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TORIUM -FREMSTILLING I NORGE

B 0561.4322 FENSFELTET - EN ØKONOMISK VURDERING

A/S MEGON

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THE ECONOMICS OF THORIUM

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Throughout the tables in this report, the following abbreviations are used:-

... not available
- none, not separately listed
ø under one half of one unit
( ) estimate
others n.s.l. others not separately listed

In the original sources from which the figures in the statistical appendix were taken, there is sometimes a discrepancy between the total in the original source, and the arithmetic sum of the figures for individual countries. Where this is too large to be a rounding error, it is noted in a footnote.

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1. Summary

1.1. The thorium industry has traditionally been associated with the rare earths industry, because for a long time both were obtainable only from monazite. This situation has now changed; thorium supplies have been obtained from other thorium ores which do not contain rare earths (notably from Canada and from Malagasy), and rare earths are obtained in large quantities from bastnasite, an ore produced mainly in the U.S. which contains rare earths but not thorium. The two groups of products have thus become more separated, but they are still connected to the extent that monazite is the major source of thorium, and it is also the preferred source for some types of rare earths.

1.2. Our previous report on thorium treated it together with the rare earths and yttrium. On this occasion, we have separated the subject in two; the rare earths and yttrium appear in a companion report in this series. It is hoped that readers will find this more convenient, since a joint report would, as well as being very bulky, have been more confusing to a reader interested only in the market for thorium.

1.3. Despite the growing separation of the thorium and rare earths, there is still some connection. The nature of this connection, and the way in which it can change quite rapidly, is illustrated neatly by the following quotations from the "Minerals Facts and Problems" series of the U.S. Bureau of Mines which best represents the informed view of the industry at the time. The 1960 section on Rare Earth Metals said:

> "The major immediate problem of the industry is that production capacity is geared to thorium output and exceeds demand. Each pound of thorium recovered from monazite results in 7 to 12 pounds of rare-earth metals, and demand for thorium has created large stocks of rare-earth products"

The 1970 section on Thorium reads:

> "Domestic production of thorium is merely a by-product of rare earth mineral development. As a result, domestic production of thorium is totally dependent on the demand for rare earth compounds"

The 1970 section on Rare Earth Elements reads:

> "Resource problems are created by the complex relationship of the rare earth elements rather than by scarcity. The problem is intensified by the accumulation of surplus rare-earth materials as by-products of other commodities or of particular rare-earth elements in greater demand. The current situation is one of oversupply for most of the rare earth elements, and the main problem is that of finding markets"

1.4. In just 10 years, the situation has changed from rare earths being a by-product of thorium production to thorium being a by-product of rare earth production from monazite. The report which follows shows no foreseeable area of growth of demand for thorium apart from nuclear power, which will not be a significant factor until the 1980's. However, some caution must be exercised; it is always possible that some new use will be developed quite qucikly for thorium, and this could radically alter the supply and demand relationship, and the co-product relationship with the rare earths.

1.5. A major difficulty in obtaining a balanced view of the supply and demand for thorium is that no published source gives U.S. production of monazite. Production data is withheld in U.S. Bureau of Mines publications because there has for some years been only one important producer. However, a 10-year average of production has been released, and production figures for the first two of the 10 years were much lower than the average, indicating that there was a considerable increase later in the period. By piecing together various other isolated bits of information, we have made an estimate of U.S. production for the years 1967 to 1970; these show that production increased from 3,800 short tons in 1967 to 10,200 short tons in 1968, and then declined to an estimated 4,700 short tons in 1970 (and probably to some 4,000 short tons in 1971). Meanwhile stocks of monazite rose from some 6,000 short tons in 1967 to some 27,000 short tons in 1969, and only declined to some 26,000 short tons in 1970. The most likely explanation for this outcome was that both the U.S. producer and importers of monazite thought that the yttrium boom would last much longer than it did, so both production and imports expanded in 1968 while in fact consumption by chemical processors declined to about a third of the 1967 level.

1.6. The estimates of U.S. production have enabled us to make the first comprehensive published estimate of world production of monazite available since 1958. We estimate that world production was around 10,000 short tons in both 1965 and 1966, expanded to 20,400 short tons in 1969, and has since declined to 16,800 short tons in 1971. In 1971, Australia and the U.S. accounted for about a quarter of total world production each, and India, Brazil and Malaysia accounted for nearly all of the remainder.

1.7. The thorium content of this monazite (including Canadian thorium by-product from uranium mining) was 840 short tons ThO_2 in 1967, rose to 1,260 short tons in 1969, and declined to 1,120 short tons in 1971.

1.8. International trade in monazite is dominated by two importing countries (U.S. and France) which appear to account for about 90 per cent of world trade (if, as seems likely, some of the imports recorded in the Australian export statistics as going to the Netherlands are in fact transhipped there and go to France as recorded in the French import statistics). Australia accounts for some 60 per cent of world exports, and Malaysia for over half of the remainder.

1.9. As in other reports of this series, we have assembled all the available published information on the countries which are significant producers, potential producers, or consumers of thorium minerals and products.

1.10. Australian production of monazite has grown from 2,163 tons in 1967 to 3,929 tons in 1970. It is produced mainly as a by-product of the production of ilmenite in Western Australia. There is little doubt that production of monazite from this source will expand, because ilmenite production is expected to expand, and that if, for any reason which is not at present apparent, demand for monazite grew, producers would find it worthwhile to install further by-product recovery plant which would possibly double production. The factors governing production of ilmenite are discussed in our companion report on titanium; however, production is mainly controlled by a few large, vertically integrated companies. The Rare Earths Corporation of Australia started operations as a monazite processor in 1968; they are mainly concerned with rare earth materials, but also offer some thorium products.

1.11. Brazil has been a major producer of monazite for many years, but no monazite has been exported since the government forbade it in 1951. (Until 1967, they even insisted that the uranium and thorium content of any exports of ilmenite or zircon must be later returned to Brazil). There is some local production of lighter flints, and some rare earth chlorides concentrates are exported.

1.12. Canadian production of thorium concentrates as a by-product from uranium mining operations has been discontinued in view of the low prices obtainable for thorium. Production of uranium is expected to expand considerably in the future, and large quantities of thorium will either by accumulated in tailings (where they can be recovered later) or will be produced for sale if market conditions warrant it.

1.13. France has been a major importer of thorium ores for many years, originally of monazite and uranothorianite from Madagascar, but more recently of monazite from Australia and other countries. Pechiney-Ugine-Kuhlmann are the major processors.

1.14. Germany is a major importer of thorium compounds (though not of monazite) and the amounts involved have grown considerably in 1970 and 1971. The growth may be the thorium demand for the "pebble-bed reactor" or it may be some new use which has not yet been publicised.

1.15. India has extensive reserves of monazite in beach sands, but has (like Brazil) prohibited its export. However, substantial quantities of rare earth chlorides have been exported, and lately thorium nitrate has been offered for sale from India. Other thorium products have been offered in the past.

1.16. Japan imports thorium both in monazite and in thorium compounds, and estimated thorium content of imports and demand for thorium, almost entirely for the manufacture of gas mantles, appear to be in balance.

1.17. Malaysia produces considerable quantities of both monazite and of xenotime, primarily from the tailings dumps of "amang" (tin-mining residues). Production is very variable, but could probably be expanded considerably if it were profitable to do so. Production was 1,000 tons in 1967, and has probably doubled since then.

1.18. Some monazite is also produced as a by-product of Nigerian tin-mining operations, but these have been disrupted considerably in the last few years by the civil war and its aftermath.

1.19. South Africa was a major producer of monazite from a vein deposit until 1963. Palabora Mining Corp. is reported to have commissioned a plant at the Palabora copper mine to recover by-product uranium oxide and thorium sulphate from a heavy mineral concentrate.

1.20. The United Kingdom has had interests in thorium since 1914 when Thorium Ltd. was formed. Until 1968, most of their requirements were met from Canadian by-product thorium production, but since then have probably been met by imports of monazite. Thorium Ltd. have substantial interests in the rare earth business; their sales of thorium compounds are probably a minor part of their business. We estimate their output at 20 to 30 tons ThO_2 content a year.

1.21. The major source of monazite in the U.S. for the last few years has been the Humphreys Mining Co., but another producer (NL Industries) is believed to be starting production in 1972. Monazite production by American Metal Climax Inc. as a by-product from their molybdenum mine in Colorado was discontinued in 1970. There are a number of other possible commercial sources, which could presumably be developed if monazite prices rose. Two companies dominate monazite processing in the U.S., and they have substantial excess capacity. A number of other U.S. companies have interests in thorium fabrication and processing, primarily for nuclear fuels.

1.22. Ceylon, Egypt, Indonesia, South Korea, Malagasy, Malawi, Mauretania, Somali Republic, and Zaire are also discussed in the report; they are all either potential producers of monazite, or current producers on a very small scale.

1.23. We estimate that incandescent gas mantles accounted for 78 per cent of free world consumption of ThO_2 in 1971. We believe this use has been and is now a more important end-use for thorium than is usually thought. The incandescent mantle trade is increasingly devoted to soft mantles which use more thorium per mantle than the 1 lb. ThO_2 per 1,000 mantles which is conventionally assumed. Hong Kong statistics of imports of thorium nitrate compared with exports of mantles show that the ratio nowadays is probably about 2.2 lb. per 1,000 mantles. Substantial quantities are wasted in the manufacture of mantles. The total quantity of thorium nitrate used for mantle manufacture in 1971 is estimated at 160 m. tons ThO_2, of which Austria, France and Hong Kong account for 91 m. tons between them. The U.S., Japan, West Germany, and the U.K. are the other important manufacturing countries.

1.24. Magnesium-thorium alloys have been a major source of thorium demand in the past, and little information has been available about thorium consumption for this purpose because the master alloy is sold in the only important market, the U.S., by only one company. The master alloy is made in the U.K. It has proved possible to find the trend of demand from detailed examination of the possible customs categories; the trend is strongly downwards, and consumption of thorium in magnesium thorium alloys is estimated at no more than 12 m. tons in 1971, of which half was in the U.S.

1.25. All other uses are estimated to have required 33 m. tons of thorium in 1971.

1.26. Thorium is used in other metal alloys, particularly for dispersion hardening of nickel, but also of cobalt, molybdenum and tungsten. These uses appear regularly in the literature, but do not appear to be of much current commercial importance.

1.27. Nuclear energy is not of current commercial importance as a source of demand for thorium, but its importance will grow in the future, primarily due to the success of Gulf General Atomic in selling the first four large HTGR reactors, which will be completed in the late 1970's. Future demand for thorium for nuclear energy is still very much an open question. Demand for these four reactors is likely to be about 200 m. tons of thorium for the initial charge, and 50 tons a year for refuelling from the second year after commissioning onwards. The prospects for this type of reactor seem quite good, partly on cost grounds and partly because the design appears to have an even lower risk of accidents than the light water reactors which are the dominant type in the U.S. Potential demand is very high, but it will not materialise until well into the 1980's.

1.28. Thorium is also used as a refractory for very high temperature work, as a catalyst, in various electronic applications, in photo-conductive films, and in inert arc welding electrodes, and in fuel cell elements. These are all of little commercial importance.

1.29. The price of thorium and thorium compounds is expected to stay at or a little below the present level for the next few years. There are considerable problems of over-supply, mainly due to surplus thorium being produced by rare-earth processors using monazite, and this problem may get considerably worse if by-product thorium is produced in quantity from Canadian uranium operations. This will obviously tend to depress the price; however, we do not expect that the price will in fact fall much, because all processors know that the demand for thorium in gas mantles, in magnesium-thorium alloys, and in nuclear energy, is not likely to be increased if price is reduced.

1.30. The price of monazite is also expected to stay at about the same level. The reason for this is that there are a number of producers who could expand their present production or start new by-product production facilities if the price rose, and equally there are a number who would stockpile monazite or cease operating their by-product facilities if the price fell. This will tend to stabilise the price around the present level, which it is known is sufficiently low to divert some of the demand from rare earth processors away from bastnasite (which is in most respects easier to use) to monazite. Bastnasite prices have been stable for years, and are likely to remain so.

2. Reserves and main ores

2.1. Monazite

Monazite is a phosphate of the rare earths of the cerium sub-group, which commonly contains several per cent of thorium. It is pale yellow to brown, rarely green, with a hardness H5 to 5½ and a specific gravity between 4.9 and 5.3.

It is found as an accessory mineral in igneous and metamorphic rocks, in vein deposits, and in placers. Most monazite has started off in small inclusions in host rocks; when these break down under the action of the weather, the inclusions are released, and the inert ones eventually end up as sand grains on beaches. Some beaches which are, or have been, very stable tend to concentrate heavy minerals under the continued action of waves and tide; these beaches are most likely to be found near the mouth of a river which enters the sea across a sloping shelf, in a coast line which has well-marked indentations without prominent headlands.

Such deposits are known as placers, and are usually found on existing coastlines, though some inland placers are known (and were formed and later left isolated by land movements). The only placers known in Europe are in the Urals, but they occur in many other parts of the world. It is never worthwhile to work placer deposits purely for the monazite. The commercially important sources of monazite are worked for their content of another heavy mineral, most commonly ilmenite, rutile, zircon, or sometimes gold or cassiterite.

The only commercially important vein deposit is the Steenkampskraal deposit in South Africa which was worked until 1963, but was then shut down.

Monazite varies considerably in its thorium content, as shown in table 1 below.

Table 1 : Idealised thorium content of monazite

Country	Per cent ThO_2
India	8.5
Malaysia	8.0
Malagasy	7.5
Australia	7.0
Brazil	6.5
Ceylon)	
Indonesia)	
South Korea)	6.0
Nigeria)	
South Africa)	
U.S.	4.0

Source: U.S. Bureau of Mines Information Circular 8476

The rare earth content of monazite is almost always about 60 per cent, and in monazite the light group of rare earth elements predominate. The fact that monazite contains rare earths in such quantities means that it is also a valuable commercial source of some rare earth materials, which in turn means that demand for rare earths exerts a considerable influence on the supply of thorium. Supply at present considerably exceeds demand for this reason.

This dependence of the two markets on each other is complicated by the fact that the yttrium content of monazite varies considerably from one monazite to the other. This has only been important in the last 10 years when for a short period demand for yttrium was very high. There are no reliable figures for yttrium contents of different monazites, but Malayan monazite is reputed to be highest in yttrium.(1)

2.2. Canadian uranium-thorium ores

Large deposits of complex uranium-thorium ores occur in the Blind River and Bancroft areas of Canada. The ores are mainly brannerite, thucolite, pitchblende and uranothorite and uraninite;

(1) For a description of the geology of monazite, see Davidson, Economic Geology of Thorium, Mining Magazine, April 1966. For methods of ore treatment see R.J. Callow, Industrial Chemistry of the Lanthanons, Yttrium, Thorium, and Uranium (Pergamon Press, 1967).

all but pitchblende contain some thorium. The uranium content is very small, which means that large quantities of ore must be processed; the thorium content is even smaller,,but it is worthwhile to recover the thorium as a by-product. This is not currently an important source of thorium, but growing amounts are likely to become available as uranium production increases to meet the needs of the growing number of nuclear reactors, and there are believed to be large amounts of thorium in existing tailings dumps from previous uranium extraction.

2.3. Uranothorianite

Uranothorianite is an impure thorium oxide which invariably contains uranium, and is mined for this reason. The main source of this ore in recent years has been the Malagasy Republic.

2.4. Xenotime

Xenotime is isodimorphous with monazite; it is a phosphate of yttrium which contains some thorium though usually less than monazite. Malaysia is the main source of xenotime, though some has been produced recently in Australia.

2.5. Reserves

Reserves are defined as material which is economically exploitable under present conditions, and resources are all other deposits.

World reserves of thorium minerals were estimated at 745,000 short tons in high-grade easily mined placer deposits at the Third United Nations International Conference on the Peaceful Uses of Atomic Energy at Geneva in 1964, as shown in table 2.

Table 2: Thorium: Estimated world reserves of high grade minerals

Country	000 short tons ThO_2	Principal type of deposit
India, Ceylon, Nepal, Pakistan, Afghanistan	250(1)	Placer
Canada	200	Sedimentary, igneous and metamorphic rocks
U.S.A.	100	Vein, placer
U.S.S.R. and Eastern Europe	100	
Brazil	30	Placer, igneous and metamorphic rocks
We_ern Africa	15	Placer, igneous and metamorphic rocks
Australia	10	Placer, igneous and metamorphic rocks
Egypt	10	Placer
Malagasy Republic	10	Placer, igneous and metamorphic rocks
Malawi	10	Placer
South Africa	10	Vein
	745	

The main point to be noted from this table is that the reserves in the countries which had the major share of world production of thorium minerals before 1964 (namely South Africa and Brazil) are low in relation to their production at that time. In fact, the reserves listed above, while they may be economically exploitable, have not seemed so to their owners; shipments from South Africa have ceased, and shipments from Brazil were severely restricted though they now seem to be rising again.

(1) The Indian AEC estimated Indian deposits at 400,000 tons ThO_2 in 1971.

3. World production of thorium minerals

Table 3 shows the world production of monazite for the years from 1965 to 1971. This table includes production of xenotime, and uranothorianite. It has been compiled from a number of sources, including the U.S. Bureau of Mines Minerals yearbook and the Engineering and Mining Journal Annual Reviews. Some of the figures have been derived directly from the production statistics of the country concerned. A particular difficulty with the U.S. figures is that official production figures have been witheld since 1959, and there are no published estimates. The figures we give for U.S. production have been derived from a careful analysis of limited data available for stocks of monazite and apparent demand for rare earth minerals. We believe these figures are fairly close to the truth; our reasons for this opinion are given in detail in section 5.19.2.

In table 4 the thorium content of world production is estimated, using the idealised thorium contents of monazite given in table 1 with our estimates for Thailand and Zaire. This table includes an estimate for Canadian by-product thorium from uranium operations.

Table 3: World production of monazite (short tons)

	1965	1966	1967	1968	1969	1970	1971
Australia	2,600	2,200	2,900	2,050	3,800	4,400	4,500
Brazil	700	800	1,800	1,850	2,200	2,500	2,500
Ceylon	ø	ø	ø	50	50	ø	ø
India	2,500	2,800	2,900	2,900	2,700	3,800	3,500
Indonesia	ø	...	ø	ø	ø	ø	ø
South Korea	...	ø	ø	-	-	-	-
Malagasy	1,200	900	ø	-	-	-	-
Malaysia	800	1,000	1,100	2,400	2,300	1,800	2,000
Nigeria	ø	ø	100	ø	-	ø	ø
South Africa	-	-	-	-	-	-	-
Thailand	-	-	-	-	100	100	100
U.S.	2,000	2,250	3,800	10,200	9,000	4,700	4,000
Zaire	ø	ø	ø	ø	200	150	150
Total of figures given	9,800	9,950	12,600	19,450	20,350	17,450	16,750
Estimates for small producers	100	100	100	50	50	50	50
Total	9,900	10,050	12,700	19,500	20,400	17,500	16,800

Note: Estimates are made to the nearest 50 tons. ø indicate under 25 tons.

Table 4: World: Estimated thorium content of thorium minerals production (short tons ThO_2)

	Idealised ThO_2 content (per cent)	1967	1968	1969	1970	1971
Australia	7	205	145	265	310	315
Brazil	6½	115	120	145	165	165
Canada	...	25	40	50	20	-
Ceylon	6	∅	5	5	∅	∅
India	8½	245	245	230	320	300
Indonesia	6	∅	∅	∅	∅	∅
South Korea	6	∅	-	-	-	-
Malagasy	7½	∅	-	-	-	-
Malaysia	8	90	195	185	145	160
Nigeria	6	5	∅	-	-	-
South Africa	6	-	-	-	-	-
Thailand	(6)	-	-	5	5	5
U.S.	4	150	410	360	190	160
Zaire	(6)	∅	∅	10	10	10
Total (including estimated 5 tons for small producers)		840	1,165	1,260	1,170	1,120

Note: estimates are made to the nearest 5 tons
∅ indicates under 2½ tons.

4. International trade

International trade in thorium ore and products is difficult to describe, mainly because the quantities involved are comparatively small, and as a result, thorium ores and products are quite frequently put into miscellaneous categories in customs statistics.

The problems are exemplified in the tables of world imports and exports which follow. Data for 1969 and for 1970 is as complete as it will ever be; data for 1971 is still not available in as complete a form.

For 1969, the trade figures for 7 importing countries and for 3 exporting countries are available. None of the figures are in exact agreement, for two main reasons:

(i) monazite is normally sent by sea, and since the two main exporting countries, Australia and Malaysia, are a long way from their customers, an export from one of these countries at the end of one year may recorded as an import in the country of destination at the beginning of the following year. This is accentuated by the fact that imports are not usually recorded until the documents are presented to Customs, which may be some time after the goods have arrived.

(ii) monazite for a number of European destinations is sometimes transhipped in the Netherlands. In both 1969 and 1970, it appears likely that monazite destined for the Netherlands (and so recorded in Australian export statistics) in fact was sent on to France, and recorded on arrival there as of Australian origin.

Despite the discrepancies, the main features of the monazite market are tolerably clear. Total world trade amounted to 4,500 to 5,000 m. tons in 1969, and increased considerably in 1970, probably to some 6,000 to 7,000 m. tons. In both years, Malaysia accounted for about 1,600 m. tons of the exports, and Australia for about 95 per cent of the balance; the remainder came in quantities of under 200 m. tons from other small exporting countries. The United States is much the largest importer, and accounted for about three-quarters of total imports in 1969, and at least half the total in 1970. France was the only other significant importer of monazite. 6 other importing countries probably accounted for a maximum of 10 per cent of total demand.

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Country of origin	Belgium	France	W. Germany	Japan	Netherlands	U.S.A.	Total imports by countries listed
	Importing Country						
Australia	...	305	-	10	-	2,247	2,562
Ceylon	...	-	-	101	-	-	101
Hong Kong	...	-	-	-	-	151	151
Malaysia	...	-	-	-	-	1,416	1,416
U.S.A.	...	40	-	-	-	-	40
Zaire	...	176	-	-	-	-	176
Others, n.s.l.	10	12	-	-	20	-	42
Total	10	533	-	111	20	3,815	4,489

Table 6: World Imports of Monazite 1970 (m. tons)

Country of origin	Belgium	France	W. Germany	Japan	Netherlands	U.K.	U.S.A.	Total imports by countries listed
	Importing Country							
Australia	...	1,892	...	-	-	-	1,793	3,685
Indonesia	...	152	...	-	-	-	-	152
Malaysia	...	254	...	50	-	-	1,186	1,490
Nigeria	...	63	...	-	-	-	-	63
Thailand	...	-	...	-	-	-	148	148
Zaire	...	126	...	-	-	-	-	126
Others, n.s.l.	10	17	15	-	-	-	-	42
Total	10	2,504 (1)	15	50	-	-	3,127	5,706

(1) Total given as 2,441 in original source.

Table 7: World Exports of Monazite, 1969 (m. tons).

Country of destination	Exporting Country: Australia	India	Malaysia	U.S.A.	Total exports by countries listed
Austria	4	-	-	...	4
Belgium	-	-	-	...	-
France	204	-	-	...	204
West Germany	-	-	-	...	-
Italy	-	20	-	...	20
Japan	150	175	178	...	503
Netherlands	127	-	-	...	127
U.K.	-	3	243	...	246
U.S.A.	2,238	-	1,185	...	3,423
Others, n.s.l.	-	-	-	17	17
Total	2,723	198	1,606	17	4,544

Table 8: World Exports of Monazite, 1970 (m. tons).

Country of destination	Exporting country: Australia	India	Malaysia	U.S.A.	Total exports by countries listed
Austria	5	-	-	...	5
Belgium	152	-	52	...	204
France	978	-	-	...	978
West Germany	1	-	-	...	1
Italy	-	-	-	...	-
Japan	5	5	30	...	40
Netherlands	1,218	-	356	...	1,574
U.K.	106	-	-	...	106
U.S.A.	2,522	-	1,219	...	3,741
Others, n.s.l.	31	3	-	1	35
Total	5,018	8	1,657	1	6,684

5. Notes on main countries

5.1. Australia

Australia is a major producer of monazite and has been the most important commercial producer since 1960. During much of this period, the export of Indian and Brazilian monazite has been prohibited, though in both cases processed rare earth chlorides have been exported. Production from other countries has either been for a limited period (e.g. South Africa) or on a smaller scale.

Production in recent years is given in table 9 below.

Table 9: Australia : Production of monazite by states, 1967 - 70 (tons)

	1967	1968	1969	1970
Queensland	237 (1)	243 (1)	175 (1)	52 (1)
New South Wales	434 (1)	476 (1)	332	359
Western Australia	1,492	1,130	2,913	3,518
	2,163	1,849	3,420	3,929
Value ex-mine ($A000)	289	237	439	554
Average value per ton ex-mine ($)	134	128	128	141

Exports in 1970 were about 5,000 tons, reflecting in part the liquidation of stocks. Some 70 tons of xenotime containing 34,500 lb. of yttrium oxide were produced in Western Australia.

The Australian Bureau of Mineral Resources, Geology and Geophysics consider that production of monazite could be almost doubled if required. This opinion is substantiated by comparison of production figures for monazite and ilmenite in Western Australia, which show that production of monazite per 1,000 tons of ilmenite rose from 4.3 tons in 1969 to 4.7 tons in 1970 (compared with about 2.5 tons in 1967-68 though the figures are not exactly comparable). This increase reflects the increasing willingness of Australian producers to install the necessary extra equipment to separate the monazite. It is generally

(1) Shipments

considered that (anyway for East Coast producers) the price of monazite would have to increase to make separation worthwhile, but this point has probably been overemphasised. West Coast production is by far the most important, and ilmenite production there is forecast to expand considerably; monazite production is almost certain to go up with it.

The major producer of monazite in Australia is Western Titanium NL, who are the main ilmenite producers in Western Australia. Consolidated Gold Fields of Australia holds 85 per cent of the equity, and Mining Traders Ltd. about 11 per cent. Until 1969, monazite from this source was sold entirely on forward contract to American Potash and Chemical Corp. Production of monazite has been expanding rapidly as ilmenite production is expanded, as shown in table 10 below. Very limited quantities of xenotime are also produced.

Table 10: Australia : Production of monazite and other minerals by Western Titanium NL, 1966 to 1970 (tons)

Years ending 30th January	1966	1967	1968	1969	1970
Monazite	864	686	1,009	1,244	1,654
Xenotime	-	-	13	31	77
Other minerals (mainly ilmenite)	183,110	193,440	212,097	227,668	283,646
Total	183,974	194,126	213,119	228,943	285,377

Westralian Sands Ltd., 44 Parliament Place, West Perth 6000 W.A. was formerly known as Westralian Oil NL, and is a major producer of monazite as a by product from its ilmenite operations. It is a subsidiary of Austiox Pty. Ltd. and therefore a sub-subsidiary of British Titan Ltd. Capacity in 1968 was reported to be 80,000 tons of ilmenite; production in 1968/69 was in fact 99,070 tons. At that time expansion plans were in hand to raise ilmenite capacity to 130,000 tons, and to raise monazite capacity from 750 to 1,500 tons a year. The monazite is produced by the company's dry separation plant at Capel, W.A.

Cable (1956) Ltd. operates on the north shore of Koombana Bay near Bunbury, and has a capacity of about 130,000 tons of ilmenite a year. The company is wholly owned by Kathleen Investments (Australia) Ltd. Production of monazite was 465 tons in 1969 and 470 tons in 1970.

Western Mineral Sands Ltd. are also large ilmenite producers on the West Coast, but they do not appear to produce monazite. This company is owned by British Titan Ltd. and by Westralian Sands Ltd. (see above).

On the East Coast, the major producer is Associated Minerals Consolidated (known as AMA) formed in 1953 and controlled since 1961 by the Consolidated Gold Fields group who have a 41 per cent beneficial interest. They operate in New South Wales and Queensland; a subsidiary, Titanium and Zirconium Industries Ltd. (TAZI) has two large floating dredges with a combined capacity of 1,200 tons per hour. Full production figures are not available but the company produced 263 tons of monazite as a by-product from 64,000 tons of total production in the third quarter of 1970, and 179 tons of monazite as a by-product from 51,000 tons total production in the first quarter of 1971.

Mineral Deposits Ltd. have treatment plants at Crescent Head and Hawks Nest, N.S.W. They are a subsidiary of Titanium Alloy Manufacturing Co. Pty. Ltd. which in turn is a subsidiary of N.L. Industries Inc., New York. Monazite is produced as a by-product of rutile and zircon extraction. In 1971, 852 tons of monazite were produced as a by-product from 118,000 tons of rutile and zircon. In the previous year, 113,000 tons of rutile and zircon were produced, but apparently no monazite was extracted, possibly because the price of monazite was not judged sufficiently high to warrent the expense of extraction. The company has reserves of 1.2 mill tons of rutile and 1.2 mill tons of zircon.

Rutile and Zircon Mines (Newcastle) Ltd. are also believed to produce small quantities of monazite. They are associated with Kathleen Investments (Australia) Ltd.

Total production of ilmenite and rutile in Australia was just over 1 mill. tons in 1969, and has risen since. Among the producers of ilmenite and rutile not listed above are Coastal Mining Development Pty. Ltd., Consolidated Rutile Ltd., Cudgen R.Z. Ltd., Murphyore Holdings Ltd., Naracoopa Rutile Ltd., Northern Rivers Rutile Pty. Ltd., Queensland Titanium Mines Pty. Ltd., and Signal-Dillingham. All of these companies are probably potentially in a position to produce monazite, and while the total potential for any one company is unlikely to be more than a few hundred tons a year, their ease of entry into the monazite market would tend to cut short any tendency for the price of monazite to rise, should this develop as a result of increased demand.

Prospecting for new titanium ore bodies continues very actively, and some of these are proving viable. For example, Mid East Minerals NL has proved reserves of 1 mill. tons of ilmenite, zircon, monazite and leucoxene in the Busselton area of Western Australia, and was expected to start operations at 140,000 tons a year from early 1972. Some 1,000 tons a year of this will probably be monazite, if the company consider it worthwhile extracting it. Details of other companies engaged in exploration are given in the associated report in this series "Titanium minerals, chemicals, metal and alloys".

A discovery of mineral sands at Eneabba in southwest Western Australia is an important potential source of monazite.

There are also some sources of rare-earth materials which are independent of the production of ilmenite, rutile, and zircon.

Two Australian companies, Field Metals and Chemicals Pty. Ltd. of Sydney, and Australian Ceramic Industries Pty. Ltd. of Adelaide, purchased a uranium plant at Port Pirie from the South Australian government in 1968. Their intention was to process monazite in order to produce uranium and rare earth oxides. The tailings dam at Port Pirie is claimed to contain the world's largest known supplies of scandium. Production of rare earth materials was scheduled to start in 1969. This operation is believed to be carried out now by the Rare Earth Corporation of Australia Ltd.(1), of 209 East Terrace, Adelaide, S. Australia. The company marketed high grade mixed oxides in Europe and Japan and yttrium oxide in Europe. The range of saleable products is being expanded to include concentrates and compounds of cerium, lanthanum, gadolinium, samarium, praeseodymium, and didymium, as well as thorium hydroxide and sodium sulphate.

Rare Earth Corporation of Australia estimated in 1970 that the company's target of 2,000 tons of monazite a year would be achieved early in 1971. The source of this monazite is not known. At their annual general meeting held late in 1971, their marketing director said that it had been established that there was a market for Australian rare earth materials. Australian production of monazite at 5,000 to 5,500 tons a year is about 40 per cent of world output, and proper advantage should be taken of this situation to become major suppliers of rare earth concentrates and products.

Mary Kathleen Uranium Ltd. was adversely affected by the export restrictions place by the Australian government on uranium in 1968, and started to examine the possibility of producing rare earths from the uranium mill residue stored in the tailings dam at their mine in Queensland. It was later reported that the company had constructed a rare earth pilot plant to provide bulk samples and confirm operating procedures. Mary Kathleen Uranium (an associate of the RTZ group) has apparently not yet started to sell rare earth materials, but they are likely to be able to do so at fairly short notice.

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(1) The 1970 Australian Mineral Industry Review reported that Rare Earth Corporation Ltd. was established at Port Pirie in 1969.

5.3. Brazil.

Brazil was a major source of monazite concentrates, particularly in the period between 1887 and 1913. Unprocessed rare earth materials have not been exported since 1951 when government restrictions were imposed.

All Brazilian rare earth and thorium production is regulated by the CNEN (Comissao Nacional de Energia Nuclear). There appear to be 3 main production areas;

(a) Cumuruxatiba CNEN plant, 25 miles north of Prado (Bahia). This plant recovers monazite from black sands by hydraulic concentration in Humphreys spirals followed by drying on a rotary drier at 80 deg. C and electrostatic separation of the monazite and zircon from the ilmenite and rutile. The concentrate capacity has been given as 1,200 tons a month containing 18 per cent of monazite, or say 2,600 short tons of monazite a year. The monazite concentrates go to Sao Paulo where there is a plant belonging to Orquima do Brazil producing rare earth chlorides, most of which are exported. No monazite is exported as such. The other minerals are stockpiled. The Cumuruxatiba sand deposits are estimated to contain about 180,000 tons. They extend for 6 km. south of the town, and are about 1 m. thick. They contain about 58 per cent ilmenite, 18 per cent monazite, 2 per cent rutile and 21 per cent zircon.

(b) Barra de Itabapoana CNEN plant. (Rio de Janeiro).

(c) Ponta da Truta and Guarapari (Espirito Santo). These deposits are worked by MIBRA (Monazita & Ilmenita da Brazil Ltda) which is the successor company to the Société Minière Franco-Brasilienne which worked sands in the area until 1923. The Guarapari plant is stated to be larger than the Cumuruxatiba plant; total production of both has been estimated (1968) at under 1,500 tons of monazite a year.

The processing of monazite concentrate by CNEN in 1970 yielded 2,064 tons of rare earth oxide and 5 tons of rare earth chloride. Companha Industrial Fluminense, Sao Joao del Rei (Minas Gerais) produces 100 tons of mischmetal a year for lighter flints.

5.4. Canada.

Thorium was produced as a by-product from the Elliott Lake uranium operations (Nordic mill) of Rio Algom Mines Ltd. from 1959 to 1968. The product was a thorium sulphate containing between 35 and 40 per cent ThO_2 and was mainly shipped to Thorium Ltd. in the U.K. (Rio Algom is an associate, and Thorium Ltd. a subsidiary, of Rio Tinto-Zinc Corporation Ltd. of London) Small quantities were refined to metallurgical grade (99.8 per cent ThO_2) for Dominion Magnesium Ltd., of Haley, Ont. who produce refined thorium metal, pellets and powder, though in limited quantities; the quantity shipped to Dominion in 1969 (the only year for which figures are available) was only 919 lb.

Production figures have not been published but can be estimated from the U.K. import figures for thorium compounds given at the end of this report, as follows:

Table 11: Canada: Estimated production of thorium sulphate (tons ThO_2 content)

	Possible range	Best estimate
1966	16 to 58	25
1967	38 to 55	40
1968	44 to 60	50
1969	20 to 23	20
1970	-	-
1971	-	-

A range of estimates has to be given since the country of origin of U.K. imports is given only for some of the months in the official statistics. The true total is likely to lie at the lower end of the range, since, if the importer had no objection to publication of the country of origin for some months, he is unlikely to have done so for others, and the balance is thus probably composed of imports of processed thorium from some other country. (Some information on the value of shipments supports this view).

The capacity of the Rio Algom by-product plant was given as 150 to 200 tons of ThO_2 and 100,000 lb. of rare earth concentrate.

In 1969, Rio Algom started a $40 mill. development programme, which involved temporary suspension of the Nordic mine, sinking a new shaft at the Quirke mine, rehabilitation the Quirke mill, and recommissioning the Panel mine and mill. When completed, Rio Algom expected to have capacity for 5,000 tons of U_3O_8 a year, which would imply a possible maximum production of 2,000 tons of thorium oxide if demand could be found.

Demand for uranium is at present weak, largely due to the massive stockpiles accumulated by the governments of Australia, Canada, France, South Africa, U.K. and U.S. Most of these governments would like to liquidate some of their stockpiles but have been unable to do so due to the weak market conditions.

This situation could however change quite rapidly in the future. A recently published report (Uranium and Thorium in Canada; Resources, Production and Potential, Dept. of Mines and Resources, Ottawa, 1971) estimates that 1 ton of ThO_2 is associated with every 2.3 tons of U_3O_8 in reasonably assured reserves in Canada which can be economically mined when the selling price is low (less than $10 per lb. of U_3O_8). Uranium production in the past reached a maxmimum of 15,000 sh. tons U_3O_8 in 1959, and has since declined to some 3,000 sh. tons. The report estimates that the world annual uranium requirement (excluding Communist countries) will be 130,000 sh. tons a year in 1985. Canadian production will probably be about 20 per cent of the total, which implies that Canadian production of by-product thorium could be 11,000 sh. tons in 1985.

Unless there is a demand for thorium for nuclear power stations these thorium by-products will be stockpiled. In the current state of the thorium market, it would appear hardly worthwhile to extract the thorium from the tailings, and this may well continue to be the case. If there is a demand for thorium for nuclear power stations, Canadian by-product thorium is likely to provide a major part of the supply.

Denison Mines Ltd. also have an uranium operation at Elliott Lake, but as far as is known, have not produced by-product thorium. Stanrock Uranium Mines Ltd. produced uranium and yttrium oxides until 1969, when they went out of production; there are no reports of any thorium production from that source either.

5.4. Ceylon.

The Ceylon Mineral Sands Corp. has a plant on the north coast at Pumoddai, about 35 miles from Trincomalee. Its main purpose is the production of ilmenite. The reported capacity of the plant was 60,000 tons of ilmenite concentrates a year, but exports from Ceylon (mainly to Japan) have been somewhat in excess of this, which suggests that capacity may have been increased. This deposit contains only traces of monazite, and it is doubtful whether it is extracted. It was, however, reported in 1968 that the company was going to install a plant at Trincomalee to recover rutile and zircon from tailings, and that it was planned to produce monazite concentrates as well.

Monazite occurs in some abundance in other beach deposits, particularly that at Induruwa (which was actually worked for monazite from 1918 to 1922). Small tonnages of monazite were produced from this source by a Government plant at Nagoda, and they were sold by tender in small tonnages. The latest reported are 300 tons in 1963 and 125 tons in 1965. The Japanese import figures show that 101 m. tons were imported in 1969. There have also been reports of a Government plant (almost certainly the same one since the two places are very close) at Katukuranda near Kalutara, which was set up as an experimental and research station under the direction of the Government Mineralogist. Raw material was obtained by harvesting the beach sands at Beruwalu and Kaikawala at suitable times of year, and more recently it has used material from Polkotuwa.

5.5. Egypt.

Black sand deposits at Rosetta were reported in 1962 as having been worked since 1959 for the monazite and other heavy mineral content, but no further reports have been made, and it is likely that production is either small or non-existent. The Government owned Egyptian Black Sands Co. took over the plant of the former Anglo-Egyptian Mining Co. in 1957.

5.6. France

The former Sté des Terres Rares was taken over by Pechiney in 1960, and since then Sté Pechiney-Saint-Gobain has been the major processor in France. Their plant at La Rochelle produces a wide range of rare earth and thorium products. Following the merger of Ugine-Kuhlmann and Pechiney to form Péchiney-Ugine-Kuhlmann in 1971, a new subsidiary Sté. Francaise des Metaux Speciaux has taken over the function of the Metaux Speciaux department of Ugine-Kuhlmann and the Sté. General de Magnesium, and, from 1st April, 1972 part of the activities of Trefimetaux. The new company will have interests in marketing thorium and rare earth metals, salts, oxides, and semi-fabrications, together with wide interests in other metals.

Until 1967 Pechiney obtained most of its raw materials from Madagascar under an arrangement with the French atomic energy authority (CEA) who retained the thorium while Pechiney took the rare earth content. The CEA have a plant at Le Bouchet, and has been active in monazite and uranothorianite in Madagascar. In 1970, Australia accounted for 75 per cent of French imports of rare earth ores, and most of the remainder came from the Congo, Indonesia and Malaysia. This change in sources of supply occured due to a combination of factors, including growing production difficulties in Madagascar and probably a reduced requirement for thorium by the CEA.

The main organisations in France with an interest in thorium or thorium products are the CEA, and the Pechiney-Ugine-Kuhlmann group. Pechiney included both mantle grade and nuclear grade thorium nitrate in its range of products in 1971.

S.A. Dannat of 196 Rue St. Jacques, Paris 5^{e} and C.I.C.A.F., Site Industrielle St. Pierre, Bollene 84 sell thorium compounds.

5.7. West Germany

The thorium situation in Germany is far from clear. Before the war Auer Gesellschaft (wholly owned by Degussa) were the leading manufacturers of rare earths in Germany, and they used imported monazite as their main raw material. After the war, the use of monazite was prohibited because it contained radioactive material, and when these restrictions were lifted, Auer decided not to resume production at their factory in Berlin. Their chemists were transferred to Th. Goldschmidt.

West German imports of monazite in recent years have been small. There were no imports in 1968, 1969 or 1971. Imports in 1970 were 15 m. tons. Imports in 1967 were almost exactly balanced by exports.

On the other hand, imports of thorium compounds (in which category are included compounds of depleted uranium, which are, however, thought to be insignificant) are quite substantial, amounting to 33 m. tons in 1967, 41 m. tons in 1968, 29 m. tons in 1969 and again in 1970, and 94 m. tons in 1971. Exports in this category have not exceeded 4 m. tons in any of these years.

It seems clear therefore that monazite is not used as a raw material for rare earth production in Germany, but there are substantial imports of thorium compounds. It is difficult to see what these are used for. There is some production of gas mantles in Germany, but this is not likely to consume more than 10 to 15 m. tons of thorium oxide each year. It is possible that the imports, mainly from the U.S., are thorium nitrate, in which case the 10 to 15 tons thorium oxide content would correspond to about 20 to 30 tons thorium nitrate content. This provides sufficient explanation for the years up to 1970, but it is difficult to explain the trebling of imports in 1971, unless perhaps there was some exceptionally favourable opportunity to purchase supplies forward due to the considerable oversupplies in the United States at that time. This does not, however, seem very likely in view of the fact that the average value of imports in 1971 was twice the average value of 1970 imports.

The most likely explanation in our view is that some new use of thorium compounds is under development in West Germany, and that it involves the use of thorium oxide rather than nitrate. There is no published information available to suggest what this use might be.

The "pebble-bed" reactor discussed in section 64 may account for some of this increase in demand though the amount appears too large and too early for this.

5.8. India

India was an important producer of monazite from about 1910 to 1940, but since 1948 the export of monazite has been prohibited and the industry has declined.

The main production area is at Quilon in Kerala State. 2,708 tons of monazite were produced there in 1969/70. All of this monazite is supplied to the plant of Indian Rare Earths Ltd. at Alwaye in Kerala who produced 3,850 tons of rare-earth chloride in that year.

In earlier years the entire production came from Manavalakurichi (MK) Madras State near the southern tip of India. These deposits were thought to be exhausted before the war, but some production there has been reported since. Indian Rare Earths No. 2 plant at MK was reported as reopened in 1969, and produced 2,700 tons of monazite for processing at Alwaye in 1969/70.

Both sources were formerly worked by Travancore Minerals Ltd., which was first nationalised and then absorbed as the minerals division of Indian Rare Earths Ltd.

Indian Rare Earths Ltd. was operating only its Tamil Nadu plant in 1969. The other at Kerala was closed for modernisation and expansion. When completed the new plant will have an annual output of 100,000 tons of ilmenite and 5,850 tons of rutile together with "substantial" amounts of monazite.

The plant at Alwaye, Kerala State, was completed in 1952 with technical aid from Societé Banque Morocaines de Credit and Societé de Products Techniques de Terres Rares. The plant had a capacity of 2,500 tons of monazite a year, which was raised to 3,000 tons in 1962. Rare earth chloride, carbonate, and hydroxide, and also thorium hydroxide, is produced. There is also a plant producing cerium fluoride for arc carbons, with a capacity of 120 tons a year. The Alwaye plant was operated only at partial capacity (probably about 50 per cent) in 1970; sales of thorium hydroxide to the Indian government amounted to $90,000 in that year. Another plant at Trombay, Bombay produces thorium nitrate and oxide from the hydroxide produced at Alwaye. A pilot scale lanthanum oxide and mischmetal plant has also been reported.

Indian Rare Earths Ltd. were offering for sale through their European agents (Mineral AG Schwyz of Brunnen, Switzerland) in 1972 the following products:

Thorium nitrate
Cerium nitrate
Mixed rare earth chloride
Cerium fluoride
Cerium oxide

Sales of rare earth chloride to Europe were 4,960 sh. tons valued at $ U.S. 1.125 mill. in 1969/70, nearly double those in the previous year.

In 1968 they were also offering pure neactor-grade thorium nitrate and oxide, and thorium metal.

5.9. Indonesia

Small quantities of monazite have been produced as a by-product of tin recovery on the island of Singkep. The Government-owned operator is Perusahaan Negara Tambang Timah Singkep (PNTTS) which is part of the Indonesian State Tin Mining Enterprise.

There are periodic reports of parcels of thorium or rare earth materials on offer from Indonesia. 152 m. tons of Indonesian monazite were imported by France in 1970. No other trade is recorded in their statistics or in the statistics of the more likely recipients, and it is unlikely that production in Indonesia is significant.

5.10. Japan

Japan is probably the third largest importer of monazite, though the quantities involved are considerably less than the two major importers (the U.S. and France).

The main companies concerned with importing and processing monazite and manufacture of thorium compounds in Japan are shown in table 12.

Table 12: Japan : Producers and distributors of thorium ores and products

Thorium ores and minerals
Ishibara Industrial Co., Osaka.
Mitsubishi Shoji Kaisha, Tokyo. (Distributor)
Mitsui and Co. Ltd., Tokyo. (Distributor)
Nichimen Company Ltd., Osaka.
Okura Trading Co. Ltd., Tokyo.
Toyo Menko Kaisha, Ltd., Osaka.
Wako Bussan Co. Ltd., Tokyo. (Distributor)

Thorium compounds and metal
Kinsho Mataichi Co. Ltd., Tokyo.
Mitsubishi Shoji Kaisha, Tokyo. (Distributor)
Mitsui and Co. Ltd., Tokyo. (Distributor)
Morita Kagaku Kogyo Co. Ltd., Osaka.
Nagase and Co. Ltd., Osaka. (Distributor)
Nissho Iwai Co. Ltd., Osaka.
Ohara and Co. Ltd., Osaka. (Distributor)
Toho Zinc Co. Ltd., Tokyo.
Wako Bussan Co. Ltd., Tokyo.

Incandescent gas mantles
Mitsubishi Shoji Kaisha, Tokyo. (Distributor)
Mitsui and Co. Ltd., Tokyo. (Distributor)
Nissho Iwai Co. Ltd. Osaka.

The estimated thorium content of imports of thorium ores into Japan is shown in table 13 below.

Table 13: Japan : Estimated thorium content of imports of thorium ores, 1967 to 1971

Country of origin	Est. ThO_2 content (per cent)	Estimated ThO_2 content of ore imports (m. tons)				
		1967	1968	1969	1970	1971
Australia	7½	4.0	-	0.7	-	3.6
Ceylon	6	-	-	6.0	-	-
S. Korea	6	0.5	-	-	-	-
Malaysia	8	11.4	1.6	-	4.0	1.7
South Africa	6	-	-	-	-	0.2
Thailand	(6)	-	-	-	-	2.9
U.S.A.	4	∅	-	-	-	-
Zaire	(6)	-	-	-	-	3.6
Total		15.9	1.6	6.7	4.0	12.0

Imports of inorganic or organic compounds of thorium or depleted uranium have ranged between 6 m. tons in 1968 and 61 m. tons in 1967. From the value figures, however, it is clear that imports in this category from Australia are almost certainly a monazite concentrate of a fairly low grade, probably containing no more that 10 per cent thorium at the outside. Most of the remainder is likely to be nitrate. This gives estimated imports of thoria in both ores and thorium compounds of 21 m. tons in 1970 and 19 m. tons in 1971.

Total Japanese requirements for thoria in gas mantles are estimated at 15 m. tons in 1971, and there are presumably some small requirements for other uses.

5.11. South Korea

Monazite placer deposits in South Korea were exploited by the Japanese in World War II. Korea Rare Elements Development Co. announced in 1956 that they could produce low grade monazite concentrates from the Pi-in deposits, and that they intended to install equipment to produce high grade concentrates. Han Kook Monazite Ore Separating Ltd. separated monazite and zircon from black sands. There were reported to be two mines concerned with cerium (probably monazite) in operation in 1965.

Japan is much the most likely market for monazite produced in South Korea, but the only recorded imports were 9 m. tons in 1967; 44 tons were imported to the U.S. in the same year. Production in South Korea since 1967 is therefore assessed as very small, probably negligible.

5.12. Malagasy Republic

Deposits of beach sands containing ilmenite and zircon as well as monazite along the south east coast of the island were worked by Société de Traitement des Sables de Sud Madagascar SOTRASSUM at Antété from 1959 to 1967. This company had proved reserves of about 4 mill. tons of sands containing 2½ per cent monazite. Their output was 493 tons in 1962/63. SOTRASSUM are affiliated with the Commissariat de l'Energie Atomique and the Pechiney S.A. There were plans for a large scale mineral sands operation, but these were abandoned because of shipping and marketing difficulties (since neither parent has much interest in the ilmenite and zircon which would be the main products recovered).

Another company engaged in maonzite recovery, in the Manatenina area, was Société d'Exploration des Monazites, a subsidiary of the French manufacturer of lighter flints, Etablissements Tricot. Their operations ceased in 1966.

The French import figures show no imports from Madagascar after 1967, which confirms the impression that production of monazite has now ceased.

Small tonnages of euxenite were exported to France in the years 1967 and 1968. There have also been reports that Société Le Quartz is engaged in mining bastnasite, and had produced 165 tons (of which 122 tons was exported); in 1967 Pechiney was carrying out further prospecting for this company.

5.13. Malawi

A large deposits containing at least 110,000 tons of monazite which can be mined by open pit methods is known to exist at Kangankunde Hill. The monazite is low in thoria, and high in europium, and indeed has a rare earth distribution similar to Mountain Pass bastnasite. The government granted exclusive prospecting rights to Lonrho Ltd. in 1968 (and the company reported this in their annual report for that year,) but the product has not been referred to by them since. It was reported that several hundred tons of bastnasite were shipped from Malawi in 1969.

A further report of the "discovery of good quality monazite" was made in Malawi in 1971.

5.14. Malaysia

Monazite occurs as a by-product of tin-mining operations. It is contained in the residue, known as amang, which consists mainly of ilmenite. Production of monazite concentrates in Malaysia was reported as follows: (tons)

1963	885
1964	303
1965	694
1966	866
1967	947

Production figures since then are not available, but the export figures suggest that production must have been about 2,000 tons per year. Production fluctuates considerably from year to year because much of the production of monazite and also of xenotime is derived from tailings dumps of amang rather than the by-product arising from current tin mining operations.

Malaysian production was considerably increased as a result of the sale of 150 tons of yttrium concentrates containing 25 per cent Y_2O_3 in 1966. One of the leading exporters of Malayan xenotime is Sharikat Harpet Gilfillan Berhad, who in 1968 were studying the possibility of installing a plant to upgrade Malayan xenotime to 60 per cent Y_2O_3 concentrate. Technical assistance was to be obtained from British Rare Earths Ltd. This plant was planned to assure yttrium consumers of a stable source of supply, and to encourage the many small Malaysian producers to continue production. Recent changes in ownership of BRE may however has upset this arrangement.

Other companies which are believed to produce monazite are the Malayan Tin Dredging Co. Ltd.,[(1)] and the Pahange Consolidated Co. Ltd. The Ishihara Industrial Co. of Osaka Japan has also produced by-product monazite from ilmenite workings in Trengganu state.

A Malaysian trade mission visited Japan in 1967 to discuss a supply agreement for xenotime. It was stated that 600 tons had been exported, many to the U.S. in the previous four years and that production capacity at Gainbang in Pahang State could be up to 150 tons a year. 1.5 tons of xenotime was exported to the U.S. in 1971 at a price of $1.80 per lb. contained Y_2O_3.

(1) The company realised £44,133 from sales of ilmenite, monazite, and zircon in the year ending 30th June, 1971, and £58,093 in the following year.

5.15 Mauretania

Large deposits of monazite containing, according to one report, 3.8 per cent of Y_2O_3 have been found at Bou-Naga about 60 miles west of Akjoujt. They are being developed by a company controlled by Pechiney which is called SOMIREMA (Socīété Minière des Reserches de Mauretanie). It was announced in 1968 that the open pit mine would be developed to produce up to 1,000 tons of ore a year, which would be shipped from Nauakchott to the Pechiney plant at La Rochelle. The mine produced 1,400 m. tons of ore containing 4.4 per cent Y_2O_3 and 6 to 8 per cent heavy REO. 600 m. tons of concentrate was shipped to France but the mine was closed early in 1970 because of surplus stocks held by Pechiney.

5.16 Nigeria

Monazite is obtained as a by-product when cleaning the concentrates from some of the tin mines. Production is stated to be largely dependent on demand. There are no recent figures available but production in 1967 was 114 tons.

Production of tin in recent years has been:

	tons
1967	9,340
1968	9,644
1969	8,606
1970	7,830

The producers of tin in Nigeria are:

Amalgamated Tin Mines of Nigeria Ltd.

Janta Nigeria Ltd.

Exlands Nigeria Ltd.

Bisichi Tin Co. (Nigeria) Ltd.

5.17. Somali Republic

The United Nations was reported in 1968 to be exploring a large ore body containing uranium, thorium, yttrium, ytterbium and scandium, at Alio Ghelle, 150 miles north-west of Mogadisco. No production has been reported from this source, however. Nucleare Somali (affiliated with Ente Nazimale Idrocarburi of Italy) and White Star Mining Co. Inc. (affiliated with Western Nuclear Inc.) were investigating radio-active deposits "in a northern region" in 1971.

5.18. South Africa

South Africa was an important source of monazite in the period 1952 to 1963 during which a total of 60,000 short tons was produced at the Steenkampskraal mine near van Rhynsdorp in the Namaqualand desert by the Anglo-American Corp. of South Africa Ltd. This vein deposit of monazite is very unusual; most other monazite sources are beach placers. Here the monazite and apatite together made up 80 per cent of an extensive vein which also contained zircon, magnetite, pyrite, chalcopyrite and galena. All of the output is believed to have been sold to the Lindsay Chemical Division of American Potash and Chemical Corporation.

Capacity of the plant was 8,000 short tons of concentrate a year. The mine was open from 1952 to 1959 and was re-opened in 1962 and 1963 to fulfill a specific contract for 8,000 short tons for Lindsay. Contrary to some reports, reserves at the mine are still large, and it is likely that it could be re-opened if the price of monazite rose sufficiently to warrant it.

Small amounts of samarskite and euxenite are exported occasionally from South Africa (and also from Mozambique) but these are not of current importance. Very limited amounts of monazite are produced as by-products of the heavy mineral workings on the Natal coast. A subsidiary of Anglo-American Corp. operated at Umgababa until 1964, and another company has recently been operating at Morgan Bay.

The Atomic Energy Board reported in 1971 that the Palabora Mining Corp. had commissioned a plant at the Palabora copper mine for the recovery of by-product uranium oxide and thorium sulphate from a heavy mineral concentrate containing uranothorianite.

5.19. U.K.

The U.K. has substantial interests in processing of thorium.

Thorium Ltd. was formed in 1914 when the outbreak of war left Britain without a source of thorium supply. After the war, there was strong competition from Continental suppliers, but the Government imposed a protective tariff and they survived. At the beginning, they processed Norwegian thorite, but during the 1920s, Hopkin and Williams (who had helped to found Thorium Ltd.) developed the Kerala beach deposits of monazite, which were later taken over by the Indian government. Thorium Ltd. diversified into manufacture of rare earth products and mesothorium (a form of radium used in luminous compounds). Cerium fluoride for arc carbons was a staple product in this period. During the second world war, a factory was established at Widnes.. In 1959, Imperial Chemical Industries Ltd. and Howards and Sons Ltd. who then controlled the company disposed of their interest toRio Tinto Ltd. and Dow Chemical, and in 1966 Dow in turn disposed of their interest.. Since then, Thorium Ltd. have been a wholly-owned subsidiary of Rio Tinto-Zinc Corporation Ltd.

The Ilford plant was closed down in the 1950s and the Widnes plant was expanded. In 1959, experimental production of rare earths by the solvent extraction process was started, and it was shown that this was a suitable method for bulk production of high quality products at a lower cost than alternative processes. At this point, Thorium Ltd. changed from processing monazite to processing bastnasite from Mountain Pass for the light rare earths, and processing Rio Algom concentrate for thorium and yttrium. A new rare earths plant was commissioned at a cost of £1.5 mill. in October 1968. The plant is said to use 1,000 tons of bastnasite a year.

The sales, costs and profits of the company for the last 5 years are shown in table 14.

Table 14: Thorium Ltd. : Summary of financial results, 1966 to 1970 (£000)

	1966	1967	1968	1969	1970
Sales: to RTZ group	18	12	31	12	18
to other UK customers	645	861	452	357	351
to other overseas customers			362[1]	467	453
Royalty receipts	202	33	11	7	7
Sub-total	865	906	856	843	829
Costs	615	689	764	909	763
Depreciation		33	40	78	81
Trading profit	250	154	12	-155	-15

It will be seen that the new plant added substantially to costs, and nearly doubled the depreciation charge, but it did not significantly affect revenue, presumably because the expansion of praeseodymium and lanthanum sales was not sufficient to compensate for the drop in sales of yttrium and europium. Also of interest is the substantial royalty receipts (£202,000) in 1966, presumably from sales of know-how on the solvent extraction process.

Thorium compounds are probably now a rather minor part of the output of Thorium Ltd. The import figures suggest that imports of Rio Algom concentrates which were discontinued in 1969 were an average of 30 tons ThO_2 content between 1966 and 1969. This sets an upper limit on thorium production by Thorium Ltd. The lower limit is set by the estimated demand for U.K. incandescent mantle manufacture (9½ tons ThO_2 content) plus exports which are identifiable only from the import statistics of other countries. This gives a range of possible output of between about 20 and 30 tons ThO_2 content a year.

British Flint and Cerium Manufacturers Ltd. of Tonbridge, Kent, were a subsidiary of Spark Holdings Ltd. until August 1969, when they were acquired by Ronson Corp. of the U.S. for £125,000. They were at that time reported to rely on imported cerium chloride, from which they manufactured mischmetal and lighter flints. Earlier reports had suggested that they used monazite as a raw material, but this does not seem likely now, since they would have problems disposing of the thorium content.

(1) Exports in 1967 were mainly to Japan.

Koch-Light Laboratories Ltd., Colnbrook, Slough, Bucks., sell thorium compounds, and so do Fisons Scientific Apparatus Ltd., of Loughborough, Leicestershire.

Magnesium Electron Ltd., of Swinton, Manchester produce thorium alloys.

5.20 United States

5.20.1. Ore producers

Monazite has been produced in the United States for many years. The major source in the last few years has been the beach deposits near Folkston Georgia which are mined by Humphreys Mining Co., a subsidiary of Humphreys Engineering Co. Production figures are withheld, but output in 1970 increased by 6 per cent, mainly due to demand for rare earths. Estimates of their production are made in section 5.20.2.

The Skinner plant of N.L. Industries Inc. near Jacksonville, Florida ceased production of monazite in 1965, but in 1970, it was reported that Titanium Enterprises, jointly owned by American Cyanamid and Union Camp Corp. had been formed to exploit titanium and associated minerals at Green Cove Springs, 20 miles south of Jacksonville. Production was scheduled to begin in July, 1972, but there have been no reports as to whether production began on schedule.

American Metal Climax Inc. have produced significant tonnages of monazite, recovered as flotation concentrate, from their molybdenum mine in Colorado, but this operation was discontinued in 1970.

An underground mining operation for uranium-thorium ore was started in 1971, at Kendrick Bay, Prince of Wales Island, Alaska. The ore is transported from the faces in large diesel trucks to barges for shipment to Seattle, and then by rail and truck to the Dawn Mining Co. uranium processing plant at Ford, Wash., which has a capacity of 500 t.p.d. Reserves at Kendrick Bay were estimated at 50,000 tons, mostly high grade, with a market value of about $7 mill. About 22,500 tons had been shipped by August 1971. The proportion of thorium in these deposits was not stated.

Monazite occurs in a number of other places in the United States. Deposits which have possibilities as commercial sources are:

the Trail Ridge ilmenite deposits developed by E.I. du Pont de Nemours and Co. Inc.

the Natchez Traces State Park heavy mineral placer deposit containing rutile, ilmenite and zircon, in addition to monazite, which had pilot plant tests conducted by Kerr-McGee Chemical Corp. in 1970.

The workings at Allen, S.C. of the Marine Minerals Co., a subsidiary of Heavy Minerals Co., which was in turn owned by Vitro Corp. of America, Crane Co., and Pechiney of France. This operation closed in 1958.

the Idaho river workings, were worked in the 1950s by a number of dredging companies, including Baumhoff-Marshall Inc., Warren Dredging Corp., and Idaho-Canadian Dredging Co.

the Lemhi Pass deposit on the Idaho-Montana border, which is reported to be a large potential source, and is periodically described as "being evaluated". Sawyer Petroleum Co. and the Union Pacific Railroad have an interest in this deposit which is reported to contain 0.75 per cent thoria.

5.20.2. Estimated U.S. production of monazite

A major difficulty in assessing the world supply situation for thorium arises because U.S. production of monazite since 1964 has been almost entirely by one producer, Humphreys Mining Co. of Folkston, Georgia, and as a result monazite production figures since then have been withheld.

The only published figures are the average for the decade 1959 to 1968 inclusive, when average production was 110 short tons ThO_2 content. Since most U.S. monazite is low in thorium, and typically contains 4 per cent, the average annual production can be assessed at 2,750 tons.

The only annual figure published during this period was for the year 1959, when 770 tons of monazite were produced.

An estimate of monazite production can however, be derived from the import figures for monazite, coupled with some information about changes in the level of monazite stocks which appear in the annual US Bureau of Mines Minerals Yearbook section on rare earth elements. The apparent consumption of monazite by chemical processors can be obtained for one year (1970) by subtracting apparent bastnasite consumption from total apparent consumption of all rare earth materials. Apparent bastnasite consumption can be worked out because production figures for each year are given by Molycorp, and in that year, they also gave a figure for the change in stocks. The calculation, which is rather lengthy, is explained in more detail in the companion report in this series on the rare earths. The results are shown in table 15 below.

Table 15: U.S.: Roskill estimate of U.S. production and stocks of monazite. (short tons)

	1967	1968	1969	1970
Monazite:				
Stocks at 1st Jan.	6,790	6,180	18,450	27,150
Production	3,800	10,200	9,600	4,700
Imports	2,090	4,370	4,200	3,450
Sub-total	12,680	20,750	31,650	35,300
Less: stocks at 31st Dec.	6,180	18,450	27,150	26,300
exports	-	-	-	-
Apparent consumption by chemical processors	6,500	2,300	4,500	9,000

These figures should be treated with some caution, since they involve fitting together many small pieces of information which do not exactly tally. The general picture they give is we believe, a good one; in particular they quantify adequately the threefold increase in monazite stocks recorded in 1968 at a time when consumption by chemical processors went down to one-third of the 1967 level.

The most likely explanation for these figures is that the yttrium boom was widely expected to continue well into 1968 and beyond, and both imports and domestic production of monazite were expanded considerably in this expectation. In the event, yttrium demand fell off quite rapidly because phosphor manufacturers were overstocked, and both production and imports were slightly cut back in 1969. The extent of the necessary outback was not, however appreciated, and stocks continued to rise in 1969. In 1970, drastic cutbacks in both US production and imports occurred, and stocks were slightly reduced as a result. However, it will obviously be a considerable time before the stocks of monazite accumulated as a result of these forecasting errors are disposed of.

5.20.3. Thorium products

The principal U.S. companies engaged in the processing and fabrication of thorium products are given in table 16 below.

Table 16: U.S.: Processors and fabricators of thorium products

Product code[(1)]	Company name and address
p	Davison Chemical Division, W.R. Grace and Co., Pompton Plains, N.J. and Chatanooga, Tenn.
p	Gallard-Schlesinger Chemicals Manufacturing Corp., 584 Mineola Avenue, Carle Place, N.Y. 11514.
f	General Electric Co., San Jose, Calif., and Wilmington, N.C.
pf	Gulf General Atomic Inc., San Diego, Calif.
pf	Kerr-McKee Chemical Corp., Oklahoma City, Ocla., Cimarron, Okla., and W. Chicago, Ill.
pf	Metal Hydrides, Inc., Beverley, Mass.
pf	N.L. Industries Inc.,[(2)] Nuclear Division, Albany, N.Y.
pf	Nuclear Chemicals and Metals Corp., Huntsville, Texas.
pf	Nuclear Fuel Services Inc., Erwin, Tenn.
pf	Nuclear Materials and Equipment Corp., Apollo, Pa., and Leechburg, Pa.
f	Tennessee Nuclear Specialites Inc., Jonesboro, Tenn.
pf	United Nuclear Corp., New Haven, Conn., and Henrietta, Mo.
pf	Westinghouse Electric Corp., Bloomfield, N.J., and Columbia, S.C.

Davison Chemical Division of W.R. Grace and Co. are primarily processors of monazite. The Grace facilities at Chatanooga were owned until 1965 by Vitro Chemical Co., who obtained their know-how from the former Société des Terres Rares (now part of Pechiney-Ugine-Kuhlmann). Grace's total monazite processing capacity was stated some years ago to be 10,000 tons of monazite a year. Present demand is considerably lower than this. Grace is the dominant monazite processor, and is probably still operating with substantially under-utilised capacity. However, production in 1970 was 50 per cent higher than in 1969. The Pompton Plains plant makes rare-earth polishing powders.

(1) Product code: f - fabricator; p - processor.
(2) Previously known at National Lead Co.

W. R. Grace and Co. are joint owners with American Machine and Foundry Inc. of Nuclear Fuel Services Inc. of Erwin, Tenn.

Gallard-Schlesinger Chemical Manufacturing Corp. are primarily interested in the manufacture of thorium chemical products, partly through their Atomergic Chemicals Division.

Gulf General Atomic Inc. are the main contractors for the large high-temperature gas-cooled reactors (HTGR) recently ordered by Philadelpia Electric Co. (see section 6.3.).

Kerr-McGee Chemical Corp. have an interest in thorium materials which extends back to the beginning of the century when the former Lindsay Light Co. made thoria for gas mantles in Chicago. Lindsay eventually became part of American Potash and Chemical Corp., which was taken over by Kerr-McGee in December, 1967. In 1970, all the chemical, fertiliser, and non-fuel mineral interests of Kerr-McGee Corp. were merged into a single subsidiary, Kerr-McGee Chemical Corp. There is no recent published information about this company's thorium interests; rare earths rate only one line in their 1970 annual report ("Sales of rare earth products in particular were down") and presumably their thorium sales are less important than their rare earth sales. This company is the only other processor of monazite in the U.S.

N.L. Industries Inc. are interested in thorium for atomic purposes. They also have extensive interests all over the world in ilmenite mining operations, and therefore in monazite production, particularly in Australia.

Nuclear Materials and Equipment Corp. are mainly producers of uranium and plutonium-bearing fuels; they were acquired by Atlantic Richfield Corp. in April 1967.

The remaining companies in the table are believed to be interested in thorium for nuclear purposes only.

Producers and distributors of thorium metal and salts are listed in table 17.

Table 17: U.S.: Producers and distributors of thorium metal and salts

Product code(1)	Company(2) name and address
a	Allied Chemical Corp., Speciality Chemicals Division, POB 1087R, Morristown, N.J.
e	Apache Chemicals, POB 17, Rockford, Ill. 61105.
b	Atlantic Equipment Engineers, 181 Reid Ave., Bergensfield, N.J. 07621.
g	Atomergic Chemicals Co., Division of Gallard-Schlesinger, 584 Mineola Ave., Carle Place, N.Y. 11514.
f	Brain Metallurgical Chemicals Co., 245 W. Chelton Ave., Philadelphia, Pa 19144.
g	Cerac Inc., 13460 W. Silver Spring Rd., Menomonee Falls, Wis. 53051.
ab	Davison Chemical, Division of W.R. Grace & Co., 101 N. Charles Str., Baltimore, Md. 21203.
g	Electronic Space Products Inc.,
abf	Fairmount Chemical Co. Inc., 117 Blanchard Street, Newark, N.J. 07105.
	(D) Goldsmith D.F. Chemical and Metal Co.
bce	Kerr McGee Chemical Corp., Oklahoma City, Okla. 73102.
e	Ozark Mahoning Co., 1870 S. Boulder, Tulsa, Okla. 74119.
be	Poly Research Corp., 29 Werman Ct., Plainview, N.Y. 11803.
b	Polysciences Inc., Paul Valley Ind. Pk., Warrington, Pa 18976.
b	Research Chemicals Division Nuclear Corp. of America, POB 14588, Phoenix, Ariz. 85031.
abf	United Mineral and Chemival Corp.
abcef	Var - Lac - Oid Chemical Co.

(1) Products

(a) thorium nitrate (b) thorium oxide (c) thorium sulphate
(d) thorium alloys (e) thorium fluoride (f) thorium metal
(g) all thorium products

(2) Distributors are prefixed (D).

5.20.4. Magnesium-thorium alloys

The principal producers and fabricators of magnesium alloys containing 3 per cent thorium are listed in Table 18.

Table 18 : U.S.: Producers and fabricators of magnesium alloys containing 3 per cent thorium

American Light Alloys Inc., Little Falls, N.J.
Bendix Foundries, Teterboro, N.J.
Brooks and Perkins Inc., Detroit, Mich.
Controlled Castings Co., Plainview, N.Y.
Dow Chemical Co., Madison, Ill.

Hills McKenna Co., Carpentersville, Ill.
R.C. Hitchcock and Sons Inc., Minneapolis, Minn.
Havard Foundry Co., Chicago, Ill.
Rolle Manufacturing Co., Lansdale, Pa.
Wellman Dynamics Corp., Bay City, Mich.

The magnesium-thorium alloy hardener ("master alloy" which contains 40 per cent thorium) is not produced in the U.S. but is imported from the U.K. and distributed in the U.S. by Magnesium Elektron Inc. of New York.

Imports of master alloy were reported by one source as 45,000 lb. in 1969, but no published estimates have been given since. Imports in 1967 were about 200,000 lb. and were probably about 125,000 lb. in 1968. (see section 6.2)

5.21. Zaire

Zaire was known until recently as Congo (Kinshasa).

Zaire appears as a source of thorium minerals in the French import statistics.

The only report relating to monazite in Zaire was in 1971, when a new company (SOMUCAR) was formed jointly between Société Minière de Lushe (SOMILU), Union Carbide of the U.S. (which controls SOMILU) and the Zaire government. The chief purpose of the new company is to exploit a pyrochlore deposit, but it has also undertaken to exploit a monazite deposit at Kabengelwa.

There have been reports of bastnasite production from Zaire; it is most likely that the recorded imports are in fact of bastnasite, (which should however have been classified to another heading in the tariff classification).

6. Uses

6.1. Incandescent mantles

Incandescent mantles are the oldest commercial use for thorium compounds, and are still the most important one.

Incandescent mantles are of two types. For fixed installations, such as the old gas street lamps, or the butane or propane gas lamps used in isolated buildings, caravans and boats, the mantles are attached to a ceramic holder which is held by gravity onto a fitting in the lamp. Pressure lanterns burning paraffin (kerosene) or petrol are used in mobile lamps, ranging from outdoor situations like fishing boats in the Mediterranean to the quantitatively much more important use as a light source in buildings remote from electricity supplies.

Both types of mantles are made by knitting the mantle shape, usually in rayon, but sometimes of cotton or other fibres and impregnating it with a solution of thorium nitrate which contains 1 per cent cercus nitrate and some other minor additives. Mantles for fixed installations ("hard" mantles) are then attached to their holder, the fibre burnt off, and the resulting web of thorium oxide (to which the nitrate is converted on ignition) is coated with collodion to preserve the oxide web during transport. Mantles for pressure lamps ("soft" mantles) are attached by the user to a holder in the lamp which holds the mantle in two places; when the lamp is lit, the fibre burns off, leaving a web of oxide which is incandescent.

Statistics on the export of incandescent mantles are fairly good; the available statistics are given at the end of the report, and are summarised in Table 19. One complication in making the assessment is that the original units vary from country to country, but we give estimates of the total exports in millions of mantles in table 20 and in table 21 these are converted to thorium oxide equivalent using a conversion factor of 350 kg. per mill. mantles for hard mantles, 500 kg. for soft ones, and 420 kg. for types not specified.

Table 19: World: Main countries exporting incandescent gas mantles.

In original units	1969	1970	1971
Austria (m. tons)(1)	80.4	70.0	80.4
Brazil (m. tons)	0.9	...	...
France (mill.)	0.2	22.2	28.3
West Germany (m. tons)	38.3	33.9	28.5
Hong Kong (000 doz)	2,625	2,634	2,710
Italy (m. tons)(1)	18.9	17.7	13.1
Japan (m. tons)(1)	93.1	92.6	66.1
Netherlands (m. tons)(1)	63	65	43
U.K.(soft)(000 gross)	} 52.7	(26.5	29.9
(hard)(000 gross)		(18.9	30.6

Table 20. World : Estimated exports of incandescent mantles (mill.)

	1969	1970	1971
Austria	25.7	22.4	25.7
Brazil	0.2	...	...
France	0.2	22.2	28.3
West Germany	12.3	10.8	9.1
Hong Kong	31.5	31.6	32.5
Italy(2)	3.0	2.8	2.0
Japan(2)	15.0	15.0	10.0
Netherlands(1)	10.0	10.0	6.0
U.K. (soft)	} 7.6	3.8	4.3
(hard)		2.7	4.4
	105.5	121.3	122.3

(1) Includes wicks
(2) Estimated from a guess of the division between wicks and mantles

Table 21. World : Thorium content of mantles in international trade ($m.\ tons\ ThO_2$)

	Thoria content (m. tons ThO_2)		
	1969	1970	1971
Austria	10.8	9.4	10.8
Brazil	0.1	0.1	0.1
France	0.1	9.3	11.9
West Germany	5.2	4.5	3.8
Hong Kong	13.2	13.3	13.7
Italy	1.3	1.2	0.8
Japan	6.3	6.3	4.2
Netherlands	4.2	4.2	2.5
U.K. (soft)	3.2	1.3	1.5
(hard)		1.4	2.2
Total	44.4	51.0	51.5

Note: These estimates do not allow for waste (see text and table 24)

The conversion factor is conventionally taken at 1 lb. of ThO_2 per 1,000 mantles (455 kg. per mill. mantles). This is a slight over-simplification since soft mantles have nearly twice the surface area of hard ones, and thus require significantly more thorium oxide. A better factor would be about 0.75 lb. per 1,000 mantles for hard mantles, and 1.3 lb. per 1,000 mantles for soft ones. This gives an average of around 1 when hard and soft mantles are manufactured in approximately equal proportions, but, anyway in export markets, soft mantles predominate, so the average is probably rather above 1 lb. per 1,000 mantles.

A more serious defect of the conversion is that it takes into account only the thorium which is retained on the surface of the mantle, and ignores waste, which is known to be substantial. There is no easy way of checking the actural quantities used, but an indication is given by the Hong Kong statistics for imports of thorium nitrate and exports of gas mantles, which are shown in table 22.

Table 22 : Hong Kong: Comparison of imports of thorium nitrate and exports of incandescent mantles, and calculated usage of thorium nitrate and oxide equivalent per 1,000 mantles

	Imports of thorium nitrate (000 lb.)	Exports of gas mantles (000)	Consumption per 1,000 mantles (lb.)	
			Thorium nitrate	ThO_2 equivalent
1967	137.9	27,093	5.1	2.4
1968	238.6	44,403	5.4	2.5
1969	167.0	31,497	5.3	2.5
1970	82.5	31,603	2.6	1.2
1971	170.0	32,527	5.2	2.5
Total	796.0	167,123	4.8	2.2

Hong Kong mantles are probably mainly soft ones, for which it appears that a figure of 2.2 lb. ThO_2 per 1,000 mantles (equivalent to 1 m. ton per mill. mantles) is a better one than the 1.3 lb. derived above. Wastage, anyway in Hong Kong, appears to be of the order of 40 per cent.

Statistics on the production of incandescent gas mantles are very limited. The U.K. Census of Production included incandescent gas mantles in a miscellaneous heading until 1963, so the only data available is from the 1968 Census. In 1968, total production of "incandescent mantles for all purposes, whether collodionised or not" amounted to £721,000. U.K. exports in that year of "wicks of woven plaited or knitted textile materials for lamps stoves etc., mantles for incandescent lighting whether collodionised or not" amounted to 9.5 mill. units valued at £257,000. Judging by the 1970 and 1971 figures, when wicks were classified separately from mantles, mantles were much the largest part of the total classification, and probably amounted to £200,000 worth of exports in 1968. This leaves a balance of about £520,000 worth of U.K. production for the home market. (Imports are not substantial).

This division between home and export markets does not correspond well with the published company reports of one major British manufacturer, Falks Ltd. (now a subsidiary of Jessel Securities Ltd.) who have manufactured mantles under the trade name Veritas for many years. Their annual report for 1968 says that the Veritas Mantle Works enjoyed another highly successful year, and that 90 per cent of the output is exported, either direct or through home customers. The 1969 report refers to the full utilisation of capacity, and increased exports to the United States.

The apparent discrepancy can be reconciled to some extent because the hard mantles sold in the home market have a very much higher unit value than the soft mantles which are predominantly sold in the export market. The unit value of hard mantles is about 6 times that of soft ones, and allowing for the different product mixes in home and export markets, the average unit value of home sales is probably about 5 times that of export sales. This would imply that 1968 sales by the industry were:

	Units (mill.)	Total value (£000)
Export	9.5	240
Home	3.8	480
	13.3	720

This would imply that unit sales in the home market are about 30 per cent of total sales. This does not correspond closely with the Falk's figure of 10 per cent of all sales on the home market.. The difference may be accounted for because Falk may be misinformed about the destination of the mantles they manufacture under contract for other organisations, or because other producers have a different export ratio to Falks. (The latter explanation is not very likely, because, while the number of manufacturers is not known because it is withheld in the Census to avoid disclosure, it is believed that there is only one or possibly two other manufacturers, on a smaller scale than Falks).

We are however inclined to accept the higher figure of 3.8 mill. units on the U.K. home market, mainly because it corresponds better with the apparent situation in the U.S.

The U.S. Census of Manufacturers includes incandescent mantles as part of category 36426 85: "parts and accessories for non-electric lighting including reflectors and fittings, incandescent gas mantles, etc." Total production in this category is given in table 23 below. Figures for pressure lamps are given for comparison.

Table 23: U.S.: Production of kerosene and gasoline lamps and lanterns and of parts and accessories for non-electric lighting.

	Shipments ($ mill.) of kerosene and gasoline lamps and lanterns	Shipments ($ mill.) of parts and accessories for non-electric lighting incl. reflectors and fittings incandescent gas mantles etc
1954	5.9	3.0
1958	6.5	7.5
1963	8.2	6.2
1967	14.2	4.7

These figures are not of much help except in setting an upper limit to incandescent mantle production. Another basis for estimate is that of the US Bureau of Mines, who have estimated the quantity of thorium used in gas mantles at some 60 tons a year for many years. (It is not clear whether or not this includes the 2 tons or so of thorium imported each year in imported mantles). Allowing 40 per cent for waste and converting at 700 kg. per 1,000 mantles, this would imply total U.S. production of some 78 mill. mantles. U.S. exports of gas mantles are insignificant, and imports were stated to be 3,400 lb. ThO_2 equivalent, which implies some 4 mill. mantles. This gives a total of 82 mill. mantles. This seems an extraordinarily high figures. The U.S. population is about 200 mill. which gives a ratio of about 410 mantles sold annually per 1,000 population. This may be compared with the apparent U.K. ratio of .69 mantles sold annually per 1,000 population.

It seems absurd that U.S. demand for incandescent mantles should be 6 times as much per head as the U.K. If 60 short tons of thorium oxide were used in domestic manufacture (of which 36 short tons would be used on the mantles and the remainder wasted) and 1.7 short tons were contained in imports, the value of domestic production would be expected to be 21 times that of imports (or probably rather more since imports would have to be of lower unit value to compete successfully). Imports in 1968 were valued at 330,000, which would give a figure of $6.9 mill. for U.S. production of incandescent mantles in 1968. This substantially exceeds the total value of all parts and accessories for non-electric lighting according to the Census of Manufactures.

It is not possible to go into this subject further than this. The figures are inconsistent and some are unreasonable, and it is necessary to take a view on the most likely possibilities. Our view is that U.K. production in 1971 was about 13 mill. units (and about 66 per cent by number were exported) and that U.S. production was not more than 30 mill. units.

On this basis, the total amount of thorium consumed in mantle manufacture would be about 9½ m. tons in the U.K., and 21 m. tons in the U.S. The only other countries with a large home market which appear to have domestic mantle manufacturers are France and West Germany, whose combined thorium demand for mantle manufacture is estimated at 5½ m. tons. The thorium demand for mantles exported from these and other countries is estimated from the export statistics given previously in table 19 and table 20 at a total of 119 m. tons ThO_2. Total thorium demand for gas mantles is therefore estimated at 160 tons ThO_2 equivalent, divided approximately as follows:

Table 24. Estimated world requirements of thorium nitrate for mantle manufacture, 1971 (m. tons ThO_2)

	Home	Export	Total
U.S.	21	-	21
Hong Kong	-	33	33
Austria	1	26	27
France	3	28	31
Germany	2½	9	11½
Japan	5½	10	15
Netherlands	½	6	6½
U.K.	2½	7	9½
Rest of the world, say	5	-	5
Total	41	119	160

It must be recorded that the only other estimate we know of world thorium demand is incompatible with the conclusion we reach above that demand for thorium nitrate for gas mantle manufacture is about 20 m. tons ThO_2 in the U.S. and 140 m. tons ThO_2 in the rest of the world. The U.S. Bureau of Mines estimated in "Mineral Facts and Problems" 1970 edition that total world demand in 1968 was 198 short tons (180 m. tons) of ThO_2 of which the total for the rest of the world was 80 m. tons (which is less than our estimate of consumption for gas mantle manufacture alone), and the total for U.S mantle manufacture is 55 m. tons.

It is easy enough for two different estimates to differ, in view of the incomplete nature of much of the data; we hope that we have made out sufficient grounds for prefering our view, which rests mainly on the proposition that it is not reasonable that a product like incandescent mantles, which is known to be used widely in developing countries without a developed infrastructure of electricity supplies, should be used to a greater extent in the United States than in the whole of the rest of the world put together.

6.2. Magnesium-thorium alloys

Alloys of thorium and magnesium are used primarily for space and aero-engine applications where high strength is required at high temperatures. The alloy is supplied in the form of a master alloy containing about 40 per cent thorium; the master alloy is used by the processor to produce the final alloys in which the thorium content is 3 per cent. This use was the dominant one for thorium in the U.S. from about 1960 to 1965, but since then demand has declined. This decline is probably partly due to a decline in demand for space applications, and possibly also to growing competition from high-temperature titanium alloys.

There is some conflict between different sources about the quantities of thorium used in this application, and also about the sources of the alloy and of the thorium.

Some figures have been given in the Engineering and Mining Journal annual survey sections on Thorium (which are signed by members of the staff of the U.S. Bureau of Mines) as follows:

Table 25: U.S.: EMJ estimates of imports of thorium-magnesium master alloys (short tons)

	Master alloy	Th content
1967	100	...
1968	63	22
1969	22	...
1970	...	...
1971	...	...

No figures are given in the two most recent annual surveys, presumably because they have continued to decline; if they had increased, this would have been worth mentioning..

On the other hand, figures given in the U.S. Bureau of Mines Minerals Yearbook for U.S. industrial demand for non-energy uses enable a different series of figures for the thorium content to be derived, as shown in table 26.

Table 26: U.S. : USBM Minerals Yearbook estimates of thorium consumption in thorium-magnesium alloys. (short tons)

	Apparent industrial demand for non-energy uses	Consumption of thorium magnesium alloys	
		Per cent of apparent industrial demand	Thorium content
1967	120	...	...
1968	110	30	33
1969	115	15-20	20
1970	110	30	33
1971	...	...	...

This gives a somewhat different impression of the pattern of demand from the previous table, and might lead to the hope that demand was continuing at around the same level, though naturally there would be slight changes from one year to another.

Some further light can be thrown on the problem from the U.S. import figures. There appear to be two possible tariff classifications under which thorium magnesium alloys could appear, which are shown in tables 27 and 28 below.

Table 27: U.S. : Imports of magnesium alloys unwrought

Tariff heading TSUS 6286700 Magnesium alloys unwrought

	1967	1968	1969	1970	1971
Quantity (short tons)					
Canada	85	450	262	53	28
U.K.	269	169	205	59	58
Other	1	33	-	-	13
Total	355	652	467	112	99
Value ($000)					
Canada	112	349	169	49	39
U.K.	1,414	865	1,005	251	238
Other	2	14	-	-	9
Total	1,528	1,228	1,175	300	286
Average value ($000 per ton)					
Canada	1.3	0.8	0.6	0.9	1.4
U.K.	5.3	5.1	4.9	4.2	4.1

Another possibility, suggested in the U.S. Bureau of Mines Information circular 8476 is that it appears in a miscellaneous classification which includes alloys of thorium, presumably in order to protect company confidentiality since most of the hardener is produced by one manufacturer and handled by a single U.S. representative.

All sources agree that the single domestic representative is Magnesium Elektron Inc., of New York City. They also agree that the alloy is imported from the U.K. The manufacturer is given in some sources as Thorium Ltd. and in others as Magnesium Elektron Ltd. of Clifton Junction, Swinton, near Manchester.

The imports recorded under the miscellaneous classification are given in table 28 below.

Table 28: U.S. : Imports of alloys of calcium, boron, barium, strontium, thorium or vanadium (TSUS 6326.800)

	1967	1968	1969	1970
Quantity (lb.)				
Canada	4,000	-	-	-
West Germany	3,879	17,675	2,094	356
Total	7,879	17,675	2,094	396
Value($)				
Canada	3,480	-	-	-
West Germany	59,632	206,559	22,869	7,629
Total	63,112	206,559	22,869	7,629

Thorium-magnesium master alloys cannot therefore appear under heading TSUS 6326.800 since the total quantities recorded are too small for the quantities of master alloy imported in 1967 and 1968 (which were certainly over 50 tons or 100,000 lb.) and also since no imports from the U.K. are recorded under this heading.

They must therefore be included in heading TSUS 6285.700, which may however include some other magnesium alloys as well. The quantities imported from the U.K. are of the right order, and the average declared value of \$2.05 per lb. fits tolerably well with the selling price of thorium-magnesium master alloy (40 per cent Th) of \$5 per lb.

6.3. Other metal alloys

There are numerous references in the literature to other metal alloys containing thorium. Total demand for thorium for alloys, apart from the thorium magnesium alloys discussed earlier, has never been very large, and is probably no more than 5 or possibly 10 tons ThO_2 at present.

The best known of these alloys is TD Nickel, developed by du Pont, though it was reported in 1967 that they were seeking to dispose of their interests in TD Nickel to Fansteel. TD Nickel is a high-strength alloy, which offers higher strength at temperatures above 2,000 deg. F. than more conventional super-alloys, and also has good corrosion resistance. It consists of 98 per cent nickel and 2 per cent ThO_2; the thorium oxide is present as a uniform critical dispersion of sub-micron size particles. Variations of this alloy contain some chromium for improved resistance to oxidation, or some molybdenum for increased strength. These alloys are known as "dispersion-hardened" alloys.

The main advantage of these dispersion hardened alloys is that their creep-rupture strength falls off with temperature considerably less rapidly with temperature than is the case with other "superalloys". For example, the stress to cause rupture in 1,000 hrs. in TD Nickel bar is 15,000 lb. per sq. in. at 1,700 deg. F and declines only to 6,000 lb. per sq. in. at 2,400 deg. F. By contrast, a more conventional nickel alloy such as Hastelloy, Inconel, or Nimonic would have a stress value to cause rupture within 1,000 hrs. which would be under (often well under) 6,000 lb. per sq. in. at only 1,700 deg. F (though it would be in the range 40,000 to 100,000 lb. per sq. in. at 1,100 deg. F).

TD Nickel and other dispersion hardened alloys thus find their applications where the strength required is not very high, but it is required to maintain this strength at higher temperatures than can be obtained with most other alloys. It was introduced in 1962, and has naturally attracted considerable attention as its uses and properties have been explored. It is mainly used in turbojet aircraft, and industrial furnaces. The consumption of thoria in this application is unlikely to change substantially in the future, since, while it is superior to other alloys above 2,000 deg. F, applications where this requirement is the controlling one are always likely to be a very small part of total demand.

Small percentage additions of thorium, usually 2 per cent ThO_2, are used to give similar improvements in performance at high temperatures when alloyed with cobalt, molybdenum and tungsten. Thoria is reported to be added to some tungsten lamp filaments at between 0.8 and 1.2 per cent ThO_2; this is certainly not a universal requirement, since U.S. demand for tungsten for filament lamps is estimated(1) at 1,300 tons, which would give a demand of between 10½ and 15½ tons of thoria a year. This would be over 10 per cent of U.S. demand for thorium, and there is no suggestion in any published source that demand for tungsten filament lamps is over 1 or 2 per cent of the total. It is concluded that thoria is used only by some manufacturers or for some special purposes. Demand for filament lamps is growing comparitively slowly in both the U.S. and the U.K.

6.4. Nuclear energy

Nuclear power stations are being commissioned at a high rate all over the world. In 1972, there were 15 countries with a total of 127 nuclear power stations; by 1977 there will be 27 countries with 319 nuclear power stations.

The nuclear power capacity of the more important countries is shown in table 29 below.

Table 29 : Main countries: Estimated number and capacity of nuclear power stations, 1977

	Number of reactors	Capacity MW (e)
U.S.	122	94,705
U.K.	44	14,365
USSR	31	10,469
Japan	26	15,259
W. Germany	19	8,142
France	11	2,933
Canada	9	4,016
Sweden	9	5,311
Spain	8	3,573
Other countries	40	...
Total	319	...

Source: International Atomic Energy Authority Handbook, 1971.

(1) See the companion report on tungsten in this series.

Total installed capacity in January, 1971 was 19,600 MW (e), of which 7,500 MW (e) was in the United States and 4,000 MW (e) was in the U.K.

Nuclear reactors are known by their initials; the main types of power reactors in service in April 1971 are shown in Table 30 below (this table does not include research or military reactors).

Table 30 : World: Classification of types of nuclear power reactors, and number in service, April 1971

Initials	No. of power reactors in service	Description
PWR	19	Pressurised water cooled reactor
BWR	24	Boiling water reactor
GCR	34	Gas-cooled reactor (graphite moderated)
AGR	1	Advanced gas cooled reactor
HTGR	2	High temperature reactor (gas-cooled)
LWGR	10	Light water cooled, graphite moderated
HWR	8	Heavy water reactor
Other types	4	
	102	

The types of reactor may be distinguished by the choice of fuel and of moderating material:

(i) Graphite-moderated gas-cooled reactors which include GCR s, AGR s and HTGR s. These use natural uranium as a fuel. All the current U.K. reactors feeding power to the national electricity grid are of this type.

(ii) Light water moderated reactors, cooled by light water either with boiling (BWRs) or without boiling (PWRs). These types derive from the U.S. submarine nuclear propulsion programme; they use enriched uranium as a fuel. Nearly all the commercial reactors in the U.S. are of this type.

(iii) The heavy water moderated reactors, with heavy water or light water as coolant. They use natural uranium as a fuel. The Canadian pressurised heavy water cooled and moderated (Candu) reactors are examples of this type.

(iv) The light water, graphite moderated reactors (LWGRs) which are mainly in the U.S.S.R.

(v) The fast breeder reactors, which are fuelled with a mixture of plutonium and uranium. The uranium may either be natural, or depleted uranium from diffusion plant waste or from spent fuel from thermal reactors. They do not employ a moderator. Fast breeder reactors require an initial charge of 3 tons per thousand MW (e) output, and they will themselves produce twice that amount of plutonium in 15 years.

All of these types have developed using natural or enriched uranium as a fuel. Thorium-fuelled reactors are theoretically attractive because the thorium 232 - uranium 233 nuclear chain produces more neutrons than the uranium 238 - plutonium 239 chain, and also because thorium is more abundant than uranium.

The following reactors are known to use, or to have used, thorium as a fuel.

1) The Consolidated Edison Thorium Reactor at Indian Point, N.Y. This had a capacity of 275 MW (e) including a super-heater driven by fossil fuel. It produced some 3½ mill. kWh. of electricity between April 1962 and September 1964, when it was shut down. The original charge consisted of 2,420 lb. of enriched uranium oxide and 37,440 lb. of ThO_2. It was later redisigned to use uranium only.

2) The Elk River, Minn. boiling water reactor owned by the Rural Co-operative Power Association, with a capacity of 22 MW (e). This reactor produced 510,000 mWh of electricity in the first 5½ years after it went critical in November 1962.

3) The Peach Bottom, Pa. reactor of Philadelphia Electric Co. with a capacity of 40 MW (e). This reactor went critical in March 1966, and produced 400,000 mWh. in the period up to June 1969. This reactor was originally fuelled with 4,400 lb. of thorium blanket and 380 lb. of enriched uranium; the original core was replaced by one of improved design in 1970.

4) The molten salt reactor experiment, built by the US AEC at Oak Ridge, Tenn. This prototype has been the only reactor system operating on man-made uranium 233 since it began operating in late 1968.

Apart from these there are a number, probably 6 in all, of small research reactors based on thorium.

The Peach Bottom Pa. HTGR reactor has been outstandingly succesful, and the main contractors, Gulf General Atomic, have a further 330 MW (e) station under construction for the Public Service Co. of Colorado, at Fort St. Vrain, Colo. This reactor will have an initial charge of 25 tons of ThO_2 with 1.3 tons of uranium. The refuelling requirement is not known.

In September 1971, a further two HTGR reactors were ordered from Gulf General Atomic by Philadelphia Electric Co. They will each have a capacity of 1,150 MW (e). These reactors will have an initial fuelling requirement of 40 tons of ThO_2, with refuelling requirements of 10 tons a year after the second year. The company have since then taken a further order in December 1971 for two 770 MW (e) HTGR reactors from Delmarva Power and Light Co. All these reactors are scheduled for completion in 1979. In June 1972, Gulf received an order for a 770 MW (e) HTGR for United Power Associates in Minnesota. In this case, the alternatives considered were a conventional power station at the mouth of a lignite mine, and a PWR; the HTGR was selected since it would give the cheapest power.

Gulf General Atomic is a late entrant to the nuclear field and cannot claim the experience of the companies such as General Electric, Westinghouse, Babcock and Wilcox, and Combustion Engineering, who are associated with the large programme of light water reactors. Gulf is, however, very optimistic about the HTGR design, which it is claimed will give higher operating efficiency, less thermal discharge, and fewer radiation problems.

One major advantage claimed for HTGR's (and for U.K. gas cooled reactors) is that they are inherently safer than any water cooled system; water cooled systems are designed to very strict safety standards, but there is still a remote possibility that radio-activity could, in some accident, escape to the atmosphere by way of the cooling water. The Gulf reactor is enclosed in a prestressed concrete pressure vessel 16 ft. thick, which is inherently stronger than the steel pressure vessels which have to be used for water cooled systems. There is also some doubt about the long-term stability of stainless steel under radiation; it may become brittle in time.

A potential disadvantage is that there will be difficulties in having the thorium-uranium fuel reprocessed. There are no U.S. plants available for this, though there are facilities in Europe.

Another line of development which involves the use of thorium is being pursued by the U.S. A.E.C.; a "seed-blanket" of uranium-233 and thorium-232 is used in the reactor core of the LWR at Shippingport, Pa. This approach offers the possibility of breeding from LWRs, and thus improving their fuel efficiency from the 1 or 2 per cent they attain at present to a very much higher figure. This work has not received much comment in the recent past, however, and it is possible that the line of research has proved abortive.

In the U.K., the two nuclear power consortia are undergoing some difficulties, mainly because of the low and uncertain level of home demand and the lack of any export orders for the British nuclear reactor systems. The two groups are the Nuclear Power Group, and British Nuclear Design and Construction. There has been considerable press comment on the need to rationalise these companies into one large organisation, possibly dominated by the U.K. General Electric Company Ltd. No new orders for nuclear power stations have been placed since 1970, and a Government committee is now considering the types of reactors which should be produced in the future.

In West Germany, a 300 MW (e) "pebble-bed" THTR (thorium high-temperature reactor) is shortly to start construction. A key part of the contract is a solid moderated reactor which is being built by the U.K. A.E.A., which is designed to go criticial in 1976; its function is to control the re-cycling of the small pellets of graphite containing uranium fuel and thorium breeder material to ensure complete burning. This work has developed from a research contract placed by the European Atomic Energy Commission (Euratom) with two German groups: Brown Boveri/Krupp and Kernforschunglager, Julich Nordrhein-Westfalen in 1964. The reactor is to be built at Schmehausen, near Dortmund; the solid moderated reactor will be built and calibrated at Winfrith, Dorset, before being sent to Germany. The thorium charge for this project is not known.

Canada has developed a natural uranium system, the Candu pressurised heavy water moderated and cooled reactor (PHWR). The programme has suffered from considerable delays. The prototype at Douglas Point has given trouble. The 250 MW (e) Gentilly plant had been subject to criticism from abroad. The system has only obtained two export orders, from India and Eastern Europe. In February, 1971, the first of the 4 Candu reactors, each of 500 MW (e) at Pickering, near Toronto went critical, and in 95 days was up to full power. Pickering 2 took only 53 days, and Pickering 3 only 18 days to reach full power. 4 further Candu plants, of 750 MW (e) are under construction at Bruce on Lake Huron, and will start coming into operation in 1976.

India is specially interested in thorium reactors because of her large reserves of monazite. In 1964, Russian scientists were stated to have supplied India with technical data and designs of thorium-fuelled nuclear power plants built in the USSR. However, the two Candu 200,000 KW nuclear plants ordered from Canada in 1967 will use uranium. In April 1967 it was announced that a 400 MW station at Kalpakkam near Madras would be based on thorium. In March 1972, India signed a 5-year agreement with the West German atomic energy agency, the object of which was to select the right process for producing enriched uranium. India already has a sophisticated plutonium separation plant at Trombay. The enrichment of uranium is a major obstacle in the development of the nuclear power programme.

In the longer-term future, it is expected that fast breeder reactors will be the dominant type constructed in the 1980s. The U.K. and French atomic energy authorities have concentrated on this type of work; a small prototype has been operating at Dounreay in Scotland since 1950, and a 250 MW (e) station was due for completion in 1972. Construction of a similar reactor, called Phénix, was started in France in 1968 at Marcoule.

Because breeder reactors use fuel much more efficiently, they are likely to have lower operating costs than the present generation of thermal power stations. The breeder programme is of special interest in the U.K. because it relies on the use of plutonium, which is produced only in natural uranium reactors. U.K. stocks are expected to be about 20 tons in 1980, with an annual by-product production of some 6 tons.

US technology in breeder reactors is considerably behind; the first American prototype is unlikely to be completed until 1977. President Nixon has however made the successful development of such a reactor by 1980 into an U.S. national goal.

The prospects for thorium thus appear to depend on two main factors:

(i) the rate of commercial acceptance of the Gulf General Atomic design of HTGR

and (ii) the rate of development and commercial acceptance of the fast breeder reactors (FBRs)

The situation is difficult to assess, but it is clear that there are still a few years, probably ten and perhaps even more, when the HTGR will be competing against other thermal reactors, particularly the PWRs and BWRs also developed in the United States. Gulf has shown that it can compete successfully in the past two years. In the immediate future, demand for new power reactors is expected to be rather higher than in the past(1) In the U.S. for example, total orders in 1972 are expected to amount to some 40,000 MW (e) compared with the 1971 total of 23,400 MW (e). An increased level of demand is likely to lead to capacity problems for the larger manufacturers; this, together with the apparent advantage HTGRs enjoy on safety and cost grounds, should ensure a reasonable flow of orders, anyway in the U.S. The advent of the fast breeder reactors is very uncertain, but it seems in current circumstances that there is not much enthusiasm in government and commercial circles for moving into radically new designs as compared with improving and refining existing designs, and this would indicate that breeders will come later rather than sooner. It is also likely that the growing climate of conservationist opinion will impose considerably higher standards on the new generation of breeder reactors, and this is likely in turn to delay the programme.

(1) This may tend to increase demand for thorium reactors since it is widely feared that there will be a shortage of U-235 enrichment facilities needed for light water reactors.

If four HTGR stations were commissioned every year from 1980 to 1990, this would imply a demand for say 200 tons of ThO_2 for initial charges in each of these years, and a refuelling requirement building up from 50 tons a year in 1982 to 550 tons a year in 1992, and continuing at that rate for the life of the reactors.

While any figures can only be speculative at this stage, it is clear that the demand is not going to come suddenly because of the long lead times necessary to construct atomic reactors, but that it is quite possible that in the 1980's demand for thorium for nuclear use could easily be many times the demand for thorium for all other uses put together.

6.5 Refractories

Thorium oxide is used to a limited extent as a refractory material in small scale applications and in the laboratory. The main advantage of thoria as a refractory material is that it has the highest melting point of any material known, 3,300 deg. C. This compares with the melting points of more common refractory materials, such as Al_2O_3 (2,015 deg. C), MgO (2,800 deg. C), CaO (2,600 deg. C), and ZrO_2 (2,677 deg. C).

U.S. consumption of thorium for refractories was estimated by the U.S. Bureau of Mines at 6 tons in 1968, and demand in the rest of the world was probably of the same order.

Thoria crucibles and simple shapes are made by slip casting, and can be used to melt most metals. 1 per cent of calcium oxide is used to assist sintering when the material is fired. Thoria is stable as a refractory material, but it has poor resistance to shock and low strength. A further limitation is that when used for melting metals, particularly transition metals, there is likely to be some solution of the thorium oxide in the metal.

6.6 Catalysts

Small amounts of thorium are consumed as catalysts, but there is little information available on this application, and it seems that thorium catalysts have no overwhelming advantage in any of the known processes. Catalytic reactions for which thorium catalysts have been reported are:

ammonia to nitric acid
sulphur dioxide to sulphur trioxide
"organic chemicals"

The U.S. Bureau of Mines estimated that 5 tons of thorium were used for catalysts in 1968. Demand in the rest of the world was probably rather lower than this.

6.7 Other uses

There are a number of other uses for thorium and its compounds which are mentioned in various published sources, but are probably of no economic importance.

These are:

- target materials for X-ray tubes
- gaseous discharge tubes and photo-electric tubes
- radiation detectors
- computer memory components
- photo-conductive films
- inert-arc welding electrodes
- fuel cell elements

Total U.S. demand for these uses was estimated by the U.S. Bureau of Mines at 6 tons in 1968, and we guess that demand in the rest of the world was, again, rather lower than this.

6.8 Estimated world demand in 1970

The estimated world demand for thorium in 1970 (excluding the Communist countries) is given in table 31 below.

Table 31: Free World: Consumption of thorium and its compounds in the U.S. and the rest of the free world, 1971 (m.tons ThO_2)

	U.S.	Rest of the free world.	Total
Incandescent mantles	20	140	160
Magnesium-thorium alloys	6	6	12
Nuclear energy	-	-	-
Other uses	21	12	33
Total	47	158	205

The method of arriving at the estimate for incandescent mantles is explained in section 6.1. The estimate for magnesium-thorium alloys is difficult to make for the reasons given in section 6.2, but it seems most likely that demand has been falling off rapidly and is now very small in the U.S., and probably no bigger in the rest of the world. Nuclear energy demand for thorium is unlikely to arise until say 3 years before a reactor using thorium is commissioned; the 25 tons of thorium for the Fort St. Vrain reactor will therefore have been purchased in 1969/70, and the thorium for the other Gulf General Atomic reactors on order will presumably not be purchased till 1976. The estimates for other uses in the U.S. have been taken from the U.S. Bureau of Mines; these are the only ones available, and there is no method of cross-checking them from other sources. We would, however, guess that, if they are in error, they are much more likely to be too high than too low. The estimate for other uses for the rest of the world has been derived from the U.S. estimate; this again is more likely to be too high than too low.

The total estimated world demand for thorium and thorium products is therefore estimated at 205 m. tons in 1971.

There are no reasons to expect any major changes in the pattern or amount of consumption in the next 5 years to 1976, except that the initial fuelling requirement for the 4 HTGR reactors recently ordered from Gulf General Atomic will perhaps start to be met in that year. The total requirement is likely to be for about 150 m. tons, and there will also be a requirement of possibly 10 m. tons for the refuelling of the Fort St. Vrain reactor. Any growth in the incandescent mantle demand due to rising standards of living is likely to be countered, in our view, by reduction in demand due to more widespread supply of electricity in developing countries. Our estimate of total free world demand in 1976 is therefore 365 m. tons (of which 160 m. tons is for nuclear grade).

For a longer term view, we give the U.S. Bureau of Mines estimate of world demand for thorium in table 32 below. We would not agree with this estimate at all points, but the central feature of the estimate confirms our view that demand for power reactors is potentially much the largest use for thorium which can be foreseen, and that there is considerable uncertainty about the likely extent of this demand.

Table 32: World: U.S.B.M. contingency forecasts of demand for thorium divided by end use, year 2000 (short tons Th)

	U.S. demand			Rest of the world	
	1968	2000		2000	
		Low	High	Low	High
power reactors	-	-	2,170	775	5,240
gas mantles	55	120	140)		
aircraft alloy	33	72	90)		
refractories	6	13	22)		
catalysts	5	11	20)		
dispersion-hardening			)	265	360
alloys	5	11	35)		
other uses	6	13	33)		
Total	110 (1)	240	2,500	1,040	5,600

Source: U.S. Bureau of Mines Mineral Facts and Problems, 1970

The U.S.B.M. forecasts are in short tons Th, whereas our estimates in table 31 are given in m. tons ThO_2; to convert short tons Th to m.tons ThO_2 equivalent, multiply by 1.25.

The U.S.B.M. median estimates for the year 2000 are 1,370 tons for the U.S. and 3,320 tons for the rest of the world. Our forecast is only for the year 1977, by which time we expect total free world demand to have grown from 205 m. tons ThO_2 to 365 m. tons ThO_2.

(1) Average demand over 10 year period.

7. Prices

7.1. Historical data

7.1.1. Thorium and thorium compounds.

The prices of thorium products given by the U.S. Bureau of Mines are:-

	Thorium nitrate	Thorium oxide	Magnesium-thorium hardener. Per lb. ThO_2 content (1)
1965	2.50 to 2.65	5.80 to 10.00	9.18
1966	...	...	9.18 to 10.00
1967	3.50	6.00 to 12.30	11.50 to 12.00
1968	2.25 to 3.50	6.00 to 12.30	11.50 to 12.00
1969	2.75	7.00	12.00
1970	2.45 to 2.55	7.00 to 20.00	(12.00)

The prices of some American producers in 1970 are given in table 33.

Table 33 : U.S: Prices of thorium oxide and salts, 1970.

		$ per lb.
W.R. Grace and Co. (Davison Chemicals Division):		
Thorium nitrate	wine grade 47 per cent ThO_2	2.45 - 2.50
	mantle grade 47 per cent ThO_2	2.50 - 2.55
	ceramic grade 99.9 per cent ThO_2	5.80 - 10
	refractory grade 99.9 per cent ThO_2	7 - 11
Lindsay Rare Earths:		
(99.9 per cent purity)		
	Thorium chloride	6
	Thorium iodide	65
	Thorium nitrate	2.55 - 6.00
	Thorium oxide	7 - 20
	Thorium oxalate	4 - 6

The price of thorium metal has remained unchanged at $15 per lb for some years

(1) plus the market value of the contained magnesium.

7.1.2. Monazite.

The published price of monazite has remained unchanged for some years. Published prices are not a good guide to the figures at which sales are actually made, since buyers and sellers of reasonable quantities of monazite are few, and much of the monazite which is sold is subject to special arrangements, including some longterm contracts. Historically, movements in published prices have been infrequent, and have been considerable when they have occurred. The published prices are shown in table 34.

Table 34 : Monazite prices $ per long ton c.i.f. U.S. port 1920-71

Period	Low	High
1920	180	252
1921	180	180
1922-25	120	160
1926-30	120	130
1929	60	130
1930-35	50	63
1936-46	60	75
1947	100	150
1948	150	200
1949	200	245
1950	245	260
1951	350	350
1952	330	380
1953-55	260	440
1956-58	260	400
1959-64	280	400
1965-67	160	240
1968-70	180	200
1971	165	200

Source: E. & MJ Metal and Minerals Market and Metal Week.

The price of Australian monazite, min. 60 per cent REO plus Thoria, per long ton c.i.f. is shown in table 35 below.

Table 35 : Price of Australian monazite 1966 to 1972

Dates of change.		Price of Australian monazite min. 60 per cent REO plus thoria £ per long ton c.i.f.
1966	22nd March.	60 - 70
	23rd September.	70 - 75
	23rd December.	70 - 85
1967	9th June.	75 - 90
	8th September.	75 - 80
	24th November.	80 - 90
1968	9th April.	65 - 80
	17th September.	65 - 75
	25th October.	70 - 75
1969	15th April.	75 - 85
1970	16th October.	80 - 90 (1)
1971	1st January.	79 - 89
1972	7th May.	78 - 86

(1) About half of this increase represents an increase in freight charges.

Source: Metal Bulletin.

It was reported in June 1972 that the price of monazite was being affected by the rapid increase in the price for mischmetal required for alloying columbium-containing steel pipes for North Sea Gas (see our report on the rare earths and yttrium).

The best indication of long term price trends is probably the average value of U.S. imports given in table 36 below with some recent Australian export figures for comparison.

Table 36 : Average value of U.S. imports and Australian exports of monazite.

Year	U.S. imports.		Australian exports
	$ per short ton	$ per lb. ThO_2	$A per long ton.
1954	221	...	...
1955	217	...	...
1956	216	...	...
1957	209	...	...
1958	206	...	...
1959	188	...	...
1960	...	...	...
1961	143	...	...
1962	146	...	...
1963	119	1.00	...
1964	88	0.71	...
1965	93	0.77	...
1966	114	0.96	...
1967	129	1.08	238
1968	129	1.07	135
1969	117½	0.98	128
1970	124	1.03	137

Source: U.S. Bureau of Mines Minerals Yearbook & Australian export statistics.

7.2. Forecast price changes.

7.2.1. Thorium and thorium compounds.

The U.S. Bureau of Mines have forecast that U.S. domestic demand for thorium will be in the range of 240 to 2,500 short tons a year in the year 2000, and that the price by then will have fallen from $6.82 per lb. Th in ThO_2 to $3.40 (in constant 1968 dollars).

The wide range of demand estimates arises from uncertainty about the nuclear programme (see section 6.4

Trend projection of either demand or price is often hazardous; the main argument in favour of the USBM projection is that the price in the middle 1950's was about twice the 1968 price.

We consider this projection is too pessimistic. It would be reasonable to expect some decline of price in response to the oversupply position if:

a) demand were likely to increase with lower thorium prices

and b) there was little likelihood of new sources of demand developing

In our view, neither of these conditions are fulfilled. The major end-uses for thorium in the recent past, incandescent mantles and magnesium alloys, are most unlikely to be price sensitive, anyway as far as reductions in price are concerned. No mantle manufacturer will buy more nitrate if the price were reduced, because there is no possibility of an increase in sales of incandescent mantles if their price were reduced; also there is no substitute for the use of thoria in incandescent mantles, nor is there likely to be. The same is probably true for magnesium alloys; being specified mainly for space vehicles and aircraft, they are used if technical considerations do not permit the use of cheaper alternatives, and small differences in the price of thorium (which is only 3 per cent of the final alloy) are unlikely to affect the final price of the machined part to any significant extent, or to affect demand for the part even if the price were significantly altered.

Producers and processors thus face an inelastic demand curve for thorium, and they have the prospect that there will be some increase in demand when the HTGR reactors recently ordered come into operation, and that the increase may be many times present demand. Producers in the thorium business have had to take a long view, and have had to be prepared to look after by-product residues for many years in the hope that they will come in useful some time. At present, developments in the HTGR programme give a considerable degree of assurance that there will be an increase of demand for thorium in the late 1970's, and we would be surprised if there were any pressure from producers to reduce the price of thorium meanwhile.

Much of the demand for HTGR thorium (or possibly all of it) will arise in the United States. This raises three problems which affect prices:-

a) there is one domestic monazite producer, and domestic production of monazite could quite easily be expanded. Stocks of monazite held by producers are at present large, and there is little likelihood of their being reduced within the foreseeable future. Any upward pressure on thorium price would be unlikely to persist for any length of time because of these large stocks, and also for the other reasons listed below.

b) The US government stockpile, in the form of thorium nitrate, has remained at 1,832 short tons ThO_2 equivalent, of which only 40 tons is the "objective". The surplus is available for disposal, but it has not been practical to dispose of it under present conditions when supply of thorium exceeds demand. Demand for the nuclear programme would presumably be met to some extent from this surplus of 1,800 tons. This would exert a considerable dampening effect on prices. If the surplus stockpile filled all the earliest orders for HTGR thorium, it would take the first 6 years of the possible programme outlined in section 6.4 before it has been exhausted.

c) there are growing stockpiles of thorium compounds accumulating at rare earth processors plants, due to the preference of some producers of rare earths to use monazite rather than bastnasite, even though they have no immediate outlet for the thorium. It is difficult to estimate the extent of these thorium stockpiles, but they are clearly of a substantial size. Comparison of the thorium content of monazite production[(1)] (table 4) and estimated world demand for thorium (table 31) shows a surplus of 480 m.tons ThO_2 in 1970, and 450 m. tons in 1971.[(2)] These stocks will also serve to reduce the growth in demand for thorium from new production.

Another relevant factor is that, during the 1980's when demand for HTGR thorium is expected to develop, growing amounts of by-product thorium from Canadian mining operations will be available. This might be expected to drive down the price of thorium, but the limited evidence available (namely that only one uranium mill has found it worthwhile to recover by-product thorium) suggests that at current price levels, by-product recovery is barely economic. It appears likely that the marginal extra recovery costs are only just counterbalanced by the revenue from thorium sales. This in turn suggests that the Canadian producers of by-product thorium would have no interest in reducing the price of their thorium.

In this situation, it seems virtually certain that there will be no increase in the price of thorium or its compounds in the future, anyway until well into the 1980's, and there seems some possibility of a small decrease in price, though not beyond the point where Canadian producers find it uneconomic to extract the thorium from the uranium mining residues. Producers extracting thorium from monazite would always find it economic to extract and sell the thorium at the lowest price acceptable to Canadian producers (however low this was) since the thorium extraction is the first stage in monazite processing, and the thorium extracted requires little further processing before sale, and would always contribute something to the total revenue of the operation (most of which would come from the rare earth content of the monazite).

(1) including India and Brazil
(1) plus some 450/500 tons retained in India and Brazil and subject to export restrictions.

Our forecast is therefore that the price of thorium in thorium compounds will remain at or slightly below the current price level. We would not expect it to decline by as much as 50 per cent in real terms at any time in the next 15 years, and it does not seem likely on present trends that the decline would be as much as that even later in the century.

7.2.2. Monazite.

The average value of monazite imported into the U.S. in 1970 was $124 per short ton, which is about 6 cents per lb of monazite, which gives a price of about $1 per lb. contained Th. The price of thorium nitrate in 1970 was equivalent to about $6 per lb. contained Th, and the price of the cheapest grade of thorium oxide was about the same.

Monazite forms only a small part of the price of thorium products, and the quantity of rare earth materials which can be extracted from a ton of monazite is many times the quantity of thorium which can be obtained. Both factors mean that there is little connection between the price of thorium and the price of monazite.

Under current conditions, the demand for monazite is determined by the requirements of rare earths producers, and thorium residues are stockpiled. The prospects for the price of monazite will therefore be determined by demand for rare earths for the foreseeable future, unless demand for HTGR reactors is very high and for some reason Canadian by-product thorium suitable for nuclear reactors cannot be provided in the necessary quantities.

For reasons given in our companion report on rare earths, we do not expect much change in the price of monazite. The main factors involved in this prediction are that demand for yttrium(which is present to a greater extent in monazite than in bastnasite) has declined, that for most of the other rare earths it is more convenient to use bastnasite than monazite (though it is also more expensive), and that we think the price of monazite is probably self-correcting, in that a higher price would result in increased production, for example, from native U.S. resources, or from Australian producers who do not at present recover all of the possible by-product monazite from their ilmenite operations; while a lower price would result in the monazite not being recovered or being stockpiled until the price recovers. To some extent, the price of monazite must be influenced by the price of bastnasite; the price of bastnasite is effectively controlled by one dominant U.S. producer, and has been held constant for some years. The producer concerned (Molycorp) is attempting to expand demand for rare earth products as fast as possible, and is unlikely to want to raise the price of bastnasite. Stability in the bastnasite price will tend also to stabilise the price of monazite.

8. Customs Tariffs.

Table 37 : U.K.: Customs Tariff October, 1972.

Heading	Title	per cent
26.01	Thorium ores	Free
28.52	Compounds, inorganic or organic of thorium or of uranium depleted in uranium 235	23 (1)
81.04	Thorium, wrought, unwrought, waste or scrap	10 (1)

(1) Free for Commonwealth and E.F.T.A.

Table 38 : EEC : Customs Tariff, October, 1972.

Heading	Title	per cent
26.01	Thorium ores: I : Monazite; urano-thorianite and other thorium ores containing more than 20 per cent by weight of thorium.	Free (1)
	II : Other	Free (1)
28.52	Compounds: inorganic or organic, of thorium or of uranium depleted in U235, whether or not intermixed.	Free
81.04	Thorium: unwrought, waste and scrap wrought bars, rods, angles, shapes, sections wires, plates, sheet and strip	Free
	wrought: Other	1½

Added value Taxes.	per cent	
Belgium (26.01)	6	)
Belgium (28.52 & 81.04)	18 (2)	) on duty
France	23	) paid
Germany	11	) value
Luxembourg	10	)
Netherlands	14	on delivered value

No added value tax.

Italy: all headings:	1	admin. fees on c.i.f. value
	4	general turnover tax on duty paid value
(26.01)	-	)
(28.52)	3.6	) compensatory tax
(81.04)	1.2	)

(1) Technical visa required from Commissariat a l'Energie Atomique

(2) Plus customs stamp 2 per cent of duty, and remittance tax 0.1 per cent on VAT, duty and customs stamp.

Table 39 : U.S.: Customs Tariffs, October 1972.

TSUSA heading	Description	Tariff per cent ad valorem
601.45	Thorium ore including monazite sand	Free
	Thorium, unwrought, waste and scrap:[1]	
632.52	Other than alloys	6
632.68	Alloys	7½
422.10-14	Thorium nitrate, oxide & other compounds	17½

(1) Tariff on waste and scrap temporarily suspended.

Table 40 : Japan: Customs Tariff, October 1972.

Tariff Heading	Description	Rate of duty
26.01	Ores and concentrates of uranium and thorium	Free
28.52	Compounds, organic or inorganic, of thorium or of uranium depleted in U235	Free
81.04	Thorium unwrought; powders, flakes, waste and scrap of thorium.	10
81.04	Thorium, other	15

All imports under these headings are subject to individual licensing control.

PN/PJ/PN/C

Roskill Information Services.

24th November, 1972.

286.00.00 Table 41 : Australia: Exports of uranium and thorium ores and concentrates.

Quantity (cwt)	1966 (1)(2)	1967 (1)(3)	1968 (1)	1969 (1)	1970 (1)	1971
Austria	-	4,005	-	-	-	-
Belgium/Luxembourg	-	2,015	1,401	-	3,000	-
Finland	-	-	-	-	-	3,132
France	8,605	6,097	-	4,010	9,755	14,753
West Germany	6,898	7,534	-	-	-	-
Japan	-	2,135	-	-	1,753	2,027
Netherlands	3,262	1,003	-	2,000	20,488	32,982
U.K.	-	-	-	-	2,081	4,000
U.S.A.	25,582	23,599	31,711	59,681	17,503	44,562
Others n.s.l.	2,212	-	1,878	1,202	307	1
Total	46,630 (4)	46,388	34,970 (5)	66,893	54,887	101,457

Value ($000)	1966 (1)(2)	1967 (1)(3)	1968 (1)	1969 (1)	1970 (1)	1971
Austria	-	26	-	-	-	-
Belgium/Luxembourg	-	16	10	-	18	-
Finland	-	-	-	-	-	74
France	47	37	-	26	53	124
West Germany	33	49	-	-	-	-
Japan	-	13	-	-	11	14
Netherlands	16	7	-	14	139	218
U.K.	-	-	-	-	14	27
U.S.A.	143	144	209	382	112	295
Others n.s.l.	13	-	16	7	5	-
Total	253	291	235	430	353	752

(1) Year ending 30th June
(2) Code 39780 Monazite concentrates
(3) Code 286.00.01 Monazite given in table; 286.00.09 others had no recorded exports.
(4) Figures given add to 46,559
(5) Figures given add to 34,990

2601. 37 Table 42 : Belgium/Luxembourg: Exports of thorium & uranium minerals.

Quantity (m. tons)	1967	1968	1969	1970	1971
France	-	-	-	-	120.0
West Germany	-	6.2	-	-	-
Others	-	-	-	-	-
Total	-	6.2	-	-	120.0
Value (Frs. 000)					
France	-	-	-	-	63,000
West Germany	-	3,701	-	-	-
Others	-	-	-	-	-
Total	-	3,701	-	-	63,000

2601.37 Table 43 : Belgium/Luxembourg: Imports of thorium & uranium minerals.

Quantity (m. tons)	1967	1968	1969	1970	1971
Total	-	...	10.0	10.0	14.4
Value (Frs. 000)					
Total.	-	30	110	102	311

26.01.26 Table 44 : France : Imports of Monazite, urano-thorianite and other minerals containing more than 20 per cent thorium.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
Australia	406	506	-	305	1,892	2,336
Congo (Kinshasa)	-	-	25	176	126	101
Indonesia	-	-	-	-	152	-
Madagascar	992	475	-	-	-	-
Malaysia	-	79	-	-	254	101
Nigeria	-	-	-	-	63	-
U.S.A.	-	70	45	40	-	-
Other n.e.s.	-	3	-	12	17	19
Total	1,398	1,133	70	533	2,441(1)	2,557

Value (Frs. 000)	1966	1967	1968	1969	1970	1971
Australia	306	492	-	299	1,858	2,426
Congo (Kinshasa)	-	-	113	735	505	411
Indonesia	-	-	-	-	135	-
Madagascar	1,289	630	-	-	-	-
Malaysia	-	90	-	-	241	50
Nigeria	-	-	-	-	63	-
U.S.A.	-	97	61	50	-	-
Other n.e.s.	2	14	2	12	24	20
Total	1,597	1,323	176	1,096	2,826	2,907

(1) Figures given add to 2,504.

26.01.27 Table 45 : France: Imports of other thorium minerals.

Quantity (m.tons)	1966	1967	1968	1969	1970	19
Brazil	-	...	-	20	-	
Other	-	...	-	1	-	
Total	-	...	-	22	-	
Value (Frs. 000)						
Brazil	-	-	-	331	-	
Other	-	2	-	1	3	
Total	-	2	-	332	3	

26.01.57 Table 46: West Germany: Exports of monazite & thorium minerals containing 20 per cent thorium[1]

Quantity (m.tons)	1967	1968	1969	1970	1971
Netherlands	24	-	-	-	-
U.S.A.	21	-	-	-	-
Other	-	-	-	-	-
Total	45	-	-	-	-
Value (DM 000)					
Netherlands	23	-	-	-	-
U.S.A.	15	-	-	-	-
Other	-	-	-	-	-
Total	38	-	-	-	-

(1) 2601.58 other thorium minerals no imports or exports between 1967 and September 197

2601.57 Table 47: West Germany: Imports of monazite & thorium minerals containing over 20 per cent thorium(1)

Quantity (m.tons)	1967	1968	1969	1970	1971
Netherlands	21	-	-	...	-
Malaysia	24	-	-	...	-
Other	-	-	-	...	-
Total	45	-	-	15	-
Value (DM 000)					
Netherlands	20	-	-	...	-
Malaysia	22	-	-	...	-
Other		-	-	...	-
Total	42	-	-	28	-

2601.017(2) Table 48 : Italy: Exports of monazite, uranothorianite and other thorium minerals containing more than 20 per cent thorium.

Quantity (m.tons)	1967	1968	1969	1970	1971
France	0.4	-	-	-	-
Total	0.4	-	-	42.3	-
Value (Lit.000)					
France	110	-	-	-	-
Total	110	-	-	116	-

(1) 2601.58 other thorium minerals no imports or exports between 1967 and September 1971.
(2) 2601.010 before June 1968

2601.017[(1)] Table 49: Italy: Imports of Monazite, uranothorianite and other thorium minerals containing more than 20 per cent thorium.

Quantity (m.tons)	1967	1968	1969	1970	1971
Australia	20.0	-	-	-	-
Total	20.0	-	-	-	-
Value (Lit.000)					
Australia	2,326	-	-	-	-
Total	2,326	-	-	-	-

2601.021[(2)] Table 50. Italy: Exports of other thorium minerals.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total	-	-	-	-	36.4
Value (Lit.000)					
Total	-	-	-	-	3,450

(1) 26.01.010 before June 1968.
(2) 26.00.013 before June 1968.

26.01.021(1) Table51 : Italy: Imports of other thorium minerals.

Quantity (m.tons)	1967	1968	1969	1970	1971
Australia	13.0	-	-	-	-
U.S.A.	40.8	91.1	-	-	-
Total	53.8	91.1	-	2.3	-

Value (Lit.000)	1967	1968	1969	1970	1971
Australia	1,506	-	-	-	-
U.S.A.	8,467	32,363	-	-	-
Total	9,973	32,363	-	2,530	-

26.99.01 Table 52: India: Exports of rare earth metals, ores and concentrates.

Quantity (m.tons)	1967(1)	1968(1)	1969(1)	1970(1)	1971(1)	1972
Australia	-	1	-	-	-	-
France	-	-	20	-	-	-
Italy	-	-	-	20	-	-
Japan	430	360	100	175	5	10
Mexico	-	-	-	-	3	-
Netherlands	150	-	-	-	-	-
U.K.	52	55	55	3	-	-
U.S.A.	250	300	-	-	-	-
Total	882	716	175	198	8	10

Value (R)	1967(1)	1968(1)	1969(1)	1970(1)	1971(1)	1972
Australia	-	1,192	-	-	-	-
France	-	-	34,067	-	-	-
Italy	-	-	-	30.627	-	-
Japan	652,513	671,903	201,225	337,370	17,857	49,721
Mexico	-	-	-	-	23,611	-
Netherlands	296,018	-	-	-	-	-
U.K.	103,387	113,368	91,800	4,635	-	-
U.S.A.	504,650	571,661	-	-	-	-
Total	1,556,568	1,358,124	327,092	372,632	41,468	49,721

(1) 26.01.013 before June 1968
(1) Year ending 31st March.
No other exports. Imports not covered.

286-000 Table 53 : Japan: Imports of ores and concentrates of uranium and thorium.

Quantity (m.tons)	1967	1968	1969	1970
Malaysia	143	22	-	50
Australia	53	-	10	-
Thailand	-	-	-	-
Ceylon	-	-	101	-
Congo	-	-	-	-
S. Korea	9	-	-	-
S. Africa	-	-	-	-
U.S.A.	-	-	-	-
Total	205	22	111	50

Value (000 yen)	1967	1968	1969	1970
Malaysia	11,813	1,250	-	2,508
Australia	4,185	-	917	-
Thailand	-	-	-	-
Ceylon	-	-	6,059	-
Congo	-	-	-	-
S. Korea	2,830	-	-	-
S. Africa	-	-	-	-
U.S.A.	176	-	-	-
Total	18,554(1)	1,250	6,976	2,508

26 01 Table 54 : Malagasy: Exports of thorium ores.

Quantity (m.tons)	1966	1967	1968	1969	1970
France	1,398	683	81	-	-
Total	1,398	683	81	-	-

Value (F. Mg.000)	1966	1967	1968	1969	1970
France	752	383	42	-	-
Total	752	383	42	-	-

(1) Total of figures given is 19,004.

286 Table 55 : West Malaysia: Exports of Monazite Ore and Other Ores of thorium, 1966-68.

Quantity (tons)	1966	1967	1968
Australia	-	-	-
Belgium/Luxembourg	30	-	13
France	5	78	-
West Germany	5	2	-
Japan	178	422	240
Netherlands	100	102	2
Norway			
U.K.	95	296	15
U.S.A.	608	303	1,901
Total	1,021	1,202	2,172

Value ($000)	1966	1967	1968
Australia	-	-	-
Belgium/Luxembourg	58	-	167
France	162	2,245	-
West Germany	65	65	-
Japan	993	1,604	474
Netherlands	49	186	22
Norway			
U.K.	545	2,466	79
U.S.A.	209	180	759
Others n.s.l.	-	-	-
Total	2,082	6,746	1,500

Table 56 : West Malaysia: Exports of Monazite Ore and Other ores of thorium, 1969-70

	Monazite Ore		Other Ores of Thorium	
Quantity (tons)	1969	1970	1969	1970
Australia	-	-	1	-
Belgium/Luxembourg	-	51	-	-
France	-	-	5	70
West Germany	-	-	-	-
Japan	175	30	110	30
Netherlands	-	350	40	191
Norway	-	-	-	1
U.K.	239	-	-	85
U.S.A.	1,166	1,200	5	10
Total	1,580	1,631	161	387
Value ($000)				
Australia	-	-	4	-
Belgium/Luxembourg	-	16	-	-
France	-	-	22	325
West Germany	-	-	-	-
Japan	68	11	437	140
Netherlands	-	130	156	959
Norway	-	-	-	7
U.K.	96	-	-	465
U.S.A.	477	454	16	75
Total	640	613	636	1,972

2601 37 Table 57 :Netherlands: Exports of uranium and thorium minerals.

Quantity (m.tons)	1967	1968	1969	1970	1971
France	96	-	-	-	-
West Germany	26	-	-	-	-
U.S.A.	65	-	-	-	-
Total	187	-	-	-	-
Value (Gld'000)					
France	545	-	-	-	-
West Germany	57	-	-	-	-
U.S.A.	40	-	-	-	-
Total	643	-	-	-	-

2601 37 Table 58 :Netherlands: Imports of uranium and thorium minerals.

Quantity (m.tons)	1967	1968	1969	1970	1971
West Germany	24	-	-	-	-
Indonesia	50	-	-	-	-
Malaya	87	-	-	-	-
Total	161	-	20	-	-
Value (Gld'000)					
West Germany	16	-	...	-	-
Indonesia	22	-	...	-	-
Malaya	38	-	...	-	-
Total	77	-	6	-	-

Table 59: U.K.: Imports of rare earth minerals and concentrates containing not less than 40 per cent and not exceeding 95 per cent by weight of rare earth compounds calculated as rare earth oxides (2532 0321)

	Quantity (tons)		Value (£)	
	1970	1971	1970	1971
Belgium	-	8	-	887
Brazil	53	-	7,693	-
Malaysia	73	37	52,130	26,763
Norway	-	ϕ	-	206
U.S.A.	1,266	717	199,645	152,797
Total	1,392	762	259,468	180,653

Table 60 : U.S.A.: Exports of Thorium Ores and Concentrates (2860020)

Quantity (lb. of ThO_2)	1965	1966	1967	1968	1969	1970	1971
U.K.	37,063	-	...	-	-	-	...
West Germany	-	45,921	...	-	-	-	...
Other n.s.l.	2,639	-	...	1,476	1,544	81	...
Total	39,702	45,921	...	1,476	1,544	81	...
U.K.	71,209	-	...	-	-	-	...
West Germany	-	160,984	...	-	-	-	...
Other n.s.l.	7,796	-	...	11,201	11,181	1,296	...
Total	79,005	160,984	...	11,201	11,181	1,296	...

Not separately listed for 1967 or 1971.

Table 61 : U.S.A.: Imports of Thorium Ore including monazite sand (6014500)

Quantity (long ton)	1966	1967	1968	1969	1970	1971
Thailand	-	-	-	-	147	...
Malaysia	701	244	1,352	1,394	1,167	1,403
Australia	1,377	1,375	2,509	2,212	1,765	1,609
Hong Kong	-	-	-	149	-	...
West Germany	-	21	21	-	-	...
Nigeria	-	119	17	-	-	...
Indonesia	-	64	-	-	-	...
Korea	-	44	-	-	-	...
South Africa	103	-	-	-	-	...
Total	2,181	1,867	3,899	3,755	3,079	3,012
Value ($000)						
Thailand	-	-	-	-	19	...
Malaysia	92	38	188	174	157	165
Australia	177	195	369	300	251	218
Hong Kong	-	-	-	20	-	...
West Germany	-	4	4	-	-	...
Nigeria	-	13	2	-	-	...
Indonesia	-	13	-	-	-	...
Korea	-	7	-	-	-	...
South Africa	9	-	-	-	-	...
Total	277	270	563	494	427	383

28.52.00 Table 62 : Austria: Imports of compounds of thorium, uranium and rare earth metals

Quantity (m.tons)	1967	1968	1969	1970	1971
Brazil	699.3	499.8	499.1	593.6	728.0
Canada	0.1	-	-	-	-
France	14.5	7.1	6.9	15.2	20.5
West Germany	58.9	32.8	26.5	25.9	13.0
India	1.0	13.2	30.4	601.0	800.0
Italy	1.5	32.0	26.0	41.9	30.0
Switzerland	1.0	-	1.0	-	
U.K.	0.3	0.5	11.2	9.5	22.4
U.S.A.	-	1.1	0.7	-	1.2
Total	776.7	586.5	601.8	1287.5	1615.3

Value (S'000)					
Brazil	6,559	4,709	4,839	5,021	6,471
Canada	42	-	-	-	-
France	1,722	744	813	1,438	1,863
West Germany	2,039	1,280	956	1,168	855
India	14	1,301	1,076	4,960	7,189
Italy	52	597	457	456	322
Switzerland	110	-	129	-	-
U.K.	21	70	798	677	1,801
U.S.A.	-	34	79	-	133
Total	10,571 (1)	8,747 (1)	9,155 (1)	13,777 (1)	18,691 (1)

(1) The arithmetic totals are 10,559 8,735 9,147 13,720 and 18,634 respectively.

515.30.00 Table 63 : Australia: Imports of compounds and mixtures, n.e.s. of thorium, of uranium, etc.

Value ($000)	1967 (1)	1968 (1)	1969 (1)	1970 (1)	1971 (1)
Japan	-	-	-	-	9
U.K.	20	10	15	19	13
U.S.A.	10	14	10	26	17
Others n.s.1.	8	21	7	11	9
Total	38	45	32	55	48

28.52.20 Table 64 : Belgium/Luxembourg: Exports of organic & inorganic compounds of thorium and of uranium depleted in uranium 235.

Value (Frs'000)					
France	...	...	706	...	...
Other	...	...	135	...	...
Total	139	9	841	93	85

28.52.20 Table 65 : Belgium/Luxembourg: Imports of organic or inorganic compounds of thorium and of uranium depleted in uranium 235.

Value (Frs'000)					
Total	105	56	105	606	357

(1) Years ending 30th June.

28.52.50 Table 66 : Finland: Imports of organic and inorganic compounds of thorium, uranium depleted in uranium 235, rare earth metals including yttrium and scandium and intermixtures.

Quantity (m.tons)	1967	1968	1969	1970	1971 (Jan-Oct)
Australia	-	-	-	25.9	...
France	-	0.1	0.2	4.4	...
West Germany	0.1	0.3	1.7	0.9	...
Japan	-	-	ø	ø	...
Netherlands	-	ø	-	-	...
Norway	-	ø	-	-	...
Sweden	-	0.1	0.4	0.5	...
Switzerland	ø	ø	ø	ø	...
U.K.	0.9	0.5	0.4	53.1	...
U.S.A.	ø	0.1	100.0	121.9	...
U.S.S.R.	-	...	0.3	-	...
Total	1.0	1.0	103.0	206.7	1,132.0

Value (Mk000)	1967	1968	1969	1970	1971 (Jan-Oct)
Australia	-	-	-	67	...
France	-	1	3	30	...
West Germany	5	16	75	43	...
Japan	-	-	19	3	...
Netherlands	-	ø	-	-	...
Norway	-	1	-	-	...
Sweden	-	3	6	9	...
Switzerland	1	1	1	1	...
U.K.	24	16	7	149	...
U.S.A.	1	4	336	302	...
U.S.S.R.	-	14	66	-	...
Total	31	57	513	604	1,940

28.52.01 Table 67 : France: Exports of Thorium oxide.

Quantity (Kgs)	1966	1967	1968	1969	1970	1971
West Germany	-	2,000	...	-	2,300	3,630
Hong Kong	-	3,000	...	-	-	-
Japan	-	-	...	-	2,806	-
Netherlands	-	-	...	1,300	1,000	-
U.K.	32,512	-	...	-	-	-
Other	1,389	3,123	...	110	594	2,153
Total	33,901	8,123	1,381	1,410	6,700	5,783

Value (Frs 000)	1966	1967	1968	1969	1970	1971
West Germany	-	80	...	-	129	107
Hong Kong	-	78	...	-	-	-
Japan	-	-	...	-	315	-
Netherlands	-	-	...	95	82	-
U.K.	861	-	...	-	-	-
Others	67	116	...	10	32	110
Total	928	274	60	105	558	217

28.52.01 Table 68 France: Imports of Thorium oxide.

Quantity (Kgs)	1966	1967	1968	1969	1970	1971
Total	-	-	6	-	-	-
Value (Frs 000)						
Total	-	-	5	-	-	1

28.52.02 Table 69 : France: Exports of inorganic salts & compounds of thorium.

Quantity (Kgs.)	1966	1967	1968	1969	1970	1971
Argentina	-	-	5,300	5,400	4,900	9,000
Austria	3,995	-	3,500	3,550	13,545	17,793
West Germany	-	3,175	-	-	-	-
Hong Kong	20,040	31,000	58,050	45,000	20,000	52,100
Indonesia	-	5,000	-	-	-	-
Iran	-	-	-	-	3,010	2,515
Italy	-	-	-	2,651	-	-
Japan	-	-	-	-	2,502	4,100
Turkey	-	-	-	-	-	3,060
U.S.A.	60,532	-	-	-	-	-
Other	1,225	6,873	3,047	4,920	3,780	4,399
Total	35,792	46,048	69,897	61,521	47,736	92,967

Value (Frs'000)	1966	1967	1968	1969	1970	1971
Argentina	-	-	112	115	145	192
Austria	91	-	68	88	256	370
West Germany	-	75	-	-	-	-
Hong Kong	518	807	1,506	1,211	588	1,658
Indonesia	-	103	-	-	-	-
Iran	-	-	-	-	63	52
Italy	-	-	-	83	-	-
Japan	-	-	-	-	162	122
Turkey	-	-	-	-	-	50
U.S.A.	360	-	-	-	-	-
Other	34	143	66	108	105	88
Total	1,003	1,128	1,752	1,605	1,319	2,532

28.52.02 Table 70 : France: Imports of Inorganic salts and compounds of thorium.

Quantity (Kgs.)	1966	1967	1968	1969	1970	1971
Total	200	-	ø	-	7	- (1)
Quantity (Kgs.)						
Total	6	-	1	-	2	1

28.52.03 Table 71 : France: Exports of organic salts & compounds of thorium.

Quantity (Kgs.)	1966	1967	1968	1969	1970	1971
Argentina	2,300	6,300	...	-	-	-
Austria	9,750	13,600	...	3,150	-	-
Hong Kong	-	-	-	5,000		-
Japan	-	-	...	-	2,202	13,589
Turkey	2,506	-	...	-	-	-
Others	470	972	...	850	100	1,000
Total	15,020	20,872	5,995	9,000	2,302	14,589
Value (Frs'000)						
Argentina	52	136	...	-	-	-
Austria	218	298	...	64	-	-
Hong Kong	-	-	-	129	-	-
Japan	-	-	...	-	76	200
Turkey	79	-	...	-	-	-
Other	13	27	...	21	9	5
Total	362	461	114	214	85	205

28.52.03 Table 72 : France: Imports of organic salts & compounds of thorium.

Quantity (Kgs)	1966	1967	1968	1969	1970	1971
Total	11	-	12	-	∅	-
Value (Frs'000)						
Total	1	-	1	-	1	-

28.52.11,15 Table 73 : West Germany: Imports of compounds of thorium and of depleted uranium.

Quantity (m.tons)	1967	1968	1969	1970	1971
Belgium/Luxembourg	-	8	-	-	-
France	2	3	3	14	5
India	-	7	5	-	-
Japan	-	1	4	-	-
U.K.	14	8	3	4	4
U.S.A.	16	15	14	11	85
Other n.e.s.	1	-	-	-	1
Total	33	41	29	29	94

Value (DM'000)	1967	1968	1969	1970	1971
Belgium/Luxembourg	-	296	-	-	-
France	69	54	35	252	110
India	-	109	84	-	-
Japan	-	32	123	-	-
U.K.	259	163	83	108	392
U.S.A.	281	153	91	50	758
Other n.e.s.	19	4	7	18	8
Total	628	811	423	428	1,268

28.52.11,15 Table 74 : West Germany: Exports of compounds of thorium and of depleted uranium.

Quantity (m.tons)	1967	1968	1969	1970	1971
Turkey	1	3	-	...	...
U.S.A.	-	...	ϕ	...	...
Other n.e.s.	-	-	-	...	...
Total	1	3	ϕ	4	ϕ
Value (DM'000)					
Turkey	26	77	-	...	...
U.S.A.	-	32	44	...	...
Other n.e.s.	28	57	47	...	...
Total	54	166	91	102	77

51.42.53 Table 75 : Hong Kong: Imports of Thorium nitrate.

Quantity (cwt.)	1967	1968	1969	1970	1971
Belgium/Luxembourg	117	-	-	99	79
China (People's Republic)	-	24	69	-	119
France	511	1,159	1,081	395	905
India	57	142	80	143	155
Japan	-	10	-	-	-
U.K.	148	317	118	80	120
U.S.A.	399	479	143	20	140
Total	1,232	2,131	1,491	737	1,518
Value (HK$000)					
Belgium/Luxembourg	169	-	-	108	84
China (People's Republic)	-	30	98	-	135
France	688	1,570	1,419	435	956
India	79	218	109	198	208
Japan	-	13	-	-	-
U.K.	240	501	176	104	164
U.S.A.	658	852	249	27	190
Total	1,835	3,183	2,050	873	1,737

28.52.001 Table 76 : Italy: Imports of organic and inorganic compounds of thorium, depleted uranium and inter mixtures.

Value(1) (Lit000)	1967	1968	1969	1970	1971
Belgium/Luxembourg	-	2,810	...	...	...
France	11,630	1,084	...	...	...
West Germany	142	-	...	...	...
Switzerland	249	257	...	...	...
U.K.	4,269	1,369	...	...	...
U.S.A.	677	-	...	...	...
Total	16,967	5,520	80,940	11,710	13,435

28.52.00 Table 77 : Italy: Exports of organic and inorganic compounds of thorium, depleted uranium & inter mixtures.

Value (1) (Lit000)	1967	1968	1969	1970	1971
Bulgaria	103	-	...	-	...
Cuba	-	56	...	-	...
Czechoslavakia	38	48	...	-	...
France	332	-	...	-	...
Rumania	43	133	...	106	...
Yugoslavia	194	-	...	-	...
Other n.s.l.	200	-	...	210	...
Total	910	237	48	316	156

(1) Quantity not available.

515.310 Table 78 : Japan: Exports of Inorganic or organic compounds of thorium or uranium depleted in U 235.

Quantity (m.tons)	1967	1968	1969	1970	1971
Australia		-	25	-	-
West Germany	0	-	-	-	-
U.S.A.	61		9	-	-
Total	61	-	34	-	-
Value (000 yen)					
Australia	-	-	2,228	-	-
West Germany	169	-	-	-	-
U.S.A.	116,993	-	8,920	-	-
Total	117,162	-	11,148	-	-

515.310 Table 79 : Japan: Imports of Inorganic or organic compounds of thorium or uranium depleted in U235.

Quantity (kg)	1967	1968	1969	1970	1971
Australia	-	-	24,846	50,800	-
France	-	-	-	25,797	17,933
West Germany	5	1	-	8	13
India	-	-	-	550	500
U.K.	-	-	-	925	109
U.S.A.	61,248	6,369	9,338	5,327	18,906
Total	61,253	6,370	34,184	83,407	37,461
Value (000 yen)					
Australia	-	-	2,208	3,753	
France	-	-	-	40,816	25,872
West Germany	169	335	-	872	658
India	-	-	-	846	741
U.K.	-				
U.S.A.	-	-	-	1,002	505
Total	117,162	19,729	11,148	41,688	46,092

28.52.20 Table 80 : Netherlands: Exports of organic and inorganic compounds of thorium and uranium depleted in uranium 235.

Quantity	1967	1968	1969	1970	1971
Total	-	...	98	6	10
Value (Gld'000)					
Total	-	4	6	1	1

28.52.20 Table 81 : Netherlands: Imports of organic and inorganic compounds of thorium and uranium depleted in uranium 235.

Quantity (kg)	1967	1968	1969	1970	1971
Belgium/Luxembourg	...	...	364	310	...
France	10,000	1,000	2,400	1,300	...
U.S.A.	-	-	829	-	...
Total	10,000	1,000	3,593	1,610	307
Value (Gld'000)					
Belgium/Luxembourg	1	2	27	22	...
France	18	27	93	61	...
U.S.A.	-	-	261	-	...
Total	19	29	381	83	9

28.52.00 Table 82 : Portugal: Imports of organic and inorganic compounds of thorium, uranium depleted in uranium 235 and rare earth metals.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
Austria	-	-	-	0.4	0.2	0.6
France	-	ø	ø	ø	0.7	3.5
West Germany	ø	ø	ø	ø	ø	ø
Switzerland	-	ø	ø	-	ø	ø
U.K.	0.7	0.5	0.8	1.2	3.0	1.2
U.S.A.	ø	-	-	ø		-
Total	0.7	0.6	0.8	1.7	4.0	5.3

Value (Esc.000)	1966	1967	1968	1969	1970	1971
Austria	-	-	-	39	16	43
France	-	8	2	1	69	309
West Germany	1	10	12	16	5	20
Switzerland	-	1	2	-	4	5
U.K.	87	74	86	98	221	128
U.S.A.	8	-	-	8		-
Total	99 (1)	94 (1)	104 (1)	165 (1)	318 (1)	504 (1)

515.300 Table 83 : Singapore: Imports of Salts & compounds of thorium, uranium and base metals.

Value ($)	1967	1968	1969	1970	1971
West Germany	93	195	39	428	77
Japan	4,080	52,080	15,190	-	-
Netherlands	125	-	-	-	-
U.K.	5	58	456	-	195
U.S.A.	32	51	149	-	2,650
Total	4,335	52,380 (1)	15,834	428	2,922

Exports are insignificant.

(1) Addition of figures shown differ from totals given by up to 4 units.

Table 84 : Spain: Exports of compounds of thorium and uranium including intermixtures.

Quantity (Kgs)	1967	1968	1969	1970	1971
Belgium/Luxembourg	-	-	-	-	47
Brazil	-	500	50	-	-
Total	-	500	50	-	47

Value (Pesos'000)	1967	1968	1969	1970	1971
Belgium/Luxembourg	-	-	-	-	78
Brazil	-	490	49	-	-
Total	-	490	49	-	78

Table 85 : Spain: Imports of compounds of uranium & thorium including intermixtures.

Quantity (kgs)	1967	1968	1969	1970	1971
Belgium/Luxembourg	ϕ	-	-	-	-
France	1,248	1,235	1,000	1,000	1,000
West Germany	4	11	12	8	26
India	-	500	500	500	500
Italy	-	ϕ	-	-	-
Switzerland	-	-	ϕ	-	-
U.K.	75	150	56	147	550
U.S.A.	3	-	ϕ	17,000	2
Total	1,330	1,896	1,000 (1)	18,000 (2)	3,000 (3)

Value (Pesos'000)	1967	1968	1969	1970	1971
Belgium/Luxembourg	1	-	-	-	-
France	353	426	424	306	425
West Germany	14	37	51	23	75
India	-	140	140	138	148
Italy	-	1	-	-	-
Switzerland	-	-	ϕ	-	-
U.K.	28	64	101	190	167
U.S.A.	52	-	6	165	7
Total	450	668	724	823	824

(1) Total of figures given is 1,568
(2) Total of figures given is 18,655
(3) Total of figures given is 2,078

28.52.009 Table 86 : Sweden: Imports of organic and inorganic compounds of thorium, rare earth metals and of yttrium and scandium including intermixtures.

Quantity (m.tons)	1967	1968	1969	1970	1971
Finland	-	1	-	-	-
France	3	2	4	5	6
West Germany	-	1	-	-	∅
U.K.	4	5	3	3	4
U.S.A.	∅	∅	1	1	1
Total	8	8	8	10	12

Value (Kr'000)	1967	1968	1969	1970	1971
Finland	-	15	-	-	-
France	49	31	64	65	82
West Germany	-	13	-	-	12
U.K.	69	60	37	44	64
U.S.A.	14	15	175	20	22
Total (1)	141	137	296	146	186

28.52.00 Table 87 : Thailand: Imports of Salts and other compounds of thorium, uranium or of rare earth metals.

Quantity (m.tons)	1967	1968	1969	1970
France	...	...	...	5
U.S.A.	...	...	...	∅
Total	...	...	...	5

Value (000 Baht)	1967	1968	1969	1970
France	...	...	...	52
U.S.A.	...	...	...	39
	...	...	...	90

(1) Totals of figures given are 132, 134, 276, 129 and 180.

Table 88 : U.K.: Imports of thorium compounds.

Quantity (cwt)	1966	1967	1968	1969	1970	1971
Austria	-	ϕ	-	-	-	-
Canada	892	1,924	2,206	994	-	-
France	1	-	-	-	-	40
India	-	-	-	-	157	-
Lichtenstein	-	-	-	-	-	ϕ
Switzerland	-	-	-	-	-	ϕ
U.S.A.	126	504	232	251	138	1
Sub-total	1,019	2,428	2,438	1,245	295	41
Estimate for remaining months	1,990 (1)	827	810	150	5	14
Total	3,009	3,255	3,248	1,395	300	55

Value (£)	1966	1967	1968	1969	1970	1971
Austria	-	13	-	-	-	-
Canada	28,702	58,602	83,764	37,287	-	-
France	303	-	-	-	-	4,358
India	-	-	-	-	11,855	-
Lichtenstein	-	-	-	-	-	228
Switzerland	-	-	-	-	-	186
U.S.A.	15,483	66,150	38,063	39,934	20,664	445
Sub-total	44,488	124,765	121,827	77,221	32,519	5,217
Estimate for remaining months	121,200	41,766 (1)	40,000	12,000	500	1,700
Total	165,688	166,531	161,827	89,221	33,019	6,917
No. of estimated months.	5 (1)	1 (2)	3	1	1	3
Max. errors of estimate:						
Plus:	...	-	...	...	-	700
Minus:	52,000	-	10,000	2,000	500	700

(1) The total (737 cwt; £44,428) but not the country division is given for 2 of the 5 months.

(2) The total but not the country division is given for this 1 month of 1967.

688.00.00 Table 89 : Australia: Imports of uranium, thorium and their alloys shapes and sections.

Value ($000)	1967 (1)	1968 (1)	1969 (1)	1970 (1)	1971 (1)
Total	-	2	6	2	...

8104.400 Table 90 : Finland: Imports of Thorium & uranium metal.

Quantity (m.tons)	1967 (2)	1968 (2)	1969	1970
West Germany	-	ϕ	-	-
U.K.	ϕ	-	ϕ	ϕ
Value (Mk 000)				
West Germany	-	ϕ	-	-
U.K.	ϕ	-	ϕ	ϕ

8104.74 Table 91 : France: Exports of Thorium unwrought, waste & scrap.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
Total	...	...	...	4	...	...
Value (Frs'000)						
Total	8	18	10	48	29	9

8104.76 Table 92 : France: Exports of bars profiles wire strips and sheets of wrought thorium.

Value (Frs'000)	1966	1967	1968	1969	1970	1971
Total	7	1	1	-	-	9

8104.76 Table 93 : France: Imports of bars, profiles, wire, sheets and bands of wrought thorium.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
U.S.A.	...	-	...	-	1	-
Total	...	-	...	-	1	...
Value (Frs'000)						
U.S.A.	-	-	-	-	58	-
Others	...	-	...	-	-	4
Total	4	-	19	-	58	4

(1) Year ending 30th June.

8104.78 Table 94 : France: Exports of other wrought thorium.

Value (Frs'000)	1966	1967	1968	1969	1970	1971
Total	108	-	11	9	-	-

8104.78 Table 95 : France: Imports of other wrought thorium.

Value(1) (Frs'000)	1966	1967	1968	1969	1970	1971
Total	5	-	-	4	4	-

8104.64 Table 96 : West Germany: Imports* of wrought thorium.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total	-	-	1	...	-
Value (DM'000)					
Total	-	-	6	1	-

8104.62 Table 97 : West Germany: Imports* of thorium, unwrought, waste and scrap.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total	...	2	1	2	-
Value (DM'000)					
Total	4	15	6	18	-

8104.63 Table 98 : West Germany: Exports of bars, profiles, wire, strips sheets and leaves of thorium.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total	-	...	-	...	-
Value (DM'000)					
Total	-	5	-	1	-

8104.63 Table 99 : West Germany: Imports of bars, profiles, wire, strips sheets and leaves of thorium.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total	...	-	...	...	-
Value (DM'000)					
Total	2	-	3	1	-

(1) Quantity not available.
* There were no exports in this period.

8104.017 Table 100 : Italy: Imports of thorium metal, waste & scrap.

Value (1) (Lit'000)	1967	1968	1969	1970	1971
Total	-	-	594	-	-

688.029 Table 101 : Japan: Import of thorium and its alloys; its articles thereof n.e.s. *

Quantity (Kg)	1967	1968	1969	1970	1971
U.S.A.	...	...	ϕ	8	1
Value	...	...	ϕ	8	1
Value (Yen000)					
U.S.A.	...	...	139	627	1,291
Value	...	...	139	627	1,291

8104.01.01 Table 102 : Portugal: Imports of unwrought uranium and thorium.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
France	-	0.2	-	-	-	...
West Germany	-	-	-	-	ϕ	...
Total	-	0.2	-	-	ϕ	...
Value (Esc'000)						
France	-	39	-	-	-	...
West Germany	-	-	-	-	15	...
Total	-	39	-	-	15	...

(1) Quantity not available.
* No exports in this category.

8104.02.01 Table 103 : Portugal: Imports of semifabricated uranium and thorium.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
Austria	ϕ	-	-	-	-	...
France	-	-	-	-	ϕ	...
West Germany	-	-	-	-	ϕ	...
U.K.	ϕ	-	-	-	-	...
Total	ϕ	-	-	-	ϕ	...

Value (Esc'000)	1966	1967	1968	1969	1970	1971
Austria	3	-	-	-	-	...
France	-	-	-	-	6	...
West Germany	-	-	-	-	8	...
U.K.	3	-	-	-	-	...
Total	7	-	-	-	15	...

8104.51 Table 104 : Spain: Imports of thorium & uranium, unwrought.

Quantity (Kgs)	1967	1968	1969	1970	1971
U.K.	...	-	-	-	-
U.S.A.	...	-	-	1	-
Total	...	-	-	1	-

Value (Pesos'000)	1967	1968	1969	1970	1971
U.K.	4	-	-	-	-
U.S.A.	-	-	-	21	-
Total	4	-	-	21	-

8104.52.53.54 Table 105 : Spain*: Exports* of thorium & uranium, wrought.

Quantity (Kgs)	1967	1968	1969	1970	1971
Mexico	-	-	-	-	50
Total	-	-	-	-	50

Value (Pesos'000)	1967	1968	1969	1970	1971
Mexico	-	-	-	-	60
Total	-	-	-	-	60

* There were no imports in this period.

8104.400 Table 106 : Sweden: Imports of wrought and unwrought uranium and thorium metal.

Quantity (m.tons)	1967	1968	1969	1970	1971
France	-	-	∅	-	-
West Germany	-	-	∅	-	-
Total	-	-	∅	-	-

Value (Kr'000)	1967	1968	1969	1970	1971
France	-	-	11	-	-
West Germany	-	-	24	-	-
Total	-	-	38(2)	-	-

8104.400 Table 107 : Sweden: Exports of wrought & unwrought uranium and thorium metal.

Quantity (m.tons)	1967(1)	1968	1969	1970	1971
Finland	∅	-	-	-	-
France	1	-	-	-	-
West Germany	-	-	-	-	∅
Total	1	-	-	-	∅

Value (Kr'000)	1967	1968	1969	1970	1971
Finland	10	-	-	-	-
France	135	-	-	-	-
West Germany	-	-	-	-	19
Total	146	-	-	-	19

(1) Uranium only.
(2) Total as stated in original source; total of individual figures is 35

688.0000 Table 108 : U.S.A.: Exports of uranium & thorium and their alloys, unwrought or wrought.

Quantity (lbs.)	1967	1968	1969	1970	1971
Canada	284	337	-	335	59,495
Belgium/Luxembourg	-	-	-	-	-
Italy	-	-	-	-	3,437
Japan	-	5,272	-	4,885	1,993
Others n.s.l.	259	626	788	283	667
Total	543	6,235	788	5,503	65,592

Value ($)	1967	1968	1969	1970	1971
Canada	12,617	15,000	-	17,010	827,774
Belgium/Luxembourg	-	-	-	-	-
Italy	-	-	-	-	71,933
Japan	-	98,811	-	59,509	28,623
Others n.s.l.	9,346	11,875	26,182	9,502	15,630
Total	21,963	125,686	26,182	86,021	943,960

655.82.00 Table 109 : Australia: Exports of wicks etc.

Value ($000)	1967(1)	1968(1)	1969(1)	1970(1)	1971(1)
Total	2	2	...	...	...

655.82.03 Table 110 : Australia: Imports of incandescent gas mantles.

Value ($000)					
U.K.	...	35	25	43	...
Others n.s.l.	...	9	8	15	...
Total	...	45	33	58	...

(1) Year ending 30th June.

59.14.00 Table 111 : Austria: Exports of wicks and incandescent gas mantles.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total (1)	64.8	82.1	80.4	70.0	80.4
Value (S'000)					
Total	14,780	19,210	18,479	16,779	21,034

5914.00 Table 112 : Belgium/Luxembourg: Exports of fabric wicks and incandescent gas mantles.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total (1)	2.1	2.1	1.9	4.1	6.2
Value (Frs'000)					
Total	378	339	283	739	1,013

5914.00 Table 113 : Belgium/Luxembourg: Imports of fabric wicks and incandescent gas mantles.

Quantity (m.tons)	1967	1968	1969	1970	1971
West Germany	-	...	7.3	...	...
Netherlands	4.3	...	7.2	...	...
U.K.	0.7	...	-	...	...
Others n.s.l.	1.1	12.1	1.9	6.9	6.7
Total	6.1	12.1	16.4	6.9	6.7
Value (Frs'000)					
West Germany	-	...	1,176	...	...
Netherlands	707	...	1,140	...	...
U.K.	352	...	-	...	...
Others n.s.l.	335	2,305	774	1,651	2,012
Total	1,394	2,305	3,090	1,651	2,012

(1) Country division given in original source

78796 Table 114 : Brazil: Exports* of incandescent gas mantles.

Quantity (m.tons)	1966	1967	1968	1969	1970
Argentina	0.2	0.1	...	0.2	...
Bolivia	-	-	...	ϕ	...
Chile	-	-	...	0.4	...
Paraguay	-	-	...	0.3	...
Total	0.2	0.1	...	0.9	...
Value ($US'000)					
Argentina	1.0	0.7	...	1.2	...
Bolivia	-	-	...	0.3	...
Chile	-	-	...	1.9	...
Paraguay	-	-	...	0.4	...
Total	1.0	0.7	...	3.7	...

5914.200 Table 115 : Finland: Exports of incandescent gas mantles.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total	-	-	0.2	-	ϕ
Value (Mk'000)					
Total	-	-	8	-	3

* Imports in category 78796 are negligible.

59.14.21 Table 116 : France: Exports of incandescent gas mantles.

Quantity ('000)	1966	1967	1968	1969	1970	1971
Total (1)	3,069	9,612	202	210	22,222	28,309
Value (Frs'000)						
Total	38	112	110	105	216	248

59.14.21 Table 117 : France: Imports of incandescent gas mantles.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
Austria	5	5	6	9	12	12
Italy	-	-	...	...	1	1
Malta	-	-	-	-	-	1
U.K.	-	1	2	2	2	-
Others n.s.l.	..ø	..ø	...ø	...ø	...ø	..ø
Total (weight)	5	6	8	11	15	14
Total (number:000)	3,677	1,955	2,655	3,849	4,424	4,544
Value (Frs'000)						
Austria	356	336	345	580	775	851
Italy	-	-	52	56	110	55
Malta	-	-	-	-	-	60
U.K.	-	51	123	138	146	..
Others n.s.l.	20	12	9	12	8	87
Total	376	399	529	786	1,039	1,053

(1) Country division given in original source.

59.14.50 Table 118 : West Germany: Exports of incandescent gas mantles.

Quantity (kgs)	1967	1968	1969	1970	1971
Total (1)	48,309	53,133	38,335	33,900	28,595
Value (DM'000)					
Total	1,971	2,330	1,747	1,568	1,483

59.14.50 Table 119 : West Germany: Imports of incandescent gas mantles.

Quantity (kgs)	1967	1968	1969	1970	1971
Austria	2,177	1,981	2,886	1,904	4,467
U.K.	607	778	657	-	-
Others	975	502	134	1,010	1,147
Total	3,659	3,261	3,677	2,914	5,614
Value (DM'000)					
Austria	117	97	99	88	146
U.K.	19	23	20	-	-
Others	12	15	7	40	41
Total	148	135	126	128	187

655821 Table 120 : Hong Kong: Exports of incandescent gas mantles.

Quantity (000)	1967	1968	1969	1970	1971
Total(1)	27,093	44,403	31,497	31,603	32,527
Value (HK$'000)					
Total	4,673	7,690	5,723	5,234	5,885

(1) Country division given in original source.

59.14.000 Table 121 : Italy: Exports of wicks and gas mantles.

Quantity (kgs)	1967	1968	1969	1970	1971
Gas Mantles	135	304 (1)	...	...	...
Wicks	25,363	...	...	...	...
Total	25,498	20,436	18,900	17,700	13,100

Value (Lit'000)	1967	1968	1969	1970	1971
Gas Mantles	1,653	7.834 (1)	...	...	...
Wicks	41,130	...	...	...	...
Total	42,783	46,371	39,210	46,381	37,209

655.820 Table 122 : Japan: Exports of wicks of textile materials for lamps, lighters, candles and the like, tubular knitted gas mantle fabrics, and incandescent gas mantles.

Quantity (kg)	1967	1968	1969	1970	1971
Total	68,662	64,644	93,095	92,655	66,110

Value (Yen000)	1967	1968	1969	1970	1971
Total	44,447	59,328	94,459	88,439	83,970

(1) Country division given in original source.

655.821 Table 123 : Japan: Imports of wicks of textile materials for lamps, stoves, lighters, candles, and the like, tubular knitted gas mantle fabrics and incandescent gas mantles: cotton.

Quantity (kg)	1967 (1)	1968	1969	1970	1971
Austria	324	-	-	-	-
France	16	12	-	-	-
Netherlands	78	29	75	104	112
Sweden	2,070	1,774	1,604	2,364	4,478
U.K.	13,610	9,996	15,688	19,727	20,850
U.S.A.	4,682	5,330	13,869	4,272	8,775
Total	20,780	17,141	31,236	26,467	34,215
Value (Yen000)					
Austria	1,000	-	-	-	-
France	243	185	-	-	-
Netherlands	352	160	271	622	758
Sweden	3,263	3,304	3,686	3,856	8,841
U.K.	32,967	36,601	37,150	53,959	61,270
U.S.A.	10,579	7,489	19,502	6,274	12,965
Total	48,404	47,739	60,609	64,711	83,834

655.829 Table 124 : Japan: Imports of wicks of textile materials for lamps, stoves, lighters, candles and the like, tubular knitted gas mantle fabrics and incandescent gas mantles n.e.s.

Quantity (kg)	1967 (2)	1968	1969	1970	1971
Austria	...	1,013	-	28	237
France	...	10	21	50	10
U.S.A.	...	18	14	-	-
Total	...	1,041	35	78	247
Value (Yen000)					
Austria	...	2,700	-	158	799
France	...	204	348	836	173
U.S.A.	...	263	386	-	-
Total	...	3,167	734	994	972

(1) Category 655.820 (which includes 655.829 given separately for 1968 onwards in the table following).
(2) Included with category 655.821 in 1967

655.820 Table 125 : West Malaysia: Imports of wicks and incandescent gas mantles.

Value ($000)	1966	1967	1968	1969	1970
Formosa	-	ø	-	8	...
Hong Kong	181	255	288	279	185
Japan	5	14	15	11	...
Singapore	164	35	7	6	...
Other countries n.s.l.	27	17	15	8	28
Total	367 (1)	322	328	314	212

5914.00 Table 126 : Netherlands: Exports of lamp wicks and incandescent gas mantles.

Quantity (m.tons)	1967	1968	1969	1970	1971
Total (2)	90	69	63	65	43
Value (Gld'000)					
Total	892	680	584	745	521

59.14.03 Table 127 : Portugal: Exports of wicks and incandescent gas mantles.

Quantity (m.tons)	1966	1967	1968	1969	1970	1971
Total (1)	0.2	0.4	0.5	0.2	0.4	ø
Value (Esc'000)						
Total	40	52	51	33	23	4

65558.20 Table 128 : Singapore: Exports of incandescent gas mantles.

Value ($000)	1967	1968	1969	1970	1971
Total (2)	162	132	208	170	350

(1) Total of figures given is 377
(2) Country division given in original source.

6558.20 Table 129 : Singapore: Imports of incandescent gas mantles.

Value ($000)	1967	1968	1969	1970
Austria	-	-	-	-
Brazil	-	-	-	5
China	35	1	2	2
France	ϕ	-	ϕ	-
West Germany	5	3	4	6
Hong Kong	812	1,661	1,384	1,046
India	13	-	-	-
Italy	40	15	18	23
Japan	16	32	63	74
Malaysia (West)	7	24	26	7
Pakistan	6	-	-	-
Sweden	-	2	-	-
U.K.	20	37	24	33
U.S.A.	36	26	4	6
Total	991	1,802	1,527	1,201

594.00 Table 130 : Spain: Exports of wicks & incandescent gas mantles.

Quantity (kgs)	1967	1968	1969	1970	1971
Total (1)	28,047	35,581	40,000	62,000	34,000
Value (Pesos'000)					
Total	3,777	5,250	5,775	7,221	5,139

59.14.200 Table 131 : Sweden: Exports of Tubular knitted gas mantle fabric and incandescent gas mantles.

Quantity(m.tons)	1967	1968	1969	1970	1971
Total (1)	ϕ	ϕ	1	-	ϕ
Value (Kr'000)					
Total	20	29	44	-	25

(1) Country division given in original source.

Table 132 UK Exports of gas mantles and of wicks.

Wicks of woven plaited or knitted textile materials for lamps stoves etc, mantles for incandescent lighting whether collodionised or not (E65.586)		Quantity (Gross)	Value (£000)
1966	Total(1)	64,377	220
1967	Total(1)	64,414	237
1968	Total(1)	65,839	257
1969	Total(1)	52,758	215
Mantles for incandescent lighting, whether or not collodionised, containing:			
over 10 per cent man-made fibres (5914 0006)	1970	16,603	67
	1971	21,371	73
10 per cent or less of man-made fibres (5914 0294)	1970	9,931	61
	1971	8,555	58
no man-made fibres	1970	18,864	98
	1971	30,638	146
total (all types)	1970	45,398	226
	1971	60,564	277

7553000 Table 133 : U.S.: Mantles alcohol gas etc chemically treated.

Quantity (000 doz)	1967	1968	1969	1970
Austria	16.6	19.9	6.2	7.0
West Germany	4.8	13.5	30.1	29.2
Hong Kong	4.0	...	...	...
U.K.	261.8	252.9	298.6	303.9
Other n.s.l.	-	0.1	4.5	1.3
Total	287.3	286.3	339.4	341.5
Value ($000)				
Austria	6.7	10.1	3.4	10.1
West Germany	3.2	21.3	41.8	51.1
Hong Kong	1.4	-	-	-
U.K.	261.9	298.0	350.8	352.5
Other n.s.l.		0.3	2.4	1.2
Total	273.2	329.8	398.4	409.1

(1) Country division given in original source.

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THORIUM

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THORIUM

By Charles E. Shortt [1]

Current U.S. demand for thorium is small and consists almost entirely of nonenergy applications, such as its uses in gas mantles, catalysts, refractories, and alloys. Nevertheless, the development of thorium utilizing reactors appears a distinct possibility in the near future and would create a substantial market for thorium.

Under a high contingency assumption which assumes the commercial development of economically attractive thorium reactors by 1980, the annual tonnage of total domestic thorium demand in the year 2000 is forecasted to be 2,500 short tons, with the cumulative requirement during 1968–2000 amounting to 27,500 short tons. Excluding the thorium reactor assumption, annual demand for the year 2000 will reach a forecast low of only 240 short tons, with cumulative demand of only 5,400 short tons during the period. These requirements can be compared with the apparent consumption in 1968 of 110 short tons, at which time demand was approximately met by domestic production.

Unlike the United States, many countries in the rest of the world are without domestic supplies of fossil fuels or uranium but have plentiful supplies of low-cost thorium. As a result, it is expected that thorium-utilizing reactors will be used throughout the forecast range. For the low contingency forecast, it is expected that the thorium demand will be similar to the forecast base of the U.S., while the rest-of-the-world high will be roughly twice as great as that anticipated in the domestic market. The foreign forecast range for the year 2000 is expected to be from 1,040 to 5,600 short tons, compared with 88 tons estimated for 1968. The cumulative demand for the 1968–2000 period is expected to range from 17,900 to 59,000 short tons.

Even with the attainment of both the domestic and foreign high ranges of forecast demand, there should be no reason for concern over a shortage of thorium supply nor a rise in the price of thorium.

Assumptions which could lead to the attainment of the high forecast for domestic thorium include: (1) A demonstration of the economic viability of the high temperature gas-cooled reactor (HTGR) by 1980, (2) a shift toward HTGRs by utilities concerned over placing sole reliance on uranium as a fuel for power reactors, (3) the establishment of tough thermal pollution regulations which economically favor the thorium-uranium consuming HTGR relative to the nonthorium utilizing light-water reactors (LWR), (4) the sale of highly enriched uranium from the Government's stockpile at a price equivalent to its slightly enriched blend value thus resulting in a cost advantage to HTGRs relative to that of LWR, and (5) the establishment of less expensive containment requirements of the HTGR relative to LWRs because of inherently safer characteristics of this reactor.

The assumptions which could lead to the forecast low are reduced to: (1) An unsuccessful demonstration of the HTGRs economic viability leads to no further consideration of this reactor, domestically, as reactor type for power generation, and (2) the development of a modest nonenergy market for thorium.

For the United States, if domestic consumption increases substantially as a result of successful development of thorium-fueled thermal or breeder reactors, the forecast cumulative demand of 27,500 short tons by the year 2000 could be met by domestic production from relatively high-grade thorite deposits of Idaho and Montana. A supply of 528,000 short tons of domestic thorium is believed to be currently available at less than $10 per pound.

With increased demand, it is estimated that commercially marketable thorium could decline in price from its current $6.82 per pound level—the price of thorium as contained in thorium oxide—to approximately half that level by the end of the century. Contributing to the prospect of a price decline is the increasing availability of byproduct thorium both from domestic and foreign sources and a potential reduction in the cost of primary thorium production through the economic gains of large-scale production.

Ample thorium supplies are also available from widely dispersed sources throughout the world, with more than one million short tons believed available for less than $10 per pound. In addition to potential expansion of production as a byproduct of rare earths, large quantities of low-cost

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thorium are expected to become available in the coming decades as a byproduct of uranium production throughout many parts of the world.

Because of the potential technological benefits of thorium in both thermal and breeder reactors, and as a supplement or replacement for uranium which is less abundant, the reactor market could create a long-term, growing market for this resource. Thorium will also continue to play a small, but vital, role in catalysts, refractories, and dispersion-hardening alloys, as well as dominant use in gas mantles. If current encouraging research for its use in superconductor applications becomes a commercial fact, significant quantities of thorium may be required in a potential new market.

The verification of the principles of fission and the development of the nuclear bomb was followed by the discovery in 1946 that Th^{232} could be transmuted into U^{233}, a fissionable isotope. As a result of this development India in 1947 and Brazil in 1951 nationalized the production of monazite for their own use. These actions jeopardized marketable supplies to the United States. However, large domestic resources were found, and a rich monazite mine at Steenkampskraal, Republic of South Africa, began production in 1953. This mine became a major thorium producer and market stabilizer until it was closed in 1963 when minable ore was depleted.

In 1959, production began from the Elliot Lake area in Ontario, Canada, where thorium was recovered from waste uranium-plant solutions. Although it is estimated that more than 35,000 tons of thorium oxide is contained in these uranium waste discharges, thorium processing was discontinued during 1968 because of lack of demand (*14*).[2]

Since the early 1960's, Australia has grown to be the prime supplier of United States monazite. It now provides more than 60 percent of U.S. imports and accounted for one-third of the free world's production of monazite during 1968.

BACKGROUND

Thorium was discovered in 1828 by the Swedish chemist Baron Jons Jakob Berzelius in a mineral now called thorite. Thorium did not come into commercial use until 1885 when Dr. Carl Auer Von Welsbach of Vienna discovered that thorium oxide became incandescent when heated. From this discovery he developed the Welsbach mantle which was widely adopted in gaslighting and later for kerosine and gasoline lamps.

Thorium derived from monazite was produced as early as 1893 in the Carolinas; however, the production was soon eclipsed by production from Brazil which started in 1895. A decade and a half later, production began in India. At the same time, German manufacturers developed an almost complete monopoly of the thorium nitrate industry. World War I cut off German supplies, and this enabled domestic production of thorium nitrate to expand. However, monazite ore supplies continued to be obtained from India and Brazil as their prices were so low that domestic producers could not compete.

By the early 1920's, electricity began to displace gas for general lighting purposes, and the need for thorium mantles declined. Nevertheless, the use of rare-earth elements increased, and thorium supplies became a byproduct of the rare-earth elements.

INDUSTRY PATTERN

The thorium industry, as small as it is, is widely dispersed among various countries, each of which controls only a limited portion of the industry. Although thorium is produced as a byproduct of uranium in Canada, most thorium has been derived from monazite and currently is coproduced with the rare-earth elements.

Free world production of monazite concentrates and its contained thorium has risen by more than 55 percent during the 1964–68 period. New additions to free world production capability are expected to add appreciably to world production in the coming year.

In Canada, thorium recovery is a byproduct of uranium mills at Elliot Lake, Ontario. In the past, most of the production has been shipped to the United Kingdom as part of an integrated thorium enterprise. While the integrated Canadian operations have a design capacity for 150 to 200 tons of thorium concentrates annually, by mid-year 1968 production ceased because of lack of demand.

In India, one firm, which is State controlled, is the only producer of beach sands. In Brazil, Comissão Nacional de Energia Nuclear (CNEN) continues to operate its two beach-sand processing plants. In both India and Brazil, the State controls all nuclear materials, including thorium, and none can be exported.

In Australia, mineral sands are produced by about a dozen firms. Approximately two-thirds of the country's monazite production is recovered as a byproduct of ilmenite operations in Western Australia, and the balance is recovered as a byproduct of rutile mining along the east coast. Essentially all of this monazite is exported. Following a recent plant expansion, the country's

[2] Italicized numbers in parentheses refer to items in the list of references at the end of this chapter.

major monazite producer has an annual capacity of 1,200 tons. A second producer, which also recovers byproduct monazite, has announced plans to double its monazite production capability to 1,500 tons annually.

Mining companies, which are usually producers of titanium or zirconium products sell the relatively small quantities of byproduct monazite to rare-earth processors or to mineral traders.

Although some 12 firms had the capacity to process and fabricate thorium during 1968, only two monazite processors are operating in the United States, one in West Chicago, Ill. and the other in Chattanooga, Tenn. Both recover thorium compounds which are sold to others who fabricate thorium commercially. In addition, some nine firms possessed the capacity to produce and fabricate magnesium-thorium alloys.

Magnesium-thorium hardeners were not produced domestically during 1968, and domestic alloy producers relied upon imported master alloys produced in the United Kingdom. The source of this thorium is believed to be from Canadian mills as a byproduct of uranium mining operations.

TECHNOLOGY

Definition of Terms, Grades and Specifications

The element thorium chemical symbol Th or isotopic symbol Th^{232}, has an atomic weight of 232.05, atomic number 90, and lies in the fourth subgroup of the Periodic Table with titanium, zirconium, and hafnium. It is mildly radioactive with a half-life of 1.39×10^{10} years, decaying through 12 intermediate radioactive isotopes, finally yielding a stable isotope of lead, Pb^{208}.

Th^{232} is not fissionable in itself but is a *fertile material;* that is, by irradiating it with slow neutrons, it is converted into Th^{233} which is highly radioactive with a half-life of 23 minutes and decays to protactium, Pa^{233}, with a half-life of 27.4 days, which in turn decays to uranium 233 (U^{233}). U^{238} is a similar fertile material that will produce plutonium, Pu^{239}, by neutron bombardment which is discussed in the Uranium chapter. Both U^{233} and Pu^{239} are artificial elements and are fissionable. The production of fissionable material from fertile material is known as *breeding*, and a nuclear reactor that produces more fissionable material than it consumes is called a *breeder reactor.*

Metallurgical-grade thorium oxide (ThO_2) is better than 99.8 percent pure. For nuclear uses, a higher grade product is usually required by specifications established by each reactor manufacturer. Reactor-grade material, either oxide or metal, must be 99.9 percent pure and must be especially low in high-neutron-absorbing elements, such as boron, cadmium, gadolinium, samarium, dysprosium, and europium, which must be well below 1 part per million; most other metallic impurities must be below 50 parts per million.

Thorium-magnesium master alloy, sometimes referred to as magnesium-thorium hardener, is used for producing magnesium alloys and contains from 20 to 40 percent Th.

Thorium nitrate as made by modern solvent-extraction methods is a very pure material and is used as an intermediate product for the production of oxide or metal.

Mineralogy and Geology

Thorium is widely distributed in nature and is usually associated with uranium or the rare-earth elements. Its geochemical abundance is estimated to be between 10 to 20 parts per million in the earth's crust, about three times that of uranium.

Monazite, an important thorium-bearing mineral, is essentially a phosphate of the rare-earth elements, containing from less than 1 percent to as much as 18 percent ThO_2.

Monazite has a specific gravity of 5.0 to 5.3 and a hardness of 5 to 5.5 on the Mohs' scale. It occurs widespread as small accessory grains and crystals in granites, gneisses, and syenites, occasionally in large masses and crystals. Weathering of these rocks and water action concentrates the monazite in placer deposits along river beds and beaches. The most important deposits occur in India and Brazil, and others are found in Australia, Ceylon, Indonesia, Malagasy Republic, Malaysia, the Republic of South Africa, Canada, and the United States.

Important domestic deposits have been worked in Florida and South Carolina where monazite was recovered as a byproduct of ilmenite and in Idaho and Montana where it occurs with euxenite. Other known deposits are in North Carolina, Michigan, and California. Pegmatite occurrences are in Virginia, North Carolina, Colorado, Connecticut, New Mexico, and Arizona.

Thorianite, ThO_2, and thorite, $ThSiO_4$, are the only two true thorium minerals, and both may have varying amounts of UO_2 and UO_3 replacing ThO_2. Thorianite is isomorphous with uraninite and may contain up to 90 percent ThO_2 and up to 33 percent U_3O_8. When U_3O_8 content is above 15 percent, the mineral is called uranothorianite. Thorite may contain up to 80 percent ThO_2 and up to 25 percent U_3O_8. When it contains more than 5 percent U_3O_8, it is called uranothorite.

Important thorianite deposits occur in pyrometasomatic veins in the Bancroft Region, Ontario, Canada, and near Fort Dauphin, Malagasy Republic. It has been found in small quantities in sand and gravel deposits in Alaska, California, and Montana in the United States and in Ceylon, New Zealand, and other places. Uranothorianite in the Malagasy Republic is in masses and lenses of pyroxenite which contain from 0.3 to 0.4 percent uranothorianite ranging from 57 to 83 percent ThO_2 and 8 to 26 percent U_3O_8.

Thorite is found in pegmatites, carbonatites, veins, and placers, and also as an accessory mineral in many igneous rocks. Notable deposits of thorite occur in Colorado as veins in a Precambrian complex of gneisses and quartzite and in the Lemhi Pass district along the Idaho-Montana line as quartz-hematite-copper fissure veins from a few inches to 10 feet wide and as much as 500 feet long. Thorite also occurs in beach sands in New Zealand and Central California and in gold placers along the Tuolumne, Cosumes, and other rivers. Lesser deposits are found in North Carolina, Texas, Australia, Norway, and Japan.

Current Technology

Mining, Milling, and Processing (2).—Monazite is generally recovered from river and beach sands by placer mining methods. Tables, jigs, and Humphreys spirals are used to make a bulk concentrate of the heavy minerals, known as black sands. This concentrate is treated to separate the various components into marketable products. Heavy minerals may be present in the monazite, such as magnetite, ilmenite, rutile, zircon, cassiterite, garnet, staurolite, and others.

Monazite treatment involves a complex series of chemical processing methods to separate thorium from a predominant quantity of rare-earth elements and phosphate. Initial treatment is either with hot concentrated sulfuric acid or hot concentrated sodium hydroxide solutions.

Digestion of monazite with sodium hydroxide (50 percent NaOH at 140° C) solubilizes the phosphate, leaving hydrous oxides of thorium, uranium, and the rare-earth elements after filtration. This residue is dissolved in hydrochloric acid, and then the solution is neutralized carefully with sodium hydroxide. All thorium and uranium are precipitated with only a small quantity of the rare-earth elements. This crude thorium hydroxide is dissolved in nitric acid and purified by solvent extraction, as with the crude thorium phosphate precipitate from the acid process.

Solvent extraction is an efficient method of separating and purifying thorium, and it has superseded all other methods. Several variations of the method have been developed for different conditions.

When in operation, the thorium-recovery plant near Elliot Lake, Ontario, received the waste solution from the uranium mill. This solution contained about 1 pound of thorium per thousand gallons and was processed for thorium extracted by solvent extraction. The organic extractant was stripped to form a precipitate containing from 35 to 40 percent ThO_2. The precipitate was either refined into metallurgical-grade thorium oxide or was used to produce thorium metal or thorium-magnesium master alloy.

Reduction and Refining (4).—The production of pure thorium metal is very difficult as it is very reactive and has a high melting point (1,840° C). It is prepared by reduction of the halides with calcium or magnesium, reduction of thorium oxide with calcium or sodium, fused-salt electrolysis, or thermal decomposition of thorium tetrachloride by the Van Arkel-de Boer process (*12*).

Thorium also has been produced by metallothermic reduction of thorium tetrachloride by sodium, potassium, calcium, and magnesium. Magnesium reduction is similar to the Kroll process for producing titanium and zirconium (*3, 7*).

Although thorium is too reactive to be deposited electrolytically from aqueous solutions, it has been prepared on a small scale by electrolysis of the oxide, fluoride, and chloride in molten-salt electrolytes.

Research

The tremendous potential of thorium utilization in nuclear reactors has been recognized for some years, and a program of research and development work is being conducted by the Atomic Energy Commission (AEC), its contractors, and some cooperative utilities. In 1968, the AEC continued to recover uranium-233 from fuel elements irradiated in its production reactors located at Savannah River, S.C. and Richland, Wash. Three thorium-cycle converter reactor systems were being investigated as follows:

1. The HTGR by Oak Ridge National Laboratory (ORNL) but primarily by Gulf General Atomic Corporation (GGA).
2. The molten-salt converter reactor experiment (MSRE) by ORNL.
3. The seed blanket or light-water breeder reactor (LWBR) at Bettis laboratory.

The farthest advanced of these reactors is the HTGR system, which has an operating 40 megawatt prototype unit at Peach Bottom, Pa. On the basis of the encouraging results achieved by this reactor, a larger HTGR nuclear-power unit, having an electrical generating capacity of 330 megawatts (MWe), is currently under construction for the Public Service Co. of Colorado by GGA. This system, designated the Fort St. Vrain reactor, is scheduled to become operational in 1971 and go into commercial operation in 1972.

Investigations of the physical, mechanical, and irradiation properties of thorium metal and alloys were reported, and the thorium fuel cycle was described and analyzed in detail during this past year (*8*).

Although considerable research effort is being performed on the molten-salt converter reactor experiment MSRE, commercial fruition of this research is more than a decade into the future. Both the HTGR and the MSRE reactor systems offer a higher conversion ratio and greater thermal efficiencies than the present light-water uranium-fueled reactors. The HTGR reactors must compete, however, on the basis of total energy cost—including fuel cycle, operating, and capital costs which will determine their marketability. Thorium breeder reactors (MSRE) must do likewise while competing with breeders using plutonium produced from uranium.

Studies of thoria-strengthened nickel, cobalt, and molybdenum alloys indicated that optimum dispersion strengthening and creep resistance occurred in alloys with thoria concentrations of 2 percent (*10–11*).

APPARENT RESERVES

World thorium resource estimates have changed only slightly in the past several years, as the small demand and oversupply was not conducive to exploration and development. Thorium oxide resources available at a cost of $5 to $10 per pound (*6*) are as follows (in thousand short tons):

Country	Measured ore	Inferred ore	Total
India	300	250	550
United States	100	500	600
Canada	80	150	230
Central and South Africa and Malagasy Republic	50	50	100
Australia	10	..	10
Denmark (Greenland)	15	..	15
Brazil	10	20	30
Malaysia	10	10	20
U.S.S.R.	100	100	200
Total	675	1,080	1,755

The thorium content of the ore is equivalent to 88 percent of quantities indicated.

More than half of the known low-cost thorium is to be found in placer deposits in various parts of the world. Most of the remainder is in the United States and in the uranium ores of the Elliot Lake District of Canada.

Most of the reasonably assured thorium resources of the United States, 100,000 tons of ThO_2 for $10 per pound or less, are in the Lemhi Pass District of Idaho and Montana.

Domestic ThO_2 resources available up to about $100 per pound have been estimated at 7 million tons reasonably assured and up to 35 million tons potential resources, including such occurrences as those in the Conway granites of New Hampshire. Even these sources may be economic in the future if an efficient breeder reacter is developed.

For all practical purposes, Indian and Brazilian resources cannot be considered to be available to the rest of the world as long as their present embargo on nuclear source material remains in effect. Brazil even requires the return of equivalent quantities of thorium and uranium contained in exportable materials like columbium and zircon concentrates.

SUPPLY-DEMAND RELATIONSHIPS

World production of thorium in 1968 was 780 short tons. The United States produced about 14 percent of the total, or an estimated 110 short tons, based on figures for the last decade; actual domestic production data for 1968 are not available. World production by country, sources of U.S. supply, and demand by domestic industry groups are shown in figure 1. Australia and Malaysia continued to be major monazite-thorium producing and exporting nations. India and Brazil, while large producers, have nationalized their production of thorium and do not permit its export. Canada, a sizable producer in early 1968, terminated its production of thorium by mid-year because of lack of demand.

Domestic monazite production came predominantly from the mining operation of one company in Georgia and the reworking of tailing piles by one company in Jacksonville, Fla. This reworking operation, however, was discontinued early in 1968.

Although sufficient monazite is produced domestically to satisfy thorium demand, large quantities of monazite are imported, because it is the cheapest source of several of the rare-earth elements and yttrium. Under today's market conditions thorium is recovered in the processing of monazite for the production of rare-earth elements. Therefore, thorium supply has depended on the production of rare-earth elements and has generally been in excess of demand. Since estimated domestic supply continues to exceed domestic demand, sizable quantities of thorium are being added to industrial stocks (see fig. 1). Based on the current demand level, industry stocks are sufficient to supply market requirements for approximately 8 years.

Thorium production in the rest of the world increased by more than 55 percent during the 1964 to 1968 period, while the contained thorium in monazite imported into the United States more than doubled during the same period.

Imports constituted about two-thirds of the new additions to domestic thorium supplies in 1968. In terms of thorium oxide, the imports amounted to 262 short tons valued at $563,000. Imports of thorium metals and other thorium compounds are normally small and are valued at less than $50,000. Exports of thorium ore and concentrates were small in 1968, amounting to 1,476 pounds of contained thorium oxide valued at $11,201. Exports of thorium metal and alloys represented a value of $125,686 and were shipped largely to Japan (85 percent), Spain (8 percent), and Canada (5 percent) (*9*).

No imports of thorium nitrate were reported in 1968. Imports of thorium-magnesium hardeners during the year decreased approximately 53 percent with essentially all this material being

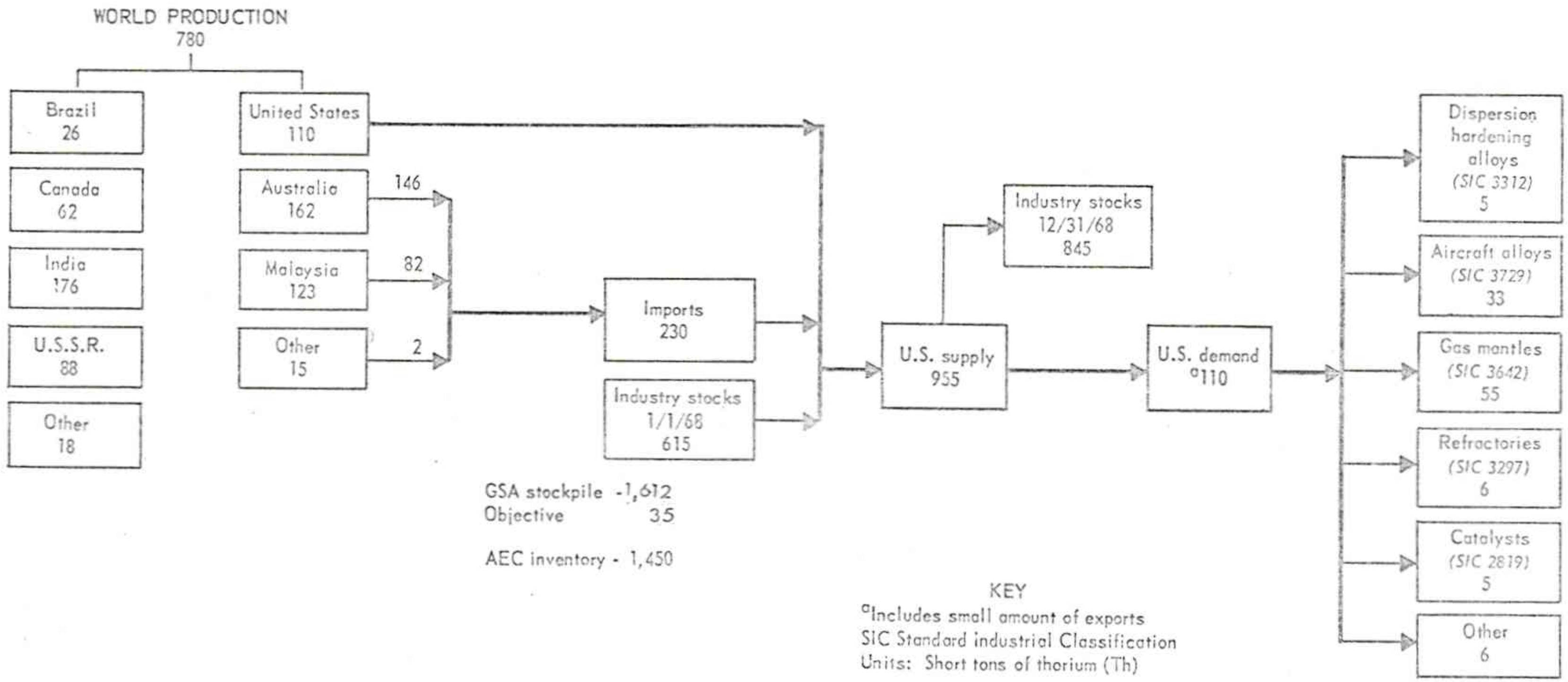

FIGURE 1.—Supply-Demand Relationships for Thorium, 1968.
(All figures estimated)

imported from the United Kingdom. Imports of thoriated gas mantles increased during the year and totaled more than 3.4 million mantles at a value of $329,814. For this application 1 pound of thorium oxide provides sufficient material for about 1,000 gas mantles.

Thorium demand for nonenergy purposes in the United States has been small but reasonably stable for the past decade. However, nuclear energy demand has been in the experimental stages. To meet the modest thorium research demand, ample stockpiles were accumulated by AEC in the early 1960's. World demand, like that in the United States, is much smaller than production. As a result, thorium continued to be added to stockpiles.

Conservation

The abundance of thorium resources and the lack of demand for thorium products have not stimulated the development of any significant conservation measures in past years. Nevertheless, the tremendous long range potential of thorium in the nuclear energy field and new uses in the nonenergy application will doubtless witness the development of sound and effective conservation measures in the future.

In the future, it is unlikely that substantial quantities of thorium will be recovered as a byproduct in the mining of domestic beach sands for titaniferous minerals in view of the increasing concern by the public over disturbing the environment. Increasing emphasis on beautification and the growing demand for recreational facilities will discourage mineral exploitation in these areas.

BYPRODUCT-COPRODUCT RELATIONSHIPS

Monazite, the principal source of thorium, is a coproduct, or byproduct, in the mining of ilmenite, rutile, and zircon. Malaysian monazite is a byproduct of tin mining which also produces zircon. Thorium and uranium are coproducts in many uranothorite and uranothorianite ores, and thorium occurs in small amounts in many uranium ores, often in recoverable quantities, such as in the Blind River area of Ontario, Canada.

CONSUMPTION PATTERN

Uses

Nonenergy demand for thorium continued the slightly rising trend started in 1966. As shown in figure 1, the total apparent consumption of thorium in 1968 was estimated at 110 short tons.

The principal use of thorium is in the manufacture of Welsbach-type incandescent gas mantles which utilized an estimated 50 percent in the form of thorium nitrate. An additional 30 percent was used in the production of magnesium-base alloys which contain about 3 percent thorium. The use of ThO_2 in the production of dispersion-hardening metal, such as stainless steel, nickel, and tungsten accounts for about 10 percent. The remainder was used in specialized refractories and as catalysts in the manufacture of organic chemicals.

Because both thorium and thoria are capable of withstanding temperatures exceeding 3,000° C, these compounds are being considered for use in a number of elevated temperature applications. Minor amounts of other thorium compounds are used in electronic devices, such as electric discharge tubes, radiation detectors, computer memory components, photo-conductive films, and fuel-cell elements. The use of thoria in structural alloys for aerospace and military projects, while small in quantity, was of sufficient importance to justify its retention on the Government's list of strategic and critical materials.

The demand for thorium in nuclear energy applications was very small and was supplied completely from AEC's stockpile. The development of successful thorium thermal and breeder reactors would require large tonnages of thorium in future years. However, until these reactors are developed, the accumulated requirements of thorium for nuclear energy purposes are not expected to total more than a few tons.

Of the various reactors adaptable to thorium fuel utilization, the high-temperature gas-cooled reactor HTGR is the only reactor now being offered for the domestic commercial market. Although no commercial orders have been placed for this reactor type to date, the economics of the reactor is reportedly attractive.

Alternate Materials

No satisfactory alternative materials are suitable for most nonenergy uses of thorium, particularly in gas mantles and in alloys. Zirconium and titanium are superior to thorium as a getter in electronic tubes. Beryllia and yttria can often be substituted for thoria as a refractory above 2,000° C.

Uranium breeder reactors are potentially competitive with thorium breeder reactors. Nevertheless, neither type of breeder has been sufficiently developed to predict which will find greater use.

ECONOMIC FACTORS

Prices and Costs

During 1968 the nominal price of monazite ore (sands) as quoted periodically in *Metals Week* ranged from $180 to $200 per long ton (based upon rare-earth oxide (REO) content only). This range is equivalent to 8 to 9 cents per pound.

The quoted price of thorium metal, pellets,

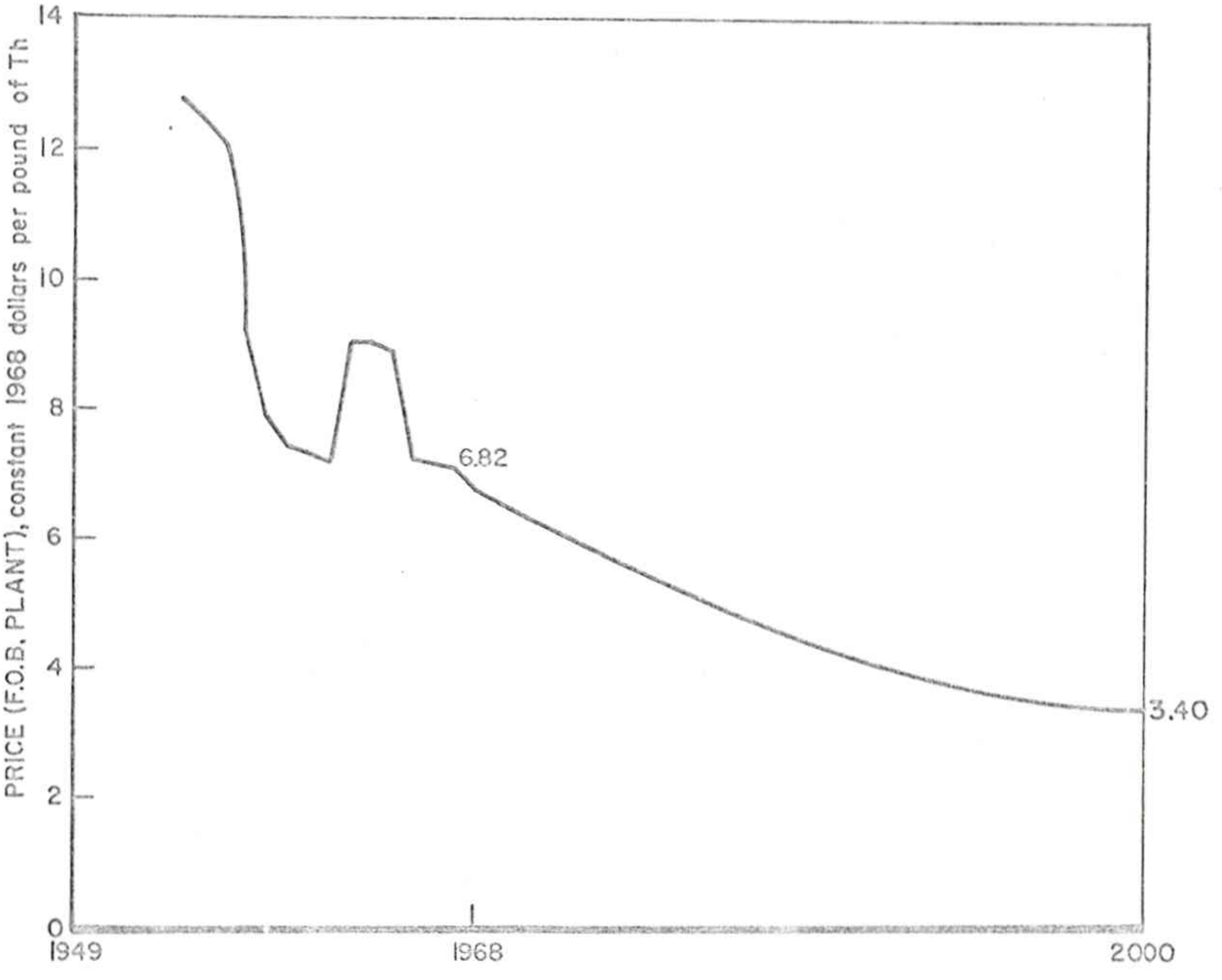

FIGURE 2.—Time-Price Relationship for Thorium.

and powder remained steady at the previous year's level of $15 per pound. During the year, thorium nitrate reportedly sold in the range from $2.25 to $3.50 per pound and the price of thorium oxide ranged from $6 to $12.30 per pound. The master magnesium-thorium alloy hardener containing 30 to 40 percent thorium was quoted at $11.50 to $12 per pound of contained thorium plus the market value of the contained magnesium, 32.25 cents per pound. On this basis, the cost of 40 percent thorium hardener was about $4.82 per pound.

On the basis of the estimated thoria content, the value of imports in 1968 averaged $215 per ton of contained ThO_2. This was $1 per ton less than the average value reported in 1967 and some $24 per ton greater in current dollars than the average value reported in 1966. While the price trend for thorium oxide has been somewhat sporadic, the general direction has been downward in constant dollars. On the basis of the thorium content in ThO_2, figure 2 shows the historical cost trend of thorium for the 1954–68 period. The downward trend in thorium price is expected to continue for the remainder of the century as stockpiles of thorium become increasingly available.

The total value of thorium production in 1968 was $1.5 million.

Taxes and Tariffs

Thorium is entitled to 23 percent depletion allowance for domestic operations and 15 percent for operations in foreign areas. There is no tariff on thorium ore; however, tariffs do exist on processed thorium materials. Based on the "Kennedy round" tariff negotiations, the agreed upon reduction in tariffs, percent ad valorem are:

Year	Metal	Alloys	Nitrates and other compounds
1968	11	13	31
1969	10	12	28
1970	8.5	10	24
1971	7.0	9	21
1972	6.0	7.5	17.5

The statutory tariff levels for the metal, alloys, and compounds, however, will remain constant at 25 percent, 25 percent, and 35 percent ad valorem duties, respectively.

Government Programs

Thorium exploration is eligible for financial assistance of up to 50 percent of authorized costs by the Office of Minerals Exploration (OME). AEC is charged with the control of all fissionable material, as well as any source material used to produce fissionable materials. Unless authorized by a license issued by AEC, no person may transfer, deliver, or export any source material after removal from its place of deposit in nature. A detailed discussion of AEC's responsibility of nuclear materials is found in the Uranium chapter. Other Federal Government programs are discussed in the following Strategic Considerations section.

Strategic Considerations

Thorium-contained supplies held in the U.S. Government's Supplemental Stockpile in 1968 totaled nearly 4,000 short tons of thorium nitrate which represents over 1,800 short tons of thorium oxide equivalent. In view of the minimal near-term need for thorium, the stockpile objective was revised downwards in the mid-sixties to 250 short tons of contained ThO_2. Again in early 1969, the stockpile was further reduced to establish a level equivalent to 40 short tons of thorium oxide. Given these requirements, the strategic stockpile contains over 1,760 short tons of thorium oxide in excess of projected emergency needs.

Although the surplus has congressional authorization for disposal, the material is currently restricted for Government use only because of the detrimental impact this material would have on the already "soft" commercial thorium market.

The President may direct AEC to acquire such quantities of special nuclear material as he deems necessary in the interest of national defense. It is known that AEC purchased thorium in the past, but the quantities were not disclosed until 1959. AEC holds stocks equivalent to about 1,600 short tons of thorium metal for use in nuclear research. Because of the relatively modest current program for developing thorium technology, AEC's inventories of thorium have not changed significantly for the past several years.

In August 1964, the Atomic Energy Act of 1954 was amended to permit private ownership of nuclear materials. By January 1, 1971, all new distributions of nuclear materials must be by sale, rather than by lease as historically required, and by June 30, 1973, all leased material must be purchased by the leasing firm or returned to AEC. AEC will still retain its licensing and regulatory functions.

Resources of thorium in the United States assure complete self-sufficiency in a national emergency, even though at present these resources cannot be exploited economically. In addition, the large potential resources in the Blind River and other areas of Canada provide assurance of self-sufficiency for North America. Brazil's large reserves of monazite form a third source of supply within the Western Hemisphere. Consequently, a sudden large-scale development of thorium thermal and breeder reactors would not suffer from lack of resources. Processing facilities are capable of a manyfold increase in demand and could be expanded quickly.

ENVIRONMENTAL CONSIDERATIONS

The environmental considerations in mining, processing, fabricating, and utilizing thorium products are similar in order of hazard to uranium. The chemical toxicity of most thorium compounds is low, but radiation toxicity is significant and is the controlling hazard. In recent years much research activity has been devoted to the reduction of radiation hazards by improvement in design of process equipment and ventilation systems. It is noteworthy that although the AEC issued revised radiation protection standards (10 CFR Part 20) during 1968, the acceptable quantities listed for natural thorium (50 microcuries) remained unchanged because of the low specific activity and attendant low risk of human intake associated with this material.

The spontaneous ignition of dust layers of both thorium and thorium hydride and the relative ease with which dust clouds ignite make it imperative that great care be taken in handling either powder. Potential fire and explosion hazards also exist in the charges employed in some thorium reduction procedures, and great care must be exercised in handling in these operations.

OUTLOOK

DEMAND

The total U.S. demand for thorium oxide in the year 2000 is expected to range between 240 and 2,500 short tons. The contingency forecast represents annual average growth rates of 2.5 to 10.2 percent for the 1968 to 2000 period. A number of contingency assumptions were considered for projecting thorium demand and each of the present and anticipated end uses shown in table 1. The contingencies include some intuitive judg-

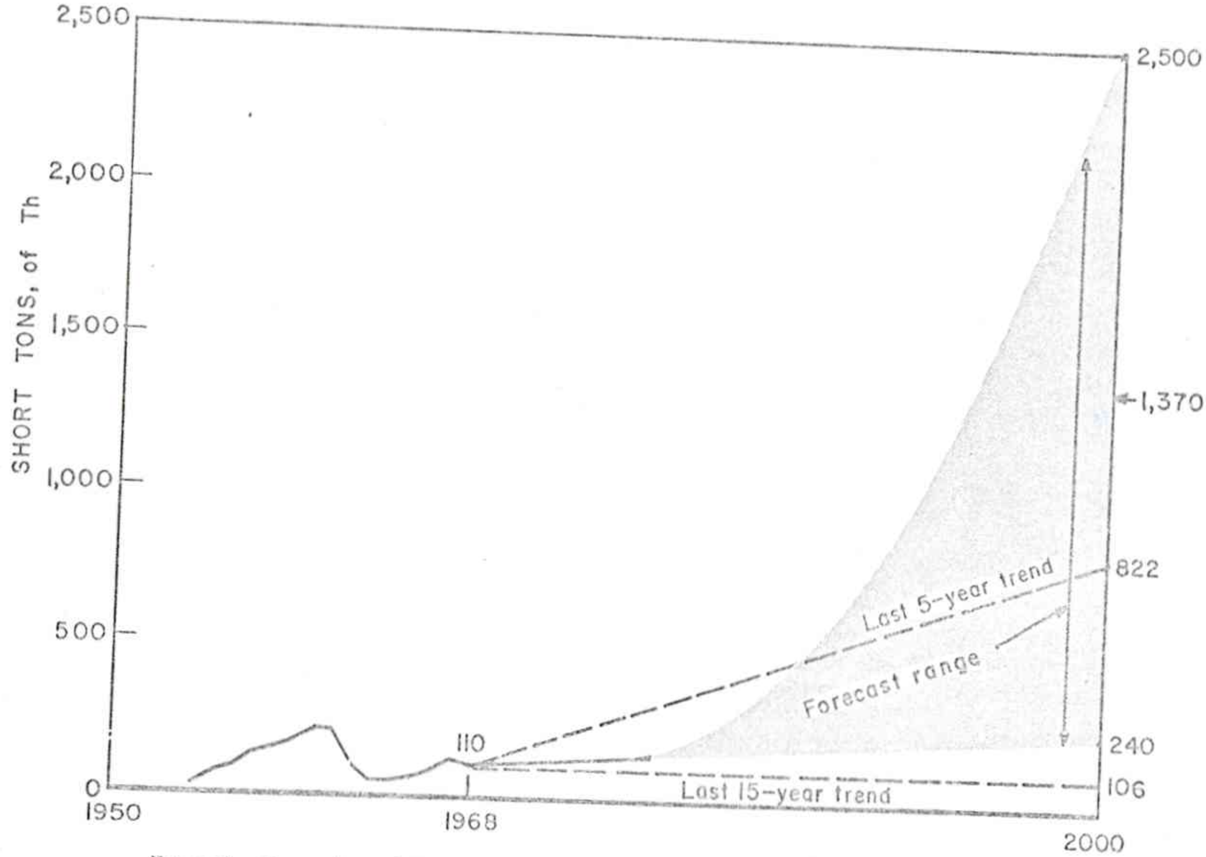

FIGURE 3.—Comparison of Trend Projections and Forecasts for Primary Thorium Demand.

ment and consider action of the technological and economic shifts, as well as alternate environmental, social, and political impacts on the future supply and demand pattern which would result in a low and high demand for thorium. Indications used anticipated nonenergy applications of thorium in the year 2000 and included the projected growth rate in U.S. population of 1.6 percent and 4 percent for gross national product (GNP) during the 1968 to 2000 period. Almost a half-century of experience in using thorium in commercial nonenergy uses has existed. Although new uses are expected to develop, the growth for end uses in the nonenergy category is believed to be stable. For the forecast base, it is assumed that nonenergy applications of thorium, including new uses in this category, will experience a growth rate near 3 percent per year for the remainder of the century. Therefore, the U.S. nonenergy forecast demand base for thorium is projected to be approximately 280 tons.

The following summary tabulation shows the 1968 thorium demand and the year 2000 demand forecast range interval for the United States and the rest of the world.

	Forecast range of demand for thorium (short tons)	
	1968	2000
United States:		
High	110	2,500
Low		240
(Median)	...	(1,370)
Rest of the world:		
High	88	5,600
Low		1,040
(Median)	...	(3,320)

TABLE 1.—Contingency forecasts of demand for thorium by end use, year 2000
(Short tons)

End use	Demand 1968	U.S. forecast base 2000	Demand in year 2000: United States, Low	United States, High	Rest of the world, Low	Rest of the world, High
Power reactors	...	770	...	2,170	775	5,240
Gas mantles	55	125	120	140	265	360
Aircraft alloy	33	84	72	90		
Refractories	6	15	13	22		
Catalysts	5	14	11	20		
Dispersion-hardening alloys	5	20	11	25		
Other uses	6	22	13	33		
Total	110	...	240	2,500	1,040	5,600
			(Median 1,370)		(Median 3,320)	

The year 2000 forecast base demand for thorium in the energy field is related to the projected rate of reactor development during the 1968 to 2000 period. The applications of thorium for energy purposes is not as yet commercially viable. The growth in thorium demand for use in thermal reactors is contingent upon the broader indicators discussed in the Uranium chapter. More specifically, however, it is dependent upon the results of the current research and development effort directed toward a demonstration of a commercially viable thorium high-temperature gas-cooled reactor HTGR.

For the forecast base, it is believed that completion of construction of the first commercial plants in the late seventies, followed by an increasing number of plant orders, would result in a total cumulative capacity by the year 2000 of 85 thousand megawatts. The projected thorium demand for the growing HTGR market is based upon the requirement of 0.4 short ton of ThO_2 required for initial reactor core loading per 10 megawatts MWe of electrical capacity. Annual reloading requirements would require approximately 0.01 short ton of ThO_2 per megawatt beginning after the second year (*5*). This would represent a projected thorium demand by the year 2000 of 770 short tons when new plant additions would cease as low-cost non-thorium breeders begin to capture the available utility market. Based on these fueling characteristics and non-energy demands, the cumulative thorium requirement for the 1968 to 2000 period would be a total of 18,200 short tons with the annual requirement in the year 2000 of 1,050 short tons.

It may be anticipated that the demand for thorium in energy uses in the rest of the world will develop commercially sooner and more rapidly than in the United States. Although it is unlikely that underdeveloped nations will participate significantly in this growth due to the continued technological gap, many of the advanced nations can be expected to construct reactors to utilize thorium. From a foreign standpoint, the growth of thorium-utilizing reactors offers slightly more promising prospects with the desire to minimize reliance on other nations for energy resources—particularly for enriched uranium. Countries possessing sizable quantities of thorium will probably provide a market for thorium-utilizing reactors, even in the low contingency forecast, and a substantial market, greater than that foreseen domestically, in the high forecast.

The low contingency forecast of 1,040 short tons for the rest of the world in the year 2000 assumes that as much as 85,000 megawatts of nuclear capacity using thorium will exist throughout the rest of the world by the year 2000. The high range of 5,600 tons of demand in the rest of the world assumes that a potentially better reactor will be developed and a possibly higher price rise in uranium will encourage a high contingency forecast growth of more than 400 thousand megawatts of cumulative capacity for the rest of the world by the year 2000. The better thermal characteristics of the thorium-based reactor in comparison with those of the LWR and the better air pollution control characteristics in comparison to those of the fossil-fired plant helps improve the competitive position of this reactor in foreign lands. The economics of this reactor is further improved by the lower rates of return that generally exist on foreign electric generating facilities (most foreign utilities are government-owned). In addition, the HTGR will look attractive to many countries because of generally higher costs of fossil fuels in many parts of the world. Without significant quantities of foreign aid, it is unlikely that many of the lesser developed countries will significantly employ the thorium reactor before the mid- or late 1980's.

Figure 3 shows the trend of domestic demand for thorium from 1954 to 1968, the projected historical trends, and the low and high forecast demand range for the year 2000. Projections of consumer demand based on the last 5 years (1964–1968) and 14 years (1955–1968) are shown for comparison with the forecast range. The low demand forecast for the year 2000 is well over twice as great as the extrapolated trend of demand for thorium based on the last 14 years; however, the low forecast is approximately three and a half times smaller than the projected demand trend of the more recent 5 years. The high demand forecast for thorium in the year 2000 is three to six times greater than the projected demand trends of the last 5 and 14 years, respectively.

The contingencies assumed for establishing the forecast range for the end uses in 2000 shown in table 1 are discussed as follows:

Energy

Power Reactors.—The high contingency forecast demand of 2,170 short tons in the year 2000 suggests that thorium technology will be successful in its application to nuclear reactors. In addition to a strengthening of the factors encouraging HTGR plant orders under the forecast base, it is assumed that the AEC will take two steps which aid the relative growth of HTGR in comparison to LWR: (1) Incremental costing of GDP production will permit a reduction in the price of highly enriched uranium, and (2) a full or partial disarmament move could result in further reductions in highly enriched uranium prices.

First, since the military requirement for new highly enriched uranium is expected to dwindle in the coming decades, it is possible that a reduction in per unit cost of obtaining enriched uranium may be forthcoming for those reactors requiring highly enriched uranium, such as in the case of the HTGR, but not the LWR. Since the lower level enrichment stages of the Government-owned gaseous diffusion plants are expected to be fully utilized by the end of the coming decade to meet the demand of LWRs, while the highly enriched stages may be used very little, it is conceivable that an incentive, "off peak" schedule may develop to encourage customers who require highly enriched uranium. In the extreme case, any rate schedule which covered all the variable cost items—power input, labor, etc.—and makes any contribution to the capital cost of these "topping" facilities would be advantageous to the Government as an alternative to shutting the facilities down.

The second possibility would develop if serious disarmament negotiations resulted in turning military warfare into peaceful energy supplies. The sizable quantities of highly enriched uranium could be used in HTGRs or blended with natural uranium for use in LWRs. Since highly enriched uranium costs more per unit of enrichment relative to the low enriched uranium as used by LWRs, the reactors utilizing highly enriched uranium would obtain a greater benefit vis-à-vis LWRs if a blending value were assigned.

With greater emphasis placed on the environmental as well as economic benefits, more than 180,000 megawatts of capacity-utilizing thorium are visualized in the high case for the year 2000. In addition, successful thermal breeding is believed to continue the growth of thorium throughout the remainder of the century. The fueling of these reactors would require an annual demand of 2,170 short tons of thorium (Th) in the year 2000 and a cumulative demand of more than 27,500 short tons for the 1968 to 2000 period.

For the low contingency of no reactor demand for thorium in the year 2000 forecast, it is assumed that while the uranium-thorium-uranium fuel cycle is technically feasible, the economics makes the HTGR and MSRE reactors unattractive domestically where sizable quantities of uranium reserves exist. As a result, domestic reactors probably will not be dependent upon thorium as an energy source.

Nonenergy

Gas Mantles.—The use of thorium mantles in outdoor gas lighting systems in new housing developments and recreation could almost triple by the year 2000. This major nonenergy use of thorium could reach a high of 140 short tons in 2000 if future architectural design requirements for outdoor illumination of private housing should utilize gas mantle lamps. The use of thorium mantles in portable kerosine and gasoline camping lamps will also contribute to the high demand. If the trend is toward electrical lighting, the requirement for thorium gas mantles would be reduced to about 120 tons.

Aircraft Alloys.—The anticipated increase in the aviation industry in the next 30 years to fulfill the transportation requirements of the growing population is expected to require a high of 90 tons of thorium in magnesium-thorium structural alloys by the year 2000. The radioactivity associated with thorium would not be significant since the small amount of radiation would be shielded by the magnesium alloying material. However, the further development of high strength titanium alloys for structural materials in high speed jet aircraft would reduce the requirement for thorium in aircraft alloys to a low of about 72 tons.

Refractories.—The use of thoria (ThO_2) as a high temperature refractory material finds specialized application as crucibles used for melting high-temperature metals. The demand for thorium in this application is expected to reach a high of 22 tons in 2000. The use of crucibles made from other refractory materials and from zirconium and platinum would reduce the demand for thorium in this application to about 13 tons.

Catalysts.—Thorium oxide, used as a catalyst in the petroleum and chemical industries to convert ammonia to nitric acid, and sulfur dioxide to sulfur trioxide and sulfuric acid, is expected to reach a high of 20 tons in 2000 if economical methods for shielding the associated radiation are developed. If economically commercial methods of shielding are not developed and if other catalysts, such as rhenium and platinum-rhenium are used as substitutes for thorium oxide, the demand for thorium would be reduced to the forecast low of 11 tons.

Dispersion-Hardening Alloys.—The use of small amounts of thorium, as thorium dioxide (ThO_2), in high-temperature alloys of nickel, cobalt, tungsten, and molybdenum to impart dispersion hardness is expected to increase as the commercial application of these high-temperature metals grows. It is expected that the demand for thorium in this application could reach a high of 25 tons in 2000 if present usage continues. The radioactivity of thorium used would be shielded by the dense alloys. If high-temperature alloys, such as tungsten-rhenium are economically competitive as a substitute for thorium in dispersion-hardening alloys, the demand for thorium in this application would be reduced to about 11 tons.

Other uses.—The demand for thorium metal for use as target material in X-ray tubes, for thorium oxide in thoriated tungsten electrodes used in inert-arc welding, and as nonconsumable electrodes used in arc melting of high melting point metal, for thorium in high-temperature superconducting alloys, and for other minor applications is expected to reach a high of 33 tons in the year 2000. If more economical substitutes are de-

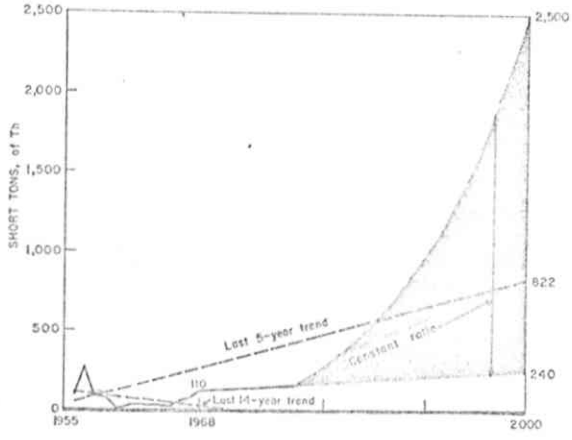

FIGURE 4.—Comparison of Trend Projections and Forecasts for Thorium Production.

veloped for thorium in these applications, the demand forecast would be reduced to 13 tons.

SUPPLY

Domestic sources of economically recoverable thorium at prices of less than $10 per pound are estimated to be approximately 600,000 short tons. This substantially exceeds the cumulative low and high forecast demands for thorium through the 20th century, amounting to 5,400 tons and 27,500 tons, respectively.

Figure 4 illustrates the availability of thorium at declining prices as cumulative demand accelerates from 1968 to 2000.

In the State of Idaho alone, estimates indicate that some 250,000 tons of thorium oxide resources exist (*13*). A large part of these resources is associated with rare-earth minerals.

Although the United States will not find it necessary to depend upon thorium supplies from the rest of the world, competitive pricing of thorium may result in substantial quantities of imported byproduct thorium.

It has been estimated that some 280,000 tons of Canadian thorium dioxide are available as a byproduct to present and potential reserves of U_3O_8—i.e., at a price of $20 or less. Prognosticated additional byproduct thorium from these Canadian uranium-thorium reserves is estimated to include almost 500,000 additional short tons of thorium associated with U_3O_8 at prices less than $20 per pound. Currently, Canadian thorium oxides are being stockpiled, due to the lack of sufficient market, which results in a substantial surplus over current demand requirements (*1*).

POSSIBLE ADVANCES IN TECHNOLOGY

Cost reduction in both mining and processing can be anticipated because of improved technology. Refining has been costly because of high reagent cost, but recent improvements in ion exchange and solvent extraction are already pointing the way to simpler methods.

Thorium, as it occurs in nature, is not a fissile material and therefore cannot produce nuclear energy. The only natural material which will be used directly to readily undergo fission and release energy is U-235, a rare isotope of uranium. Additional fissionable material can be produced, however, by absorption of neutrons in certain fertile material which are relatively abundant, such as thorium-232 and uranium-238. When thorium-232 is irradiated with neutrons, it is transmuted to uranium-233 which is fissionable and can be used to produce nuclear energy. Physicists state that thorium theoretically can breed new fuel, uranium-233, at a faster rate than plutonium can be bred from uranium-238. Thus, cost savings appear possible relative to the now popular light-water reactors. In the United States, a prototype high-temperature gas-cooled reactor (HTGR) is now in operation and a second generating plant is under construction with plans for commercial operation by 1972. This uranium-thorium reactor will determine the economic viability of the near-term thorium technology in this country. There is sufficient confidence in the technical and economic characteristics of this reactor concept that orders are being actively solicited for commercial production of this advanced converter reactor. Although it is assumed that the fuel cycle cost of the HTGR is on the order of 10 to 15 percent less expensive than that of a light-water reactor, the prospects are for a higher capital cost for the HTGR facility.

Some utilities can be anticipated to purchase HTGRs on the basis of their relatively superior safety characteristics. In the event of an unlikely accident condition in the nuclear reactor system

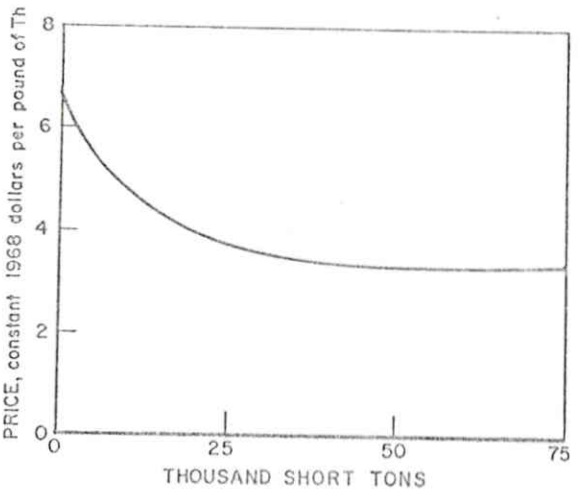

FIGURE 5.—Projected Domestic Availability of Thorium.

which might conceivably release radioactive material from the nuclear core, the time available for correcting the problem is generally much greater—hours versus minutes—with an HTGR than with a LWR. Concern over this aspect of public acceptability may encourage purchases of HTGRs by utility executives.

In the more distant future, it is possible that the molten-salt reactor, a breeder reactor which also utilizes thorium, may also become economically attractive. The forecast in thorium growth for energy applications, therefore, is more closely related to the prospects of thorium reactors penetrating the electric generating market, the trend in uranium prices, the timing of the introduction of breeder reactors, as well as whether breeders will be utilizing thorium- or uranium-produced breeding fuel.

Thorium is finding new and potentially exotic applications as a high-temperature superconductor alloying element. Although thorium's characteristics for this application has just recently been announced, it is likely that the increasing interest in superconductor research will result in thorium finding a useful place in this area within a few short years.

FUTURE SUPPLY-DEMAND RELATIONSHIPS

Domestic demand for thorium in the year 2000, ranging from 240 to 2,500 short tons, will result in a cumulative demand during the 1968–2000 period of 5,400 to 27,500 short tons of thorium.

If the domestic producers continue to provide the same percentage of demand in the year 2000 as they do today, then domestic production would equal demand as shown in Figure 5. It should not be overlooked, however, that more than twice as much foreign ore is produced for domestic inventories than for consumption. For speculative purposes, however, figure 5 compares the quantity of domestic production in the year 2000 as derived from projection of historical production records. A linear projection based on the most recent 5-year trend—1964–68—would result in thorium production of 822 short tons in the year 2000. This quantity is somewhat less than the midpoint of the forecast range of 1,370 short tons. Based on the 14-year trend—1955–68—for which production data are available, the projection of production would approach zero within the current decade. Obviously, neither production trend is a reliable indicator for projecting domestic production since the most likely course is that domestic production will tend to be in balance with demand. Nevertheless, of the quantities of thorium produced for stockpiling and consumption, domestic producers provided only 30 percent of the total. Figure 5 does not project the annual amount of thorium that is committed to inventories. The prospects appear reasonable that the price of thorium, as contained in thorium oxide, will drop in price from its current level of $6.82 to approximately half that price or $3.40 by the end of the century (fig. 2). The increasing availability of world supplies with a relatively limited demand will put a continuous downward pressure on the price of thorium.

Based on the expected direction in thorium prices, the total value of U.S. production and demand in 1968 and for the forecast range in the year 2000 shown in table 1, are as follows (values are in terms of million constant 1968 dollars):

	1968	2000	
		High	Low
Demand	1.5	17.0	1.6
Production, constant ratio	1.5	17.0	1.6

PROBLEMS

The domestic thorium industry is faced with a pair of interrelated problems. First, the growth in demand for thorium, historically, has been inadequate to develop an independent thorium industry. Second, the less advanced development of HTGR technology creates a growing handicap with each delay in establishing its economic viability in the market place.

Domestic production of thorium is merely a byproduct of rare-earth mineral development. As a result, domestic production of thorium is totally dependent upon the demand for rare-earth compounds. Although the projected growth in thorium demand for both the base and high contingency forecasts includes energy applications of thorium, most thorium-utilizing reactors which appear attractive are less well-developed than competing uranium systems. In addition, the presence of U^{232} and U^{236} in recycle fuel requires that special fuel fabrication facilities be built. Consequently, thorium converter reactors in the United States are faced with significant problems.

The status of development of the HTGRs, on the one hand, is such that they will not be in commercial operation before the mid- or late 1970's, and by then, the light-water reactors will have a considerable technological, economic, and operational headstart. On the other hand, there are large programs directed towards the development of plutonium breeders, and the belief is that the plutonium breeders' economic attractiveness can be demonstrated by the mid- to late 1980's. Therefore, if thorium-utilizing reactors are to find a market, they must become competitive and be built in quantities by the early 1980's. Thorium-type breeders with low fissile inventories may be able to compete with the plutonium breeder if their costs are favorable relative to fast reactors.

The second problem results from the fact that a rapid growth in demand for uranium by reactors of all kinds will mean that considerable thorium will be mined as a byproduct in many parts of the world. In the event an energy market develops for thorium, it is understandable that those countries which have large quantities of produced ThO_2 in surplus stockpiles as a result of uranium production will obtain a competitive edge on meeting market demand in countries without import restrictions. The imposition of import restrictions, however, will tend to discourage to some extent the development of thorium reactor technology.

Since the quantities of uranium required substantially exceed the requirement for thorium for even thorium-utilizing reactors, it is clear that thorium pricing can be expected to play a subordinate role to that of uranium in the world supply and pricing picture where these minerals are found together, as is frequently the case. Even thorium-utilizing reactors, such as the HTGR, require more uranium than thorium since it requires more than 10 times as many tons of U_3O_8 for initial loadings of reactors and slightly more than that amount for reloading requirements. The contained thorium in the uranium ore bodies for Canada, for example, suggests the likely production of 6 tons of ThO_2 for each 10 tons of U_3O_8 developed (*1*). Therefore, it can be anticipated that the rapid growth in demand for uranium by light-water reactors, which are based solely on the fueling of uranium, will probably generate a large surplus supply of byproduct thorium as production of uranium-thorium deposits become increasingly developed.

Although the United States has an embargo on foreign uranium for domestic use, it is likely that this import restriction will be lifted by the mid-seventies. This will be at a time when the number of domestic commercial power reactors in operation will be increasing rapidly. Even assuming that thorium ore is shipped at a rail rate as high as 2 cents per ton-mile for a distance of 3,000 miles (which is much further away from Ontario than most potential U.S. markets), the added cost per pound of ThO_2 will be no more than 3 cents. The large quantities of low-cost byproduction thorium from uranium production that are produced in Canada will make an independent thorium industry economically unattractive. Only if new domestic ore finds result in similar type uranium-thorium ore bodies will the domestic situation improve substantially.

A major problem of U.S. thorium producers is the availability throughout the world of high-grade thorium ore deposits. As a result, a pressing need will be to develop means of reducing production costs of the less rich domestic deposits to compete with foreign ore. Unless thorium develops an energy market, the prospects are dim for mining thorium domestically in sufficient quantities to benefit from the large-scale, low-cost mining techniques that have been successful in the United States. Although domestic firms will benefit from lower transportation costs relative to foreign ores, the relatively high price of thorium oxide makes this element of cost somewhat less determining.

Another problem that must be reckoned with is the increasing quantities of thorium that are being stockpiled by industry. Since thorium is a byproduct of rare earths in monazite, the quantities of thorium oxide produced are greater than the demand. The result is that both domestic and foreign thorium become a stockpile item at the end of the rare-earth processing plant. When new demand does develop, these inventory build-ups of thorium must be worked off before sensible, stable production of thorium can take place. While this is a self-correcting problem, the prospects are for greater inventory build-ups during the seventies.

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