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Evolving Landscape of Low-Energy Nuclear Physics Publications

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Abstract Evolution of low-energy nuclear physics publications over the last 120 years has been analyzed using nuclear physics databases. An extensive study of Nuclear Science References (NSR), Experimental Nuclear Reaction Data (EXFOR), and Evaluated Nuclear Structure Data File (ENSDF) contents provides a unique picture of refereed and non-refereed nuclear physics references. Significant fractional contributions of non-refereed reports, private communications and conference proceedings in EXFOR and ENSDF databases in the 1970's reflect extensive experimental campaigns and an insufficient number of research journals. This trend has been reversed in recent years because the number of measurements is much lower, while number of journals is higher. In addition, nuclear physics results are mainly published in a limited number of journals, such as Physical Review C and Nuclear Physics A. In the present work, historic publication trends and averages have been extracted and analyzed using nuclear data mining techniques. The results of this study and implications are discussed and conclusions presented.

Keywords Nuclear Science Trends, Publication Analysis, Nuclear Data Mining, Relational Databases

MSC 01-02, 58Z05

JEL C810, C920

1 Introduction

It has been 120 years since Becquerel and Rontgen published their revolutionary works on nuclear radiation (Becquerel 1896, Rontgen 1896). These publications have been precursors to enormous changes in science that resulted in harnessing of atomic energy and eventual political and economic changes worldwide. Initially, nuclear physics research and subsequent publications were at a relatively limited scale and mostly associated with academic journals. The rate of publications changed dramatically in the 1930's, in light of the major discoveries of neutron and uranium fission (Chadwick 1932, Hahn and Strassmann 1939). Further, unprecedented scale developments in nuclear physics produced a large number of new findings and practical applications that have been archived in many publications.

To investigate these phenomena and archival sources, I will analyze nuclear physics articles using the Nuclear Science References (Pritychenko, Betak, Kellet, et al. 2011), Experimental Nuclear Reaction Data (Otuka, Dupont, Semkova, et al. 2014), and Evaluated Nuclear Structure Data File (Burrows 1990) database contents maintained by the U.S. Nuclear Data Program in collaboration with the IAEA. The brief description of databases is presented below.

The NSR database is the most comprehensive source of low- and intermediate-energy nuclear physics bibliographical information since the beginning of nuclear science. It consists of primary (journals) and secondary (proceedings, lab reports, theses, private communications) references. The main goal of the NSR is to provide bookmarks for experimental and theoretical articles in nuclear science using keywords. NSR keywords are assigned to articles that contain results on atomic nuclei and masses, nuclear decays, nuclear reactions and other properties. Keywords are also used to build author and subject indexes, which allow users to search for articles by subject (Coulomb excitation, B(E2), $T_{1/2}$, etc.) or author. This database is updated weekly and serves as a primary source of bibliographical information for the ENSDF database.

The ENSDF database contains evaluated nuclear structure and decay data. An international network of evaluators contributes to the database. For each nuclide, all known experimental data used to deduce nuclear structure information are included. Each type of experiment is presented as a separate dataset that includes NSR keynumbers that link publications and data sets. In fact, ENSDF evaluators carefully select the most relevant published data manually. Information in the database is regularly updated and most of this information is also published in Elsevier Nuclear Data Sheets journal as A-chain evaluations. Due to the large scope of the database, evaluation updates are often conducted on an ~10-year basis, with some nuclides updated more frequently.

The EXFOR database contains an extensive compilation of experimental nuclear reaction data. The EXFOR library was started in 1967 at a meeting of the four major nuclear data centers: National Nuclear Data Center, Brookhaven National Laboratory, USA; NEA Databank, Paris, France; Nuclear Data Section, IAEA, Vienna, Austria; and Nuclear Power Engineering Institute, Obninsk, Russian Federation. EXFOR or EXchange FORmat file was established for information interchange between the four major data centers (Holden 2005). The library consists of data entries that contain complete records of individual experiments. Each experiment may include multiple nuclear reaction data sets (subentries) and several research papers because EXFOR compilers group multiple publications from a particular experiment into a single entry and archive the best data. Another important feature of the library is that all experimental data are compiled as published, only obvious errors are corrected. Historically, EXFOR was created in support of nuclear energy research and development activities. The initial database scope was limited to neutron-induced reactions in order to provide support for Evaluated Nuclear Data File evaluations. Later, the scope was extended to charged-particle and photon-induced reactions.

Finally, I will calculate total and fractional averages, evaluate the ranges of fractional journal contributions, and deduce historic trends. Data analysis methods and corresponding results are presented in the following sections.

2 Nuclear Bibliography Data Mining

Low-energy nuclear physics publications serve an important role for archiving and dissemination of experimental and theoretical results. Over the last 100 years, the publishing process has evolved from labor-intensive hand writing and typewriter work to computer word-processing techniques. An explosion of nuclear physics activities after World War II has generated a strong need for additional avenues of data archiving. Many new journals have been founded in recent years to satisfy the need for rapid data dissemination. These new journals have improved the publication process, and research articles have evolved from a half-page note at the end of the 19th century to several-hundred-page manuscripts at the beginning of the 21^{st} century. These large articles that include multiple graphic illustrations and tables would not have been possible without a revolution in publishing.

Additional analysis shows that the annual total number of articles has not changed over the last 30-40 years because the number of nuclear physics research facilities has dwindled (Pritychenko 2015).

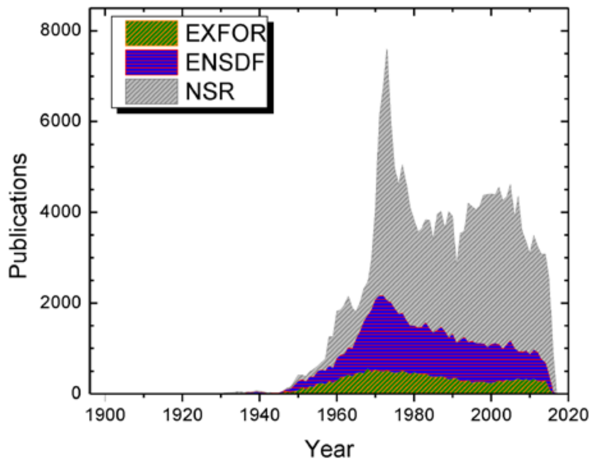

Fig.1. Distributions of bibliographical content in nuclear physics databases.

Nuclear bibliography represents the foundation for nuclear data compilations and evaluations. U.S. Nuclear Data Program and International Atomic Energy Agency data scientists systematically have collected these materials and compiled database records over the past 65 years. The NSR database (http://www.nndc.bnl.gov/nsr) contains metadata for more than 220,000 publications and 94,000 individual authors (Pritychenko, Betak, Kellet, et al. 2011). The references database provides almost complete coverage of nuclear physics results and is relatively clear of high-energy physics papers. It is a prime source of nuclear bibliography worldwide and an excellent resource for investigation of publication trends from 1896 to present.

Historically, the NSR database has been used for searches of experimental nuclear structure references for the ENSDF database. In the 1990's, its scope was extended to all nuclear science references, and the experimental nuclear reaction compilation community has started to use NSR as a bibliographical source for the EXFOR database. The ENSDF and EXFOR databases contain 55,000 and 22,000 references, respectively, and compile unique experimental results only, while NSR scope is very broad. Annual distribution of bibliographical content for three databases is shown in Fig. 1. Contents of the databases, as of May 2016, have been examined with nuclear data mining techniques. A custom-written Java code with embedded SQL queries has been employed to examine the databases, process metadata, and deduce historic averages, ranges, and trends. The results of this study are presented below.

3 Analysis of Contents of Nuclear Physics Databases

The large variety of nuclear physics publications and consecutive submissions of experimental and theoretical results to different journals inflates the overall quantity of nuclear physics publications and obscures the picture. It is worthy to investigate the nuclear physics databases by separating papers that contain unique measurements and rejecting duplicates. This can be accomplished by comparing ENSDF and EXFOR experimental references that have been preselected by nuclear data compilers with the NSR database that contains an almost complete archive of nuclear physics publication metadata. Following NSR convention, I will investigate the abovementioned databases for fractional contributions of primary and secondary publications, such as journal articles and preprints, private communications, theses, reports, books, and conference proceedings. Such analysis will provide information on publication trends over the years and identify original data sources.

Historic evolution of the experimental nuclear bibliography from the ENSDF and EXFOR databases is shown in the upper and lower panels of Fig. 2, respectively. These data show that initially results have been published in journals. Later, the overall volume of research findings exceeded journal capacities, and many unique results were published as laboratory reports or conference proceedings. Over the years, the volume of nuclear physics research has dwindled, while the latest computer technologies have helped to increase journal volumes. These developments have decreased the value of laboratory reports or conference proceedings, and present-day journals could accommodate almost all major findings. It is expected that the remaining secondary data sources will be dominated by data sets.

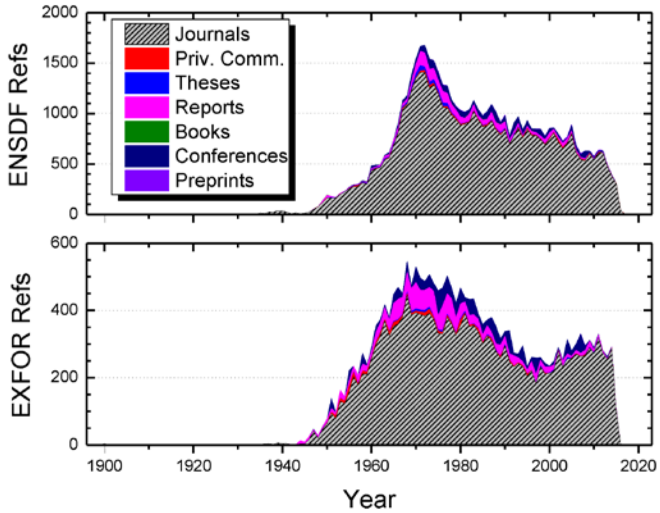

Fig.2. Historic evolution of references for unique experimental nuclear physics results. Data were taken from the ENSDF and EXFOR databases.

It represents a separate interest to investigate a timeline for the golden age of secondary publications. Analysis of Fig. 2 indicates that secondary publications such as laboratory reports blossomed in the days before modern computers, when typewriters were used, and have almost died out. As shown in Fig. 3, fractional contribution of laboratory reports to ENSDF and EXFOR databases provides more detailed information on the previous findings. The reports played a major role in the 20th century as the final destination for new results and lost this function in recent years in favor of journals and modern data dissemination tools.

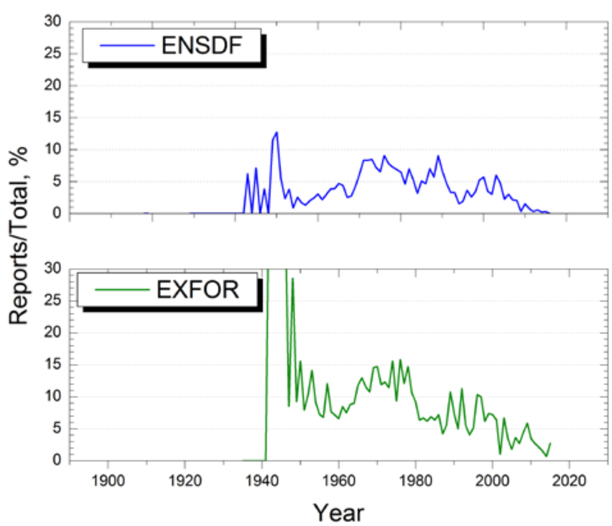

Fig.3. Fractional contributions of nuclear physics reports to unique experimental nuclear physics publications. Data were taken from the ENSDF and EXFOR databases.

Subsequent analysis of journal publications in EXFOR and ENSDF databases further enhances the previous findings. Fig. 4 data demonstrate that the large volume nuclear reaction data sets (i.e. EXFOR database contents) could not be accommodated by old-fashioned publication technologies and often were disseminated as laboratory reports or private communication. Later, computer and Web dissemination technologies have evolved and adapted to the large volumes of data that are presently published as supplementary Web files. Here, I would like to stress that many conference proceedings are now published in journals, such as Procedia, JPS Conference Proceedings, EPJ Web of Conferences, and Acta Physica Polonica B. This, effectively, leaves Ph.D. dissertations and private communications as the only secondary references that contain unique information.

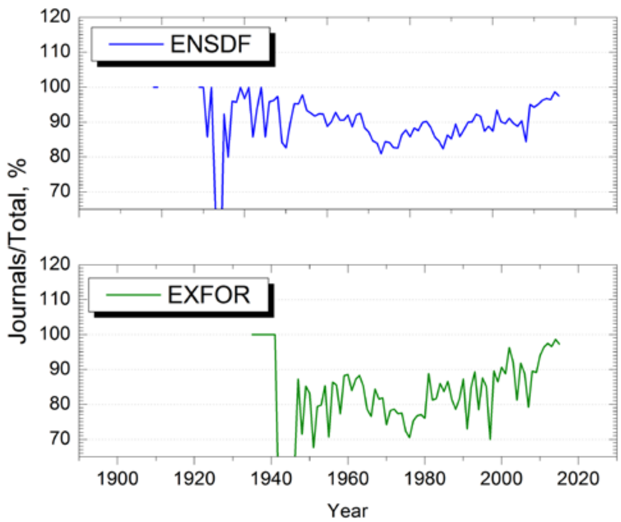

Fig.4. Fractional contributions of nuclear physics journals to unique experimental nuclear physics publications. Data were taken from the ENSDF and EXFOR databases.

It is known that nuclear structure and reaction physics are mutually-related fields. Consequently, it is necessary to investigate an overlap between two databases. For this purpose, the larger ENSDF database was examined for EXFOR references in order to deduce the overlapping publications. As shown in Fig. 5, the fraction of EXFOR publications in ENSDF of ~10-15% supports the current work assumption that major databases are mutually-related. Further analysis of the smaller EXFOR database indicates a presence of 25-30% ENSDF references. The relatively high portion of ENSDF references in EXFOR reflects the fact that only ~2/3 of EXFOR references are present in the NSR database, effectively increasing EXFOR values in the present analysis by ~50%. An additional factor is associated with the ENSDF database decay data references that are barely present in EXFOR. In fact, the EXFOR database contains only ^{252}Cf spontaneous fission and several beta delayed neutron decay publications. Accurate accounting of these two factors in the last 10 years would increase the reaction fraction of ENSDF database and reduce the structure fraction of EXFOR database to a common level of ~15%.

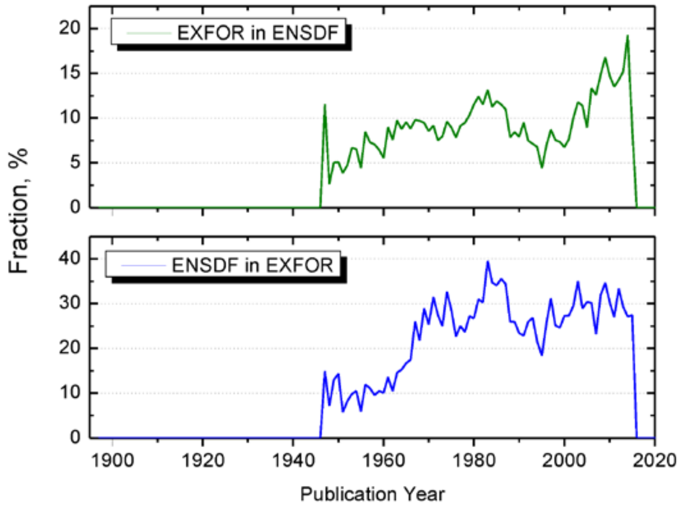

Fig.5. A common fraction of publications in the ENSDF and EXFOR databases.

4 Trends in Nuclear Physics Publications

The nuclear physics publication process takes its roots from fundamental science journals such as Comptes Rendus Physique, Nature and Naturwissenschaften, where scientists have published their groundbreaking discoveries. Over the years, nuclear physics has evolved from a purely academic pursuit into a more applied science, and the original nuclear science journals have changed their scopes and requirements. The present-day list of selected nuclear physics journals is shown in Table 1. All journals are ranked using a SCImago journal rank (SCImago 2016), and the Table also includes H-index, 2-year citation, and country of origin.

Table 1. Present-day nuclear physics journals and common citation indicators. SCImago Journal Rank (SJR indicator) is an estimate of scientific reputation of journals that include the number of citations and the importance of the journals where such citations come from. The H-index is a metric that describes both the number of the most cited publications and the number of citations that they have received in other publications.

Title	**SCImago Journal Rank (SJR)**	**H index**	**Cites / Doc. (2years)**	**Country**
Nature Physics	13.7	157	14.8	United Kingdom
Physical Review Letters (PRL)	4.4	452	6.7	United States
Physics Letters, Section B (PL/PLB)	3.2	208	5.5	Netherlands
Physical Review C (PR/PRC)	2.1	152	3.4	United States
Nuclear Physics A (NP/NPA)	1.2	126	1.8	Netherlands
European Physical Journal A (ZPA/EPJA)	0.8	67	1.2	United States
Physics of Atomic Nuclei (YF/PAN)	0.4	30	0.5	Russian Federation

These nuclear physics journal contents are compiled in nuclear databases. The NSR database has the largest collection of references among databases that are used by physicists. It contains a wealth of information and can provide information on the evolution of the nuclear physics publication and data dissemination processes. Historic trends in fractional contributions of major nuclear physics journals to the NSR database are shown in Fig. 6. The integrated values of fractional contributions for all databases are shown in Table 2.

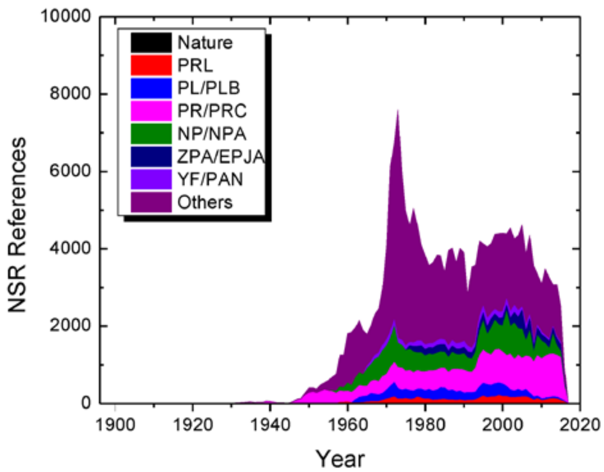

Fig.6. Absolute contributions of nuclear physics journals in the NSR database.

Table 2. The integrated values of fractional contributions of major nuclear physics journals to nuclear databases in %.

Database	Nature	NPA/NP	PLB/PL	PRC/PR	PRL	PAN/YF	EPJA/ZPA
EXFOR	0.00	19.91	3.02	34.41	2.57	3.16	2.75
ENSDF	0.12	16.56	4.90	24.05	3.55	2.29	5.02
NSR	0.09	12.98	5.00	18.00	3.01	2.77	3.54

Further analysis of Fig. 6 and Table 2 data shows many interesting patterns in nuclear publications and helps to identify the major nuclear physics archival journals. Three databases display similar fractional contributions of major nuclear physics journals; they also contain significant contributions of other journals, conferences proceedings, and laboratory reports. Nature was one of the original nuclear physics journals that was later overshadowed by Physical Review and Nuclear Physics journals. In this paper, I will analyze in detail the nuclear physics articles in the last two journals. Historically, these journals have been a primary destination for archiving theoretical and experimental studies performed in the United States, Canada and Europe. These geographical regions are responsible for more than 70% of all nuclear physics measurements (Pritychenko 2015). The fractional contributions of experimental results in the PRC and NPA journal contents are reflected in three nuclear physics databases. The data shown in Fig. 7 indicate the absolute values of experimental publications in PRC has not changed for the last 50 years, while Nuclear Physics A is losing its experimental articles rapidly. This journal scope effectively changes over the years. Experimental contributions do not represent the majority of journal articles nowadays; these journal volumes are often replaced with nuclear theory or high-energy contributions. Another observation suggests that PRC and NPA nuclear physics journal volumes grow over the years by increasing the overall number of published articles.

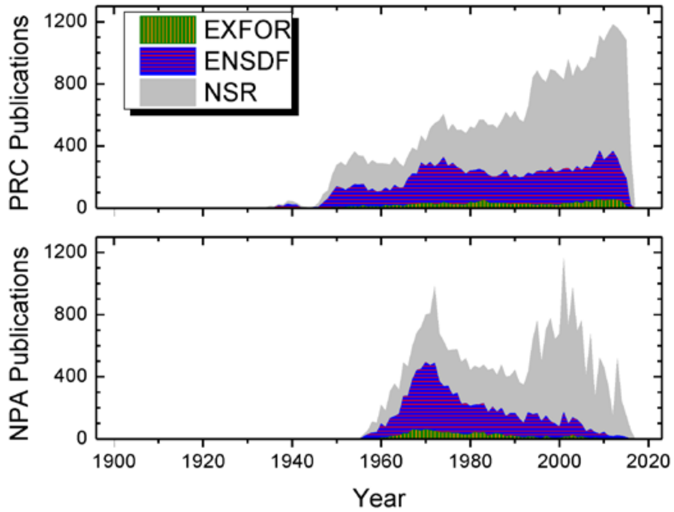

Fig.7. Physical Review C and Nuclear Physics A experimental contents publication trends.

5 Conclusions

Low-energy nuclear physics publications and the publication process in the last 120 years have been analyzed. Historic evolution of publication process, fractional contributions of non-refereed reports, private communications, and conference proceedings in EXFOR and ENSDF databases reflect the extensive experimental campaigns in the 1970's and technical difficulties with publication of large data sets. Nowadays, these issues have been resolved, and almost all experimental results are published in journals. Another important finding is associated with an ~15% overlap between nuclear structure and reaction fields.

A complementary analysis of individual journals and ENSDF and EXFOR databases sheds additional light on described phenomena. The major journals have grown in size and accommodate very diverse contents; i.e. nowadays Physical Review C publishes twice as many articles as in the 1970's, while the Nuclear Physics A original scope has evolved. However, it is premature to deduce a monopoly of a few major journals in nuclear physics publishing.

The observed trends predict that further developments in nuclear physics research would force publishers to find new, more creative ways of accommodating Big Data challenges. The journals would move into electronic forms of publication by becoming completely paperless, incorporating the latest technical developments, and becoming more interactive in order to accommodate large data sets.

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