NUCLEAR POWER STATIONS OF NATURAL OR ENRICHED URANIUM COMPARISON OF THE EXPENDITURES IN FOREIGN CURRENCY UNDER BRAZILIAN CONDITIONS

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RESUMO

Neste trabalho, a introdução de geração elétrica nuclear no Estado de São Paulo, é considerada de um ponto de vista essencialmente econômico e financeiro.

Ênfase é dada às estimativas de dispêndios em moeda estrangeira e ao custo do kwh gerado.

A dificuldade em estabelecer valores exatos para custo específico de capital (US$/ /kW) bem como para as parcelas do custo absorvido pela participação da indústria e mão de obra nacionais, recomendou que fôsse feito um estudo paramétrico. Neste, foram considerados valores otimistas e pessimistas para os custos específicos de capital e para a participação nacional.

Tipos definidos de centrais nucleares - não foram fixados à priori, porém julgou-se prudente sòmente se considerar, para fins comparativos, aquêles tipos para os quais havia uma experiência operacional que garantisse integràlmente os investimentos necessários.

Assim, foram comparados os seguintes tipos de centrais nucleares:

a) Urânio Natural, Gás, Grafita - Tipo Magnox (desenvolvido na França e Inglaterra);

b) Urânio Natural, Água Pesada - Tipo CANDU (desenvolvido no Canadá);

c) Urânio Enriquecido, Água Leve - Tipo B W R (escolhido para representar a família de centrais nucleares desenvolvidas nos Estados Unidos da América do Norte).

O estudo econômico-financeiro de cada tipo levou em conta os seguintes itens:

I - Custo de Capital: específico e total;

II - Participação da indústria e mão de obra brasileiras;

III - Ciclos de combustível nuclear;

IV - Custos de operação e manutenção;

V - Condições de financiamento;

VI - Localização da central nuclear;

VII - Custo de geração de energia;

VIII - Dispêndios anuais e cumulativos em moeda estrangeira.

O custo da energia gerada foi determinada supondo-se que a central nuclear fôsse construida e operada por uma Companhia Econômica Mista.

A potência líquida da Central nuclear foi fixada em 250.000 kW(e), de acôrdo com as recomendações da referência (19).

A taxa oficial do dolar, de 1 US$ = Cr$ 1800, vigente em dezembro de 1964, foi a adotada neste trabalho.

RÉSUMÉ

Dans le présent travail on étude les possibilités de l'utilisation de l'energie d'origine nucléaire dans l'Etat de São Paulo (Brésil), avec une attention spéciale aux aspects économiques et financiers.

Une attention spéciale est donnée aux dépenses en monnaie étrangère et au coût du Kwh produit.

Les difficultés dans la fixation de valeurs bien determinées, principalement pour le coût specifique du capital (US$/kw), pour la participation de l'industrie nationale et pour la main d'oeuvre, ont recommendé la réalization d'un étude paramétrique, dans lequel on a utilisé des valeurs optimistiques et pessimistiques, pour le coût specifique du capital, pour la participation de l'industrie brésiliense et pour la main d'oeuvre. On n'a pas consideré des types definis d'usines nucléaires pour la génération de l'énergie, mais on a consideré, pour des raisons de comparaison, seulement les usines dont l'expérience d'operation pouvait donner des garanties raisonnables pour l'investissement.

On a consideré les types suivants de réacteurs:

a) Uranium naturel; graphite-gas-type Magnox, developpés en France et en Angleterre;

b) Uranium naturel; eau lourde - type Candu; developpée au Canada;

c) Uranium enrichi; eau légère - type BWR; ce type a été choisi comme représentant la filière d'usines nucléaires developpées aux États Unis.

Les études financiers et économiques de chacun de ces types ont pris en considération les sujets suivants:

I - Coût du capital; specifique et total;

II - Participation de l'industrie et de la main d'oeuvre brésiliennes;

III - Cycles des combustibles nucléaires;

IV - Les coûts d'operation et de manutention;

V - Conditions financières;

VI - La localisation de l'usine nucléaire;

VII - Le coût de la géneration nucléaire;

VIII - Les dépenses annuelles et accumulatives en monnaie étrangère

Le coût de l'energie produite a été determiné en supposant que l'instalation nucléaire pour la géneration d'énergie a été construite et operée par une "Compagnie d'Economie Mixte" (Service publique, avec participation de la economie privée).

La puissance de base de la station á été fixé en 250.000 Kw(e), suivant les récommendations de la réference (19).

On a utilisé un taux de conversion de 1 US$ = Cr$ 1.800, effective en Décembre de 1964.

ABSTRACT

The introduction of nuclear power generation in the State of São Paulo, Brazil, is considered in this paper essentially from an economic and financial point of view.

Emphasis is given to the estimates of expenditures in foreign currency and the generated kWh cost.

The difficulty in fixing firm values, mainly for the specific capital cost (US$/kW) and for the national industry and labour participation, recommended that a parametric study

be made, where optimistic and pessimistic values were used, for the specific capital cost and for the brazilian industry and labor participation in the utility. Definite types of nuclear power stations have not been fixed "a priori", but it was thought safe to choose for comparative proposes, those whose operational experience gives full guarantee to the required investments.

Thus nuclear power stations of the following types were compared:

a) Natural Uranium; Gas Graphite - Magnox Type; developed in France and England;

b) Natural Uranium; Heavy Water - Candu Type; developed in Canada;

c) Enriched Uranium; Light Water - BWR Type; chosen to represent the line of nuclear power stations developed in the USA;

The financial-economic study of each type considered the following items:

I.- Capital Cost; specific and total;
II - Brazilian industry and labour participation;
III - Nuclear fuel cycles;
IV - Operation and maintenance costs;
V - Financing conditions;
VI - Nuclear power station site;
VII - Energy generating cost;
VIII - Annual and cumulative expenditures in foreign money.

The cost of generated energy has been determinated, supposing the nuclear power station constructed and operated by a "Mixed Economy Company". (Public Utility, with private participation).

The basic net power output has been fixed at 250 000 kW(e), according to the recomendations of reference (19).

The oficial conversion rate of 1 US$ = Cr$ 1.800, effective in December 1964, has been adopted.

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INTRODUCTION

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I - CAPITAL COST: SPECIFIC AND TOTAL

Maximum and minimum values were determined for the specific capital cost (US$/kW) and herewith for the total capital cost. The criteria adopted in such determination were the following:

1 - Extensive bibliographical consultation taking into account the existing discrepancies amongst the quoted values.

2 - Determination of a minimum value for the specific capital cost of each power station type. For the BWR and Candu, those minima have been taken from references (22) and (9) respectively.

3 - After the minima values have been determined the maximum specific cost values have been fixed according to probable increments due to the fact that the nuclear power station will be constructed in Brazil.

Therefore the following basic data were considered:

a) MAGNOX type Nuclear Power Stations

1. Minimum specific cost.

A value of US$ 280.00 US$/kw has been assumed as an approximate price for the construction of a 280 000 kW nuclear power station, replica of the British Olbury Station.

The adoption of that value, even for a 250 000 kW, is justified considering that Brazilian wages are cheaper when compared with the French or British ones.

Therefore it seems to be conservative to admit that the rise in specific cost due to both power decrement and deviations from the replica character of the power plant under consideration are compensated by the lower cost of the Brazilian labour component.

2. Maximum specific cost.

A value of 310.00 US$/kW, in other words, about 10% higher, has been assumed to insure that a safety margin exists to compensate for the eventual specific cost rise due to deviations from the replica character or to the lowering of the net power output of the plant, without taking into account the lower Brazilian wages.

Note that this price is still above the mean price which is obtained by considering the recent plants of Magnox type now in construction.

Thus it is a pessimistic assumption.

b) CANDU type Nuclear Power Station

1. Minimum specific cost.

A value of 310.00 US$/kW has been assumed as an estimative according to the Canadian General Electric (C.G.E.) rule, that establishes a 10% increase over the interpolated values given in table 1.8-1 of reference (9), which refer to two-units power plants.

2. Maximum specific cost.

As published in "Nuclear Canada", reference (10) the total cost of a power plant of this type, with a 200 MW unit , to be constructed in India, is estimated to be about Cr$ .... $ 68.400.000,00, i.e., 342.00 US$/kW.

Taking into account the similar technological development between that country and Brazil, it seems reasonable to admit an identical value for the same power plant if constructed in Brazil. Thus under same construction conditions, as the power output increased from 200 MW to 300 MW, the especific cost would be evidently lowered.

Using for a 300 MW plant the same decreasing factor found in Table 1.8-1, reference (9), a value of 300.00 US$/ /kW is obtained.

For the 250 MW_e power station of this study, the average value between the 200 MW and 300 MW plants, has been, hence, assumed as a maximum especific cost, that is 320.00 US$/kW.

c) BWR type Nuclear Power Plants

1. Minimum specific cost.

The International General Electric has published in October 1964 (22) a price list for nuclear power plants of the BWR type, in which, for a power output of 250 000 kW (one unit, without super-heater, dual cycle) the especific cost is 190.00 US$/kW if constructed in USA. If constructed in Brazil this cost very probably will be higher as happened in India (2).

Because of that it had been considered safe to assume this value as a minimum cost compatible with the Brazilian industry possibilities.

2. Maximum especific cost.

A careful analysis of the cost differences presented by International General Electric to justify the discrepancy between the Tarapur Nuclear Station cost in India and the Oyster Creek Nuclear Station in the USA, led to the conclusion that a reasonable maximum value for Brazil, will be 230.00 US$/kW.

This analysis is given, in detail, in reference (19).

II - BRAZILIAN INDUSTRY AND LABOUR PARTICIPATION

The criteria followed for obtaining a cost breakdown both for foreign and Brazilian expenditures have been the following:

1 - For each type of nuclear power plant considered, the percentual expenditures related to each item of direct and indirect costs have determined through careful search in specialized literature and informations obtained during the III Geneva Nuclear Conference.

2 - Analysing, then, the scanty data, in the specialized literature, a percentual breakdown of each item has been done for:

a) materials and equipment.
b) labour.

3 - For "materials and equipments", the technical caracteristics of the several components of each power station have been analysed and then an estimate was made of the percentual maximum and minimum limits of the Brazilian participation in production and supply. Identical process has been followed related to "labour", taking into account the amount of

specialization associated with the respective operations.

4 - All percentual values indicated above are always applicable upon the total capital cost.

5 - The maximum and minimum total percentual values of the Brazilian participation for "materials" and for "labour" have been obtained by simple addition of those related to each item of the total capital cost.

It was possible to follow that criteria only after an extensive bibliographical search and by consulting representative entities of the Brazilian industry. Particularly, the conclusions of Kennedy & Donkin and Internuclear Co. were taken into account. This consulting firm made in 1961 a study for the Brazilian Nuclear Energy Commission, in which they analysed the Brazilian industry, looking for an evaluation of its participation in the construction of nuclear power stations.

Those studies were brought up to date and generalized.

Tables II-1 and II-6 show an example for a Magnox type reactor:

1. The total capital cost breakdown.
2. The percentual values assumed, and the corresponding values of foreign and Brazilian capital expenditures.
3. The first fuel charge price.
4. The total investment and the interests during construction, due to foreign financing.
5. The more favourable case, that is, minimum cost of total capital and maximum Brazilian participation is given in Table II-1.
6. The more unfavourable case, that is, maximum cost of total capital and minimum Brazilian participation is given in Table II-2.

III - NUCLEAR FUEL CYCLE

Each fuel element type has been considered separately according to the following main points:

1 - Transport: all steps are considered from the uranium or corresponding salt plant to delivering of the complete fuel element in the nuclear power station, as well as the return of the burnt elements to the reprocessing plant.

2 - Production costs, including enrichment.

3 - Reprocessing cost.

4 - Credits, specially from plutonium.

5 - Present and future Brazilian possibilities.

Specific technological metallurgical problems were not considered but the economic and financing influences of Brazilian fabrication of fuel elements were taken into account.

6 - Prospectives of a lowering of unit cost (US$/kg U) as a result of technological developments, utilization of new techniques or methods of fuel element fabrication.

Taking into account the Brazilian reserves of Thorium ore, it seems to be incongruent not do consider the Thorium cycle. But the scope of this paper is restricted to nuclear plants whose operational experience gives full guarantee for the required investments.

The cost of the first fuel charge was determined assuming net unit prices quoted either directly by fabricators or supplemented by calculations considering the complete fuel cycle, as the case may be. In all cases the six items quoted above were considered.

The results are the following ones:

a) MAGNOX type

The prices obtained during the III Geneva Conference for French and British reactors, for a given guaranteed burn up are given in tables III-1 and III-2.

The fuel elements for the Magnox type power station being of metallic natural uranium, the purchase of yellow-cake of commercial purity can be done freely in the world market with a price that varies between US$ 4.00 and US$ 8.00 per pound (U_3O_8), in accordance with the particular transaction conditions.

With the development of chemical and metallurgical techniques at the Institute of Atomic Energy of São Paulo, it can be possible, perhaps in a short time, to produce in Brazil such fuel elements.

The importation would then be restricted to components whose local production would be anti-economical. In order to calculate the first fuel charge price, an integral importation has been assumed. The unit price was taken as the average of the values given in tables III-1 and III-2. In such conditions, the price of first fuel charge is found to be:

US$ 9,163.000.00 + Cr$ 485.100.000, - corresponding to 268,5 Tone of fuel, including a reserve of 10%.

b) <u>CANDU type</u>

The unit value obtained directly from reference (9) is given in table III-3. Because of the high burn-up attainable in this type of reactor, the plutonium credit has been considered as zero.

In this case the same considerations as for the Magnox type power plant are applicable regarding the fuel element production in Brazil. The price of the first charge including 10% reserves, calculated from the values of the table above is:

US$ 4,089.000.00 + Cr$ 102.960.000, - corresponding to 57,2 Ton of fuel.

c) BWR Type

The method of calculation followed for this type of reactor is described in reference (12).

The results are presented in table III-4.

It is of interest to note that the price quoted by International General Electric for fabrication of the BWR fuel elements is very close to that given in the price table of reference (22).

Analysing the related percentages in the net cost of the various items, it is seen that even considering the future integral production of such fuel elements in Brazil, the net expenditure, in foreign exchanges, would decrease only about 36%.

Actually such decrease is a maximum. Indeed, until uranium ore is discovered in Brazil, there will be extra expenses in foreign currency needed to buy raw material; and the importation of special equipment for the fabrication plant will add extra foreign expenditures.

The first charge cost, plus 10% as fuel reserve, in the conditions presented in the above table will be:

US$ 16,646.000.00 + Cr$ 914.166.000, - corresponding to 56.43 Tone of Uranium.

IV - OPERATION AND MAINTENANCE COSTS.

1 - Personnel needed.

The operation and maintenance of a nuclear power station differ in some points from those of a conventional power plant.

To give some idea on the influence of these two factors, the numbers of specialized personnel, engineers, technicians and others, needed in nuclear power plants of the three lines considered are indicated in table IV-1.

TABLE IV-1

Type of Power Station	BWR (1 reactor)	CANDU (2 reactors)	MAGNOX (2 reactors)
Total Power	100-200-300-400	100-200-300-400	100-200-300-400
Engineers	13- 20- 20- 20	- 16- 16- 16	- - 39 -
Technicians	21- 32- 34- 29	- 70- 77- 84	- - 293 -
Others	5- 8- 8- 9	- 10- 10- 10	- - 10
Total	39- 60- 62- 68	- 96-103-110	- - 342

Evidently such numbers do not have an absolute value, varying among nuclear stations of the same type and pratically the same power output according to internal managing procedures of different electric power companies. It is interesting, however, to note the increasing number of people when one goes from a BWR, to a Magnox type power station.

Such increase in the number of specialized personnel is easily explained if the details of the several functions in the three power plants considered are analysed. For exemple, in the american power plants refuelling is absent with the reactor on load. Thus no extra personal for such operation is necessary, while needed in the Canadian, French and British nuclear power plants, in which on-load refuelling is used.

Besides the conventional operation groups in charge of the turbo-generating groups, electric equipments etc and of the load dispatching, there are in the nuclear plants specialized groups for the reactor operation and other activities related to its proper functioning.

The presence of radioactivity in well defined areas of the plant buildings, the control of eventual radioactivity polution, the cleaning of absolute filters of the ventilations systems, are characteristic examples, peculiar to nuclear plants, requiring especialized health-physics personnel.

It is still important to note that automatization in a large scale is quite feasible in nuclear power station, thus reducing the number of the technical and graduated personnel needed for the stations operation. In addition preventive maintenance techniques are fully utilized, leading also to a decrease of the associated expenses.

2 - Costs associated with operation and maintenance

The values given in the literature as estimates of these costs are almost quite invariant with regard to the 3 nuclear plant types, taken into consideration.

Thus the increase due to a larger number of specialized personnel must be partially counter balanced by a lower maintenance cost. For example, the following values obtained in reference (1) illustrate this point:

TABLE IV-2

Nuclear Power Station	Type	Net Power MW_e	Annual Cost of Operational & Maintenance US$/kW & Year
1. Indian Point	PWR	151	6.3
2. Nine Mile Point	BWR	500	4.2
3. Bodega Bay	BWR	313	4.7
4. Douglas Point	CANDU	200	7.0
5. Hunterston	MAGNOX	2 x 160	4.9

The above costs include:

a) personnel

b) maintenance material in general

c) insurance (For the approximate value of 0.50% of the specific cost (US$/kW) was assumed (corresponding to twice the percentage adopted for conventional power plants).

3 - Operation and maintenance costs in Brazil

The values assumed for the following economic analysis are given in table IV-3.

TABLE IV-3

Operation, Maintenance and other Costs

250 MW_e Nuclear Power Station

Nº	Item	BWR US$/kW (per year)	BWR Cr$/kW (per year)	CANDU US$/kW (per year)	CANDU Cr$/kW (per year)	MAGNOX US$/kW (per year)	MAGNOX Cr$/kW (per year)
1.	Personnel		2.700,		3.450,		3.750,
2.	Material f. maintenance	1.00	3.000,	1.00	3.000,	0.60	3.000,
3.	Taxes and Insurance	0.64	3.000,	0.90	3.000,	1.09	3.000,
4.	Total	1.64	8.700	1.90	9.450	1.69	9.750

Values given in item 4 show that they are lower than those cited for the foreign countries, excluding British reactors. The reason for this low value applicable in Brazil is due to the lower Brazilian salaries when compared with American or Canadian (converted in cruzeiros at a rate of Cr$ 1.800, - per dollar).

V - FINANCING CONDITIONS

1 - Amount of foreign expenditures

This amount has been calculated by the addition of the following parcels:

a) The fraction of the total capital cost corresponding to the foreign participation.
b) The first fuel charge cost, including 10% reserve.
c) Interests during construction.

The following financing conditions were admitted:

i) 4 years period of grace;
ii) amortization in 20 years with an interest of 6% per annum;
iii) all extra expenses were neglected.

The interests during construction have been calculated for 5 years at a 6% annual rate. An average value of 15% over the total capital cost resulted as a good estimate from detailed calculation, by considering that the foreign money investment follows a cumulative cost curve similar to that given in reference (20).

2 - Amount of Brazilian expenditures

This amount has been calculated by the addition of the following parcels:

a) the fraction, in cruzeiros, of the total capital cost corresponding to the Brazilian industry and labour participation.
b) working capital (about 2 months of average monthly income) (20).
c) Replacement materials (estimated).

Admitting the hypothesis that a Mixed Economy Company would construct and operate the nuclear station, 51% of the amount obtained, would represent the minimum required by law, to be covered by a Government department. The remainder 49% could be integrated through three different ways:

i) Internal financing - not considered
ii) Integration bonds - not considered
iii) Integration by the same or various government departments.

This latter hypothesis was adopted.

VI - NUCLEAR POWER STATION SITE

The amount of radioisotopes present in an operating nuclear reactor requires to choose such sites to give full guarantee of a high safety factor, without excessive increase of the capital cost.

An optimized selection of the site will be of great influence in reducing the construction cost as well as the transport losses of the generated energy to the load center.

Because of the lack of previous experience in Brazil, several norms and recomendations of the IAEA and other nuclear energy organizations of countries that have power reactors in operation or in construction were carefully analysed, specially taking into account:

a) The general recomendations by A Barbreau, from the French Atomic Energy Commission (21).
b) The criteria established by the IAEA (15).
c) The studies carried out by the U.S. Atomic Energy Commission (16).
d) The F.R. Farmer Criteria (17).

Consideration of reactor hazards around the nuclear power station site, as a function of reactor power output, gives rise to a series of Safety Parameters. The following have been considered for the preliminary selection of various sites:

- demography;

- psychological factors;
- meteorological, micro-meteorological and climatological conditions;
- seismographic events;
- industrial and agricultural development;
- eventual risks of water contamination;
- studies and control of the fauna and flora of the region.

Economical considerations, on the other hand, lead to a set of Technical Parameters.

The following have been considered:

- cooling water
- geology with respect to heavy foundations;
- minimum distance to the interconnection point with the grid system of the load center;
- site access facilities;
- cost of land.

For the preliminary selection the most important parameters, both technical and of safety, were: demography, geology and cooling water; but the other ones were also taken into account (15) (16) (17) (21).

Several sites in differents regions, in a 200 km radius around the principal load center - São Paulo City - have been studied and preliminary evaluations of their usefulness have been done.

Six sites were then selected by elimination of the other ones: four of them close to the sea and the other two close to a river.

The sites selected are indicated in the appendix VI-1; all of them are potencially favourable for the implantation of nuclear station.

The final selection will be done after the completion of the studies still going on related with geology, soil mechanics, meteorology, micro-meteorology, bulk ocean water movements and streams, oceanic sedimentation and topography and radioactive effluents dilution.

VII - ELECTRIC ENERGY GENERATING COST

The method adopted for the calculation of the cost of generated kWh is based on data, hypothesis and Brazilian legal rules, as follows:

1 - Decree Nr. 41019, Feb. 1959 (20) from which the following fixed charges rates have been taken:

a) remunerable investment: 10% annual rate.
b) depreciable investment: 4% annual rate.

2 - Fuel specific costs, as determined in Chap. III.

3 - Operation and maintenance costs, as determined in Chap. IV.

4 - Financing conditions, is accordance with Chap. V.

All basic data necessary for the calculations are given in table VII-1 for the three types of nuclear power stations: Magnox, Candu and BWR respectively.

The Appendices BWR-VII-1 and BWR-VII-2 show examples of the calculation method adopted, by using the basic data related to a BWR power station.

By application of the same calculation method and using the IBM-1620 computer of the Institute of Atomic Energy of São Paulo, similar sheets were obtained for MAGNOX and CANDU power stations. The results have been resumed, for comparison in Table VII-3 and in the Graphs VIII-1 and VIII-2.

The analysis of the results presented in Table VII-2 and VIII-2, show clearly that the minimum values for the kWh cost do not correspond to the minimum expenditures in foreign currency.

Particularly the minima kWh costs resulted for the BWR type, but nevertheless the minimum expenditures in foreign currency are found to belong to the Magnox type power station.

The main reasons for these results are fundamentally associated with the nuclear fuel cycle prices and with the rate of Brazilian industry and labour participation. The fuel cycle particularly, is connected with both the annual expenses and the kWh generating cost.

These conclusions may be modified due to changes in each one of the above reasons or in both.

The partial or total fuel element fabrication in Brazil; a "tool enrichment" contract type for the supplying of enriched uranium for example, if taken into account, could modify the results of the analysis.

Such possibilities are being further considered in the Institute of Atomic Energy of São Paulo, with the aim of broadening the field of the parametric study presented in this paper.

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TABLE II

Type of Power Station: MAGNOX		VARIANT : max. INVESTMENT : min. BRAZILIAN PARTICIPATION					
Net Electric Power : 250.000 kW	%	Material		Labour		Total	
		10^9 Cr$	10^6 US$	10^9 Cr$	10^6 US$	10^9 Cr$	10^6 US$
A- DIRECT CONSTRUCTION COST							
1. Structure & Improvements	12	(7)8.820	(1)0.700	(3)3.780	(1)0.700	(10)12.600	(2)1.400
2. Reactor Plant Equipment							
- Reactor, Heat Transfer Systems Instrumentation and Control	43	16.380(13)	11.200(16)	10.080(8)	4.200(6)	26.460(21)	15.400(22)
- Turbine Generator & Auxiliaries	12	5.040(4)	3.500(5)	2.520(2)	0.700(1)	7.560(6)	4.200(6)
- Electrical Equipments	5	2.520(2)	0.700(1)	2.520(2)	-	5.040(4)	0.700(1)
- Miscellaneous	5	2.520(2)	0.700(1)	2.520(2)	-	5.040(4)	0.700(1)
Sub Total 2		(21)26.470	(23)16.100	(14)17.540	(7)4.900	(35)44.100	(34)21.000
3. Transport & Insurance	5	(5) 6.300	-	-	-	(5) 6.300	-
Total A		(33)41.580	(24)16.800	(17)21.420	(8)5.600	(50)63.000	(32)22.400
B- INDIRECT CONSTRUCTION COST							
1. General & Administrative	11	-	-	7.560(6)	3.500(5)	7.560(6)	3.500(5)
2. Engineering, design and Inspection	2	-	-	1.260(1)	0.700(1)	1.260(1)	0.700(1)
3. Contingencies	5	-	-	3.780(3)	1.400(2)	3.780(3)	1.400(2)
Total B		-	-	(10)12.600	(8)5.600	(10)12.600	(8) 5.600
C- TOTAL CAPITAL COST		(33)41.580	(24)16.800	(27)34.020	(16)11.200	(60)75.600	(40)28.000
	100	EQUIVALENTS				(100)126.000	(100)70.000

		I - Total Capital Cost	70.000
		II - Cost of First Fuel Charge + 10% Reserve	9.160
SPECIFIC CAPITAL COST	280.000 US$/kW	Total Investment	79.160
		III - Interests during Construction	4.200
		Total Cost	83.360

TABLE II

Type of Power Station : MAGNOX

VARIANT: Max. INVESTMENT: Min. BRAZILIAN PARTICIPATION

Net Electric Power : 250.000 kW	%	Material		Labour		Total	
		10^9 Cr$	10^6 US$	10^9 US$	10^6 US$	10^9 US$	10^6 US$
A- DIRECT CONSTRUCTION COSTS							
1. Structures & Improvements	12	(7)9.765	(1)0.775	(3)4.185	(1)0.775	(10)13.950	(2)1.550
2. Reactor Plant Equipment							
-Reactor, Heat Transfer Systems Instrumentation and Control	43	16.740(12)	13.175(17)	9.765 (7)	5.425 (7)	26.505 (19)	18.600(24)
-Turbine Generator & Auxiliaries	12	4.185(3)	4.650(6)	1.395 (2)	1.550 (2)	5.580 (4)	6.800(8)
-Electrical Equipments	5	1.395(1)	1.550(2)	1.395 (1)	0.775 (1)	2.790 (2)	2.325(3)
-Miscellaneous	5	1.395(1)	1.550(2)	1.395 (1)	0.775 (1)	2.790 (2)	2.325(3)
Sub Total 2		(17)23.715	(27)20.925	(11)13.950	(11)8.525	(27)37.665	(38)29.450
3. Transport & Insurance	5	(5) 6.975	-	-	-	(5) 6.975	-
Total A		(29)40.455	(28)21.700	(13)18.135	(12)9.300	(42)58.590	(40)31.000
B- INDIRECT CONSTRUCTION COSTS							
1. General & Administrative	11	-	-	6.975 (5)	4.650 (6)	6.975 (5)	4.650 (6)
2. Engineering, design and Inspection	2	-	-	1.395 (1)	0.775 (1)	1.395 (1)	0.775 (1)
3. Contingencies	5	-	-	2.790 (2)	2.325 (3)	2.790 (2)	2.325 (3)
Total B		-	-	(8)11.160	(10)7.750	(8)11.160	(10) 7.750
C- TOTAL CAPITAL COST		(29)40.455	(28)21.700	(21)29.295	(22)17.050	(50)69.750	(50)38.750
	100	EQUIVALENTS				(100)139.950	(100)77.500

SPECIFIC CAPITAL COST 310.00 US$/kW	I - TOTAL CAPITAL COST	77.500
	II - COST OF FIRST FUEL CHARGE + 10% RESERVE	9.160
	TOTAL INVESTMENT	86.660
	III - INTERESTS DURING CONSTRUCTION	5.800
	TOTAL COST	92.460

TABLE III-1

Cost per kg U of MAGNOX type fuel elements

a) Complete importation of the fuel elements from France
b) Maritime transport by Brazilian ships
c) Burn up 3500 MWd/ton

Nº	Item	Expenditure US$/kg U	Expenditure Cr$/kg	Credit US$/kg U	% of net expenditure US$	% of net expenditure Cr$
1.	Transport	1.50	1.800,	-	4.01	1.663
2.	Fabrication of the fuel elements	35.00	-	-	93.4	-
3.	Net expenditure	36.50	1.800,	-	100 %	

TABLE III-2

Cost per kg U of MAGNOX type fuel elements

a) Complete importation of the fuel elements from GREAT BRITAIN
b) Maritime transport by Brazilian ships
c) Burn-up 4000 MWd/ton

Nº	Item	Expenditure US$/kg	Expenditure Cr$/kg U	Credit US$/kg U	% of net expenditure US$	% of net expenditure Cr$
1.	Transport	1.50	1.800,	-	4.52	3.01
2.	Fabrication of the Fuel Elements	30.70	-	-	92.47	48.78
3.	Net expenditure	32.20	1.800,	-	100 %	

TABLE III-3

Cost, per kg U of CANDU - type fuel elements

a) Complete importation of the fuel elements from CANADA
b) Maritime transport by Brazilian ships
c) Burn-up 9.300 MW d/t

Nº	Item	Expenditure US$/kg U	Expenditure Cr$/kg	Credit US$/kg U	% of net expedinture US$	% of net expedinture Cr$
1.	Transport	1.50	1.800,	...	2.07	1.38
2.	Fabrication of the fuel elements	70.00	-	-	96.55	-
3.	Net expenditure	71.50	1.800,	0	100 %	

TABLE III-4

Cost per kg U of BWR - type fuel elements

a) Enriched U, fuel elements fabrication and reprocessing completely purchased from USA.
b) Transportation by Brazilian ships
c) Burn-up 16.550 MWd/ton (as Bodega Bay)

Nº	Item	Expenditure US$/kg U	+ Cr$/kg	Credit US$/kg U	% of net expedinture US$	% of net expedinture Cr$
1.	Transport	18.36 +	16.200,	-	6.01	3.06
2.	Cost of UF_6 enriched	228.34	-	-	74.79	-
3.	Fabrication of the fuel elements	109.65	-	-	35.91	-
4.	Processing	34.88	-	-95.25	(-19.76)	
5.	Sub Totals	391.233 +	16.794	-95.25	100 %	
6.	Total fuel cycle cost *	295.98	16.200			

* Fuel Price at Power Plant.

T A B L E V I I - 1

BASIC DATA OF THE ECONOMIC ANALYSIS

Net Electric Power : 250 MW
Conversion Rate : US$ 1.00 – C$ 1.800

Item	Type of Power Station Variant		MAGNOX A	MAGNOX B	CANDU A	CANDU B	B.W.R. A	B.W.R. B	REMARKS
1	Efficience	%	33.6	33.6	29.1	29.1	30.5	30.5	
2	Basic Cost	10^6 US$	70.00	77.5	77.5	80	47.5	57.5	
3	Brazilian Participation	%	60	50	50	35	55	40	in C$, on equivalent of (2)
4	Fuel price	US$/ kg U	34.00	34.00	71.50	71.50	296	296	
5	" "	C$ / kg U	1.800	1.800	1.800	1.800	16.200	16.200	Transport by Brazil Ships
6	" charge	metric ton	245	245	52	52	51.3	51.3	
7	Burn-up	MWd/ ton	4.000	4.000	9.300	9.300	16.550	16.550	
8	Working Capital	10^9 C$	3.950	4.350	4.250	4.450	4.000	3.900	
9	Store	10^9 C$/year	0.378	0.317	0.446	0.234	0.308	0.228	2% of (2)
10	"	10^6 US$/year	0.322	0.432	0.512	0.666	0.238	0.368	
11	Personnel & Administration	10^9 C$ / year	0.940	0.940	0.860	0.860	0.675	0.675	
12	Material	"	0.900	1.100	1.350	1.450	0.750	0.900	
13	Insurance	"	0.630	0.720	0.700	0.740	0.430	0.520	0,5% sôbre (2)
14	Interests d. Construction	10^6 US$	4.200	5.800	5.800	7.900	3.200	5.200	
15	Financing interests	% p. year	6	6	6	6	6	6	15% ou (2)-(100%-(3)%
	Payment time	years	20	20	20	20	20	20	

Variant A : Admitted most favourable – Minimum Capital Cost ; Maximum Brazilian participation
Variant B : Admitted most disfavourable – Maximum Capital Cost ; Minimum Brazilian participation

APPENDIX VII-1

(1 US$ = 1.800 Cr$)

I - CENTRAL TYPE = BWR

Net electric Power = 250 MW_e

Net Efficiency = 30.5%

II - BASIC CAPITAL COST

Brazilian component = Cr$ 47.025.000.000, - (55%)

Foreign component = US$ 21,375.000.00 (45%)

Total .... = Cr$ 85.500.000.000,

III - COST PER kW INSTALLED = US$ 190/kW = Cr$ 342.000/kW

IV - FUEL ELEMENT COST (imported)

1. Net price CIF Central = US$/kg 296.00 + Cr$/kg 16.200,-
2. Core Loading, including 10% reserve = 56.430 kg
3. Cost of first loading = US$ 16,646.000.00 + Cr$ .... $ 914.166.000,-
4. Burn-up (average) = 16.550 MWd/Ton = 121.146 kWh_e/kg
5. Fuel Cost = 2.435 mills/kWh + 0.1337 Cr$/kWh

V - CALCULATION OF THE DEPRECIABLE AND THE REMUNERABLE INVESTMENT (Brazil Government Decree 41019/26.2.57)

	10^6 US$ +	10^9 Cr$ =	10^9 Cr$
1. Capital Cost (art.44 & 58)	21.375	47.025	85.500
2. Art. 157 I	0	0	0
3. Working Capital	0	4.000	4.000
4. Material Stock	0.238	0.308	0.736
5. Half of first loading	-8.323	0.457	5.439
	29.936	51.790	105.675

DEDUCTIONS	10^6 US$	+ 10^9 Cr$	= 10^9 Cr$
1. Art. 158 (I, II, III, IV, V)	0	0	0
A. REMUNERABLE INVESTMENT	29.936	51.790	105.675
2. Working Capital	0	4.000	4.000
3. Land (Art. 168, §2)	0	0	0
B. DEPRECIABLE INVESTMENT	29.936	47.790	101.675

VI - CALCULATION OF THE TOTAL ANNUAL CHARGES

(Brazil Government Decree 41019/26.2.57)

1. Fixed annual charges	10^9 Cr$
A. Operation and Maintenance	
a) Labour & Administration	0.675
b) Materials	0.750
c) Insurance & Taxes	0.430
Sub Total	1.855
B. Investment depreciation (4% of V-B)	4.087
C. Investment remuneration (10% of V-A)	10.567
Total	16.489

2. Variable annual charges

Fuel cost with Load Factor	10^6 US$	+ 10^9 Cr$	= 10^9 Cr$
50.0	2.666	0.146	4.945
55.0	2.933	0.161	5.440
60.0	3.199	0.175	5.935
65.0	3.466	0.190	6.429

2. Variable annual charges

Fuel cost with Load Factor	10^6 US$ +	10^9 Cr$	= 10^9 Cr$
65.0	3.466	0.190	6.429
70.0	3.732	0.204	6.924
75.0	3.999	0.219	7.418
80.0	4.266	0.234	7.913
85.0	4.532	0.248	8.408
90.0	4.799	0.263	8.902
95.0	5.066	0.278	9.397
100.0	5.332	0.292	9.891

VII - CALCULATION OF THE kWh COST

(Brazil Government Decree 41019/26.2.57)

Load Factor	Production 10^9 kWh/year	Total annual Cost 10^9 Cr$	Energy Prices Cr$/kWh=mills/kWh
50.0	1.095	21.435	19.575 = 10.875
55.0	1.204	21.930	18.206 = 10.114
60.0	1.314	22.424	17.066 = 9.481
65.0	1.423	22.919	16.100 = 8.944
70.0	1.533	23.413	15.273 = 8.485
75.0	1.642	23.908	14.556 = 8.086
80.0	1.752	24.403	13.928 = 7.738
85.0	1.861	24.897	13.375 = 7.430
90.0	1.971	25.392	12.982 = 7.157
95.0	2.080	25.886	12.442 = 6.912
100.0	2.190	26.381	12.046 = 6.692

VIII - RATE OF RETURN ANALYSIS

1. Assumed price of kWh with

load factor 80%	Cr$/kWh :	13.928
assumed min. and max.load factors	70%	90%
Values	10^9 Cr$/year	10^9 Cr$/year
2. Annual income	21.352	27.453
3. Annual expenses		
A. Operation & Maintenance	1.855	1.855
B. Fuel	6.924	8.902
C. External Loan Annuities *)	6.469	6.469
D. Depreciation Charge ----------	4.067	4.067
Total	19.315	21.293

*) The payment of the external was calculated as follows:

a) External Loan	10^6 US$	10^9 Cr$
A. Foreign component of capital cost	21.375	
B. Price of 1st Fuel Load + 10% reserve	16.646	
C. Interest during construction	3.200	
Total	41.221	74.199
b) External Loan Annuity (20 years, 6% p.year)	3.594	6.469

4. Annual net Profit	10^9 Cr$	10^9 Cr$
with Load Factor	70%	90%
A. Annual Income	21.352	27.453
B. Annual Expenses ------------	19.315	21.293
Annual Net Profit	2.037	6.159

5. Calculation of Return Rate

1. Capital Invested Cr$ 51.790.000.000,-
2. Rate of return = $\frac{\text{Annual net Profit}}{\text{Capital Invested}}$

2. Rate of return = $\frac{\text{Annual net Profit}}{\text{Capital Invested}}$

at load factor	70% (min.)	90% (max.)
	3.93%	11.89%

****

APPENDIX VII-2

(1 US$ = 1.800 Cr$)

I - CENTRAL TYPE = BWR

Net electric Power = 250 MW_e

Net efficiency = 30.5%

II - BASIC CAPITAL COST

Brazilian component = Cr$ 41.400.000.000,- (40%)

Foreign component = US$ 34.500.000.00 (60%)

Total .... = Cr$103.500.000.000,

III - COST PER kW INSTALLED = US$ 230/kW = Cr$ 414.000/kW

IV - FUEL ELEMENT COST (imported)

1. Net price CIF Central = US$/kg 296.00 + Cr$/kg 16.200,-
2. Core Loading, including 10% reserve = 56.430 kg
3. Cost of first loading = US$ 16.646.000,00 + Cr$ .... $ 914.166.000,-
4. Burn-up (average) = 16.550 MWd/Ton = 121.146 kWh_e/kg
5. Fuel Cost = 2.435 mills/kWh + 0,1337 Cr$/kWh

V - CALCULATION OF THE DEPRECIABLE AND THE REMUNERABLE INVESTMENT (Brazil Government Decree 41019/26.2.57)

	10^6 US$ +	10^9 Cr$ =	10^9 Cr$
1. Capital Cost (art. 44 & 58)	34.500	41.400	103.500
2. Art. 157 I	0	0	0
3. Working Capital	0	3.900	3.900
4. Material Stock	0.368	0.228	0.890
5. Half of First Loading	8.323	0.457	15.439
Total:	43.191	45.985	123.729

DEDUCTIONS	10^6 US$ +	10^9 Cr$ =	10^9 Cr$
1. Art. 158 (I, II, III, IV, V)	0	0	0
A. REMUNERABLE INVESTMENT	43.191	45.985	123.729
2. Working Capital	0	3.900	3.900
3. Land (Art. 168. §2)	0	0	0
B. DEPRECIABLE INVESTMENT	43.191	42.085	119.829

VI - CALCULATION OF THE TOTAL ANNUAL CHARGES
(Brazil Government Decree 41019/26.2.57)

1. Fixed annual charges	10^9 Cr$
A. Operation and Maintenance	
a) Labour & Administration	0.675
b) Materials	0.900
c) Insurance & Taxes	0.520
Sub Total	2.095
B. Investment depreciation (4% of V-B)	4.793
C. Investment remuneration (10% of V-A)	12.372
Total:	19.261

2. Variable annual charges

Fuel cost with Load Factor	10^6 US$ +	10^9 Cr$ =	10^9 Cr$
50.0	2.666	0.146	4.945
55.0	2.933	0.161	5.440
60.0	3.199	0.175	5.935
65.0	3.466	0.190	6.429

2. Variable annual charges

Fuel cost with Load Factor	10^6 US$ +	10^9 Cr$ =	10^9 Cr$
65.0	3.466	0.190	6.429
70.0	3.732	0.204	6.924
75.0	3.999	0.219	7.418
80.0	4.266	0.234	7.913
85.0	4.532	0.248	8.408
90.0	4.799	0.263	8.902
95.0	5.066	0.278	9.397
100.0	5.332	0.292	9.891

VII - CALCULATION OF THE kWh COST

(Brazil Government Decree 41019/26.2.57)

Load Factor	Production 10^9 kWh/year	Total annual Cost 10^9 Cr$	Energy Prices Cr$/kWh=mills/kWh
50.0	1.095	24.207	22.106 = 12.281
55.0	1.204	24.701	20.507 = 11.393
60.0	1.314	25.196	19.175 = 10.652
65.0	1.423	25.690	18.047 = 10.026
70.0	1.533	26.185	17.081 = 9.489
75.0	1.642	26.680	16.243 = 9.024
80.0	1.752	27.174	15.510 = 8.617
85.0	1.861	27.669	14.863 = 8.257
90.0	1.971	28.163	14.289 = 7.938
95.0	2.080	28.658	13.774 = 7.652
100.0	2.190	29.153	13.311 = 7.395

VIII - RATE OF RETURN ANALYSIS

1. <u>Assumed price of kWh</u>

load factor 80%		Cr$/kWh :	15.510
assumed min.and max.load factors		70%	90%
	Values	10^9 Cr$/year	10^9 Cr$/year
2. Annual income		23.777	30.571
3. Annual expenses			
A. Operation & Maintenance		2.095	2.095
B. Fuel		6.924	8.902
C. External Loan Annuities *)		8.842	8.842
D. Depreciation Charge	---------	4.793	4.793
	Total:	22.655	24.633

*) The payment of the external loan was calculated as follows:

	10^6 US$	=	10^9 Cr$
a) External Loan			
A. Foreign component of capital cost	34.500		
B. Price of 1st Fuel Load + 10% reserve	16.646		
C. Interest during construction	5.200		
Total:	56.346		101.424
b) External Loan Annuity (20 years, 6% p.year)	4.912		8.842

4. ANNUAL NET PROFIT

with Load Factor	10^9 Cr$ 70%	10^9 Cr$ 90%
A. Annual Income	23.777	30.571
B. Annual Expenses -------------	22.655	24.633
Annual net Profit	1.122	5.937

5. <u>Calculation of Return Rate</u>

1. Capital Invested Cr$ 45.985.000.000
2. Rate of return = $\frac{\text{Annual net Profit}}{\text{Capital Invested}}$

2. Rate of return = $\frac{\text{Annual net Profit}}{\text{Capital Invested}}$

at load factor	70% (min.)	90% (max.)
	2.44%	12.91%

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T A B L E V I I - 2

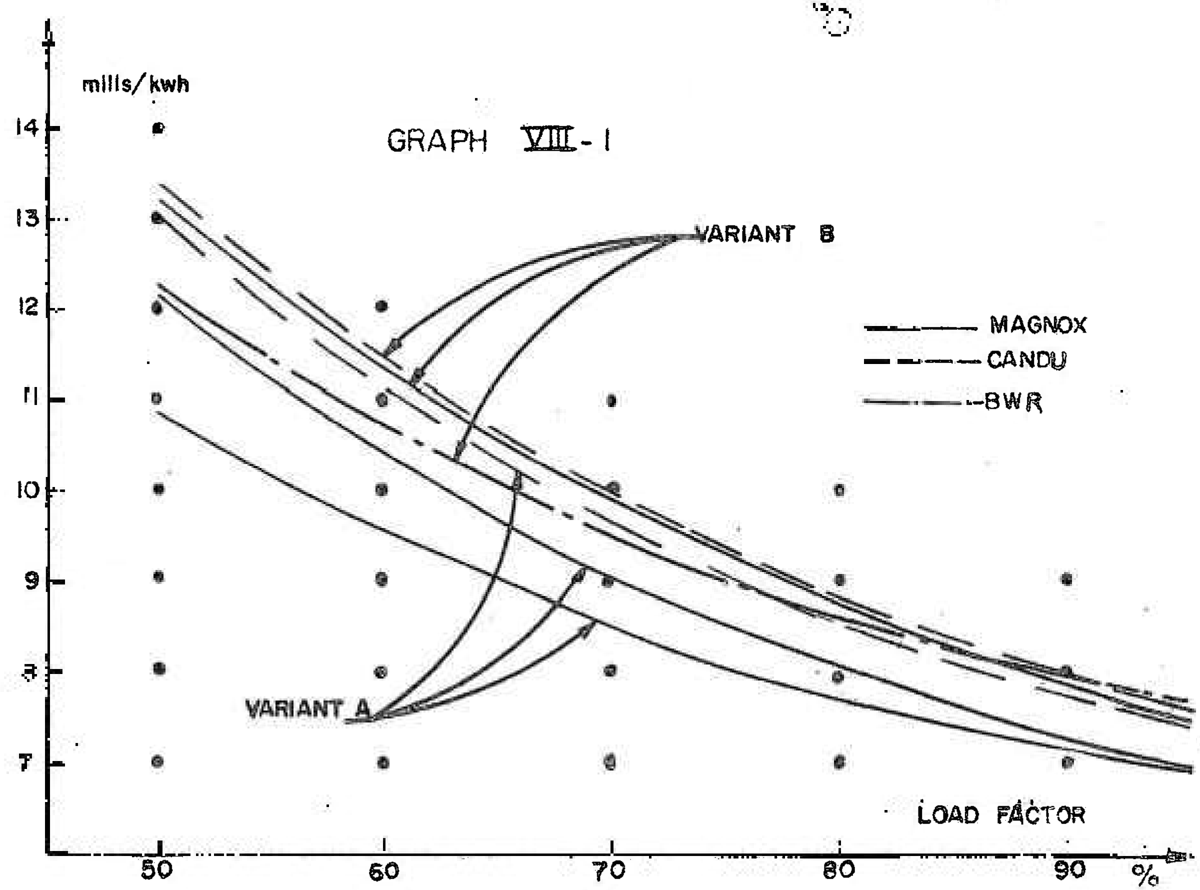
RESUMED RESULTS OF THE ECONOMIC ANALYSIS

Net Electric Power : 250 MWe
Change : 1 US$ = C$ 1.800

Item	Type of Power Station Variant		MAGNOX		CANDU		B.W.R.		REMARKS
			A	B	A	B	A	B	
	Energy Cost with load factor	mills/KWH							
1	**50%**	"	12.184	13.295	13.079	13.484	10.875	12.281	
2	**60%**	"	10.334	11.260	11.085	11.423	9.481	10.652	
3	**70%**	"	9.013	9.806	9.661	9.950	8.485	9.489	
4	**80%**	"	8.022	8.716	8.593	8.846	7.738	8.617	
5	**90%**	"	7.251	7.868	7.762	7.987	7.157	7.938	
6	**100%**	"	6.634	7.190	7.097	7.300	6.692	7.395	
7	Capital repayment	10^6 US$/ year	3.606	4.682	4.240	5.578	3.593	4.912	in 20 years, with 6% interest
8	Fuel Cost	"	1.846	1.846	1.928	1.928	4.266	4.266	at 80% load factor

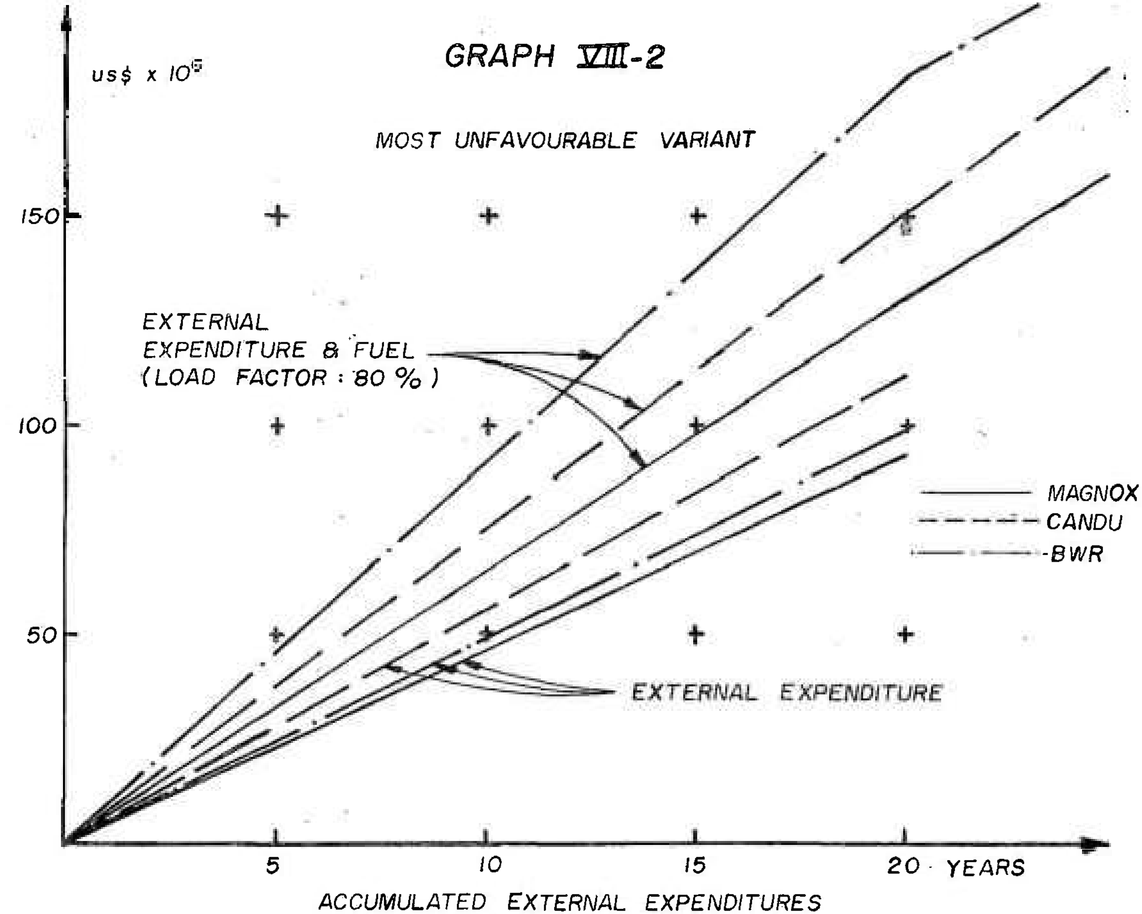
Variant A : Admitted most favourable
Variant B : Admitted most disfavourable

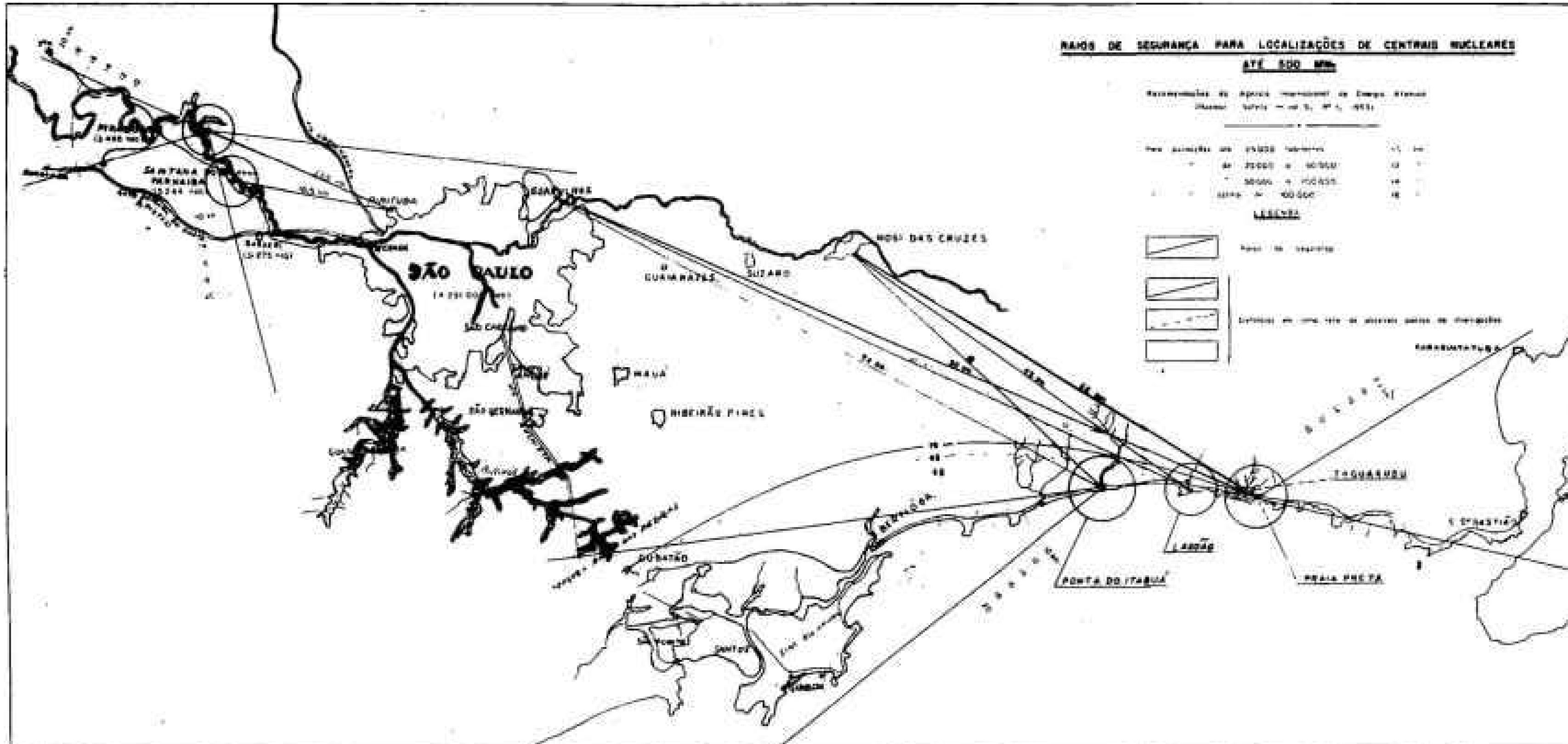
GRAPH VIII - I



VARIANT: A MOST FAVOURABLE
VARIANT: B MOST UN FAVOURABLE

GRAPH VIII-2


us$ x 10^6
MOST UNFAVOURABLE VARIANT
150
100
50
EXTERNAL
EXPENDITURE & FUEL
(LOAD FACTOR : 80 %)
EXTERNAL EXPENDITURE
MAGNOX
CANDU
BWR
5
10
15
20 YEARS
ACCUMULATED EXTERNAL EXPENDITURES


RAIOS DE SEGURANÇA PARA LOCALIZAÇÕES DE CENTRAIS NUCLEARES
ATÉ 500 MWe
LEGENDA
SÃO PAULO
GUARULHOS
MOGI DAS CRUZES
SUZANO
GUAIANAZES
MAUÁ
RIBEIRÃO PIRES
CUBATÃO
SANTOS
BERTIOGA
PONTA DO ITAGUÁ
LAGÃO
PRAIA PRETA
S. SEBASTIÃO
CARAGUATATUBA
SANTANA DE PARNAÍBA

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