BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
08-03A (2020) 01-16

Funding and finance issues related to the decommissioning of Brazilian NPPs

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ABSTRACT

It is has a consensus that, for a nation to grow and develop in economic terms, an adequate supply of power should be available to provide its industrial sector as well as the needs of its people. Brazil did in the past make the decision to include the power generated from a nuclear source in its power generation matrix. The country today has two nuclear power plants in operation, Angra I and Angra II. The Angra I facility is nearly 40 years old and, should this country not manage to extend its lease of life, it should be decommissioned and taken apart, as provisioned for in prevailing legislation. In order to face the decommissioning costs of a nuclear power generation facility a sizeable amount of financial resources should be available to implement the decommissioning plan the operator is required to submit to the regulatory body. As the expected operating life of a nuclear power plant is of 40 years, some extensions were added to it to see the facilities go through successive and different governments and economic plans. This work studies some of the economic and financial aspects that go into the decommissioning of the Angra I power plant, pursuant to the IAEA documents published on the subject, covering different scenarios for yearly interest and the manner of the deposits, such as those of an uniform series of deposits and those of a growing and finite arithmetic progression.

Keywords: **Decommissioning, NPP, uniform payments, nuclear energy.**

ISSN: 2319-0612
Accepted: 2020-07-27

1. INTRODUCTION

It is easy to consider the importance that energy-related resources have in the economy, in its different aspects, especially that of its decisive a strategic role in the development of a nation. The rise of different sources of power supply had significant importance for the acceleration of development process in the modern world of today [1]. There is no question that nowadays the main source of energy at hand is that of fossil fuel. A trend that shows in the Brazilian Energy Matrix that consists of the supply of power from renewable and non-renewable sources, with a predominance of the non-renewable ones, which includes nuclear power.

In Brazil, the Eletrobras Eletronuclear (ETN) - is the operator of the Angra I and Angra II nuclear power plants, also charged with the construction of the Angra III. These three plants form the Almirante Álvaro Alberto – CNAAA - facility that generates approximately 3% of the electricity used in the country and more than 30% of the power used in the state of Rio de Janeiro.

As with all power plants, whether dependent on coal, natural gas or uranium atom fission (nuclear), they have a working lifespan upon which there comes a time in which it is no longer feasible to continue with their operation. In other words, at some point, a given power plant should be de-activated, even if with life-extending measures and upgrades made to their original design. This is the scenario that should be seen at the Angra I power plant, a facility that came into operation in 1984, planned to operate for forty (40) years, which will be due in 2024. Theoretically, this plant will be decommissioned at that point, that is, it should be cleaned and demolished so that the site where it stood can be put to a different use without creating hazards for future generations.

The decommissioning of facilities involves a wide range of actions that are carried out in the presence of a variety of radiological and non-radiological hazards and associated risks [2]. It also involves several organizations, the key organizations being the government, the regulatory body and the licensee. In spite of that, the decommissioning of nuclear facilities is a routine activity in the nuclear power industry, given that until March 2017 nearly 105 commercial reactors and 250 research facilities, along with units belonging to the chain of nuclear fuel had been deactivated and/or taken apart. One element in the equation is that proper financial planning is needed in order to bear face the costs of such an operation. We should point here that, in the case of commercial-application reactors, they generate income whilst in operation, with sizeable liabilities the operator should face at the time of decommissioning.

This study aims at determining, based on the principles of Finance Mathematics what the level would be of monthly financial transfers needed, and the accompanying interest rates of that to honor the financial obligations produced by the decommissioning of the Angra I nuclear power plant pursuant to prevailing standards and best international practices. The basis for justification of this paper is the reality Brazil faces due to the impending need to bear the costs of taking apart the Angra I plant when the latter is not producing income for the operator. Having that in mind, a description will be offered here with a simplified calculation chart on what a strategy for financial planning could be, towards setting up a monetary fund capable of bearing the brunt of decommissioning as planned for the Angra I plant. Two different scenarios will be presented, namely one for the decommissioning to happen in 2025 as initially planned or that with an extension of the working life for a further 20 years.

2. DECOMMISSIONING OF NUCLEAR POWER PLANTS

It is a consensus that large-scale economies should have reliable power sources with low levels of CO_2 emissions. Many specialists in energy and environmental policies say that it is very difficult to align these two elements without the participation of nuclear power in the energy matrix [3]. An example of energy that does not contemplate such criteria is the use of natural gas as this increases the levels of CO_2 emissions, something that also boosted the trend towards nuclear power plants. An evidence of that is the option for thermonuclear plants contained in the 2030 PNE - Brazilian Energy Plan - as produced by the EPE - Office for Energy Research - a state company under the MME - Brazilian Department of Mining and Energy [3].

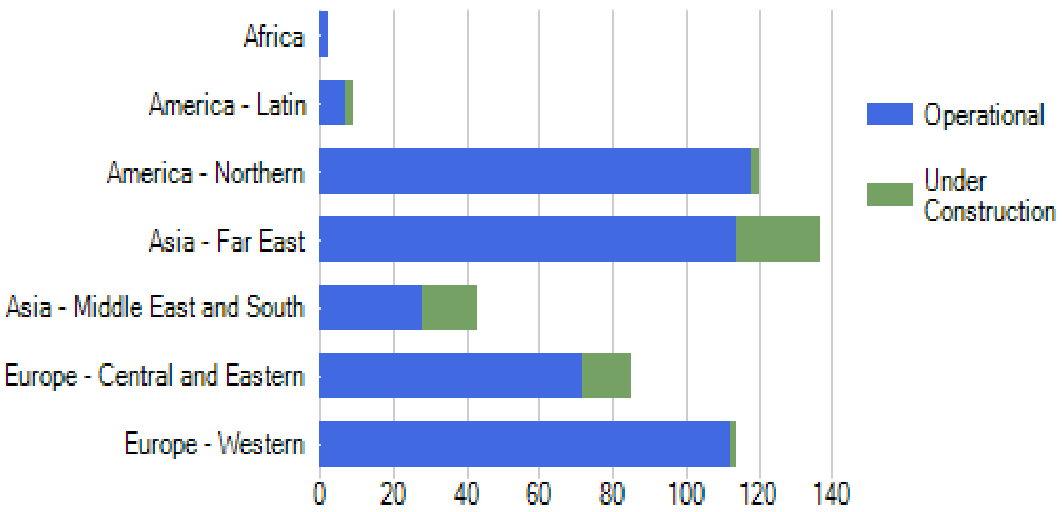
According to the Brazilian 2030 PNE, aimed at the long-term planning of the power sector of the country, to drive trends and acting as a reference for alternatives to expand the sector in the coming decades. There is an economic logical reasoning in the use of nuclear power as a core power supply source that would cater for the demands of a country that wants to be developed.

In a power distribution system that is based on hydraulic power generation, it is desirable that there is flexibility in the acquisition and use of thermal fuels (coal, natural gas) in the operating regime of thermal power plants. The more flexible the operating regime is, the greater the possibility of appropriation of the hydraulic power 'surplus' will be, at time s when the hydrology is favourable.

As regards such thermal power plants, which are expensive to run and large producers of greenhouse gases, the economic reasoning states that they should be shut down in periods of high/abundant hydrological reserves, as the power demands of a grid are met. In other words, these thermal power plants would run in a supplemental regime, something that is not advisable for thermal power plants, as they should operate at constant power levels for the sake of fuel usage optimization and operating safety, something that could justify their use as core energy supply elements.

Presently the world has 55 plants under construction and some 150 planned. Figure 1 shows the present global scenario on the use and plans to use new nuclear power plants, per region.

Figure 1: *Nuclear reactors in operation and under constructions in the world as of April 2019.*



Source: IAEA (2019) [2]

Despite de aforementioned benefits nuclear power plants bring to the logics of Economics when they are added to the power matrix of a country, their working lives will reach an end, and at that point, whether because of no longer being economically feasible or for safety reasons, they should be decommissioned. As already mentioned, Brazil has two plants in operation and one under construction. Table 1 shows data on these facilities.

Table 1: Basic data on CNAAA units.

Installation	Power (MWe)	Year of start of operation (Commissioning)	Start of decommissioning
Angra I	648	1985	2025
Angra II	1,372	2000	2040
Angra II	1,372	2025 (planned)	2065 (planned)

At first, both the Angra I and Angra II plants were designed to operate in safety for forty (40) years until the start of their decommissioning by the regulatory agency, a formal process that is laid out in specific standards of the industry (CNEN NN 9.01 [4] and CNEN NN 9.02 [5]), both updated in 2017.

There already exists vast international expertise on the subject of decommissioning of nuclear facilities. To permanently shut down a nuclear reactor is but one of the steps in the process. The fact is that, when shutting down a nuclear reactor and stopping the production and resulting distribution of the power it produces, leads to the cessation of the revenues such distribution entails, producing liabilities the operator will have to honor with resources it is hoped it accrued during the years in which it operated. Figure 2 shows the numbers for nuclear power plants that have been permanently shutdown around the world in recent years IAEA [2].

According to Article 9 of the CNEN NN 9.01 standard, three strategies are set in place: immediate dismantling, protracted dismantling, and confinement. Notwithstanding the strategy adopted, which will lay between immediate and protracted dismantling, Article 15 of the standard provides that operator should ensure that adequate financial resources should be at hand to cover the costs associated with a safe decommissioning of the plant. In addition, that such resource should be readily available as soon as they are required, even if in the case of an early stoppage of the operation due to an accident or after a corporate decision of the operator. Article 6 of the CNEN NN 9.02 standards provides that the operator should appoint a Federal Financial Institution [IFF in the Brazilian Portuguese acronym] to accumulate the funds set aside, in a conservative investment option, so that such funds see a guaranteed and stable monetary adjustment, with the least risk of financial loss. Article 9 of the said standard also provides that the financial institution chosen to bank such funds should demonstrate, at any time that a conservative path for the management of the funds has been adopted. They are reserved for the time of decommissioning, at the same time allowing audits of such custody and management by the regulatory agency, as set in Article 15, §4 of the CNEN NN 9.01 standard.

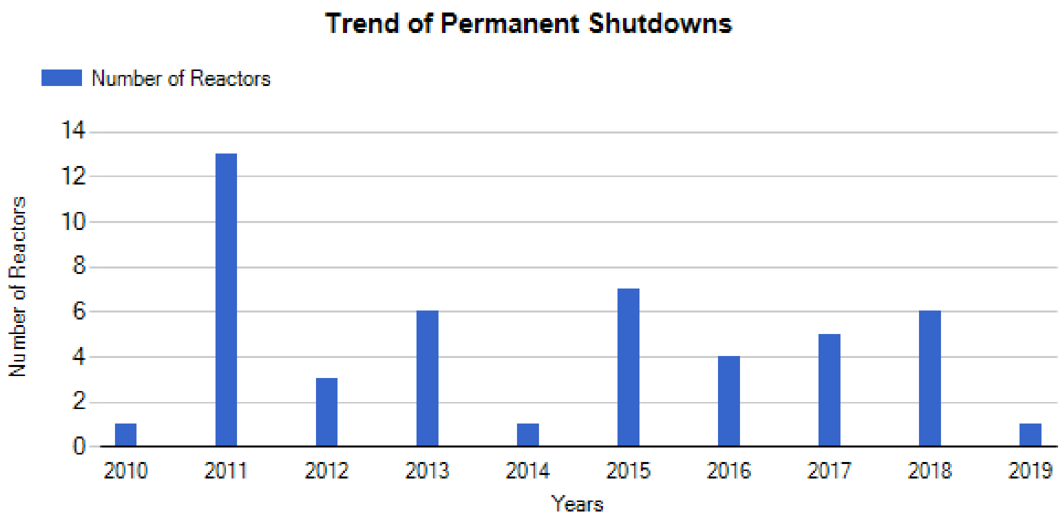


Figure 2: *Numbers for nuclear power plants that have been permanently shut down around the world. Source: IAEA (2019) [2]*

3. FORMATION OF FINANCIAL RESERVE FUNDS TOWARDS DE-COMMISSIONING – ANGRA I

The problem at hand, as dealt with in this work, can basically be split into the following scenarios:

1 – Knowing that in X years an amount equivalent to Y US dollars will be needed to face the costs of decommissioning a nuclear installation, what would the monthly amount set aside be as deposited by the operator, in the knowledge that the earnings of such a fund are constant and equal to 1% mo (monthly = mo)? This matter will be dealt with as an early series aimed at the redemption that should coincide with the last deposit (late series) or in a period dafter the last deposit (early series).

2 – In the case where X US dollars are needed to face the costs of decommissioning a nuclear installation. What would the increasing monthly amount set aside as in a finite arithmetic progression at the rate of G be as deposited by the operator, in the knowledge that the earnings of such a fund are constant and equal to 1%mo? This matter will be dealt with as an item of a plan aimed at the redemption that should coincide with the last deposit (pre-redemption) or after the last deposit (post-redemption).

In order to understand the calculations that will be done in this work, we should bring to mind some basic concepts of Finance Mathematics [6]:

A – Main (Principal) Amount: The sum expressed in monetary units; B – Amount: The future sum expressed in monetary units; C – Interest Rate: The rate to which both the Principal as the Amount are subjected to, expressed as a percentage that is bound to a time unit; D – Capitalizations Periods: They represent the number of periods in which the Principal will be subjected to a given interest rate; E – Cash Flow: Concept that refers to cash entries and expenses through time. F – Compound interest: Compound interest consists of interest on interest.

With the above concepts well understood, it is possible to gauge what monthly payments the operator should direct periodically so to build a sum adequate for the time of setting in motion the plan to decommission the power plant.

3.1. Series of Uniform Payments

It is possible to define a series of payments as a set of payments of amounts $P_1, P_2, \cdots, P_n$, distributed through time and corresponding to a $'n'$ number of periods, to constitute a cash flow. These payments could consist of constant or different amounts. In this section, we will deal with the problem in which all the payments will be of an equal value, something that can mathematically be expressed thus:

$$P_1 = P_2 = \ldots = P_n = P. \quad (1)$$

3.1.1 Early series

In the case of payment of monetary sums in time, with the goal of their redemption in a period after the last deposit, one has an early series, depicted here in Figure 3.

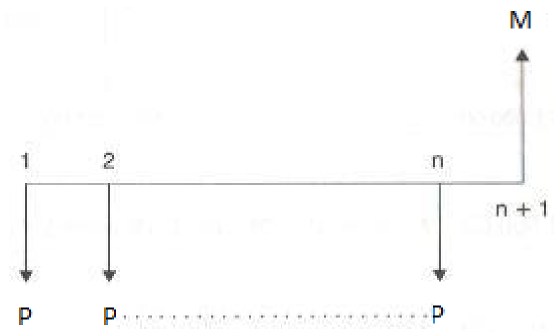


Figure 3: *Chart for the cash flow of an early series. Adapted from Azevedo [6]*.

Mathematically, after series of deposits with a fixed amount of P and capitalized a composite interest at the rate of $i\%$, one has that the sum accrued until the period $(n+1)$ immediately after the last deposit is given by the summation:

$$M = P(1+i) + P(1+i)^2 + P(1+i)^2 + \ldots + P(1+i)^{n-1} + P(1+i)^n \quad (2)$$

Equation (2) can be re-written as a geometrical series of $'n'$ terms which may be written thus:

$$M = P \times \sum_{k=1}^{n} (1+i)^k \ , \tag{3}$$

where the first term is $(1+i)$, the *n-th* term is $(1+i)^k$ and the rate is:

$$R = \frac{(1+i)^2}{1+i} = 1+i \ . \tag{4}$$

It is therefore possible to apply the formula of the sum of the terms of an arithmetic progression with $'n'$ terms, whose rate is q and the first term being a_1 (Silva & Filho, 2005):

$$Sum = a_1 \frac{q^n - 1}{q - 1}, \tag{5}$$

to obtain the following expression:

$$M = P \times (1+i) \times \frac{(1+i)^n - 1}{(1+i) - 1} = P(1+i)\left[\frac{(1+i)^n - 1}{i}\right], \tag{6}$$

where in Eq. (6) the factor between brackets is called the Capital Accrual Factor - $FAC(i, n)$.

3.2 Series of Payments in a Rising and Finite Arithmetic Progression

In this case the series of deposits required would not be an uniform one but rather, as the deposits increased periodically and according to a set G gradient, as such a gradient produces a geometric progression at the rate of G, this gradient producing a geometric progression at the rate of G. Again, only the case where the redemption is done after a period following the last deposit (early series) will be dealt with.

3.2.1 Early series

Let us consider the payment of monetary units through time with the goal of redeeming them one period after the last deposit (early) although with deposits made in non-uniform manner and that increase in an arithmetic progression at the rate of G. This type of series of payments is useful when at first no funds are at hand for large deposits but there is a forecast for improvement of the financial health of the paying party so that a continuous increase in the size of the transfers is possible. This series is depicted in Figure 4.

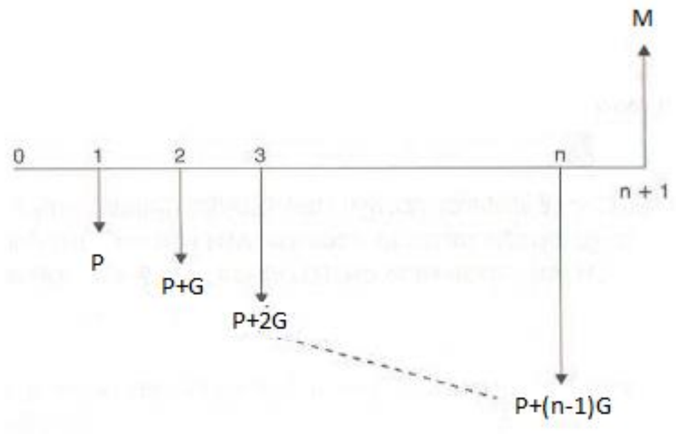


Figure 4: *Cash flow chart for a non-uniform series of payments whose transfers increase in an arithmetic progression at the rate of G. Adapted from Azevedo [6].*

In this case it is possible to separate the series of payments as the sum of a constant series whose monetary value is of the deposit added by a series of the terms produced by the constant gradient G. Demonstrating that the following formula calculates the sum after 'n' payments lies beyond the scope of this paper:

$$M = (1+i)^{n+1} \times (SU + SG)\,, \tag{7}$$

where SU is the uniform series and SG is the gradient series, respectively written by:

$$SU = P \times \left[\frac{(1+i)^n - 1}{(1+i)^n \times i}\right], \tag{8}$$

$$SG = \frac{G}{(1+i)^n \times i} \times \left[\frac{(1+i)^n - 1}{i} - n\right]. \tag{9}$$

3.3 Calculation Premises

In accomplishing the calculations in this work, the following premises and estimates will be considered:

1 – The interest rate considered will be that of the mean earnings of savings accounts, taking the financial data from April 2016 to May 2020. The data on savings accounts were obtained from the IPEA [7] - Institute for Applied Economic Research - and can be seen in Figure 5 which as built based on a data series whose average (0.54%), maximum (0.76%) and minimum value (0.500%) as well as its standard deviation (0.072%) in relation to the average were taken into account. As a result, the value for the interest rate we will use will be equal to $i = 0.54\% / mo$.

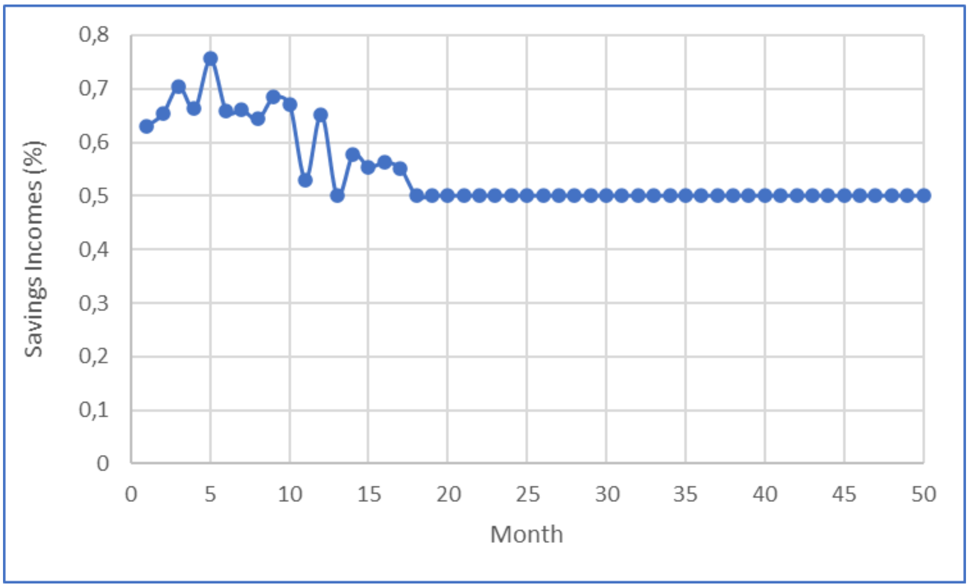


Figure 5: *Temporal series for monthly savings accounts earnings from April 2016 to May 2020. Source: author's own data [7].*

2 – In order to correlate he sums in BRZ into USD, the currency upon which some 20% of the cost of decommissioning is calculated, we used the rates published from April 2016 to May 2020, collapsed per month, using IPEA data as the source (IPEA, 2020). The regular rate of exchange for the USD was chosen as a reference due to its widespread use in foreign trade and monetary transfers as well as in capital transfers made abroad by the Government.

One of the major issues in analyzing the value of money over time lies in the variations the rates of exchange can experience. For this reason, and in this specific case, the average might not have been the best rate to be used, given the significant amplitude shown by the data. We will use in this paper a constant value of R$ 4.66, although it is known that the present balance is calculated based on the last rate (R$ 5.64). This amount was chosen due to its being equally distant from the average (R$ 3.68) and the maximum (R$ 5.64) rates [7]. It is known that there are mechanisms in place to protect balances held in USD such as the purchase of currency in the futures market and small contracts offered by BM&F Bovespa - Commodities Futures Market - but that lie outside the scope of this paper.

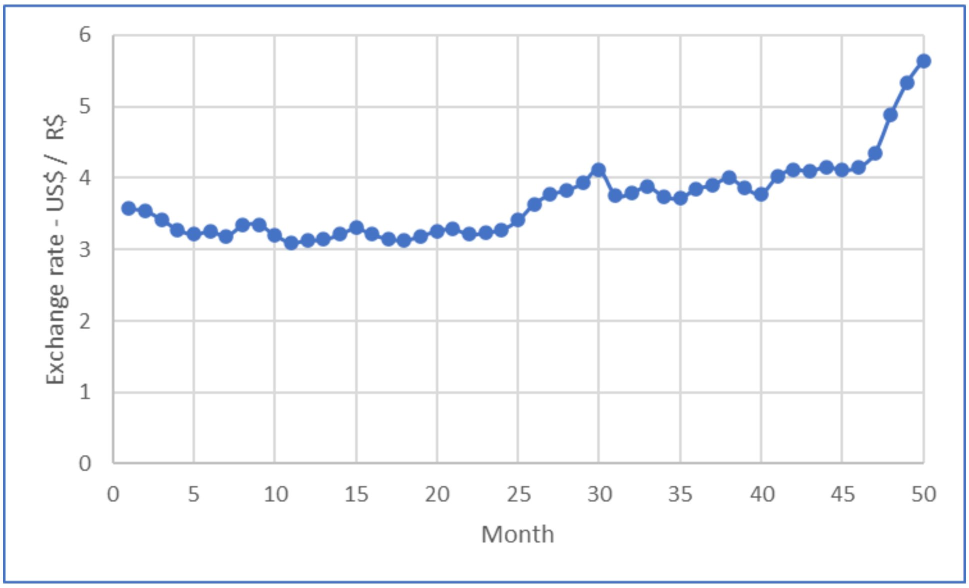


Figure 6: *Temporal series for USD-BRZ rates of exchange from April 2016 to May 2020. Source: author's own data [7].*

3 – The cost of decommissioning considered in this work is estimated at USD 600.000.000,00, a sum compatible with that of other similar plants, and complies with the calculation methodology of the International Structure for Decommissioning Costing (ISDC)" as published by the OECD/NEA. This mount will be considered in USD both for the decommissioning with no extension of the working life as for that with its extension. In both cases and for the sake of simplicity, we use the same rate of exchange. We also take into account the fact that there already exists a fund of R$ 1.200.000.000,00 and that the deposits will be made on a monthly basis.

4 – As regards the problem of non-uniform series in which there is a gradient that arithmetically increases the volume of monthly deposits, we will consider that there already exists a R$ 1.200.000.000,00 fund that should reach the required USD amount until 2025, when the license to operate of the plant will no longer be in force. In this case, the remaining life of the facility will be of 5 years and the progression as well as the G gradient, along with the interest rate will be capitalised on an annual basis at a rate of $i = 0.54\% = \left[\left(1+\frac{0.54}{100}\right)^{12} - 1\right] \times 100 \cong 6.7\% / yo$ (yearly = yo). We will also consider a last annual payment of USD 50.000.000 to find what the G gradient would be in order to reach the sum needed to bear the costs of decommissioning.

4. RESULTS AND DISCUSSION

4.1 Scenario 1 - Early series

In this case, in order to obtain the amount for the monthly transfer, one should invert Equation (6), to make explicit variable P:

$$P = \frac{i}{(1+i)\left[(1+i)^n - 1\right]} \times M \ . \qquad (10)$$

For the case with no Long Term Operation, $n=5\times 12=60$, $i=0.54\%/mo$ and $M=USD600.000.000,00-USD\left(1.200.000.000/4.66\right)\approx USD336.263.736,00$ one obtains the following value for the monthly USD transfers:

$$P=\frac{0.54\times 10^{-2}}{\left(1+0.54\times 10^{-2}\right)\left[\left(0.54\times 10^{-2}\right)^{60}-1\right]}\times 336.263.636\approx USD4.734.844{,}00/\text{month}\,. \qquad (11)$$

As a result, and line with the calculation result from Equation (11), an annual deposit of USD 40.494.617,64 , comparable to the sum already estimated in the premises for this work, would be sufficient to face the costs of decommissioning. For the case of extending the working life, n=5x12 + 20x12 = 300, with all the other variables remaining unchanged:

$$P=\frac{0.54\times 10^{-2}}{\left(1+0.54\times 10^{-2}\right)\left[\left(0.54\times 10^{-2}\right)^{300}-1\right]}\times 336.263.636\approx USD448.032{,}00/\text{month}\,. \qquad (12)$$

4.2 Scenario 2 – Early non-uniform series

In this case, and according to the premises described in the previous section one has that in $n=5$ years and where the operator should produce a sum of $USD336.263.736,00$. As a result, it is necessary to invert Eq. (7) so to find the G gradient that would allow, with an initial payment level of USD 50.000.000,00/year, for the sum necessary to be attained and based on this approach:

$$G=\frac{i}{\left(1+i\right)^{n}-(1+ni)}\times\left[\frac{Mi}{1+i}-P\left(1+i\right)^{n}-1\right], \qquad (13)$$

and replacing the numerical values, one obtains the following figure for the gradient on annual transfers:

$$G=\frac{0.067}{\left(1+0.067\right)^{5}-(1+5\times 0.067)}\left[\frac{336.263.736\times 0.067}{1+i}-5.0\times 10^{7}\left(1+0.067\right)^{5}-1\right]=USD2.742.800{,}63 \qquad (14)$$

In order to have a better numerical grasp of the result obtained, the operator already was making a deposit equal to USD 50.000.000,00/year and should only at first raise the level of the payment by 5.2%. Table 2 shows the plan that shows that, although the gradient holds constant, it slowly decreases in percentage terms as the years go by.

Table 2: Calculation plan for Scenario 2 – Early non-uniform series in USD.

Term	Initial	Annual interest	Financial support	Accumulated	% increase G
0	--	--	$50 000 000.00	$50 000 000.00	5.5
1	$50 000 000.00	$53 350 000.00	$52 742 800.63	$106 092 800.63	5.2
2	$106 092 800.63	$113 201 018.27	$55 485 601.26	$168 686 619.54	4.9
3	$168 686 619.54	$179 988 623.04	$58 228 401.89	$238 217 024.94	4.7
4	$238 217 024.94	$254 177 565.61	$60 971 202.52	$315 148 768.13	4.5
5	$315 148 768.13	$336 263 735.60			

5. CONCLUSION

This paper made an attempt to evaluate, in a simplified manner, the level of annual transfers to be made by the operator so to build a fund to honor the cost of decommissioning of a Nuclear Power Plant such as Angra I, for example. The cost of decommissioning is of around USD 600,000,000.00 and where an amount of USD 336,263,736.00 should still be set aside and accrued. Two different scenarios were considered, and for both of them, something around the annual USD 50,000,000.00 save project deviations would suffice. As a continuation of this work is relevant to assess the effect of important uncertainties associated with decommissioning costs such as exchange rate fluctuations and on how that could affect the project, as well as the variations in USD rates of exchange. Taking into account a more realistic proportion between the parts of the project that would be contracted in BRZ or in foreign currency. In addition, the strong coupling needed between decommissioning and waste management policy is an important source of uncertainties that must be taken into account, since it causes a significant variation in the year of commencement of decommissioning.

ACKNOWLEDGMENT

This research project is supported by the following Brazilian institutions: Brazilian Nuclear Energy Commission (Cnen), Nuclear Technology Development Center (CDTN), Research Support Foundation of the State of Minas Gerais (Fapemig), Brazilian Council for Scientific and Technological Development (CNPq), and Support Foundation of the State of Rio de Janeiro (Faperj).

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