

# VARIATION IN THE PRICE OF THE ENERGY IN FUNCTION OF THE RATE OF RETURN APPLIED AT THE COST OF THE URANIUM

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## ABSTRACT

The Brazilian Nuclear Plan (BNP) forecasts the construction of, at least, four nuclear power plant besides Angra-3 till 2030. It also contemplates the possibility of other eight 1000 MWe nuclear power plants being built. Brasil holds the 6th largest uranium reserves in the world. Considering that only about one third of the territory has been prospected to date, fuel supply for those nuclear plants, as far as uranium ore reserves are concerned, is already assured. Fuel cycle technology dominance also guarantees to the country a position in an exclusive group of nations. The BNP outlooks the expansion of the nuclear fuel cycle looking for independence of foreign sources of supply. Estimating the nuclear fuel cost from national fuel cycle cost is still difficult due to lack of real cost data. Based on these facts it is presented a sensibility analysis of the nuclear fuel cost, taking into consideration exchange rate variation and the investment in internal rate of return.

## 1. INTRODUCTION

Uranium is distributed over the whole earth crust appearing as constituent of majority of rock. The reserves, to make it economically attractive, depending on the content of this uranium as an alternative technology used to be utilized. Estimates of reserves of uranium are separated into categories that reflect different levels of confidence in observed quantities, defined below [1]:

- Reasonably assured reserves (measured): refer to uranium that occurs in known mineral deposits and the size, grade and configuration and designed such that the quantities have their costs calculated. The estimates of tonnage and degree are based on specific samples, measured of the deposits and in the knowledge of the characteristics of them.
- Estimated additional reserves (indicated): refer to uranium, in addition to the reserves reasonably assured, which is inferred as existing, mainly based on direct geological evidence, in extensions of well-explored deposits, or deposits in which geological continuity was established, but where specific data, including measures of the deposits and knowledge of the characteristics of deposits are deemed inadequate to be classified as reasonably assured.
- Speculative reserves (inferred): refers to estimates made based on knowledge of geological characteristics. The location of the deposits in this category can only be specified as being in some place inside of one given region. As the term suggests, the existence and size of the reserves are speculative.

According to the World Nuclear Association, there are 436 nuclear power plants operating in the world generating approximately 16% of the world's electricity needs. Nuclear energy's

share of worldwide consumption is expected to at least remain constant or perhaps grow to 18% by the year 2030. Current worldwide production of uranium falls significantly short of consumption and the gap between production and consumption has been filled by secondary supplies, such as inventories held by governments, utilities and others in the fuel cycle, These secondary supplies are currently meeting nearly a third of worldwide demand, but as they are depleted future production will have to rise closer to demand [4].

**Table 1. Worldwide uranium resource**

	Tonnes U	Percentage of world
Australia	1243000	23%
Kazakhstan	817000	15%
Russia	546000	10%
South Africa	435000	8%
Canada	423000	8%
USA	342000	6%
Brazil	278000	5%
Namibia	275000	5%
Niger	274000	5%
Ukraine	200000	4%
Jordan	112000	2%
Uzbekistan	111000	2%
Indian	73000	1%
China	68000	1%
Mongolia	62000	1%
Others	210000	4%

The uranium market, like all commodity markets, has a history of volatility, moving not only with the standard forces of supply and demand, but also to whims of geopolitics. It has also evolved particularities of its own in response to the unique nature and use of this material [2].

Unlike other metals such as copper or nickel, uranium is not traded on an organized commodity exchange such as the London Metal Exchange. Instead it is traded in most cases through contracts negotiated directly between a buyer and a seller. Recently, however, the New York Mercantile Exchange announced a 10-year agreement to provide for the trade of on and off exchange uranium futures contracts. The structure of uranium supply contracts varies widely. Pricing can be as simple as a single fixed price, or based on various reference prices with economic corrections built in. Contracts traditionally specify a base price, such as the uranium spot price, and rules for escalation. In base-escalated contracts, the buyer and seller agree on a base price that escalates over time on the basis of an agreed-upon formula, which may take economic indices, such as GDP or inflation factors, into consideration [3].

A spot market contract usually consists of just one delivery and is typically priced at or near the published spot market price at the time of purchase. However 85% of all uranium has been sold under long-term, multi-year contracts with deliveries starting one to three years after the contract is made. Long-term contract terms range from two to 10 years, but typically run three to five years, with the first delivery occurring within 24 months of contract award. They may also include a clause that allows the buyer to vary the size of each delivery within

prescribed limits. For example, delivery quantities may vary from the prescribed annual volume by plus or minus 15%.

Before uranium is ready for use as nuclear fuel in reactors, it must undergo a number of intermediary processing steps which are identified as the front end of the nuclear fuel cycle: mining it (either underground or in open pit mines), milling it into yellowcake, enriching it and finally fuel fabrication to produce fuel assemblies or bundles. This technologically complicated and challenging process is simple in comparison to the complexity of the market that has evolved to provide these three services.

For the use of fissile material and nuclear fuel are needed several industrial processes, from the mining of material, irradiation in the reactor to the storage and reprocessing or final destination of radioactive waste. All the processes and services associated with the nuclear fuel are called Fuel Cycle. There are several possible cycles depending on the type of reactor and fuel type used. Emphasis will be given to the fuel cycle for LWR type reactors whose spent fuel is enriched uranium [1]. The various steps of the fuel cycle are:

- Prospection and research of uranium ore;
- Improvement of uranium ore;
- Production of chemically pure uranium concentrate (“yellow cake”);
- Conversion to  $UF_6$ ;
- Isotope enrichment;
- Preparation of  $UO_2$  and fabrication of fuel element;
- Reprocessing;
- Storage (temporary or final).

These steps can be grouped into three phases, the pre-reactor (“front-end”) which includes the steps of the cycle that comes before the burning in the reactor and where to prepare fuel from mining to final form in fuel elements. The process of irradiation itself, which added fuel in the reactor will generate power. The post-reactor (“back end”) includes the steps that process the spent fuel to recover the material for commercial or strategic value and subsequent packaging to avoid danger of radioactive contamination of the environment [5].

## **2. METHODOLOGY**

### **2.1. Cycle storage**

For the analysis of the market price of uranium was chosen cycle storage directly, or after the course of irradiation in the reactor core the fuel is stored for a period of 5 years in the reactor storage pool and is then taken to a temporary storage where they remained for 40 years to be decided the final destination (reprocessing or permanent storage) [5].

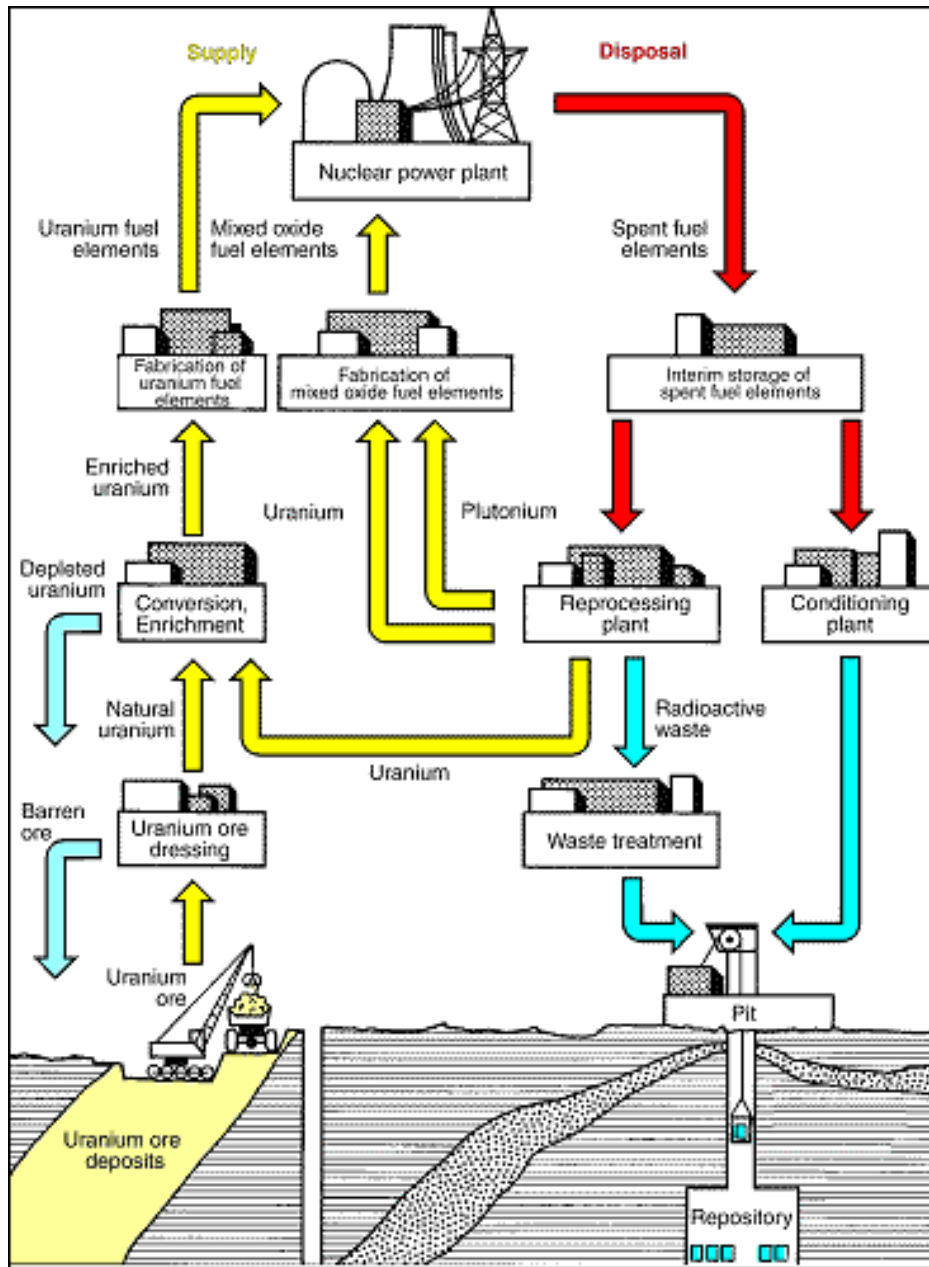


Figure 1. Combustivel cicly.

## 2.2. Analyzed reactor

The Angra I plant was chosen as a reference for the review of the price of uranium on the international market taking into account time of operation, thermal power and cycle storage.

Was considered a theoretical cycle of operation a year which allows a more precise analysis of the price of uranium as compared to other reactors, as the first cycles of loading of Angra I had different times [6].

The thermal capacity of Angra I is a 657 MW thermal capacity factor (it is defined as the ratio of its production of energy during the year on aenergia generated with the nominal capacity in operation for one year - 8760 hours) of 85% .

### 2.3. Front-end

The pre-reactor ( "front-end") which includes the steps of the cycle that comes before the burning in the reactor and where to prepare fuel from mining to final form in fuel elements. The process of irradiation itself, which added fuel in the reactor will generate power.

- Prospection and research of uranium ore;
- Improvement of uranium ore;
- Production of chemically pure uranium concentrate (“yellow cake”);
- Conversion to UF<sub>6</sub>;
- Isotope enrichment;
- Preparation of UO<sub>2</sub> and fabrication of fuel element.

### 2.4. Back -end

The post-reactor ("back end") includes the steps that process the spent fuel to recover the material for commercial or strategic value and subsequent packaging to avoid danger of radioactive contamination of the environment. It was adopted the direct cycle storage.

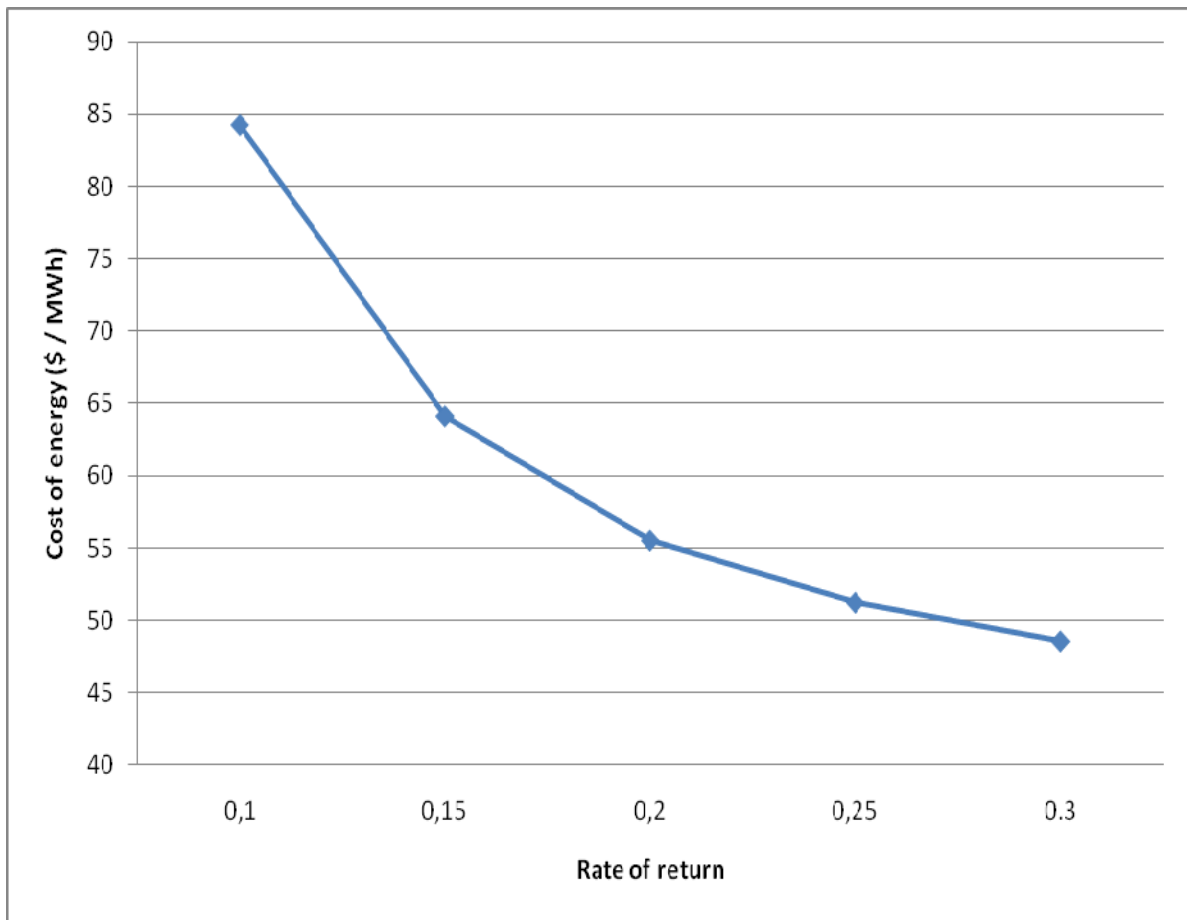
### 2.5. Analysis of interest

Commodities such as uranium and other goods are traded in scholarships, so their prices are set at a global level in the international market. For the success of an enterprise the size of a nuclear plant are necessary to ensure such as rate of return (defined as the discount rate that equals to zero the net present value of an investment) that provide relatively high profit investment. The return rates are set by the company to generate energy. The time involved depends on the fuel cycle and selected suppliers [7].

Were adopted five values for the rate of return taking into account the international market and the domestic interest of the country.

**Table2. Variation in the price of the energy of Angra I in function of the rate of return applied at the cost of the fuel**

Rate of return	Cost of energy (\$/MWh)
0.1	84.2565689
0.15	64.1013947
0.2	55.4978981
0.25	51.2005424
0.3	48.5126762



**Figure 2. Cost of the energy of Angra I in function of the return rates.**

### 3. CONCLUSIONS

The cost of electricity generated in thermonuclear plants in Brazil is viable and competitive as the rates of return to the high investment with a guarantee of profit and cheap energy.

### ACKNOWLEDGMENTS

The authors are grateful for financial support from the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

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