

TREND OF R&D PUBLICATIONS IN PRESSURISED HEAVY WATER REACTORS: A STUDY USING INIS AND OTHER DATABASES

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Abstract. Digital databases INIS (1970-2002), INSPEC (1969-2002), Chemical Abstracts (1977-2002), ISMEC (1973-June2002), Web of Sciences (1974-2002), and Science Citation Index (1982-2002), were used for comprehensive retrieval of bibliographic details of research publications on Pressurized Heavy Water Reactor (PHWR) research. Among the countries contributing to PHWR research, India (having 1737 papers) is the forerunner followed by Canada (1492), Romania (508) and Argentina (334). Collaboration of Canadian researchers with researchers of other countries resulted in 75 publications. Among the most productive researchers in this field, the first 15 are from India. Top three contributors to PHWR publications with their respective authorship credits are: H.S. Kushwaha (106), Anil Kakodkar (100) and V. Venkat Raj (76). Prominent interdomainary interactions in PHWR subfields are: Specific nuclear reactors and associated plants with General studies of nuclear reactors (481), followed by Environmental sciences (185), and Materials science (154). Number of publications dealing with Geosciences aspect of environmental sciences are 141. Romania, Argentina, India and Republic of Korea have used mostly ($\geq 75\%$) non-conventional media for publications. Out of the 4851 publications, 1228 have been published in 292 distinct journals. Top most journals publishing PHWR papers are: *Radiation Protection and Environment* (continued from: *Bulletin of Radiation Protection* since 1997), India (115); *Nuclear Engineering International*, UK (84); and *Transactions of the American Nuclear Society*, USA (68).

1. INTRODUCTION

The concept of heavy water reactors was introduced in 1944 and the first heavy water power reactor became critical on 11 April 1962 in Canada. The Canadians were the pioneers in the transition from research reactor to power reactor using heavy water. Subsequent research and development in Pressurized Heavy Water Reactors (PHWR) resulted in significant improvements in their design, efficiency and operation. Their cumulative benefits are quite substantial in many aspects; most important among them is utilization of uranium resources [1-5]. The study of publication output in a field is a good indicator of status of research work in that field. Bibliographic databases are representative samples of publication activity in any field of knowledge. This paper reports the findings of a study based on some databases where bibliographic details of PHWR publications are likely to occur. The results of this study could be beneficial to PHWR researchers in understanding the progress in this field and making them aware of the research status for appreciation and possible decision-making.

2. Materials and Methods

Keywords PHWR, and Pressurised or Pressurized Heavy Water Reactor were used for searches in title or descriptors. The searches resulted in a total of 5863 records. Taking INIS as base the duplicate records (1012) from INIS and other databases were identified and removed. Remaining 4851 records (Table I) were considered for the further study. A manual examination of Abstracts of each randomly selected 500 records among 4851 records showed that about three per cent records were not directly related to PHWR research but were only remotely related in passing remarks. The discussion and conclusions of this paper may be viewed in this light. It may be noted that, in general, results and conclusions of this paper will not be drastically affected due to the above observation. However, to ensure credibility of

conclusions, the records pertaining to specific results were scrutinized for records directly related to PHWR results.

Table I: Databasewise PHWR related records

Database	PHWR records
INIS (1970 - 2002)	4655
INSPEC (1969 - 2002)	117
Chemical Abstracts (1977 - 2002)	63
ISMEC (1973 - June 2002)	9
Web of Sciences (1974 - 2002)	5
Science Citation Index (1982 - 2002)	2
Total	4851

Collaboration coefficient percentage discussed in the present paper is defined as percent ratio of the number of publications having country-country affiliations (in the byline) to the total number of publications of each country.

For the data analysis of bibliographic records some programs written in Visual C++ language and SQL were employed. International Nuclear Information System (INIS) classification scheme [6-7] was followed to quantify domainary and inter-domainary content-wise global publications.

2.0. 3. Results and Discussion

3.1. GROWTH OF PUBLICATIONS

The most famous 'Ideal Logistic Growth Model' of literature in a field has been well discussed in early 1990s [8-10]. Logistic growth assumes that the growth rate is proportional to the product of present size and future growth. The escalating growth after maturation implies that old topics of research are no longer relevant and new directions in research, new discoveries, and new opportunities keep growing. According to Gompertz the logistic growth of any field of knowledge ideally takes an extended S-shape [11]. Fig. 1 depicts year-wise and

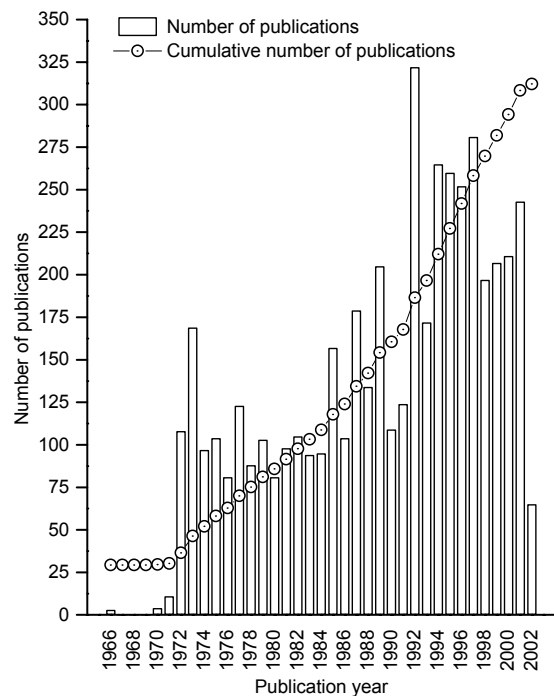


FIG. 1. PHWR related R&D publications

cumulative number of R&D publications related to PHWR since 1966.

3.2. Country-Productivity and Collaboration

Even though PHWR type reactors are not common to all countries, nevertheless 46 countries have contributed to PHWR research. Country-wise productivity is given in Table II.

Table II. Productivity-wise list of countries contributing to the PHWR related research (1966-2002)

Country	NUMBER OF PUBLICATIONS AND COUNTRY-WISE AFFILIATIONS						TOTAL	%	C C (%)
	Single country	International collaborations							
		Two Cou ntries	Three Count ries		Four Countries				
			I	I	II	I			
India	17 24						737	4.84	0 .75
Canada	14 17	9	9				492	9.92	5 .03
Romania	48 2	1	0				08	0.19	5 .12
Argentina	32 0						34	.70	4 .19
Republic of Korea	20 1	0					19	.39	8 .22
Germany	16 4		6				89	.79	1 3.23
USA	97	6					25	.51	2 2.40
UK	67						0	.40	4 .29
Pakistan	54						0	.20	1 0.00
Austria	36						8	.96	2 5.00
USSR	27						7	.54	0 .00
Japan	13						9	.38	3 1.58
Sweden	19						9	.38	0 .00
Italy	14						8	.36	2 2.22
Egypt	11						2	.24	8 .33
France	8						1	.22	2 7.27
Australia	8							.18	1 1.11
Saudi Arabia	7							.16	1 2.50
Brazil	5							.14	2 8.57
Israel	7							.14	0 .00
China	3								5

a	Czechoslovakia	6				.12	0.00
							0
						.12	.00
							0
	Yugoslavia	6				.12	.00
							0
	Indonesia	5				.10	.00
							0
	Spain	5				.10	.00
							0
	Turkey	5				.10	.00
							2
	South Africa	3				.08	5.00
							7
	Sweden	1				.08	5.00
							1
	Hungry					.06	00.00
							1
	Switzerland					.06	00.00
							0
	Finland	2				.04	.00
							0
	Mexico	2				.04	.00
							5
	Netherlands	1				.04	0.00
							0
	Taiwan	2				.04	.00
							0
	Belgium	1				.02	.00
							0
	Denmark	1				.02	.00
							0
	Iraq	1				.02	.00
							1
	Latvia					.02	00.00
							0
	Norway	1				.02	.00
							1
	Peru					.02	00.00
							0
	Philippines	1				.02	.00
							0
	Poland	1				.02	.00
	Republic of						
Moldova		1				.02	0.00
	Slovakia	1				.02	0.00
							1
	Tunisia					.02	00.00
	Ukraine	1				.02	0.00

(CC = Collaboration Coefficient, I = First author(s) country, II = Second author(s) country,

India is at the top position followed by Canada, Romania, and Argentina. With respect to international collaborations, Canada is at the top with 75 publications, followed by USA (28), Romania (26), Germany (25), and Republic of Korea (18). However, international collaborations for publication activity were very low as indicated by the Collaboration

Coefficients of top ten most contributed countries: Austria (25.0), USA (22.4), Germany (13.2), Pakistan (10.0), Republic of Korea (8.2), Romania (5.1), and Canada (5.0).

As per Katz and Hicks [12], collaborative papers have more impact than non-collaborative papers. Total number of internationally co-authored scientific and technical articles in ISI databases [13] had increased by 115% in ten years from 1986. Table II also gives the international collaboration pattern of the PHWR research. Out of 4851 publications, 106 (2.19 %) are of bilateral collaborative nature. Also there are thirteen publications with a collaboration of three countries, and one publication with a collaboration of four countries. A possible interpretation of low collaboration coefficient observed for India is high degree of self-reliance in this field.

The total literature output on PHWR related research from top 6 countries amounted to about 90 per cent. Growth of publications by top ten highly productive countries is given in Fig. 2. Stepping in of Romania and Republic of Korea after 1992 in PHWR research is remarkable. The Fig. 2 also shows that India has overtaken Canada in year 2000 in publication activities.

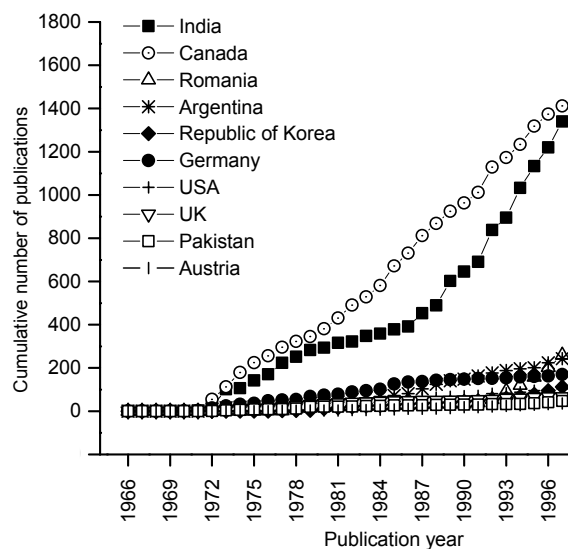


FIG. 2. Year-wise cumulative number of publications by top 10 countries in PHWR related research

3.3. Author-wise Productivity

Individual contribution to any field of science indicates the individual's expertise in that field. The PHWR records from all the databases show that, 5837 distinct authors have contributed to this field of study. The rank-wise list of the number of papers of first 52 authors (those who have at least 15 papers to their credit) is given in Table III. Out of 111 top most authors 83 are Indians with 17 of them occupying the first 14 rank positions, and three authors have more than 75 papers each to their credit. The productivity history of the top five authors in the PHWR related research is given in Fig. 3.

Table III. Most productive authors (those who have ≥ 15 publications to their credit) in the field of PHWR related research (1966-2002)

Sr.	Author	Country	Authorships	Rank
1.	Kushwaha-HS	India	106	1
2.	Kakodkar-Anil	India	100	2
3.	Venkat-Raj-V	India	76	3
4.	Narasimhan-SV	India	48	4
5.	Mahajan-SC	India	44	5

6.	Mathur-PK	India	39	6
7.	Dutta-BK	India	37	7
8.	Das-M	India	36	8
9.	Raj-Baldev	India	29	9
10.	Ganguly-C	India	28	10
11.	Gurg-RP	India	25	11
12.	Mehta-SK	India	24	12
13.	Ghosh-AK	India	24	12
14.	Bajaj-SS	India	24	12
15.	Nair-KVK	India	24	12
16.	Gupta-SK	India	23	13
17.	Velmurugan-S	India	22	14
18.	Rotaru-I	Romania	21	15
19.	Vijayan-PK	India	20	16
20.	Purandare-HD	India	20	16
21.	Varadhan-RS	India	20	16
22.	Venkateswarlu-	India	20	16
23.	Srivenkatesan-R	India	19	17
24.	Bhardwaj-SA	India	19	17
25.	Chudalayandi-K	India	19	17
26.	Singh-RK	India	19	17
27.	Rustagi-RS	India	18	18
28.	Rastogi-BP	India	18	18
29.	Suk-HC	Rep. of	18	18
30.	Krishnani-PD	India	18	18
31.	Srinivasan-KR	India	18	18
32.	Glodeanu-F	Romania	18	18
33.	Murthy-LGK	India	17	19
34.	Soni-RS	India	17	19
35.	Babar-AK	India	17	19
36.	Govindarajan-G	India	17	19
37.	Sinha-RK	India	17	19
38.	Venkateswaran-G	India	17	19
39.	Frischengruber-K	Argentina	16	20
40.	Jagannathan-V	India	16	20
41.	Purushotham-	India	16	20
42.	Sharma-VK	India	16	20
43.	Galeriu-D	Romania	16	20
44.	Woodhead-LW	Canada	15	21
45.	Balakrishnan-K	India	15	21
46.	Chawla-DS	India	15	21
47.	Bapat-CN	India	15	21
48.	Iyengar-MAR	India	15	21
49.	Kumar-AN	India	15	21
50.	Markandeya-SG	India	15	21
51.	Ramamirtham-B	India	15	21
52.	Chirica-T	Romania	15	21

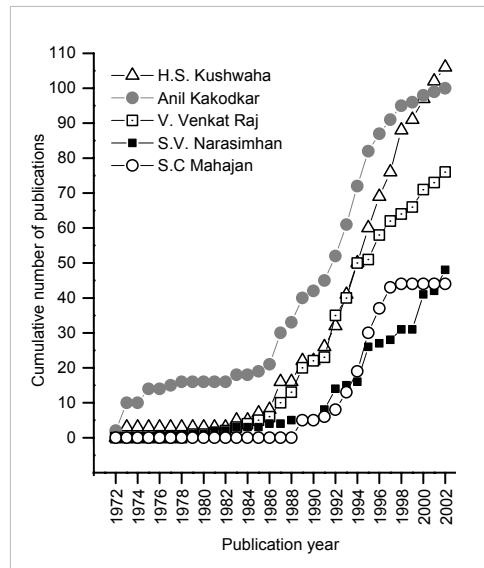


FIG. 3. Year-wise cumulative publications of top five authors in PHWR related research

3.4. Content Analysis

Table IV shows the cluster analysis of top 18 subject categories in the field of PHWRs. Number of records prominently occurring with S21: specific nuclear reactors and associated plants were:

- S22: general studies of nuclear reactors (481);
- S54: environmental sciences (185);
- S36: materials science (154);
- S29: energy planning, policy and economy (133);
- S42: engineering (120);
- S61: radiation protection and dosimetry (112); and
- S58: geosciences (98).

Table IV. Clusters of PHWR papers (1966-2002) as per INIS classification

Subject	21	22	54	29	42	36	99	61	11	58	12	37	07	46	98	63	20	38
S2	827	81	85	33	20	54	2	12	8	8	9	6	3	6		6	7	
22		22	4	3	5	2	1	0	0	2							6	
54			54					7		41	5							
29				61					7									
42					44	3					1							
36						13												
INIS Subject Categories							99	02										
S07 Isotopes and radiation sources																		
S11 Nuclear fuel cycle and fuel materials							61	94										
S12 Management of radioactive wastes, and non-radioactive wastes									11	58	3							
from nuclear facilities																		
S20 Fossil-fueled power plants																		
S21 Specific nuclear reactors and associated plants									58	46								
S22 General studies of nuclear reactors																		
S29 Energy planning, policy and economy																		
S36 Materials science										12	39							
S37 Inorganic, organic, physical and analytical chemistry																		
S38 Radiation chemistry, radiochemistry and nuclear chemistry																		
S42 Engineering																		
S46 Instrumentation related to nuclear science and technology																		
S54 Environmental sciences																		
S58 Geosciences																		
S61 Radiation protection and dosimetry																		
S63 Radiation, thermal, and other environmental pollutant effects on living organisms and biological materials																		

37	4						
	07	3					
		46	1				
			98	4			
				63	1		
					20	8	
						38	3

Interdomainary contents of S54: environmental sciences with S58: geosciences is in 141 publications followed by:

- S21: specific nuclear reactors and associated plants with S12: management of radioactive wastes, and non-radioactive wastes from nuclear facilities (39);
- S21: specific nuclear reactors and associated plants with S63: radiation, thermal, and other environmental pollutant effects on living organisms and biological materials (36);
- S22: general studies of nuclear reactors with S42: engineering (25); and
- S22: general studies of nuclear reactors with S54: environmental sciences (24).

2.1.

2.2. 3.5. Types of Publication Media

INIS: guide to bibliographic description [14] was used to group the records according to their publication media. Out of the 4851 publications, 3005 (61.95%) were published as conference/symposium papers, 1228 (25.31%) were journal articles, 555 (11.44%) were technical reports and 63 (1.30%) were other publication media like books, theses, dissertations, patents, films, etc. Comparison of growth in literature of PHWR related research in terms of their publication media are given in Fig. 4. The number of conferences/symposia/seminars, etc. held with power reactors especially PHWR type reactors as the theme, was high during this period.

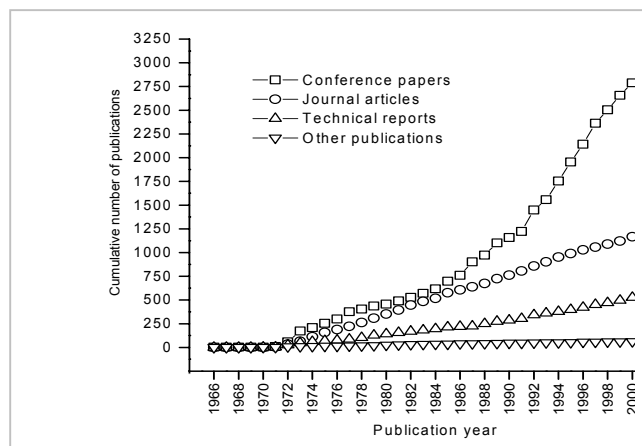


FIG. 4. Publication media-wise cumulative number of publications of PHWR related research

Observation to the growth pattern indicates that the period from 1990 to 1993 was a landmark in PHWR research. Publication media-wise highly productive mode years were: conference papers (1992) and journal articles (1985), technical reports (1992) and other publications

clubbed (1972). It is interesting to note the high percentage of Non-Conventional Literature (NCL) which includes technical reports; conference/symposia/seminar papers; theses; dissertations, etc. The percentages of NCL for the top ten countries mentioned above are Romania (84.50 %); Argentina (81.71 %); India (78.42 %); Korea, Republic of (72.07 %); Austria (68.00 %); Canada (67.49 %); USA (63.49 %); Pakistan (59.70 %); Germany (47.12 %); and UK (18.31 %), etc. The high proportion of NCL may be due to urgency of communication to the targeted audience [15].

3.6. Journal-wise Productivity

For the past 2-3 decades scientometricians have focused their studies on journal articles since they form a major share of peer reviewed and quality scientific research output as compared to NCL including technical reports, conference papers, monographs etc. In the present study, it is found that 292 distinct journals were used to publish 1228 publications (25.31%) out of a total of 4851 publications. Out of these journals, 171 were used prior to the year 1992. After 1992 most popular journals preferred were 80 only. However, 41 journals were common in both the periods. Table V documents journals (having at least 6 publications) preferred by PHWR researchers. By the year 2002, the journal *Radiation Protection and Environment* (continued from the journal *Bulletin of Radiation Protection* since 1997) contained the maximum number of publications on PHWR.

Table V. Journals preferred for publishing articles on PHWR related research (1966-2002)

Journal Title	IMPACT FACTOR (2001)	COUNTRY	N o. of Papers	Paper s/ Year
<i>Radiation Protection and Environment*</i>	N A	India	1	4.79
<i>Nuclear Engineering International</i>	0 .610	UK	8	3.36
<i>Transactions of the American Nuclear Society</i>	N A	USA	6	2.52
<i>Nuclear Canada/Canada Nucleaire</i>	N A	Canada	4	1.68
<i>Modern Power and Engineering #</i>	N A	Canada	3	3.25
<i>Nuclear Engineering and Design</i>	0 .233	The Netherlands	3	1.23
<i>Journal of the Korean Nuclear Society</i>	N A	Republic of Korea	8	2.07
<i>Energetica. Seria A</i>	N A	Romania	9	1.18
<i>Nuclear Canada Yearbook</i>	N A	Canada	2	1.47
<i>Nuclear Technology</i>	0 .421	USA	5	1.14
<i>Annals of Nuclear Energy UK</i>	0 .358	UK	2	0.92
<i>Canadian Nuclear Society Bulletin</i>	N A	Canada	2	1.62
<i>Atomwirtschaft Atomtechnik Germany</i>	N A	Germany	2	1.33
<i>Journal of Nuclear Materials</i>	1 .366	The Netherlands	1	0.95
<i>Ascent Canada</i>	N A	Canada	9	1.31
<i>Atomkernenergie Kerntechnik Germany</i>	N A	Germany	7	2.43
<i>Atomnaya Tekhnika za Rubezhom</i>	N A	USSR	7	0.63
<i>Canadian Energy News</i>	N A	Canada	1	3.00
<i>Atom und Strom</i>	N A	Germany	1	1.00
<i>Nucleus Karachi</i>	N A	Pakistan	4	0.93
<i>Canadian Chemical Processing</i>	N A	Canada	4	0.83
<i>Fusion Technology USA</i>	0 .582	USA	0	0.91
<i>International Journal of Pressure Vessels and Piping</i>	0 .250	UK	0	0.53
3 journals with 9 papers each			2	
4 journals with 8 papers each			7	
4 journals with 7 papers each			3	
6 journals with 6 papers each			2	
10 journals with 5 papers each			2	
12 journals with 4 papers each			8	
17 journals with 3 papers each			3	
46 journals with 2 papers each			6	
167 journals with 1 paper each			5	
Total 292 journals			0	
			4	
			8	
			1	
			9	
			2	
			1	
			67	
			1	
			228	

(NA = Not Available; * continued from: *Bulletin of Radiation Protection India* since 1997; # ceased publication from 1984)

Profiles of PHWR related publications in seven core journals namely *Radiation Protection and Environment*, *Nuclear Engineering International*, *Transactions of the American Nuclear Society*, *Nuclear Canada/Canada Nucleaire*, *Modern Power and Engineering Canada* (Ceased from 1984), *Nuclear Engineering and Design*, and *Journal of the Korean Nuclear Society* are presented in Fig. 5.

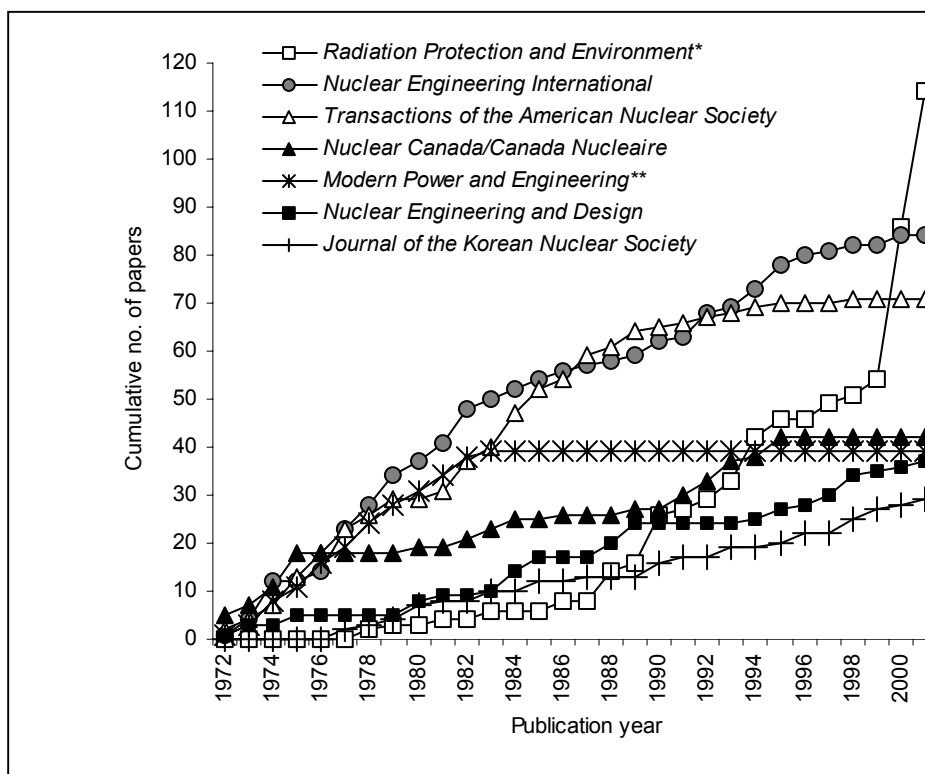


FIG. 5. Year-wise cumulative number of papers published in the core journals

(* Continued from *Bulletin of Radiation Protection* since 1997; ** Ceased from 1984)

4. CONCLUSIONS

Pressurized Heavy Water Reactor related R&D publications at global level during 1966-2002 were 4851. India has emerged as leader in PHWR followed by Canada, Romania, Argentina, and Republic of Korea. Expertise of H.S. Kushwaha, Anil Kakodkar, V. Venkat Raj, S.V. Narasimhan, and S.C. Mahajan in the area of PHWR is evident from the number of publications to their credits. The scientists working in the field have preferred to publish their research papers as conference/symposia papers followed by journal articles and technical reports. Highly used channels of communication were *Radiation Protection and Environment*, *Nuclear Engineering International*, *Transactions of the American Nuclear Society*, *Nuclear Canada/Canada Nucleaire*, *Modern Power and Engineering Canada* (Ceased from 1984), *Nuclear Engineering and Design*, and *Journal of the Korean Nuclear Society*.

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