THORIUM
Occurrences, Geological Deposits and Resources

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“World Thorium Occurrences, Deposits and Resources“

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Thorium Occurrences, Geological Deposits and Resources

Thorium: discovered 1828 by Berzelius in Sweden.

Atomic no.90, atomic weight: 232, radioactive.

Half life time: approx. 14 billion years.

End product of radioactive decay: Pb 208.

Major natural occurrence:

oxide (thorianite), silicate(thorite).

>60 minerals with Th in oxides, hydroxides, silicates, phosphates (monazite), carbonates (rare).

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: ~0.1million 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, +/- **<u>Thorite, Thorianite etc</u>**

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.

Tentative new classification, continued

1.b. Igneous epigenetic

-pegmatite

-veins associated to alkaline rocks

-veins associated to carbonatite,

-veins associated to granitic rocks.

Tentative new classification, continued

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),
- BARTHEL&DAHLKAMP: Thorium, in GMELIN 1991.
- IAEA TM, Trivandrum, Kerala, India, 17-21 Oct.2011.
- IAEA TM, Vienna, Austria, 24-27 Sept.2013

Resource terminology

IAEA/NEA terminology

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

Last assessment: IAEA/NEA Red Book 2011.

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.

Limitations of Assessment

- ***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

Country	Total resources of Th (1000 Th)	of which are RAR < USD 80/kg Th
Norway	87	NA
Greenland	86-93	54
Russian Fed.,Europ. part	55 est.	55 ?,est.
Others (Turkey[374]*, Finland, Sweden, France). * Data for Turkey are not officially confirmed TOTAL EUROPE	~500 720	NA **>109 ?**

Resource estimates for major countries N+S America,

Country	Total resources of Th (1000 t Th)	of which are RAR <USD80/kg Th
Brazil	632*	172
United States	595	122
Venezuela	300**	NA
Canada	172**	NA
Others (Peru,Uruguay, Argentina) *Est. author, papers. ** Not updated	24	NA
Total AMERICA	1 722	> 294

Resource estimates for major countries Africa

Country	Total resources of Th (1000 t Th)	of which are RAR<USD 80/kg Th
Egypt*	380*	NA
South Africa	148	18
Morocco*	30*	NA
Nigeria*	29*	NA
Others: Angola, Dem. Rep.Congo, Kenia, Madagascar, Mozambique,Malawi, etc *Not updated	63*	NA
Total AFRICA	650	> 18

Resource estimates for major countries

Asia

Country	Total resources of Th (1000 t Th)	of which are RAR <USD 80/kg Th
India China Russian Fed., Asian part	846 >100* >100*	319 NA NA
Iran	30*	NA
Malaysia (CIS	18 1 500*	NA NA)
Others :Kazakh., Uzbek., Bangla Desh, Thailand, Taiwan, Vietnam, S-Korea, Sri Lanka. * estimated	104-117*	NA
Total ASIA	>2500	>319

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)***

Type	**of**	**deposits**	**and**	**their**	**resources**
Carbona-tite	31 %	as of 2009	**29 %**	**as of 2014**	- 2
Placer	25 %	„	**35 %**	**„**	+ 10
Vein	21 %	„	**25 %**	**„**	+ 4
Peralka-line rocks	18 %	„	**10 %**	**„**	- 8
Others World total	5 % 6.1 million t	„ „	**2 %** **6.2million t**	**„** **„**	- 3 + 1

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 $(Na_2O+K_2O)/Al_2O_3 > 1$.

Thorium Provinces

- **Carbonatites, peralkaline rocks and veins are characterized by rare element mineralization (e.g. Nb, Ta) and occassionally 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 com-position (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 com-position (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 ^{0} 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

- ***<u>Nuclear applications</u>***
- **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!

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Thank you!