AN EVALUATION OF THORIUM CYCLE POSSIBILITIES ON BRAZILIAN NUCLEAR POWER PROGRAM

J. C. Santos
J. C. Mello
C. W. Urban
S. S. Brito

1. INTRODUCTION

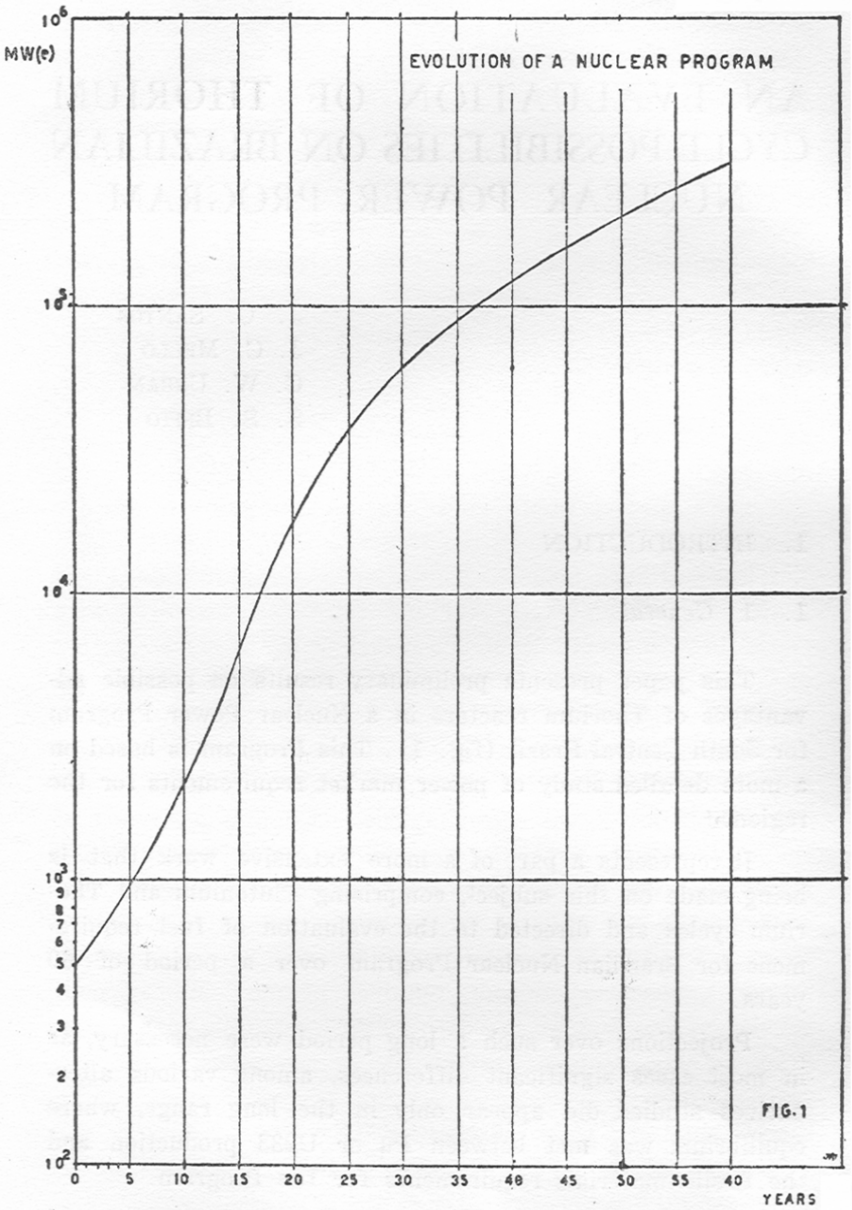
1. 1 *General*

This paper presents preliminary results on possible advantages of Thorium reactors in a Nuclear Power Program for South Central Brazil (fig. 1). This Program is based on a more detailed study of power market requirements for the region.

It represents a part of a more extensive work that is being made on this subject, comprising Plutonium and Thorium cycles and directed to the evaluation of fuel requiremens for Brazilian Nuclear Program over a period of 60 years.

Projections over such a long period were necessary, as in most cases significant differences, among various alternatives studied did appear only in the long range, where equilibrium was met between Pu or U233 production and the fissile materials requirements for the Program.

Growing uranium market restrictions could be expected in Occident from the end of the 70's, when, in particular, USA and Europe present known low cost reserves would be exhausted (1).



At the time, countries that would depend on world market to meet their own uranium requirements would be constrained "to buy all their uranium at bad economical conditions, subject to political hasards" (1).

Uranium prospection in Brazil is in a preliminary stage and even considering that no significant uranium reserves are known, new discoveries could be expected. Whatever the results of present prospection work could be, it seems clear that Brazil must use its uranium reserves in the best way, directing its nuclear policy towards independence of foreign nuclear fuel supplies, in the long range. The efficiency of such a policy could be evaluated by two fundamental parameters: the amount of basic natural uranium requirements and the time required to reach a self-sustained balanced economy on nuclear fuel.

1. 2 *Pu-U238 Cycle*

The first step in the study was an evaluation of various programs to meet demand requirements using Pu-U238 cycle. The cases studied included utilization of Graphite-Gas, Light Water or Heavy Water start-up converter reactors, with "once-through" fuel burnup, Pu recycling in the same reactors or Pu use in fast reactors (With or without excess Pu recycling in converters).

Results are shown in fig. 2. "Once-through" results are not discussed here. They show that such a program is not worthwhile due to the enormous fuel consumption for any of the three reactor types referred above. Pu recycling would result in a great saving of natural uranium but resulting total consumptions are still too large. In all cases it is necessary to go on to advanced breeders to situate uranium consumption at reasonable levels. Results obtained by the combination of converters and fast Pu breeders seems compatible with a program expected to use Brasilian fuel.

2. THORIUM CYCLE POSSIBILITIES

2.1 *Generalities*

Brazilian resources on Thorium ores lead to a particular interest in studing its utilization in a power program to verify if a reasonable saving in uranium consumption could be

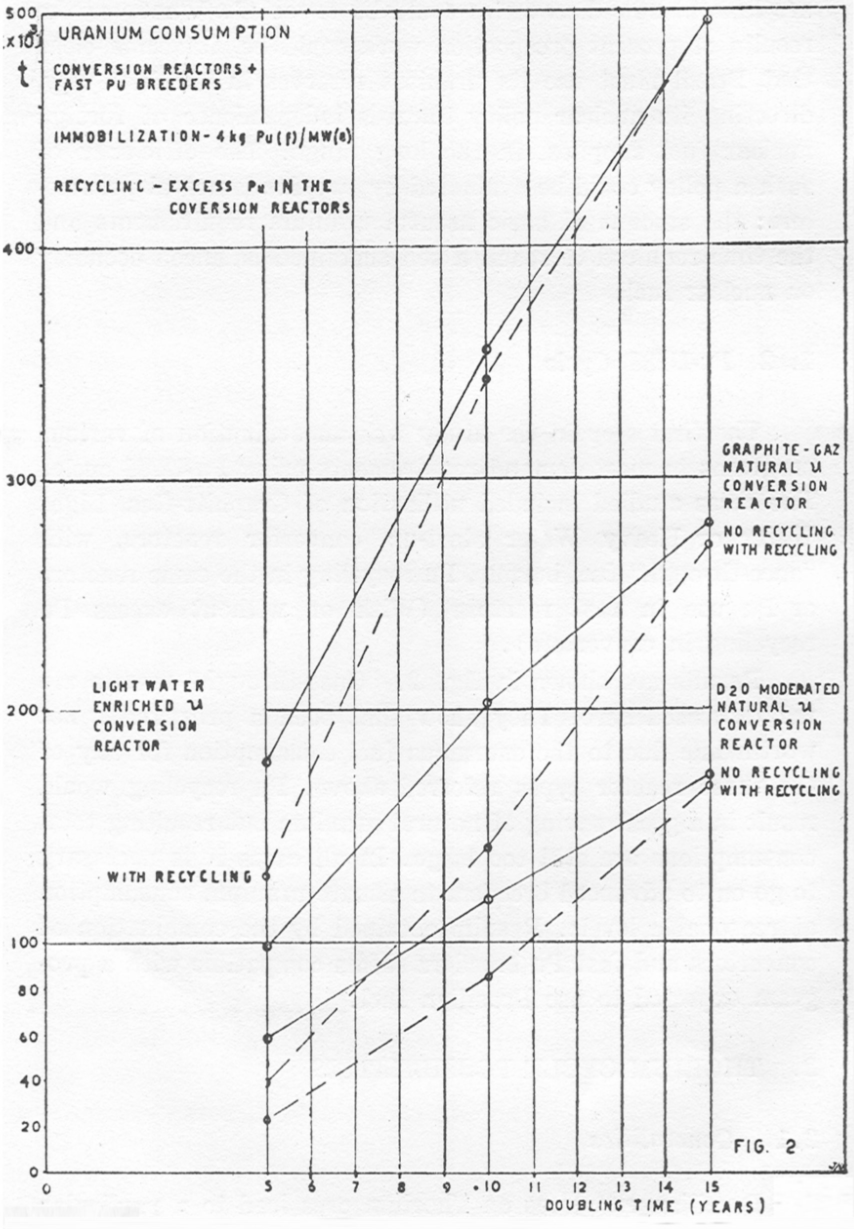

URANIUM CONSUMPTION
CONVERSION REACTORS + FAST PU BREEDERS
IMMOBILIZATION - 4 kg Pu(f)/MW(e)
RECYCLING - EXCESS Pu IN THE COVERSION REACTORS
t (x10³)
500
400
300
200
100
80
60
40
20
0
GRAPHITE - GAZ NATURAL U CONVERSION REACTOR
NO RECYCLING
WITH RECYCLING
LIGHT WATER ENRICHED U CONVERSION REACTOR
D2O MODERATED NATURAL U CONVERSION REACTOR
NO RECYCLING
WITH RECYCLING
WITH RECYCLING
0
5
6
7
8
9
10
11
12
13
14
15
DOUBLING TIME (YEARS)

FIG. 2

achieved or if general competitivity with Plutonium cycle is obtained.

In the case of Thorium cycle, studies where less detailed than in Pu cycle, due to the fact that various reactor parameters involved are not easily found in literature.

Two start-up reactors have been considered, both D_2O moderated; Thorium breeders doubling time was adopted as a parameter. In the Thorium cycle such reactors have a thermal or near-thermal spectrum while in the Plutonium cycle the spectrum is fast.

Results are compared with those obtained for the Pu cycle with natural uranium, heavy water, El-4 type start up reactors (which, in particular, leads to minimum uranium consumption, on Pu cycle).

2.2 *Reference Reactors*

For thorium cycle, start up reactors and equilibrium reactors (breeders) are of D_2O type.

Two concepts of D_2O -Thorium, reactors were considered to start-up Th cycle:

- — Du Pont de Nemours concept, called here "D. N," (2).
- — The under-moderated D_2O reactor concept which is being studied at Comissão Nacional de Energia Nuclear — characterized by "S.M." (*).

Doubling time of the breeder reactors was varied in the same way in both cases.

There is, however, a difference between them: for the D.N. case breeder reactors are the same start-up reactors, with U-233 recycling, while for the S.M. case breeder reactors are different from start-up reactors.

In both cases highly enriched U-235 fuel was assumed to start-up.

(*) The studies are in a preliminary phase. The parameters used in this paper are subjected to corrections with the progress of the studies.

2. 3 *Parameters*

Physical parameters used in each case were the following:

D.N. Reactor concept: (*)

- 0,800 metric tons of natural uranium/Mw (e) necessary for each reactor to achieve equilibrium.
- two hypotheses (7 and 10 years) were assumed for the time required by the reactor to reach equilibrium. (**).

S. M. Reactor concept:

— Fuel inventory (expressed in metric tons of natural uranium):	0,500 t/Mw (e)
— Natural Uranium consumption	0,160 t/Mw y (e)
— Diffusion plant tail enrichment	0,30%
— U-233 net production	0,600 kg/Mw y (e)

The immobilization assumed for the Pu-breeder reactor was 4 kg Pu (f)/Mw(e). For the Th-breeder reactors this was 2 kg U-233/Mw(e) divided into:

1,5 kg — charge
0,5 kg — cooling; reprocessing; refabricating.

This value can be justified if it is assumed that the life time of reactor charge is 900 days corresponding to 3 years of reator operation, with a load factor of 80%.

One year delay was assumed for fuel cycle outside reactor.

Specific power of thorium cycle reactors was 10 Mw/t (Th).

(*) Other data on this type are in ref. (2).

(**) The reference quoted does not give any information about delay to reach equilibrium, Hypothesis assumed resulted from brief calculations. oout delay to lations.

A "waiting time" of 12 years was admitted for thorium in order to permit decay of Th-228 and its descendents resulting in a thorium immobilization of 0.4 t/Mw(e). This hypothesis is pessimistic, and was deliberately used in view of obtaining maximum values to compare with Brazilian Thorium reserves (upper curve, fig. 6).

Thorium requeriments would be substantially decreased if appropriate reprocessing and fabrication methods could be used; so, a thorium immobilization of 0,14 ton/Mw(e), which corresponds to a "out-of-reactor" time of 1 year, has been also considered (lower curve, fig. 6).

Technological developement would depend on the conditions of the thorium market. Probably, thorium consumption will be given at first by the upper curve and will approximate the lower one as thorium requirements increase.

The following ranges were chosen for doubling time:

— 5 to 15 years for fast breeders of the plutonium cycle.

— 15 to 25 years for thermal breeders of thorium cycle.

These two ranges are believed to be comparable. Values comprised between 5 and 15 years are commonly accepted for fast Pu breeders. For thermal U-233 breeders the values 15 to 25 years are based on breeding possibilities that are being investigated in another study.

Preliminary curves on the dependence between doubling time, breeding factor and fuel immobilization are shown in fig. 3.

In these curves it is seen that 15 to 25 years is a possible range in agreement with the chracteristics of thorium fuelled thermal reactors.

The expression used for doubling times is valid if total installed output as well as annual rate of reactor installation are high.

The immobilization comprises fuel charge and fuel outside reactor. Breeding factor is defined as

$$b = 1 + \frac{Cf - Ci}{C_q}$$

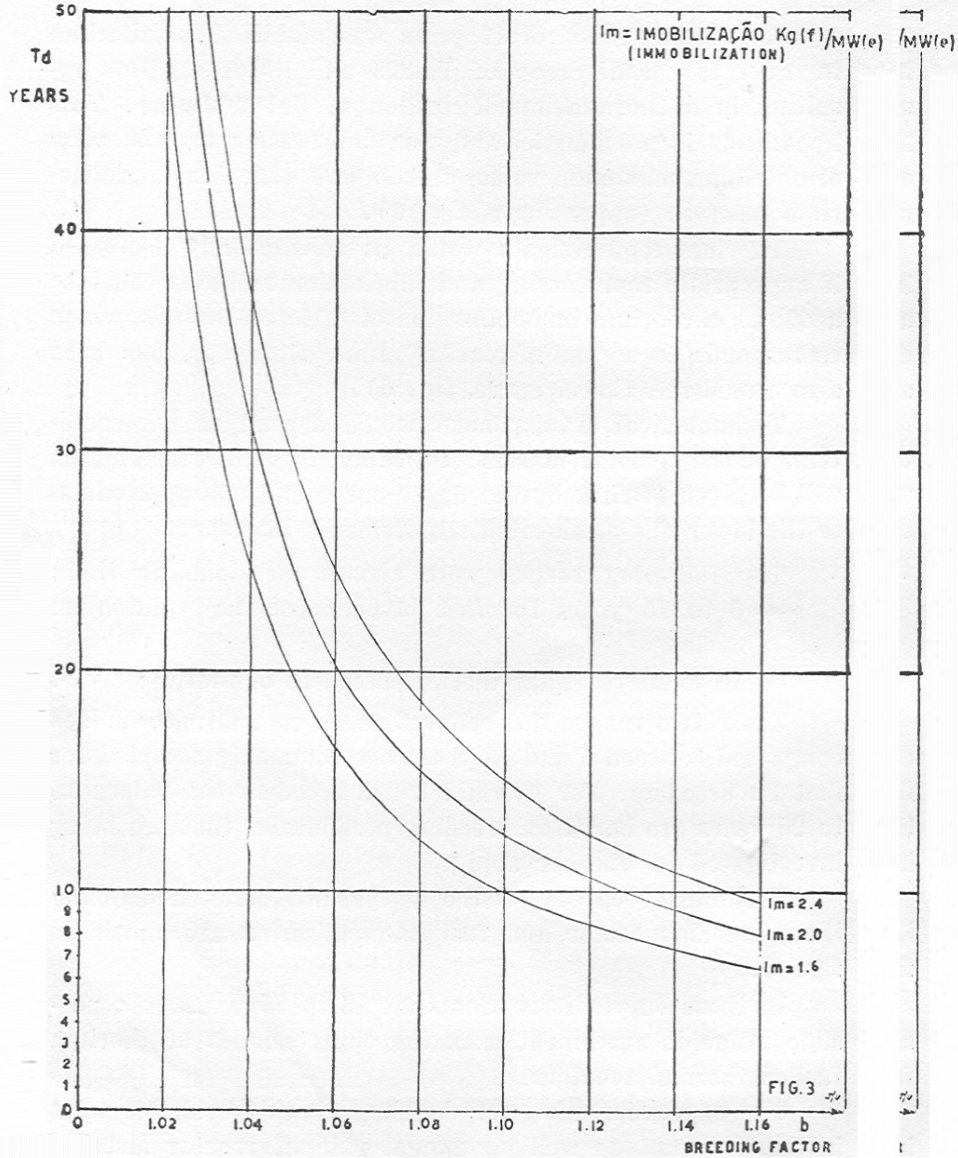


FIG. 3

Cf = final concentration of fissile material in irradiated fuel.

Ci = inicial concentration of fissile material.

C_q = fissile material burned during irradiation.

3.4 *Results*

Accumulated uranium consumption is represented for each case (Fig. 4). Assumed doubling times limit a range for each hypotheses.

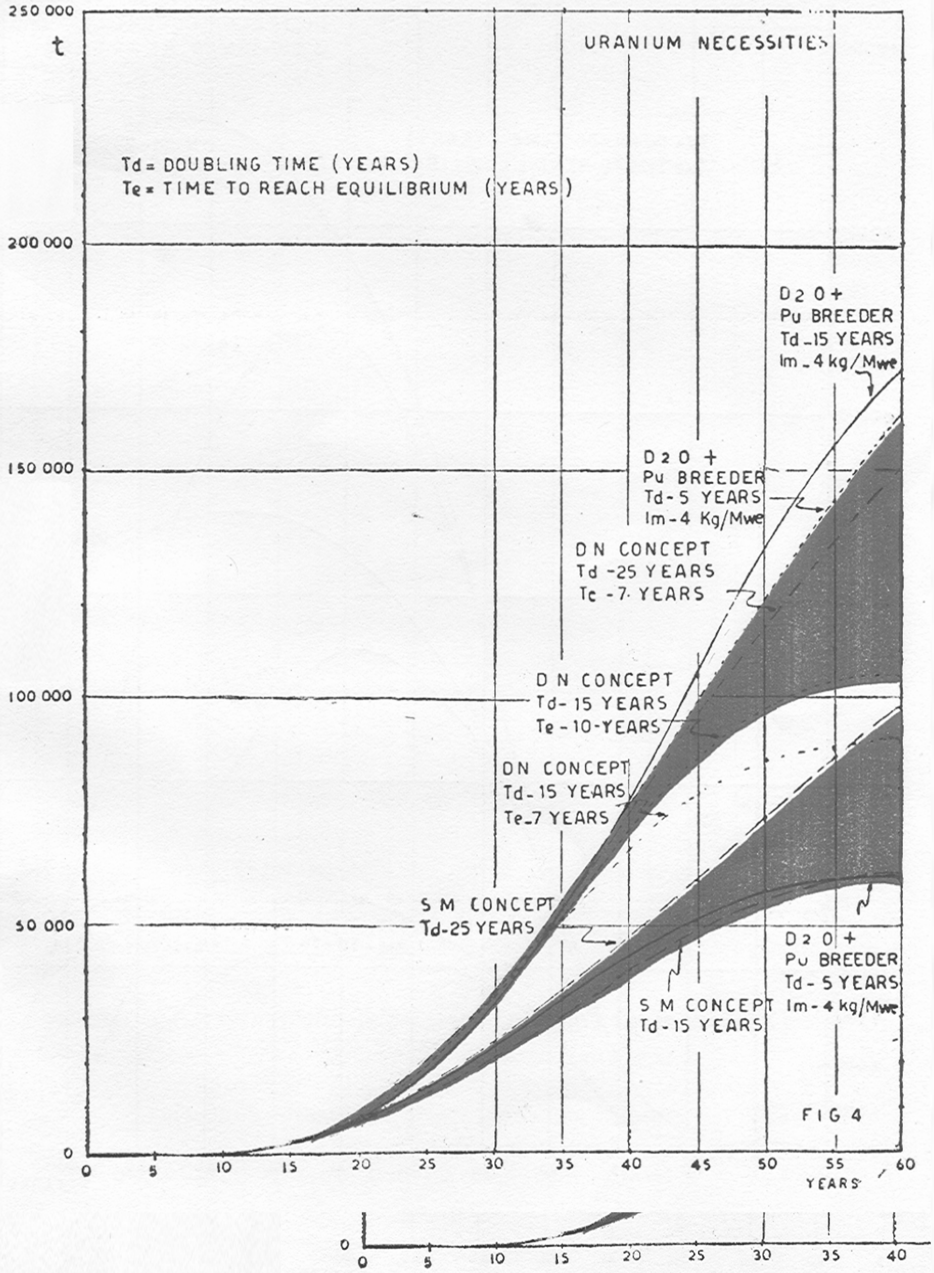


FIG 4

A long the first 25 years consumptions are not very different. After this, the range in each case are enlarged with the following tendency: the DN-Type for Th-cycle reac-

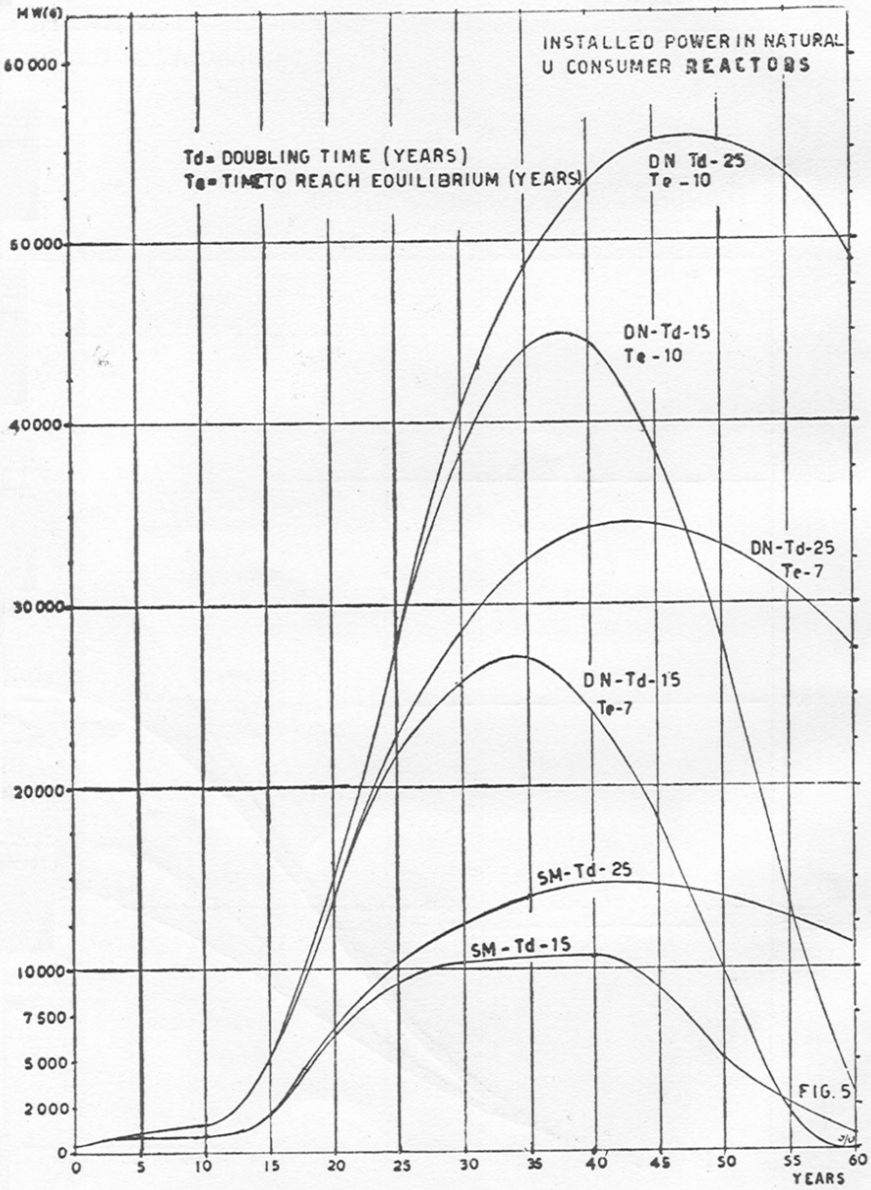


FIG. 5

tor is near the most pessimistic hypothesis for Pu-cycle while the SM-type is near the optimistic one.

Fig. 5 shows total power in converter for the Th-cycle.

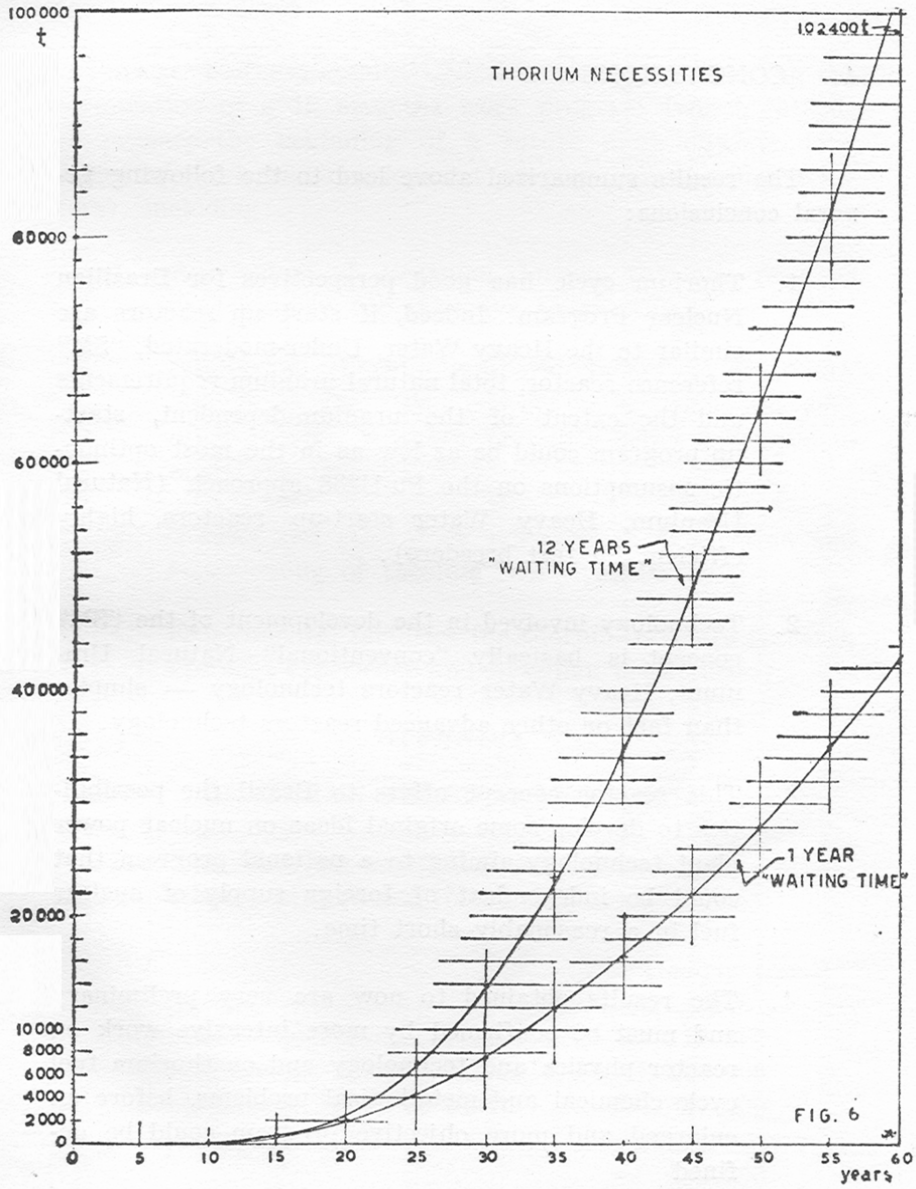


FIG. 6

Note in this respect the strong influence of equilibrium time, Te.

Fig. 6 represents thorium compsumption. It is assumed to be the same for all cases.

4. CONCLUSIONS

The results summarized above lead to the following general conclusions:

1. Thorium cycle has good perspectives for Brazilian Nuclear Program. Indeed, if start up reactors are similar to the Heavy Water, Under-moderated, "SM" reference reactor, total natural uranium requirements and the extent of the uranium-dependent, start-up program could be as low as in the most optimistic assumptions on the Pu-U238 approach (Natural Uranium, Heavy Water start-up reactors, highly efficient Pu fast breeders).

2. Technology involved in the development of the "SM" concept is basically "conventional" Natural Uranium; Heavy Water reactors technology — simpler than fast or other advanced reactors technology.

3. This reactor concept offers to Brazil the possibilities to develop some original ideas on nuclear power plant technology aiming to a national program that could be independent of foreign supply of nuclear fuel in a reasonably short time.

4. The results obtained to now are very preliminary and must be confirmed by more intensive work on reactor physics and technology and on thorium fuel cycle chemical and metallugical problems, before an enlarged and more objective program could be defined

5. In all cases, a coherent program on research and development and on nuclear power production, could not be realized before domestic uranium and thorium ressources are estimated to some degree of confidence.

Aware of these results, CNEN is actively considering the formulation of a 12 mounths work program (which intends to prepare the beginning of a future more objetive long range research and development program on thorium reactors), including:

1. Assessment of Brazilian known thorium reserves and uranium ore intensive prospection.

2. Studies on thorium reactors, including feasibility studies on the "SM" concept to be compared with other thorium reactors, presently being developed in other countries.

3. Studies and laboratory research on fabrication and reprocessing of thorium fuel elements.

4. Experimental facilities for thorium reactors research (foreign experience and Brazilian possibilities).

APPENDIX

BRAZILIAN THORIUM RESOURCES

Brazilian Thorium ocurrences are of two types: Monazitic sand beach placers and inland deposits.

		(metric tons) ThO_2
Monazitics sands	~	15.000
Pyrochlore of Araxa	~	130.000
Bastnasite of Morro do Ferro	~	37.000
	~	182.000

Other ocurrences not yet evaluated are: São João del Rey, Serra Negra, Tapira, etc. (Ref. 5, 6).

The present day exploration is restricted to monazitic sands. This exploration is being done by Orquima estimulated by government, and destinated to rare earth salts and trorium oxide production.

The present production capacity is 300 t ThO_2/y and the Comissão Nacional de Energia Nuclear stoks are about 1.000 t.

This number is quite sufficient for the firsts years of the Power Program.

ACKNOWLEDGMENTS

We are pleased to acknowledge Prof. Borisas Cimbleris for helpful discussions and suggestions during the preparatins of the present paper, as well as Brazilian Nuclear Energy Commission and Instituto de Pesquisas Radioativas for the permission to publish.

REFERENCES

1. Communauté Europeène de l'Energie Atomique — Le problème des ressources et de l'approvisionnement en uranium à long terme — EUR/1414/Bruxelles, 1963.

2. St. John and Wade — D_2O Reactors for Breeding with Thorium; Nucleonics Sep. 1964.

3. J. Bussac — L'Utilization du plutonium dans les réacteurs à neutrons thermiques et dans les réacteurs à neutrons rapides — — Baden Baden, Septembre 1963.

4. R. Naudet et M. Salesse — Les cycles de combustibles dans les reacteurs de puissance à cau-lourde refroidis par gaz. Baden Baden, Septembre 1963.

5. O. H. Leonardos — Revista de Minas e Metalurgia — Vol. XXII, n 127 (Julho de 1955); vol. XXIII, n. 137 (1956).

6. Sylvio Froes de Abreu — Recursos Minerais do Brasil — Rio de Janeiro, 1962.