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An Outcome of Nuclear Safety Research in JAERI

-Case Study for LOCA, FP, Criticality and Reprocessing-

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An outcome of nuclear safety research done by JAERI was case studied by the bibliometric method. (1) For LOCA (loss-of-coolant accident) a domestic share of JAERI in monoclinic research paper was 63% at the past (20) 1978-1982 but was decreased to 40% at the present 1998-2002. For co-authored papers a domestic share between JAERI and PS (public sectors) is almost zero at past (20) but increased to 4% at the present. Research cooperation is active between Tokyo University and JAERI or between JAERI and Nagoya University. (2) Project-type research is to have a large monopolization in papers and that of basic-type research is to have a large development of reseach networking (DRN). (3) For FP, a share of co-authored paper is high due to an enhanced cooperation among JAERI-PO (Public Organization)-PS. For criticality, research activity was enhanced after JCO accident, especially at NUCEF. (4) For reprocessing, PS had a monopolistic position with a domestic share of 71% and a share of JAERI was about 20%. (5) LOCA and RIA outputs born by NSR-JAERI coincided partly to those of the Safety Licensing Guidelines but a share of contribution done by JAERI was ambiguous due to the lack of necessary information.

Keywords: Bibliometric, Nuclear Safety Research, Outcome, LOCA, FP, Criticality, Reprocessing, Development of Research Networking

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原研における原子力安全性研究のアウトカム
-冷却材喪失事故、核分裂生成物、臨界および再処理に関するケーススタディ-

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原研で実施された原子力安全研究のアウトカムにつき計量書誌学的手法を用いた個別事例研究を行った。（１）Past(20)1978-1982 の 5 年間における LOCA(冷却餧喪失事故)研究では、原研研究員を筆頭著者とする単独論文の国内シェアは 63%を占めていたが、present1998-2002 の 5 年間ではそのシェアは 40%に減少した。原研の著者を筆頭著者とする公的研究機関との共著論文は、past(20)では殆どゼロであったが present では 4%にまで増加した。（２）プロジェクト研究では単独論文の数が大きくなる傾向にあるが、基礎研究では共著論文の数が大きくなって研究ネットワーキングが進展する。（３）核分裂生成物（FP）研究では、原研-民間-公的研究機関の間の共同研究が盛んで共著論文のシェアが大きくなる傾向にある。臨界(Criticality)研究では、JCO の事故により研究が加速され、特に NUCEF での研究が加速された。（４）再処理(Reprocessing)研究では、公的研究機関の国内シェアが 71%を占め原研のシェアは約 20%であった。（５）原研の安全性研究から生まれた冷却材喪失事故や反応度事故（RIA）の成果は、部分的に安全審査指針に取り込まれている事は分かったが、原研の寄与率は必要な情報が十分でなく求まらなかった。

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1 Introduction

In our previously study [1-3], a predominance of nuclear safety research conducted by Japan Atomic Energy Research Institute (JAERI♣1) was examined by the comparative predominant index (CPI). The conclusion was that the nuclear safety research in JAERI ((hereinafter abbreviated as NSR-JAERI) is still keeping an important role in this field. Additionally, it is revealed that NSR-JAERI changes its stress point from the reactor-oriented accident to the downstream of nuclear fuel cycling. In the present paper, to study an outcome of NSR-JAERI we made a case study. Parameters considered are LOCA (loss-of-coolant accident)♣2 , fission products (FP), Criticality and Reprocessing. Our main interest is to know how those parameters developed a research networking during past 25-year period. As to the case of LOCA, an influence of outcome of NSR-JAERI on the existing Safety Licensing Guideline prepared for ECCS/LOCA in Japan is studied.

2 Methodology

2.1 Development of research networking (DRN)

To visualize DRN quantitatively, NSR papers published by JAERI, PS (Public Sectors) and PO (Private Organizations) were indexed by the affiliation of the first author as a function of research time span; every 5 and 25 years. The DRN is shown by a rectangular shape as depicted in **Fig. 1.** To make more detail analysis, we developed a SOCIOECO computer code [4], which can discriminate the affiliations of all authors in a paper and journalize it as the JAERI-PS -PO. The further details are as follows:

- One paper is corresponded to the rectangular area of 1mm x 1mm. A whole area of the rectangular shape is proportional to the total number of indexed papers. The scale is absolute at all representations.
- The area shown by ①, ② and ③ represents the total number of *single* organization papers, where the author(s) belongs to a single organization. The magnitude of the

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♣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 socio-economic evaluation of the Nuclear Safety Research that has been carried out by JAERI.

♣2 According to the Joint Thesaurus prepared by IAEA (2002), *LOCA* is recommended to be used in the form of *loss of coolant* when one inputs it into the INIS. Indeed, the number of papers found using *LOCA* is very low compared with those found using *loss of coolant*. For INIS operation we used *loss of coolant* instead of *LOCA*.

area is proportional to the number of papers published by JAERI, PS and PO. If it is necessary, PS is further divided into GS (Government Sectors; left) and U (Universities; right), separated by the dotted line. This indicates the magnitude of monopolization.

- The area shown from A to F represents the total number of co-authored or multiple organization papers, where the authors in a paper belonged to two different organizations. Strictly speaking, area A shows the total of co-authored papers between JAERI and PS while area C shows those between PS and JAERI. In the subsequent sections, the sum of A and C is used frequently.
- The area shown by G represents the total number of co-authored or multiple organization papers from three or more different organizations. The area is usually small in magnitude, if the research networking among JAERI-PS-PO is not developed well. However, as discussed in the **Appendix I,** it will be large enough when a mutual collaboration among JAERI-PS-PO is activated. In the illustration, it is denoted as TR (triplet).

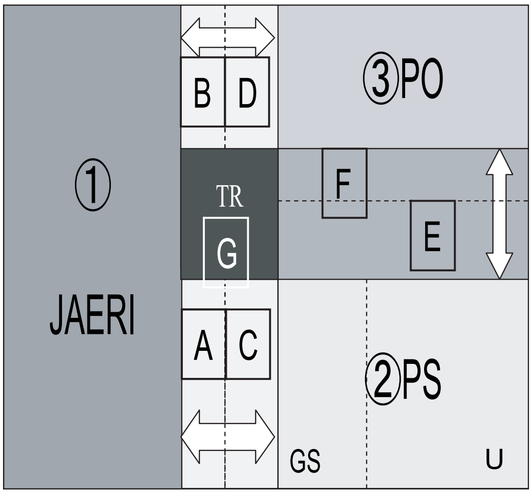

Fig. 1 Definition of the development of research networking (DRN) ; one paper corresponds to an area of I mm^2. A whole area corresponds to a total number of research paper studied. Area A+C, E+F, B+D and G are corresponding to co-authored or multiple organization papers between JAERI-PS, PS-PO, PO-JAERI and JAERI-PS-PO, respectively. Area ①,② and③ corresponds to single organization paper represented by JAERI, PS and PO.

2.2 S-matrix

To build a framework of NSR-JAERI, we picked up the top (97) keywords from JOLIS database, which was fabricated by JAERI. So, the results of this bibliometric study are inevitably biased for JAERI. To counteract this negative image, *S-matrix* is prepared. A main role of it is to consider more about co-authored papers than single organization paper. The basic concept may be understandable by the following example.

Example:

At past (10)1988-1992, a keyword LOCA was used as input of INIS. Output of INIS prepared for bibliometric study is stored first by SOCIECO computer for determining an organization (affiliation) belonged to the 1st author. As shown in **Table 1,** a number of LOCA papers belonged to JAERI are found to be 154, while those belonged to Toshiba Corporation are 38 and so on. A total sum of the row 2 in the table is as many as 312. SOCIOECO operated and found that co-authored papers of JAERI (1st author) -Tokyo University (2nd author) are 3 and those of JAERI (1st author)-MAPI (2nd author) are as many as 1. This was repeatedly done to the last.

Table 1 Partial result of SOCIOECO analysis; keyword=LOCA, past (10)1988-1992
Total papers from rank1 to rank 40 are 312

Rank	Papers	Organization	JAERI	Toshiba	Hitachi	Tokyo U	NAIG	MHI	Kyoto U	MAPI	NFI	TITECH
1	154	JAPAN ATOMIC ENERGY RESEARCH INST(JAERI)	0	0	0	3	0	0	0	1	0	0
2	38	TOSHIBA CORP	0	0	0	2	0	0	0	0	0	0
3	19	HITACHI LTD	0	0	0	0	0	0	0	0	0	0
4	9	TOKYO UNIV (TokyoU)	3	0	1	0	0	0	0	1	0	0
5	9	NIPPON ATOMIC INDUSTRY GROUP CO (NAIG)	0	1	0	0	0	0	0	0	0	0
6	8	MITSUBISHI HEAVY IND (MHI)	0	0	0	1	0	0	0	0	0	0
7	7	KYOTO UNIV (KyotoU)	0	0	0	0	0	0	0	0	0	0
8	5	MITSUBISHI ATOMIC POWER IND(MAPI)	0	0	0	1	0	1	0	0	0	0
9	5	NUCLEAR FUEL IND (NFI)	0	0	0	0	0	0	0	0	0	0
10	5	TOKYO INST. OF TECH (TITECH)	0	1	0	0	0	0	0	0	0	0

S-matrix is formulated generally by

$$= \begin{Bmatrix} S11 & S12 & S13 & S14 & - & S1n \\ S21 & S22 & S23 & S24 & - & S2n \\ S31 & S32 & S33 & S34 & - & S3n \\ S41 & S42 & S43 & S44 & - & S4n \\ - & - & - & - & - & - \\ Sm1 & Sm2 & Sm3 & Sm4 & - & Smn \end{Bmatrix} \cdots\cdots\cdots\cdots /1/$$

Suffix *"m"* is agreed with a total numbers of research organizations registered in INIS. For the demonstrated case, it will be 40. Theoretically, suffix *"n"* is infinite depending on the numbers of co-authored papers. Here, we set it as 40. Due to this treatment, a size of *S-matrix* for the LOCA at past (10) is *(m, n) = (40, 40).* Practically, what we obtained from SOCIOECO study is as follows.

$$\begin{Bmatrix} JAERI-JAERI & JAERI-Toshiba & JAERI-Hitachi & JAERI-TokyoU & - & S1n \\ Toshiba-JAERI & Toshiba-Toshiba & Toshiba-Hitachi & Toshiba-TokyoU & - & S2n \\ Hitachi-JAERI & Hitachi-Toshiba & Hitachi-Hitachi & Hitachi-TokyoU & - & S3n \\ TokyoU-JAERI & TokyoU-Toshiba & TokyoU-Hitachi & TokyoU-TokyoU & - & S4n \\ - & - & - & - & - & - \\ Sm1 & Sm2 & Sm3 & Sm4 & - & Smn \end{Bmatrix}$$

Although JAERI (first author's affiliation)–JAERI (second author's affiliation) is so-called "single organization paper" existed as many as 154, we set it as zero because *S-matrix* is prepared only for counting co-authored papers. Therefore *S-matrix* will be

$$\begin{Bmatrix} 0 & 0 & 0 & 3 & - & S1n \\ 0 & 0 & 0 & 2 & - & S2n \\ 0 & 0 & 0 & 0 & - & S3n \\ 3 & 0 & 1 & 0 & - & S4n \\ - & - & - & - & - & - \\ Sm1 & Sm2 & Sm3 & Sm4 & - & Smn \end{Bmatrix} \cdots\cdots\cdots\cdots\cdots\cdots /2/$$

Numerals seen from the row 4 to the row 13 in the table is coincided with those shown in the equation /2/. Where, diagonal elements $\{Smn, m = n\}$ are zero as mentioned in the above. Elements, for example, $\{S11,\ S12,\ -,\ -,\ S1n\}$ are the co-authored papers where the 1st author affiliated to JAERI and the 2nd authors are individually affiliated to Toshiba, Hitachi, Tokyo University and so on.

Conversely, elements $\begin{Bmatrix} S11 \\ S21 \\ - \\ - \\ Sm1 \end{Bmatrix}$ are the co-authored papers where the 2nd author was fixed to JAERI and the 1st authors are individually affiliated to Toshiba, Hitachi, and Tokyo University and so on. During this procedure, any institute which has not the honor of a 1st author at all, then the *S-matrix* cannot register his name. Detail results about LOCA is shown in the subsequent section together with data plotting.

3 Results and Discussion

3.1 Development of Research Networking

Of selected four keywords, LOCA and FP represent the reactor-oriented accidents and Criticality and reprocessing do the down stream of nuclear fuel recycling.

(1) LOCA

For almost 25 years, LOCA kept the 1st rank out of top (97). CPI(Comparative predominance index), however, pointed out that the real activity of LOCA did not constant as shown in **Fig. 2.** The LOCA activity became peak at the past (15) 1983-1987 and started to decrease towards the present 1998-2002.

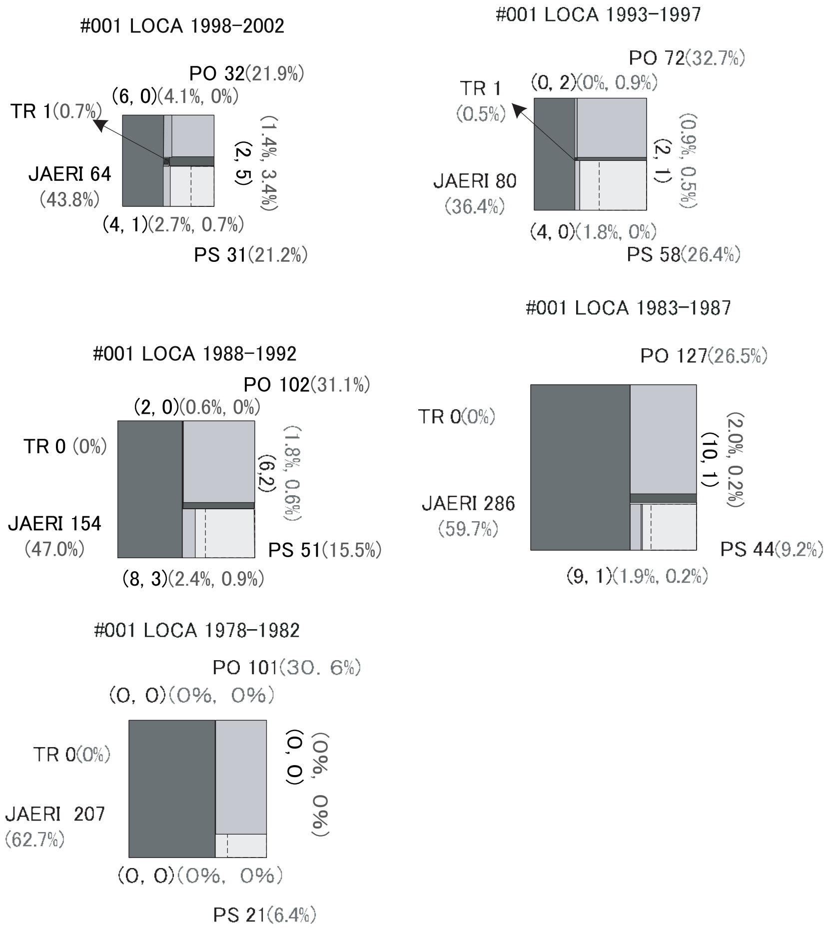

Fig.2 DRN of LOCA

As shown in **Fig. 3,** during past (20)1978-1982, JAERI (full circle) shared 63% of the total LOCA papers in Japan, while PO [asterisk (*)] shared about 30%. Co-authored papers at the period were negligible. During past (15) hence after occurrence of TMI-2, LOCA papers as seen in the Fig.2 increased to the maximum (479 papers). At this period, co-authored papers between JAERI-PS (U, GS) and PS-PO became significant and increased to a magnitude of 2%, that is, 10 papers. Taking this period as a turning-point, LOCA activities in JAERI started to decrease as much as about 40%, though it was a still high level. One of principal reason for this phenomenon may be the set up of ECCS Guideline performed by the Japanese Authority. The share of PO did not change the level of 30%. Chernobyl accident occurred in the period of past (15) gave less impact on LOCA study.

At the present, the co-authored papers between JAERI-PS, JAERI-PO, and PS-PO increased the value as much as about 4% Though the value is small in magnitude, increase of co-authored papers from 2% (past (15)) to 4% (present) is impo rtant because DRN is more activated among competing researching bodies. TR (JAERI-PS-PO) for LOCA is negligible. It can be said from the aforementioned fact that JAERI had a big predominance for LOCA study.

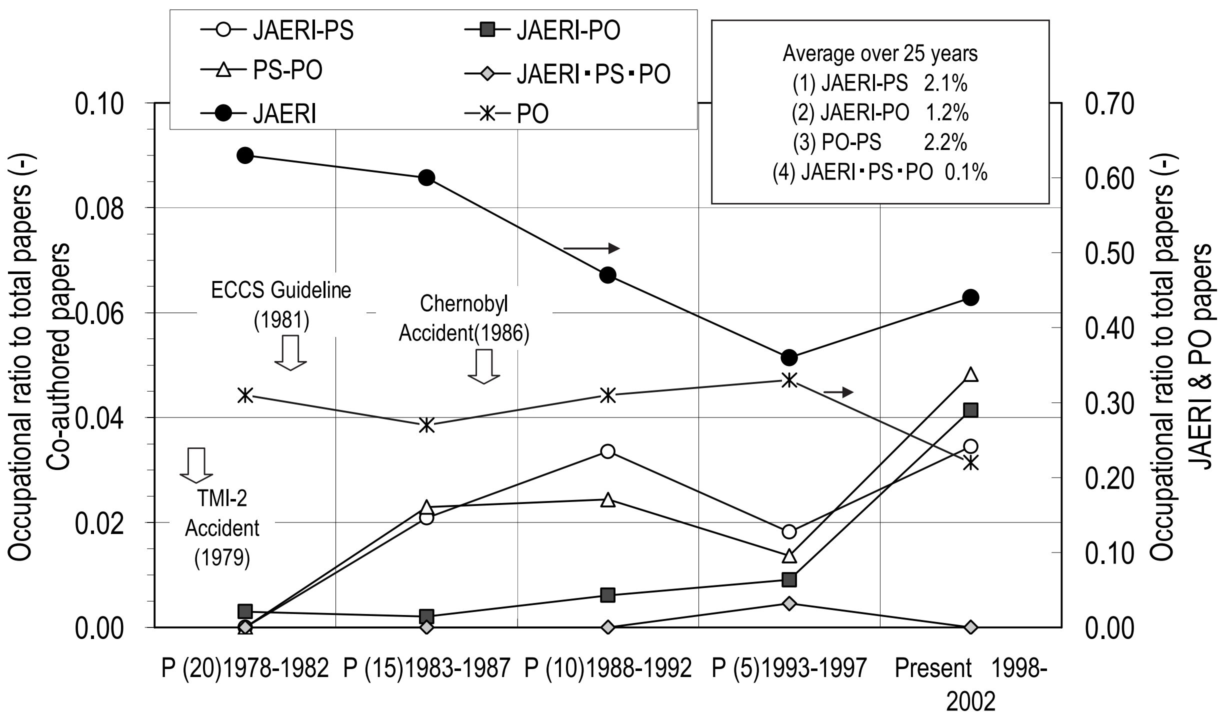

Fig. 3 Occupational ratio to total papers per 5 years is plotted for the co-authored papers (left-hand side) and for JAERI and PO papers (right-hand side). Total papers from the past (20) to the present are 330, 479, 328, 220 and 145. The occurrence of the TMI-2accident and Chernobyl accidents and the set up of ECCS (emergency core cooling system) guideline is indicated by an arrow.

-S-matrix of LOCA

For LOCA, a total sum of co-authored papers became peak at past (10) 1988-1992. Because affiliation of the 1st author was journalized into 40, SOCIOECO had a 40 x 40 matrix. Due to limited space, here, a 14 x 14 matrix instead of a 40 x 40 is shown in **Fig. 4.** To show the data point clearly, we set the JAERI at the front corner. If you looked into X-axis (the 1st column) , JAERI is fixed as the 2nd author and (GS, U, PO) is fixed as the 1st author (Toshiba Corporation-JAERI, Hitachi Ltd.-JAERI, Tokyo University-JAERI and so on). The number of co-authored papers is shown in the Z-axis (0 for Toshiba-JAERI but 3 for Tokyo University-JAERI). This leads that as a research partner of LOCA, JAERI worked well with Tokyo University.

Similarly, the 2nd column shows the Toshiba Corporation as the 2nd author (JAERI-Toshiba Corporation, Hitachi Ltd.-Toshiba Corporation, Tokyo University-Toshiba Corporation and so on).

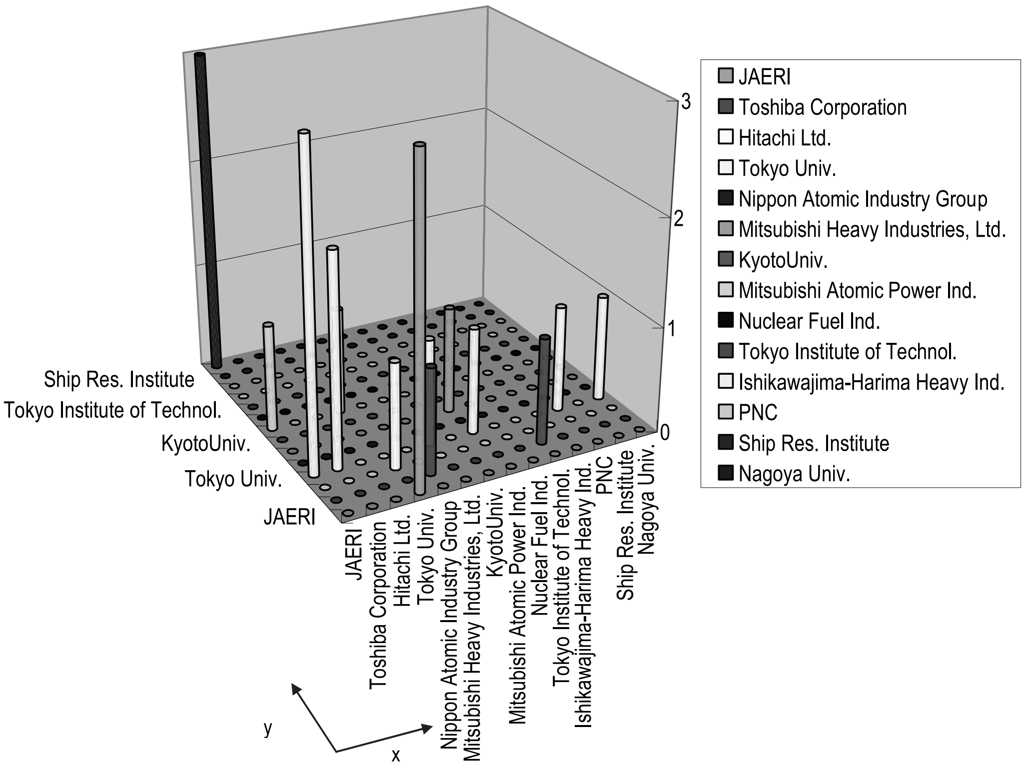

Fig. 4 Co-authored papers for LOCA, those are indicated by a 14x14 S-matrices; the x-axis(1st column) shows JAERI as the 2nd author in the co-authored paper while the y-axis(1st row) shows JAERI as the 1st author in the co-authored paper. Data are for the past (10)1988-1992.

The co-authorship is established not only at the Nippon Atomic Industry Group (NAIG)-Toshiba Corporation (one co-authored paper) but also at Tokyo Institute of Technology-Toshiba Corporation (one co-authored paper). For the 3rd column, the Hitachi Ltd. is the case (JAERI-Hitachi, Toshiba-Hitachi, Tokyo University-Hitachi and so on.). Co-authorship is observed at Tokyo University-the Hitachi Ltd (one co-authored paper). For the 4th column, Tokyo University is the case. Tokyo University had a good cooperation with JAERI, Toshiba Corporation, Kyoto University, Mitsubishi Atomic Power Industry (MAPI), PNC and Nagoya University. Namely, Tokyo University is superior to having multiple research cooperation with other institutions.

Reversely, Y-axis (the 1st row) fixed JAERI as the 1st author and (GS, U, PO) as the 2nd author. There existed a good cooperation between JAERI-Tokyo University (3 papers), JAERI-MAPI (1 paper) and JAERI-Nagoya University (3 papers). For the 2nd row, Toshiba Corporation is fixed as the 1st author. The Toshiba Corporation worked well with Tokyo University (two papers). As a result of good cooperation JAERI (the first author)-Tokyo University (the second author) could produce three co-authored papers and Tokyo University (the first author)-JAERI (the second author) also published three papers. As shown here, the *S-matrix* can succeed to show the DSN between the different organizations. For JAERI, the research cooperation is significantly established at Tokyo University-JAERI and JAERI-Nagoya University.

Comparison of LOCA with Neutron

The comparison is interesting because LOCA is the typical project-type research and neutron is the typical basic science in JAERI. Results born at the past (15) are shown in **Fig. 5.** To our surprise, DRN of neutron is about five times the LOCA. On the other hand, the monopolized rate in JAERI is 20% for neutron and 60% for LOCA, because the former is studied aiming at reflecting its achievements to a variety of research subjects and the latter is studied aiming at reflecting its achievements on regulatory aspects. It is typical to say that project-type research tended strongly to have monopolization than basic-type research.

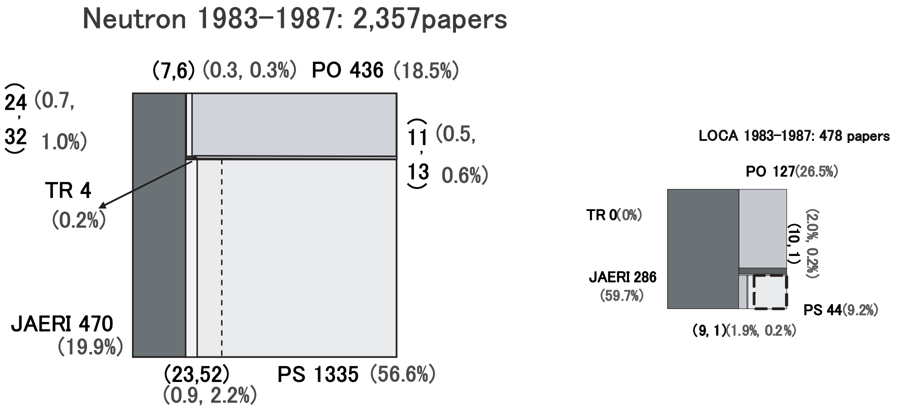

Fig. 5 Research networking of neutron (left) and that of LOCA (right) during the past (15)1983-1987. It is worth to mention that neutron (2,357 papers in total) represents the study of basic science and LOCA (478 papers in total) represents the study of the nuclear safety project. The dimensional scale between the two was fixed at the same level.

(2) FP (fission products)

The term FP was ranked at 59th in top (97) keywords and judged as predominance. FP is important for designing LWR fuel rod integrity under steady-state operation because its increase is directly correlated to rod internal pressure. Additionally, during a reactor accident, FP will be released from the degraded reactor core to the environment. Preventing people from radiation exposure, a safety evaluation for FP is imposed for licensing procedure. **Fig. 6** shows the DRN of FP. It is significant to mention that the well-developed cooperation is observed among JAERI-PS-PO; where PO keeps high share. Co-authored papers between JAERI and PS was 0.3% during past (20) but increased up to 6% at the present. Total papers produced over 25 years were 2,250. FP is a typical project-type research. The main reason for high share of co-authored papers is attributed to the use of a hot cell facility, which is usually located at the district nuclear sites. In the hot-cell, many researchers have to collaborate with others, especially during the post-irradiation examination.

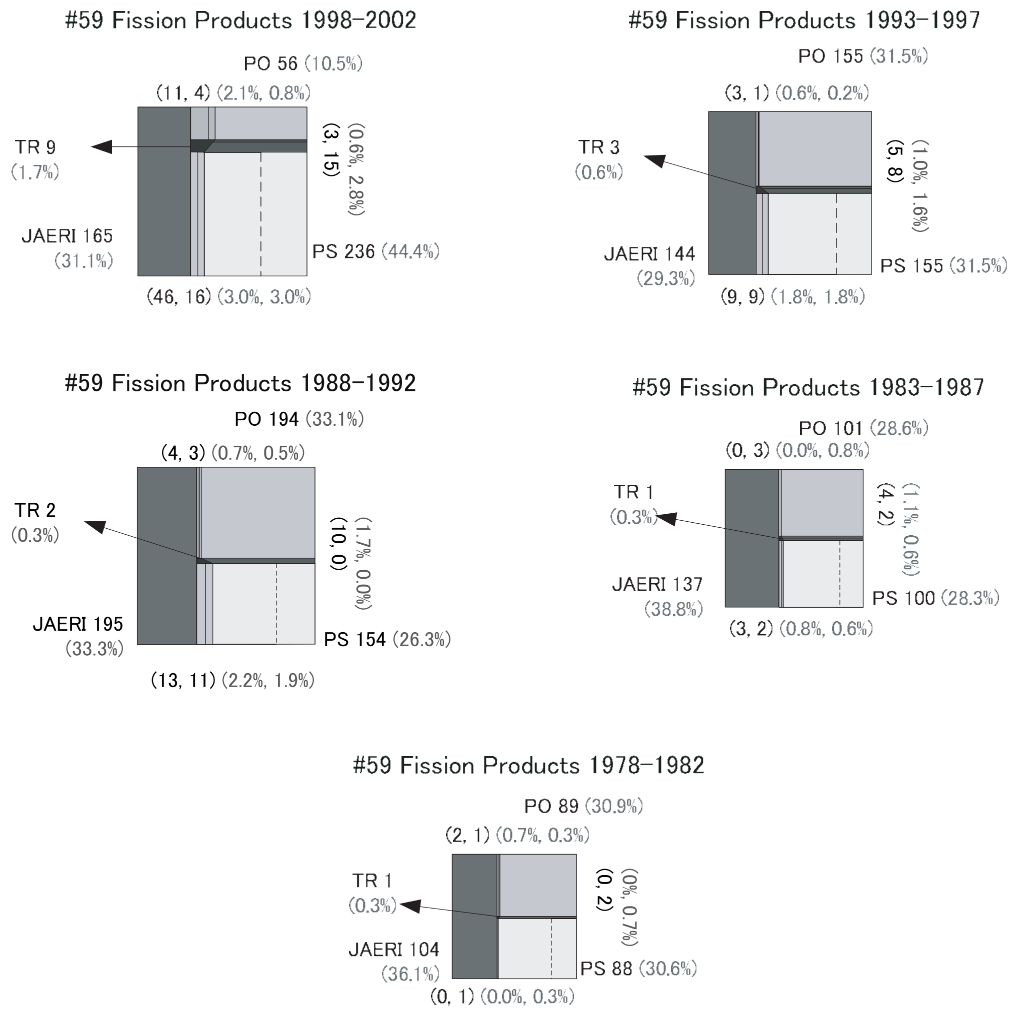

Fig.6 Socio-economic networking (SEN) of FP (fission products)

(3) Criticality

Criticality was ranked at 39^{th} of the top {97} and judged as predominance. Its DRN is shown in **Fig. 7.** The total area (that is the same as research activity) increased gradually and lastly became largest at the present 1998-2002. This is reverse to the LOCA case. Most JAERI facilities such as TCA (tank-type critical assembly) and NUCEF[♣3] are located at the fields for reprocessing. With respect to DRN, total papers from the past (20) to the present varied from 95 to 498. For JAERI monopoly papers, the numbers were increased from 52 (55%) to 194 (39%). The reduction of the percentage was

[♣3] NUCEF: The nuclear fuel cycle engineering facility established at 1994. This enabled the carrying out of safety related experiments on solvent spent fuel in the form of uranium and plutonium.

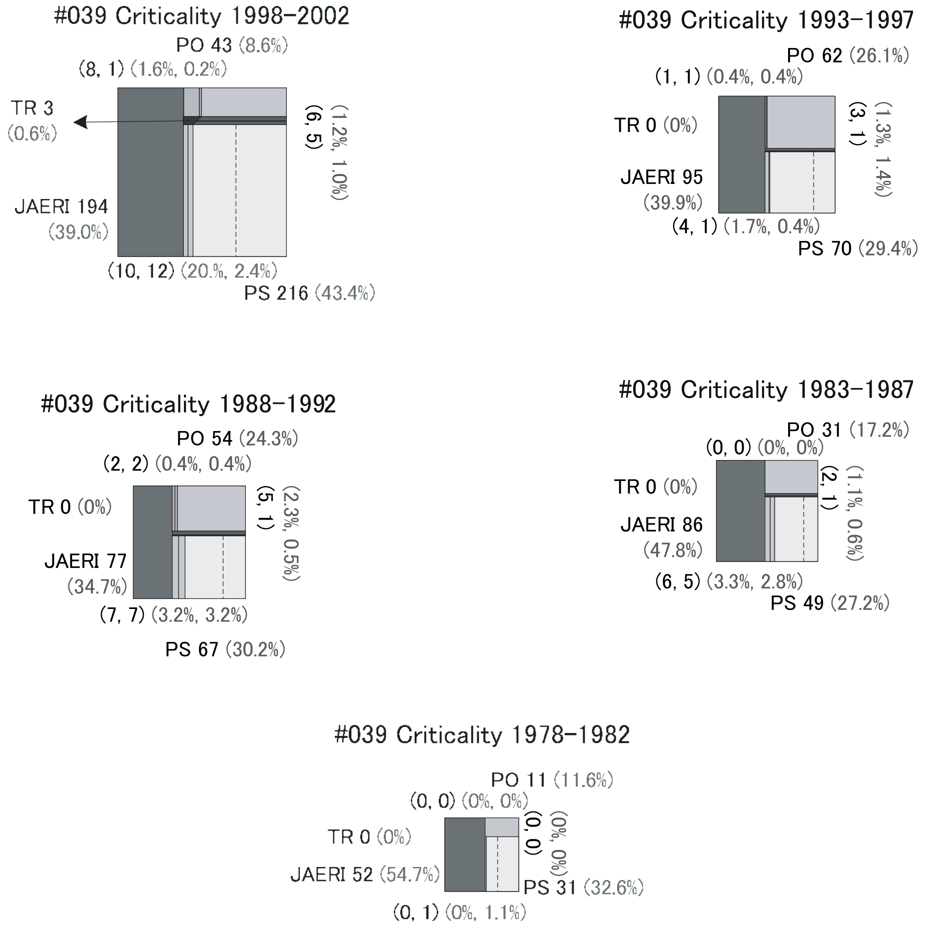

Fig.7 DRN of criticality, criticality is the representative keyword in the down stream of nuclear fuel recycling. The whole size o f DRN increased from the past to the present.

influenced by the increased share at PS; namely, the co-authored papers between JAERI and PS was about 1% at the beginning but increased recently to about 4%.

The JCO criticality accident that occurred in 1999 in Tokai-mura, Ibaraki, Japan♣4 may have had an impact on a variety of studies related to criticality, because several post-accident tests were necessary to carry out at the NUCEF facility. A total of 1,233 papers of criticality were published over a 25-year period.

(4) Reprocessing

DRN

Reprocessing was ranked at 6th of the top (97) and judged as weaken predominance.

♣4 According to Dr. F. Tanabe (2005), this JCO criticality accident occurred on September 30th, 1999. JCO operators poured Uranyl-Nitrate solution (>16.6kg-U, 18.8% enriched U) into a deposition tank having a critical mass limit of 2.4kg-U.

This technical term is very classical. Related studies were promoted vastly in foreign countries other than in Japan. For example, during the past (20) Japan's share (201 papers) was only 5%; it was small to the world (3,662 papers). However, at the present, Japan's share (673 papers) has increased to 25%; it was large to the world's share (2,687papers). For more quantitative understandings, **Fig. 8** is shown. During past (20)1978-1982, PS (cruciform symbol) had a top share of 71% because the full-scale operation of reprocessing facilities in PNC♣5 (one of PS) was started. The share of JAERI (full circle) was about 20% and that of PO (asterisk mark) was 9%. The percentage in JAERI and PO were comparatively lower than that of PS represented by PNC. Co-authored papers are negligible; indicating that research communication among JAERI-PO-PS was not enough. Partly because of the success of full-scale operation, PS tended to decrease the actual activity at the past (15). However, PO behaved reversely. This different behavior between PS and PO may be attributed to some kinds of reasons

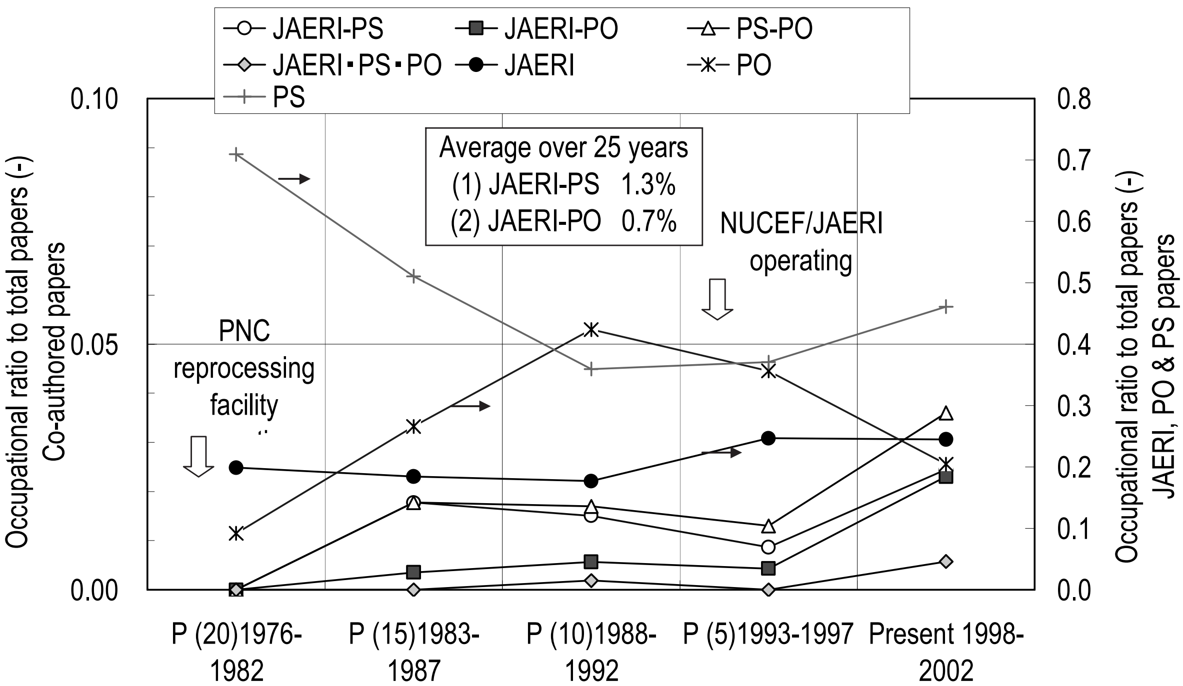

Fig. 8 Occupational ratio to total papers per five-year period is plotted for the co-authored papers (left-hand side) and for JAERI, PO and PS papers (right-hand side). Total numbers of papers from the past (20) to the present are 196, 282, 531, 693 and 694, respectively. The initiation of full-scale operating of reprocessing facilities at PNC

♣5 PNC: Power Reactor & Nuclear Fuel Development Corporation, the predecessor of the Japan Nuclear Cycle Development Institute (JNC). In 2005, it reorganized further to become JAEA (Japan Atomic Energy Agency).

and that of NUCEF at JAERI is indicated by arrows.

what we can not clarify. The activity of JAERI, however, was accelerated from the early stage of P (5) because of the full-scale operation started from NUCEF facilities (1994). The share at that period was about 30%. This situation coincided with the CPI analysis done before [2]. Differing from the aforementioned section, DRN at PS-PO (triangle) was larger than that of JAERI-PS (open circle). The *S-matrix* (see below) will be relied on to support this tendency.

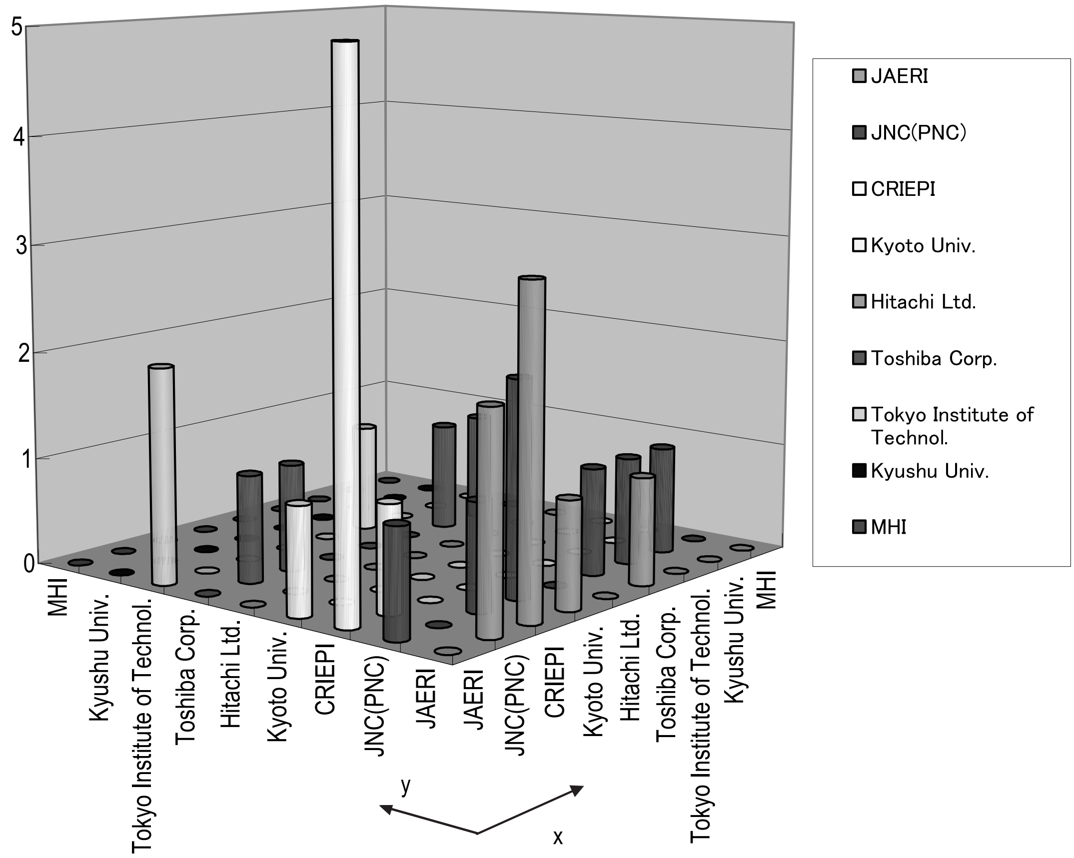

Fig. 9 Co-authored papers for reprocessing, those are indicated by a 9 x 9 S-matrices; the x-axis (1st column) shows JAERI as the 2nd author in the co-authored paper. Hence, for example there existed two papers between JNC (1st author)-JAERI (2nd author). Y-axis (1st row) shows JAERI as the 1st author in the co-authored paper. Hence, for example, there exited one paper between JAERI (1st author)-JNC (2nd author). Data are for the present 1998-2002.

S-matrix

To understand more the cooperation observed between PS-PO, a 95 x 95 S-matrix was prepared for the present 1998-2002 case. At least 95 organizations were cooperated during that period. **Figure 9** is a 9 x 9 matrix chosen from original 95 x 95, which includes JAERI (170), JNC (G, 189), CRIEPI♣6 (G,47), Kyoto University (U,27), Hitachi Ltd. (PO, 16), Toshiba Corporation (PO,15), Tokyo Institute of Technology (U,15), Kyushu University (U, 10) and Mitsubishi Heavy Industries Ltd. (hereinafter abbreviated as MHI: PO,9). The numeral in each parenthesis shows the total numbers of papers published♣7. In this plot, the research activity of JAERI-CRIEPI or CRIEPI-JAERI is significantly high in magnitude. Except for JAERI, JNC had a good collaboration with CRIEPI, Kyoto University, Toshiba Corporation, Tokyo Institute of Technology and Kyushu University. Namely, DRN was increased to the magnitude of 2-3% up to the present 1998-2002. The listed PS-PO had an important role to push the DRN to a relative high value.

3.2 Outcome of NSR-JAERI for setting up of Safety Guideline

The NSR is, so to speak, the primary task imposed from the Government to JAERI, who is known widely as the R&D performer in our country. As described in the **Appendix II**, NSR-JAERI is governed not only by the Long Term Research Plan established by the Atomic Energy Commission but also by the Annual Research Program established by the Nuclear Safety Commission. The existing safety frame for research evaluation can be schematically drawn in **Fig. 10.** For intensive study, NSR outputs are provided widely to variety of policy makers. During licensing, many discussions may be made at the advisory bodies and the special committees in the Nuclear Safety Commission and the Atomic Energy Commission in the Cabinet Office, Government of Japan. Additionally, more concrete outcomes are desired to cause an impact in the course of safety standard establishment and the safety guidelines build up for the existing LWR and nuclear facilities. The result may contribute to the operational stability and dissemination of the conventional LWR.

Here, we studied the relationship between outputs obtained from 4 parameters and the Safety Standards. To date, there exists many important Safety Standards, however, a name or a kind of the main contributor is not cleared in the public records. Therefore, no

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♣6 CRIEPI: Central Research Institute of the Electric Power Industry

♣7 For this presentation, Hitachi Ltd. and the MHI Ltd. had no co-authored papers with the other eight institutions. Depending on the size of the S-matrix, this may happen.

one can construct a quantitative bridge between outputs of 4 parameters and the existing Safety Standards. The difficulty is that for licensing at past decades it was very hard to find out the detailed processes taken by many intellectuals gathered for preparation of licensing guidelines. If one consults a book relating to the Safety Standards, one meets no detail explanation list for the funds invested to and no list of specialists who contributed to the build up of licensing. Key references are only seen at the end of a book. Recently, however, in some cases a list of specialist is attached to the context of book. Under these situations, we tried to clarify the relationship between outcome of 4 parameters and the existing Safety Licensing Guideline.

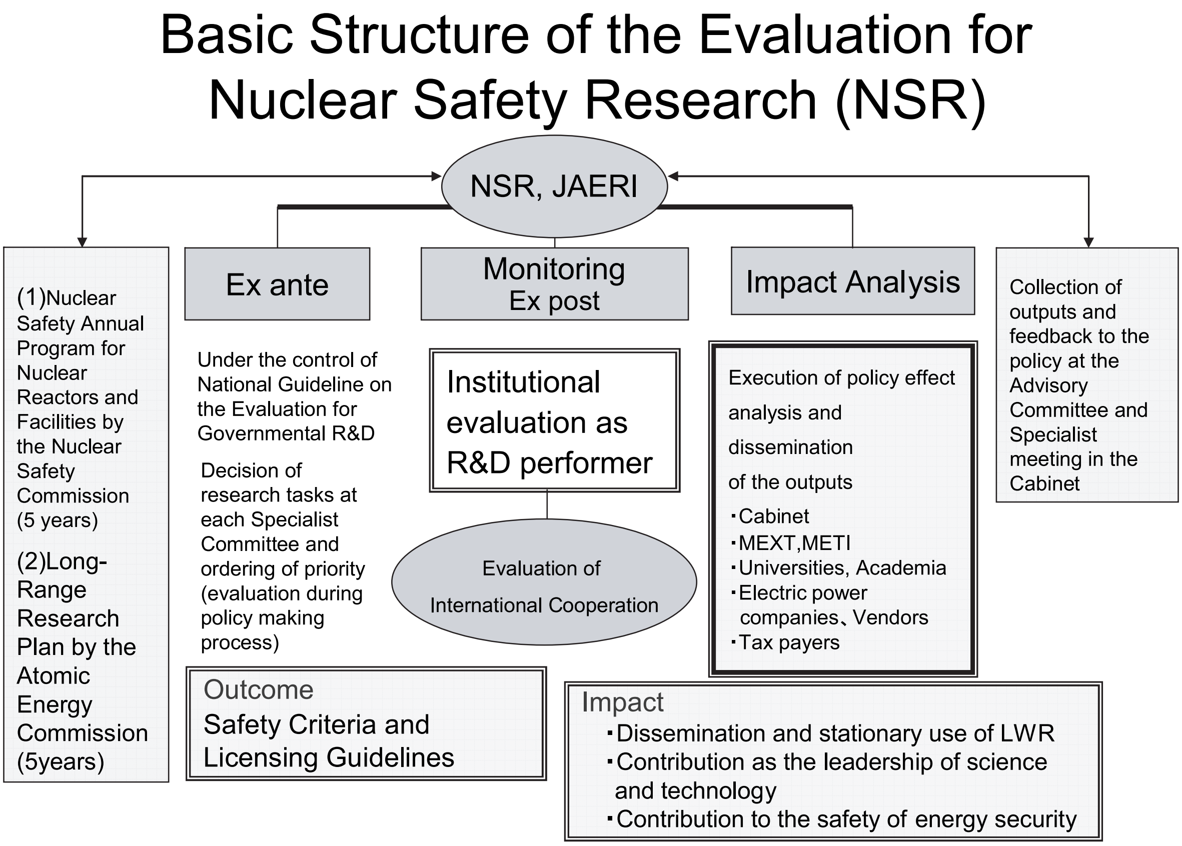

Fig. 10 Basic structure for evaluating the NSR-JAERI

(1)An outcome from fuel research

With respect to a fuel performance study in NSR-JAERI, we have to cite a very classic but a representative international cooperation known as the “Halden Programme”. It was run by OECD/NEA♣8. Since 1967, JAERI participated in the Programme on behalf

♣8 OECD/NEA: Organization for Economic Co-operation and Development/The Nuclear Energy Agency, of Japan and continued to date. The major objective of such a long cooperation is to study nuclear fuel behavior, especially concerning the prevention of LWR fuel failure during steady-state operation and demonstrating the reliability of newly developed LWR remedy fuels as corroborated examination. The role of JAERI is to pay the participant fee (in some cases in-core experimental fee) to the Halden Project and is to dispatch young researchers for working at data acquisition and education. The project provides us the necessary irradiation bed for test of Japanese fuel rods. The obtained fuel behavior data served not only the best interests of JAERI but also those of many fuel vendors. The output data of the project is broadly divided into two categories; one is the common data to be delivered to international participants and the other is the a la carte data to be delivered to the specified country as the tacit knowledge. The irradiation fee for the former is prepared by the project due to the common irradiation experiment and that for the latter is prepared by each participant due to the execution of the optional irradiation experiment.

Usually JAERI serves as the window for receipt of two kinds of data from the project. Obtained data from the Project is handed to domestic PO and PS because so-called Halden collaborative research joint operating committee authorized by JAERI is existed as a domestic mechanism. The committee promoted research networking between JAERI-PO and JAERI-PS. The networking is quite similar to that explained as DRN. Namely, the committee had a function to produce the co-operational data (so to speak; 2nd or 3rd effect) and to deliver those through domestic research networking for better discussion about in-core fuel behavior with the researchers on duty. Of course, this experimental data will be utilized for the verification of the mechanistic physical models installed into a computer code. The representative computer code is known as FEMAXI-III[♣9] developed by JAERI. Of course all results obtained from verification work is disclosed to the public and recognized as an important output of NSR. Through networking, JAERI output is immediately transmitted to relevant PO; they are the nine commercial electric power companies, PWR and BWR fuel fabrication farms represented by MHI., Hitachi Ltd., Nuclear Fuel Industries, Ltd., and CRIEPI . Further they are transmitted not only to PS known as several U (Universities) represented by the University of Tokyo and Osaka University but also to GS represented by PNC. The data

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headquartered in Paris, France. The Halden Programme was started in 1958 under the OECD/NEA. The project is operating the Halden Boiling Water Reactor (HBWR) with coolant pressure at 3.4MPa and coolant temperature at 240 degrees Celsius; the test reactor is located at Halden, Norway.

[♣9]FEMAXI-III: The computer code developed by cooperation between JAERI and PO-PS, which can predict the fuel in-core behavior represented by the fuel temperature, FP gas release, and the cladding inner stress caused by a pellet-cladding mechanical interaction. The code is opened to the public (JAERI-M 83-056).

transmittal is aiming at modifying the conventional fuel fabricating parameters and developing a high performance fuel at the nuclear fuel design office at each company. This is a typical example showing an outcome of NSR-JAERI that contributed markedly to the increase of LWR fuel rod integrity being on sale in our domestic market. The reflection of these domestic and international activities on a cost benefit effect has not been evaluated yet because of a difficulty for determining the share between JAERI and others (PO, PS).

Another important usage of the Halden in-core data is to establish a judging criteria for the prevention of fuel rod failure. One representative criterion established from Halden data is known as "The Fuel Design Method for Commercialized LWR decided by the Nuclear Safety Commission (12th May 1988)". The output data from NSR-JAERI are known to be included in the criteria. It is worth mentioning that the domestic reactor known as the JMTR (Japan Materials Testing Reactor) owned by JAERI is also utilized for the study of fuel behavior, especially aiming at testing the BOCA (the boiling capsule)[♣10]. As well as the Halden data, JMTR results are disclosed and distributed to the related PO and PS though the local networking mechanism. This also contributed to the increased safety margin for LWR fuel reliability. This type of networking can be categorized as the *3rd effect of DRN* explained in Appendix I. Highlighted topics obtained from this networking is the reduction of the rate of fuel failure to 0.001%. Although the percentage seems to be very small in magnitude, it should be noted that the numbers of fuel rods loaded in one LWR are very large, on the order of 20,000-30,000. Therefore, the value obtained from multiplication of the two factors is practically important to make a quantitative evaluation. According to one of authors' calculation, a LWR shutdown caused by a fuel failure may lose retail sale by 17 M$ per day. If one increase the rate of fuel failure ten times, then one will lose retail sale to the amount of 170 M$ per day. The difference between 0.001% and 0.01% causes a huge amount of loss in money generated by a LWR.

As a psychological factor, an unexpected reactor shutdown will make minds of Japanese people restless. An old JAERI proverb says that nuclear fuel is the driving force for all kinds of distress. To subjugate the source of the distress, efforts to increase of fuel reliability were made earnestly not only by JAERI but also by PO and PS under the utilization of well-developed domestic and international research networking. A principal motive force worked on this point is that a fuel study needs a fairly long time scale (usually as long as at least 10 years) for obtaining a reliable result and a large amount of funds should be deposited to reach the goal. Because JAERI does not own a

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[♣10] BOCA: this boiling capsule is used in the JMTR for determining the LWR fuel failure threshold.

commercial nuclear power reactor, technological information how to transform the output of a fuel behavior into an economic outcome is needed, especially from a research evaluation point of view. Transferred knowledge from JAERI to the PS will be utilized for further modification of LWR fuel design parameters. As the result of many efforts the reduction of the rate of fuel failure is succeeded and the increase of fuel reliability for longer operation of a LWR commercial power plant is enabled. Therefore, we would like to say that JAERI output caused feedback to produce a valuable outcome and to increase, in part, of economic growth.

Practically, it is seldom and exceptional to consider about economic benefit obtainable from the outcome of the fuel reliability study. The reason is quite simple because results of NSR-JAERI are oriented mostly to data fabrication for the use of licensing criteria, where a value of fuel in commercial markets is ignored. The outcome has rather political meanings than economic. Under such situations, the outputs from NSR-JAERI will benefit more the safety regulatory side. This tendency is observed elsewhere in NSR-JAERI.

(2) *A relationship between the outputs of NSR-ESRF and the existing Safety Licensing Guideline*

Here we are interested in discussing about the quantitative relationship between the outputs of NSR-JAERI revealed by the bibliometric method and the existing Safety Licensing Guideline. This is uneasy task because the Safety Licensing Guideline is usually made by the regulatory side using the conventional outcomes born by several different safety research projects performed in Japan and foreign countries. Usually the Safety Licensing Guideline [5] is issued in a variety of formats depending on the editorial supervision; then the Safety Licensing Guideline is compiled under the supervision of the Nuclear Safety Commission and the Atomic Energy Commission. Chapter IV in the Safety Licensing Guideline seems to be related to NSR. It consisted of four headings; (I) the location & seismic, (II) the safety design sections, (III) the evaluation of safety design, and (IV) the radiation measurement & exposure evaluation. Each heading was further divided into 3, 8, 18, and 7 categories, in order to describe the items of the standard, the guide, a way of thinking, methodologies and so on. From the third heading we selected two representative Safety Standard Guidelines for further discussion.

(2-1) ECCS/LOCA Guideline

The title of the book is “Performance Evaluation Guideline of ECCS Systems for Light Water-type Power Reactors Decided by the Atomic Energy Commission on 20th July 1981”

In the text and appendix of the Guideline, a total of 33 papers are listed as references. They are nine domestic papers [three from JAERI♣11, three from PWR and two from BWR vendors, one from NEDO (New Energy and Industrial Technology Development Organization)], and 24 from foreign papers. The keywords obtained from the titles of three JAERI papers listed in the Guideline are 11; *BWR (two), small break, LOCA (two), analytical code, reflood, LWR, safety, evaluation, code, reactor heat up, simulation*. Parenthesis indicates the frequency. It is clear that LOCA from the present study coincided partly with those derived from the Safety Licensing Guideline. However, it is difficult to numerate the contributing share of JAERI to the existing Safety Licensing Guideline due mainly to the lack of necessary information in the Guideline.

(2-2) RIA Guideline

The title of the book is "Evaluation Guideline on the Reactivity Initiated Phenomenon for the Commercialized LWR-type Nuclear Facilities Decided on 9th January 1984"

There is no doubt that this Guideline was established based on RIA experiment data performed at NSRR in JAERI. In the text, 11 references (four domestic and seven foreign references) were used and in the appendix, a further 20 NSRR papers were cited. This Guideline was amended recently. The original Guideline was prepared for the RIA of un-irradiated fuels and the amended version is for the RIA of irradiated fuels. The latter was organized by the Special Committee for the Reactor Safety Standard until 13th April 1998. Adding original data to amended version, the committee used PBF and SPERT data (USA) as well as CABRI data (France) to make the database more accurate and reliable. We found that in the text a total of six references [three from NSR-JAERI and three from others (USA and France)] were cited. While, in the appendix, a total of 20 papers; nine domestic papers (six JAERI, two BWR vendors, and one PWR vendor) and 11 foreign papers were cited. Observed common keywords were NSRR and RIA, completely the same as those found in the present work. Although it is a very broad manner, we tried to find the relationship between NSR-JAERI and the cited JAERI references in the Safety Licensing Guideline as follows.

For research evaluators, the most important thing is to know the contribution (share) of JAERI for the drawing up of each Guideline. The number of specialists joined to codifying the licensing and the number of papers cited in the text or appendix are only valuable information given explicitly. For the latter, each paper has different findings

♣11 In a NSR licensing guideline, referential papers obtained from JAERI, PO and PS were used. Focusing on NSR-JAERI, a reference originating from JAERI was selected according to one of the author's experience who had worked at JAERI for a long time. Then the selected data were provided for comparison. Because the title of each JAERI paper is written in Japanese, the author put them into English.

and research values. For the former, the recent Safety Licensing Guideline lists up to seven specialists. They are one from RIST (Research Organization for Information Science & Technology), three from JAERI, 2 from NMCC (Nuclear Material Control Center) and one from the University of Tokyo. If one simply accepts this at face value, the contribution from JAERI is 43% (3/7). However, one from the RIST and one from the NMCC are specialist just retired from JAERI. This is to show the difficulty when one wants to determine the exact contribution of JAERI.

Strictly speaking, not only the guideline but also referential papers discussed above do not necessarily disclose the affiliations of the authors. This is really true! As a unique trial, we asked a nonprofessional researcher to join our study for making an effort to select the JAERI papers from the aforementioned two Safety Standard Guidelines. The results of her trial are as follows:

Specialists concerned with the drawing up of the existing Safety Licensing Guideline cannot be clarified from any of open literature cited. Referential papers listed in the Guideline do not show the author's affiliation, therefore, no one can find out the relationship between NSR-JAERI and the existing Safety Licensing Guideline. Under this situation, the contribution share of JAERI is invisible. The contribution share of NSR-JAERI to the existing Safety Licensing Guideline is not readily determined. It means that the taxpayer does not understand the role of JAERI for the codification of those Safety Licensing Guidelines. There is no doubt that the existing Safety Licensing Guideline does not tell the magnitude of the contribution of JAERI, which is inevitable for disseminating the achievement of JAERI. Main reason for this failure is that cited references in the Safety Licensing Guideline do not always show the affiliation of authors. This is the real situation making a quantitative evaluation very difficult.

(3) Tasks for the future

Through discussion of the NSR-JAERI evaluated by the biblimetric method, the following tasks were found. Because they seem to be fundamental examinations for R&D evaluation at nuclear facilities, a study should be continued collaborating with administrative organizations related to the tasks.

(3-1) The promotion of R&D to establish the cost benefits effect (CBE) with "intellectual stocks and its embodiment".

Previously the CBE of JAERI for the stable and regular use of domestic LWR was studied [6]. As for estimating the whole income brought to JAERI, the flow (money)-based annual budget was utilized. To date, reviewing our procedures taken at that time, we recognize that the use of the stock-based annual budget may be better than the previous budget for the following reasons. The outputs of NSR-JAERI related to conventional LWR are, as seen from this study, reflected on the drawing up of the Safety Licensing Guidelines as well as the formation of intellectual stocks of nations. The vendors also utilize the outputs of JAERI not only for designing the installations and equipment but also for the intellectual base and the supporting tool for the operations. Recognizing these achievements as ”intellectual stocks “or the “embodiment of intellect to facilities”, users of these achievements will apply them in future situations. This is the main reason why we considered stock-based evaluation as better for estimating CBE.

(3-2) The fulfillment of authentic information for determining the contributing share of JAERI

When one is executing the analysis of CBE, an important matter to encounter is how to determine the contribution of JAERI to the whole achievement [7]. For example, the contribution of NSR to the land-based use of LWR is interesting to know but practically, as seen in the previous discussion, it is too difficult to determine quantitatively. A conventional way is to send questionnaires to ex-house intellectuals asking what the share is. On this point, however, one must make more effort to obtain high-grade authentic information from the subjective point of view by using multilateral methods such as the R&D investment analysis and bibliometric analysis. The aim of the effort is addressed to have comprehensive judging criteria for determining the contribution of JAERI as well as that of the other participants (G, U and PO).

(3-3) Fulfillment of evaluation documents understandable by taxpayers

Prior to clarifying the accountability of JAERI, one must prepare comprehensive evaluation documents understandable by taxpayers. The outcome and impact, that is, the repercussion effects of JAERI, should be prepared according to the individual requests by the stakeholders (GS, PO, foreign organizations). Especially for the outcome, a proper and intelligible logic model is necessary for determining contribution share not only for the establishment of safety standards and licensing guideline but also for the establishment of the plan to prevent disasters.

4 Conclusions

The following concluding remarks are obtained.

(1) For LOCA, NSR performed by JAERI has a domestic share of the research paper up to 63% at past (20) 1978-1982 but the magnitude is decreased to 40% at the present 1998-2002. For co-authored paper, JAERI-PS and PS-PO is almost zero at past (20) but

the share to both cases is increased to about 4% at present. Research cooperation is active at Tokyo University-JAERI and JAERI-Nagoya University.
(2) The DRN of neutron (basic-type) is compared with that of LOCA (project-type). The DRN is larger in the former than that in the latter. However, the magnitude of monopolization (single paper) is larger in project-type research than that in basic research.
(3) For FP, the share of co-authored paper is high because the use of a hot cell facility, where many researchers from JAERI, PS and PO have to collaborate with others, especially during the post-irradiation examination. For criticality, DRN expanded from the past to the present. The JCO criticality accident that occurred in 1999 enhanced the study on criticality mainly at the NUCEF facility.
(4) For reprocessing, PS represented by the PNC (JNC) had a top share of 71% during the past (20) 1976-1982. PNC had a good collaboration with JAERI, CRIEPI, Kyoto University, Toshiba Corporation, Tokyo Institute of Technology and Kyushu University and so on. For JAERI, the share of reprocessing was about 20% during the past (20).
(5) For the relationship between LOCA outputs from JAERI and the existing Safety Licensing Guideline for ECCS/LOCA, there exists a part of consistency between the two. However, it is difficult to numerate the contributing share of JAERI to the existing Safety Licensing Guideline due to the lack of necessary information should be prepared in the Guideline.

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References

[1] K. Ito, C. Katsuki, K. Kawashima, K. Yanagisawa, H. Terada, M. Fujita, H. Nakajima, M. Yonezawa: *"Socio-economic Evaluation of Nuclear Engineering Safety Project in JAERI-(I) Keyword Ranking*", 2005 Fall Meeting of the Atomic Energy Society of Japan, M7, p630 (2005).{in Japanese}.

[2] K. Kawashima, C. Katsuki, K. Ito, K. Yanagisawa, M. Yonezawa: *"Socio-economic Evaluation of Nuclear Engineering Safety Project in JAERI-(II) Emphasized Research Field*", 2005 Fall Meeting of the Atomic Energy Society of Japan, M8, P.631 (2005).{in Japanese}.

[3] C. Katsuki, K. Kawashima, K. Ito, K. Yanagisawa: *"Socio-economic Evaluation of Nuclear Engineering Safety Project in JAERI-(III) Socio-economic Networking"*, 2005 Fall Meeting of the Atomic Energy Society of Japan, M9, P.632 (2005). {in Japanese}.

[4] The Ad hoc Committee for Evaluation of R&D Achievements, *"Evaluation of Socio-economic Effects of R&D Results at JAERI (II)-Socio-economic Evaluation of the Basic research at JAERI-*", JAERI-Review 2003-036 (2003).{in Japanese}.

[5] Energy-forum (Denryoku-shinpousha): '99 genshiryoku-jitsumu roppou, edited by the Agency for Natural Resources and Energy (1999). {in Japanese}.

[6] K. Yanagisawa: "*The Cost Benefit Effect of Light Water Reactor Safety Study in JAERI*", International Journal of Nuclear Governance, Economy and Ecology, Vol.2, No2, PP.212-223 (2008).

[7] K. Yanagisawa: "*Evaluation of Nuclear Knowledge Management (NKM)-An Outcome in JAERI*", International Journal of Nuclear Knowledge Management, Vol.2, No.2, P.91 (2006).

[8] A. J. Salter, B. R. Matin; *"The Economic Benefits of Publicly Funded Basic Research ; a Critical Review"*, Research Policy vol.30, P.509 (2001).

[9] Yuubikaku : "*Keizaijiten, ver. 3*."(1998). {in Japanese}.

[10] JAERI; "*40 years chronology of JAERI*", (1996), {in Japanese}.

Appendix I: Dynamics of DRN

According to Salter et al, [8] socio-economic effect (hereinafter abbreviated as SEE) has following components:

1) Increasing the stock of useful knowledge
2) Training skilled graduates
3) Creating new scientific instrumentation and methodologies
4) Forming networks and stimulating social interaction
5) Increasing the capacity for scientific and technological problem-solving
6) Creating new firms.

For the case of JAERI, concept 1) is related to a publication of research papers, concept 2) the trainees, concept 3) the newly constructed research facilities and patents, and concept 6) the established venture businesses. For concept 5), there is no experience to increase the capacity for problem solving because of its new idea. Lastly, concept 4) seems to be strongly linked to DRN. In the following, we will discuss DRN more deeply.

The DRN has a relation to an economic term of "the external effect of networking" [9]. Simply saying that the economic term indicates a benefit produced either by the number of users for the goods or by the size of the networking. A direct effect of the term is come out by the increased benefit by goods occurred through the increase of users. An indirect effect of the term is the increased number of users gaining the benefit under the influence of the existing extra goods. Referring to this idea, we considered that DRN is time dependent and would be expanded accompanying with three different effects. *The 1st effect*- Original knowledge reported in a research paper is then available to other researchers through reading the paper; then a propagation of knowledge will occur from one to another through additional finding or knowledge. It may occur like a geometric series accompanied by many citations. Practically this effect happens in the form of a single or co-authored paper publication in an institute. In DRN, this effect is appeared as monopoly paper by JAERI, PS or PO. *The 2nd effect*- Because many modern researches are highly specialized and fractionated, many researchers working in a similar research environment or a related field will utilize the networks that develop at joint research conferences and at workshops held for the purpose of exchanging mutual ideas, research results and opinions. By doing so, a development of mutual research may occur with a synergistic effect. Practically this effect occurs in the form of co-authored paper publication from two different institutions. In DRN, this effect is appeared as co-authored paper JAERI-PS, JAERI-PO or PS-PO. *The 3rd effect*- The efficiency of

R&D will be increased by the collaboration and the formation of networking among academic scientists in the universities, special researchers in the public sectors (PS), and industrial engineers in private organizations (PO); when many researchers are focusing on the recent trend of needs, useful findings of basic science are expected to create a new market. Practically this effect happens in the form of a co-authored paper publication from three or more different institutions. In DRN, this effect is appeared as co-authored paper JAERI-PS-PO, where PS is further divided into governmental sectors (GS) and the universities (U). We consider that the bigger the third effect, the larger the socio-economic effect in the corresponded research field.

Appendix II: Chronology and Budget invested to NSR

Chronology of NSR

The main purpose of NSR is to certify and verify the engineering margin for the safety of the commercial LWR from the viewpoint of double checking because the LWR was originally introduced by the USA. The relation between a research plan decided by Japanese government and NSR performed by JAERI is clearly dictated by the Atomic Energy Commission. In the 1st version of Long-Range Research Plan on the Research, Development and Utilization of Nuclear, decided by the Atomic Energy Commission (AEC), Japan, a main purpose of the research was to develop home-produced power reactors (1956.9). In the 5th version of the Long-Range Research Plan, the promotion of a Large-Scale Safety Demonstration Test to obtain the corroborated experimental data for verifying the safety margin of LWR was decided (1978.9). At the same time, the Nuclear Safety Commission, Japan developed the Nuclear Safety Annual Program for Nuclear Reactors and Facilities (1st version in 1976, 2nd version in 1981) to indicate the annual goal of nuclear research in related organizations. Around this period, research activities of project-type nuclear safety were initiated on a full scale at the level of policy making.

Budgets invested to NSR

Annual rough budget invested by the Japanese Government to JAERI was traced [10] and the results are shown in **Fig. A-1**. Significant economic damages impacted to our country after the Nixon Shock seemed to be the 1st oil shock (trigged by the 4th Middle-East War in 1973) and the 2nd oil shock (trigged by the Iran Revolution in 1978). After these shocks, the Japanese government took counter plans. For energy matters, governmental policy was developed to utilize a variety of non-oil energy sources such as nuclear, wind and solar energy coupled with an idea for reducing energy consumption. The plan started around 1978. The rough budget funded to NSR might be 10-20M$ (million dollars) around the 1st oil shock period, however, it increased rapidly to the level of 50M$ around the 2nd oil shock period. In this era, as represented by the construction of the Nuclear Safety Research Reactor (NSRR, criticality in 1976) in JAERI, a construction and preparation of nuclear facilities relating to NSR occurred rapidly. In the era of the bubble boom that happened from the second half of 1980 to the first half of 1990, the rough budget for NSR increased to about 110M$ around 1990. The phenomenon might be influenced by the Chernobyl reactor accident (1986), though our present bibliometric study did not find the effect of Chernobyl accident on NSR-JAERI. Detail observation of the rough budgets implies that the highest beneficiary of NSR at that period was thrown to a research field of Critical Safety. From the 2nd half of 1990 the rough budget degraded rapidly from 110M$ to 40M$ due mainly to the crash of the bubble boom. However, many efforts were made to overcome that precipitous fall in financial support to date.

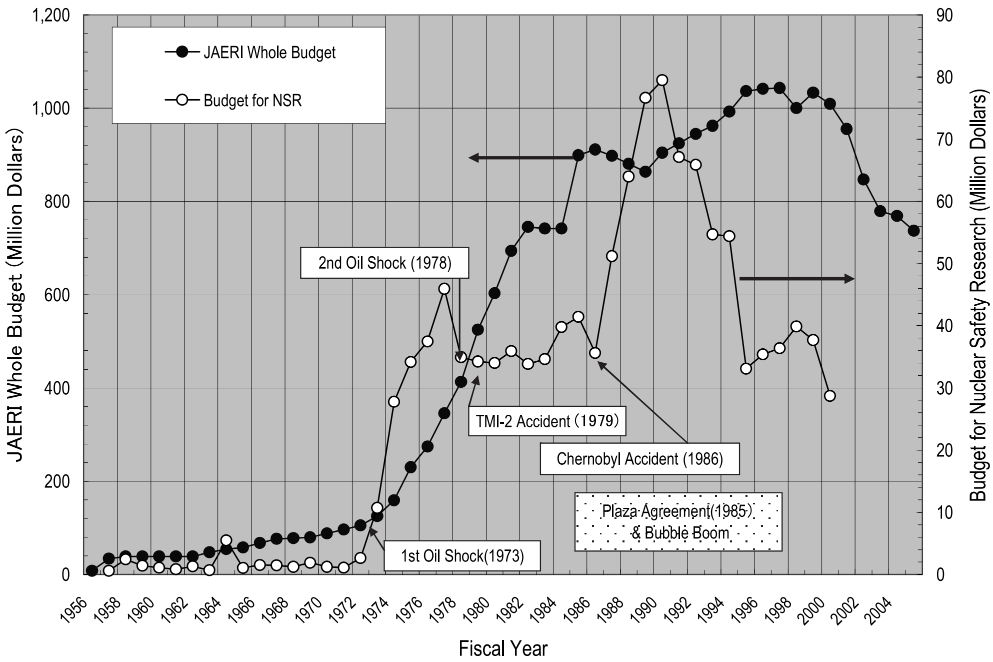

Fig. A-1 Chronology change of JAERI rough budget (full circle, left-hand side in Y-axis) and that of NSR (open circle. right-hand side of Y-axis) operated since 1956. Major events that occurred during the period are indicated.

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^{4}m^2
リットル	L，l	1L=11=1dm^3=10^{3}cm^3=10^{-3}m^3
トン	t	1t=10^3 kg

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)×10^{-19}J
ダルトン	Da	1Da=1.660 538 86(28)×10^{-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)×10^{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^{5}Pa
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^{4}cd m^{-2}
フォト	ph	1 ph=1cd sr cm^{-2} 10^{4}lx
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 ≙ (10^3/4π)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=3.7×10^{10}Bq
レントゲン	R	1 R = 2.58×10^{-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 µ =1µm=10^{-6}m

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