Preliminary Proposal for a Joint Project on Utilization of Thorium in Nuclear Reactors

Experiments in the IPEN/MB-01 Zero-Power Reactor

Paulo E. O. Lainetti

Nuclear and Energetic Research Institute - IPEN/CNEN-SP

Ministério da
Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

CNEN
Comissão Nacional
de Energia Nuclear

Why thorium?

^{232}Th

Ministério da
Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

CNEN
Comissão Nacional
de Energia Nuclear

In December 2010, in the event IBEROEKA in Rio, I highlighted the importance of the concept of the **Homogeneous Molten Salt Reactor.**

In my opinion, the most interesting of the fourth-generation advanced reactors proposed, considering the use of thorium.

China is Leading Now...

Wednesday 30 March 2011

The Telegraph:

Safe nuclear does exist, and China is leading the way with thorium

"China revealed that it was launching a rival technology to build a safer, cleaner, and ultimately cheaper network of reactors based on thorium"

"China's Academy of Sciences said it had chosen a "thorium-based molten salt reactor system". The liquid fuel idea was pioneered by US physicists at Oak Ridge National Lab in the 1960s, but the US has long since dropped the ball. Further evidence of Barack `Obama's "Sputnik moment", you could say.

Chinese scientists claim that hazardous waste will be a thousand times less than with uranium. The system is inherently less prone to disaster. "

Thorium

- Thorium naturally occurs on earth and is slightly radioactive in its natural form

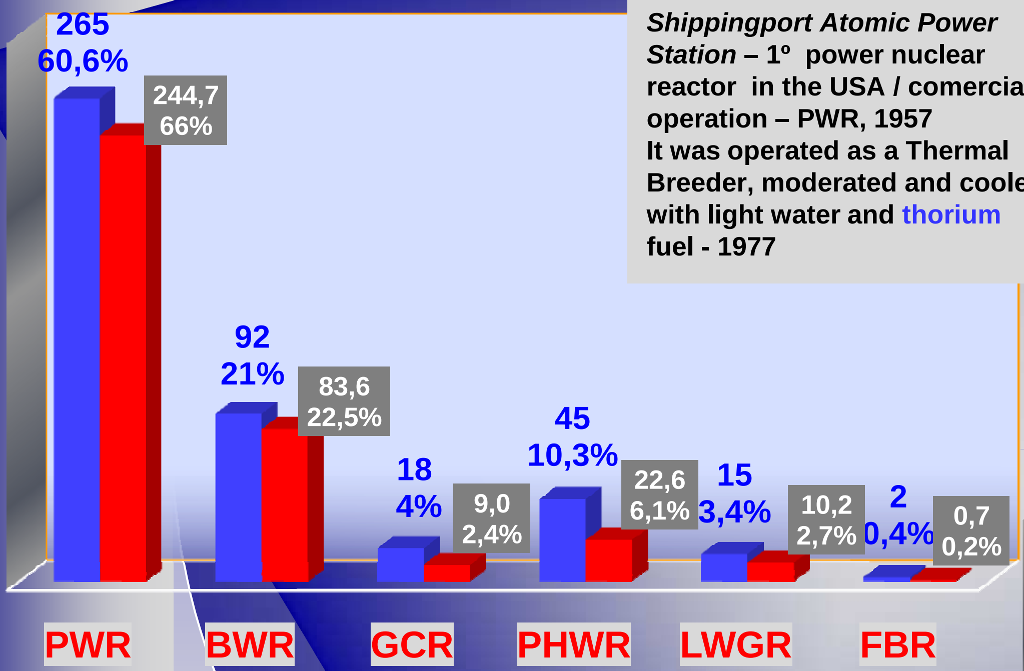
- In nature, thorium is found in the isotope 232 and decays slowly by emitting alpha particles

- The half life of Thorium-232 is 14.05 billion years ~ age of Universe

- The greatest interest in thorium is in its ability to be used in the *Liquid-Fluoride Thorium Reactor* (LFTR) with significant advantages over the nuclear reactors operating nowadays

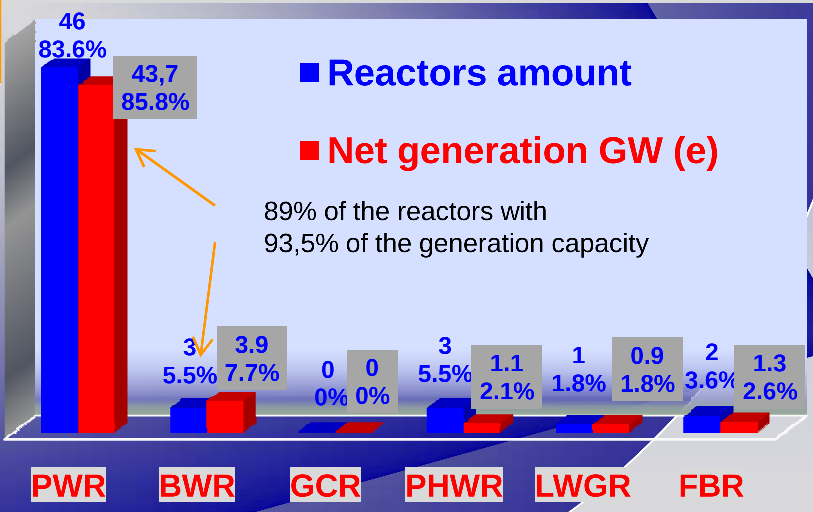
- Alternative use of Thorium was considered before the predominance of LWR (PWR / BWR) – 70s

Nuclear Reactors in Operation and Construction (by type) and Generation Capacity GW (e)



Shippingport Atomic Power Station – 1º power nuclear reactor in the USA / comercial operation – PWR, 1957
It was operated as a Thermal Breeder, moderated and cooled with light water and thorium fuel - 1977

Total: 55 reactors under construction on 31/12/2009 in 14 countries with generation capacity total of 50.9 GW (e)



89% of the reactors with
93,5% of the generation capacity

Fonte: Nuclear Power Reactors in the World, Reference Data Series No.2, IAEA 2010

ipen

CYTED

Ministério da Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

cnen Comissão Nacional de Energia Nuclear

Consumption and Price of Uranium

- Current world nuclear generation capacity = 370 GW(e), consuming 65 to 70 mil tU/year

- Scenarios for 2050: $600_{(L)}$ to $1400_{(H)}$ GWe Source: IEA-NEA 2008

- Each additional GWe requires + ~ 195 tU / year

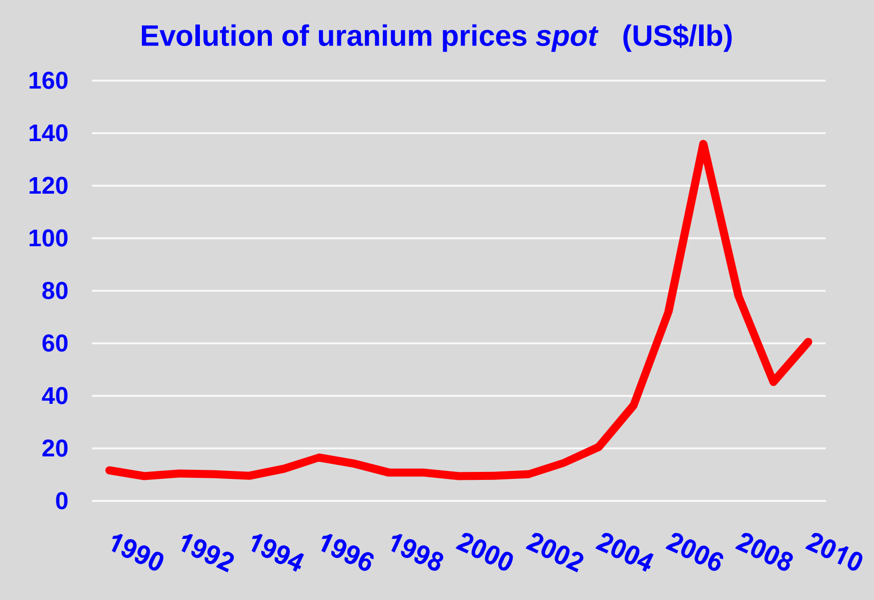
- With $1000_{(l)}$ GW(e):

consumption will be 190,000 tU/year

- Limited resources of U in Asia and

Latin America

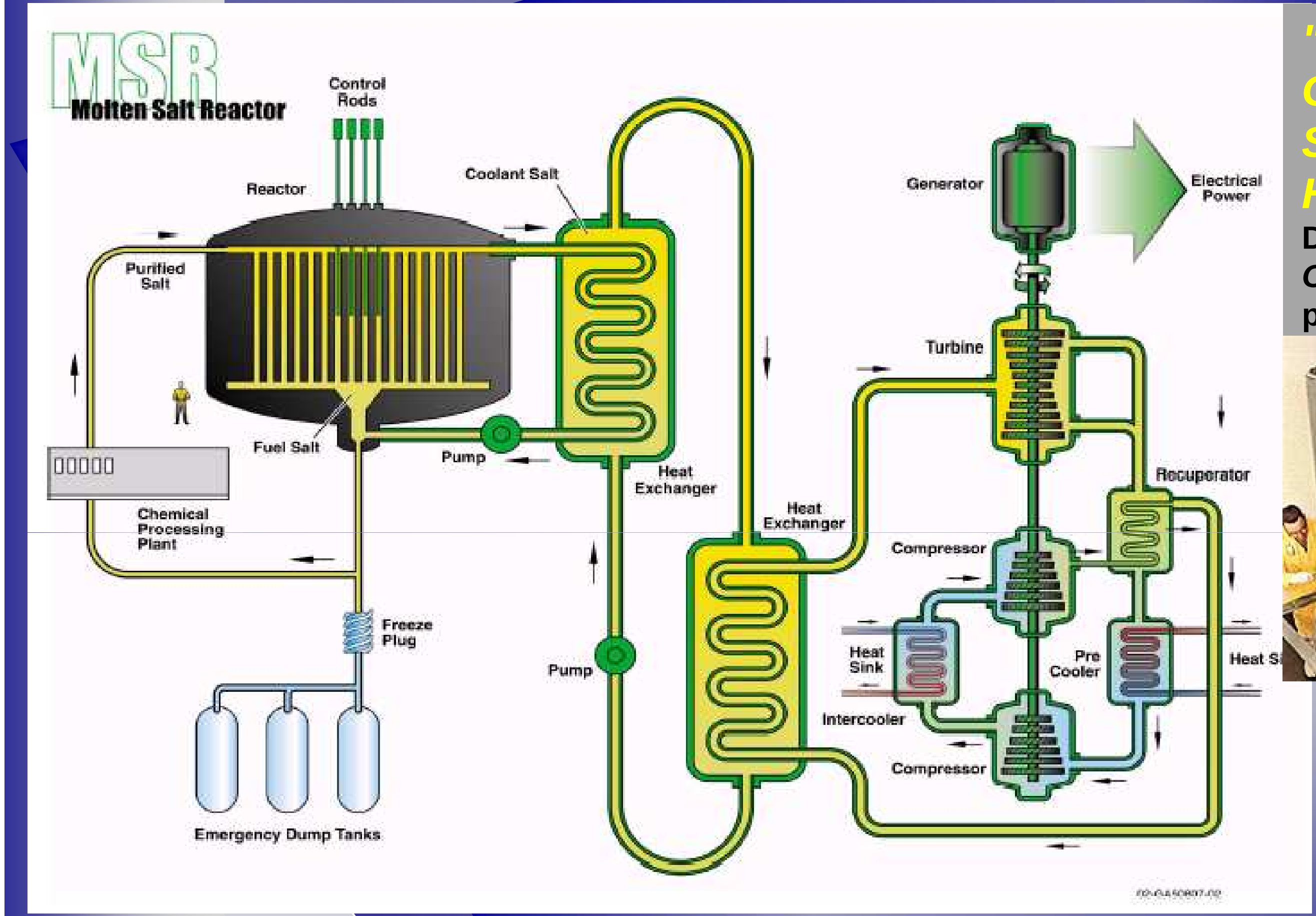
- U price ???



Fonte: http://www.cameco.com/marketing/uranium_prices_and_spot_price

Dr. Paulo Lainetti
June, 2011

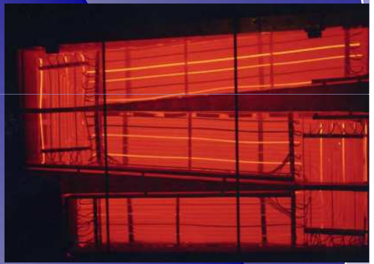
Liquid-Fluoride Thorium Reactor - LFTR



"MOLTEN SALT WAS A GOOD IDEA...MOLTEN SALT STILL IS A GOOD IDEA, I HOPE SOMEONE DOES IT."

Dr. Alvin Weinberg, former-director do *Oak Ridge National Laboratory* (PWR patent)

***Molten Salt Reactor Experiment* - ORNL**



Dissipating heat from the MSRE

MSR is the only reactor system from the GEN IV reactor family for which the thorium fuel is actually considered

***Molten Salt Reactor Experiment*, ORNL- USA Homogeneous reactor, operated from 1965 to 69. From jan. to may 1969 operated with ^{233}Th as fuel.**

Liquid-Fluoride Thorium Reactor - LFTR

- **The LFTR fuel is constituted by a mixture of thorium, uranium, lithium and beryllium fluoride salts: ThF_4 and UF_4 dissolved in $^7LiF–BeF_2$**

- **These salts are chemically stable, they are immune to radiation damage and will not corrode the vessels that contain them**

- **MSR can be operated either as thorium breeder: thermal spectrum, $^{232}Th–^{233}U$ fuel cycle or as actinide transmuter: epithermal spectrum, burning transuranic waste**

- **Because these characteristics, the LFTRs can sustain high temperatures and radiation levels, giving them increased efficiency and reduced size**

Benefits of an LFTR

- **LFTRs are an extremely safe, self regulating design: in case the reactor overheats an emergency salt “freeze plug” melts and the molten salt in the core is drained to a passively-cooled tank**

- **LFTRs burn pratically all their fuel and would generate 1000 to 10000 less nuclear waste than the current reactors**

- **83% of the wastes of LFTRs are safe within 10 years and 17% in 300 years (compared to 10000 years of current reactors waste)**

- **Compared to traditional nuclear reactors which "burn" the fissile isotope ^{235}U, the LFTR uses fissile ^{233}U which is derived from ^{232}Th, have no refueling outages and are able to continually refuel and remove waste product**

- **^{235}U constitutes only 0.7 percent of mined natural uranium, but practically all of the thorium can be converted to ^{233}U (no processing for enrichment is needed)**

- **LFTRs operate at high temperatures with thermal/electric conversion efficiency of ~ 50%, have low initial costs (do not need huge pressure vessels or containment domes for safety), have low cooling requirements and are air cooled (feasible for locations with water scarcity)**

But, if LFTRs are a “distant dream” (for us, by now): What could be done? What would be feasible at this time?

ipen

PROGRAMA IBEROAMERICANO
CYTED
CIENCIA Y TECNOLOGÍA PARA EL DESARROLLO

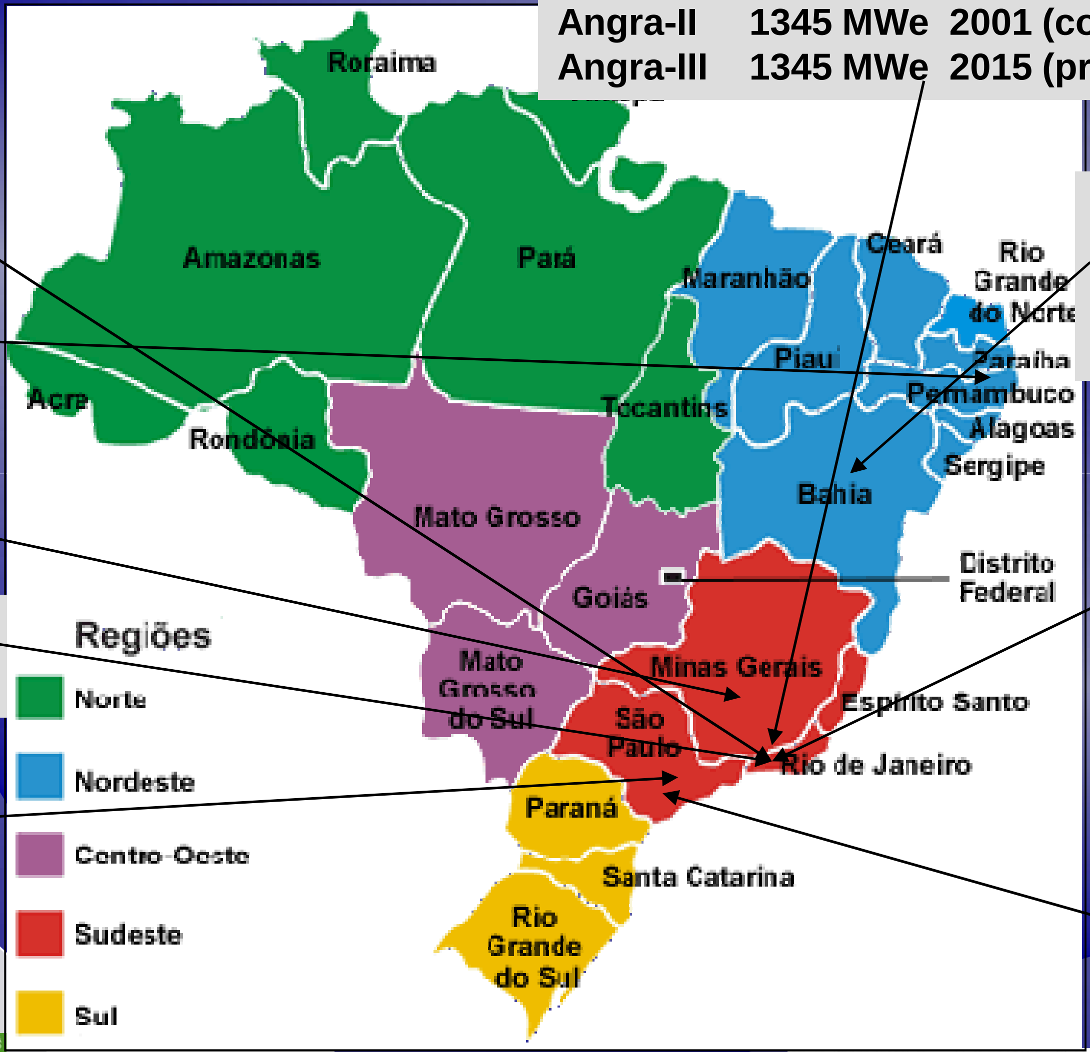
Ministério da
Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

CNEN
Comissão Nacional
de Energia Nuclear

Main Brazilian Nuclear Facilities



Two nuclear power plants/one under construction:

Angra-I	657 MWe	1985 (com.op.)
Angra-II	1345 MWe	2001 (com.op.)
Angra-III	1345 MWe	2015 (prev.op.)

CNEN
R & D Centers

CRCN

CDTN
1 RR

IEN 1 RR
and IRD

IPEN
2 RRs

Sixth uranium reserves in the world

310,000 t U_3O_8 L.C.

Caitite county - Ba

Eletronuclear
NUCLEP
FCN INB

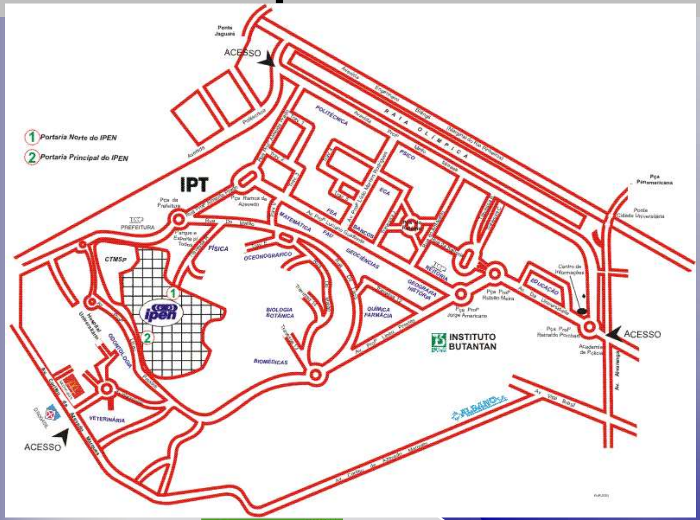
CTM - Aramar
Brz. Navy
2 RRs
(design/construction)

Ministério da
Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

IPEN-CNEN/SP
Nuclear and Energetic Research Institute

- Is an institution owned by the Government of Sao Paulo State
- Is supported and operated technical and administratively by the Brazilian Nuclear Commission - CNEN
- Is associated to the University of Sao Paulo for postgraduate courses purposes
- It was created in 1956 with the main purpose of performing research and development of nuclear energy peaceful applications



IPEN is located in the Sao Paulo City inside the Campus of Sao Paulo University, with an area of nearly 500,000 square meters

Dr. Paulo Lainetti
June, 2011

IPEN / MB - 01 Research Reactor

IPEN-MB 01 is a genuinely Brazilian nuclear reactor, designed by researchers and engineers from IPEN-CNEN/SP, financed and built by the Navy of Brazil, reached its first criticality on 15 hours and 35 minutes on 9th November 1988.

Ministério da
Ciência e Tecnologia

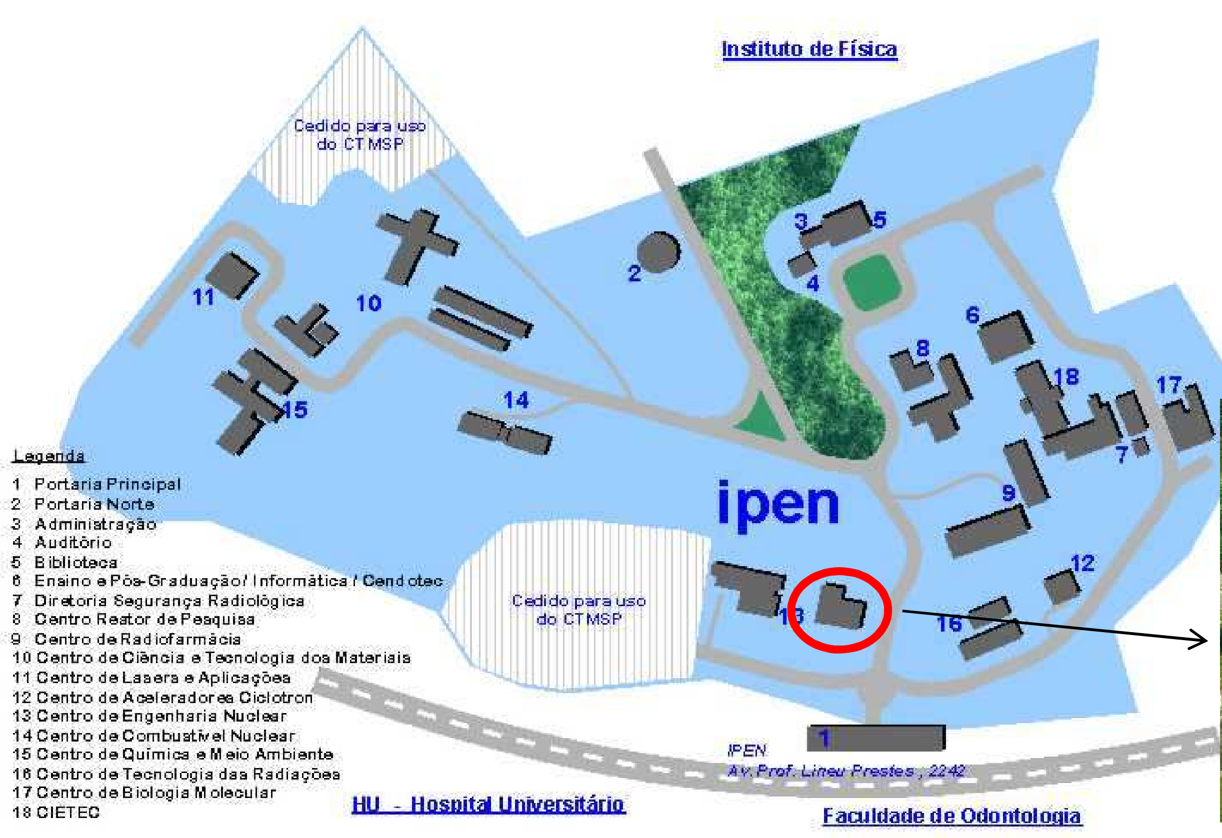
Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

CNEN
Comissão Nacional
de Energia Nuclear

IPEN / MB - 01 Research Reactor

The IPEN/MB-01reactor is a nuclear facility that allows the simulation of all the characteristics of a large-scale nuclear reactor without the need to build up a complex system of heat removal.



Dr. Paulo Lainetti
June, 2011

IPEN / MB - 01 Research Reactor

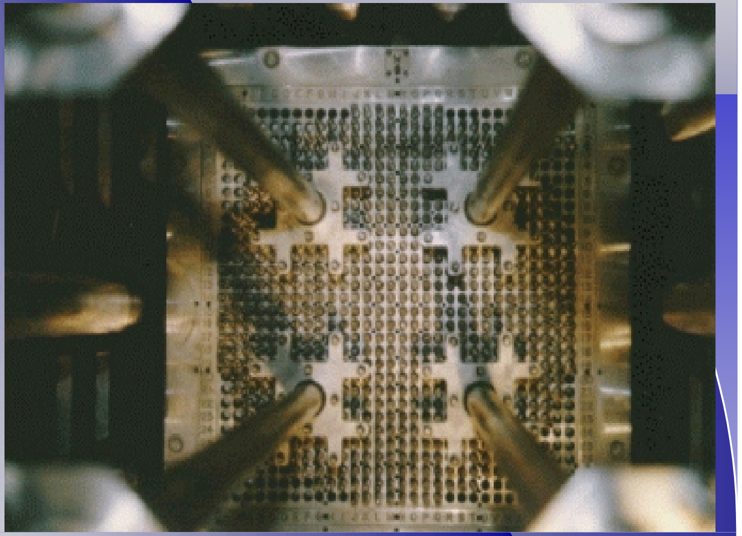
Reactor Description

- The first IPEN/MB-01 reactor core has a parallelepiped shape with dimensions of the active region of 39 x 42 x 54,6 cm, consisting of a 28 x 26 array of 680 fuel rods and 48 guide tubes, for insertion of control / security rods, responsible for the chain reaction control and reactor's shutdown.

- In this configuration, said rectangular, there are 680 fuel rods. However, the core of the Nuclear Reactor IPEN/MB-01 allows different critic assembly arrangements, namely core configurations.

- The matrix plate that holds the reactor core has 900 holes spaced by 15 mm, in a 30 x 30 array. The reactor fuel rods are made of stainless steel AISI-304 tubes, containing in its interior 52 UO_2 fuel pellets enriched to 4.3% ^{235}U.

- The production of the fuel pellets, since the UF_6 reconversion to AUC, was accomplished in IPEN (1986-88).



Dr. Paulo Lainetti
June, 2011

International Thorium Joint Project:

Main objective: search and consolidation of the knowledge for possible future use of the thorium in nuclear reactors

A proposal of an **International Joint Project** for developing some research regarding Th utilization for PWR reactors or for actinides incineration (Energy Amplifier proposed by the nobel laureate Carlo Rubbia)

The Project would include since the production of ThO_2 and $(Th\text{-}U)O_2$ fuel pellets until the accomplishment of some experiments in the IPEN/MB-01 reactor.

The main results would include keeping and expanding capabilities of existing laboratories and research groups / obtaining reactor physic data for thorium fuels.

Participants of different countries could participate in several activities: preliminary neutronic calculations; fuel pellets production and rods assembling; collect data in experiments with different core configurations...

ipen

PROGRAMA IBEROAMERICANO
CYTED
CIENCIA Y TECNOLOGÍA PARA EL DESARROLLO

Ministério da
Ciência e Tecnologia

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

CNEN
Comissão Nacional de Energia Nuclear

Proposal for Th Use in the IPEN / MB - 01

This proposal is based on a previous work accomplished in 1996-97, presented and published in the Proceedings of the:

VII CGEN – Congresso Geral de Energia Nuclear 98/99

B. Horizonte – MG / Brasil

UMA PROPOSTA DE ESTUDO BRASILEIRA VISANDO A UTILIZAÇÃO DE TÓRIO EM REATORES

João Manoel Losada Moreira*,
Alfredo Yuutiro Abe*,
Paulo Miranda de Figueiredo Filho e**
Paulo Ernesto de Oliveira Lainetti**

*Centro Tecnológico da Marinha em São Paulo – CTM/SP
Av. Prof. Lineu Prestes 2242 - Cidade Universitária. CEP 05508-900. São Paulo, SP

**Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN-SP
Travessa R 400 - Cidade Universitária - CEP 05508-900 - São Paulo, SP

Proposal for a Th Core in the IPEN / MB - 01

Possible specific objectives:

- Development of ThO_2 and $(Th\text{-}U)O_2$ fuel production and characterization;
- Measure neutron flux distributions in U and Th mixed cores;
- Measure temperature coefficient of reactivity and reactivity of the rods ThO_2 and $(U\text{-}Th)O_2$;
- Measure ratios of internal reactions of the ThO_2 and $(Th, U)O_2$ rods;
- Obtain Nuclear Data for Th-^{233}U cycle and validate experiments in the reactor IPEN/MB-01;
- Establish more accurate neutronic methods of analysis for thorium cycles;
- Update the knowledge of thorium cycles for the participants

- **CTM - Navy's Technological Center in Sao Paulo has facilities for uranium enrichment and may provide the enriched UF_6 for the manufacture of the fuel pellets;**

- **IPEN can supply the thorium nitrate / oxide and different production steps (maybe with the CDTN , CTM, ??? : conversion of UF_6 into uranyl nitrate; pellets compactation, sintering and grinding; assembling of fuel rods; neutronic calculations; chemical and physical characterization (Contribution of other research centers of different countries?)**

ipen

CYTED

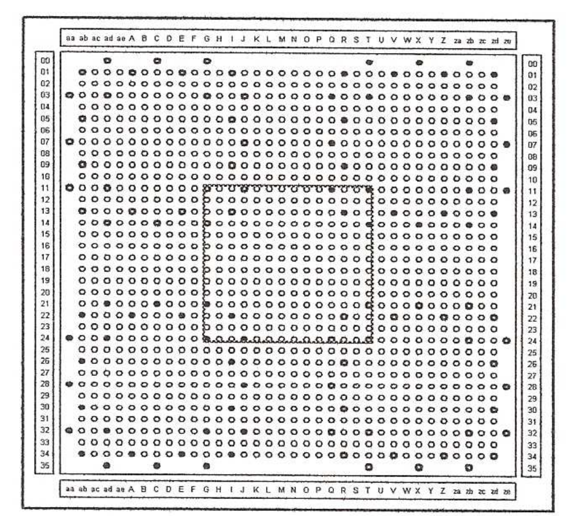
Ministério da
Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

CNEN
Comissão Nacional
de Energia Nuclear

Proposal for Th Use in the IPEN / MB - 01



Schematic diagram of UCRI's core. The square indicates the core region for testing with thorium

Fuel pellets and assembling of a fuel rod

Reactor core
IPEN-MB01 (UCRI)

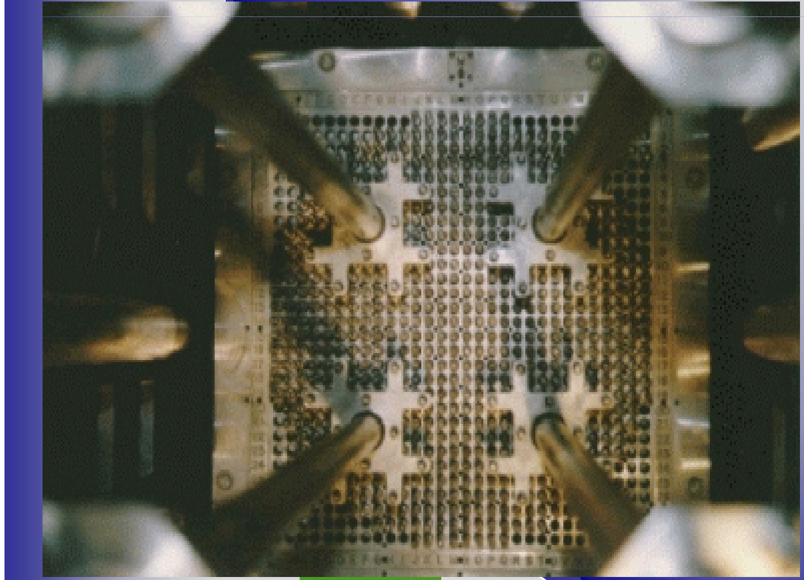


TABLE 1: Masses required of enriched U and Th for the neutronic experiments aiming Th development

Region of test	**ThO_2 (kg)**	**$(Th\text{-}U)O_2$ (kg)**	**U (5%) (kg)**	**Th (kg)**
ThO_2 8 x 8	21.2	-	-	18.7
$(Th\text{-}U)O_2$ 50 % Th 12 x 12	-	47.7	21.3	20.7
$(Th\text{-}U)O_2$ 75 % Th 10 x 10	-	33.1	7.4	21.7

Dr. Paulo Lainetti
June, 2011

Conclusion

- We have the main tool:

  Research Reactor facilities for the experiments, with participation of different groups / countries

- We have the main materials:

  Thorium* compounds (purified) and U (enriched)

* Maybe, in a Joint Scientific International Project, IPEN could provide the Thorium to other participants for a Intercomparative program

Acknowledgements

On behalf of IPEN/CNEN-SP and myself,

I am grateful to:

- *Dr. Luis Lopez and CNEA*
- *Dr. Harikrishnan Tulsidas and IAEA*
- *Prof. Dr. Roberto C. Villas-Bôas and CYTED*

Thank all of you, for your attention!

ipen

PROGRAMA IBEROAMERICANO
CYTED
CIENCIA Y TECNOLOGÍA PARA EL DESARROLLO

Ministério da
Ciência e Tecnologia

Dr. Paulo Lainetti
June, 2011

GOVERNO FEDERAL
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

cnen
Comissão Nacional
de Energia Nuclear