There was no reported domestic production, imports, or exports of thorium ores and concentrates in 2013. Data for thorium alloys, compounds, and metal used by the domestic industry were derived from imports or stocks. India was the sole source of thorium compound imports to the United States in 2013. Owing to limited demand, domestic imports for consumption and exports of thorium compounds decreased significantly in 2013, according to data collected by the U.S. Census Bureau (tables 1, 2). The United States was a net importer of thorium compounds. The value of thorium compounds imported by the domestic industry in 2013 ($184,000) continued a decline that began in 2012.

Thorium occurs widely but is concentrated in only a few geologic deposit types. Three principal sources of thorium are of commercial interest—monazite in heavy-mineral sand placer and vein deposits, thorite ores in vein deposits, and thorium recovered as a byproduct of uranium mining. Thorium and its compounds were produced primarily from the mineral monazite, which was recovered as a byproduct of processing heavy-mineral sands for zircon and the titanium minerals, ilmenite and rutile, or the tin mineral cassiterite. Monazite was recovered primarily for its rare-earth element (REE) content, and only a small fraction of the byproduct thorium produced was consumed. In 2013, monazite-producing countries were, in decreasing order of production, India, Brazil, Malaysia, Thailand, and Vietnam (table 3). Quantitative data related to China’s production of monazite and thorium compounds as a byproduct of rare-earth production were not available.

Issues associated with thorium’s natural radioactivity were a significant deterrent to its commercial use. In 2013, limited global demand for thorium continued to create an oversupply of thorium compounds and residues. Excess thorium that was not designated for commercial use was either disposed of as a low-level radioactive waste or stored. Although research into thorium-fueled nuclear reactors continues, there were no industrial-scale nuclear reactors using thorium in 2013.

In the United States, only minor amounts, about 1 metric ton (t) of thorium oxide (ThO₂), are typically used annually. Principal uses include chemical catalysts, lighting, welding electrodes, and heat-resistant ceramics, in descending order of use. Large fluctuations in apparent consumption are caused by intermittent use, especially for applications that do not require annual replenishment.

Production

Domestic mine production data for thorium-bearing minerals were developed by the U.S. Geological Survey from a voluntary canvass of U.S. thorium operations. The one mine to which a canvass form was sent responded. Although monazite itself may be recovered as a byproduct of processing heavy-mineral sands for titanium and zirconium minerals, in 2013, monazite was not recovered domestically as a salable product. Separation capacity to produce monazite concentrate from heavy-mineral sands has been on care-and-maintenance status for several years.

Consumption

Thorium consumption worldwide is small compared with that of most other mineral commodities. As a naturally occurring, low-level radioactive element, thorium is used in a variety of catalysts, ceramics, optics, and metal applications. In catalysts, ThO₂ is used in petroleum cracking and in the production of nitric and sulfuric acids. One of the major uses of thorium is in the form of thoriated tungsten metal. Thorium lowers the energy necessary for electrons to escape from a tungsten surface and enhances the thermionic emission. In welding and plasma cutting, thoriated tungsten electrodes improve ignition and arc stability. Thoriated tungsten filaments are used in high-intensity discharge lamps, vacuum tubes for radio transmitters and hi-fi amplifiers, and cathode heaters. As a fluoride, thorium is used within antireflection materials in optical coatings. One of the oldest uses of thorium is in the manufacture of incandescent gas mantles. Gas mantles containing ThO₂ provide an intense white light but were not produced domestically owing to the availability of suitable substitutes. In the past, thorium has been used as an alloying agent in magnesium and nickel alloys for heat-resistant applications. Because of concerns about its naturally occurring radioactivity, thorium has been replaced by nonradioactive materials in many uses. Interest in thorium as a nuclear fuel continues in part due to its high abundance relative to uranium.

Statistics on domestic thorium consumption were developed by evaluating import and export data and surveying processors and manufacturers. Domestic thorium producers and processors that were surveyed reported no consumption of ThO₂ equivalent in 2013 and were idle owing to the lack of thorium demand. Additional information on domestic consumption was not available. Essentially all thorium alloys and compounds used by the domestic industry were derived from imports or stockpiled inventory.

Several companies and countries were active in the pursuit of commercializing thorium as a nuclear fuel material. Thorium-based nuclear research and development programs have been or are underway in Belgium, Brazil, Canada, China, the Czech Republic, Germany, India, Israel, Japan, the Netherlands, Norway, Russia, the United Kingdom, and the United States. In the United States, companies known to be involved in these efforts included Babcock & Wilcox Nuclear Energy, Inc. (Charlotte, NC), Flibe Energy Inc. (Huntsville, AL), Lightbridge Corp. (McLean, VA), Martingale Inc. (Tavernier, FL), and Transatomic Power Corp. (Cambridge, MA).

In 2013, Lightbridge entered into a memorandum of understanding with Babcock & Wilcox Nuclear Energy to...
develop a pilot-scale facility to demonstrate fabrication of Lightbridge’s metallic nuclear fuel. At yearend, Lightbridge anticipated the approval of a U.S. patent covering its multilobed metallic fuel rod design and fuel assemblies (Lightbridge Corp., 2014, p. 7).

Prices

Published prices for ThO₂ and thorium nitrate were not available. The average unit value of imported thorium compounds was $65.0 per kilogram, a 5% decrease compared with $68.1 per kilogram in 2012. The average unit value of exported thorium compounds increased to $518 per metric ton from $232 per metric ton in 2012. The significant increase may be attributed in part to a change in the quantity of low-unit-value exports to China. In 2012, a significant portion of the total exports were sent to China at $33 per kilogram; however, in 2013, no exports of thorium compounds were sent to China. In 2012, average export value not destined for China was $455 per kilogram.

Foreign Trade

Owing to limited demand, thorium ores and concentrates and thorium compounds are imported and exported sporadically. There were no reported imports or exports of thorium ores and concentrates in 2013. Exports of thorium compounds from the United States were 1.01 t valued at $523,000, a decrease from 3.16 t in 2012 (table 2). Principal destinations were Singapore and the United Kingdom. Imports of thorium compounds in 2013 totaled 2.83 t valued at $184,000, a decrease from 4.4 t valued at $300,000 in 2012. India was the leading supplier of thorium compound imports in 2013.

World Review

Thorium demand worldwide remained depressed because of concerns about its naturally occurring radioactivity. Industrial consumers expressed concerns about the potential liabilities, the cost of environmental monitoring to comply with regulations, and the cost of disposal at approved waste burial sites. Interest in thorium increased worldwide, however, as various countries investigated the use of thorium-fueled nuclear power as an alternative to uranium. In 2013, exploration and development of rare-earth projects associated with thorium were underway throughout the globe.

China.—China produced substantial but unquantifiable quantities of thorium byproducts during the processing of domestic and imported mineral concentrates for the production of rare-earth compounds. In 2013, sources of China's imports of thorium ores and concentrates were led by Malaysia, Vietnam, and Brazil, in descending order of tonnage. Thorium may also be present in mixed heavy-mineral concentrates not specifically classified as thorium bearing. One Chinese company reported imports of 9,600 metric tons per year (t/yr) of monazite concentrates (Asian Metal, 2013).

The Chinese Academy of Sciences continued a research initiative to develop thorium molten-salt reactor (TMSR) technologies. The effort was led by the TMSR Center at the Shanghai Institute of Applied Physics. In 2013, the TMSR Center advanced its timeline for the construction of two 2-megawatt (MW) research reactors by 2017. Construction of a 1,000-MW reactor in the 2030s was expected to help demonstrate the commercial feasibility of the technology (Endicott, 2013, p. 14; Xu, 2013, p. 24).

France.—Areva Group, a French nuclear technology company, entered into a $17.3 billion research and development agreement with Belgian-based Solvay to investigate the responsible management of thorium including possible uses of thorium as a nuclear fuel. Both companies have generated inventories of byproduct thorium materials. Thorium byproducts were generated by Solvay during the processing of rare-earth materials (including monazite) and by Areva during uranium mining and processing activities (Solvay SA, 2013). Areva Med, an Areva Group subsidiary, began production of lead-212 in their new facility located at Bessines-sur-Gartempe. Using proprietary technology, Areva extracted and purified lead-212 from thorium for use in innovative treatments for certain cancers (Areva Inc., 2013). This new medical use was not expected to consume a significant quantity of thorium.

Greenland.—In October, Greenland's parliament voted to remove a 25-year-old ban on mining thorium and uranium. The policy change may allow for the development of thorium-bearing rare-earth deposits in Greenland including Greenland Minerals and Energy Ltd.'s Kvanefjeld mining project. In 2013, Greenland Minerals and Energy was conducting pilot plant studies of mineral concentration via froth flotation and lab-scale production of a mixed rare-earth carbonate via a sulfuric acid leach. The company continued environmental baseline studies in the Kvanefjeld area. Greenland Minerals and Energy planned to secure a mining license for Kvanefjeld in 2016 (Greenland Minerals and Energy Ltd., 2014, p. 2, 9, 10).

India.—India's producers of monazite concentrate include Indian Rare Earths Ltd. (IREL) and Kerala Metals & Minerals Ltd. (KMML). IREL's Manavalakurichi (MK) division near Kanyakumari, Tamil Nadu, is a heavy-mineral sands operation with a capacity to produce as much as 6,000 t/yr of monazite concentrate. KMML's production capacity at its Chavara, Kerala, heavy-mineral sands operation is estimated to be 240 t/yr of monazite concentrate. IREL's Aluva Rare Earth Division (RED) in the Ernakulam district, Kerala, is capable of processing monazite into rare-earth compounds and thorium hydroxide. Although India reported no production of rare-earth compounds, a small amount of thorium hydroxide was converted to nuclear-grade ThO₂ for the Bhabha Atomic Research Center and Nuclear Fuel Complex. IREL's Orissa Sands Complex (OSCOM) near Chatrapur, Odisha, is also reported to produce as much as 240 t/yr of mantle-grade thorium nitrate. Because of limited demand for thorium, significant stockpiles of impure thorium hydroxide and monazite exist in India. In 2013, IREL was in the process of adding a processing plant, which could process 10,000 t/yr of monazite, at its OSCOM operation that was expected to produce several thousand metric tons annually of rare-earth and byproduct thorium compounds; however, the completion of the project was delayed by a cyclone (Indian Bureau of Mines, 2013).

India continued its plan for a three-phase development of its nuclear power program. The first phase of the program was based on natural uranium-fueled, heavy water moderated
pressure tube-type reactors commonly known as Pressurized Heavy Water Reactors. In the second phase of the program, still under development, Fast Breeder Reactors would generate fissile plutonium (or uranium-235 for thorium reactors). The third phase of India’s nuclear power program was planned to take advantage of the country’s substantial thorium reserves; however, the large-scale use of thorium-based fuel for nuclear energy was not expected for several decades. In 2013, India’s Department of Atomic Energy continued the design and development of an advanced heavy water reactor (AHWR) fueled by a thorium-mixed oxide fuel (thorium-MOX) and its Molten Salt Reactor (MSR) technology. A 300-MW AHWR demonstration reactor was expected to be operational by 2022 (Vijayan and others, 2013).

Kazakhstan.—Summit Atom Rare Earth Co. (SARECO), a joint venture between Sumitomo and Kazakhstan’s NAC Kazatomprom, was preparing to commission a plant in Stepnogorsk to recover rare earths from uranium-ore residue. The SARECO plant was designed to initially produce as much as 1,500 t/yr of rare-earth oxide (REO) with a goal to increase capacity to 5,000 to 6,000 t/yr of REO by 2017 (Industrial Minerals, 2014). The volume and radiological activity of thorium associated with the uranium residues were unknown.

Norway.—Thor Energy AS, in partnership with an international consortium of utilities, industry, and research organizations, began a 4-year test of thorium-MOX. The objective of the test was to gather data and demonstrate that thorium-MOX fuel could operate safely in a commercial reactor. The thorium-MOX fuel is a dense ThO₂ ceramic matrix containing about 10% of finely blended plutonium oxide as a fissile driver. The testing was being performed by the Institute for Energy Technology at a fuel-testing reactor in Halden. Thor Energy is owned by Thor Corp. (81.3%), Steenkampskraal Thorium Ltd. (15%), and Statoil Ventures AS (3.7%) (Thor Energy AS, 2013; World Nuclear News, 2013).

South Africa.—Great Western Minerals Group Ltd. (GWMG), through its subsidiary Rare Earth Extraction Co. Ltd., was proceeding with plans to refurbish the Steenkampskraal monazite mine for the production of rare-earth minerals. In 2013, GWMG filed an updated NI 43–101 compliant resource report. Using a 1% REO (including yttrium oxide) cutoff grade, in situ measured resource of 85,000 t contained about 19.54% REO and 2.82% ThO₂. Using the same cutoff basis, indicated resources were estimated at 154,000 t with 14.79% REO and 2.09% ThO₂. In its preliminary economic assessment, GWMG planned to store impure thorium byproducts produced during the processing of monazite in an underground containment facility in a recoverable form. In 2014, GWMG planned to continue with its feasibility studies (Great Western Minerals Group Ltd., 2013, p. 21, 150).

Outlook

During the next decade, concerns related to thorium’s natural radioactivity are expected to continue to limit its use in nonenergy applications. The potential supply from thorium’s consumption will increase substantially if its use as a nuclear fuel becomes commercialized.

References Cited


General sources of information
TABLE 1
SALIENT U.S. THORIUM STATISTICS1

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
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<tr>
<td>Exports, gross weight:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Thorium ore, including monazite</td>
<td>metric tons</td>
<td>18</td>
<td>1</td>
<td>--</td>
<td>--</td>
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<tr>
<td>Compounds</td>
<td>do.</td>
<td>4.73</td>
<td>1.50</td>
<td>4.28</td>
<td>3.16</td>
</tr>
<tr>
<td>Imports for consumption, gross weight:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thorium ore, including monazite</td>
<td>do.</td>
<td>26</td>
<td>--</td>
<td>30</td>
<td>43</td>
</tr>
<tr>
<td>Compounds</td>
<td>do.</td>
<td>2.25</td>
<td>3.03</td>
<td>5.71</td>
<td>4.40</td>
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</table>

Prices, yearend:
Thorium compounds, gross weight2 dollars per kilogram
France do. 193 131 158 153 NA
India do. 51 58 58 60 65

do. Ditto. NA Not available. -- Zero.
1Source: U.S. Census Bureau.
2Unit value based on U.S. imports for consumption.

TABLE 2
U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIALS1

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2013</th>
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<tr>
<td>Exports:</td>
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<td></td>
</tr>
<tr>
<td>Thorium ore, monazite concentrate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compounds:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>1.97</td>
<td>$65,400</td>
</tr>
<tr>
<td>Poland</td>
<td>0.11</td>
<td>14,500</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.46</td>
<td>328,000</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.29</td>
<td>86,100</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0.10</td>
<td>17,000</td>
</tr>
<tr>
<td>Other</td>
<td>0.23</td>
<td>223,000</td>
</tr>
<tr>
<td>Total</td>
<td>3.16</td>
<td>734,000</td>
</tr>
</tbody>
</table>

Imports for consumption:
Thorium ore, monazite concentrate:
United Kingdom 43 26,400 -- --
Compounds:
India 4.00 238,000 2.83 184,000
Other 0.40 61,300 -- --
Total 4.40 300,000 2.83 184,000

-- Zero.
1Data are rounded to no more than three significant digits; may not add to totals shown.
Source: U.S. Census Bureau.

TABLE 3
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY1, 2
(Metric tons, gross weight)

<table>
<thead>
<tr>
<th>Country1</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012 est</th>
<th>2013 est</th>
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<tbody>
<tr>
<td>Brazil</td>
<td>303</td>
<td>249</td>
<td>290</td>
<td>206</td>
<td>600</td>
</tr>
<tr>
<td>India</td>
<td>5,000</td>
<td>5,200</td>
<td>5,200</td>
<td>5,400</td>
<td>5,500</td>
</tr>
<tr>
<td>Malaysia</td>
<td>25</td>
<td>622</td>
<td>571</td>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td>Thailand</td>
<td>6,675</td>
<td>9,405</td>
<td>5,088</td>
<td>200</td>
<td>210</td>
</tr>
<tr>
<td>Vietnam</td>
<td>--</td>
<td>309</td>
<td>361</td>
<td>366</td>
<td>180</td>
</tr>
<tr>
<td>Total</td>
<td>12,000</td>
<td>15,800</td>
<td>11,500</td>
<td>6,780</td>
<td>6,990</td>
</tr>
</tbody>
</table>

1Estimated. 2Revised. -- Zero.
1World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
2Includes data available through May 2, 2014.
3In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may produce monazite, but available information is inadequate for formulation of reliable estimates of output levels.
4Chinese imports from Vietnam.
5Reported figure.