# THORIUM IN BRAZIL


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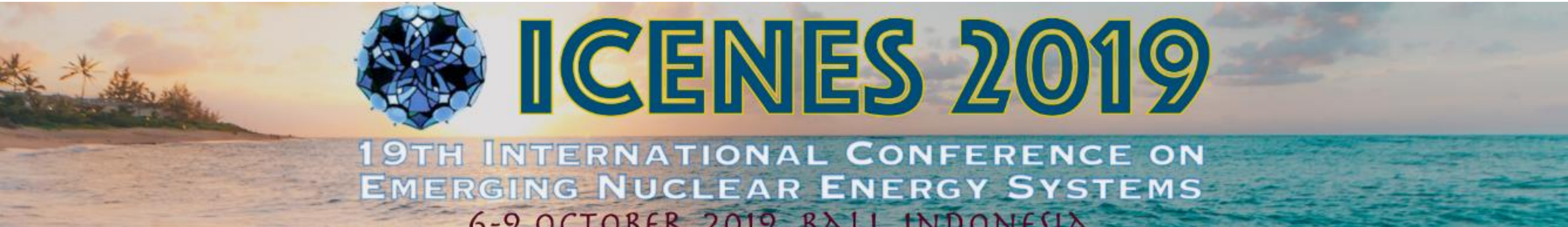

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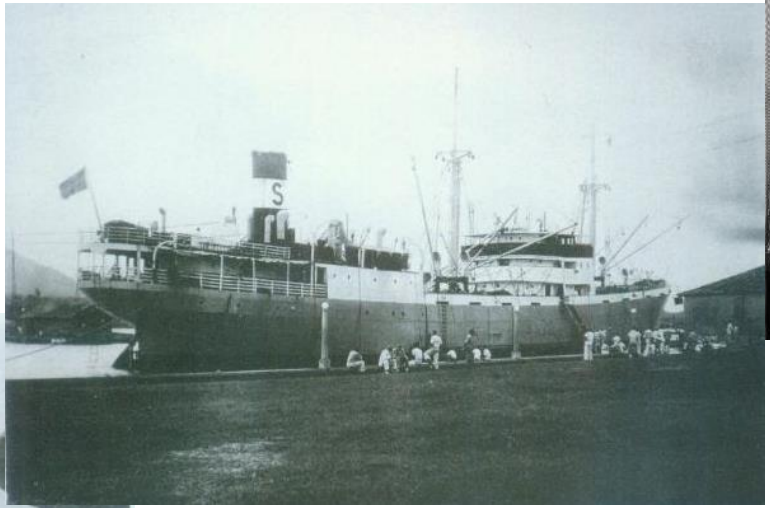
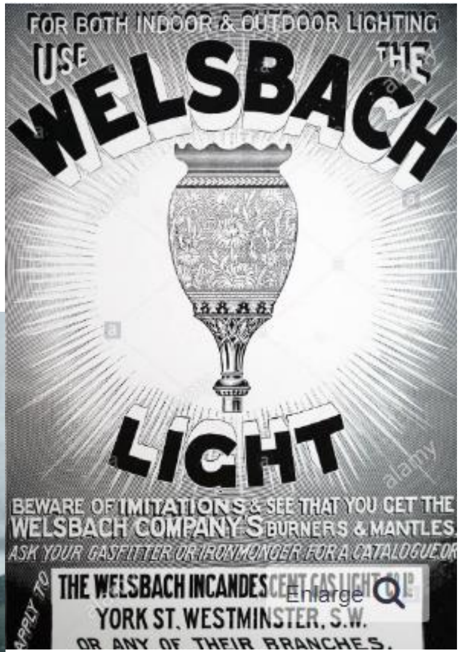
- Thorium- Reserves, Production
- R&D Projects on Thorium Reactors in Brazil
- MoU-COAUTHOR
- Final Remarks and Conclusions


8 515 767 km$^2$; 210 Millions

# 200,000 TONS OF MONAZITE WERE ILLEGALLY EXTRACTED FROM BRAZILIAN BEACHES




**The exploitation of thorium from monazite sand in Brazil date back to 1886, when Englishman John Gordon began exporting to Europe the ore mined in the municipality of Prado, Bahia State to use in lighting (incandescent gas lamps).**

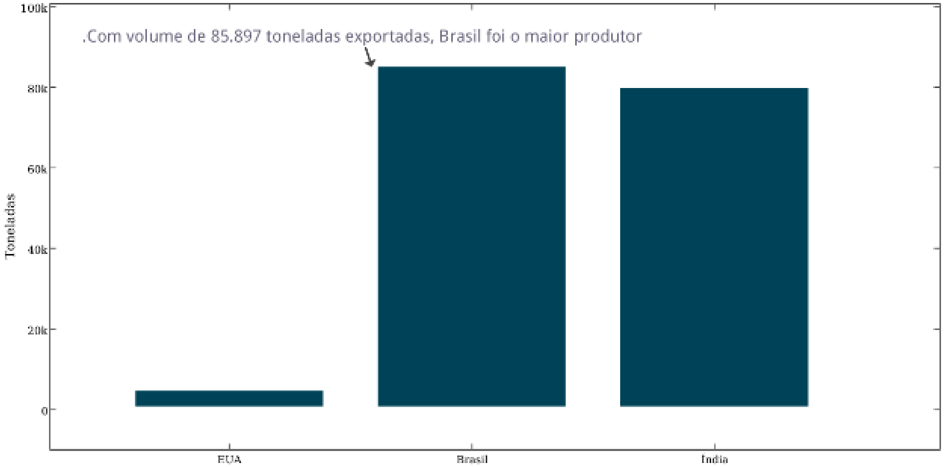
# THE MONAZITE BARONS

He arrived in Brazil in 1940 as an attorney for "Société Minière",
a French company that already had monazite exploration in Espírito Santo and, in just one year, already owned the entire radioactive heritage of the city of Guarapari. The company, which had been operating modestly since the 1920s, was transformed in 1941 into Mibra - Monazita Ilmenita do Brasil

Augusto Frederico Schmidt, owner of Orquima, commanded the extraction of monazitic sand

# THE POST WAR: RECOGNIZATION OF NUCLEAR IMPORTANCE OF THORIUM.

In 1945, the first agreement was signed with the United States, which provided for a supply of 5,000 tons of monazite annually and could be extended up to ten times. Three years later, the National Security Council denounced the deal on the grounds that there was no clear US benefit return in exchange for the monazite. Exports were interrupted demonstrating the government's first act of concern to safeguard nuclear raw materials in Brazilian soil




Admiral Álvaro Alberto (center), first Brazilian representative to the UN Nuclear Energy Commission and founder of CNPq.

The nuclear importance of thorium was recognized by the Brazilian Government just after the II war, and to avoid illegal exportation of monazite sand, established a legal framework, to avoid such practice. Nowadays by constitutional law, the exploitation, processing, and use of nuclear material (uranium and thorium) is monopoly of the State and conducted by a state company INB (Brazilian Nuclear Industry)


# THORIUM

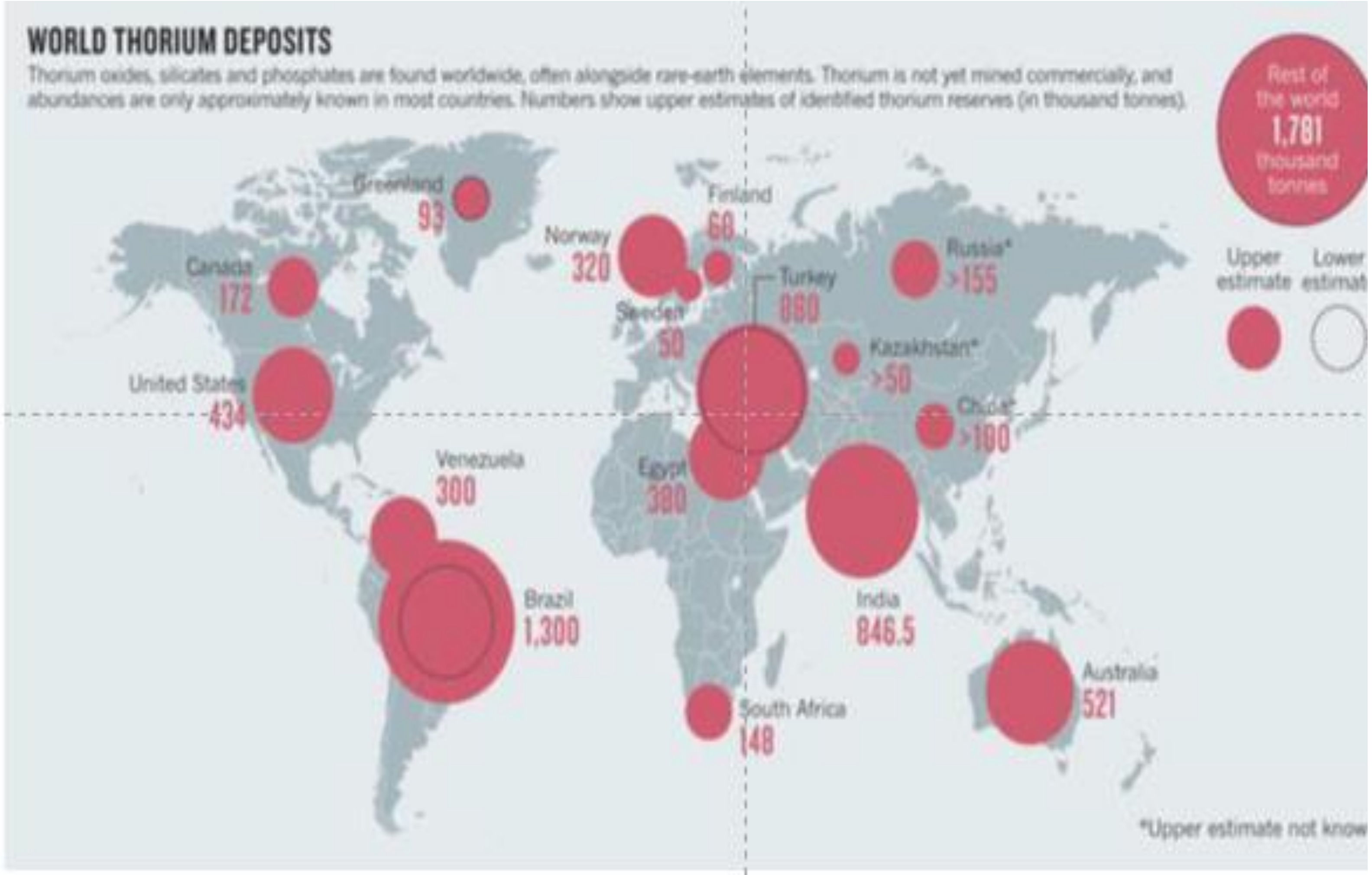
Thorium (Th ) is an actinide, metallic element, and it is named for “ Thor”, the Scandinavian god of thunder by his discover, Jöns Borzelius, a Sweden in 1829. The abundance of Th in the earth is 6,000 ppb, three times that of uranium, and it is found naturally in its isotope $^{232}Th$ (100%), being radioactive (T1/2= $1.4x10^{10}$ years), and in its natural chain decay produces isotopes like

$^{228}Ra$; $^{228}Ac$; $^{228}Th$, $^{224}Ra$, $^{220}Rn$, $^{216}Po$, $^{212}Pb$, $^{212}Bi$, $^{208}Tl$ to a stable $^{208}Pb$

The minerals of thorium are thorianite($ThO_2$); monazite(39% of cerium oxide, 5% of yttrium, 6% of thorium oxide and 0.3% of $U_3O_8$+ lanthanides); thorite ($ThSiO_4$)

# THORIUM RESERVES IN THE WORLD

| Country | Tonnes |
|---|---|
| India | 846,000 |
| Brazil | 632,000 |
| Australia | 595,000 |
| USA | 595,000 |
| Egypt | 380,000 |
| Turkey | 374,000 |
| Venezuela | 300,000 |
| Canada | 172,000 |
| Russia | 155,000 |
| South Africa | 148,000 |
| China | 100,000 |
| Norway | 87,000 |
| Greenland | 86,000 |
| Finland | 60,000 |
| Sweden | 50,000 |
| Kazakhstan | 50,000 |
| Other countries | 1,725,000 |
| **World total** | **6,355,000** |



# THORIUM RESERVES IN BRAZIL

Table 2: Thorium Potential Resources in Brazil[1].

| Occurrence | Associated Mineral | Average Content (%) | Measured, t $ThO_2$ | Estimated, t $ThO_2$ |
|---|---|---|---|---|
| Coastal deposits | Monazite | 5 | 2,250 | - |
| Morro do Ferro(MG) | Thorite and others | 1 to 2 | 35,000 | - |
| Barreiro, Araxa(MG) | Pyrochlore | 0.09 | - | 1,200 000 |
| Area Zero, Araxa(MG) | Pyrochlore | 0.09 | 30,000 | - |
| Aluvial and Pegmatite | Monazite | 5 | 3,000 | 2,500 |
| Total | | | 73,500[a] | 1,202,500 |

note: The IAEA gives 606,000 t as indicated reserves and 700,000 t of inferred reserves

# OCORRÊNCIAS E DEPÓSITOS DE MINERAIS DE TÓRIO

# THORIUM PRODUCTION

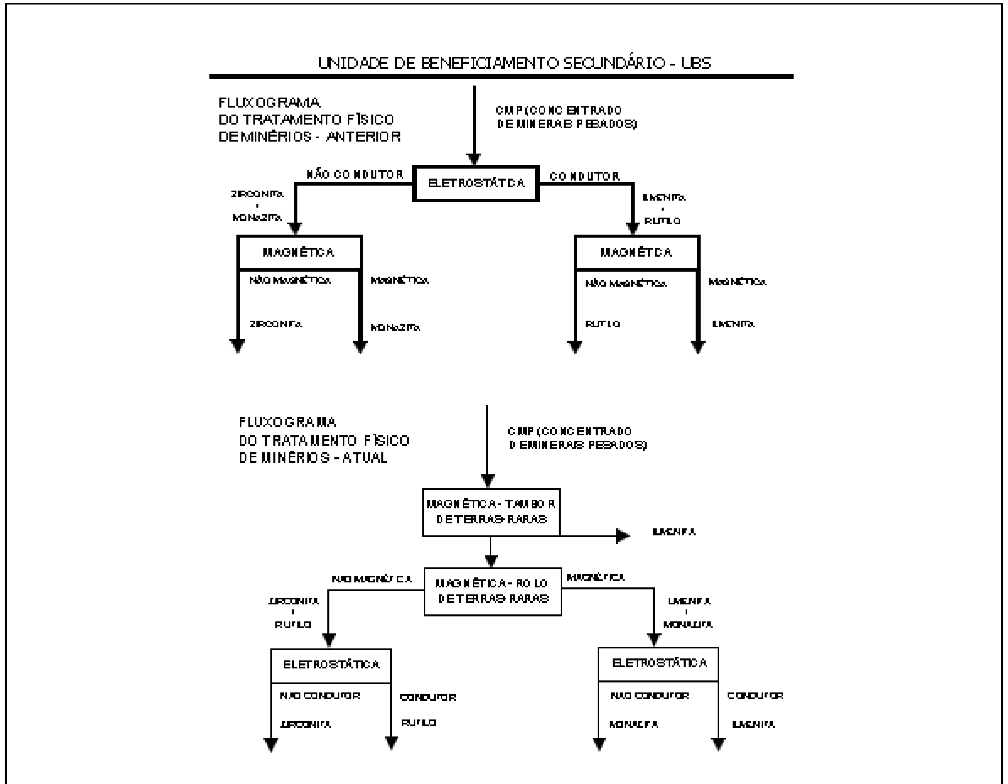
Thorium is presently produced by processing Monazite sand by 5 countries, as illustrated in table , but the production is more interested in the production of rare-earth compounds, being thorium storage as low level waste or for use in the future thorium reactors. Recently, worldwide only minor amounts of ThO2 are typically used annually. Principal uses include chemical catalysts, lighting, welding electrodes, and heat-resistant ceramics, in descending order of use.

| Country | Metric tons |
|---|---|
| India | 5500 |
| Brazil | 600 |
| Malaysia | 500 |
| Thailand | 210 |
| Vietram | 180 |
| Total | 6990 |

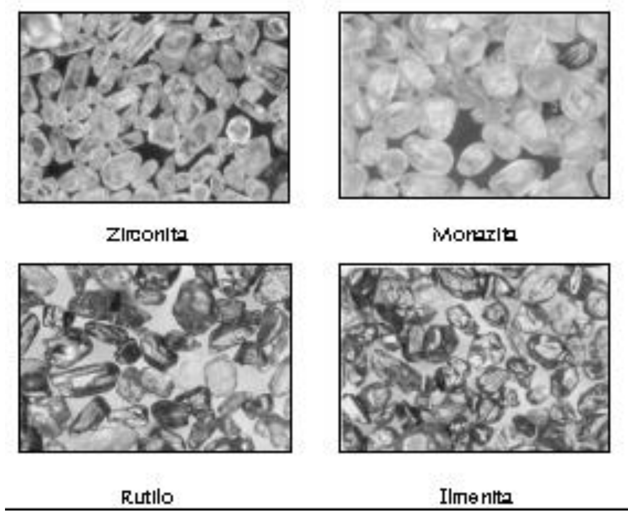


Note: China also produces thorium, but the data are not available

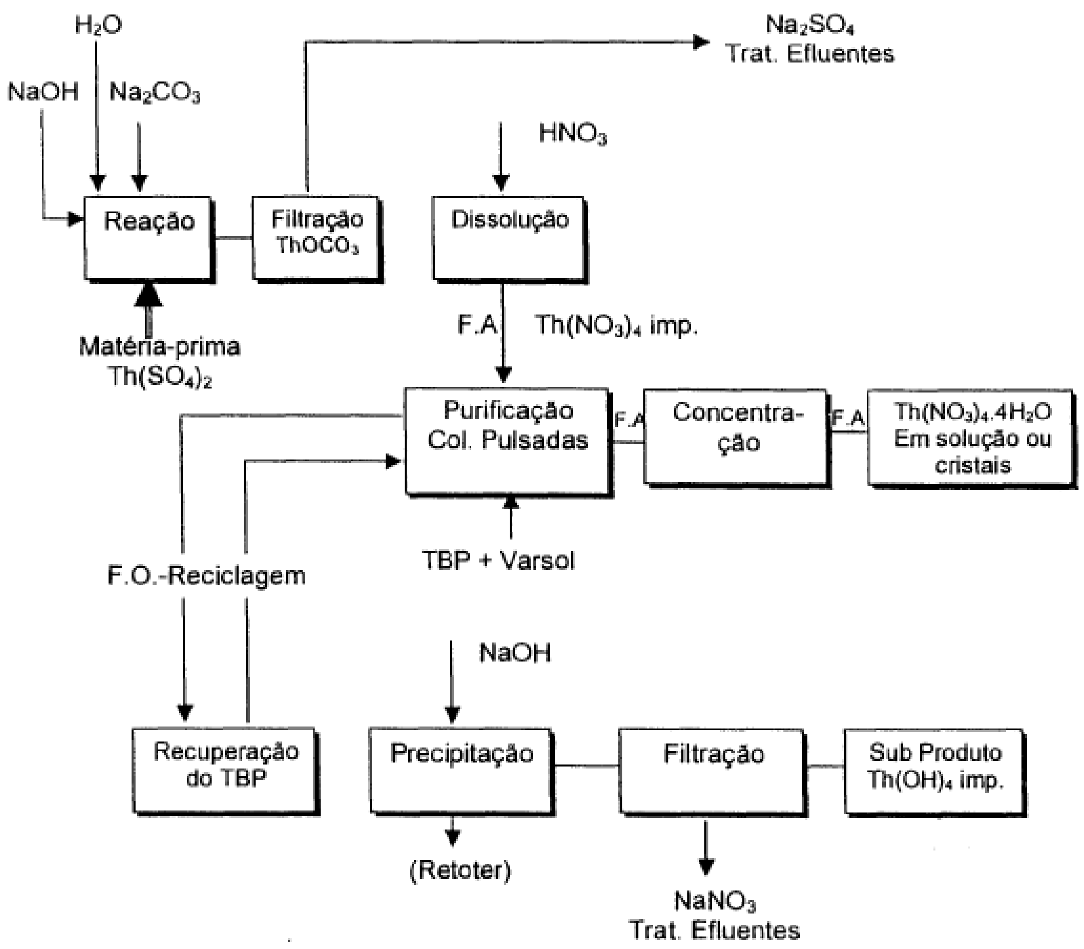
**In 1949, the chemical processing of monazite, to produce lanthanide chlorides and tri-sodium phosphate, was started at the Santo Amaro mill (Usina Santo Amaro – USAM that belonged to the company Orquima S/A), located in Sao Paulo city. The first phase of the monazite processing consists of the extraction, washing and drying of monazite bearing sands taken from beaches. Then, physical separation processes separate the four minerals: ilmenite, rutile, monazite and zircon. Owing to public pressure, economic and radiological problems, the chemical processing of monazite stopped in 1992**

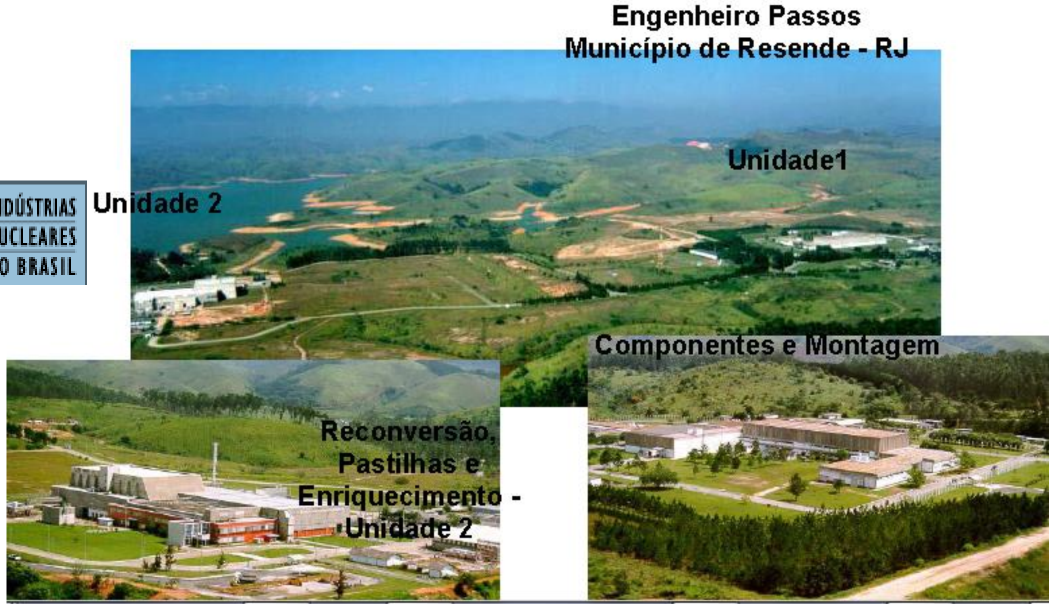



**NUCLEMON-INB**
**Buena, Rio de Janeiro State**



**Instituto de Pesquisas Energéticas e Nucleares -IPEN produced high purity thorium nitrate to serve the Brazilian industry that used in incandescent gas mantle, by purifying the thorium concentrates resulting from monazite processing in a Pilot plant illustrated in the Figure. $Th(N0_3)_4$ produzes $ThO_2$**



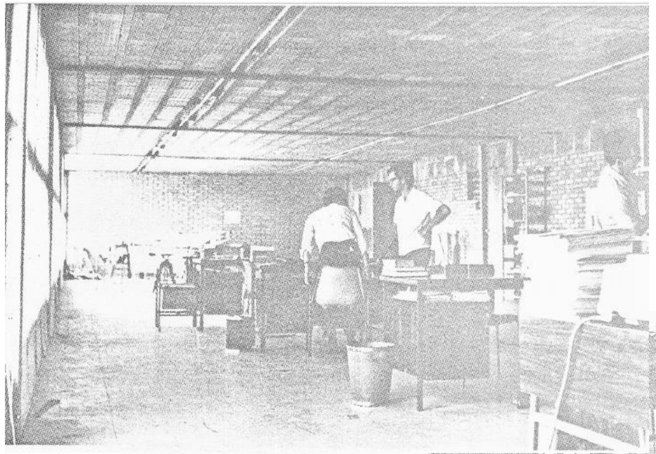

# R&D ON THORIUM REACTORS IN BRAZIL

**The role of Nuclear Energy in Brazil is complementary to other sources of Energy. Presently two PWR NPP are in operation (ANGRA I and II) with a total of 2007 MWe installed power, and a third unity is under construction. Even though with such relatively small nuclear park in international standards, Brazil has one of the biggest world nuclear resources (uranium and thorium), being the sixth natural uranium resource in the world (309,000 t U3O8), one of the first world thorium natural resource estimated as 1.3 million t of ThO2), and has a fuel cycle industry (INB) capable to provide fuel elements for the National NPP, including the enrichment. Besides Energy Generation, Brazil is conducting R&D through the Research Institutes of the Brazilian Nuclear Energy Commission (CNEN) and in Universities. Also, a National Development Program for Nuclear Propulsion, conducted by the Brazilian Navy is underway, and Brazil is participating in the International initiatives such as Generation IV and INPRO, although without a clearly defined type of reactor and associated fuel cycle.**

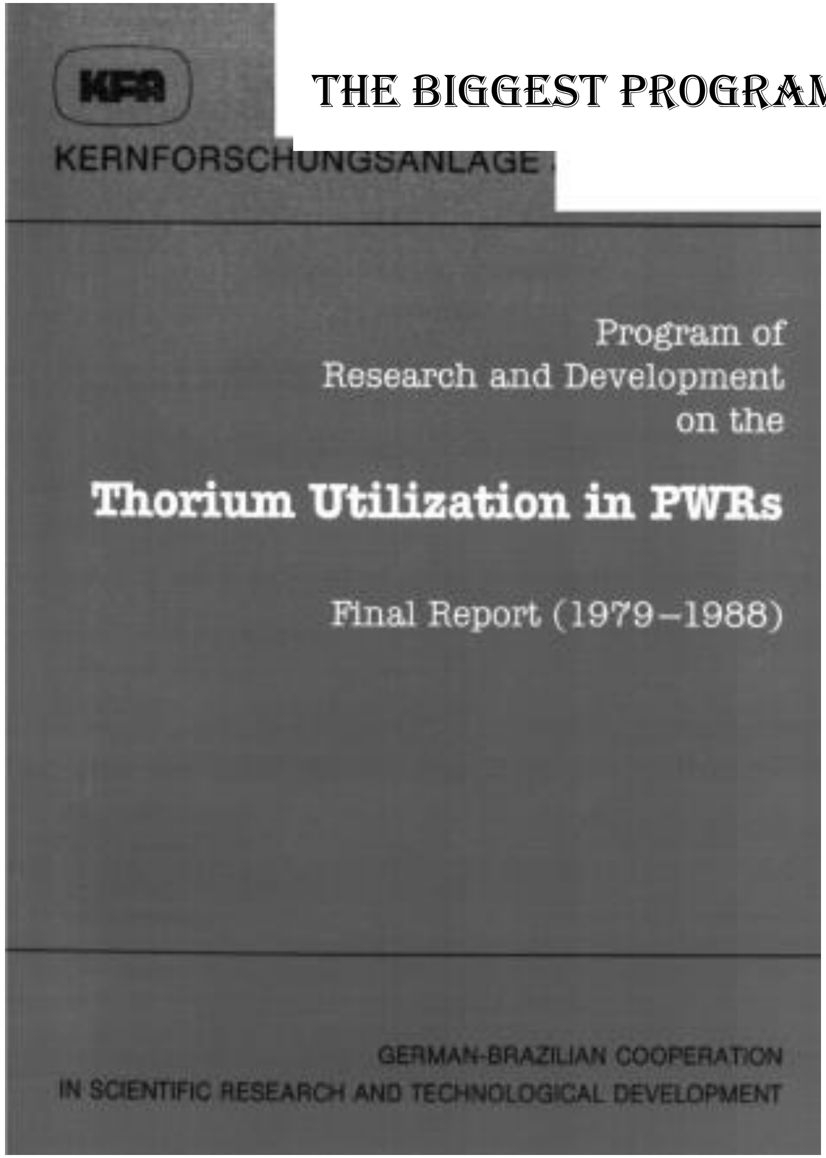
# THE PIONEERS PROJECTS

Since the beginning of Nuclear Energy Development in Brazil in the sixties, it was recognized the strategically of the thorium utilization for the country. In fact the first project was conducted by a research group from a Brazilian State, Minas Gerais, very rich in mineral resources, including thorium. This research group was called the “Thorium Group”, and in the framework of a cooperation agreement with the French CEA aimed at the development of a thorium fueled PHWR with a concept of a prestressed concrete reactor vessel. This project was officially nominated “ Instito/ Toruna”, and realized several progresses in the conceptual design( fuel technology, reactor physics, thermal hydraulics, reactor vessel, materials and component test and fuel cycle economics). These studies resulted in some reports, most of them in Portuguese. With the decision of the Brazilian Government to build a Westinghouse PWR (ANGRA I) in a turn key bases, in the late sixties, beginning of seventies, discontinued the activities of the” Thorium Group”, however the human power and knowledge developed under the frame work of this initiative were very useful for the future Brazilian Nuclear Programs (staff highly qualified in different aspects of the analysis and design of NPP).

Also, in the beginning of the seventies, in the framework of a cooperation agreement of IPEN, in São Paulo, with the USA General Atomic (GA), several activities, theoretical and experimental, were developed on thorium technology and utilization in HTGR.



# The Biggest Program- Brazilian German Agreement




The signature of the ambitious program of technology transfer signed between Brazil and Germany( 1975), for the construction of 8 PWR, and the complete light water reactor fuel cycle industry( enrichment, reprocessing, heavy equipment's etc)

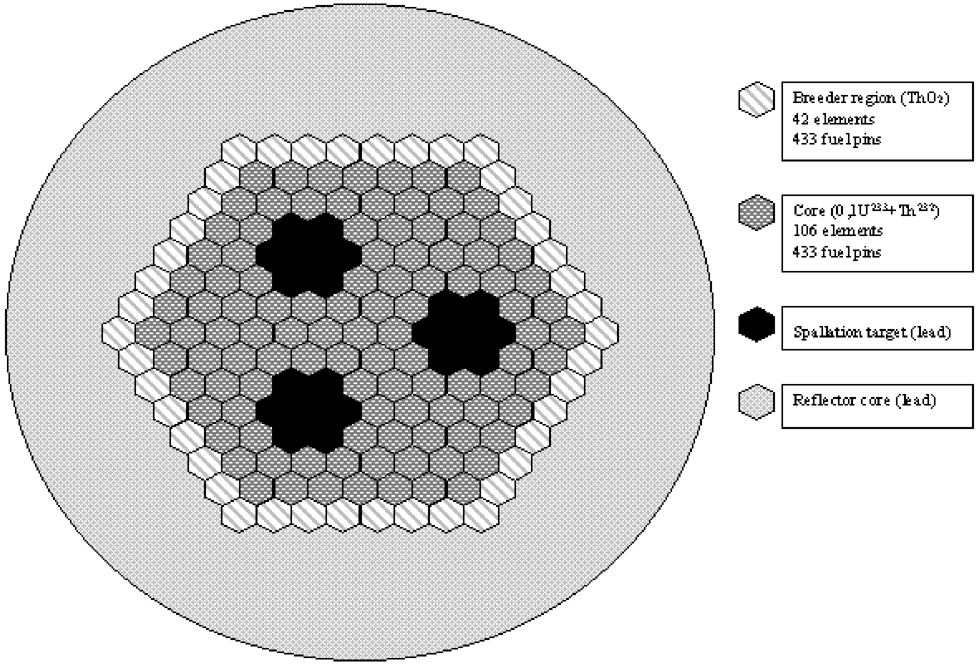
it was in the framework of the Brazilian German agreement that the biggest R&D program on thorium utilization was developed. This program was conducted by the CDTN), in that time the R&D branch of the former holding, NUCLEBRAS, and the Germans KFA- Jülich, Siemens A.G-KWU, and NUKEN. The general objectives of the program were, a) to analyze and prove thorium utilization in PWR, b) to design PWR fuel elements and core for the Th-fuel cycle, c) to manufacture, test and qualify Th-U and Th-Pu fuel elements under operating conditions, d) to study spent fuel treatment and to close the thorium fuel cycle by reprocessing spent Th-containing PWR fuel assemblies. The program starts in 1979, and was interrupted in 1988, A final report contains detailed technical results obtained by this program, in i)Nuclear core design and strategy for a standard 1,300 MW Siemens PWR, ii) Fuel Technology, for $(Th\text{-}U)O_2$ and ( $Th\text{-}Pu)O_2$ , iii) Fuel design and modeling, including the fuel behavior in irradiation experiment(FRJ-2 at KFA, Jülich), and a test fuel assembly for the ANGRA I reactor , and iv) Spent Fuel treatment, including laboratory investigation on reprocessing spent fuel thorium with non-irradiated elements

# Thorium Reactors in the Academy

In the beginning of this century with the interest of IPEN to study ADS, with a thorium utilization motivation, some academic work have been reported, mainly by the author in the annual meetings of the IAEA TWG-FR, national and international conferences, and a Ph.D. thesis was presented at USP, proposing a modified conceptual fast energy amplifier ADS and using $^{232}Th$ and $^{233}U$ as fuel

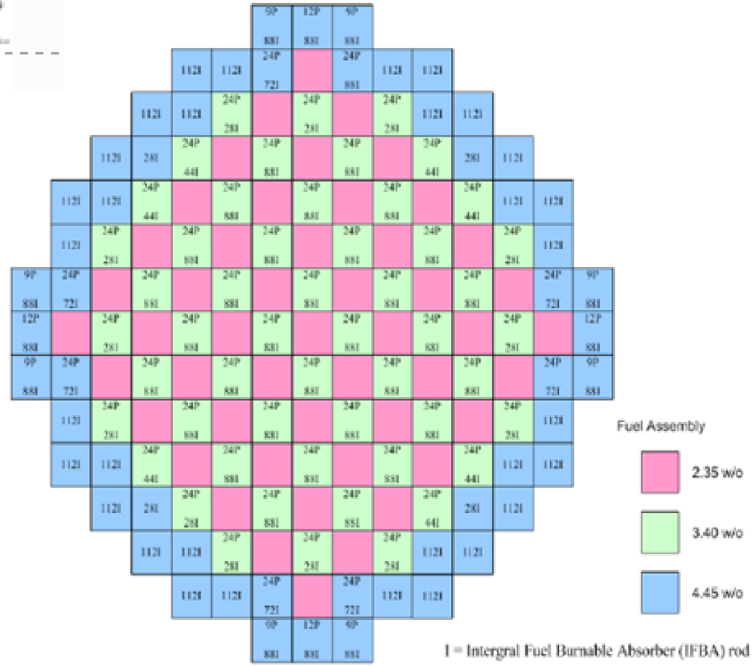
Also, in cooperation with Argonne National Laboratory a comparative study between two gas cooled subcritical fast reactor as dedicated transuranic (TRU) transmutes: using a spallation neutron source or a D-T fusion neutron source based on ITER was realized . The two concepts are compared in terms of a minor actinides burning performance.

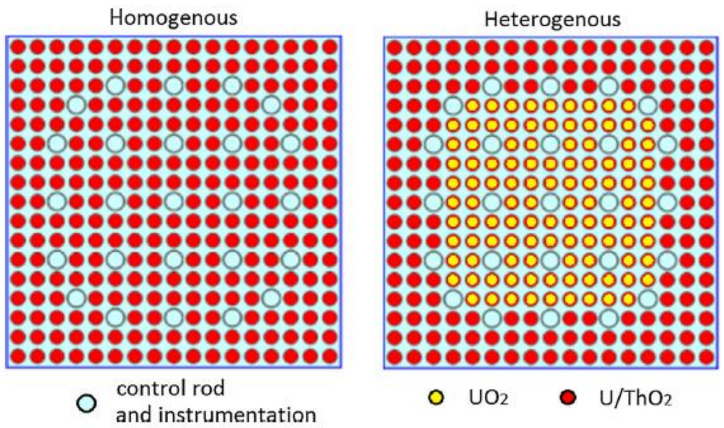
Presently, thorium reactors research is conducted by Federal University of ABC(UFABC), and Federal University of Minas Gerais (UFMG).




| | |
|---|---|
| Power | 105 MWth |
| Accelerator | Cyclotron, Ep=500MeV, Ip=3 mA |
| Multiplicity(n/p) | 10.06 |
| Source Criticality Factor, | 0.98 |
| Target | Liquid Lead (windowless) |
| Multiplication Factor | 0.97 |
| Gain | 70(Ep=500 MeV); 110( 1GeV) |
| Radial Peak Factor | 1.854 |
| Specific Power( W/g) | 2.58 |
| Power Density( W/cm2) | 25.82 |
| N233/N232 | 0.107 |
| Fuel | $0.1^{233}UO_2 + ^{232}ThO_2$ |


# FEASIBILITY TO CONVERT AN ADVANCED PWR FROM UO2 TO A MIXED U/THO2 CORE



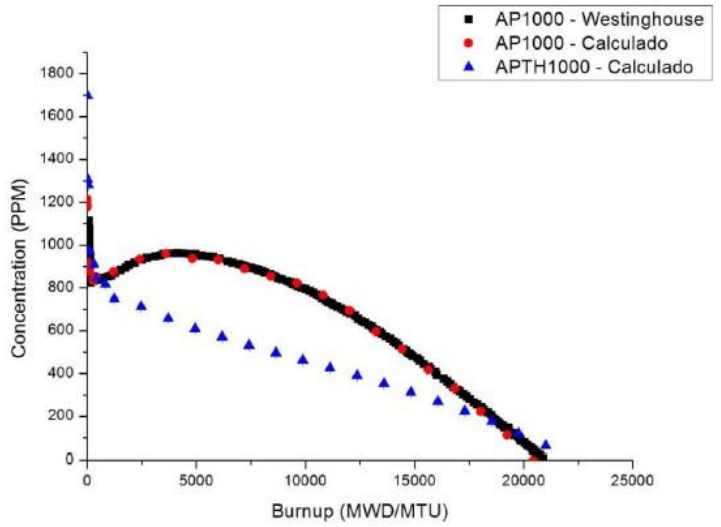



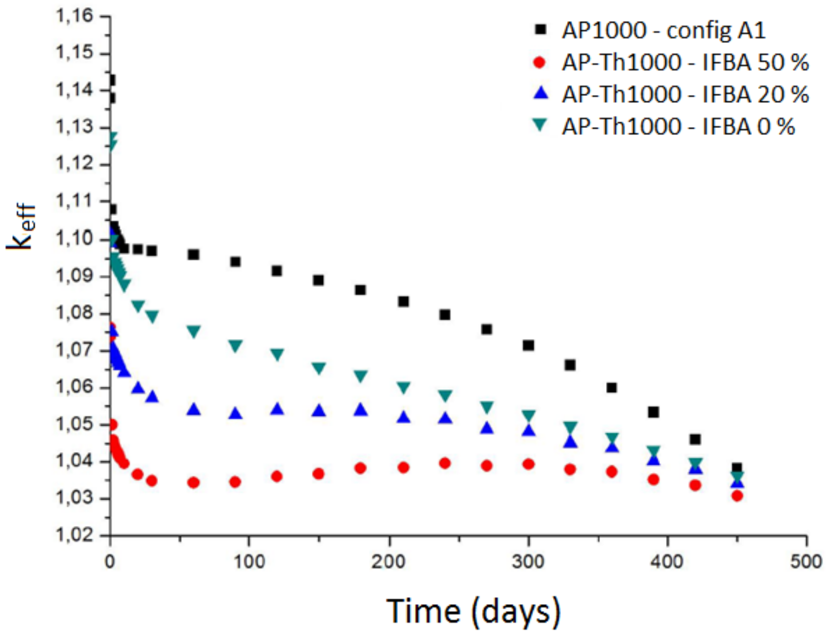

CRITERIA

- Produce the maximum amount of fissile $^{233}U$ at end of cycle (EOC).
- Generate minimum amount of fissile plutonium to reduce long lived waste generation (an important sustainability criterion for nuclear power);
- Ensure that the maximum centre line fuel temperature and maximum linear power density do not exceed the values from the AP1000 reference core;
- Ensure that kinetics parameters and temperature coefficient of reactivity do not change significantly to maintain similar current AP1000 safety and transient behaviour;
- Ensure that the fuel cycle life is 18 months or longer. Discharge average burnup ~60 MWD/kgHM at equilibrium cycle.

# RESULTS

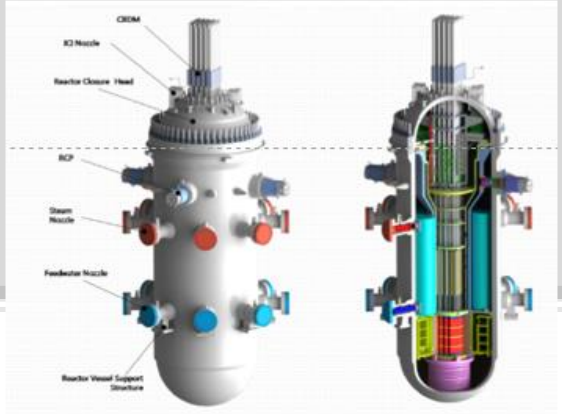
- The results obtained for these 20 cases for the $k_{eff}$ at BOC and EOC, conversion factor, $\beta_{eff}$, maximum linear power density, fuel centre line temperature, and mass of $^{233}U$; $^{239}Pu$, $^{241}Pu$, can be found in [28]. These results showed that the configurations based on the heterogeneous concept presents the better reactor physics properties but the highest peak linear power densities. They were dismissed simply because of thermal hydraulic limits, i.e., high maximum centre line fuel temperature. Among the configurations with EOC keff greater than 1.05000 the $q'_{max}$ was always larger than the reference AP1000 value by 30–67%. For the homogeneous configurations, most of them satisfied the criteria's, however the configuration with three different mass proportion zones, the first containing (32wt% $UO_2$-68wt%$ThO_2$); the second with (24wt% $UO_2$-76wt% $ThO_2$), and the third with (20wt% $UO_2$-80wt% $ThO_2$), using $^{235}U$ LEU (20 wt%), and corresponding with the 3 enrichment zones of the AP 1000 (4.45 wt%; 3.40 wt%; 2.35 wt%).was the one which produces more $^{233}U$ at EOC, as well as a lower linear power density, and therefore it was the one choose to be the converted core of AP 1000.

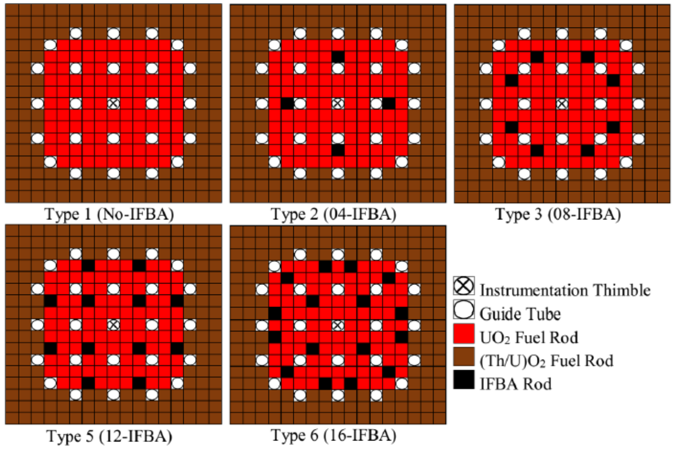


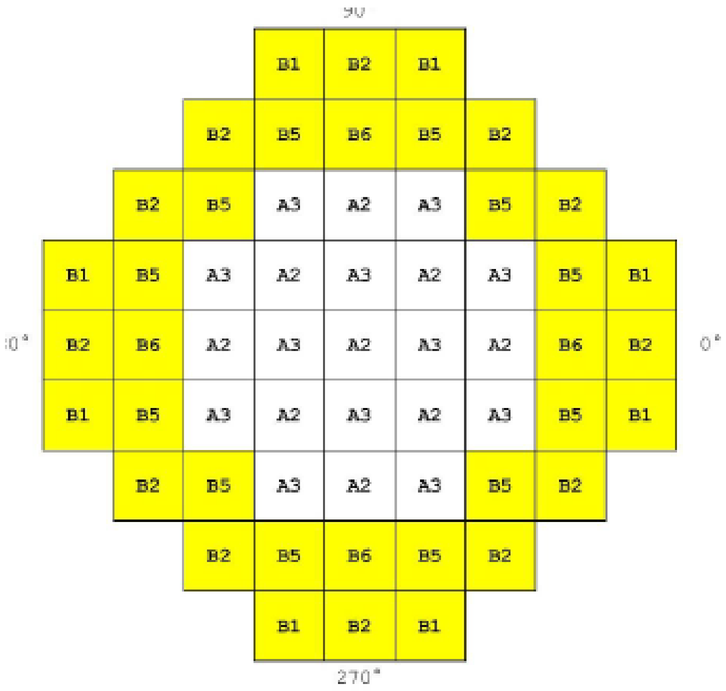



# THE UTILIZATION OF THORIUM IN SMALL MODULAR REACTORS

- A study to convert a Small Modular Reactor(SMR), to use U-Th)$O_2$ was successfully made, and just conclude that a Korean SMART Reactor can use a mixed fuel core with 65wt% and 10wt% thorium respectively in the central and outer zone, with a longer cycle than reference SMART core. In the reference core 680 burnable absorber rods have been used while in the proposed thorium mixed oxide core 388 burnable absorber rods have been used that means a large reducing in the amount of poison material. Also, analysis of the soluble boron changes during the cycle shows that in the proposed core we can used less amount of soluble boron during the cycle.





COAUTHOR

Consortium of Academics from Universities promoting the use of Thorium

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