Content analysis of thorium research publications

E.R. Prakasan; Sandeep Kadam; K. Bhanumurthy
Scientific Information Resource Division,
Knowledge Management Group,
Bhabha Atomic Research Centre, Mumbai – 400 085 (India)
* Author for correspondence, E-mail: prak@barc.gov.in

Abstract

Research and Development on thorium utilization for the power production is in its peak for the last one decade. The established researchers and new researchers are trying to explore the area of thorium where less work is done. The present paper make an endeavor to show which are the areas where intensive research on thorium is already and automatically less researched will be highlighted.

Introduction

Interest in thorium as a nuclear fuel began in the 1960s [Branan, 2008]. In the last few years peculiarities, problems and aspects of thorium fuel cycle have been discussed in the international nuclear community much more actively than it was 10-15 years ago [Dekoussar et al., 1999]. Many countries all over the world are conducting research exploring alternative fissile material for energy production in the nuclear reactors. The three most important fissile materials used in the reactors for power generation are Uranium-233, Uranium-235, and Plutonium-239. Besides, there are other fissionable materials which can be converted to fissile isotope such as Uranium-238 (which generates Plutonium-239) and Thorium-232 (which generates Uranium-233). It is estimated that thorium is three times more abundant in the earth's crust than Uranium which means three times more availability of nuclear energy. Hence many countries have evinced keen interest to explore the possibility of having nuclear reactors which can run on thorium fuel for energy production [IAEA, 1966, 1967, 1999; Basu and Srinivasan, 1990; Anantharaman et al., 2000].

The use of thorium fuel cycles have been studied for about 30 years, but on a much smaller scale than uranium or uranium/plutonium fuel cycles. Many incentives have been identified for its use including the fact that public concerns have increasingly focused on the high radiotoxicity and long lived of radioactive waste produced during reactor operation. In addition, the end of the

Cold War raised concerns about the non-proliferation of nuclear power, that is, on the large stockpiles of Pu produced in civil and military reactors. These changes have further stimulated consideration of thorium based fuel cycles. Thorium based fuel can be used in all proven reactor types, including PWRs, WWERs, BWRs, HWRs, FBRs, HTRs/HTGRs and in possible future reactor concepts, such as the molten salt reactor or aqueous homogenous suspension reactors. Thus it may be possible to realize economic benefits through its use. However, significant financial input will be necessary to reach the same large scale industrial status already attained by the U/Pu cycle. The consideration of possible advantages, especially for constraining plutonium production and reducing long term fission waste levels, has led to renewed international interest in the thorium based fuel cycle [IAEA, 2000].

Research and Development

Basic research and development on the thorium fuel cycle has been conducted in Germany, India, Japan, the Russian Federation, the United Kingdom, and the USA. Studies included the determination of material data, fabrication tests on a laboratory scale, irradiation of Th-based fuel in material test reactors with post-irradiation examinations, and investigations into the use of Th-based fuel for LWRs (including WWERs), LMFBRs, and HTRs/HTGRs. Test reactor irradiation of thorium fuel to burn-ups at high specific heat loads (up to 680 W/cm) has also been conducted and several test reactors have been either partially or completely loaded with Th-based fuel.

Evaluation is a very key component of any research and development activity. One well known productivity indicator is the number of publications produced by the scientists, institutions and countries. Such studies provide some insights into the complex dynamics of research activity and enable the scientists, policy makers and science administrators to provide adequate facilities and proper guidance in which direction the research has to be conducted [Kademani et al., 2006]. Contents of the published documents say the direction of research, shortcomings and the voids. Content analysis helps young researchers in identifying the gap in the micro-fields he/she wants to take up research.

Bibliographic databases are representative samples of publication activity in any field of knowledge [Vijai Kumar, 2004]. The analysis of the publication records gives trend of direction of research, pitfalls, and current trends in a micro field. The aim of the study is to identify new research areas and fields of possible collaborative works on thorium. The results may give some insight into the aspects where the thorium has been extensively studied. Naturally the less studied areas also will be identified. The work may be most useful for those who have just about to begin research on thorium. The paper may be a pointer towards the area yet to be explored on thorium.

Results and Discussion

The present study has searched the INIS database for bibliographic records on thorium related research during the period 1970-2010 of the database. The 'Thorium' keyword is searched in the DEI (INDEXER-ASSIGNED DESCRIPTORS) field of the INIS Database to retrieve the relevant publications on thorium. The reason for searching in the above said field is that if the particular keyword (i.e. 'Thorium') is appeared in the DEI field, it can make sure that the publication certainly related to thorium not a casual mention of the keyword in the record. There were a total of 19,994 records in the database during the period. These records were transferred to spread sheet application for analysis and arrived at the following results.

Publication Growth

It has been observed two phases in the progress of the research on thorium during 1970-2010 as presented in Figure 1. The phase during 1970-1997, found a linear and steady growth in number of publications and in the second phase there is a sudden growth in number of publications from 1998 onwards. Uneven growth has been occurred after 1998 with a highest number of published documents (783) in the year 2005.

The study has analysed the countries in the affiliations of the authors and it has found that majority are from India. Thorium meets the Indian domestic nuclear fuel resources requirements in the last decade as it is one of the largest deposits of thorium in the world (~ 360,000 tons) in the beach sands of Southern India [Majumdar and Purushotham, 1999]. India has a plentiful supply of thorium in the rare earth monazite, found in its beach sands. US Geological Survey, Mineral Commodity Summaries, January 1999 report says that India and Australia have almost same amount of thorium reserves [Maitra, 2005]. The other leading countries involved in thorium research following India are: USA; Japan; Germany; Russian Federation; China; France; Brazil; UK; Canada. It has also been noted that the collaborated research works on thorium of USA and Germany are evident in the analysis. Germany is also extensive collaborative research programmes with France, Russia, and Poland. The collaboration of USA with France is also very remarkable.

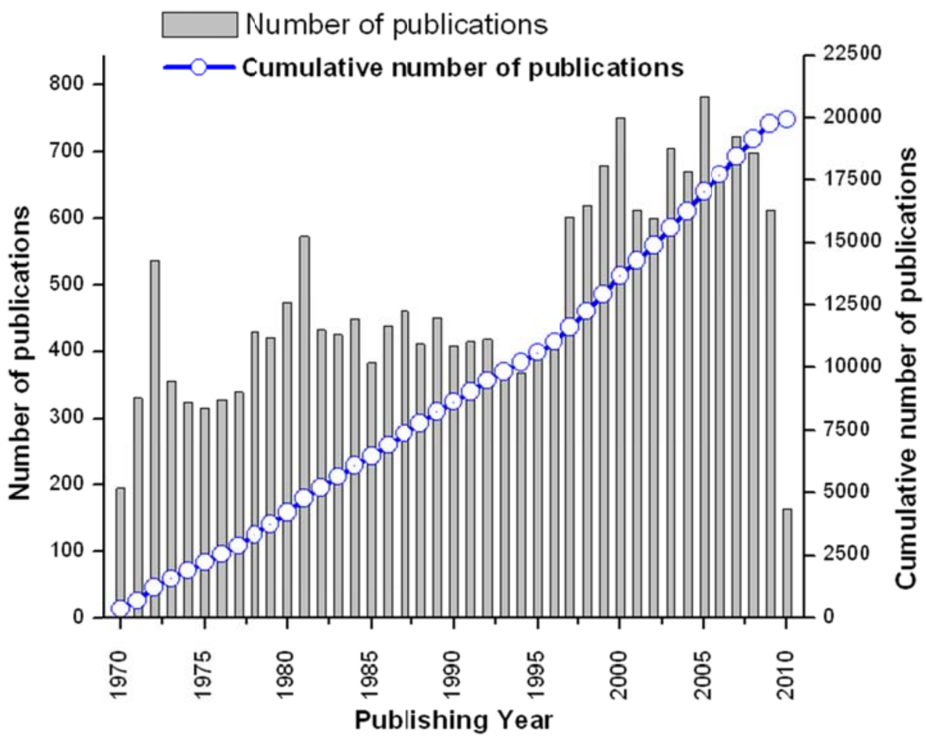

Figure 1.: Trend of thorium research publications during 1970-2010 as per INIS Database

Bhabha Atomic Research Centre, Mumbai, India; Kernforschungsanlage Juelich G.m.b.H., Germany; Joint Inst. for Nuclear Research, Dubna, Germany; Instituto de Pesquisas Energeticas e Nucleares, Brazil; Japan Atomic Energy Research Inst., Tokai, Ibaraki, Japan are the leading five institutions pursuing extensive research on thorium. Also, the analysis found that among all the published literature on thorium journal articles constitute 46 %, 24 % conference/symposia papers, 23 % technical reports and rest of the 7 % constitutes books, theses/dissertations, patents, standards, microfilms etc.

Research Aspects

The research scholars who are about to enter the R&D on thorium may at most in need of an area in which he/she wanted to pursue the research. There won't be any readymade guide which tells them where to begin with or where are the lapses in the research. They may be in dilemma as which aspect of thorium he/she has to take up for the research. The present study has segregated the publications based on the aspects of thorium research and presented in Table 1. The Table has made three zones of aspects of research on thorium as highly researched, moderately researched, and less researched but with equal number of publications. The less studied areas are more important for a new entrant in to the area and moderate studied may be useful for those who have already in the R&D on thorium.

Table 1.: Researched aspects of thorium as per INIS database (1970-2007)

Aspect of research	% of total studies	Research Level
INORGANIC, ORGANIC, PHYSICAL AND ANALYTICAL CHEMISTRY	13.11	High
NUCLEAR PHYSICS AND RADIATION PHYSICS	10.32	
ENVIRONMENTAL SCIENCES	10.04	
NUCLEAR FUEL CYCLE AND FUEL MATERIALS	9.64	Moderate
GEOSCIENCES	8.82	
SPECIFIC NUCLEAR REACTORS AND ASSOCIATED PLANTS	8.49	
MATERIALS SCIENCE	6.49	
RADIATION PROTECTION AND DOSIMETRY	6.28	Less
RADIATION CHEMISTRY, RADIOCHEMISTRY AND NUCLEAR CHEMISTRY	4.65	
MANAGEMENT OF RADIOACTIVE WASTES, AND NONRADIOACTIVE WASTES FROM NUCLEAR FACILITIES	4.02	
ISOTOPES AND RADIATION SOURCES	3.31	
RADIATION, THERMAL, AND OTHER ENVIRONMENTAL POLLUTANT EFFECTS ON LIVING ORGANISMS AND BIOLOGICAL MATERIALS	2.31	
INSTRUMENTATION RELATED TO NUCLEAR SCIENCE AND TECHNOLOGY	1.94	
MANAGEMENT OF RADIOACTIVE WASTES, AND NON RADIOACTIVE WASTES FROM NUCLEAR FACILITIES	1.78	
PARTICLE ACCELERATORS	1.46	
CONDENSED MATTER PHYSICS, SUPERCONDUCTIVITY AND SUPERFLUIDITY	1.23	
GENERAL STUDIES OF NUCLEAR REACTORS	1.20	

PLASMA PHYSICS AND FUSION TECHNOLOGY	1.07	
ATOMIC AND MOLECULAR PHYSICS	1.02	
ASTROPHYSICS, COSMOLOGY AND ASTRONOMY	0.92	
APPLIED LIFE SCIENCES	0.55	
ENERGY PLANNING, POLICY AND ECONOMY	0.35	
RADIOLOGY AND NUCLEAR MEDICINE	0.29	
PHYSICS OF ELEMENTARY PARTICLES AND FIELDS	0.28	
CLASSICAL AND QUANTUM MECHANICS, GENERAL PHYSICS	0.27	
NUCLEAR DISARMAMENT, SAFEGUARDS AND PHYSICAL PROTECTION	0.17	

Thorium Isotopes and Compounds in Research

The study has analysed which isotopes and compounds of thorium are most studied. Here also, the less researched isotopes or compounds are more important for the researchers (both for new and established). Table 2 lists the thorium isotopes and compounds with the number of publications.

Table 2.: Most studied thorium isotopes and compounds evident from publication records in INIS database (1970-2010)

Thorium Isotopes	**No. of studies**	**Thorium Compounds**	**No. of studies**
thorium-232	4484	thorium-oxides	2074
thorium-230	1228	thorium-nitrates	327
thorium-228	910	thorium-alloys	221
thorium-234	504	thorium-fluorides	189
thorium-229	254	thorium-carbides	158
thorium-233	114	thorium-phosphates	121
thorium-231	110	thorium-chlorides	111
thorium-227	93	thorium-minerals	105
thorium-224	90	thorium-additions	87
thorium-226	76	thorium-hydroxides	69
thorium-238	45	thorium-nitrides	51
thorium-222	44	thorium-hydrides	35
thorium-220	40	thorium-bromides	32
thorium-216	24	thorium-silicates	23
thorium-223	17	thorium-sulfates	21
thorium-218	16	thorium-iodides	18
thorium-236	13	thorium-sulfides	16
thorium-237	10	thorium-base-alloys	12
thorium-235	9	thorium-alpha	11
thorium-213	8	thorium-arsenides	10
thorium-214	8	thorium-borides	10
thorium-217	8	thorium-carbonates	9

thorium-225	8	thorium-phosphides	8
thorium-212	7	thorium-selenides	8
thorium-221	6	thorium-silicides	6
thorium-215	5	thorium-beta	5
thorium-219	5	thorium-tellurides	4
thorium-211	3	thorium-base-alloy	2
		thorium-oxide	2
		thorium-perchlorates	2
		thorium-carbide	1
		thorium-tungstates	1

Thorium in Nuclear Reactions, Thorium in Fuel Cycle and General Research

Comparatively less number of studies are conducted on thorium nuclear reactions than studies on their isotopes or compounds. Table 3 presents a number of studies on thorium isotopes involved in different nuclear reactions, thorium cycle and general studies. Among the total number of general studies on thorium (7121 research papers), majority are dealt with environmental aspects of thorium.

Table 3.: Research Publications on thorium reaction, thorium cycle, and general studies evident from publication records in INIS database (1970-2010)

Thorium Reaction	**No. of studies**	**Thorium in General/ Cycle**	**No. of studies**
thorium-232-target	916	thorium	7121
thorium-ions	174	thorium-cycle	847
thorium-230-target	59	thorium-ores	270
thorium-232-reactions	33	thorium-reactors	86
thorium-229-target	25	thorium-reserves	50
thorium-233-target	12	thorium-deposits	49
thorium-228-target	8	tables-2-thorium	1
thorium-231-target	6		
thorium-234-target	5		
thorium-238-target	2		
thorium-239-target	2		

Keyword Analysis

Keywords are one of the best scientometric indicators to understand and grasp instantaneously the thought content of the papers and to find out the growth of the subject field. By analyzing the keywords appeared either in the title or assigned by the indexer or the author himself help in knowing in which direction the knowledge grows. The high frequency keywords in a micro-field will enable us to understand the direction of research in the micro-field. The keywords occurred along with the thorium related records are analysed and arrived at the Table 4. Uranium and some of its isotopes are appeared on the top of the table. Potassium-40 and environmental radioactivity are next two highly inter-related areas with thorium.

Table 4.: Most occurred (more than 500 times) Indexer assigned descriptors/keywords with thorium related publication records in INIS database (1970-2007)

Rank	Indexer assigned descriptor/keyword	No. of times occurred
1	uranium	4781
2	uranium-238	3252
3	radium-226	1981
4	potassium-40	1835
5	experimental-data	1730
6	natural-radioactivity	1569
7	gamma-spectroscopy	1401
8	soils	1159
9	uranium-233	1109
10	radiation-doses	1090
11	isotope-ratio	1086
12	gamma-radiation	1047
13	uranium-235	1046
14	potassium	1015
15	radiation-monitoring	1004
16	radioactivity	1002
17	plutonium	963
18	radionuclide-migration	902
19	cesium-137	893
20	uranium-234	862
21	cross-sections	825
22	solvent-extraction	758
23	sediments	757
24	fuel-cycle	734
25	comparative-evaluations	716
26	quantitative-chemical-analysis	705
27	plutonium-239	680
28	fission	676
29	uranium-dioxide	673
30	nuclear-fuels	664

31	chemical-composition	605
32	ph-value	576
33	radiation-protection	571
34	ground-water	569
35	trace-amounts	566
36	temperature-dependence	565
37	radium-228	562
38	daughter-products	559
39	uranium-isotopes	550
40	lead-210	549
41	environment	545
42	burnup	542
43	radioecological-concentration	533
44	dose-rates	530
44	neutron-reactions	530
45	concentration-ratio	527
46	geologic-deposits	514
47	lead	504
48	geochemistry	500

Conclusion

The scientometric analyses are determined by lack of research guides telling the latest developments, depths and voids in a micro-field. The authors firmly believe that this manuscript can be of highly useful to those would like to explore every avenue they could think of on thorium.

It is found that the thorium research have started in the early 70's and it has took a steady growth upto year 1997 and the history say a sudden or abrupt strong increase after 1998. The year 1998 was a transition period for thorium research and the reasons for the transition can be another area of research. India, USA, Japan, Germany, Russian Federation are in the forefront of thorium research and majority of scientists prefer to publish in journals than sending to conferences/symposia or publish as technical reports.

The less studied aspects of research on thorium will definitely be a guideline for those who chose a new topic of research on thorium. It is documented that thorium-232, thorium-230, thorium-228, thorium-234, thorium-229 are the highly researched five thorium isotopes and thorium-oxides, thorium-nitrates, thorium-alloys, thorium-fluorides, thorium-carbides are highly researched five thorium compounds. There are numerous studies on environmental aspects of thorium and comparatively less number of studies on nuclear reactions involving thorium isotopes. Uranium, and the isotopes like uranium-238, radium-226, potassium-40 are the keywords frequently appeared in the thorium related research publications.

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