THORIUM
Occurrences, Geological Deposits and Resources

by
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IAEA International Symposium on Uranium Raw Material for Nuclear Energy (URAM 2014)
23-27 June 2014, Vienna, Austria
Presentation based on planned publication of IAEA “World Thorium Occurrences, Deposits and Resources”

• with contributions by

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• M. Cuney, France, B. v. Gosen, USA, S. Jaireth, Y. Miezitis, Australia, I. Lindahl, Norway, R. Villas-Boas, Brazil.
Thorium Occurrences, Geological Deposits and Resources

Major Deposit Types and Resources (approx.)
as of 2014
(resource categories and cost classes not considered)

• **Placer:** ~ 2.2 million t Th, ~ 35 %, 
• **Carbonatite:** ~ 1.8 million t Th, ~ 29 %, 
• **Vein Type:** ~ 1.5 million t Th, ~25 %, 
• **Alkaline Rocks:** ~ 0.6 million t Th, ~ 9 %, 
• **Others/Unknown:** ~0.1 million t Th, ~2 %. 

• **WORLD TOTAL:** ~6.2 million t Th
Carbonatite

• Intrusive or extrusive igneous rock consisting of more than 50 % carbonate minerals (e.g. calcite, dolomite, ankerite).

• Enriched in +/- magnetite, apatite, fluorite, REE, Ba, Nb, Ta, U, Th, Cu, Ti, V.
Placer
(heavy mineral sands, black sands)

• +/- unconsolidated material at beaches, shores or inland dunes, containing heavy minerals.

• Heavy minerals in placers:
  - ilmenite, rutile, magnetite, **monazite**, xenotime, garnet, zircon, cassiterite and others, resulting from weathering of solid rocks.
Vein Type

• Mostly of hydrothermal (or metasomatic?) origin occurring in or close to intrusive or extrusive igneous rocks (e.g. carbonatite), sometimes in metasediments or contact-metamorphics.

• Vein-like, lense-like shape or sheets, filling of joints, fissures.

• Frequently polymetallic, +/- Thorite, Thorianite etc
Alkaline Rocks

• Igneous rock containing high amount of alkali feldspar, e.g. alkali granite, syenite, etc.
• Frequently no strict definition is given:
  • alkaline – peralkaline.
• Alkaline/peralkaline rocks are often associated by carbonatites.
• Economic minerals similar to carbonatite.
Tentative new classification of thorium deposits

1.a. Igneous syngenetic
   - granite, alaskite,
   - syenite, peralkaline rocks.
   - carbonatite,
   - volcanic rocks.
1.b. Igneous epigenetic

- pegmatite
- veins associated to alkaline rocks
- veins associated to carbonatite,
- veins associated to granitic rocks.
2. Metasomatite
Alterations by fluids, addition of Fe, Na, K and +/- other metals incl. thorium.

3. Metamorphic
Igneous or sedimentary rocks altered by regional or contact metamorphism.
Tentative new classification, continued

4. Sedimentary
   a) Beach/dune placers
      - paleo placers
      - recent placers
   b) Off-shore placers
   c) River/stream placers
      - paleo placers
      - recent placers
   d) Coal, lignite
   e) Phosphates

5. Residual

6. Others
Resource terminologies

• IAEA/NEA terminology
  - Reasonably assured resources (RAR), recoverable resources,
  - Inferred resources (IR), previous: estimated additional resources cat.I, recoverable resources,
  - Identified Resources: sum of RAR and IR.
  - Prognosticated resources (PR), previous: estimated additional resources cat.II
  - Speculative resources.
Thorium Occurrences, Geological Deposits and Resources

- **Major sources of information:**
  - Red Books (Uranium Resources, Production and Demand), NEA/IAEA.
  - U.S. Geological Survey, Mineral Commodity Summaries,
  - U.S. Geological Survey Circular 1336, 2009,
  - World Nuclear Association,
  - Geoscience Australia: papers on thorium in Australia,
  - Exploration and Research for Atomic Minerals (AMD, India),
  - Mineral Sands in Asia and the Pacific (UN ESCAP),
  - IAEA TM, Vienna, Austria, 24-27 Sept.2013
IAEA/NEA terminology

In addition to resource categories cost classes are used, e.g. RAR recoverable < USD 80/kg Th.


Identified resources: 6.7-7-6 million t Th, (no cost classes !)

of which RAR <USD80/kg Th: 0.8 million t Th,
additional PR 1.4 million t Th (2009).
Resource terminology

United Nations Framework Classification (UNFC)

Three major classes were introduced:

E economic development,

F degree of feasibility,

G degree of geological knowledge.

The three major classes are further subdivided, e.g. E1: resources viable under current market conditions.
• **Recent updates on thorium resources are not available worldwide.**

• Resource assessments during “boom“ years of exploration for uranium, thorium assessments are mainly a „fall-out“.

• **Recent assessments: Australia, Brazil, India, United States.**
# Resource estimates for major countries

## Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Total resources of Th (1000 Th)</th>
<th>of which are RAR &lt; USD 80/kg Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>87</td>
<td>NA</td>
</tr>
<tr>
<td>Greenland</td>
<td>86-93</td>
<td>54</td>
</tr>
<tr>
<td>Others (Turkey[374]*, Finland, Sweden, France).</td>
<td>~500</td>
<td>NA</td>
</tr>
</tbody>
</table>

* Data for Turkey are not officially confirmed

**TOTAL EUROPE**

<table>
<thead>
<tr>
<th>Country</th>
<th>Total resources of Th (1000 Th)</th>
<th>of which are RAR &lt; USD 80/kg Th</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>720</td>
<td>&gt;109 ?</td>
</tr>
</tbody>
</table>
Resource estimates for major countries N+S America,

<table>
<thead>
<tr>
<th>Country</th>
<th>Total resources of Th (1000 t Th)</th>
<th>of which are RAR &lt;USD80/kg Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>632*</td>
<td>172</td>
</tr>
<tr>
<td>United States</td>
<td>595</td>
<td>122</td>
</tr>
<tr>
<td>Venezuela</td>
<td>300**</td>
<td>NA</td>
</tr>
<tr>
<td>Canada</td>
<td>172**</td>
<td>NA</td>
</tr>
<tr>
<td>Others (Peru, Uruguay, Argentina)</td>
<td>24</td>
<td>NA</td>
</tr>
<tr>
<td>Total AMERICA</td>
<td>1722</td>
<td>&gt; 294</td>
</tr>
</tbody>
</table>

*Est. author, papers.  ** Not updated
# Resource estimates for major countries Africa

<table>
<thead>
<tr>
<th>Country</th>
<th>Total resources of Th (1000 t Th)</th>
<th>of which are RAR&lt;USD 80/kg Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt*</td>
<td>380*</td>
<td>NA</td>
</tr>
<tr>
<td>South Africa</td>
<td>148</td>
<td>18</td>
</tr>
<tr>
<td>Morocco*</td>
<td>30*</td>
<td>NA</td>
</tr>
<tr>
<td>Nigeria*</td>
<td>29*</td>
<td>NA</td>
</tr>
<tr>
<td>Others: Angola, Dem. Rep.Congo, Kenia, Madagascar, Mozambique, Malawi, etc</td>
<td>63*</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Total AFRICA</strong></td>
<td><strong>650</strong></td>
<td><strong>&gt; 18</strong></td>
</tr>
</tbody>
</table>

*Not updated
<table>
<thead>
<tr>
<th>Country</th>
<th>Total resources of Th (1000 t Th)</th>
<th>of which are RAR &lt;USD 80/kg Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>846</td>
<td>319</td>
</tr>
<tr>
<td>China</td>
<td>&gt;100*</td>
<td>NA</td>
</tr>
<tr>
<td>Russian Fed., Asian part</td>
<td>&gt;100*</td>
<td>NA</td>
</tr>
<tr>
<td>Iran</td>
<td>30*</td>
<td>NA</td>
</tr>
<tr>
<td>Malaysia (CIS)</td>
<td>18</td>
<td>NA</td>
</tr>
<tr>
<td>Others : Kazakh., Uzbek., Bangla Desh, Thailand, Taiwan, Vietnam, S-Korea, Sri Lanka.</td>
<td>104-117*</td>
<td>NA</td>
</tr>
<tr>
<td>Total ASIA</td>
<td>&gt;2500</td>
<td>&gt;319</td>
</tr>
</tbody>
</table>
Resource estimates for Australia

Identified Resources: 489 000 t Th,
In situ 595 000 t Th,
Recoverable RAR <USD 80/kgTh: 75 600 t Th
WORLD total Th resources

• Total resources: >> 6.2 million t Th

1. Asia: >2 500 000, >40 %,
2. America: 1 700 000, 27 %,
3. Europe: 720 000, 12 %
4. Africa: 650 000, 10 %,
5. Australia: 595 000, 10 %.

RAR: 0.8-1.5 million t Th (?) = ~ 15-25% of world total.
Recoverable RAR < USD 80/kg Th
=829 000 t Th

1. Asia: >319 000, 38.5 %,
2. America: 294 000, 35.6 %,
3. Europe: > 109 000, 13.1 %,
4. Australia: 75 600, 9.2 %,
5. Africa: > 18 000, 2.3 %.
## World Thorium Resources and Deposits

### Comparision of Resource Assessments 2009 and 2014 (tentative)

<table>
<thead>
<tr>
<th>Type</th>
<th>of deposits</th>
<th>and deposits</th>
<th>their resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatite</td>
<td>31 %</td>
<td>as of 2009</td>
<td>29 % as of 2014</td>
</tr>
<tr>
<td>Placer</td>
<td>25 %</td>
<td>„</td>
<td>35 % „</td>
</tr>
<tr>
<td>Vein</td>
<td>21 %</td>
<td>„</td>
<td>25 % „</td>
</tr>
<tr>
<td>Peralkaline rocks</td>
<td>18 %</td>
<td>„</td>
<td>10 % „</td>
</tr>
<tr>
<td>Others</td>
<td>5 %</td>
<td>„</td>
<td>2 % „</td>
</tr>
<tr>
<td>World total</td>
<td>6.1 million</td>
<td>„</td>
<td>6.2 million</td>
</tr>
</tbody>
</table>
Thorium Provinces

• > 90% of thorium are in four deposit types: carbonatite, peralkaline rocks, veins, placers (heavy mineral sands, densities >3 to >7).

• Carbonatite, peralkaline rocks and veins are often occurring associated with, leaving placers as a separate geological and geographical type.
Thorium Provinces

• Carbonatite, peralkaline rocks and associated veins are characteristic for silica under-saturated magmatic provinces.

• Carbonatites (IUGS): igneous rocks > 50% carbonate minerals (calcite, dolomite, ankerite), formed by multiple processes.

• Peralkaline rocks are defined by the ratio \((\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{Al}_2\text{O}_3 >1\).
Thorium Provinces

• Carbonatites, peralkaline rocks and veins are characterized by rare element mineralization (e.g. Nb, Ta) and occasionally enriched e.g. by thorium-bearing minerals.

• No specific geological provinces render prominent for carbonatites, except magmatic provinces of alkaline character. Examples may be: Fennoscandian Shield, Greenland, Rocky Mt. Province, Brazilian Shield.
Thorium Provinces

- **Placer deposits** with **monazite** are known from many areas around the world, e.g.:

- East and West coast of **Australia**, inland deposits in New South Wales and Victoria. „Parent“ rocks regarded as sources have a wide range in composition (mainly magmatic and metamorphic) and age (Archean to Phanerozoic).

- Coastal areas in SW (Kerala), SE (Tamil Nadu) and E (Odisha) **India**. Provinces can be distinguished according to the predominate mineral composition (**MAITHANI 2011, CHANDRASEKARAN 2012**).
Thorium Provinces

- Coastal areas in *Brazil*, specially in the areas near Rio de Janeiro, in Bahia and Espirito Santo, are known for monazite in placers.
- The delta of the Nile river in *Egypt* carries monazite in the so called „Black sands“. Deposits are believed to be the result of far transportation (source in the S).
- Research is needed on the origin of heavy mineral sands of *South Africa* and their thorium.
Recovery of Thorium

• Th can be extracted as co- or by-product of rare earth elements (REE) and others, e.g. Nb, Ta.
• Monazite in heavy mineral or black sands (placers) may be a major source of Th.
• Monazite treated by conc. sulfuric acid, 120-190 °C, several h, solutions enriched in Th several stages of treatment using organic compounds (amine), stripping and final separation of clean Th, precipitation.
Availability of Thorium

- Monazite production can be used as a measure for Th availability.
- Without commercial rare earth requirements recovery of Th from monazite is not economic.
- Extraction of Th from deposits containing e.g. Nb, Ta, may become economic by-product once commercial Th requirements progress.
Availability of Thorium

• Monazite is extracted in India, Brazil, Malaysia.
• Annually 6 300 to 7 400 t monazite between 2004 and 2008.
• Largest producer: India, ~5 000 t monazite /a.
• Later figures are not available (Chinese competition on the rare earth market?).
• Other monazite producers (unknown amounts):
  China, Indonesia, Nigeria, North and South Korea, CIS.
• Theoretical content of Th in the above reported monazite: 300 to 600 t Th.
• Th production reported: Brazil, Canada, India and others, details are not available.
Use of Thorium

- **Non-nuclear use:**
  - Light bulb,
  - Arc-light lamps,
  - Lantern mantles,
  - Welding electrodes
  - Lenses (high refractive index!)

- **Restrictions of use due to radioactivity!**
Use of Thorium

• **Nuclear fuel**
  • Th is more abundant than U.
  • All Th-232 can be used, compared to 0.7 % U-235 in natural ores.
  • Th 232 absorbs neutrons, to form fissile U-233.
  • No Pu-239 is generated (non-proliferation aspects!).
  • 1000 MW reactor, initial loading 40-50 t Th, 10-15 t high-enriched U-235, reloading ~10 t Th/a.
Use of Thorium

- **Nuclear applications**
- Past investigations of Th-based fuel cycles in the USA, Germany, Russia, India, Japan, UK.
- High-temperature gas-cooled reactors (HTGR) and pebble-bed reactors (THTR) in 1960/70 in Germany and USA. Currently shut down.
- Experimental reactors in the UK and in India.
- Currently India is leading in Th-based nuclear reactors.
- Recent research on Thorium Molted Salt Reactors.
Lifetime of Thorium Resources

• Presently economic Th resources: 829 000 t Th.
• A 1000 MW reactor needs 450 t Th in 40 years.
• Presently installed world nuclear capacity (using enriched uranium): 375 000 MW.
• If these 375 000 MW would be replaced totally by Th-operated reactors World demand would be ~170 000 t Th.
NOTICE

- The presentation is based on a manuscript

WORLD THORIUM OCCURRENCES, RESOURCES AND DEPOSITS

to be published by IAEA in 2014.

Updated material is welcome to reflect recent status!

Please don´t hesitate to contact me!

fritz.barthel@t-online.de

Thank you!