US Nuclear Data Program

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**Nuclear Data Program**

**Link between basic science and applications**

**Nuclear Science Community**
- experiments
- theory

**Nuclear Data Community**
- compilation
- evaluation
- dissemination
- archival

**Application Community**
needs data:
- complete
- organized
- traceable
- readable

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Fig. 14. The DANCE detector (picture credits: LANSCE-NSLA-UR-0802953).

Processed into physical quantities, like the total $\gamma$ cascade energy, $\gamma$ multiplicity, individual gamma ray energies, and neutron time of flight. After analysis of these data and several corrections (calibration, dead time correction, background subtraction) the neutron radiative capture cross-section $\sigma(n,\gamma)(E_n)$ is obtained. Results are presented here for three energy ranges: i) thermal energy, ii) resolved resonance region, and iii) above 1 keV in the unresolved resonance region.

i) For an incident neutron energy of 0.025 eV, the measured cross-sections for $^{175}\text{Lu}(n,\gamma)$ and $^{176}\text{Lu}(n,\gamma)$, are in good agreement with published values [64] while improving their precisions. The thermal capture cross-sections of Lu are important for nuclear reactors, where they are used to measure the core temperature.

ii) The analysis of the neutron capture experimental data in the resolved resonance region allows the determination of the energies of resonances as well as their radiative and neutron widths, and spins. For that purpose, we rely on a $R$-matrix code to fit the experimental cross-sections and determine the characteristics of the resonances.

Figures 15 and 16 display the radiative capture cross-sections measured for $^{175}\text{Lu}$ and $^{176}\text{Lu}$, respectively. These new measurements agree with previous experiments [65, 66]. Moreover, since $\gamma$ multiplicities have been measured, spin values could be attributed to several resonances.

In the resolved resonances domain, the analysis of measured data allowed to extract values of the mean radiative width ($\langle \Gamma_\gamma \rangle$), the mean $s$-wave level spacing ($D_0$), and neutron strength function ($S_0$). These values are useful for connecting the evaluations performed in the resolved resonance region (using $R$-matrix) with evaluations performed in the continuum (using the Hauser-Feshbach model).

iii) For the Lu isotopes, the unresolved resonance region extends from a few keV to 1 MeV. Unlike the resolved resonance region where models only produce a parametrization of experimental data, continuum models like the optical model potential can describe experimental data in a more predictive way. Figure 17 displays the cross-section for the $^{176}\text{Lu}(n,\gamma)$ reaction in the continuum energy region.
Who needs nuclear data?
and what for?

- **Basic science (physics)**
  - testing theoretical models
  - designing experiments
  - analyzing experimental data

- **Astrophysics**
  - origin of elements

- **Nuclear power**
  - reactors R&D
  - fuel cycle
  - operation safety
  - radiation shielding
  - waste disposal and transmutation

- **Nuclear medicine**
  - radioisotope production
  - dose calculation
  - radiotherapy
  - diagnostics

- **National/homeland security**
  - device R&D
  - stockpile stewardship
  - criticality safety
  - nuclear forensics
  - detecting illicit trafficking of nuclear materials

- **Industrial applications**
Nuclear Data
numerical values of nuclear physics quantities

ND types:

- **Bibliographical** - index of publications (partially key-worded)
- **Compiled** - formatted and searchable collection of published results (typically experimental)
- **Evaluated** - recommended values obtained using all available knowledge (assessment of available experimental data combined with nuclear theory modeling, supported by experience and, if possible, validation against integral experiments)

**USNDP objective** is to provide, in a timely manner, the highest quality nuclear data responding to the users’ needs in order to ensure safety, reliability, efficacy, and sustainability of nuclear technologies.
<table>
<thead>
<tr>
<th>Bibliographical database</th>
<th>Structure &amp; Decay</th>
<th>Reactions</th>
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<tbody>
<tr>
<td>NSR</td>
<td>&gt;208,000 publications</td>
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<td>Compilation databases</td>
<td>XUNDL</td>
<td>EXFOR/CSISRS</td>
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<td>&gt;3,000 publications</td>
<td>~20,000 experiments</td>
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<td>Evaluated libraries</td>
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<td>ENDF/B-VII.1</td>
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<td>&gt;3,000 isotopes</td>
<td>14 sub-libraries</td>
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Other popular products

- **COMMARA-2**
  COvariance Multigroup Matrix for Advances Reactor Applications

- **NNDC Web retrievals**
  USNDP 3.25 millions

- **EMPRIE**
  Nuclear Reaction Model Code

- **NUCLEAR WALLET CARDS**
  October 2011
  Jagdish K. Tuli
  National Nuclear Data Center
  www.nndc.bnl.gov
  Brookhaven National Laboratory
  P.O. Box 500
  Upton, New York 11973-5000

- **Atlas of Neutron Resonances**
  Resonance Parameters and Thermal Cross Sections
  Z=1-100
  S.F. Mughabghab

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# US Nuclear Data Program (USNDP)

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<tr>
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<td>Budget</td>
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## International collaboration

- Japan Atomic Energy Agency
- Institute for Physics and Power Engineering
- International Atomic Energy Agency
- NUKEM
- IAEC
- NSDD
- NRDC

## International organizations

- IAEA
- AENA
- IAE

## International networks

- Los Alamos National Laboratory
- Argonne National Laboratory
- Brookhaven National Laboratory
- Oak Ridge National Laboratory

## USNDP

coordinated by NNDC

Annual ND week, ND2013

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Wednesday, September 19, 12
Application of Nuclear Data
Nearly-missed reactor accident in India

3/10/2004
Kakrapar Atomic Power Station 1

- Failure of regulation system
- Power increased from 73% to nearly 100%.
- Automatic shut down - accident avoided!
- However, according to the Design Manual power rise should NOT HAPPEN!
- Atomic Energy Regulatory Board shut down KAPS until incident is understood.
- The newly released nuclear data library provided explanation and brought the plant into operation
Cargo screening for nuclear materials
Evaluated Gamma Activation File

- Capture primary $\gamma$'s easy to separate from background and difficult to shield (6-12 MeV)
- Fingerprint for the capturing isotope
- Presence of fission products is a clear indicator of actinides being present (neutrons from spontaneous fission)

EGAF library allows identification of $\gamma$-lines from $^{104}$Pd($n_{th},\gamma$)
High energy physics
GEANT4 and FLUKA adopt USNDP libraries

- Geant4 Neutron Data Library (G4NDL) based on ENDF/B-VII.0
- Thermal scattering in the ‘High Precision’ neutron models uses ENDF/B-VII.0
- The radioactive decay data from the Evaluated Nuclear Structure Data File (ENSDF)
- Also FLUKA uses ENDF/B data

ATLAS detector muon system, simulated in Geant4
Basic Science:
Study of neutrino oscillations in Daya Bay

Non-proliferation:
safeguards and reactor monitoring

Geophysics:
Earth tomography from long lived radioisotopes

Evaluate, with uncertainties, the anti-neutrino spectrum from $\beta$ decays of actinides and their fission products and archive them in ENDF/B-VII.2 for applications

NSAC meeting, Sept. 21, 2012
Isotope production: $^{96}\text{Zr}(\alpha,\text{n})^{99}\text{Mo}$
alternative (non-reactor) way of producing $^{99}\text{Mo}$

NNDC code EMPIRE used to perform calculations
Nuclear Reaction Theory in Nuclear Data Evaluation

Experiments never cover whole energy range and all reaction channels
Nuclear theory
ND is the major user and developer of nuclear modeling

- Fills gaps in experimental data
- Provides full set of observables
- Helps to choose among discrepant measurements
- Ensures consistency of the evaluation

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Mike Herman

NSAC meeting, Sept. 21, 2012
Opportunities for enhancing the Nuclear Data Program
Consistent adjustment (assimilation) linking reaction theory and integral experiments

- Users often tune multi-group evaluated files to a certain type of integral experiments
- Such adjusted file is only valid for a specific application
Modern practice is to use nuclear reaction code constrained by experimental data to produce evaluation and covariances.
Tuning is moved from multi-group file to reaction model parameters providing:
- evaluation constrained by differential and integral data and reaction theory
- covariances

**Consistent adjustment (assimilation)** linking reaction theory and integral experiments

- Classical adjustment
- Assimilation
Theoretical activities
Collaboration with the theory community

- Improve theory based modeling
  - further improvement of fission channel
  - advance covariance methodology
  - more microscopic input parameters in reaction calculations
  - explore possibility of using results of the SciDAC Universal Nuclear Energy Density Functional (UNEDF)

- Archive and disseminate results of (UNEDF)
  - codes: feasible with NNDC-GForge server
  - results: a challenge - terabytes of data per year
New data foreseen for nuclear structure & reactions involving nuclei far from the stability line

- data need to be promptly compiled, evaluated & disseminated to support scientific discoveries and preserve investment
- development of new evaluation methodologies, strategies & dissemination tools that are tailored to the specific needs
Experimental activities
preserve skills, make program more attractive

- Accepted NNDC proposals at major facilities

  Precision $\beta$-delayed neutron emission in $^{138}$I (CARIBU, ANL)
  - Reactor control, shut down, post-processing of fuel
  - $r$-process nucleosynthesis

  Precise measurement of the B(E2; 2$\rightarrow$0) in $^{12}$Be (GRETINA, MSU)
  - Confirmation and guidance of new ab-initio theories
  - Influence of loosely-bound neutrons

- In planning: measurement of $\beta$ spectra at Yale
Employ modern IT technology

- **Use modern IT tools for coordinated data development**
  - GForge collaboration system, SVN versioning system, automatic data verification.

- **Upgrade data dissemination**
  - applications for mobile devices
  - physics calculations on demand (on ND center servers)

- **New XML format (moving into XXI century)**
  - take advantage of XML flexibility and existing software
Conclusions

- **Nuclear Data Program**
  - provides essential support for basic science and applications
  - preserves knowledge by archiving experimental and evaluated data
  - develops state of the art modeling of reactions

- **Future opportunities**
  - advance evaluation methodology
  - unification of structure and reaction data
  - enhancing experimental program
  - modernization of formats and data retrievals
  - CIELO: world-wide reaction data file