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Loan, Fayaz Ahmad and Yaseen, Ufaira, "Global Research Productivity in Nuclear Waste Management: A Scientometric Analysis" (2020). *Library Philosophy and Practice (e-journal)*. 4135.

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Global Research Productivity in Nuclear Waste Management: A Scientometric Analysis

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ABSTRACT

Scientometrics has emerged as one of the prominent and fast growing fields in the Library and Information Sciences. The present study also deals with the scientometric aspect of one of the prominent fields of Nuclear Science and Technology *i.e.* Nuclear Waste Management. The data for the said study has been collected from the Web of Science database over the period 1989-2019. The results reveal that a total of 1824 publications have been published on Nuclear Waste Management and the highest number has been contributed by the USA (23.7%) of the total global output. Most of the Nuclear Waste Management literature is published in Journal Articles, the prominent journal being *ATW International Journal for Nuclear Power*. Multi authorship trend is more dominant than single authorship. The US Department of Energy and Commissariat A L' Energie Atomique (CEA), France are the topmost contributors. Since, the data were collected from one database only; cautions should be taken while generalizing the results.

KEYWORDS

Nuclear Waste Management, Nuclear Weapons, Nuclear Warfare, Nuclear Energy, Bibliometrics, Scientometrics

INTRODUCTION

Scientometrics, a popular branch of library science, is utilized as a part of the investigation of development of scholarly writing. It provides information about the structure of knowledge and the way it is communicated. Scientometrics has been defined by different authors in varied terminologies. According to Tague-Sutcliffe (1992), Scientometrics is the study of the quantitative aspects of science as a discipline or economic activity. He further describes

Scientometrics as the part of sociology of science having its application in Science Policy making. Hess (1997) defines Scientometrics as the quantitative study of science, communication in science and science policy. Scientometric studies help to analyse the quantitative aspects of science in order to have a better understanding of the mechanism of scientific research activities, thus marking a notable impact on the effective science policy-making. Scientometrics strategies incorporate quantitative, subjective and computational methodologies utilizing different systems including Publication checks, Citation tallies, Citations per distribution, Literature use checks, Impact per productions, Co-reference investigation, Co-word examination and so forth (Vinkler, 2001). The present scientometric covers the Nuclear Waste Management discipline that has emerged as one of the important aspects of Science and Technology in general and Nuclear Science and Technology in particular. Radioactive waste is the waste that is left out after the use of radioactive materials in nuclear reactors or during the production of nuclear weapons. Its management is one of the major challenges faced by mankind, as the nuclear waste originating from the nuclear reactors while performing a nuclear reaction is not easy to manage. If this waste is exposed to an open space, the radioactive particles present in it can emit the harmful radioactive rays for years. Although the long lived radioactive elements decay with time but some of these waste products may have half-lives extend up to hundreds and thousands of years emitting nuclear radiations all this long time. Therefore, the containment of these elements is an important matter. Research is actively in progress to devise new materials which can be safe for such long times or the nuclear reaction processes using nuclear particles from accelerators which may convert the long-life elements to short life elements to fall within the realm of developed materials which can be useful for safe containment for long time (Ranveer et al, 2015).

REVIEW OF LITERATURE

A good number of studies have been carried out in the sub-fields of the Nuclear Science and Technology like Nuclear Physics, Nuclear Chemistry and Nuclear Power, both globally as well as at regional levels. But the studies pertaining to one of its important aspects, Nuclear Waste Management are very rare. Kumar, Girap, Tewari, Kademani and Bhanumurthy (2011) studied the global research trend in nuclear waste management as per International Nuclear Information System during 1970-2009. The authors found that during this period, 44,529 publications were published by the scientists in the field of Nuclear Waste Management with average number of publications per year as 1113. Total of 140 countries contributed in the field of Nuclear waste Management. The USA and Japan were topping the

list with 6672 and 2859 publications respectively. Among the institutions, Japan Atomic Energy Agency (Japan) was found to be the dominating one, contributing 677 publications. Similar study has been conducted by Kademani et al (2013), who analysed the global research productivity in the field of Radioactive Waste Management over the period 1970-2011 using International Nuclear Information System (INIS) as the source database. The authors concluded that a total of 101,419 documents were indexed in INIS in the said field across all the channels of communication. The authors have recorded a continuous growth of literature during the study period. The USA, Japan and Germany were among the topmost contributors. Swarna, Rane, Aroskar, Prabhu and Bhanumurthy (2014) carried an analysis on the research output of radioactive waste management based on technical reports retrieved from the International Nuclear Information System over the years 1970-2012. The findings of the study reveal that around 43% (14,922) of the total reports published in INIS were on radioactive waste management, of which around 30% were presented in several conferences, the results thus signifying the importance of the technical reports in the dissemination of research related to radioactive waste management. The findings further depicted that over 97 countries contributed these reports in 24 different languages, the USA being at the top of the list. In an another study by Siwasami (2019), the author studied the global research trend in Nuclear Waste Management over a decade from 2008 to 2019 as reflected in Web of Science. The author found a total of 1083 records, contributed by over 3085 authors. The USA was seen as the topmost contributor, followed by France and England. Multi-authorship dominated the collaboration trend. The present study has been carried out in the same direction. However, the study covers 30 years (1989-2019) period and collected data from the most trusted - Web of Science.

OBJECTIVES

The objectives of the present study are:

1. To analyse the relative growth rate and doubling time of Nuclear Waste Management.
2. To analyse the countries contribution and collaboration.
3. To identify the prominent journals preferred by the scientists.
4. To identify the highly productive authors & authorship trends.
5. To identify the highly productive institutions and institutional networks.

METHODOLOGY

The data for the present study has been collected from the Web of Science Core Collection for a period 30 years from 1989-2019 using “*Nuclear Waste Management*” as the keyword. A total of 1824 records have been retrieved and then downloaded into an excel file for different statistical and mathematical operations. Moreover, VOS Viewer version 1.6.11 has also been used to generate scientific maps.

RESULTS AND DISCUSSION

A total of 1824 articles have been indexed in the Web of Science in the field of Nuclear Waste Management over the period 1989 - 2019 with 58.8 as the average publication count per year and a total citation score of 21,011, and 11.52 as an average citation score per item.

Annual Research Output

The table 1 depicts the chronological distribution of Nuclear Waste Management publications of study span, Relative Growth Rate and doubling time. Of the total 1824 publications published during the period from 1989-2019, the year 2018 showed the highest contribution of 115 publications (6.3%), followed by the year 2017 with 108 publications (5.9%). The least numbers of publications were recorded during the initial years of 1989, 1990 and 1991 with 6 (0.3%), 7 (0.3%) and 15 (0.8%) publications respectively. The results clearly indicate that there is an inconsistency in the relative growth of literature over the period under study, thus, indicating that the growth has not been exponential over the study period.

The Relative Growth Rate (RGR) and the Doubling time (D_t) have been calculated using the formulae:

$$RGR = \frac{(W_2 - W_1)}{(t_2 - t_1)}$$

Where RGR is Relative Growth Rate;

W1 is natural log of size of publications at time t1

W2 is natural log of size of publications at time t2

Doubling time;

$$D_t = \frac{0.693}{RGR}$$

Table 1: Publication Count, RGR and Doubling Time (Dt)

Year	Publication Count	Cumulative	RGR	Dt
1989	06	06		
1990	07	13	0.77	0.9
1991	15	28	0.76	0.9
1992	18	46	0.5	1.4
1993	21	67	0.37	1.9
1994	28	95	0.35	1.9
1995	21	116	0.2	3.5
1996	39	155	0.3	2.3
1997	51	206	0.9	0.8
1998	35	241	0.2	3.5
1999	33	274	0.2	3.5
2000	51	325	0.2	3.5
2001	49	374	0.14	5
2002	45	419	0.11	6.3
2003	52	471	0.12	5.8
2004	60	531	0.12	5.8
2005	53	584	0.1	6.9
2006	57	641	0.1	6.9
2007	55	696	0.1	6.9
2008	77	773	0.1	6.9
2009	85	858	0.1	6.9
2010	69	927	0.1	6.9
2011	87	1014	0.1	6.9
2012	96	1110	0.1	6.9
2013	101	1211	0.1	6.93
2014	88	1299	0.07	9.9
2015	107	1406	0.08	8.7
2016	93	1499	0.06	11.5
2017	108	1607	0.07	9.9
2018	115	1722	0.07	9.9
2019	102	1824	0.06	11.5

RGR=Relative Growth Rate, Dt= Doubling Time

Countries Contribution

Table 2 depict the top 10 countries contributing to the literature in the field of Nuclear Waste Management. While analysing the geographical distribution of literature, it has been found that almost 65 countries are making their contributions. The results depict that among all the

countries, the USA is topping the list contribution with 432 (23.7%) publications followed by France with 238 (13%), United Kingdom with 208 (11.4%) and Germany with 204 (11.2%).

Table 2: Top 10 contributing countries

Country	Publication Count	Percentage
USA	432	23.7
France	238	13.04
United Kingdom	208	11.4
Germany	204	11.2
Canada	98	5.4
India	98	5.4
Sweden	95	5.2
Japan	88	4.8
China	84	4.6
Switzerland	67	3.7

Country Collaboration

Figure 1: Collaboration Network of Countries

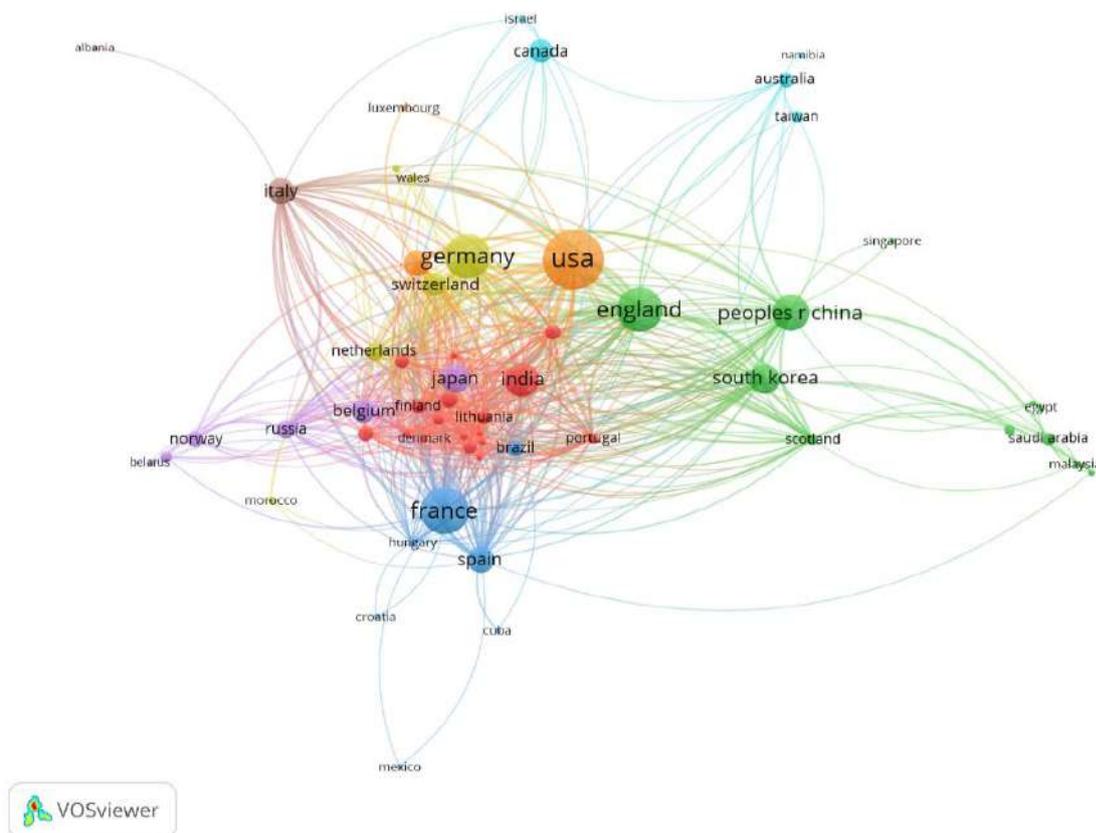


Figure 1 depicts the collaboration between countries in the research output of Nuclear Waste Management. Almost 67 countries are making their contributions in the given field. The maximum collaborating country is seen to be USA with strong collaborating links with almost 42 countries (218 publications), followed by France with 42 links (135 publications) and Germany with 39 links (120 publications). Other highly collaborating countries include England, Peoples Republic of China and India.

Preferred Journals

Journals are the most preferred sources for the dissemination of scholarly literature, they act as the backbone of modern scholarly communication. While analysing the scientists' most preferred journals in the field of the Nuclear Waste Management, it has been found that *ATW International Journal for Nuclear Power* tops the list contributing 114 (6.3%) publications followed by *Internationale Zeitschrift fur Kernenergie (International Nuclear Energy Journal)* (71, 3.9%), *Progress in Nuclear Energy* (64, 3.5%), *Health Physics* (55, 3.0%) and *Nuclear Engineering and Design* (51; 2.8%) are also making a significant contribution in the publishing of Nuclear Waste Management literature globally (Table 3).

Table 3: Most Productive Top 15 Journals

Rank	Journal	Publication Count	Percentage
1	ATW International Journal for Nuclear Power	114	6.3
2	Internationale Zeitschrift fur Kernenergie (International Nuclear Energy Journal)	71	3.9
3	Progress in Nuclear Energy	64	3.5
4	Health Physics	55	3.0
5	Nuclear Engineering and Design	51	2.8
6	Nuclear Energy Journal of the British Nuclear Energy Society	49	2.7
7	Nuclear Technology	48	2.6
8	Journal of Radioanalytical and Nuclear Chemistry	41	2.2
9	Annals of Nuclear Energy	40	2.1
9	Journal of Nuclear Materials	40	2.1
10	Journal of Nuclear Science and Technology	37	2.0
11	Risk Analysis	31	1.7
12	Applied Geochemistry	28	1.5
12	Journal of Environmental Radioactivity	28	1.5
13	Fusion Engineering and Design	27	1.4
14	RadiochimicaActa	25	1.3
15	Journal of Risk Research	23	1.2

Prolific Authors

Table 4 shows the prolific authors contributing highly to the field of Nuclear Waste Management. Burger Joanna (affiliated with the Rutgers State University, USA) tops the list with 17 publications followed by Wang Xiangke (affiliated with the North China Electric Power University, China) with 14 publications, Gochfeld Michael (Rutgers State University, USA) and Mohapatra Prasanta Kumar (Bhabha Atomic Research Centre, India) with 12 publications each..

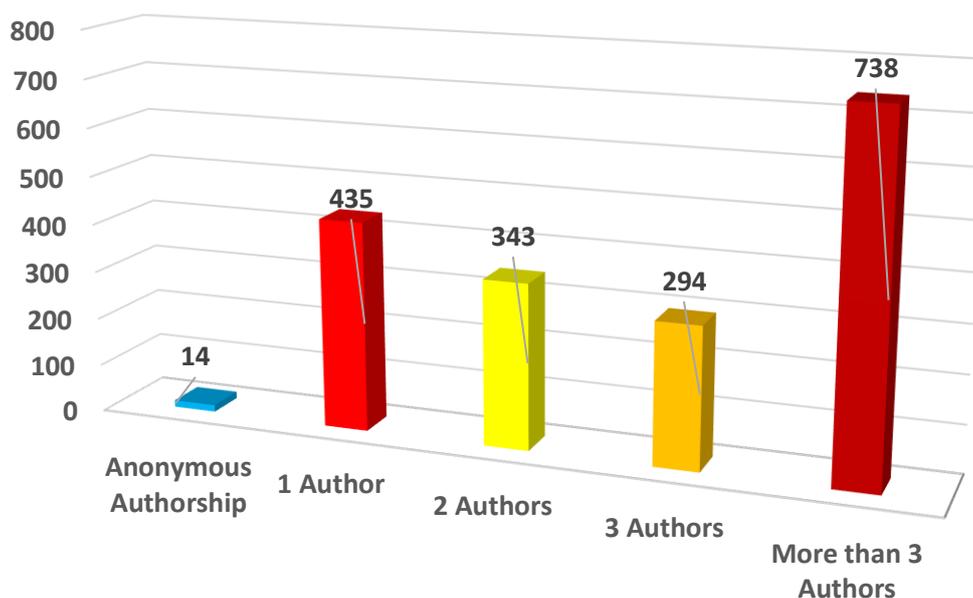
Table 4: Prolific Authors in Nuclear Waste Management

Rank	Author	Publication Count	Affiliation
1	Burger, Joanna	17	Rutgers State University, USA
2	Wang, Xiangke	14	North China Electric Power University, China
3	Gochfeld, Michael	12	Rutgers State University, USA
3	Mohapatra, Prasanta Kumar	12	Bhabha Atomic Research Centre, India
4	Zucchetti, M	11	Polytechnic University of Turin, Italy
5	Manchanda, VK	10	Bhabha Atomic Research Centre, India
6	Bosbach, Dirk	09	Research CentreJulich, Germany
6	Kowalski, Piotr M	09	Research CentreJulich, Germany
7	El-Guebaly, L	08	University of Wisconsin, Madison, USA
7	Greenberg, Michael	08	Rutgers State University, USA
7	Ozdemir, Tonguc	08	Mersin University, Turkey
8	Sneve, Malgorzata K	07	Norwegian Radioactive Protection Agency
9	Necas, Vladimir	06	Slovak University of Technology Bratislava
10	Fischer, U	05	Karlsruhe Institute of Technology, Germany

Authorship Collaboration

The overall analysis of the pattern of authorship collaboration shows that almost 76% of the publications are contributed in collaboration whereas 24% are single author publications in the field of Nuclear Waste Management. The figures reveal that 40.5% (738) of the publications are more than three authored publications followed by three authored and two authored publications with 18.8% (343) and 16.11% (294) of the total share of output respectively. The results clearly depict that the research publications brought out by the scientists preferred collaboration in research and problem solving activities (Fig. 2).

Figure 2: Authorship Collaboration in Publications



Institutional Productivity

Table 5: Contribution of Prominent Departments, Institutions and Organizations

Rank	Institution	Publication Count	Percentage
01	United States Department of Energy, US	144	7.9
02	Commissariat A L' Energie Atomique (CEA), France	121	6.6
03	Centre National De La Recherche Scientifique (CNRS), France	83	4.5
04	Universite Paris Saclay, France	78	4.3
05	Helmholtz Association, Germany	65	3.5
06	Bhabha Atomic Research Centre, India	53	2.9
07	Atomic Energy of Canada Limited, Canada	41	2.2
08	Japan Atomic Energy Agency, Japan	40	2.1
09	Chinese Academy of Sciences, China	33	1.8
10	Karlsruhe Institute of Technology, Germany	32	1.7

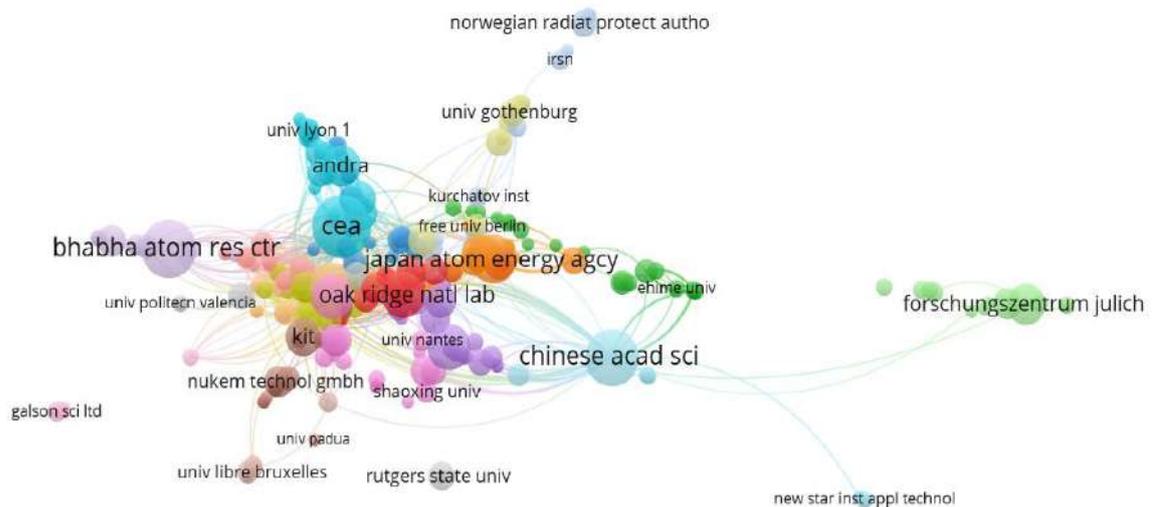
Table 5 includes the top 10 institutions which have contributed significantly for Nuclear Waste Management research globally. The analysis depicts that the *United States Department of Energy* is the most productive institute contributing around 7.9% (144) of the total output

followed by *Commissariat A L' Energie Atomique (The French Alternative Energies and Atomic Energy Commission, CEA), France* with 6.6% (121) of publication and *Centre National De La Recherche Scientifique (CNRS), France* with 4.5% (83) of the total research output. The Bhabha Atomic Research Centre, India ranks at 6th position with 2.9% (53) of publications in the world.

Institutional Networking

Figure 3 shows the networks among institutions in the field of Nuclear Waste Management. In the research productivity of Nuclear Waste Management, almost 1200 institutes from almost 67 countries have joined hands to contribute 1824 publications. However, the Oak Ridge National Laboratory, managed by the US Department of Energy, has strong maximum links (69), followed by Karlsruhe Institute of Technology, Germany with 84 links and Chinese Academy of Sciences with 83 links. The closeness of the institutes in the graph clearly indicates that there is a significant level of global collaboration among the institutes.

Figure 2: Institutional Collaboration in Nuclear Waste Management



FINDINGS AND CONCLUSION

The present study deals with identifying the scientific publications on Nuclear Waste Management from 1989– 2019 published in the Web of Science using Scientometric techniques. Scientometrics broadly constitute the quantitative analysis of scientific literature. The results revealed that a total of 1824 articles have been published in the field from 1989 to 2019, the average publication per year being 58.8. The USA is the topmost contributor with 432 publications, followed by France with 238 publications, United Kingdom with 208 and Germany with 204 publications. Other leading countries include Canada, India, Sweden, Japan and Peoples Republic of China. *ATW International Journal for Nuclear Power* has been seen as the most preferred journal for the publication in Nuclear Waste Management publishing the highest (114) records. The *United States Department of Energy* is the most productive institute contributing around 7.9% (144) of the total output and *Burger Joanna* from Rutgers State University, USA is the highly productive author with 17 publications. The authorship trend has been seen more towards multi-authorship, indicating that the authors prefer to work in collaboration. The institutions all across the world also have strong collaborative networks and links to research on the problem.

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