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- Predominance of Research -

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An Outcome of Nuclear Safety Research in JAERI
-Predominance of Research-

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Bibliometric study by means of research papers revealed the followings; (1) Nuclear Safety Research (NSR) performed in Japan is the 2nd highest in the world followed by USA. The share of JAERI for safety paper publication is about 25% in Japan (2) During past 25 years, JAERI is predominant at 39 safety fields out of 97, that is, 40% to the total. This is the fact revealed from comparison of published number of research papers with those of other organizations. (3) JAERI is recently changing its stress point from reactor-oriented accidents to the down stream of nuclear fuel cycling. There existed impact of TMI-2 accident on NSR-JAERI, especially in the field of thermal hydraulics, LOCA, severe accident and risk analysis.

Keywords; Outcome, Nuclear Safety Research, JAERI, LOCA, Bibliometrics, Safety Licensing Guidelines

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原研における原子力安全性研究のアウトカム

-研究の優位性-

日本原子力研究開発機構経営企画部
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(2009 年 12 月 8 日受理)

研究論文を用いた計量書誌学的研究により以下の事実を見出した；（１）日本で刊行された安全性研究関連論文数は世界的に見て米国に次いで第 2 位であった。わが国で刊行されたに安全性研究関連論文のうち原研（JAERI）の論文数が占める割合は全体の約 25%であった。（２）過去 25 年を振り返ると、97 に仕分けた原子力安全研究関連分野のうち 39 の研究分野(すなわち全体の４０％の研究分野)において、原研は研究の優位性を保持した事が他機関との論文数比較から分った。(3) 論文の動向分析から、原研では過去においては原子炉事故を基軸にした安全性研究に力点が置かれていたが、最近は核燃料サイクルの下流側に関する安全性研究に力点が移っていることが判明した。TMI-2 事故が原研安全性研究に及ぼしたインパクトは特に、熱水力学、冷却材喪失事故（LOCA）、シビアアクシデントおよびリスク評価といった研究分野で大きかった。

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1 Introduction

Nuclear Safety Research (hereinafter abbreviated as NSR) in the Japan Atomic Energy Research Institute (hereinafter abbreviated as JAERI)♣1 was performed since the era of 1960. A research activity was broadly divided into the two fields; engineering and environment. In the former, most research projects are addressed to study a safety of light water reactors (LWR) and a reprocessing of spent fuels. In the latter, a safety of the depository of radioactive wastes and a safety of analytical evaluation on environmental radiation/radio-activities are main research projects to study. The present paper is related mainly to the former. A predominance of NSR study in JAERI (hereinafter abbreviated as NSR-JAERI) among many Japanese institutions worked as research competitors is considered in bibliometric manner.

2 Methodology

2.1 INIS Inputs

For bibliometric study, INIS♣2 (International Nuclear Information System) is used as principal tool. As an auxiliary tool to find out the most reliable keyword group that will represents activities performed as NSR-JAERI, an in-house database JOLIS♣3 was utilized because it collected all research papers related to NSR-JAERI. Once we obtained those keywords (hereinafter defined as top (97) keywords), they are directly used as INIS inputs.

2.2 INIS Outputs

Because INIS is database collected world-wide nuclear research papers, inputted keywords can hit only domestic but also foreign papers, this situation enable us to make a comparison between NSR-Japan and NSR-USA.

♣1 The Japan Atomic Energy Research Institute (JAERI) and the Japan Nuclear Fuel Cycle Development Institute (JNC) were reorganized on October 2005 and the Japan Atomic Energy Agency (JAEA) was established. This report is focused on the Nuclear Safety Research that has been carried out by JAERI.

♣2 INIS (International Nuclear Information System) is operated by International Atomic Energy Agency (IAEA) and includes over 2.5 million indexed references inputted by 113 countries and 19 international organizations [1]

♣3 JAERI Oriented Literature Information System, developed by the Department of Research Information, JAERI. It has similar construction as INIS but logs in only the JAERI data.

2.3 SOCIOECO computer code

If you input the keyword of LOCA into INIS, as outputs you have many NSR-Japan papers and NSR-Foreign papers having LOCA as keywords. For the former, those indexed papers are journalized into more local competitive institutions, such as JAERI, private organizations (PO) and public sectors (PS). If necessary the latter is further divided into governmental sectors (GS) and the universities (U). Because INIS has no function to do so, we developed the computer code named as SOCIOECO[♣4], which can recognize the first author's affiliation and journalize it into JAERI, PO or PS (U, GS), immediately. During programming work, at least 209 universities (U), 185 GS, 414 PO and JAERI are listed in the computer. Because we have poor information about NSR-Foreign countries, this function is limited to the case of NSR-Japan.

2.4 Research Predominance

To judge the research predominance among competitors; JAERI, PO and PS, we developed a comparative predominant index (CPI) [2]. For JAERI, the CPI at the rank x of top (97) keywords is given by

$$(CPI_X) = A_X / B \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad /1/$$

Where, $x = 1 \sim 97$, representative ranked research fields.

$A_X = \{$The papers domiciliary registered to JAERI; x$\}$ / $\{$The papers domiciliary registered to Japan; x$\}$. $B = \Sigma\ \{$The papers domiciliary registered to JAERI; x$\}$ / $\Sigma\ \{$The papers domiciliary registered to Japan: x$\}$

If the case $CPI_X \geqq 1$, one defined that JAERI is predominant in the corresponding research field (x). On the contrary, if the case $CPI_X < 1$, one defined that JAERI is inferior among competitors. Of course, the equation /1/ is applied to PO and PS (GS, U) to judge their predominance.

2.5 Time span

We set the starting year as 1978, because most NSR facilities in JAERI were constructed around the year for full-scale study. The ending year is set as 2002. The whole time span is 25-years. The minimum time span is set as five years and denoted here as present (1998-2002), past (5): 1993-1997, past (10): 1988-1992, past (15): 1983-1987 and past (20): 1978-1982, respectively.

[♣4] The computer code was developed to enhance the statistical dealing of output obtained from INIS database. For example, output was classified into JAERI-PS (U, GS)-PO immediately after the INIS computer run, where PO is the public sector, U the university, GS the governmental sectors and PO the private organization, respectively. The manuals are in progress for disclosure of this code.

2.6 Ups and downs of research activity

Ups and downs of research activity (paper publications) during 5- or 25-years should occur. Namely, to study time-dependent predominance of NSR-JAERI, we developed so-called *L x S matrix*. The sub-matrix $\{L\}$ can trace the important eight research fields; such as {Fuel, Coolant, Component, Pressure vessel, Containment, Reactor, Others, Common to all}. Additionally, the sub-matrix $\{S\}$ can trace important six kinds of reactor operating conditions and one reprocessing matter; such as {Normal operation, Transient/accident, Postulated accident, Severe accident & Risk analysis, Computer code, Reprocessing}. Time dependent predominance of JAERI activity was studied against those 15 parameters through *L x S matrix*.

3 Results and Discussion

3.1 Ranking top (97)

In the course of JOLIS study, a total of 3,075 papers with 19,790 keywords over 25 years were observed. After ranking all observed keywords, we judged to use 97 keywords having a statistical frequency>21. The result of selection, that is, top (97) keywords is shown in **Table 1**. Those are brought to INIS inputs. It should be mentioned that top (97) has an inevitable bias for JAERI because they are obtained from JAERI originated database JOLIS. As can be seen from the table, the keyword at rank 1^{st} is the "LOCA (296)", 2^{nd} the "PWR (242)", 3^{rd} the "severe accident (220)", 4^{th} the "NSRR (178)" and last 98^{th} the "TMI-2 (21)". Parenthesis means a magnitude of frequency; hence the number of papers hit repeatedly. We cannot mention here about relationship between top (97) keyword and a largeness of budget invested to the field.

3.2 INIS Outputs

(1) Worldwide comparison

Putting top (97) into INIS, a total of 2,200,000 papers published in 113 different countries were indexed. SOCIOECO journalized those papers into several countries according to the first author's affiliation as shown in **Fig. 1**. It is worthy of mentioning that a share of USA for 25-years is 18% and that of Japan is 8%. On the other hand, the share of the USA at the present five years is 11% and that of Japan is 10%. Despite of the bias for JAERI, the indexed papers in the USA are the largest. The ranking worldwide is of the order of USA, Japan, Germany, England, France, Russia and Italy.

(2) Domestic comparison

INIS outputs prepared for domestic comparison are shown in **Fig. 2**. The total papers for 25-years are of the order of PO>GS>JAERI>U. This comparison has inevitable bias for

PO, GS and U because except JAERI the others are aggregate of 414 PO, 185 GS and 209 U. Even though, JAERI is predominant against U. As mentioned above, at the present:1998-2002, a share of Japan to the world is about 10% (about 40,000 papers); where a share of GS, JAERI, PO and U is respectively 31%, 27%, 22% and 20%. The share of JAERI as a single institute is high.

Table 1 Top (97) keywords ranked from JOLIS; original papers are 3,075 having 19,790 keywords during period from 1978-2002. Frequencies are abbreviated.

R001 LOCA	R033 Safety Analysis	R065 LWR Fuel
R002 PWR	R034 Reprocessing Plant	R066 Monte Carlo
R003 Severe Accident	R035 TBP	R067 Analysis
R004 NSRR	R036 Containment	R068 Burn up
R005 BWR	R037 ROSA-III	R069 Monte Carlo Method
R006 Reprocessing	R038 Simulation	R070 PUREX
R007 Safety	R039 Criticality	R071 Small Break LOCA
R008 Criticality Safety	R040 Nuclear Power Plant	R072 CCTF
R009 ECCS	R041 Integral Test	R073 Experiment
R010 RIA	R042 PCMI	R074 JACS
R011 LSTF	R043 Pulse Irradiation	R075 Finite Element Method
R012 Reactor Safety	R044 Computer Code	R076 Calculation Code
R013 Two-phase flow	R045 Reactor Pressure Vessel	R077 Database
R014 Heat transfer	R046 Seismic PSA	R078 High Burn up
R015 Reflood	R047 Extraction	R079 Oxidation
R016 LWR	R048 NUCEF	R080 Quench
R017 PSA	R049 Technetium	R081 IAEA
R018 Source Term	R050 Burn up Credit	R082 Iodine
R019 Steam Explosion	R051 Fuel	R083 Adsorption
R020 Fuel Failure	R052 TRACY	R084 Blowdown
R021 Plutonium	R053 Irradiation Embitterment	R085 Fission Gas Release
R022 Safeguards	R054 Separation	R086 MCNP
R023 Neptunium	R055 STACY	R087 Partitioning
R024 Pressure Vessel	R056 Nitric Acid	R088 RELAP5
R025 Accident Management	R057 Nuclear Safety	R089 ROSA-V
R026 ROSA-IV	R058 FCI	R090 ALPHA
R027 Aerosol	R059 Fission product	R091 Computer Program
R028 Spent Fuel	R060 High Burn up Fuel	R092 Handbook
R029 Zircaloy	R061 Cladding	R093 JMTR
R030 Criticality Accident	R062 Small Break	R094 PCT
R031 Fuel Behavior	R063 TCA	R095 PIE
R032 Uranium	R064 Transient	R096 Seismic Risk
		R097 TMI-2

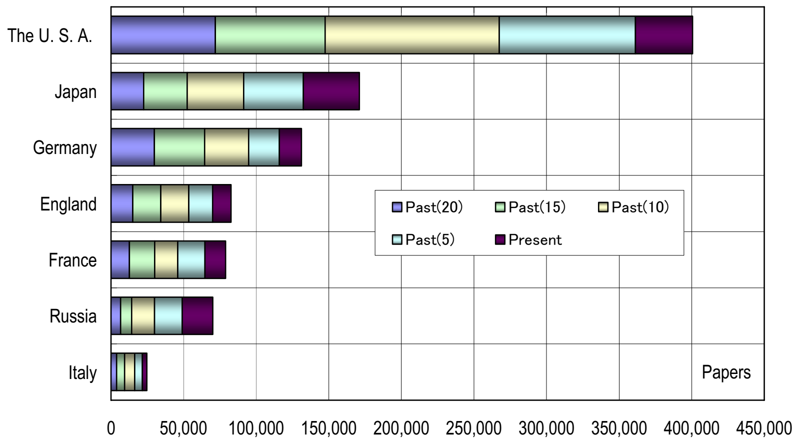

Fig.1NSR related papers seen at several countries. Top (97) were used repeatedly as input of INIS. A piece of cylinder in each country shows NSR papers published over five years and five pieces of cylinders show those published over 25 years.

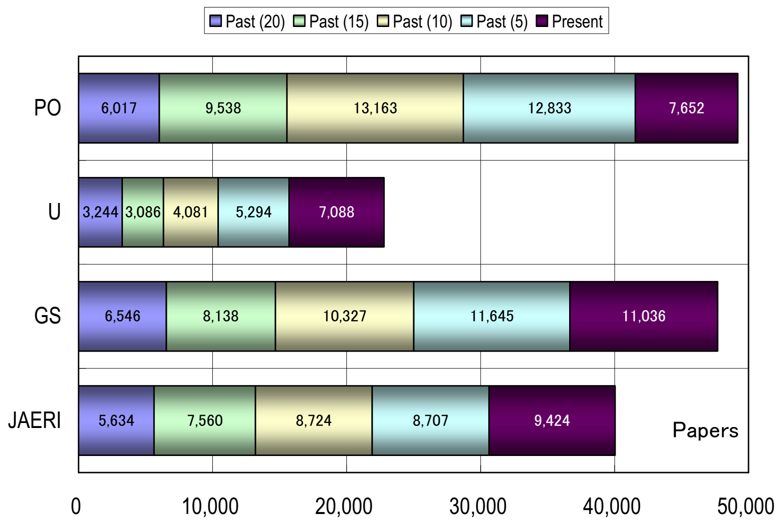

Fig.2 All NSR papers was journalized into PO, U, GS, and JAERI with aid of SOCIOECO. Each piece of cylinder is NSR papers at time span of five years

3.3 Predominance of JAERI research activity

(1) View at the present; 1998-2002

The resultant CPI obtained from JAERI, PO, GS and U is shown in **Fig. 3.** The reader should be aware that CPI of JAERI has a different four patterns as follows;

- For LOCA, CPI is resulted of the order of JAERI>U> 1 >PO>GS. Hence, JAERI is predominant for LOCA study and we denoted this situation as C-SN case for JAERI. Similar trend is seen in NSRR, Critical Safety, RIA and STACY, though they are not shown in the figure.
- For PWR, CPI is resulted of the order of PO> 1 >JAERI>GS>U. Hence, PO is predominant. JAERI had weakened predominance. This situation we denoted as M-SN case for JAERI. Similar trend is seen in BWR.
- For Nuclear Power Plant, CPI is resulted of the order of PO> 1 >U>GS>JAERI. Hence, PO is only predominant and JAERI is less predominant. This situation we denoted as E-SN case for JAERI.
- For TMI-2, the CPI of all parameters was fell to the bottom level (CPI=0) because the TMI-2 research at the period was almost terminated. In reality, from the past (20) to the past (5), TMI-2 study was active but it diminished at the present. This situation we denoted as O-SN case for JAERI.

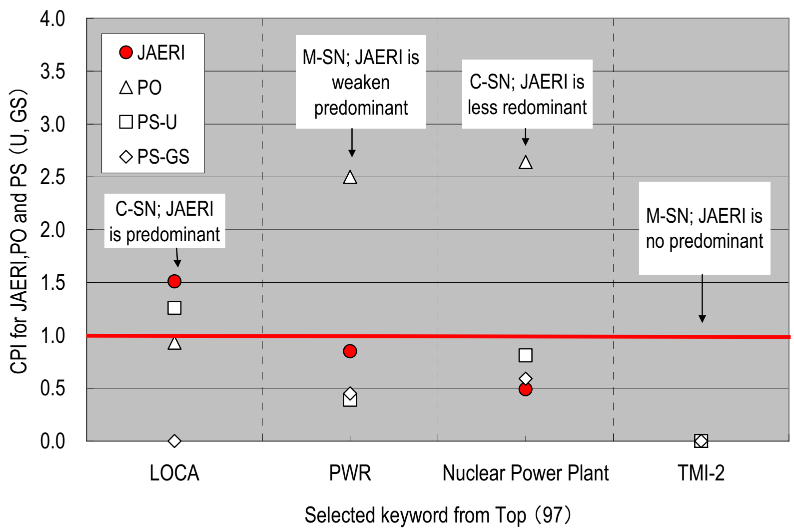

Fig.3 CPI at 4 organizations demonstrated as a function of selected keyword from top (97). Y-axis shows the CPI of JAERI (open circle), PO (triangle), U (rectangular) and GS (diamond). This comparison covers 1998-2002; that is, the present.

We studied CPI for all 97 keywords and found 39 (40%) fields are belonged to C-SN; they were LSTF（the Large Scale Test Facility）, small break, NSRR, critical safety and so on. The 48 (51%) fields are belonged to M-SN; they were seismic PSA (probabilistic safety analysis), criticality accident, severe accident, reprocessing and so on. The 4 (4%) fields are belonged to E-SN; they were nuclear power plant, separation and so on. The 7(7%) fields are belonged to O-SN. It can be said from this observation that JAERI at present period plays an important role on nuclear safety study because of high rate of predominance as much as 40%.

(2) View over 25 years

CPI study at every 5 years was extended to 25-years. For evaluation we took into consideration of significant accidents known as TMI-2 (1979.3) and Chernobyl (1986.4). The result is shown in **Fig. 4.** Each column consisted of C-SN (predominance), M-SN (weaken), E-SN(less) and O-SN (no) from the bottom to top. For example, C-SN was 41, M-SN was 43, E-SN was 5 and O-SN was 8 at the past (20). The predominance of JAERI from the past (20) to the present is respectively 41, 49, 46, 47 and 39. The maximum number 49(51%) occurred at past (15) 1983-1987 was the period after the TMI-2 accident. The TMI-2 accident (1979) should have a big impact to NSR-JAERI, especially at past (15). We understood that there was a time lag between the TMI-2 accident and observed research peak of JAERI at past (15) because the supplementing full-scale test represented by the small break LOCA experiment took about 1-3 years. With respect to the Chernobyl accident, because it has a different type of reactor as known VVER, little counter-plan might be taken at JAERI.

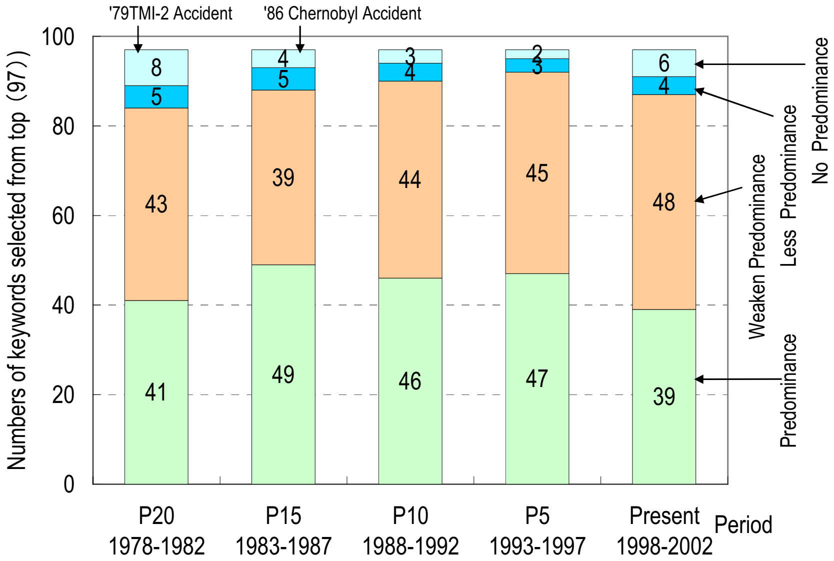

Fig.4 Chronological change of predominance in NSR-JAERI; CPI shows that the number of C-SN varied 41(42%) for past (20), 49(51%) for past (15), 46(47%) for past (10), 47(48%) for past (5) and 39(40%) for present. Hence, the predominance of NSR-JAERI becomes the maximum at past (15)1983-1987 after TMI-2 accident.

Figure 5 shows CPI of several keywords at 5-years time span. As a whole, LOCA, critical safety[♣5] and TMI-2 showed the predominance at each 5-years period. Reprocessing did not show the predominance until the present. During period at past (20) or past (15), LOCA and TMI-2 had high CPI but they decreased the value at present. On the other hand, critical safety and reprocessing had relative small CPI at the past period but they increased the value at the present. Within the limited number ob observation, however, it may be said that researches for the reactor-oriented accidents should be shifted toward researches for the down stream of nuclear fuel cycling.

[♣5] For critical safety research, a rough budget of about 15 million dollars (M$) at 1987(Showa 62) was increased rapidly to the amount of 45M$ at 1990 (Heisei 2). The tendency lasted until the completion of the nuclear fuel cycle engineering facility (NUCEF) in 1994 (Heisei 6). This enabled the carrying out of safety-related experiments on solvent spent fuel in the form of uranium and plutonium. Reflecting on this fact, the NUCEF in the consolidated rank of 48; where CPI was zero at the past (20) but increased to the magnitude of 3.13 at past (15). This implies that preceding research on NUCEF was started 10 years before the establishment of full-scale NUCEF. The STACY apparatus prepared for the steady-state experiment of solvent solution and the TRACY apparatus prepared for the transient experiment of that have a consolidated CPI ranking of 55 and 52, respectively and this became a high magnitude during the past(10). On the occasion of the criticality accident caused at the JCO Tokai establishment on September 1999, several trace experiments were carried out at NUCEF. The influence of NUCEF experiments and their reports on the value of CPI at the present stage, however, was not clarified definitely.

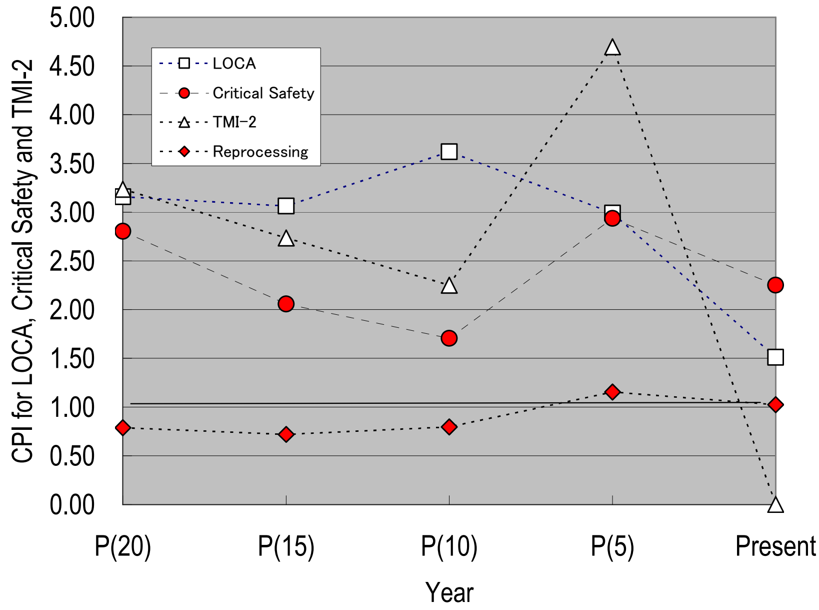

Fig.5 CPI of selected keyword at five year interval

3.4 Ups and Downs of research activity

(1) Case study

By using the *L x S matrix,* we tried to understand the time-dependent predominance occurred in NSR. **Table 2** is the result of case study.

Table 2 A representative L x S matrix indication, where four different blocks due to time (past 20 vs. present) were prepared. In each block, a magnitude of predominance is separated by color in green (C-SN), orange (M-SN), blue (E-SN) and white (O-SN). For example, at L7xS4, source term (R018) at past 20 was M-SN (orange) but changed to C-SN (green) at present meaning that the study of the source term in NSR- JAERI was more increased in its significance at present than in the past (20).

L1 (Fuel) x S1, S2 (Normal and Accident)			
Past (20) 1978-1982		Present 1998-2002	
R059	Fission product	R095	PIE
R032	Uranium	R085	Fission Gas Release
R078	High Burn up	R058	FCI
R031	Fuel Behavior	R020	Fuel Failure
R095	PIE	R078	High Burn up
R065	LWR Fuel	R060	High Burn up Fuel
R085	Fission Gas Release	R068	Burn up
R020	Fuel Failure	R031	Fuel Behavior
R060	High Burn up Fuel	R059	Fission product
R029	Zircaloy	R065	LWR Fuel
R042	PCMI	R029	Zircaloy
R068	Burn up	R021	Plutonium
R061	Cladding	R032	Uranium
R058	FCI	R051	Fuel
R021	Plutonium	R061	Cladding
R051	Fuel	R082	Iodine
R082	Iodine	R042	PCMI

L2 (Coolant) x S3 (Postulated Accident)			
Past (20) 1978-1982		Present 1998-2002	
R072	CCTF	R062	Small Break
R037	ROSA-III	R071	Small Break LOCA
R071	Small Break LOCA	R089	ROSA-V
R097	TMI-2	R001	LOCA
R001	LOCA	R009	ECCS
R084	Blowdown	R080	Quench
R062	Small Break	R084	Blowdown
R009	ECCS	R079	Oxidation
R079	Oxidation	R037	ROSA-III
R080	Quench	R072	CCTF
R089	ROSA-V	R094	PCT
R094	PCT	R097	TMI-2

L7 (Other) x S4 (Severe Accident & Risk Analysis)			
Past (20) 1978-1982		Present 1998-2002	
R017	PSA	R018	Source Term
R003	Severe Accident	R046	Seismic PSA
R033	Safety Analysis	R096	Seismic Risk
R025	Accident Management	R003	Severe Accident
R057	Nuclear Safety	R033	Safety Analysis
R027	Aerosol	R057	Nuclear Safety
R090	ALPHA	R027	Aerosol
R096	Seismic Risk	R017	PSA
R018	Source Term	R090	ALPHA
R083	Adsorption	R025	Accident Management
R046	Seismic PSA	R083	Adsorption

L7 (Other) x S6 (Reprocessing)			
Past (20) 1978-1982		Present 1998-2002	
R087	Partitioning	R055	STACY
R039	Criticality	R052	TRACY
R023	Neptunium	R048	NUCEF
R006	Reprocessing	R087	Partitioning
R056	Nitric Acid	R023	Neptunium
R028	Spent Fuel	R039	Criticality
R054	Separation	R070	PUREX
R047	Extraction	R056	Nitric Acid
R035	TBP	R035	TBP
R034	Reprocessing Plant	R006	Reprocessing
R049	Technetium	R034	Reprocessing Plant
R070	PUREX	R047	Extraction
R048	NUCEF	R028	Spent Fuel
R052	TRACY	R049	Technetium
R055	STACY	R054	Separation

The table consisted of 4 blocks. They are (1) a fuel research at steady-state and accident conditions (L1 x S1& S2) ♣6, (2) a coolant research represented by LOCA & thermal hydraulics at the postulated accident (L2 x S3), (3) a risk analysis at severe accident (L7 x S4) and (4) a reprocessing (L7 x S6). In each block, the *L x S matrices* at past (20);

♣6 The classification used here is more complicated than shown previously. Regarding L, L1 is the fuel, L2 the coolant, L3 the components, L4 the pressure vessel, L5 the containment, L6 the reactor, L7 the others not common to L1-L6, and L8 the others common to L1-L6. Regarding S, S1 is the steady-state operation, S2 the abnormal transient and accident, S3 the postulated accident, S4 the severe accident and risk analysis, S5 the computer modeling code and S6 the reprocessing. Regarding fuel, several keywords (fuel failure, fuel behavior, fission product, high burn up fuel, high burn up, fission gas release, burn up, PIE (post irradiation examination), zircaloy, etc.) those were common to steady-state operation (S1) and abnormal transient and accident (S2). As a temporary measure, they were put into the measure of steady-state operation. These should be regarded as common to S1 and S2.

1978-1982 are shown in the left-had side and those at the present; 1998-2002 are shown in the right-hand side. For example, a column for fuel study shows that C-SN are totaled 9 (fission product, uranium etc) showing by the color in green, M-SN are totaled 7 (zircaloy, PCMI and so on) showing by the color in orange and E-SN is one (iodine) showing by the color in blue. A value of CPI is greater at top than at bottom in the same colored region. It is worthy mentioning that for the fuel study, a number of C-SN and M-SN in the past (20) are the same in the present. Namely they are 9 C-SN and 7 M-SN. This might be implied that NSR on fuel field kept the almost the same potential from the past to the present. For the thermal hydraulic study, however, the numbers of C-SN were decreased from 9 to 4. Namely, research potentials are reduced. The tendency is similar in the risk analysis at severe accident. To our surprise, a rapid ascension occurred at reprocessing field, where 2 C-SN at past (20) increased to 9 at the present. The observed tendencies by *S x L matrix* coincided well with those observed in the previous section.

(2) Impact of TMI-2 on NSR-JAERI

The impact of the TMI-2 accident (1979) on NSR-JAERI might be clarified by matrix L7 x S4. The matrices before and after the TMI-2 accident are directly compared and result is shown in **Fig. 6**. Impact of TMI-2 might be significant on Source Term and Accident Management because their CPI is increased much after TMI-2 accident. For Accident Management, a man-machine communication is an important research field because one of the key igniters of the accident was a human error caused by the miscommunication between the reactor operators and the machines installed for reading steam flow at the pressure accumulator. Source Term is related to fission products (FP) released from the damaged core of TMI-2. Data point of Seismic PSA is also significant but it should be ignored because TMI-2 had no relation to seismic. The remainders did not show the CPI increase after the TMI-2 for the present study.

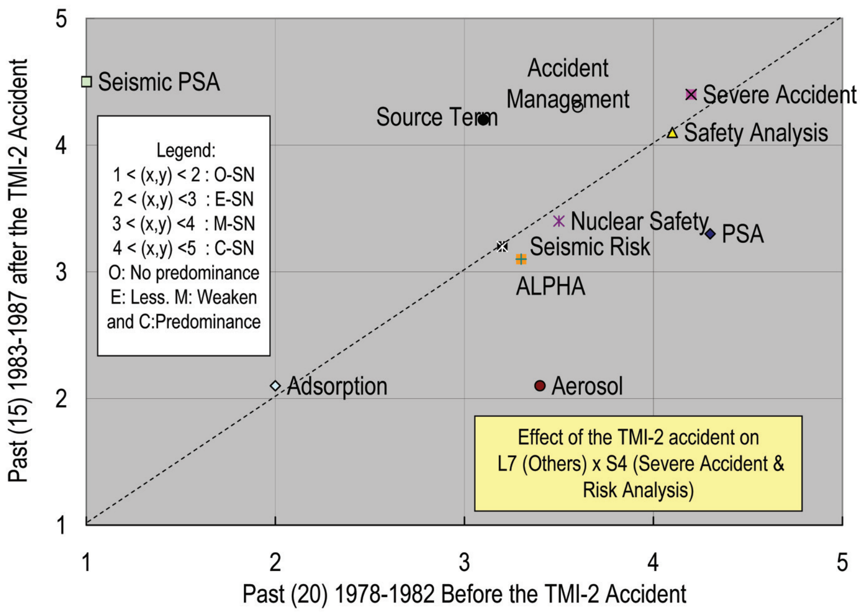

Fig.6 The magnitude of impact caused by the TMI-2 accident. The verification was made on a total of 11 keywords associating with L7 (Others) x S4 (Severe accident & Risk analysis); For example, Accident Management (circle) was associated with the M-SN at past (20) / before TMI-2 and was changed to C-SN at past (15) / after TMI-2. The impact of TMI-2 was judged to be significant for this case.

4 Conclusions

From the present bibliometric study, the followings are obtained.

(1) It is revealed that NSR-Japan over 25 years were totaled about 180,000 research papers, corresponding to about 8% of the world's sum. NSR-Japan is the 2nd largest country followed by the USA. In Japan the share of JAERI was approximately 25%, although the present study has a bias for JAERI.

(2) CPI study over 25-years revealed that JAERI had predominance in 39 (40%) fields out of 97; they are LSTF, small break, NSRR, critical safety and so on. This means that JAERI is still taking an important role in nuclear safety area.

(3) In early stage of 25-years LOCA and TMI-2 were studied with high activities. However, in late stage reprocessing and critical safety were more active. NSR-JAERI is changing its stress point from reactor-oriented accidents to the downstream of nuclear fuel cycling.

(3) TMI-2 accident gave marked impacts on NSR-JAERI represented by thermal hydraulics, LOCA, severe accident and risk analysis.

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国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度，質量密度	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
量濃度[(a)]，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率[(b)]	（数字の） 1	1
比透磁率[(b)]	（数字の） 1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン[(b)]	rad	1 [(b)]	m/m
立体角	ステラジアン[(b)]	sr[(c)]	1 [(b)]	m^2/m^2
周波数	ヘルツ[(d)]	Hz		s^{-1}
力	ニュートン	N		$m\ kg\ s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N m	$m^2\ kg\ s^{-2}$
仕事率，工率，放射束	ワット	W	J/s	$m^2\ kg\ s^{-3}$
電荷，電気量	クーロン	C		s A
電位差（電圧），起電力	ボルト	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
電気抵抗	オーム	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
磁束	ウエーバ	Wb	Vs	$m^2\ kg\ s^{-2}\ A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
セルシウス温度	セルシウス度[(e)]	℃		K
光束	ルーメン	lm	cd sr[(c)]	cd
照度	ルクス	lx	lm/m^2	$m^{-2}\ cd$
放射性核種の放射能[(f)]	ベクレル[(d)]	Bq		s^{-1}
吸収線量，比エネルギー分与，カーマ	グレイ	Gy	J/kg	$m^2\ s^{-2}$
線量当量，周辺線量当量，方向性線量当量，個人線量当量	シーベルト[(g)]	Sv	J/kg	$m^2\ s^{-2}$
酸素活性	カタール	kat		$s^{-1}\ mol$

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で"radioactivity"と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	$m^{-1}\ kg\ s^{-1}$
力のモーメント	ニュートンメートル	N m	$m^2\ kg\ s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg\ s^{-2}$
角速度	ラジアン毎秒	rad/s	$m\ m^{-1}\ s^{-1}=s^{-1}$
角加速度	ラジアン毎秒毎秒	rad/s^2	$m\ m^{-1}\ s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg\ s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2\ kg\ s^{-2}\ K^{-1}$
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	$m^2\ s^{-2}\ K^{-1}$
比エネルギー	ジュール毎キログラム	J/kg	$m^2\ s^{-2}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	$m\ kg\ s^{-3}\ K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1}\ kg\ s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m\ kg\ s^{-3}\ A^{-1}$
電荷密度	クーロン毎立方メートル	C/m^3	$m^{-3}\ sA$
表面電荷	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
電束密度，電気変位	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
誘電率	ファラド毎メートル	F/m	$m^{-3}\ kg^{-1}\ s^4\ A^2$
透磁率	ヘンリー毎メートル	H/m	$m\ kg\ s^{-2}\ A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2\ kg\ s^{-2}\ mol^{-1}$
モルエントロピー，モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	$m^2\ kg\ s^{-2}\ K^{-1}\ mol^{-1}$
照射線量（Ｘ線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1}\ sA$
吸収線量率	グレイ毎秒	Gy/s	$m^2\ s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4\ m^{-2}\ kg\ s^{-3}=m^2\ kg\ s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2\ sr)$	$m^2\ m^{-2}\ kg\ s^{-3}=kg\ s^{-3}$
酵素活性濃度	カタール毎立方メートル	kat/m^3	$m^{-3}\ s^{-1}\ mol$

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	µ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表６．SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	$1ha=1hm^2=10^4m^2$
リットル	L，l	$1L=1l=1dm^3=10^3cm^3=10^{-3}m^3$
トン	t	$1t=10^3\ kg$

表７．SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	$1eV=1.602\ 176\ 53(14)\times10^{-19}J$
ダルトン	Da	$1Da=1.660\ 538\ 86(28)\times10^{-27}kg$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$1ua=1.495\ 978\ 706\ 91(6)\times10^{11}m$

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	$1\ bar=0.1MPa=100kPa=10^5Pa$
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	$1\ Å=0.1nm=100pm=10^{-10}m$
海里	M	1 M=1852m
バーン	b	$1\ b=100fm^2=(10^{-12}cm)2=10^{-28}m^2$
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\ s\ cm^{-2}=0.1Pa\ s$
ストークス	St	$1\ St=1cm^2\ s^{-1}=10^{-4}m^2\ s^{-1}$
スチルブ	sb	$1\ sb=1cd\ cm^{-2}=10^4cd\ m^{-2}$
フォト	ph	$1\ ph=1cd\ sr\ cm^{-2}\ 10^4lx$
ガル	Gal	$1\ Gal=1cm\ s^{-2}=10^{-2}ms^{-2}$
マクスウェル	Mx	$1\ Mx=1G\ cm^2=10^{-8}Wb$
ガウス	G	$1\ G=1Mx\ cm^{-2}=10^{-4}T$
エルステッド[(c)]	Oe	$1\ Oe \triangleq (10^3/4\pi)A\ m^{-1}$

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R=2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
ガンマ	γ	1 γ=1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	µ	$1\ \mu=1\mu m=10^{-6}m$

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