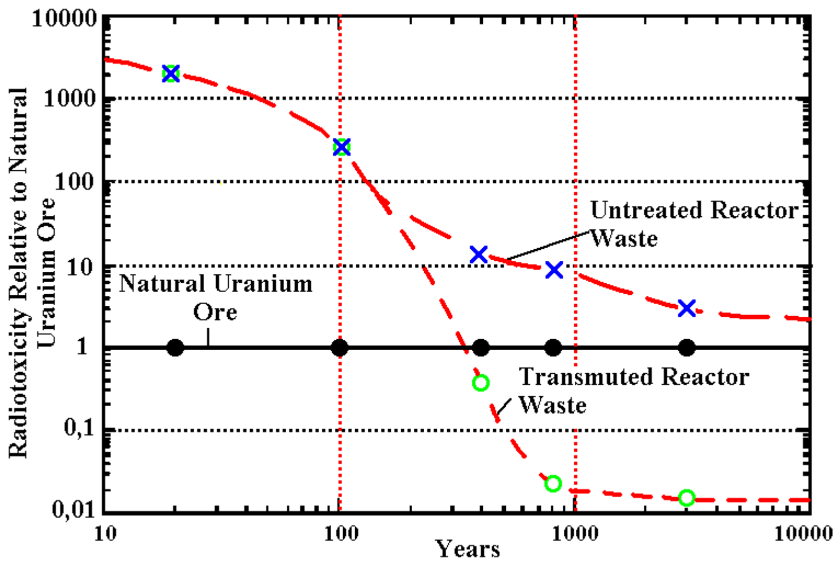

Figure 4: With transmutation, used fuel radiotoxicity is reduced to that of the source uranium ore within a few centuries

In geological repositories, the plutonium and other actinides are responsible for the largest radiological hazards and thermal load at times exceeding 600 years (Meyer 2004). The burnup of plutonium is already a reality in several countries with the use of MOX fuel type. The burnup of other actinides is part of advanced researches like the concepts IMF (inert matrix fuel) and ADS (advanced driven system).

The USA actions in the international arena are focused on aspects of non-proliferation and involve the review of concepts for the "Nuclear Suppliers Group” (NSG) and the Zangger Committee. These actions aim to strengthen technological barriers for the autonomous development of the nuclear technology. Basically, nuclear technology available within the NSG will be transferred to other member countries for purposes of generating electricity since the country abdicates the development of this technology

6. URANIUM TRADE

Taking into account the projected growth projected for nuclear energy, the needs for uranium has been reviewed by the IAEA and NEA (OECD) in the new edition of Red Book "Uranium 2005: Resources, Production and Demand" (IAEA / NEA 2006). As described in the red book, the uranium resources can be placed on 3 categories. The first category defines the resources as conventional, where the uranium is extracted as the main product, and unconventional resources, where the uranium is a byproduct. The second category is based on the level of knowledge or confidence in the quantification of the resource and is divided between measured and identified resources, and inferred and estimated resources and other denominations. Finally, the third category is determined by the cost of extraction. The resources named as conventional are listed under US$ 130/kgU3O8.

The conventional uranium resources in the world are estimated at 14.8 million tons (Mt) and from this amount 4.7 Mt resources are identified resources and about 10 million tons are estimated resources. The unconventional additional resources amount to 22 Mt. These resources are associated with phosphates and fall into the cost category less than US$ 130/kg (IAEA/NEA 2006). Based on the generation of nuclear electricity in 2004, 4.7 Mt are sufficient for about 80 years. Under the current use rates and technologies, the total resources (conventional and unconventional) last 270 years. However, using the spent fuel reprocessing, the numbers are changed for 4800-5600 years and 16000-19000 years, respectively (IAEA/NEA 2006).

Since the historic low price in 2001 (US$ 15/kgU3O8), the cost of uranium in the spot market reached US$ 94/kgU3O8 in April/2006, US$ 249/kgU3O8 in April/2007; and US$ 132/kgU3O8 in May/2008. The response of the uranium industry was new investments in exploration.

The fuel cost is a smaller part of the costs for electricity generation from nuclear sources, about 10% today. The costs of fossil fuels have impacts on the order of 40-70% in the electricity generation costs.

At the end of 2004, the world uranium production of 40,263 tons accounted about 60% of the global needs of 67,450 tons for the 443 commercial nuclear reactors in operation. According to the IAEA’s database, 30 reactors are under construction in April 2007. Over the years, the differences between production and demand were supplied by secondary sources and uranium released from military use. The reduction of the contribution from the secondary sources tends to enlarge the deficit between production and need which should be covered with the expansion of the uranium mining. The equivalent volume of U_3O_8 negotiated in 2005 more than doubled the historical record of 1996.

The electricity generation capacity from the nuclear source until 2025 has been analyzed in the red book under two scenarios, both assuming rising rates to nuclear power generation. From the current generation capacity of 370 GWe, the low projections foresee to reach 450 GWe (+22%) in 2025 (437 GWe, +20.7%, in accordance with the EIA/DOE evaluation). The high projections foresee to reach 530 GWe (+44%) in the same period. These demands represent annual increases of the uranium needs between 80,000 to 100,000 tons. According to the evaluation IAEA/NEA the resources of uranium currently measured and identified can supply this expansion.

Brazil will arrive in 2030 with an economic development below of the world average and below of other emergent countries. The Country has a limited capacity of investment that restricts the expansion of the electric energy generation matrix (Mattos and Dias, 2007). On the basis of the historical evolution of the energy-income elasticity (electricity consumption) the limited growth of the electric generation matrix will not allow the support or the improvement of economic development. The Brazilian nuclear industry can actually contribute to change this scenario since the country has uranium resources to support a park of nuclear power plants and additionally to become an import player in the international nuclear industry. These opportunities are reviewed by Mattos and Dias (2008) in the paper "The Business Opportunities of the Nuclear Renaissance" submitted for presentation at this seminar.

7. CONCLUSIONS

Continuous advances of the nuclear technology indicate a best use of the uranium resources. The new designs of reactors already under development and testing will be able to extract 30 times more energy than current reactors and also to burn the long-lived radioactive products, reducing to 300 years the design requirements for the repositories.

The messages presented by Mr. Sokolov, Director of IAEA, in launching the new edition of Red Book, were:

- There is enough uranium for the foreseeable future.

- Diverse sources of uranium enhance supply security.
- Uranium price increases have increased exploration and production but have little impact on nuclear electricity costs.
- Current expansion of production capacity needs to be continued.
- Exploration, unconventional resources and fast reactors can greatly increase the longevity of nuclear fuel resources.

The global retaken of the nuclear option and trade of uranium are economic opportunities for the producer countries like Brazil. The geological uranium reserves in Brazil are 309,000 tons, as indicated and inferred quantities. In terms of additional resources the estimation in Brazil is 800,000 tons of U_3O_8 (Tavares 2004) and, in accordance with this evaluation, the Country becomes the 3rd world reserve. As evaluated by Mattos and Dias (2007), the operation of 13 nuclear power plants like Angra II along the XXI century will demand only the reserve of 220,000 tons of U_3O_8.

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