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The Nuclear Science References (NSR) Database and Web Retrieval System

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Abstract

The Nuclear Science References (NSR) database, and associated Web interface, is the world's only comprehensive source of easily accessible low- and intermediate-energy nuclear physics bibliographic information for more than 200,000 articles since the beginning of nuclear science. The weekly-updated NSR database provides essential support for nuclear data evaluation, compilation and research activities. The principles of the database and Web application development and maintenance are described. Examples of nuclear structure, reaction and decay applications are specifically included.

The complete NSR database is freely available at the websites of the National Nuclear Data Center *http://www.nndc.bnl.gov/nsr* and the International Atomic Energy Agency *http://www-nds.iaea.org/nsr*.

Keywords: Nuclear databases, Bibliography, Semantic analysis, Nuclear structure, Reaction data, Decay data

1. Introduction

The NSR database is a bibliography of nuclear physics articles, indexed according to content and spanning more than 100 years of research. The database originated at the Nuclear Data Project at Oak Ridge National

Laboratory as part of a project for systematic evaluation of nuclear structure data [1] and was later adopted by the wider research community. It has been used since the early sixties to produce bibliographic citations for nuclear structure and decay data evaluations published in Nuclear Data Sheets. Periodic additions to the database were published as the "Recent References" issues of Nuclear Data Sheets until 2005. Presently, these issues in PDF format are available for download from the NSR Web interface *http://www.nndc.bnl.gov/nsr/recref.jsp.*

In October 1980, the database maintenance and updating became the responsibility of the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory (BNL). Since then the database has been through a scope expansion, several modernizations and technical improvements [2, 3], however, the basic structure and contents remained unchanged. In recent years, the IAEA Nuclear Data Section and the Nuclear Data Group at McMaster University, Canada, have joined the NSR compilation and development effort.

In this paper, we present the contents and features which make the NSR database the most important nuclear bibliography resource. A detailed description of the database, Web interface and update policies will be given in the following sections.

2. Database Scope and Structure

The NSR database aims to provide primary and secondary bibliographic information for low- and intermediate-energy nuclear physics [4]. Over 80 major physics journals are checked on a regular basis for articles relevant to be included as primary references. For the two journals Physical Review C and Nuclear Physics A *every* article is compiled into NSR. Secondary references are typically conference proceedings, laboratory reports, theses, preprints and private communications. Also additional specific content is regularly added following the request of ENSDF evaluators, nuclear data users or research centers.

The very diverse contents of the database are catalogued under seven major physics topics:

ATOMIC MASSES	NUCLEAR REACTIONS
ATOMIC PHYSICS	NUCLEAR STRUCTURE
COMPILATION	RADIOACTIVITY
NUCLEAR MOMENTS	

Table 1 shows some statistics pertaining to the current contents of the actual database, where it is clearly seen that there are over 200,000 articles now compiled into NSR from over 473 different journals and many other distinct sources. In addition to the online database facility, *all* articles compiled in NSR are also preserved as hardcopies in the NNDC library. As part of the NSR services, NNDC can provide copies of articles from rare journals and proceedings to data evaluators and users.

Table 1: NSR Database Content as of January 2011.

Database Entity	Total
All references/entries	201,848
Primary references (Journal articles)	148,436
Secondary references (Lab reports, theses, priv comm.)	53,412
Journals (CODENS)	473
Subjects	148
Authors	86,837
Nuclides	5,002
Reactions	6,911
Projectiles, ejectiles	970

The NSR database operation work flow is conducted in cooperation between three major centers: NNDC/BNL, IAEA and McMaster University. Nuclear physics journals are scanned for articles of interest on a weekly basis. Selected entries are compiled by one of the three centers and loaded into the database. NSR also enjoys good relations with Physical Review C authors, as they contribute directly keywords to the NSR database, and also the Nuclear Physics A journal, where keywords are produced by the IAEA for inclusion into BOTH the database AND the final manuscript prior to publishing (upon acceptance by the author). All of this information is processed centrally at the NNDC, where it is loaded into the master database.
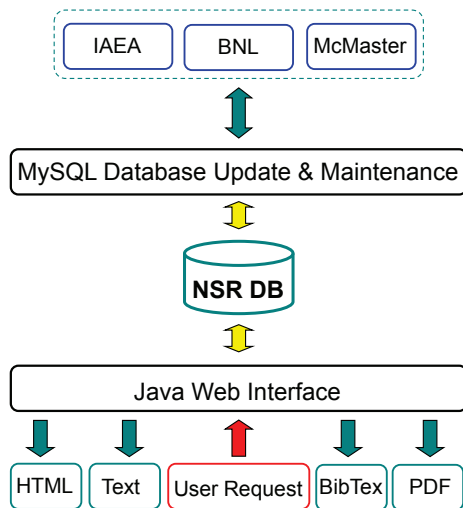
Figure 1: NSR work flow.

The complete database is mirrored to the IAEA Web server on a monthly basis. The NSR database work flow is shown in Fig. 1.

NSR entries include a wealth of useful information, starting with a unique eight-character identifier (NSR keynumber), journal/reference, publication year, article title, author list, journal digital object identifier (DOI) link and a keyworded abstract (for articles reporting on appropriate physical quantities). All entries are stored in a relational database that consists of 11 dictionary and 10 content data tables. The database schema is shown in Fig. 2.

The current software system is based on commercially available database technologies and the Java 2 Enterprise Edition, with custom-written Java Server Pages. At the NNDC this system is installed on powerful RedHat Linux (DELL PowerEdge 2900, 2x3.3 GHz Quad Core Xeon Processor, 64 GB RAM, 450 GB 15 kRPM hard drive) database, Web, and application servers. The database server is running MySQL 5 RDBMS software, while the Web server has the Apache 2/Tomcat 5.5/mod_jk 1.2 Web production environment installed. Previously, the NSR database was based on Sybase ASE 15 server [3], however, it was migrated to MySQL database server in 2009 during the overall hardware upgrade. These servers also host NNDC Web and database services. The new NSR software and hardware system is

auth_dict
akey	integer
aname	varchar(32)
a1	char(1)
a2	char(1)
modified	datetime

auth_alias
akey	integer
lname	varchar(32)
l1	char(1)
l2	char(1)
modified	datetime

auth_both
akey	integer
aname	varchar(32)
a1	char(1)
a2	char(1)

part_dict
particle	char(5)
z	int
a	int
beam	bit
modified	datetime

nuc_dict
nuclide	char(5)
z	int
a	int
targ	bit
modified	datetime

coden_dict
coden	char(5)
title	varchar(70)
modified	datetime
mnyr	smallint
mxyr	smallint
doi_pre	varchar(64)

reac_dict
reaction	char(15)
inc	char(5)
modified	datetime

reac_out_dict
reaction	char(15)
outp	char(5)
modified	datetime

reac_conv
reaction	varchar(15)
reac_alias	varchar(30)
modified	datetime
ord	tinyint

sub_dict
subject	varchar(20)
subinfo	varchar(256)
modified	datetime

sub_conv
subject	varchar(20)
sub_alias	varchar(20)
modified	datetime

exch_tbl
keyno	char(8)
line_num	smallint
line_text	char(80)

auth_tbl
keyno	char(8)
akey	integer
ord	tinyint

sub_tbl
keyno	char(8)
subkey	char(1)
subject	varchar(20)
stype	char(1)
ord	smallint

txt_tbl
keyno	char(8)
title	varchar(4096)
keywords	varchar(4096)

ref_tbl
keyno	char(8)
type	char(4)
coden	char(5)
info	varchar(70)
created	datetime
modified	datetime
prim	bit
enslnk	char(1)
doi	varchar(128)
pubyear	smallint

topic_tbl
keyno	char(8)
topic	char(3)

nuc_tbl
keyno	char(8)
subkey	char(1)
ntype	char(1)
nuclide	char(5)

az_tbl
keyno	char(8)
subkey	char(1)
ntype	char(1)
nlow	smallint
nhigh	smallint
ord	smallint

reac_tbl
keyno	char(8)
subkey	char(1)
reaction	char(15)
ord	smallint

ensdf_ link
keyno	char(8)
mass	smallint

Figure 2: NSR Database scheme. Dictionary and content data tables are shown in the upper and lower portions of the database schema, respectively.

very robust and requires low maintenance costs.

3. NSR Keywords

The main goal of NSR is to provide bookmarks for experimental and theoretical articles in nuclear science using keywords. In NSR, keywords serve a dual purpose:

1. they are used to generate database *selectors*, which produce the correct article indexing and allow specific, detailed searches to be made quickly and easily. (Searching can also be made within the general text of entries.)
2. they allow a user to quickly determine which articles are of specific interest from a list of entries returned following a given query.

In preparing the keyword abstract, NSR compilers pick out the specific physical systems being studied (isotopes, reactions, etc.), and the quantities being discussed (i.e. measured cross sections, calculated energy levels, etc.).

By the very nature of the NSR database, the keyworded abstracts are highly structured. They begin with the topic identifier, as listed in section 2, and depending on this topic, a list of nuclei, nuclear reactions or decays follows. Then the measured and/or calculated/analyzed quantities are given, followed by deduced (derived) quantities. Additional information concerning the experimental/detector details or theoretical models employed is added at the end. In some cases, keywords may be provided under *two* topics, depending on the nature of the article.

Historically, under measured quantities in NSR we understand direct results of online measurements. For example, these primary quantities will include γ-transition energy and intensity, particle-γ coincidences, number of beam particles, etc. Other quantities, such as S-factors, log *ft* and B(λ) values that are often derived offline using the primary data are considered as deduced quantities. The same philosophy applies for calculated and analyzed quantities.

3.1. An example explained

In order to illustrate the use of keywords, an example presented below, is explained in more detail.

Immediately it is clear that the keyworded article includes data relevant to a series of inelastic scattering reactions, with details of the various targets,

incident/outgoing particles and beam energies given. Information is even included, following the specification of the reactions, on how the secondary beams were produced. The *measured* quantities are then listed, followed by the *deduced* quantities, in this case information relating to the levels of the scattered particles. An additional set of three sentences then give detailed information relating to the nature of the findings of the work.

```
<KEYWORDS>NUCLEAR REACTIONS 197Au(82Ge,82Ge'), E=89.4 MeV/nucleon;
197Au(84Se,84Se'), E=95.4 MeV/nucleon; 9Be(82Ge,82Ge'), E=87.6 MeV/
nucleon; 9Be(84Se,84Se'), E=92 MeV/nucleon, [82Ge and 84Se secondary
beams from 9Be(86Kr,X), E=140 MeV/nucleon]; measured Eγ, Iγ, σ,
(particle)γ-coin; 82Ge, 84Se; deduced levels, J, B(E2), T1/2.
Intermediate energy Coulomb excitation and inelastic scattering.
Comparison with systematics of B(E2) values for first 2+ state
in N=50 isotones for Z(even)=30-42 and even-even Ge (A=64-82) and
Se (A=68-84) isotopes, and with shell-model calculations.
Systematics of first 3- states in even-even Se (A=74-82) and N=50
isotones.
```

3.2. Keyword preparation

Keyword abstract preparation is the most important part of the NSR work flow and also the most difficult to automatize. All abstracts are prepared manually, which ensures the high-quality of the keywords, however, limits the volume of processed articles. To overcome this problem NNDC started to work with XSB, Inc. on "Semantic Analysis of Nuclear Physics Publications and Automatic NSR Keyword Generation" in 2010. Selected articles in PDF format are converted to text and analyzed for keywords using the Apache UIMA Framework [5]. The initial implementation and testing of semantic analysis is showing great promise in the partial-automation of NSR keyword abstract preparation and the consequent reduction of the required manpower. However, human effort, albeit on a reduced scale, will always be necessary for ensuring the quality of any automatically generated keyword abstracts.

3.3. Added value

In the last two decades, bibliographic databases have faced increasing competition from Web search engines and corresponding databases. Google

and its Advanced Scholar Search (*http://scholar.google.com/*) complement NSR and provide users with extensive lists of indexed information that match the search criteria ordered by frequency of use.

What differentiates NSR from these essentially text pattern matching search engines is the level of detail provided in the keyword abstracts, and the resulting indexes created from them which direct the user's search. For example, a Web search engine cannot differentiate between ^{32}Mg and 32mg, nor ^{31}Na and 31na, since these are equivalent in pure plain text. Hence a Web search engine would return over 591,000 prescription drugs links containing 32mg (milli-grams) of a particular product, and in 338,000 cases, ^{31}Na would be confused with some electrical leakage current of 31 nano-amperes. While NSR, as a dedicated nuclear physics database, will produce a clean output containing only the 175 and 111 relevant articles, for ^{32}Mg and ^{31}Na, respectively.

4. NSR Retrievals

The NSR Web Retrieval Interface is an integral part of both the NNDC and IAEA Web Services [3, 6]. The Web interface is based on current Java technologies and provides retrievals of the database content in HTML, Text, BibTex and PDF formats. Shown in Fig. 3 the main Web interface actually consists of six sub-interfaces:

<div align="center">

Quick Search

Text Search

Indexed Search

Keynumber Search

Combine View

Recent References

</div>

The Quick Search allows a quick lookup of references for a given author, or nuclide or reaction within a publication period. The Text Search allows plain-text searching of the title and keyword fields, whilst an Indexed Search allows a Boolean AND search over several indexed categories (e.g. author, nuclide, etc.). The Keynumber Search retrieves the information for a specific article(s) given the NSR keynumber(s). This, a very specific retrieval, is in

Figure 3: NSR Web Interface *http://www.nndc.bnl.gov/nsr.* Example of Boolean search for author Curie and 1910-1940 time range.

great demand by nuclear structure evaluators. Finally, Combine View provides powerful analysis and combination opportunities for previous retrievals, whilst Recent References provides downloads of quarterly compilation collections in PDF format. Entries for certain theory and review articles may not include keywords abstracts, if they do not deal with specific nuclides or reactions. These may still be retrieved in other ways, including author, text, or keynumber searches.

4.1. Simple NSR retrievals

NSR retrievals are generally based on searching the indexed quantities created from the keywords, but can also be made simply by specifying an author and/or publication year. For example, searching on author *Curie* between *1910* and *1940* results in three entries, one of which is shown here:

```
1931CU01
Revs.Modern Phys.  3, 427 (1931)
M.Curie, A.Debierne, A.S.Eve, H.Geiger, O.Hahn, S.C.Lind, S.Meyer,
E.Rutherford, E.Schweidler
The Radioactive Constants as of 1930
doi:  10.1103/RevModPhys.3.427
```

As can be seen, each entry stored in the database corresponds to a full bibliographic reference that is uniquely identified by an eight character alphanumeric keynumber, e.g. *1931CU01*. The first four digits of the keynumber give the publication year of the corresponding reference, followed by the first two characters of the first author's surname, and finally a two digit incremental sequence number allocated during the database loading.

In this particular case, no keywords have been created, but one can clearly see the full bibliographic reference to volume 3 of the journal *Reviews of Modern Physics*, page 427, followed by the full list of authors, the paper title and finally the DOI (Digital Object Identifier), which through the Web retrieval system provides a direct link to the original publication webpage, although full access to the paper may be subscription dependent.

Most of the entries ($\geq 80\%$) include keyword abstracts, which provide a brief summary of the subject matter in the given reference, and as already mentioned, these are used to generate the indexed quantities in the database.

In the example below, the complete entry *2000SI01* is shown which uses the COMPILATION topic and the keywords show a list of all nuclei, of *mass*

163, reported in this article:

```
2000SI01
Nucl.Data Sheets 89, 1 (2000)
B.Singh, A.R.Farhan
Nuclear Data Sheets for A = 163
COMPILATION 163Gd, 163Tb, 163Dy, 163Ho, 163Er, 163Tm, 163Yb, 163Lu, 163Hf,
163Ta, 163W, 163Re, 163Os; compiled, evaluated structure data.
doi:  10.1006/ndsh.2000.0001
```

A partial example below illustrates the keywords for a reference using the NUCLEAR STRUCTURE "topic":

```
NUCLEAR STRUCTURE 192,193,195,199,200,201Pb; analyzed magnetic rotational
bands signature splitting.  Tilted-axis cranking, particle-rotor
models.
```

4.2. Advanced NSR retrievals

There are two powerful types of NSR retrievals that are often ignored by new users, i.e. Indexed Search and Text Search.

The Indexed Search uses the database *selectors* and allows a highly targeted Boolean AND search of up to three specific parameters. The full list of available parameters are shown in Table 2. As can be seen, all relevant fields for an entry can be searched. Although each search only allows three parameters to be specified, the results of multiple searches can be cross-compared using the Combine View sub-interface, where the Boolean OR and NOT operators can be specified, meaning that extremely refined searches can be carried out.

The Text Search sub-interface can be used to search for references based on text matches in the title and keyword fields. Searches can be restricted to one of these fields allowing searches of articles even without keyword abstracts, or can span both.

4.3. NSR retrieval statistics

An important part of monitoring NSR operation is a correct estimate of the database usage. NSR retrieval statistics are very conservative [7] and completely based on a count of successful database retrievals - any Web

Table 2: NSR Indexed Search.

| Indexed Quantity	Description
Author	Author's last name, and (optionally) one or two initials, e.g. B.A. Brown.
FirstAuthor	References where given author is *first* in the author list.
Nuclide	Nuclide of interest in the format BR-76 or 76BR.
Target, Parent, and Daughter	Same format as for "Nuclide".
Reaction	Reaction of interest, e.g. (p,a) or n,p etc.
Incident	Incident beam particle, e.g. n or p etc.
Outgoing	Outgoing particle in a reaction, e.g. p or a etc.
Subject	"Measured", "Deduced", "Calculated" required at beginning of keyword phrase, followed by an indexed quantity, e.g. σ, $T_{1/2}$, $B(\lambda)$, Q-values, S-factors, etc.
Journal (CODEN)	Five-letter code associated with a given journal, e.g. PRVCA - Phys.Rev. C, NUPAB - Nucl.Phys. A, NIMAE - Nucl.Instr.Meth. A, etc.
Topic	NUCLEAR STRUCTURE, NUCLEAR REACTIONS, RADIOACTIVITY, etc.
Z(range),A(range)	Numerical value for Z or A, and/or range.
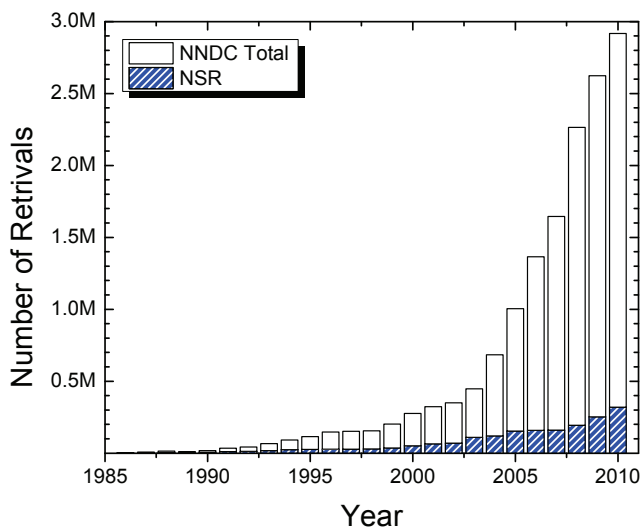
Figure 4: The time evolution of the number of electronic retrievals - web, telnet and FTP - from 1986 to 2010.

browser hits are ignored. Retrievals for non-existing entities in the database (e.g. author, nuclide, ...) which produce an empty output file are consequently not counted. Complete information for each retrieval is recorded into a separate statistics database. Normally, there are $\sim$700 retrievals/day with $\sim$800 references/retrieval from the NNDC database alone. Such a large number of references/retrieval is a direct result of the broad selection criteria entered into the Quick Search subinterface and the database size. A complementary way of statistics estimation is based on analysis of the Apache Web Server log. These logs, after removal of crawler and/or search engine activity, produce comparable results to the database retrievals count method. The time evolution for NSR retrievals at NNDC over the last 25 years is shown in Fig. 4.

Further analysis of NSR database retrievals reveals information on patterns of NSR usage, users Web browsers and operating systems, separate users and organizational activities over time, etc. These patterns are used for NSR database and Web interface quality assurance purposes. The distribution of NSR retrievals for different types of search activities is shown in Fig. 5. A large volume of ENSDF database connections (ENSDF Link) are due to direct access from the ENSDF, B(E2) and $\beta\beta$-decay webpages. More
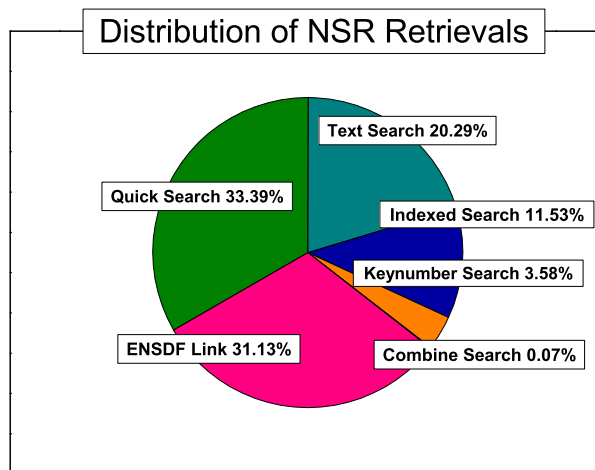
Figure 5: Distribution of NSR retrievals for different types of search activities.

information on this subject will be provided in the next section.

5. NSR Applications

The NSR database was initially created to support the Evaluated Nuclear Structure Data File (ENSDF) [8, 9, 10]. All references in ENSDF evaluations are specified by their NSR keynumbers. This practice ensures proper documentation in nuclear structure evaluations. Regular NSR database updates serve as an indicator for the international Network of Nuclear Structure and Decay Data Evaluators (NSDD) [11] on the requirement to revisit a particular mass chain. If a large number of new experimental works, for a particular mass chain, have been added since the last ENSDF evaluation update, then this would immediately alert the NSDD network about the urgent need for a mass chain re-evaluation. An example of a mass number spectrum of unevaluated experimental references is shown in Fig. 6. The large number of new articles for light nuclei is due to the general availability of these projectiles in rare isotope beam research.

In addition to ENSDF mass chain or vertical evaluations [8, 12], NSR is actively used in a large number of horizontal evaluations of atomic mass [13, 14], B(E2) values [15, 16], magnetic moments [17], etc. The NSR database
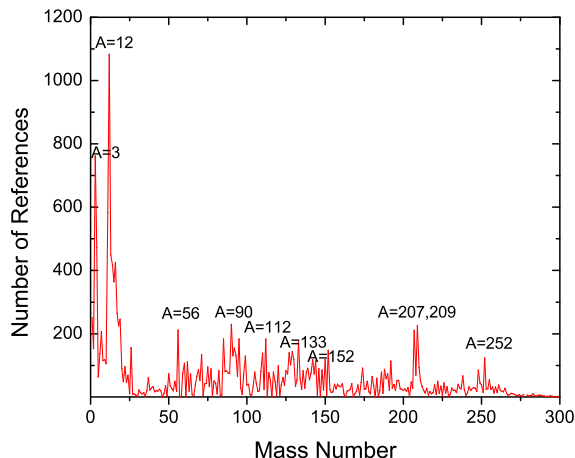
14

Figure 6: Mass number distribution of references unevaluated by the NSDD network, as of October 2010.

and Web interface are also connected to a large number of other nuclear databases: ENSDF, XUNDL and EXFOR [8, 18, 19]. Thus when a particular reference forms part of a compilation or evaluation in one of these other databases, NSR will provide a direct Web link to the original data contained therein.

Finally, the NSR database has a very broad usage spectrum worldwide with more than a half of NSR retrievals coming from users in research and educational fields. Web users from many research centers and universities such as MSU/FRIB, Yale, FSU, GSI, JINR, RIKEN, etc. actively use NSR for data mining purposes and interact with the database staff. NSR user feedback is always welcome, specifically as this can help in defining areas of future improvement.

6. Conclusion and Outlook

The NSR database and its Web interface, are available through both the NNDC (*http://www.nndc.bnl.gov/nsr*) and IAEA (*http://www-nds.iaea.org/nsr*) websites, and provide transparent and easy access to nuclear physics bibliographic information, with direct links to the original articles and data provided, where possible. Recent additions include

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many features for nuclear scientists and specifically *reaction* data users, such as user-friendly Web retrievals, Web integration with the EXFOR database and improvements in NSR terminology/keywording. NSR has a large potential in modern physics, as it is the only major nuclear database that allows searches for rare isotope beam reactions.

Further implementation of the latest technologies and computer-aided keywording and semantic procedures will improve the database maintenance procedures, reduce the workload required for keyword abstract preparation and ensure the continuing high-quality of the database content. Exponential growth of electronic access to nuclear data [3] requires continuing effort to satisfy current needs and future demands.

7. Acknowledgments

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