

## International network of nuclear structure and decay data evaluators

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**Abstract.** Compilation, evaluation and dissemination of nuclear data are arduous tasks that rely on contributions from experts in both the basic and applied sciences communities whose efforts are coordinated by the International Atomic Energy Agency (IAEA). The Evaluated Nuclear Structure Data File (ENSDF) includes the most extensive and comprehensive set of nuclear structure and decay data evaluations performed by the international network of Nuclear Structure and Decay Data evaluators (NSDD) under the auspices of the IAEA. In this report we describe the recent NSDD activities supported by the IAEA and provide some future perspectives.

### 1 Introduction

Nuclear structure and decay data are important data for a wide range of applications, from the basic nuclear sciences to other fields such as medicine, reactor design and operation, geophysics, environmental sciences, radiation safety and materials sciences. The Evaluated Nuclear Structure Data File (ENSDF) [1] is a collection of recommended data on nuclear structure properties such as decay modes, level energies and lifetimes, and radiation properties for all known nuclides. These data are evaluated and maintained by an international group of experts who form the international network of Nuclear Structure and Decay Data evaluators (NSDD) [2]. The network is under the auspices of the International Atomic Energy Agency (IAEA) since 1974,

and includes 16 data centres and over 20 internationally-recognized experts from more than 10 countries who compile and evaluate nuclear structure and decay data for all known isotopes on an agreed basis. A complete list of the NSDD Data Centres is available at URL:<http://www-nds.iaea.org/nsdd/datacenters.html>. The most recent experimental nuclear structure and decay published results are compiled in the experimental unevaluated nuclear data list (XUNDL) [3]. The evaluations are stored in the Evaluated Nuclear Structure Data File format and are also published in the journal Nuclear Data Sheets. Both the compilation and evaluation work makes extensive use of bibliographic information provided by the online Nuclear Science References (NSR) database [4] which over the years has been developed and extended to provide services not only to the NSDD network but the nuclear science community at large. The ENSDF and XUNDL databases contain

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data in computerized format and are available both online and offline. They are managed by the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory and are funded extensively through the United States Nuclear Data Program (USNDP) of the US Department of Energy (DoE). E.A. McCutchan (NNDC) is the manager of ENSDF and XUNDL, as well as editor of Nuclear Data Sheets. USNDP meets to discuss these databases at Nuclear Data Week which is held annually at Brookhaven National Laboratory (URL:<http://www.nndc.bnl.gov/usndp>).

The ENSDF database uses information on atomic masses ( $Q$  values) from the Atomic Mass Evaluation project [5] which was originally lead by CSNSM, Orsay, France and is now the responsibility of the Institute of Modern Physics, Lanzhou, China. Other data such as charge radii and nuclear moments are often obtained from corresponding horizontal compilations and/or evaluations performed outside the network.

ENSDF is a unique database, in the sense that it is comprehensive, continuously updated and serves as the source of data for several derivative, special-purposes databases and products.

The role of the IAEA is to coordinate the network, organize biennial technical meetings and expert training workshops for the evaluators, provide technical support where needed, and disseminate the results of the ENSDF evaluations. Pivotal to the introduction of new evaluators to the network and ENSDF evaluation over the years has been the organisation of joint ICTP-IAEA training workshops on nuclear structure and decay data by the IAEA. Apart from introducing the evaluation work, procedures and methodologies and useful online tools to young nuclear scientists from all over the world, the workshops have allowed the participants to become actively engaged in compilation and evaluation work which in the end is included in the XUNDL and ENSDF databases, respectively, and is published in Nuclear Data Sheets.

Some recent developments in the network activities and useful online tools are described in the following section.

## 2 ENSDF Codes

The ENSDF Analysis and Utility codes [6] are essential tools for evaluators' work and for that reason it is important that they are continuously checked for bugs, kept up-to-date with developments in physics models, statistical methods and error analysis, and evaluation methods/policies in general.

The IAEA is coordinating a data development project to address 'maintenance' of these codes, the need for them to be reviewed, properly documented and ideally re-written using modern programming tools so that they can be used by future generations of programmers and evaluators. Three meetings were held at the IAEA in 2014, 2015 and 2018, respectively, to discuss the existing ENSDF analysis codes, the needs for revision or improvement and correcting the problems that evaluators have identified and propose solutions. More details

about the meetings, presentations and technical discussions can be found on the dedicated website (<http://www.nds.iaea.org/nsdd/ensdfcodes.htm>) and the summary reports available therein.

Some of the key achievements of these meetings are:

- A new ALPHAD+RaDd code was developed [7] which essentially merges two codes, the previous ALPHAD code which calculates hindrance factors for alpha-decay to excited states of the daughter nucleus based on the tables of  $r_0$  parameter values deduced for even-even nuclei in Ref. [8], with the new RaDd code which deduces  $r_0$  values for odd-A and odd-odd nuclei by interpolation of values for neighbouring even-even nuclei. In addition, a large systematic update of  $r_0$  values for all the 182 even-even alpha emitters was performed by the above mentioned authors [9].
- A new code was written in JAVA [10] to automatize the deduction of Adopted Gamma-ray energies and photon branching ratios from multiple datasets for a nuclide following a gamma-by-gamma approach following the prescription adopted in the GAMUT code (R. Firestone: LBL-26024 (1991): A Computer Code for  $\gamma$ -ray Energy and Intensity Analysis) written in Fortran in the 80's.
- The original GABS code has been re-written [11] to (i) simplify the logical flow and to (ii) produce additional information in the ENSDF file and (iii) run with multiple options.
- The online web tool Myensdf (V. Zerkin) has been continuously updated to incorporate the new ENSDF codes as well as other useful codes for evaluators developed at the PNPI Data Centre (Petersburgh).
- A new tree-graph viewer, ensdf+ and a browser editor, ensdf±, have been developed at the IAEA by V. Zerkin.

In addition to the above listed results, the BetaShape code developed at CEA-LHNB [12] has been discussed extensively as a potential code for replacing the existing logft code after it has been adequately validated.

All the above new or revised codes are disseminated from the IAEA ENSDF Codes webpage [6].

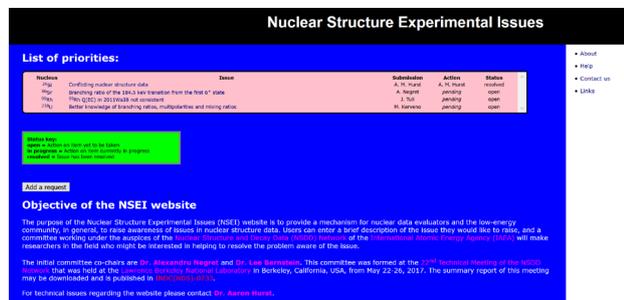
## 3 Nuclear Structure Experimental Issues Database

The Nuclear Structure Experimental Issues (NSEI) Database was created following a recommendation of the 22nd Technical Meeting of the NSDD network [2] with the purpose of collecting information on experimental data issues or gaps as identified by the ENSDF evaluators or users of ENSDF and proposing them for further discussion or action.

The NSEI web interface was designed by IFIN-HH, Romania and the University of California Berkeley, USA and is currently hosted on the UC Berkeley web servers. It can be accessed at: <https://nucleardata.berkeley.edu/hpnsrl/>.

The website allows the users to add new experimental issues and also to upload comments to the existing issues.

Both these actions are subject to the approval of the moderators of the website (L. Bernstein (LBNL/UCB) and A. Negret (IFIN-HH)) as can be seen in Fig. 1. The moderators will then reach out to researchers and experimental groups who might potentially be able to address the issue by performing a new experiment.



**Figure 1.** Nuclear Structure Experimental Issues Database interface: <https://nucleardata.berkeley.edu/hpnsr/>.

## 4 Dissemination tools

To help in the dissemination of ENSDF, apart from the main ENSDF website hosted at NNDC [1], there exist two interactive and user-friendly web interfaces, NuDaT [13] at NNDC and LiveChart [14] at IAEA. Both interfaces allow users to perform interactive searches of information from the various structure and decay data in ENSDF and XUNDL, visualize level schemes and decay schemes, and plot data across the nuclear chart as a function of mass number. The interactive LiveChart application that enables users to find the properties of nuclides, both stable and radioactive, is based entirely on nuclear structure and decay data from the ENSDF database while NuDaT takes data from the Nuclear Wallet Cards as well.

A further development at the IAEA has been the launching of the Isotope Browser app for mobile devices and tablets (see Fig. 2). The app gives properties of about 3500 nuclides and isomers based on information from ENSDF and is the mobile device version of the LiveChart. A Chart of Nuclides, with zooming and tapping enabled, and a Periodic Table of Elements are included to allow easy selection and navigation. Filter criteria can be selected and summary data are presented in a scrolling list, with a details page for each nuclide containing web links to the data sources and further information. Optimal search-and-retrieve performance is achieved with an embedded database, meaning that no network connection is required. The Isotope Browser is available in ten languages including all the UN official languages and additionally in Japanese, Italian and Slovenian. It can be downloaded from the LiveChart web site, or from Google play, Amazon.com and iTunes web sites and recently also from the Chinese website BAIDU.

## 5 Future perspectives

The evaluation and dissemination of nuclear structure and decay data is an international effort coordinated by the



**Figure 2.** Isotope Browser app for mobile devices.

IAEA. For many years, the NSDD network has been witnessing a shortfall in effort attributed to lack of adequate funding and the retirement of a large number of experienced evaluators.

On the other hand, the advent of modern radioactive beam facilities combined with advances in detector technologies are leading to a rapid growth in new measured data while the demand for up-to-date and reliable nuclear data is increasing due to the developments in basic and applied sciences.

To meet the growing demands, new approaches to nuclear data evaluation exploiting modern computing tools and enhancing international cooperation must be pursued by the NSDD network. The role of the IAEA in coordinating international cooperation and enhancing human capacity through the organization of dedicated training workshops is, in this context, important.

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