DESIDOC Journal of Library & Information Technology, Vol. 31, No. 6, November 2011, pp. 452-459

Research Trends in Nuclear Waste Management: A Global Perspective

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ABSTRACT

The present study attempts to highlight quantitatively the growth and development of world literature on nuclear waste management in terms of publication output as per international nuclear information system (INIS) database. During 1970-2009, a total of 44529 publications were published by the scientists in the field of nuclear waste management. The average number of publications published per year was 1113. The highest number of publications (2795) were published in 2001. The spurt in the literature output was reported during 1991–2007. There were 140 countries involved in research in this field. The USA topped the list with 6672 (14.98 %) publications followed by Japan with 2859 (6.42 %) publications and France with 2612 (5.87 %). Authorship and collaboration trend was towards multi-authored as more than 56 per cent of the publications were collaborative in nature. An intensive collaboration was found during 2000–2004. Maximum publications were from the domains, nuclear fuel processing and waste management aspect with 29159 publications followed by nuclear installations/reactors with 4188 publications and chemical analysis with 2452 publications. Japan Atomic Energy Agency (Japan) topped the list with 677 publications followed by Bhabha Atomic Research Centre (India) with 533 publications. The most preferred journals by the scientists were: *Transactions of the American Nuclear Society* with 528 publications, *Atw Internationale Zeitschrift fuer Kernenergie* with 244 publications, *AIP Conference Proceedings* with 238 publications. English was the most predominant language (79.56 %) used by the scientists for communication.

Keywords: Nuclear waste, nuclear waste management, radioactive waste management, scientometrics

1. INTRODUCTION

Safe nuclear waste management has been the priority of any nuclear programme. There has been immense activity starting from nuclear fuel cycle to safe disposal of nuclear waste.

As on 17th December, 2010, there were over 1118 nuclear reactors all over the world, out of which 677 were research reactors and 441 were power reactors. Out of these 193 research reactors and 125 power reactors have been decommissioned/shutdown. To provide these reactors with fuel, many other nuclear facilities exist– uranium mines, ore processing plants, fuel fabrication facilities and fuel reprocessing plants joined in a complex, worldwide transportation network[1]. Radioactive waste, arising from civilian nuclear activities as well as from defence related nuclear weapon activities poses a formidable problem for handling and protecting the environment to be safe to the present and future generations[2]. There are many other sources of radioactive wastes. They are spent nuclear fuels, waste generating from fission products, nuclear reactors as well as weapons decommissioning, legacy waste of contaminated sites, radioactive medical waste, radioactive industrial waste, naturally occurring radioactive material (NORM), coal also contains a small amount of radioactive uranium, barium, thorium, and potassium, etc., residues from oil and gas industry also produce radioactive wastes. Radioactive waste is classified as low-level waste, intermediate-level waste, high-level waste and transuranic waste according to the amount and types of radioactivity in them[3].

Nuclear waste management is becoming a major research area all over the world. Its importance is increasing day by day as many of the nuclear research and power reactors are being decommissioned all over the world and the nuclear waste arising from defence-related nuclear weapon activities and other sources which produce nuclear/radioactive waste. If the nuclear/ radioactive waste is not treated properly, it will harm the surrounding environment as well as life forms in the nature. Nuclear waste requires sophisticated treatment

Received on 14 March 2011; Revised on 18 April 2011

and management in order to successfully isolate it from interacting with the biosphere. This usually necessitates different types of treatments, followed by a long term management strategy involving storage, disposal or transformation of the waste into a non toxic form. Therefore, nuclear waste management forms an important aspect of any nuclear establishment.

Publication and citation counting techniques have been used in the assessment of scientific activity for at least fifty years. During the half–century of this activity the main thrust of interest seems to flow along two connected but parallel paths: the bibliometric path of publication and citation counts as tools for the librarian, and an evaluative path using the same tools to illuminate the mosaic of scientific activity[4]. Research publications are clearly one of the quantitative measures for the basic research activity in a country. It must be added, however, that what excites the common man, as well as the scientific community, are the peaks of scientific and technological achievement, not just the statistics on publications. There are also other kinds of research and technology development mission-oriented, industry-oriented, country-specific, etc., progress in these cannot be obviously measured by counting only the number of publications[5]. The bibliometric and scientometric techniques used to study various quantitative and qualitative aspects of scientific endeavors have been studied[6-7].

Many scientometric studies focussed on the performance of nuclear science and technology[8-20]. Scientometric studies are useful in ascertaining which methods have been most employed for various analytical determinations as well as predicting which methods will continue to be used in the immediate future and which appear to be loosing favour with the analytical community.

2. OBJECTIVES

The main objective of the study is to present the growth of world literature on nuclear waste management and make the quantitative assessment of status of the research by way of analysing the following features of research output:

- Geographical distribution of research output
- Annual growth of publications on nuclear waste management
- Domain-wise distribution of publications
- Authorship and collaboration pattern
- Highly productive institutions
- Channels of communication
- Preference of journals for communication by the scientists
- Language-wise distribution of publications
- Distribution of keywords

3. MATERIALS AND METHODS

Data was collected from the International nuclear information system (INIS) (1970–2009) database brought out by International Atomic Energy Agency, Vienna. The INIS is the world's leading information system on the peaceful uses of nuclear science and technology. Records pertaining to nuclear waste management research were downloaded using the suitable search strategy (nuclear waste* management* OR radioactive waste* management*). A total of 44529 records were downloaded for the period 1970–2009 and analysed as per objectives of the study.

4. RESULTS AND DISCUSSION

4.1 Geographical Distribution of Research Output

There were as many as 140 countries actively involved in the nuclear waste management research and produced 44529 publications. Figure 1 gives top 15 countries actively pursuing research in nuclear waste management which contributed more than 54 per cent of publications in this field.

USA topped the list with 6672 (14.98 %) publications, followed by Japan with 2859 (6.42 %), France with 2612 (5.87 %), Germany with 1819 (4.08 %), UK with 1710 (3.84 %), and the Russian Federation with 1523 (3.42 %) publications. Table 1 gives the publication share of top 15 countries in different ten year blocks.

4.2 Annual Growth of Publications on Nuclear Waste Management

During 1970–2009, a total of 44529 publications were published on nuclear waste management by various countries. The average number of publications produced per year was 1113.23. The highest numbers of publications (2795) were published in 2001. Figure 2 gives the year-wise growth of publications in nuclear waste management. It can be clearly visualised from the figure that growth of the literature was very slow before 1990 and peaked during 1999-2007. The productivity was low in 2008 and 2009 mainly due to the input time lag in the database. Kademani[21], *et al*. have estimated that about 70 % of total publications published during the particular year are input in 12 months period and remaining 30 % publications are spread over 2-3 years or more as the database has a open provision for input of records irrespective of their year of publication. This limitation may be taken into account while considering the publication productivity in 2008 and 2009.

4.3 Domain-wise Distribution of Publications

All the publications on nuclear waste management were classified into nine (9) major domains as per the INIS

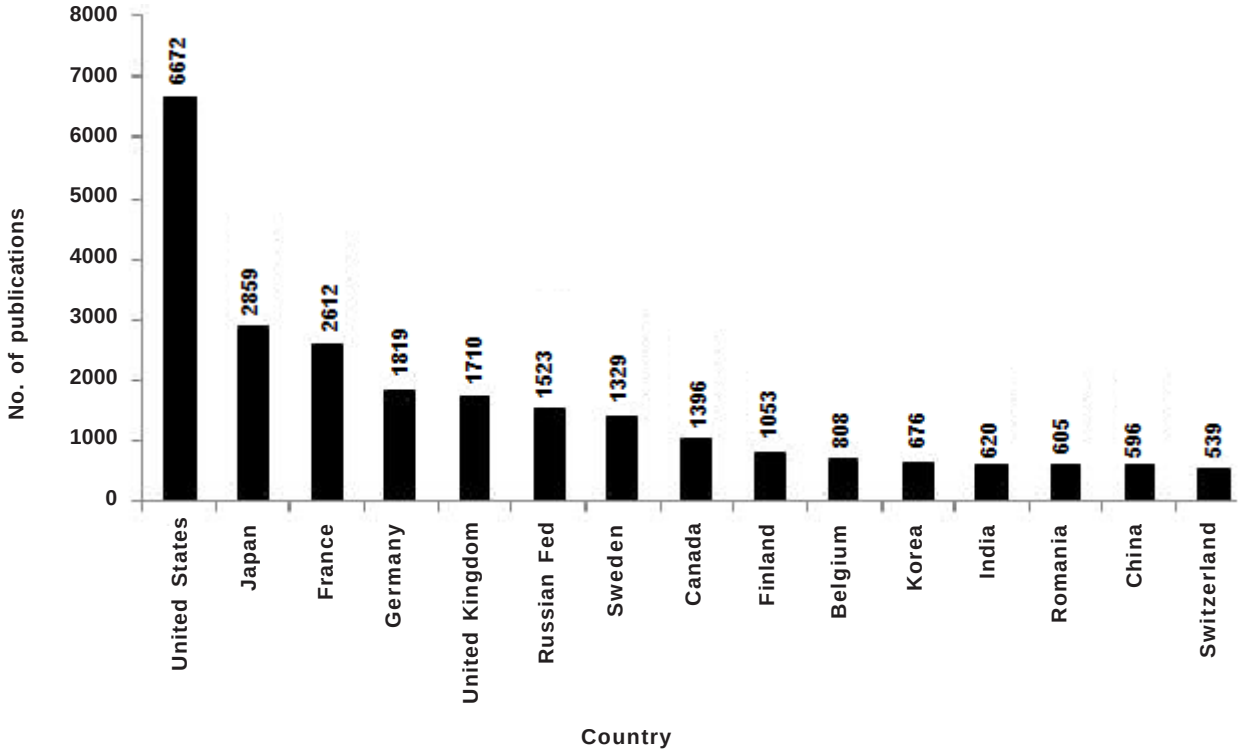

Figure 1. Publication output of top 15 countries.

Table 1. Share of top 15 countries in ten year blocks from 1970 to 2009

Country	Period				Total publications	% share (1970-2009)
	1970-1979	1980-1989	1990-1999	2000-2009		
USA	58 (5.88)	928 (15.69)	4386 (26.43)	1300 (6.18)	6672	14.98
Japan	30 (3.04)	146 (2.47)	663 (4.00)	2020 (9.60)	2859	6.42
France	21 (2.13)	279 (4.72)	660 (3.98)	1652 (7.85)	2612	5.87
Germany	45 (4.56)	320 (5.41)	484 (2.92)	970 (4.61)	1819	4.08
UK	24 (2.43)	375 (6.34)	501 (3.02)	810 (3.85)	1710	3.84
Russian Federation	Nil	3 (0.05)	315 (1.90)	1205 (5.73)	1523	3.42
Sweden	6 (0.61)	112 (1.89)	256 (1.54)	1022 (4.86)	1396	3.14
Canada	20 (2.03)	368 (6.22)	345 (2.08)	320 (1.52)	1053	2.36
Finland	Nil	63 (1.07)	103 (0.62)	642 (3.05)	808	1.81
Belgium	10 (1.01)	128 (2.16)	145 (0.87)	393 (1.87)	676	1.52
Korea	2 (0.20)	14 (0.24)	175 (1.05)	472 (2.24)	663	1.49
India	13 (1.32)	13 (0.22)	131 (0.79)	462 (2.20)	620	1.39
Romania	1 (0.10)	9 (0.15)	160 (0.96)	435 (2.07)	605	1.36
China	Nil	32 (0.54)	126 (0.76)	438 (2.08)	596	1.34
Switzerland	4 (0.41)	63 (1.07)	117 (0.71)	355 (1.69)	539	1.21
World output	986	5913	16593	21037	44529	100.00

**Figures in parenthesis indicate the share*

subject categories. The domain nuclear fuel processing and waste management aspect had the maximum number 29159 (65.48 %) of publications followed by nuclear installations/reactors with 4188 (9.41 %) publications, chemical analysis with 2452 (5.51 %) publications, radioactive materials-monitoring with 1928 (4.33 %) publications, nuclear engineering/ instrumentation with 1769 (3.97 %) publications, environmental and economic aspects with 1404 (3.15 %) publications, applied life sciences with 1206 (2.71 %) publications, earth sciences with 1005 (2.26 %) and other aspects with 1418 (3.18 %).

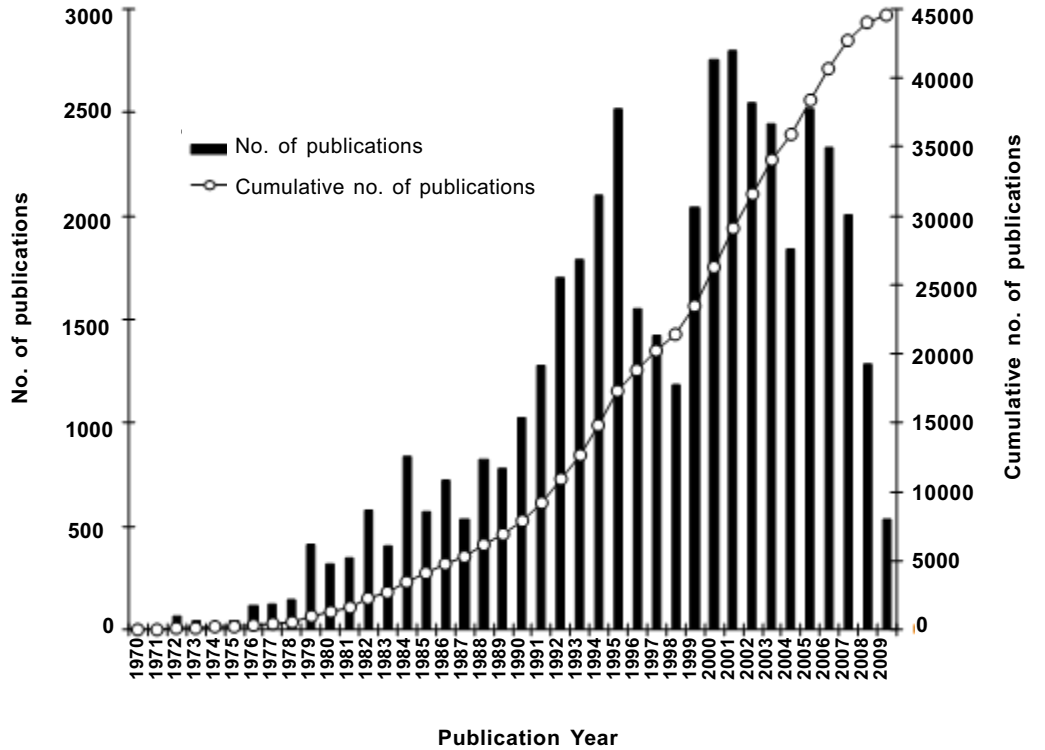

Figure 2. Annual growth of publications in nuclear waste management research.

4.4 Authorship and Collaboration Patterns

Distribution of publications and authorship patterns during five year blocks in nuclear waste management research is given in Fig. 3. Publication trend was towards collaborative publications. Multi-authored publications (2-5 authors) accounted for 48.56 per cent followed by single authored publications with 31.86 per cent followed by Mega authored publications (6 and above authors) with 8.32 per cent. There were 5013 (11.26 %) publications with no authors in the byline.

Research is becoming more and more collaborative in recent years when compared to earlier years as all the governments are giving a lot of impetus to R&D activities. Also it is because of the interdisciplinary nature of subjects and the scientific methods used in research where different subject experts are needed.

4.5 Highly Productive Institutions

There were 8285 institutions engaged in research activity in this field. Table 2 lists top fifteen institutions contributed in nuclear waste management research. Japan Atomic Energy Agency, Tokai, Ibaraki, (Japan) topped the list with 677 publications followed by Bhabha Atomic Research Centre (India) with 533 publications, Japan Nuclear Cycle Development Institute, Tokai, Ibaraki (Japan) with 525 publications, Pacific Northwest Labs., Richland, WA (USA) with 523 publications, Atomic Energy of Canada Limited (Canada) with 466 publications, Sandia National Laboratory (USA) with 442 publications, and International Atomic Energy Agency IAEA, Vienna (Austria) with 381 publications.

4.6 Channels of Communication

Scientists communicated their research results through variety of document types. Reports were the most predominant channel of communication where more than 40% of the publications were published, followed by books (25.87 %), miscellaneous (25.87 %), journals (16.03 %) and others (0.7 %).

4.7 Preference of Journals for Communication by Scientists

The distribution of 6761 journal publications were spread over 1044 journals. The leading journals preferred by the scientists were: *Transactions of the American Nuclear Society* with 528 (7.81 %) publications, *Atw Internationale Zeitschrift fuer Kernenergie* with 244 (3.61 %) publications, *AIP Conference Proceedings* with 238 (3.52 %) publications, *Radioactive Waste Management and the Nuclear Fuel Cycle* with 219 (3.24%) publications, *Radiochimica Acta* with 185 (2.74 %) publications, *Nuclear and Chemical and Waste Management* with 163 (2.41 %) publications, *Journal of Radioanalytical and Nuclear Chemistry* with 147 (2.17 %) publications. Table 3 provides the list of highly preferred journals by scientists.

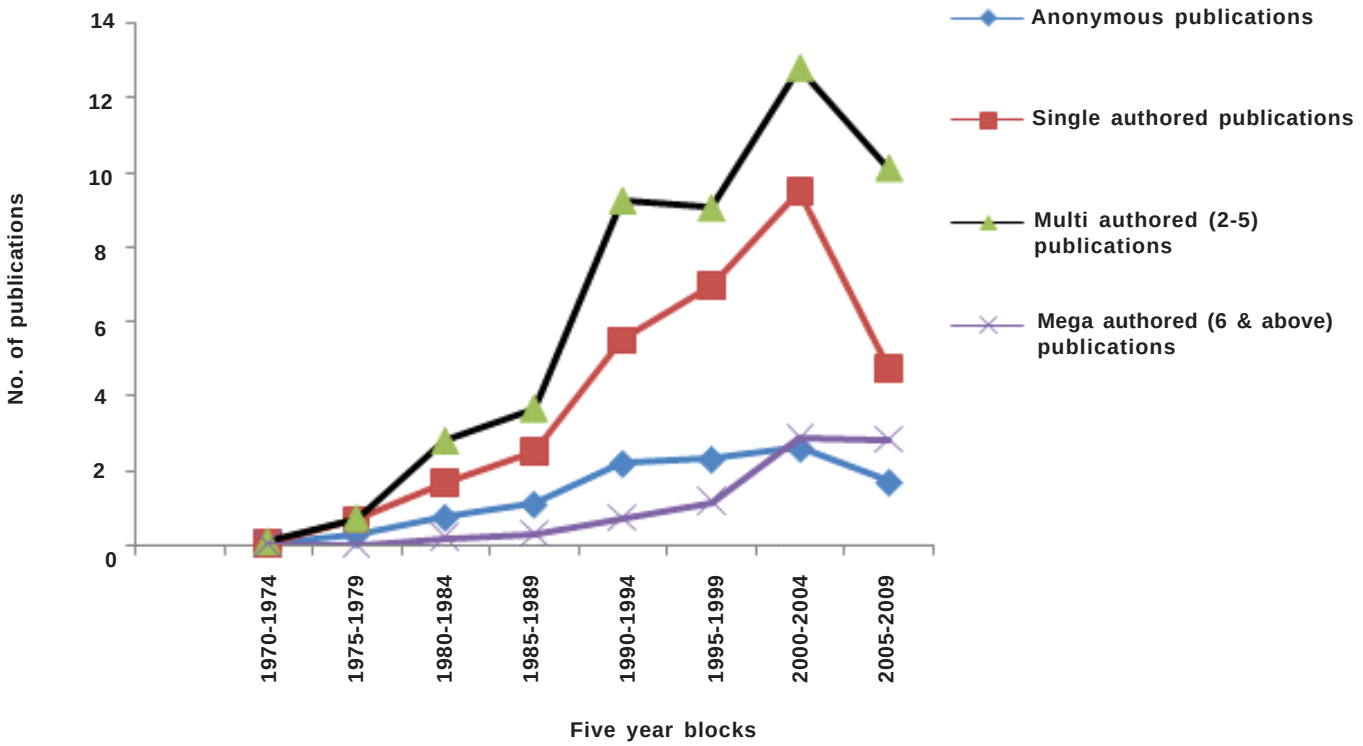

Figure 3. Publications and collaboration trends in five year blocks from 1970-2009.

Table 2. Highly productive institutions

Name of institution	Country	No. of publications	% share
Japan Atomic Energy Agency, Tokai, Ibaraki	Japan	677	1.52
Bhabha Atomic Research Centre	India	533	1.20
Japan Nuclear Cycle Development Institute, Tokai, Ibaraki	Japan	525	1.18
Pacific Northwest Labs., Richland, WA	USA	523	1.17
Atomic Energy of Canada Limited	Canada	466	1.05
Sandia National Laboratory	USA	442	0.99
International Atomic Energy Agency (IAEA), Vienna	Austria	381	0.86
Los Alamos National Laboratory	USA	356	0.80
Agence Nationale pour la Gestion des Dechets Nucleaire	France	355	0.80
Korea Atomic Energy Research Institute (KAERI)	Korea, Rep. of	349	0.78
Oak Ridge National Laboratory	USA	339	0.76
US Department of Energy, Washington D.C.	USA	331	0.74
Argonne National Laboratory, Illinois	USA	327	0.73
Lawrence Livermore National Laboratory, CA	USA	248	0.56
Swedish Nuclear Fuel and Waste Management Co. Stockholm	Sweden	232	0.52

Table 3. Highly preferred journals by the scientists for communication

Journal	No. of publications	% share
Transactions of the American Nuclear Society	528	7.81
Atw Internationale Zeitschrift fuer Kernenergie	244	3.61
AIP Conference Proceedings	238	3.52
Radioactive Waste Management and the Nuclear Fuel Cycle	219	3.24
Radiochimica Acta	185	2.74
Nuclear and Chemical and Waste Management	163	2.41
Journal of Radioanalytical and Nuclear Chemistry	147	2.17
Atomnaya Ehnergiya	145	2.14
Denryoku Chuo Kenkyusho Hokoku	99	1.46
Atomnaya Tekhnika za Rubezhom	96	1.42
Journal of Nuclear Materials	91	1.35
Revue Generale Nucleaire	86	1.27
Journal of Nuclear Science and Technology	85	1.26
Nuclear Energy	80	1.18
Bezpecnost Jaderne Energie	79	1.17

4.8 Language-wise Distribution of Publications

The publications were distributed over 40 different languages. English was the most predominant language used for communication with 35428 (79.56 %) publications followed by Japanese with 1807 (4.1 %) publications, French with 1510 (3.4 %) publications, Russian with 1403 (3.1) publications and German with 1085 (2.4) publications.

4.9 Distribution of Keywords

Keywords are the indicators of the scientometric study which gives an immediate idea about the thought content of the publications studied. It also shows the growth of the subject field.

By analysing the keywords, one gets an idea about different terminologies used by authors, indexers and also about the direction in which the subject is growing.

Table 4 gives the list of top ten high frequency keywords appeared in indexer assigned descriptors field in the nuclear waste management research publications in different domains. There may be repetition of some keywords as the publications fall into different domains.

Table 4. Top ten high frequency keywords in each domain appeared in indexer assigned descriptors field in nuclear waste management research

No.	Domain	High frequency keywords
1.	Applied Life Sciences	Radiation-Protection; Radioactive-Waste-Management; Radiation-Doses; Radioactive-Waste-Disposal; Radiation-Monitoring; Recommendations; Safety-Standards; Radioactive-Wastes; Decontamination; Contamination
2.	Chemical Analysis	Radioactive-Waste-Disposal; Radioactive-Waste-Processing; Leaching; p*H*-Value; Experimental-Data; High-Level-Radioactive-Wastes; Radioactive-Waste-Management; Radionuclide-Migration; Corrosion; Radioactive-Waste-Storage
3.	Earth Sciences	Radioactive-Waste-Disposal; Underground-Disposal; Site-Characterisation; Ground-Water; Radionuclide-Migration; High-Level-Radioactive-Wastes; Hydrology; Clays; Underground-Facilities; Computerised-Simulation
4.	Environmental and Economic Aspects	Radioactive-Waste-Management; Radioactive-Waste-Disposal; Public-Opinion; Nuclear-Power; Public-Relations; Energy-Policy; Radiation-Protection; Nuclear-Energy; Nuclear-Power-Plants; Safety
5.	Nuclear Engineering/ Instrumentation	Radioactive-Waste-Management; Radioactive-Waste-Storage; Waste-Transportation; Transport; Radioactive-Waste-Disposal; Design; Spent-Fuel-Storage; Specifications; Spent-Fuels; Containers
6.	Nuclear Fuel Processing Waste Management Aspects	Radioactive-Waste-Disposal; Radioactive-Waste-Management; Radioactive-and Waste-Processing; Underground-Disposal; Radioactive-Waste-Storage; Radioactive-Wastes; High-Level-Radioactive-Wastes; Spent-Fuels; Low-Level-Radioactive-wastes; Radionuclide-Migration
7.	Nuclear Installations/Reactors	Radioactive-Waste-Management; Reactor-Decommissioning; Reactor-Safety; Radiation-Protection; Radioactive-Waste-Disposal; Nuclear-Power-Plants; Fuel-Cycle; Radioactive-Remedial-Action; Waste-Storage; Safety
8.	Other Aspects	Radioactive-Waste-Management; Radiation-Protection; International-Cooperation; Research-Programs; Safety; Reactor-Safety; IAEA; Regulations; Progress-Report; Nuclear-Facilities
9.	Radioactive Materials–Monitoring	Radioactive-Waste-Disposal; Radionuclide-Migration; Radioactive-Waste-Management; Ground-Water; Underground-Disposal; Environmental-Impacts; Contamination; Site-Characterisation; Remedial-Action; Soils

5. CONCLUSIONS

This scientometric study attempted to highlight the research activities on nuclear waste management as reflected in INIS database during 1970-2009. A total of 44529 publications were published in this field. USA was the highly productive country with 6672 publications followed by Japan with 2859 publications, France with 2612 publications. The growth of publications was the highest during 1999-2007. The domain nuclear fuel processing and waste management aspect had 29159 (65.48 %) publications followed by nuclear installations/ reactors with 4188 (9.41 %) publications. Collaboration trend was towards multi-authored publications.

Japan Atomic Energy Agency (Japan) is the frontrunner in this field with 677 publications followed by Bhabha Atomic Research Centre (India) with 533 publications, and Japan Nuclear Cycle Development Institute (Japan) with 525 publications. More than 40 % of the literature on nuclear waste management was published in reports and only 16 % in journals. The most important journals preferred for publication were: *Transactions of the American Nuclear Society* with 528 publications, *Atw Internationale Zeitschrift fuer Kernenergie* with 244 publications, and *AIP Conference Proceedings* with 238 publications.

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