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NNDC Perspective on Nuclear Reaction Databases and ORELA

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Abstract

We discuss perspective of the National Nuclear Data Center on nuclear reaction databases, focusing on contributions from the ORELA machine over more than 3 decades. We conclude that ORELA had profound impact on nuclear reaction databases, in particular CSISRS and ENDF. In addition, ORELA contributed considerable amount of data included in the recent Atlas of Neutron Resonances, along with data of critical importance for nuclear reaction model calculations by codes such as EMPIRE.

1. Introduction

The ORELA machine, commissioned in 1971, is unique experimental facility that produced remarkable amount of neutron cross-section data and played a crucial role in the development of US nuclear reaction databases over more than three decades.

We start our discussion by displaying the front page of the web service of the National Nuclear Data Center (NNDC) in Fig. 1. Eight databases that can be seen at the top left portion of the figure include both nuclear reaction and nuclear structure databases [1]. Nuclear reaction databases (CINDA, CSISRS, ENDF) are shown in green, nuclear structure databases (XUNDL, ENSDF, MIRD) in blue, while mixed databases (NSR, NuDat) are shown in green-blue colors.

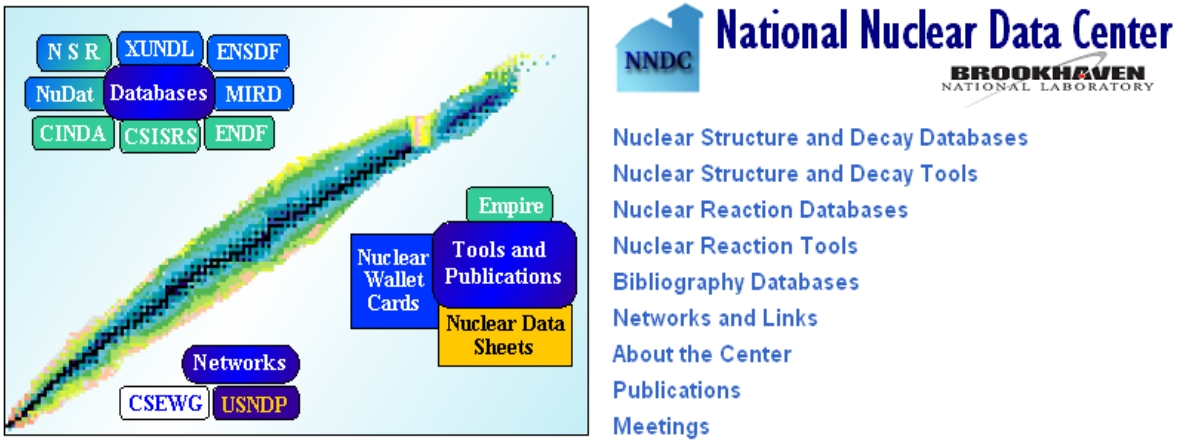

Fig.1. Front page of the web service of the National Nuclear Data Center (NNDC), www.nndc.bnl.gov, shows the NNDC portfolio of nuclear databases at top left.

In addition to basic nuclear reaction databases, we want to highlight two other products with important impact from ORELA. Namely, Atlas of Neutron Resonances that should be published in 2006 [2], and nuclear reaction model code EMPIRE [3] that serves as advanced tool for nuclear reaction evaluations in fast neutron region

2. **Basic Nuclear Reaction Databases**

The ORELA machine provided considerable input to several basic nuclear reaction databases. These are:

- Bibliography databases CINDA and NSR,
- Experimental reaction database CSISRS, and
- Evaluated reaction database ENDF.

Bibliography Databases

CINDA (Computer Index to Nuclear Data) is the oldest nuclear database, containing references to 275,000 neutron-induced reactions from 55,000 works. The database was traditionally dedicated to neutron data and in this area it is widely considered to be comprehensive. In 2005, the database was extended to cover charged-particle reactions (in general, light incident charged-particles with mass A < 12 and energy E < 1 GeV) and photonuclear reactions. In the last couple of years, CINDA is losing its role as the primary database and it is taking over a role of an index to experimental database CSISRS.

NSR (Nuclear Science References) database contains references describing contents of 180,000 articles from more than 80 journals. The database, initially known as Nuclear Structure References, evolved into a broad bibliography database for nuclear science. The strength of the database is in keywords that allow efficient search over research topics, nucleus, reaction, author etc. The database is updated weekly by the NNDC, and it contains also references on neutron-induced reactions.

Neither CINDA nor NSR provides information on facilities making it somewhat difficult to quantify ORELA impact. A more favorable situation in this respect is with the experimental reaction database CSISRS where this information can be extracted relatively easily.

Experimental Database

CSISRS (Cross Section Information Storage and Retrieval System) is one of the key nuclear reaction databases, containing numerical information on experimental cross-section data. The database is also known as EXFOR (Exchange Format), a name derived from the mechanism of worldwide exchange of information among nuclear reaction data centers. The database currently contains cross sections from more than 15,500 experiments. Neutron reactions are considered to be covered to almost 100%, charged-particle reactions (up to some excuses these are reactions induced by light charged-particles with A < 12 and E < 1 GeV) are covered much less, while photonuclear reactions are covered only to about 20%.

Information about contributions coming from the ORELA facility can be readily obtained from the CSISRS database. Results are summarized in Fig 2. In total, CSISRS contains experimental data from 334 papers produced by ORELA since 1971, with the peak productivity in the period of 1976 - 1980. In the last 10-15 years, ORELA productivity is down to the level of a few papers per year.

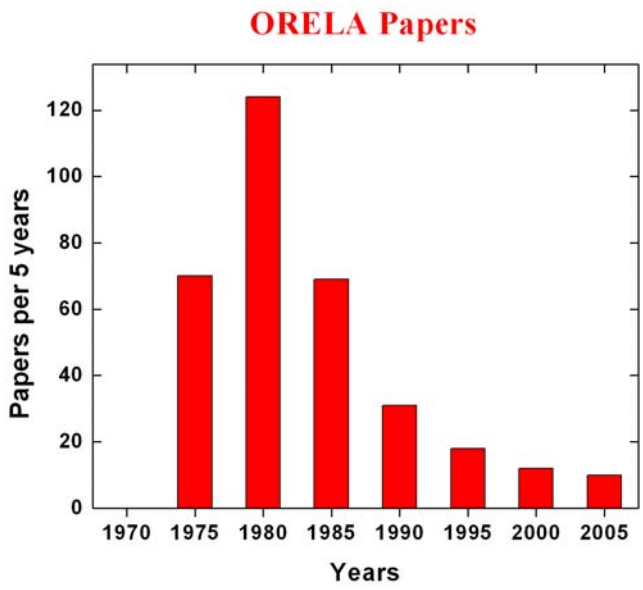

Fig. 2. Number of ORELA papers compiled into experimental database CSISRS.

Evaluated Database

ENDF (Evaluated Nuclear Data File) is the database that contains evaluated nuclear reaction cross-section data for all nuclei relevant to applied nuclear technologies. The database currently covers 328 target materials (315 isotopes and 13 elements), interacting mostly with neutrons. However, interactions with protons and other light charged particles are also included. Incident energies up to 20 MeV are mainly covered, but important cases with energies up to 150 MeV are also included.

The current version of the database, ENDF/B-VI.8, was released in October 2001. A new version of the database, ENDF/B-VII, will be released in FY 2006. The database provides input to neutronics calculations, such as design of reactors, criticality assemblies, accelerators, as well as radiation shielding and protection.

ORNL contributions to ENDF, as summarized in Table 1, are largely based on ORELA measurements. In the current ENDF/B-VI.8, majority of evaluations supplied by ORNL falls in the category of fission products. Number of ORNL evaluations in the new ENDF/B-VII will most likely decrease somewhat, but this is more than offset by several important contributions in the actinide region. In addition, ORNL should supply 10 materials with

covariance data in the resonance region, of importance to criticality safety applications. These data are produced by a new retroactive method that first simulates ORELA experiments, followed by their analysis to deduce covariances.

Table 1. ORNL & ORELA contribution of evaluated neutron reactions in the ENDF/B-VI.8 database released in 2001 and ENDF/B-VII database (2006).

Materials	**ENDF/B-VI.8**	**ENDF/B-VII**
Total number of materials	328	348
Number of materials from ORNL & ORELA	77 Mostly resonances for fission products	< 75 Several important actinides, 10 materials with covariances

3. Other Nuclear Reaction Databases and Tools

In addition to basic nuclear reaction databases, ORELA contributed a considerable amount of data or supporting information for two other important nuclear reaction products maintained by the NNDC. These are:

- Atlas of Neutron Resonances, and
- Nuclear Reaction Model Code EMPIRE.

Atlas of Neutron Resonances

Atlas of Neutron Resonances, authored by Said Mughabghab of the NNDC, is currently under completion. Elsevier should publish this impressive treatise in two volumes in 2006. Atlas continues the tradition of well-known report BNL-325 and it represents its 5-th edition. The previous 4-th edition, published in two volumes by Academic Press in 1981 and 1984, was widely used and frequently cited.

Atlas contains parameters of neutron resonances, thermal cross sections as well as average resonance parameters and quantities for 473 isotopes for all elements Z = 1 – 100. The only exception is Z = 85 and 87 that are not covered because of entire lack of experimental data. Atlas provides data resulting from careful evaluation by the leading expert with decades of experience and reputation in the neutron resonance field.

Large amount of data from ORELA measurements is used in Atlas. In particular, one should mention numerous measurements primarily by Harvey and Macklin produced in the past, and more recent data measured primarily by Paul Koehler and Klaus Guber. These data were mostly dealing with structural materials, fission products, nuclei in the Lu-Pb region, with heavy nuclei such as ^{232}Th, ^{231}Pa, ^{233,238}U, ^{237}Np and ^{241,242m}Am, and also with lighter nuclei ^{16}O, ^{19}F and ^{35,37}Cl.

Nuclear Model Code EMPIRE

The ORELA machine provided experimental basis for other data of considerable interest. In particular these are data important for model calculations, such as average resonance spacings D_0 for nuclear level densities, neutron radiative widths for photon strength functions, and neutron strength functions for optical model parameterization.

As an example we show in Fig. 3 nuclear level densities for ^{157}Gd+n system as used in the nuclear reaction model code EMPIRE [2]. Level densities are normalized, to discrete levels at low energies and to $1/D_0$ at neutron binding energy, to get a realistic description of this probably the most important quantity for neutron cross-section calculations at low energies.

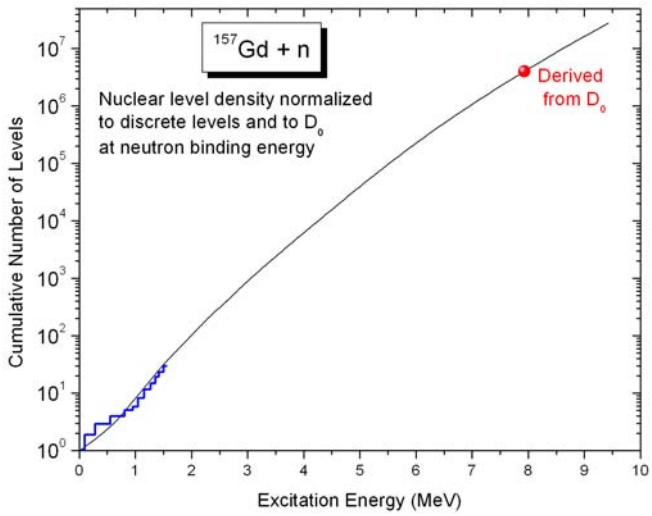

Fig. 3. Nuclear level density for ^{157}Gd+n normalized to discrete levels at low energies and to $1/D_0$ at neutron binding energy.

4. Conclusions

The ORELA machine, largely thanks to its exceptional capabilities in high-resolution neutron resonance cross section measurements, made profound impact on neutron reaction data and on nuclear reaction databases. By producing numerous experimental data of critical importance the ORELA machine put its unique and lasting imprint on nuclear technology applications as well as on nuclear reaction physics.

References

1. Nuclear Reaction Databases of the National Nuclear Data Center, www.nndc.bnl.gov.
2. S. Mughabghab, Atlas of Neutron Resonances (Elsevier, 2006), to be published.
3. M. Herman *et al*, Nuclear Reaction Model Code EMPIRE, www.nndc.bnl.gov/empire.