THORIUM, UNFC (3,3,3) IN BRASIL
URAM - 2014 – VIENNA - IAEA
ROBERTO C. VILLAS-BÔAS
CETEM - Center for Minerals Technology
CYTED – Iberoamerican Programme for Science, Technology & Development
ALL (3,3,3) and some (2,1,1) Thorium in Brasil LISTED at

IAEA/INFCIS/ThDEPO
WORLD THORIUM DEPOSITS AND RESOURCES

HTTPS://INFCIS.IAEA.ORG/THDEPO/DEPOSITDETAILS/299?
Size: 8.5 million square km
Geographical location: South America
Infrastructure: roads, education, research
Population: 195 million inhabitants
GDP: US$ 2,090,314 million
GDP – minerals: US$ 40 billion
Investments in Mining: US$ 62 billion (2010-2014)

GDP: source 2010 International Monetary Fund
GDP minerals and investments: source 2011 IBRAM
CORPORATE TAX : 15% + 10% Social Contribution of 9% based on net profit (worldwide income regime)

REMITTANCE TAX : 0% on dividends; 15% on royalties and technical service; 25% on others; 25% on services with no transfer of technology;

SPECIFIC MINING TAX : The rate varies according to the type of mineral, from 0.2% to 3%6;

FISCAL STABILITY REGIMES AND FISCAL INCENTIVES : Fiscal Stability Regime: not applicable; Depreciation: the general rule is straight line basis; Specific depreciation rules for mining;

TAX LOSS CARRYFORWARD : No limitations

ALSO : Deduction of interest from equity and Brazilian tax laws allow an interesting tax planning tool in which interest paid to shareholders in the company as a return on invested capital (equity) can be deducted from income tax purposes.
BRASIL : MINING GENERALITIES

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MAJOR PLAYER IN

- Niobium (1º)
- Iron Ore (1º)
- Manganese (2º)
- Tantalite (2º)
- Bauxite (2º)
- Graphite (3º)
- Ornamental Stones (4º)

FORMERLY A MAJOR PLAYER IN : THORIUM !
1885 to 1914 , then second to INDIA
Analysis of the Prado Sands shows them to contain the following metals in different combinations:

<table>
<thead>
<tr>
<th>Metal</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorium</td>
<td>1.5% to 3.5%</td>
</tr>
<tr>
<td>Ytrium</td>
<td>1.0% to 3.0%</td>
</tr>
<tr>
<td>Cerium</td>
<td>62.0% to 70.0%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>3.0%</td>
</tr>
<tr>
<td>Iron</td>
<td>2.5%</td>
</tr>
<tr>
<td>Lithium</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

The Monazite comprising the Prado Sands is a phosphate of serium, lithiumum and didyium with 2 to 20% of oxide of thorium, and are derived from the decomposition of the country gneiss. Their market value is said to be 7 francs per 1,000 grammes of thorium contained. A good deal of discussion has been going on in regard to the proprietary rights to these valuable deposits. It appears that Mr. Gordon acquired by purchase what is
Selected Brazilian main mining areas and HDI
SUSTAINABILITY

Human Development Indicator

BRAZIL overall:
0.748 (Firjan)

Eastern Europe and Central Asia overall:
0.771

WORLD overall:
0.624

Municipality = M
State = S
Numbers = HDI – M

CENTRAL BRAZIL

- Itabira - MG Fe (S= 0.766 M= 0.798)
- Araxá - MG Nb (S=0.766 M=0.799)
- Nova Lima - MG Au (S= 0.766 M=0.821)
- Catalão - GO P₂O₅ (S= 0.773 M=0.818)

THE AMAZON

- Parauapebas - PA Fe(S= 0.720 M=0.740)
- Barcarena - PA Al₂O₃ (S=0.720 M= 0.769)
- P.Figueiredo - AM Sn (S=0.713 M=0.742)
Types of thorium UNFC (3,3,3) in Brasil

Placer, shoreline
Placer, alluvial
Carbonatite with residual enrichment (Barreiro, Catalao)
Carbonatite (Salitre, MG)
Pitinga granites (AM)
Alkalic Igneous
What we are talking about?

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Rare Metals
Beryllium
Cesium
Gallium
Germanium
Hafnium
Indium
Lithium
Niobium
Rubidium
Tantalum
Thorium
Tin
Zirconium
BRASIL: important reserves and production
BRASIL: good possibilities
BRASIL: important resources

Rare Earths Elements
Dysprosium
Erbium
Europium
Gadolinium
Holmium
Lanthanum
Lutetium
Neodymium
Praseodymium
Promethium
Samarium
Scandium
Terbium
Thulium
Ytterbium
Yttrium
Brasil´s Rare Metals

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Nb : largest world producer

Barreiro  Alkaline Complex

Niobium

PRODUCTS

- STANDARD FERRONIOBIUM
- HIGH PURITY FERRONIOBIUM
- NICKEL NIOBIUM
- HIGH PURITY NIOBIUM OXIDE
- OPTICAL GRADE NIOBIUM OXIDE

NIOBIUM METAL

- COMMERCIAL GRADE
- REACTOR GRADE

NIOBIUM 1% zr

- COMMERCIAL GRADE
- REACTOR GRADE

HDI (Araxá) = 0.7799
Brasil´s Rare Metals

Sn: 4th world´s reserves (9.4%)

HDI = 0.6166
### Brasil´s Rare Metals
ranking of world´s metallic Sn plants

<table>
<thead>
<tr>
<th>Company</th>
<th>Production (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taboca/Mamoré</td>
<td>6,149</td>
</tr>
<tr>
<td>Gejui Zi-Li</td>
<td>7,000</td>
</tr>
<tr>
<td>PT-Koba</td>
<td>7,109</td>
</tr>
<tr>
<td>CM Vinto</td>
<td>8,800</td>
</tr>
<tr>
<td>Metallo Quimique</td>
<td>9,228</td>
</tr>
<tr>
<td>Liuzhou Chine Tin</td>
<td>12,000</td>
</tr>
<tr>
<td>Yuannan Chengfeng</td>
<td>13,500</td>
</tr>
<tr>
<td>Thaisarco</td>
<td>21,731</td>
</tr>
<tr>
<td>MSC</td>
<td>31,630</td>
</tr>
<tr>
<td>Minsur</td>
<td>38,000</td>
</tr>
<tr>
<td>PT-Timah</td>
<td>49,029</td>
</tr>
<tr>
<td>Yuannan Tin</td>
<td>58,371</td>
</tr>
</tbody>
</table>

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Brasil´s Rare Metals
ranking of world´s metallic Ta plants

TANTALUM (2008)

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves (103t Ta2O5)</th>
<th>WP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brasil</td>
<td>79.200</td>
<td>40,98</td>
</tr>
<tr>
<td>Australia</td>
<td>69.000</td>
<td>35,70</td>
</tr>
<tr>
<td>Egypt</td>
<td>14.014</td>
<td>7,25</td>
</tr>
<tr>
<td>China</td>
<td>8.370</td>
<td>4,33</td>
</tr>
<tr>
<td>Thailand</td>
<td>7.700</td>
<td>3,98</td>
</tr>
<tr>
<td>Nigeria</td>
<td>7.000</td>
<td>3,62</td>
</tr>
<tr>
<td>Mozambique</td>
<td>6.032</td>
<td>3,12</td>
</tr>
<tr>
<td>Canada</td>
<td>5.000</td>
<td>2,59</td>
</tr>
<tr>
<td>Congo RD</td>
<td>1.500</td>
<td>0,78</td>
</tr>
<tr>
<td>Rwanda</td>
<td>1.500</td>
<td>0,78</td>
</tr>
<tr>
<td>WORLD</td>
<td>193.284</td>
<td>100,00</td>
</tr>
</tbody>
</table>

Ta₂O₅

Mina Pitinga (Sn, Ta, Nb, Pb) 150-200.000 lbs/ano
Mineração Taboca S.A. (Grupo MINSUR - Peru) Município de Presidente Figueiredo – AM
HDI = 0,6166

Mina Mibra (Ta, Nb, Sn) 100 t/ano
Cia. Estanho Minas Brasil - MIBRA (Metallurg Group) Município de São João Del Rey – MG
HDI = 0,6902

Mina Cacheirinha (Sn, Nb-Ta) nd
Coop. Garimpeiros do Estado de Rondônia Município de Itapuã d’Oeste – RO 0,5427

Mina Massangana (Nb-Ta) nd METALMIG
Município de Ariquemes – RO 0,6625
What about Rare – Earths?

Because rare earth elements are often associated with the radioactive elements uranium and thorium, many rare earth deposits are discovered during exploration for these elements.

Most production of rare earth elements is from the processing of monazite and bastnäsite, the REO compounds recovered by S-X.
Rare – Earths in Brazil

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source: Lapido & Santos, CETEM, 2011

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What about Rare – Earths ?

IMPORTER ?

- Brazilian RE reported reserves (DNPM/MME ) 44,000 t measured and indicated
- Reported domestic production in 2005 and 2006 = 958 t/y
- World’s participation in 2006 = 0,8%
- THEN : CHINA !

A BIT OF...HISTORY

- In 1942 it was introduced the chemical processing of monazites to extract rare earths in Brazil in the ORQUIMA S.A. plant located in São Paulo City
- Monazite sands were mined and beneficiated at the SUPRA / SULBA plant in Buena, up to 1960
- NORM wastes bearing mesothorium (228 Ra) started to be generated in Brazil ever since (PASCHOA, 1993).
However, just in CATALÃO, Goiás, Central Brazil

<table>
<thead>
<tr>
<th>Type Ore</th>
<th>Main Mineralogy</th>
<th>Reserves (a) (ton)</th>
<th>REO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatite</td>
<td>Magnetite, dolomite, monazite, stroncianite, pyrite, other minors (b)</td>
<td>15.903.072</td>
<td>6,64</td>
</tr>
<tr>
<td>Saprolitic or Laterite</td>
<td>Quartz, apatite, magnetite, almenite, hematite, ghoetite, monazite, other minors</td>
<td>54.504.757</td>
<td>8,39</td>
</tr>
<tr>
<td>Altered / silicate (c)</td>
<td>Quartz, monazite, hematite, barite, cerianite, apatite, other minors</td>
<td>8.254.383</td>
<td>10,5</td>
</tr>
<tr>
<td></td>
<td><strong>Cut off: 5% REO</strong></td>
<td><strong>78.664.212</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL (a)</strong></td>
<td><strong>119.723.180</strong></td>
<td></td>
</tr>
</tbody>
</table>

(a) Measured + indicates + inferred  
(b) Conglomeratic mainly  
(c) Results from weathering of carbonatite ore  

Source: Ribeiro, 2008; Newmann, 1999
But, then CHINA!

Global Production of Rare Earth Oxides, 1950 – 2000

source: USGS
The Buena Mine: as a case study

The Buena monazite mine is located in the municipality of São Francisco de Itabapoana, (21° 24´36" S and 41°00´18"W), northern part of the State of Rio de Janeiro, and it is well served by several interstate roads. According to the AMB – 2004, the Brazilian Mineral Yearbook, in Buena alone there are 1,292,282 metric tons of ROM monazite ore.

Typical composition might be as follows:

<table>
<thead>
<tr>
<th>Oxide</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ThO2</td>
<td>6.5</td>
</tr>
<tr>
<td>U3O2</td>
<td>0.17</td>
</tr>
<tr>
<td>(RE)2O3</td>
<td>59.2 (includes Ce2O3)</td>
</tr>
<tr>
<td>Ce2O8</td>
<td>26.8</td>
</tr>
<tr>
<td>P2O5</td>
<td>26.0</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>0.51</td>
</tr>
<tr>
<td>TiO2</td>
<td>1.75</td>
</tr>
<tr>
<td>SiO2</td>
<td>2.2</td>
</tr>
</tbody>
</table>
The Buena Mine: as a case study  HDI = 0.6995

21° 24’36” S 41° 00’18” W

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The Buena Mine: as a case study

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- It holds the prospection, exploration, mining, industrialization and commercialization rights of the monazite sands derived from the paleoshore deposits in the region.

- The mine has been in standstill since the Chinese boom on rare earths.
Mining in Buena is conducted in a very simple, logical and rational way:

1. soil rich in organic matter is removed and stored for reclaiming purposes;
2. overburden is them shoveled of;
3. shoveling continues and extracts the monazite rich ore mineral;
4. trucks transport it to the physical beneficiation plant nearby located;
5. concentrates and wastes are produced;
6. reclaiming of the mined area is performed;

A two step physical beneficiation process is then performed:

1. Humphrey´s spirals concentrate the “heavy minerals” part of the “monazite sands”, consisting of monazite, ilmenite, zirconite and rutile. Waste product from this operation, paleo sea shore sand, is returned for the concomitant reclaiming operations.
2. the concentrates from step one are subjected to electromagnetic, electrostatic and further gravimetric operations to produce cleaner concentrates.
3. The overall ore recovery is of 85%.
4. As mentioned, reclaiming is performed concomitantly, transporting the wasted materials from the concentrations steps, one and two, to the mining trenches and covering up with the separated and stored upper soil from operation 1.
The Buena Mine : as a case study
S-X semi-commercial plant 1992/1993
La, Ce, E, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, Y

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Exempt activity concentrations (EAC) for radionuclides and AC in selected NORM wastes in Brazil. After PASCHOA, 1994.

As it is well known, the potential risks of radioactive mining wastes in which natural long lived decay products are mobilized in the case of monazite mining are 20 to 50 orders of magnitude smaller than in uranium mining.
World Th RESOURCES

RESERVES OR RESOURCES?

Figure 2.14: The World Thorium Reserves and Reserve Base (Resources).
Brazil, NE coast & interior

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Brazil (S), Uruguay, Argentina & Chile

Villas-Bôas
Brazil’s rare earths occurrences and deposits, other than monazite

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CARBONATITE

Barra do Itapirapua : 24 - 41´S / 49 - 13´W ; 6% REE in hematite mine. REE probably from hydrothermal solutions. 0,6204
Itanhaem : 24 0 08´S / 46-48´W ; REE found in biotite tinguaite dikes. 0,7517
Mato Preto : 24-45S / 49-12W ; F mine closed in 1999.
Salitre I and II : 19-02S / 46-47W ; High REE. 0,6394

CARBONATITE WITH RESIDUAL ENRICHMENT

Angico dos Dias : Bahia
Anitápolis : 27-48S / 49-05W ; P producer; REE occurrence 0,6499
Araxa (Barreiro) : 19-38S / 46-56W ; 450 Mt Nb ore @ 2.5% Nb2O5, 4.4% REO + 0.8 Mt laterite ore @ 13.5% REO, 2% Nb2O5, 0.05% U3O8 (1984); 0.546 Mt @ 10- 11% REO (1982); 462 Mt @ 0.033% REO . Nb-P producer; REE-Ba occurrence ; Weathered carbonatite with 3 separate deposits. Barreiro Complex is circular and about 4.5 km in diameter. World's largest Nb mine and deposit. 0,7799
Caiapo : 16-00S / 51-45W ; Anomalous Sr, Ba, REE in the lateritic cover.
Brazil’s rare earths occurrences and deposits, other than monazite

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CARBONATITE WITH RESIDUAL ENRICHMENT

Catalão I : 18-15S / 47-47W ; Nb-P producer; minor by producer of REE (Ce); Ti 0,8301
Catalão II : 18-02S / 47-52W ; Nb resource ; REE phosphates 0,8301
Maicuru : 00-28S / 54-13W; laterite contains 17% REE.
Maraconai : 00-32S / 53-24W;
Matum (Marum, Mutum) : 01-53S / 57-25W ; Most of intrusion lies in Guyana.
Morro Dos Seis Lagos(São Gabriel da Cachoeira) : 00-38N / 66-24W ; 0.13 Mt REE;
1.50% REO in laterite cover. 3 carbonatitic alkaline pipes that form laterite-covered hills. Laterites average 230 m in depth. 3 bill.t ore 2.8% Nb2O5 0,4526
Serra Negra : 18-55S / 46-50W ; 200 Mt @ 27.7% Ti2– Ti concentrates contain 3%REE; Hi LREE/HREE ratio. 0,6855
Tapira : 19-54S / 46-52W ; 150 Mt @ 0.03% REO; 166 @ 0.03% REO ; phosphate mine. 0,6834
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ALKALIC IGNEOUS

Arenopolis (Areianopolis) : 0,5933
16-22S / 51-32W ; Rare earths concentrated in dikes within the syenite.

Jacupiranga :
24-42S / 48-08W ; P-Lime producer; REE, Ni Occurrence. 0,6594

Mutum :
01-53N / 57-25W ; 0,6375

Poços de Caldas (Morro do Ferro): 0,8045
21-55S / 46-34W ; >1.0 Mt @ 4% REO, 1%
ThO2: 1.5 Mt bas or 0.050 t REO (1990); 6 Mt @ 3% REO. Past producer U,Zr, Bauxite.
Eudialyte contents range from 0 to 11% in the relatively small host bodies. Was once one of world's biggest baddeleyite deposits, but now nearly depleted. Weathered magnetite stockwork in alkaline rocks.

Sucunduri : 8-32S / 59-28W ;
Brazil’s rare earths occurrences and deposits, other than monazite

OTHER IGNEOUS-AFFILIATED (INCLUDING PEGMATITES AND VEINS)

Pitinga : 00-45S / 60-07W ; Potential byproduct. Greisenization of biotite granite produced primary mineralization. Also weathered zone with assoc. placers 0,6166

PLACER, Shoreline and Alluvial

already mentioned monazites

OTHER - Uranium Deposits

Carajas (Igarape Bahia) : 7 to 8 degrees S and 49 to 51 W ; Archean “Olympic Dam type” deposit ; Cu-Fe-Au-U-REE
WHY Th REACTORS?

GO TO:

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Government of India: “Thorium as a Safe and Clean Energy Source”.

Thorium Fight @ ThEC13