# Annual Report for FY2015

**Prepared by:**
*Michal Herman*
National Nuclear Data Center
Brookhaven National Laboratory
November 2015

**With contributions from**:
*Shamsu Basunia*, LBNL
*Allan D. Carlson*, NIST
*Toshihiko Kawano*, LANL
*John Kelley*, TUNL
*Filip G. Kondev*, ANL
*Balraj Singh*, BNL
*Michael Smith*, ORNL
*Alejandro Sonzogni*, BNL
*Ian Thompson*, LLNL

www.nndc.bnl.gov/usndp

**Table of Contents**

## I. Introduction

The USNDP Annual Report for FY2015 summarizes the work of the U.S. Nuclear Data Program (USNDP) for the period of October 1, 2014 through September 30, 2015 with respect to the work plan for FY2015 that was prepared in February 2013. The work plan and final report for the U.S. Nuclear Data Program are prepared for the DOE Office of Science, Office of Nuclear Physics. The support for the nuclear data activity from sources outside the nuclear data program is described in the staffing table and in Appendix A. This leverage amounts to about 33 FTE scientific, mostly at NNSA laboratories, to be compared with 21.6 FTE scientific (permanent + postdocs + contractors) at USNDP laboratories funded by the DOE Office of Science, Office of Nuclear Physics. Since it is often difficult to separate accomplishments funded by various sources, some of the work reported in the present report was accomplished with nuclear data program support leveraged by other funding.

Fiscal year 2015 was the 16th year in which the Nuclear Data Program has operated under a work plan developed by the program participants. The program continued to carry out important work in support of the DOE mission. The work balances the ongoing collecting, analyzing, and archiving of nuclear physics information critical to basic nuclear research and to the development and improvement of nuclear technologies with the electronic distribution of this information to users in a timely and easily accessible manner. The present section of the report consists of activity summaries for the major components of the U.S. Nuclear Data Program. This is followed by an updated staff level assignment table that reflects the final distribution of effort among the tasks carried out during FY2015. Then, we continue with the detailed status of work done in FY2015. Total staff assigned to USNDP activities during the year represented 26.2 FTE.

Following the July 2014 USNDP review, considerable effort was put in implementing the reviewers recommendations, mainly (a) updating the USNDP mission, (b) organizing a workshop in LBNL, which is described a few paragraphs below, (c) setting up a Nuclear Data Advisory Committee (NDAC), which will meet for the first time in November 2015.

In terms of personnel, the NNDC sadly lost Sam Hoblit in March 2015 after a two year fight with cancer. Gustavo Nobre was promoted to staff member after three years as a post-doc.

Table 1 summarizes the USNDP metrics since 2001. Table 2 shows the breakdown of the metrics by laboratory for the reported fiscal year and comparison with the previous fiscal year. The tables are followed by a definition of each metric. In particular, the FY2015 budget increased by 12.5%.

**Table 1**: Summary of the USNDP metrics in FY2001- FY2015, the definitions of the various terms follow the table.

| Fiscal Year | USNDP Funding | Change | Compilations | Evaluations | Dissemination (in thousands) | Reports | Papers | Invited Talks |
|---|---|---|---|---|---|---|---|---|
| 2001 | | | 7,139 | 334 | 667 | 21 | 25 | 22 |
| 2002 | $4,890K | | 6,159 | 300 | 799 | 23 | 40 | 22 |
| 2003 | $4,932K | +0.9% | 4,975 | 260 | 966 | 27 | 40 | 23 |
| 2004 | $5,015K | +1.7% | 6,241 | 276 | 1,212 | 35 | 36 | 43 |
| 2005 | $5,437K | +8.4% | 6,623 | 422 | 1,642 | 74 | 59 | 42 |
| 2006 | $5,099K | −6.6% | 4,936 | 318 | 1,863 | 47 | 60 | 48 |
| 2007 | $5,841K | +14.6% | 5,355 | 366 | 2,239 | 40 | 56 | 51 |
| 2008 | $5,967K | +2.2% | 5,104 | 385 | 2,996 | 48 | 72 | 68 |
| 2009 | $6,267K | +5.0% | 4,047 | 400 | 3,294 | 26 | 61 | 56 |
| 2010 | $6,549K | +4.5% | 4,662 | 395 | 2,843 | 27 | 83 | 51 |
| 2011 | $6,534K | −0.2% | 4,662 | 479 | 3,252 | 29 | 96 | 67 |
| 2012 | $6,785K | +3.8% | 5,221 | 209 | 3,013 | 22 | 90 | 48 |
| 2013 | $6,249K[*] | −7.9% | 4,925 | 282 | 3,447 | 29 | 84 | 79 |
| 2014 | $7,031K[*] | +12.5% | 3,738 | 166 | 3,411 | 7 | 107 | 81 |
| 2015 | $7,381K[*] | +5.0% | 4,849 | 271 | 4,246 | 12 | 98 | 50 |

[*]:Includes an Early Career Award of $500K to LANL.

In particular:

1. **Compilations**. Compilations efforts, including NSR, EXFOR and XUNDL databases, remain basically on the similar level. The NNDC spent some effort in better integrating with EXFOR, and as a result more compilations of older articles took place. This is better explained in the detailed status of the work plan.
2. **Evaluations**. Evaluations efforts, the number of ENDF evaluations is zero since no new releases of the library took place this year, however an important number of evaluation fixes were undertaken. The number of ENSDF evaluations has increased due to the inclusion of newly discovered nuclides. However, the number of nuclides evaluated is still below the critical number, around 330 per year, needed to make sure that every nucleus is evaluated at least every 10 years.
3. **Dissemination**. This year there has remained increased by 24%. At BNL, the most popular product continues to be NuDat that contributes nearly 70% of data retrievals.
4. **Reports**. The number of published reports has remained approximately constant over the last few years.
5. **Papers**. The number of articles published in the refereed journals decreased this year, mainly due that last year there was a larger number of articles published due to ND2013.
6. **Invited Talks**. The number of invited talks has decreased this year, mainly due that last year there was a larger number of talks due to ND2013.

**Table 2**: USNDP metrics in FY2015, numbers for FY2014 are shown for comparison.

| Laboratory | Compilations | | Evaluations | | Dissemination (in thousands) | | Reports | | Papers | | Invited Talks | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 |
| ANL | 8 | 110 | 0 | 27 | 40 | 60 | 0 | 0 | 26 | 37 | 5 | 3 |
| BNL[1] | 3,617 | 4,605 | 117 | 214 | 3,269 | 3,972 | 3 | 3 | 30 | 16 | 30 | 15 |
| LANL | – | – | 12 | 0 | – | – | 1 | 2 | 17 | 22 | 21 | 17 |
| LBNL | 30 | 45 | 15 | 12 | – | – | 0 | 0 | 8 | 15 | 6 | 9 |
| LLNL | – | – | 0 | 0 | 6 | 0 | 0 | 2 | 1 | 0 | 1 | 0 |
| ORNL | 30 | 28 | 16 | 7 | 88 | 120 | 0 | 1 | 9 | 4 | 13 | 6 |
| Universities | 53 | 61 | 6 | 11 | 107 | 94 | 1 | 4 | 12 | 4 | 1 | 0 |
| Total | 3,738 | 4,849 | 166 | 271 | 3,411 | 4,246 | 7 | 12 | 107 | 98 | 81 | 50 |

[1]: BNL compilations for FY2015 consist of 4,215 NSR, 105 EXFOR and 285 XUNDL datasets. BNL evaluations for FY2015 consist of 214 nuclides for ENSDF.

Definitions

- *Compilations*: The sum of the new entries added to the USNDP bibliographic (NSR - papers) and experimental databases (EXFOR - reactions, XUNDL - structure data sets).
- *Evaluations*: The sum of new evaluations submitted or accepted for inclusion in the USNDP evaluated nuclear databases. Structure number of evaluated nuclei (ENSDF), reactions number of evaluated reactions/covariances (ENDF).
- *Dissemination*: The number of electronic data retrievals made from USNDP maintained web sites. Data retrieval is defined as a request for data from any of the databases that receives a result. Total pages, gifs, etc. accessed is not tallied.
- *Reports*: The number of technical documents (includes papers in conference proceedings) or papers other than journal publications and invited talks. No administrative documents such as meeting minutes are reported.
- *Papers*: The number of articles published in refereed journals.
- *Invited talks*: The number of presentations given at the explicit invitation of the organizers of a conference, symposium, workshop, training course, etc.

## II. Network Coordination and Data Dissemination

The National Nuclear Data Center (NNDC) continues to serve as the core facility of the U.S. Nuclear Data Program (USNDP). It has the main responsibility for national and international coordination, database maintenance, and data dissemination. However, other program participants are also involved in coordination and dissemination activities.

### National and International Coordination

The NNDC, while serving as the secretariat for the program, has prepared the work plan for FY2015 in cooperation with the members of the Coordinating Committee. The NNDC Head serves as a chair of the USNDP Coordinating Committee, which consists of the Principal Investigators from each of the participating groups, and chairs the annual meeting of the program held at the Brookhaven National Laboratory. LANL chairs the Nuclear Reaction Data Working Group, and TUNL the Nuclear Structure Working Group. ORNL chairs the Astrophysics Task Force and LLNL chairs the Homeland Security Task Force.

In February 2015, DOE Office of Nuclear Physics conducted its annual Budget Briefing. Michal Herman, Toshihiko Kawano, William Horak, John Kelley, Filip Kondev, and Alejandro Sonzogni represented USNDP and made the case for the 2017 funding.

The NNDC serves as the focal point for U.S. collaboration in international nuclear data activities. This collaboration continued both in nuclear structure and decay data (Network of Nuclear Structure and Decay Data Evaluators, NSDD) and reaction data (NEA Working Party on International Nuclear Data Evaluation, WPEC, and Network of Nuclear Reaction Data Centers, NRDC).

The NNDC continues to chair the Cross Section Evaluation Working Group, which produces the ENDF/B evaluated nuclear data library for nuclear science and applied nuclear technology use. As in the past, the 2014 CSEWG meeting was held at BNL. The major topic of the CSEWG meeting was the progress on the CIELO evaluations.

NNDC staff were involved in the organization of a workshop on the calculation of the spectra of antineutrinos emitted by nuclear reactors, which took place at the Institute for Nuclear Theory in November 2013.

### USNDP Databases

The NNDC operates six Dell servers running the Linux operating system to support its compilation, evaluation, database maintenance, and information dissemination functions. These computers archive and serve the nuclear data produced by the U.S. Nuclear Data Program and the data obtained by other national and international collaborations. In addition, the NNDC maintains the collaboration GForge server that facilitates data and codes development and employs Subversion to keep track of changes.

The NNDC maintains seven nuclear physics databases for USNDP. These databases were updated continuously in FY2015 with new and revised information from efforts of the NNDC, USNDP and international collaborators. Distributions of all or parts of these databases have been made to national and international collaborators as scheduled.

### Data Dissemination

In FY2015, there were 3,411 million database retrievals, approximately equal to the number of retrieval in the previous year. Most of these retrievals, 95%, were from the NNDC web site, with NuDat as the most popular product.
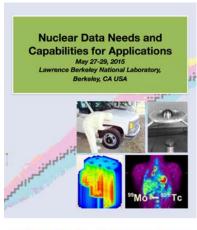
**Major Publications**

USNDP continues to publish the refereed journal Nuclear Data Sheets dedicated predominantly to nuclear structure and decay data (ENSDF evaluations). The ND2013 proceedings were published in the April, May and June issues of Nuclear Data Sheets, totaling 344 articles. The January 2015 issue will be devoted to publish the proceedings on the 2014 Covariance Workshop organized by LANL.

**Workshop on Nuclear Data Needs and Capabilities for Applications**
**Lawrence Berkeley National Laboratory, May 27-29, 2015**

On 27-29 May 2015, the US Nuclear Data Program and the Nuclear Science and Security Consortium at University of California, Berkeley, jointly hosted a Workshop on Nuclear Data Needs and Capabilities for Applications (NDNCA). The goal of the NDNCA Workshop was to compile nuclear data needs across a wide spectrum of applied nuclear science, and to provide a summary of associated capabilities (accelerators, reactors, spectrometers, etc.) available for the required measurements. Over 100 participants from 30 different institutions attended this meeting.

The needs and capabilities presented in this meeting were compiled into a a whitepaper that summarizes the results of the workshop, lists cross-cutting nuclear data needs of interest to different application areas (energy, national security, counter-proliferation, isotope production and industrial applications), and makes recommendations for how to proceed in developing a joint plan to address these needs. The whitepaper can be found at the NNDC and at the meeting website. The reference for the whitepaper is "Nuclear Data Needs and Capabilities for Applications", edited by Lee Bernstein, David Brown, Aaron Hurst, John Kelly, Filip Kondev, Elizabeth McCutchan, Caroline Nesaraja, Rachel Slaybaugh, Alejandro Sonzogni, LLNL Report LLNL-CONF-676585 (2015).

# III. Nuclear Structure and Decay Data

The nuclear structure working group emphasizes the evaluation of measured nuclear structure and decay properties for all isotopes. These data are maintained at the National Nuclear Data Center (NNDC) in the Evaluated Nuclear Structure Data File (ENSDF). Production of ENSDF is an international effort operating under the auspices of the IAEA Nuclear Structure & Decay Data (NSDD) network. ENSDF is an important source of information for derivative databases and applications including NuDat, Nuclear Wallet Cards, RIPL, MIRD and ENDF/B. Evaluations are published as peer-reviewed articles in Nuclear Data Sheets for A>20 and in Nuclear Physics A for A = 20.

**Status of ENSDF & Nuclear Data Sheets**: The ENSDF database has increased in size by roughly 1.9% over the past year. Presently there are 3296 nuclides reported. Along with many revised/updated datasets, 339 new datasets were added to ENSDF. There were 16 mass chain evaluation articles published in the Nuclear Data Sheets (FY15). The number of mass chains in the review/publishing process was given as 26. An additional 24 mass chains are listed as currently being evaluated. General usage statistics for ENSDF and products derived from ENSDF (Nuclear Data Sheets, NuDat, etc.) shows a high usage and popularity on the NNDC website and the Elsevier site.

**Status of XUNDL**: Based on regular scanning of nuclear physics journals, datasets were compiled and another updated for new publications.The XUNDL database presently carries 6442 datasets covering 2347 nuclides from over 280 mass chains. Over the past year there were an additional 50 or so communications with the authors to resolve data-related issues and obtain additional data in support of their findings. Effective October 1, 2015, E.A. McCutchan at NNDC, BNL has taken up the responsibility of coordination of XUNDL effort.

**Status of NSR**: A total of 4215 new articles were added to the NSR database. USNDP contributions are from B. Pritychenko (manager), E. Betak, B. Singh and J. Totans. The database is up-to-date and in good shape. Some effort is being spent to add "historically important" references. At the USNDP meeting, we will learn about evaluator access to the NNDC PDF library - a great step forward.

**Horizontal Evaluations and Other Data Related Activities**: A summary list of "Horizontal Evaluations and Other Data Related Activities" involving USNDP structure evaluators includes the following.

- IAEA technical meetings on ENSDF evaluation and analysis codes: Kondev, Singh, Tuli
- IAEA-CRP on Delayed Neutron Emission Probabilities: Singh, Sonzogni, McCutchan, Johnson.
- IAEA-CRP on Nuclear Data for Charged-Particle Monitor Reactions and Medical Isotope Production: F. Kondev,
- The Atomic Mass Evaluation effort (AME) and NuBase: Kondev
- K-isomer evaluations and fission hindrances: Kondev
- Atlas of Nuclear Isomers: Singh
- B(E2) evaluation for first 2+ states in all the e-e nuclei: Pritychenko, Singh
- Horizontal evaluation of beta-delayed proton emitting nuclei: Batchelder
- nucastrodata.org and the Computational Infrastructure for Nuclear Astrophysics (CINA): M. Smith,
- Collaboration with BLIP on the measurement of decay properties for a few radionuclides: E.A. McCutchan.

Other contributions:

A pressing issue connected with changes in the preparation of print-ready manuscripts for review and publication in the Nuclear Data Sheets continues to hold significant importance. Due to shrinking resources and a retirement at NNDC, the ENSDF evaluators are expected to play a greater role in preparation of the print-ready manuscripts. As detailed in Jagdish Tuli's 9-11/2014 e-mail, tools permitting an evaluator to control the .pdf output generated while processing the ENSDF files are in development. In recent months, in connection with IAEA motivated technical meetings, there has been a significant advance in McMaster's NDS-Java code that could be useful for preparation of print-ready documents for Nuclear Data Sheets. A talk and interactive discussion period are planned at the fall meeting.

**Status of ENSDF Analysis codes**: In recent years there has been extended discussion on the present state of ENSDF analysis codes. Several codes are known to have "bugs, which are in need of repair. The IAEA has sponsored technical meeting on ENSDF evaluation codes, and the

progress will be reported in sessions at the USNDP meeting.

# IV. Nuclear Reaction Data

The nuclear reaction data effort focuses on evaluation of nuclear reaction data and the related measurement and compilation activities. The USNDP also makes important contributions to nuclear reaction model code development and improvement of reaction cross-section standards.

## Reaction Data Highlights

The evaluated nuclear data library ENDF/B-VII.1, which is our latest evaluated nuclear data file recommended for use in nuclear science and technology applications, was released in December 2011. Our most important focus is to upgrade the library toward new ENDF in near future by including modern nuclear reaction modeling, updated nuclear structure information, new experimental data, and tools for evaluating covariances based on statistical theories. The work is performed closely with the US Cross Section Evaluation Working Group (CSEWG). International cooperative efforts are also indispensable to maintain the nuclear data libraries at high quality.

LANL made production measurements of the prompt fission neutron spectrum (PFNS) measured with the lithium-glass detector array for neutron-induced fission of $^{235}$U in the CH-NU neutron detector array. These are the first data in the energy range below 1 MeV for fast neutron fission.

BNL and LANL have been working closely on the new international effort on the evaluated nuclear data library, called CIELO (Collaborative International Evaluated Library Organisation), organized under the Working Party on International Nuclear Data Evaluation Co-operation (WPEC) at the Nuclear Energy Agency. New theoretical model calculations that include improved neutron scattering modeling were performed for iron and actinides to upgrade the CIELO files.

## Model Code Highlights

EMPIRE developers committed 366 updates of the EMPIRE code to the GForge server. Major improvements include (1) Moldauer approach to the width fluctuation factor, which comes in addition to the HRTW formalism, (2) Kawano's formula for elastic enhancement factor and number of degrees of freedom used in both Moldauer and HRTW calculations of the width fluctuation factor and foreseen to be also applied in the Engelbrecht-Weidenmueller transformation (3) quantum mechanical treatment of the incident deuteron breakup in the incident channel, (4) preparation for inclusion of the Engelbrecht-Weidenmueller transformation, (5) extension of the Kalman fitting capabilities. A new system for generation of covariances, advanced by S. Hoblit before his premature death, has been recovered from the Linux cluster and secured inside the EMPIRE repository. We'll attempt to make the system operational in the final phase of the iron evaluation.

LANL upgraded the CGMF code, which calculates nuclear de-excitation of fission fragments with the Monte Carlo technique, by including; (1) implemented time gates to follow the decay of isomers in fission fragments, (2) calculations extended to 20 MeV incident neutron energy for $^{239}$Pu and $^{235}$U, including multi-chance fission and pre-equilibrium processes, (3) default calculations now available for several isotopes. A new user manual is available. Making CGMF to be open source is underway.

LLNL added several new capabilities to the FREYA code, which are the new fissioning systems of $^{233}$U(n,f) and $^{241}$Pu(n,f), and production of photon lines taken from from RIPL-3, including the dipole strength functions. They demonstrated a significant improvement in comparison with experimental photon energy spectrum. The first version of FREYA was published in Comp. Phys. Comm. 191 (2015) 178.

## Nuclear Astrophysics highlights

At ORNL, two new reaction rate collections were converted into the REACLIB database format using a customized processing code. This required fitting a set of ordered pairs of (temperature, rate) where the rate varies over 30 orders of magnitude. We were able to perform this fitting to 2% over the entire relevant temperature range. A second ORNL effort was to use an advanced nuclear structure model to provide input for the FRESCO reaction code to calculate direct neutron capture on exotic Sn nuclei. These capture cross sections are crucial for predicting heavy element abundances synthesized in the r-process in supernova. We developed a method to make these calculations, and benchmarked it on stable nuclei where neutron capture measurements have been made. At BNL, a new reaction code was obtained from LANL, and other codes were transferred to a new computer system, in preparation for future research projects. At LANL, a collaboration with BNL and Notre Dame was initiated on global calculations of beta-delayed neutron yields and beta-delayed fission rates. These will be crucial for investigations of heavy element nucleosynthesis via supernovae and coalescing neutron stars.
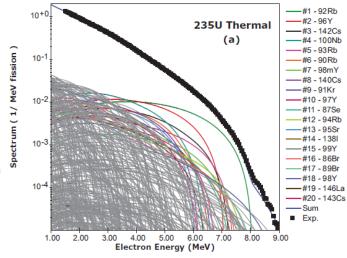
# Additional Highlights

## Nuclear Reactor Antineutrinos

Nuclear reactors are copious producers of antineutrinos, which originate in the β-minus decay of fission products. Experiments using power reactors are currently running to precisely determine the oscillation parameter $\theta_{13}$. However, preliminary results from these experiments have shown an excess of antineutrinos at energies of around 5.5 MeV, not present in the current modeling of the spectra.

Future experiments at both longer and smaller distance are being built. The former will investigate the oscillation parameter $\theta_{12}$ and mass hierarchy. The latter will study the reactor antineutrino anomaly problem, that is an apparent deficit of antineutrinos at short distances.

Additionally, reactor antineutrinos could be used to monitor reactors in non-proliferation situations.

The understanding of the antineutrino spectrum characteristics requires plenty of nuclear data. Mainly, cumulative fission yields and β-minus decay intensities. Using an updated version of the ENDF/B-VII.1 decay data sub-library, the total spectrum for the main fuel components in a reactor was decomposed into the main contributors, see plot on the side for $^{235}$U. Additionally, a systematics, similar to that of beta-delayed neutron multiplicities, was derived for the energy integrated, cross section weighted antineutrino spectrum. For more details see Phys. Rev C**91**, 011302(R) (2015).

## USNDP Staffing table FY2015

| | ANL | | BNL | | | LANL | | LBNL | | LLNL | | NIST | | ORNL | | | TUNL | | | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PhD P | PhD T | PhD P | PhD T | T/A | PhD P | PhD T | PhD P | PhD T | PhD P | PhD T/A | PhD P | PhD T | PhD P | PhD T | T/A | PhD P | PhD T | T/A | Sum |
| I. NNDC Facility Operation | | | 0.60 | | 1.70 | | | | | | | | | | | | | | | 2.30 |
| Management | | | 0.60 | | | | | | | | | | | | | | | | | 0.60 |
| Secretarial/Administrative Support | | | | | 1.00 | | | | | | | | | | | | | | | 1.00 |
| Library | | | | | 0.20 | | | | | | | | | | | | | | | 0.20 |
| Computer Operations | | | | | 0.50 | | | | | | | | | | | | | | | 0.50 |
| II. Coordination | 0.10 | | 0.55 | | | 0.15 | | 0.30 | | | 0.01 | | | 0.05 | | | 0.05 | | | 1.21 |
| National Coordination | | | 0.34 | | | 0.05 | | 0.30 | | | 0.01 | | | 0.05 | | | 0.05 | | | 0.80 |
| International Coordination | 0.10 | | 0.21 | | | 0.10 | | | | | | | | | | | | | | 0.41 |
| III. Nuclear Physics Databases | | | 0.83 | | 0.64 | | | | | 0.06 | | | | | | 0.10 | | | | 1.63 |
| Nuclear Science References, NSR | | | 0.25 | | 0.54 | | | | | | | | | | | | | | | 0.79 |
| Exper. Nucl. Structure Data, XUNDL | | | 0.10 | | | | | | | | | | | | | | | | | 0.10 |
| Eval. Nucl. Structure Data, ENSDF | | | 0.20 | | | | | | | | | | | | | | | | | 0.20 |
| Numerical Nuclear Data, NuDat | | | 0.10 | | | | | | | | | | | | | | | | | 0.10 |
| Experimental Reaction Data, CSISRS | | | 0.10 | | | | | | | | | | | | | | | | | 0.10 |
| Evaluated Nuclear Data File, ENDF | | | 0.08 | | | | | | | 0.02 | | | | | | | | | | 0.10 |
| Database Software Maintenance | | | | | 0.10 | | | | | | | | | | | 0.10 | | | | 0.20 |
| Future Database System Develop. | | | | | | | | | | 0.04 | | | | | | | | | | 0.04 |
| IV. Information Dissemination | | | 0.92 | 0.15 | 0.36 | | | | | | | | | 0.10 | | 0.10 | | | 0.55 | 2.18 |
| Nuclear Data Sheets | | | 0.30 | 0.15 | 0.16 | | | | | | | | | | | | | | 0.20 | 0.81 |
| Customer Services | | | | | 0.10 | | | | | | | | | | | | | | | 0.10 |
| Web Maintenance & Development | | | 0.62 | | 0.10 | | | | | | | | | 0.10 | | 0.10 | | | 0.35 | 1.27 |
| V. Nuclear Structure Physics | 0.70 | 1.00 | 2.55 | 1.95 | | 0.10 | | 1.00 | 1.33 | | | | | 1.00 | 0.15 | | 0.70 | 0.50 | 0.20 | 11.18 |
| NSR Abstract Preparation | | | 0.25 | 0.40 | | | | | | | | | | | | | | | | 0.65 |
| Compilation of Exper. Structure Data | 0.05 | 0.25 | 0.17 | 0.20 | | | | 0.10 | 0.15 | | | | | 0.20 | | | 0.10 | | 0.10 | 1.32 |
| Eval. of Masses & Nuclides for ENSDF | 0.25 | 0.50 | 1.63 | 1.35 | | | | 0.90 | 0.70 | | | | | 0.80 | 0.15 | | 0.30 | 0.30 | 0.10 | 6.98 |
| Ground & Metastable State Properties | 0.20 | | | | | | | | | | | | | | | | | | | 0.20 |
| Radioactive Decay Data Evaluation | 0.05 | | | | | | | | | | | | | | | | | | | 0.05 |
| Thermal Capture Gamma Data Eval. | | | | | | | | | 0.48 | | | | | | | | | | | 0.48 |
| Light Mass Eval. for Nucl. Physics A | | | | | | | | | | | | | | | | | 0.30 | 0.20 | | 0.50 |
| Nuclear Structure Data Measurement | 0.10 | | 0.40 | | | 0.10 | | | | | | | | | | | | | | 0.60 |
| ENSDF Evaluation Support Codes | 0.05 | 0.25 | 0.10 | | | | | | | | | | | | | | | | | 0.40 |
| VI. Nuclear Reaction Physics | | | 1.57 | 1.21 | 0.12 | 0.85 | 0.15 | | 0.40 | 0.05 | | 0.10 | 0.10 | 0.05 | | | | | | 4.60 |
| Experimental Data Compilation | | | 0.30 | 0.50 | | | | | | | | | | | | | | | | 0.80 |
| ENDF Manuals and Documentation | | | 0.10 | | | | | | | | | | | | | | | | | 0.10 |
| ENDF Evaluations | | | 0.52 | 0.21 | | 0.25 | | | | 0.03 | | | | | | | | | | 1.01 |
| Nuclear Reaction Standards | | | | | | 0.10 | | | 0.40 | | | 0.10 | 0.10 | | | | | | | 0.70 |
| Nuclear Model Development | | | 0.20 | 0.40 | | 0.10 | 0.10 | | | | | | | | | | | | | 0.80 |
| Nucl. Reaction Data Measurements | | | | | | 0.30 | | | | | | | | | | | | | | 0.30 |
| Astrophysics Nuclear Data Needs | | | 0.05 | | | 0.10 | | | | | | | | 0.05 | | | | | | 0.20 |
| Covariances development | | | | 0.10 | | | 0.05 | | | | | | | | | | | | | 0.15 |
| Reactor anti-neutrino & decay heat calculations | | | 0.30 | | | | | | | | | | | | | | | | | 0.30 |
| Verification and Validation | | | 0.10 | | 0.12 | | | | | 0.02 | | | | | | | | | | 0.24 |
| DOE-SC Nucl. Data Funded Staff | 0.80 | 1.00 | 7.02 | 3.31 | 2.82 | 1.10 | 0.15 | 1.00 | 2.03 | 0.11 | 0.01 | 0.10 | 0.10 | 1.20 | 0.15 | 0.20 | 0.75 | 0.50 | 0.75 | 23.10 |
| Staff Supported by Other Funds | 0.20 | | 0.30 | | 0.18 | 7.90 | 1.35 | | | 2.20 | | 0.10 | 1.30 | | | | | | | 13.53 |
| TOTAL STAFF | 1.00 | 1.00 | 7.32 | 3.31 | 3.00 | 9.00 | 1.50 | 1.00 | 2.03 | 2.31 | 0.01 | 0.20 | 1.40 | 1.20 | 0.15 | 0.20 | 0.75 | 0.50 | 0.75 | 36.63 |

PhD P: PhD Permanent,
PhD T: PhD Temporary,
T/A: Technical and administrative,
GS: Graduate student.

# Detailed Status of the Work Plan
# Fiscal Year 2015 Report

## I. NNDC Facility Operation

### A. Management

This task includes planning, budgeting, personnel, interaction with BNL management, and interaction with funding authorities.

### B. Library

NNDC maintains an archival collection of low- and intermediate-energy nuclear physics publications. This library supports the NNDC compilation activities and the U.S. nuclear reaction and nuclear structure data evaluation and international nuclear structure evaluation effort.

### C. Computer Operation

The NNDC operates several servers running Red Hat Enterprise Linux in support of its compilation, evaluation, database maintenance, and information dissemination functions. In addition, each staff member has a PC that supports an interface to these Linux servers and supports administrative functions such as word processing and email. Furthermore, MS Windows servers provide centralized backup, printing and file serving for the PCs. This task includes software upgrades, hardware and software procurements, machine operations and internal user support for both the Linux and Windows platforms.

| BNL planned activities | Status |
| --- | --- |
| Ensure compliance with DOE cyber security rules and regulations through regular scanning of NNDC servers and desktops and prompt remediation of discovered vulnerabilities within the prescribed time. Noncompliance could result in a machine's total block from network (BNL internal network and the Internet) access. | NNDC information dissemination servers were maintained at 99.9% 24x7-availability. They were also found to have met DOE cyber security requirements during Inspector General's series of audits. |
| Provide prompt and effective computer support to NNDC staff, its visitors and major end-users in their use of NNDC computing resources. | Helped external collaborators maintain their access to NNDC's internal servers and BNL's e-mail services. Dropbox replaced traditional methods of exchanging huge files securely. |
| Upgrade the suite of software powering the GForge server, the ADVANCE server and the Linux cluster to meet NNDC's and the nuclear data community's computing requirements. | USNDP collaboration server (GForge), ENDF quality assurance server (ADVANCE), and ENDF verification and validation server (Linux cluster) were maintained at 99.9% 24x7-availability. |
| Upgrade the Windows-based central backup system to be able to handle the new filesystem format being used by NNDC servers running Red Hat Enterprise Linux version 6 and higher. | Backups were performed regularly and corrupted files were restored promptly and reliably minimizing loss of productivity. |

## II. Coordination

### A. National Coordination

National coordination is required for activities under the US Nuclear Data Program as well as Cross Section Evaluation Working Group. This is mostly performed by the National Nuclear Data Center, with contributions from other laboratories (USNDP Working Groups and Task Forces as well as CSWEG Committees).

ANL: Chair the Covariance Committee the Cross Section Evaluation Working Group.

| ANL Planned Activities | Status |
| --- | --- |
| Organize and chair the CSEWG Covariance Committee | Completed. |

BNL: Chair USNDP Coordinating Committee, chair Cross Section Evaluation Working Group, develop USNDP work plan, and maintain its USNDP website.

| BNL planned activities | Status |
| --- | --- |
| Prepare FY2016 work plan for USNDP. | FY2016 plan has been prepared and posted on the NNDC Web site. |
| Organize and chair CSEWG Meeting at BNL in November 2014. | CSEWG was held as a part of the Nuclear Data Week 2014. This edition was dedicated to the international CIELO evaluation project and thus was attended by several foreign evaluators. Not all typical CSEWG matters could be discussed in the limited time frame therefore an extraordinary mini-CSWEG meeting was organized on May 7-8, 2015 to deal with the remaining topics. |
| Organize and chair USNDP Meeting at BNL in November 2014. | USNDP meeting was held as a part of the Nuclear Data Week Nov. 5-7, 2014. |

| | |
|---|---|
| Edit and publish summary reports and proceedings of the CSEWG and USNDP meetings. | Minutes of the CSEWG and USNDP meetings were prepared and posted on the NNDC Web site. |
| Maintain CSEWG and USNDP websites | CSEWG and USNDP websites were updated with the meeting minutes and viewgraphs of the presentations available from the BNL Indico server. |
| Aid LLNL to organize and chair the CSEWG Task Force on Nuclear Data Needs for Homeland Security. | CSEWG Task Force on Nuclear Data Needs for Homeland Security was not active in FY14 and there was no specific presentation at the CSEWG 2014 meeting. It is expected that the renewed interest in nuclear data by the Homeland Security community resulting from the recent NDNCA Meeting at LBNL will stimulate revival of this activity in FY2016. |

| LANL planned activities | Status |
|---|---|
| Organize and chair CSEWG Evaluation Committee meeting at BNL, November 2014. | Organized and chaired CSEWG/Cielo Evaluation meeting at BNL,November 2014, as well as mini-CSEWG in May 2014. |
| Organize and chair Nuclear Reaction Working Group meeting at USNDP meeting in November 2014. | Organized and chaired Nuclear Reaction Working Group meeting at USNDP meeting in November 2014. |

LBNL: Serve as a member of the USNDP Coordinating Committee and chair the USNDP Nuclear Structure and Decay Data Working Group in addition to overseeing, coordinating, and directing the work of members of the Isotopes Project. The latter effort includes working with LBNL management, with other members of the USNDP, and with the program officers of the DOE.

| LBNL planned activities | Status |
|---|---|
| Unplanned - Establish nuclear data activities at Nuclear Engineering Department, UCB for recruiting retired evaluators and students. | It is established and two senior evaluators of LBNL, Richard B. Firestone and Coral M. Baglin are now working for USNDP. Mark Trudel (student) has also joined the group for XUNDL compilations. |
| Coordinate EGAF Capture Gamma-ray Library evaluations with LLNL for preparation of ENDF format datasets and improved RIPL files. | Coordinated with LLNL and submitted EGAF updates for nine nuclides in ENDF |
| Unplanned - Organize a workshop as recommended by USNDP Review Committee. | Workshop on Nuclear Data Needs and capabilities for Applications (NDNCA) organized, hosted at LBNL, and chaired with members of other USNDP centers. |

LLNL: Chair the Task Force on Nuclear Data Needs for Homeland Security of the Cross Section Evaluation Working Group.

| LLNL planned activities | Status |
|---|---|
| Organize and chair the CSEWG Task Force on Nuclear Data Needs for Homeland Security. | Continuing. |

ORNL: Chair the Astrophysics Task Force, and help facilitate and coordinate nuclear astrophysics data work at different labs to advance USNDP goals; provide leadership in planning future activities in nuclear data for nuclear astrophysics

| ORNL planned activities | Status |
|---|---|
| Summarize USNDP efforts in nuclear data for nuclear astrophysics at USNDP Meeting. | Written descriptions of nuclear astrophysics - related activities were prepared for the USNDP annual report |
| Communicate current efforts and future plans with researchers in nuclear astrophysics and nuclear astrophysics data. | Efforts in nuclear astrophysics data have been recently discussed at the Origins of Matter and Evolution of Galaxies Symposium in Beijing in June 2015, and with meetings with research colleagues at Sung Kyun Kwon University, Ewha University, and the RAON facility in South Korea in April 2015. |
| Represent USNDP nuclear astrophysics efforts at international collaboration meetings on nuclear astrophysics data and in "town meetings", community meetings, and summer schools. | We initiated several discussions on nuclear astrophysics data at the Low Energy Community Meeting at MSU in August 2015. Also, efforts in nuclear astrophysics data have been recently discussed at the Origins of Matter and Evolution of Galaxies Symposium in Beijing in June 2015, and with meetings with research colleagues at Sung Kyun Kwon University, Ewha University, and the RAON facility in South Korea in April 2015. |
| Initiate collaborative research projects to raise the visibility of nuclear data projects directed at astrophysics applications. | A new project was initiated regarding benchmarking direct capture cross section predictions (with advanced structure theory input) against existing data; a paper was published on this work. |
| Discuss future plans in nuclear astrophysics data with DOE, with USNDP/NNDC, and with other funding agencies. | Numerous discussions with DOE Program officers on nuclear astrophysics activities were held over the past year. |

TUNL: Chair the USNDP Nuclear Structure Committee.

| TUNL planned activities | Status |
|---|---|
| Organize and chair USNDP Nuclear Structure Committee meeting at BNL, November 2014. | Chaired sessions and prepared meeting notes. |
| Present brief summary of USNDP Nuclear Structure Committee status at DoE budget briefing. | Completed. |

## B. International Coordination

ANL: Represent the ANL in IAEA-sponsored Nuclear Structure and Decay Data Network (NSDD) and Decay Data Evaluation Project. Participate in IAEA-sponsored coordinated research programs (CRP) and training workshops.

| ANL planned activities | Status |
|---|---|
| Participate in the IAEA Coordinated Research Project on "Nuclear data for charged-particle monitor reactions and medical isotope production" | Completed. Participated in the IAEA-CRP activities and reported results and completed milestones at the December 2014 meeting held at the IAEA Headquarters. |
| Participate in an IAEA-organized project aimed at improving the existing ensdf analysis codes. | Continuing. ANL & NSCL staff are directly involved in the development of the stand-alone version of the RULER and the NDS-JAVA codes. Validations of other codes are continuing |
| Participate in the NSDD meeting in FY2015. | Completed. Co-organizer and lecturer of an IAEA-led ENSDF training workshop following the NSDD meeting |

BNL: Represent the United States in IAEA-sponsored Nuclear Reaction Data Center Network (NRDC) and Nuclear Structure and Decay Data Network (NSDD). The NNDC center head is the U.S. member and vice-chair of the IAEA's International Nuclear Data Committee (INDC), the lead US member of the NEA Working Party on International Evaluation Cooperation (WPEC) in his position as chair of CSEWG. Many of the NNDC staff participates in IAEA sponsored activities such as Workshops and Technical Meetings.

| BNL planned activities | Status |
|---|---|
| Participate in the IAEA-sponsored NRDC meeting in FY2015. | B. Pritychenko participated in the NRDC meeting at IAEA, Vienna. |
| Participate in NEA WPEC annual meeting in FY2015. | M. Herman lead UD delegation to the WPEC meeting and participated in the meetings of several WPEC subgroups. D. Brown participated in subgroup 38 on the new nuclear data structure and several other subgroups held during the WPEC week in Paris. |
| Conduct and lecture at likely IAEA-sponsored workshop at Trieste in FY2015. Coordinate, lectures at IAEA-Sponsored ENSDF workshop at IAEA, Vienna, April 2015 | No workshops took place in Trieste during FY15. E. McCutchan, J. Tuli, B. Singh lectured at the ENSDF workshop held in Vienna in April 2015. E. McCutchan coordinated the workshop |
| Participate in IAEA organized network coordination meetings (NRDC, NSDD) | M. Herman, A. Sonzogni, E. McCutchan, J. Tuli, B. Singh participated in the NSDD meeting at IAEA Vienna. |
| Continue to participate in training/mentoring of new ENSDF evaluators through collaborative work (McMaster). | 1. Dr. Sorin Pascu from Bucharest: new evaluator, started April 2015: A=130 evaluation with B. Singh. 2. Dr. A. Chakraborti, Shantiniketan University, India: new evaluator in training since November 2014: A=98 evaluation with B. Singh. 3. Dr. Sukhjeet Singh, MM University, Mullana, India; work on A=224 and 226 with B. Singh |
| IAEA-CRP on Reference database for Beta-delayed Neutron emission probabilities | A. Sonzogni and B. Singh participated in the 2nd RCM meeting in March 2015, and status of the evaluation of data for Z=2-28 presented. |
| IAEA-organized activity for improvement and enhancement of ENSDF computer codes | B. Singh has been involved with directing the development of JAVA-GAMUT code for adopted gamma-ray energies and intensities in ENSDF; consultations with J. Chen on improving McMaster-developed JAVA-NDS code for display of ENSDF data files, and with S. Singh in India on enhancing the ALPHAD code through automatizing r0 parameter in the code, and updating Akovali's 1998 r0 table (1998Ak04) |

LANL: Participate in and chair international nuclear reaction data collaborations. This insures that the U.S. benefits from breakthroughs around the world, and plays a leadership role in new developments. LANL staff members participate in NEA/WPEC committees on covariance data and international model code development cooperation. LANL will host visits by foreign scientists with international reputations to benefit from the exchange of information and ideas.

| LANL planned activities | Status |
|---|---|
| Participate in NEA-WPEC 2015 meeting | A couple of scientists participated in NEA-WPEC 2015 meeting |
| Participate in relevant IAEA CRP meetings (fission model parameters and nuclear cross section standards). | One scientist participated in the standards meeting. There was no fission model parameters meeting in this period. We participated in the Coordinate Meeting on inelastic scattering data for major actinides. |
| Organize International Nuclear Reaction Mechanisms, Varenna, Italy, 2015. | Organized Int. Conf. Nuclear Reaction mechanisms, in Varenna, Italy, in June 2015. There were 85 participants from 18 countries. |
| Make latest version of NJOY data processing code available to the international community. | Updated NJOY2012 made available to the international community |
| Host a couple of international visitors to LANL to collaborate on the evaluation of reaction data. | Hosted one scientist from Japan, currently a postdoc funded by Japan Society for the Promotion of Science, who works on charged particle induced reactions. We also hosted on scientist from Toshiba Japan, whose expertise is nuclear reactor physics. |
| Organize a technical meeting on the international cooperative nuclear data library | This plan was not performed. However, discussion on the international nuclear data library continuues by email. |

LBNL: Participate in IAEA-sponsored training workshops, planning meetings and coordinated research programs on nuclear structure and decay

data.

| LBNL planned activities | Status |
|---|---|
| Coordinate the development of a database for the photo strength functions with International collaborators and the IAEA. | Continuing. |
| Coordinate EGAF and RIPL evaluations with the IAEA | Continuing |
| Coordinate the development of a new continuum reaction/gamma-ray database with the IAEA and researchers at the Oslo Cyclotron Laboratory. | Discontinued |
| Coordinate LBNL/Budapest/FRM-II/Julich TransActinide Nuclear Data Evaluation and Measurement (TANDEM) collaboration to measure actinide neutron cross sections. | Continuing. A white paper is published in J. Radioanal. Nucl. Chem. 304, 1359 (2015). |

TUNL: Represent TUNL at IAEA-sponsored at Nuclear Structure and Decay Data network (NSDD).

| TUNL planned activities | Status |
|---|---|
| Participate in the policy matters related to the NSDD network. | Continuing. |
| Participate in NSDD/IAEA meetings | Continuing. Chaired sessions at 2015 NSDD meeting in Vienna. |

# III. Nuclear Physics Databases

## A. Nuclear Science References (NSR)

The NNDC is responsible for NSR, the bibliographic database for nuclear physics research. This task includes quality control, file update and maintenance, and file distribution to collaborators. Updates are done on a continuing basis. The preparation of NSR entries is given under Nuclear Structure Physics.

| BNL planned activities | Status |
|---|---|
| Distribute database to collaborators. | NSR database has been distributed to the IAEA once a month. |
| Provide international coordination of NSR compilations and activities. | NSR compilations have been coordinated worldwide. NSR contract with the Institute of Physics, Bratislava has been successfully managed. |
| Database updates and maintenance. | The database contents have been updated 120 times in FY2015. |
| Explore the possibility of cooperation with OSTI on nuclear data storage and dissemination. | The possibility of cooperation with OSTI has been explored. |
| Explore the possibility of cooperation with NRDC network on the transfer of selected EXFOR nuclear reaction references to NSR. | The first group of major journal references has been transferred in collaboration with the IAEA. The next group of journals has been identified. |
| Unplanned activity. Provide Web access to NNDC library resources for NSDD evaluators. | NSR Web application was upgraded in collaboration with the IAEA, and the new version of application enables an authorized access to PDF files stored at the National Nuclear Data Center. |

## B. Experimental Nuclear Structure Data (XUNDL)

The NNDC is responsible for maintaining and providing access to the XUNDL database. This database contains compilations (in ENSDF format) of recently published or completed level-structure data for high-spin and low-spin physics. The compilation work is mainly carried out at McMaster University. The McMaster group also coordinates this work with that of other centers. The NNDC updates the database as new/revised data sets are received from McMaster.

| BNL planned activities | Status |
|---|---|
| Weekly update of the database using input received from McMaster University. | Continuing activity. Completed. |
| Distributed twice a year to the NSDD network. | Continuing activity. Completed. |

## C. Evaluated Nuclear Structure Data File (ENSDF)

The NNDC is responsible for ENSDF, a database of evaluated experimental nuclear structure and decay data. The NNDC is responsible for format and content checking, preparation of manuscript, and quality control (review) of evaluations submitted for inclusion. The NNDC maintains the database, which includes database updates and distribution to collaborators. Corrections are implemented on a continuing basis.

| BNL planned activities | Status |
|---|---|
| Maintain ENSDF database, includes continuous updating. | Continuing activity. Completed. |
| Process evaluations received from NSDD evaluators. | Continuing activity. Completed. |
| Distribute ENSDF database to collaborators twice a year. | Continuing activity. Completed. |

## D. Numerical Nuclear Data File (NuDat)

The NNDC is responsible for NuDat, which consists of a database and a suite of codes that access it, allowing web users to search for level and γ-ray properties extracted from ENSDF, ground and meta-stable state properties (Wallet Cards), atomic and nuclear radiations derived from ENSDF, and thermal neutron cross sections and resonance integrals. Additionally, NuDat contains an interactive Chart of Nuclides and interactive level schemes.

| BNL planned activities | Status |
|---|---|
| Update NuDat database as necessary, about 10 times a year. | Completed. Nudat contents and software were regularly updated. |

## E. Neutron Reaction Data Bibliography (CINDA)

The NNDC continues to contribute to the CINDA database that contains references to nuclear reaction data in the published and unpublished literature. Since 2004, CINDA also contains bibliography information on charged-particle and photonuclear reactions. The database serves as an index to the data contained in the experimental database, CSISRS. The database is maintained by the Nuclear Data Section, IAEA Vienna.

| BNL planned activities | Status |
|---|---|
| Contribute to CINDA by compiling experimental cross-section data to the EXFOR and NSR databases. | NNDC EXFOR and NSR compilation activities contributed to CINDA six-month updates. |

## F. Experimental Reaction Data File (CSISRS)

The NNDC is responsible for maintaining the CSISRS database at BNL. This database contains experimental nuclear reaction data for incident energies below 1 GeV, including neutron-induced reactions and reactions with incident charged particles of mass $A \leq 12$. Many groups worldwide compile experimental data and send it to the central database in Vienna in the EXFOR format. Then, each is responsible to update its own database. The effort described here includes quality control, file update and data transfer activities. The NNDC database is updated, as compilations are exchanged and checked from the compiling centers. The compilation activity is given under Nuclear Reaction Physics.

| BNL planned activities | Status |
|---|---|
| Update EXFOR database with compilations from cooperating centers (500 entries expected). The NNDC compilation work can be found under Nuclear Reaction Physics, chapter V of the present document. | The EXFOR database has been updated 12 times in FY2015 using the latest transmissions of NRDC network. EXFOR contracts with the Institute of Physics, Bratislava and Vienna have been successfully managed. |

## G. Evaluated Nuclear Data File (ENDF)

The NNDC is responsible for ENDF, a database of evaluated nuclear data required for many nuclear applications. The work is organized under the Cross Section Evaluation Working Group (CSEWG), coordinated by the NNDC. The ENDF file contains complete descriptions of nuclear reactions of neutrons with many nuclides and elements for energies up to 20 MeV and radiations from radioactive decay. A number of evaluations for energies up to 150 MeV and for incident charged particles and photons are also included. The data are stored in the ENDF format developed at NNDC about 35 years ago, and adopted as an international standard. In addition to the U.S. library, ENDF/B, the database contains evaluated data libraries from the European Union, Japan, Russia, and China. This activity includes the processing and quality control for the U.S. ENDF/B library, the distribution of this database in the United States and the exchange of libraries internationally. New evaluations for the next release of the library, ENDF/B-VII.1, are assembled, tested and made available to users through NNDC's Web servers and GForge collaboration server.

| BNL planned activities | Status |
|---|---|
| Maintain Linux/MySQL database system. | Continuing activity. Completed. |
| Maintain GForge/Subversion system for tracking development of the ENDF/B library. | Continuing activity. Completed. |
| Maintain and improve Sigma database and web interface for users without specialized knowledge of ENDF-6 format. (See also information dissemination, chapter IV). | Continuing activity. Completed. |
| Maintain and extend ADVANCE, the ENDF continuous integration system that continually checks for modification to the ENDF database then runs all available tests on the changed data files. | Extended ADVANCE to test photo-atomic and electo-atomic reaction data. Ported ADVANCE to most recent versions of FUDGE and NJOY. |

## H. Database Software Maintenance

This activity includes software bug fixes and enhancements for the five nuclear physics databases maintained by NNDC.

| BNL planned activities | Status |
|---|---|
| Fix bugs and develop enhancements for the six nuclear physics databases maintained by NNDC. | Completed. |

## I. Database Systems Development

The multi-year effort to migrate the USNDP databases to a LINUX/MySQL environment was completed in FY2009. Afterwards, several follow-up tasks needed to be performed. A new web interface, complementary to the existing one, should be developed to facilitate the retrieval of experimental data in CSISRS by non-ENDF users, such as nuclear astrophysicists. This interface should focus on the relevant experimental data, such as a full reference to the publication, a comprehensive reaction description and the experimental data. The existing interface, giving access to the complete compilation (with more details than the reference, reaction and data) will be retained and will still be accessible to users who need it. Also, a new ENDF interface should be developed for users who do not possess specialized knowledge of ENDF-6 format.

| BNL planned activities | Status |
|---|---|
| Upgrade periodically the Linux/MySQL system software to fix bugs, provide new functionalities and improve the system's performance, security and availability. | MySQL databases were operated at 99.9% 24x7-availability. |
| Implement and maintain automatic replication of updates from the internal MySQL database server to the external. | Database updates were regularly and reliably replicated. |

# IV. Information Dissemination

The goal of the dissemination activities of the USNDP is to provide scientists and engineers with nuclear data from the USNDP-maintained nuclear databases in a variety of user-friendly formats and media.

## A. Web Site Maintenance

The NNDC provides electronic access to the nuclear physics databases that it maintains on behalf of the USNDP as well as access to other nuclear physics information through its Web site. The NNDC Web services are powered by five Dell servers, each one has dual 2.9-GHz 8-core processors, 128-GB RAM and 15k-RPM disk drives Other USNDP members also offer nuclear physics information through their websites. These services require resources to maintain currency and improve performance.

| ANL Planned Activities | Status |
|---|---|
| Maintain and upgrade the ANL/NDM report series web site. | Continuing. Website was updated. |
| Maintain and upgrade Experimental Resources for Nuclear Data web site. | Continuing. Website was updated. |
| Maintain and upgrade ANL Nuclear Data Information web site. | Continuing. Website was updated. |

| BNL Planned Activities | Status |
|---|---|
| Continued improvement to the ENSDF and NSR web interfaces. | Ongoing effort. Changes made on request including link to bugs GForge database, wording changes, vulnerability fixes, and others. |
| Maintain web interfaces for ENDF and EXFOR databases. | Web interfaces were updated in collaboration with the IAEA. |
| Improve Sigma web interface by adding new and extended features following user's requests. | Completed. |
| Maintain web interface for double-beta decay, B(E2) and Maxwellian-averaged cross sections and reaction rates. | Web interfaces were updated to satisfy the latest cyber security requirements. |
| Maintain currency of the CSEWG, USNDP and the NNDC web sites, proactively respond to the users requests. | Ongoing effort. There were 617 commits to source control of the production web site. |
| Improve reliability of its web services by installing the latest version of Apache/Tomcat servers and mod-jk connector software for a new dual web server system. Maintain the NNDC Web Services readiness above the 99% level. | Working the system administrator from ITD, this was done and some configuration changes were implemented. |
| Strictly follow all BNL and DOE cybersecurity rules and regulations during the Web application design, development and implementation. | Web applications met DOE's cyber security requirements as per Inspector General's series of audits. |
| Maintain GForge server powering NNDC Web services. | GForge server operated at 99.9% 24x7-availability. |
| Check and upgrade when necessary all web applications for Tomcat 6 compliance. | Completed. |
| Unplanned activity: Checking and fixing vulnerabilities. | Based on reports of BNL vulnerability scanning, 3100 vulnerabilities ranging from critical to medium severity were investigated. About 300 fixes were made, including some configuration changes, many of which addressed several vulnerabilities at once, and most of the others were false positives or could not be reproduced. |

| ORNL Planned Activities | Status |
|---|---|
| Expansion of features of our online software suite to convert nuclear data to astrophysical reaction rates and plot, manipulate, combine, and share results online; this activity is at risk of termination. | We significantly enhanced our processing code that converts pointwise reaction rates into rates parameterized in the REACLIB format. We also added scripting capabilities to enable entire libraries to be fit quickly. The code performs fits on rates varying over 30 orders of magnitude to a precision of 2 percent |
| Expansion of host website nucastrodata.org to hyperlink in more relevant nuclear data sets for astrophysics research. | The link section of our website has been expanded to include the latest online datasets, and outdated links were removed. |

| TUNL Planned Activities | Status |
|---|---|
| Continue to improve the TUNL website and provide access to new information on A = 3 - 20 nuclei. | Continuing |
| Continue to prepare new PDF and HTML documents of the most recent TUNL reviews. | Continuing |

| | |
|---|---|
| Continue to provide PDF and HTML documents for FAS reviews for the A = 3 - 20 series with the most current NNDC reference keys and with the direct hyperlink of reference with TUNL keys. | We have completed FAS reviews from year 1976 to 1979. |
| Continue to provide Energy Level Diagrams (in GIF, PDF and EPS/PS formats) to accompany the PDF and HTML documents for the most recent TUNL reviews and preliminary reports, and for the earlier FAS reviews. | Continuing |
| Provide compiled and evaluated data on the decay of unstable ground states and on structure data from thermal neutron capture. | Continuing |
| Provide compiled data related to the level parameters for A = 3 - 20 nuclei populated in proton- and alpha-particle-induced reactions. | Continuing |
| Provide online access of TUNL dissertations collection. | 93% completed and includes all presently available documents. |
| Carry out a horizontal evaluation of life-times for nuclei in the A = 3 to 20 region that beta decay with a 2015 REU (Research Experience for Undergraduates) student. | Completed (except $^7$Be) and summarized in TUNL progress report contribution. |

## B. Customer Services

This task accounts for the non-electronic services which the USNDP renders to customers. At the scientific staff level, this means direct assistance to users needing advice from nuclear data experts or advice on solving complex queries via electronic access to the database. The NNDC staff allocation at the support level is for maintaining a "help desk" and for administrative/clerical support of its customer services.

| BNL Planned Activities | Status |
|---|---|
| Provide technical support to nuclear data end-users as necessary. | About 120 NSR articles were requested and sent. |
| Maintain Comments/Questions for all reaction databases, for the NNDC web services, ENDF, EXFOR and for Nuclear Wallet Cards. | More than 300 e-mails were answered in FY15 from users. |

## C. Publications

The USNDP provides some paper publications as well as electronic access to the nuclear physics databases that it maintains. This includes the Nuclear Data Sheets published by Elsevier and various versions of the Nuclear Wallet Cards.

| BNL Planned Activities | Status |
|---|---|
| Prepare issues of Nuclear Data Sheets for publication. | Seven issues of Nuclear Data Sheets were published. The January issue contained the proceedings of the Covariance Workshop organized by LANL in Santa Fe, NM, April 2014. One issue also contained a compilation of nuclear isomers and an evaluation of beta delayed neutron emitters properties with Z between 2 and 28. |
| Develop software for Nuclear Data Sheets publication (McMaster) | Presentation of JAVA-NDS and demo of a mass chain were given by B. Singh at NSDD-15 meeting in April 2015. Based on discussions at the NSDD-15 meeting, the code was handed over to Jun Chen at NSCL-MSU in April 2015 for improvement and stable workings. Much progress has been made by Jun Chen in the improvement of the code. Checking of stable working of this code by J. Chen and B. Singh in progress. |

| TUNL Planned Activities | Status |
|---|---|
| Assist with preparation of print-ready manuscripts for review and publication in Nuclear Data Sheets. | Continuing. |

# V. Nuclear Structure Physics

## A. NSR Abstract Preparation

The literature search and preparation of KEYWORD abstracts for publications included in NSR require scientific expertise. BNL continues to have the overall responsibility for this database. The IAEA is expected to provide more than 20% of the keywords. Similar contributions from other external collaborators are expected. These will be checked and edited by BNL as necessary before being added to the database.

| BNL Planned Activities | Status |
|---|---|
| Prepare entries for about 3,100 new references, and keyword abstracts for 2,000 of them. | NSR entries were prepared for 4,215 new references, keyworded abstracts 3,058. |
| Check and edit key-worded abstracts from other collaborators as applicable and necessary. | All keyworded abstracts from other centers were double checked and necessary consultations were provided. |
| Provide database updates with the missing and historic references. | 1,159 missing NSR articles were added using EXFOR database contents: --- 62 PRL, PLB, PRD --- 40 Nuclear Physics A --- 152 Nuclear Physics, 18 Physical Review C --- 742 Physical Review --- 16 ZPhys, 31 |

| | ZPhysA, 39 NIMA, 77 NIMB |
| --- | --- |
| NSR keywording for all articles in Physical Review C journal (McMaster) | 1,105 PRC articles were processed at McMaster University, including 587 keyworded abstracts. |
| NSR dictionaries update and maintenance | ---New Authors: 1,908 ---New Nuclides: 178 ---New Reactions: 147 ---New Decays: 21 ---New Journals: 6 |

## B. Compilation of Experimental Structure Data

This activity involves compilation of recently published or completed experimental nuclear structure data for inclusion in XUNDL. The compilation is done by McMaster, while the NNDC is maintaining the database. In FY09, ANL plans to start contributing to compilation effort.

| ANL Planned Activities | Status |
| --- | --- |
| Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results. | 178 XUNDL datasets were compiled by staff at ANL and NSCL. On several occasions interacted with the authors to seek additional data and/or clarifications. |

| BNL Planned Activities | Status |
| --- | --- |
| Compile new B(E2) experimental data. Continue work on a B(E2) evaluation project (in collaboration with McMaster and Central Michigan Universities). Produce a new evaluation for even-even nuclei that will include evaluated, calculated and experimental B(E2) values. | The latest compilation and evaluation of B(E2) data with the September 2015 cut-off has been produced. This work has been accepted for publication in Atomic Data and Nuclear Data Tables journal. The total number of new nuclide compilations for FY2015 is 35. |
| Compile new double-beta decay experimental data. Produce evaluated half-lives and nuclear matrix elements. | The total number of new nuclide compilations is 11. Analysis of the experimental research, evaluated half-lives and nuclear matrix elements analysis has been published in Journal of Physics G. |
| Maintain, update and distribute XUNDL. | Completed. |
| Compile data sets (in ENSDF format) for current experimental nuclear structure publication. Scan the webpages of prominent journals in nuclear physics for new papers. Review compiled data sets submitted by other data centers prior to inclusion in the XUNDL database. Communicate with the authors of the original papers for data-related problems and to request additional details of unpublished data. Train a new undergraduate student in 2014 for XUNDL and other compilation work. Compile new mass measurements and submit data file to nuclearmasses.org webpage at ORNL. (McMaster) | Based on regular scanning of nuclear physics journals, 326 datasets were compiled and another 30 updated for new publications from the same groups as in earlier papers. 304 datasets received from other US-NDP centers were reviewed and in many cases edited. There were about 50 communications with the authors of the papers to resolve data-related issues and obtain additional data in support of their papers. The data file for new mass measurement papers published during Oct 2014 and Oct 2015 is being compiled for scheduled submission to ORNL by early November 2015. |

| LBNL Planned Activities | Status |
| --- | --- |
| Unplanned activity, XUNDL compilation. | Forty five data sets from thirty papers were compiled for XUNDL. Mark A. Trudel, a student from UCB, along with Lee Bernstein compiled some as a new compilers. |

| ORNL Planned Activities | Status |
| --- | --- |
| Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results. | ORNL compiled 36 data sets for XUNDLE. A new student was trained to help out with these compilations. |

| TUNL Planned Activities | Status |
| --- | --- |
| Compile datasets for current experimental nuclear structure data publications on A=2-20 nuclei for inclusion in the XUNDL database. | TUNL contributed 61 datasets to the XUNDL database during the period from 10/01/2014 - 09/30/2015. |

## C. Data Evaluation for ENSDF

The USNDP evaluates nuclear structure and decay data for inclusion in the ENSDF database. This effort includes the critical analysis of all available experimental nuclear structure and radioactive decay data for a nuclide or a group of related nuclei to deduce recommended values from the measured data and prepare a file in ENSDF format that is the basis for publications in Nuclear Data Sheets ” and is used to update the contents of the USNDP nuclear structure and decay database, ENSDF. The US effort is supplemented by foreign contributions prepared under the auspices of the IAEA-sponsored international Nuclear Structure and Decay Data network.

| ANL Planned Activities | Status |
| --- | --- |
| Evaluate 0.5 equivalent mass chains from the ANL region of responsibility. | 2 mass chains (A=109 (ANL) and A=40 (NSCL)) were evaluated and submitetd to NNDC for review; 2 mass chains (A=112 (ANL) and 209 (ANL)) were published in Nuclear Data Sheets. |
| Review mass chain evaluations, as requested. | The review of one mass chain is continuing. |
| unplanned Nuclear Data Evaluation Mentoring | Hosted and mentored Dr. S. Kumar (Delhi University), who was holder on the prestigious INDO-US fellowship and was on sabbatical at ANL (no cost to USNDP). Mentored a part-time post-doc (J. Chen). |

| BNL Planned Activities | Status |
|---|---|
| At least 6 mass chains, or their equivanent nuclides, will be evaluated. | Mass chains for A=41 (with ORNL), 57 (McMaster, LBNL, Romania), 70, 79 (McMaster) 140, 144, 182 (McMaster) and 238 were submitted. Additionally, 122 individual nuclides were submitted to ENSDF, mostly evaluated in McMaster. A total number of 214 nuclides were submitted. |
| At least 6 mass chains, or their equivanent nuclides, will be reviewed. | 7 A-chains were reviewed. |
| Continue mentoring new ENSDF evaluators. | A. Sonzogni worked with J. Lee from Korea, E. McCutchan worked with G. Gurdal from Milsaps College, and B. Singh worked with Sorin Pascu from Bucharest, A. Chakraborti from Shantiniketan University in India, and S. Singh from MM University in India. |
| 3.0 equivalent mass chains and the data for new nuclides (as mentioned below) will be evaluated. Mass chains will be reviewed as requested. Update ENSDF for the identification of new nuclides and for the first publications on the findings of the excited states of nuclides. Collaborate with a new center/evaluator as part of mentoring process, as needed (McMaster). | Completed, see description above. |
| All evaluations submitted for publications are edited including checking for their format and physics content. Extensive changes are often made by NNDC staff. | Completed. |

| LBNL Planned Activities | Status |
|---|---|
| Evaluate the equivalent of at least 2 mass chains, including a minimum of one from the A=21-30 region. Emphasis will be placed on evaluating data of current interest to the nuclear structure and nuclear application communities. | Mass chain evaluation for A=22 submitted and published, A=57 was completed in collaboration with McMaster and IFIN-HH, Romania, and submitted, and 99% of A=26 evaluation was completed. Also 215U isotope was evaluated for ENSDF. |
| Review mass-chain evaluations, as requested. | Mass chain A=198 was reviewed |
| Work with the NNDC to include DDEP decay data and EGAF capture gamma-ray data in the ENSDF file and publish it in Nuclear Data Sheets. | Discontinued - more data and coordination would be needed. |
| Train new compilers and evaluators. | Mark A. Trudel (student), Lee Bernstein, Aaron Hurst have joined compilation of nuclear structure data for XUNDL database. Aaron Hurst also collaborated on A=26 mass chain evaluation. |

| ORNL Planned Activities | Status |
|---|---|
| Complete evaluation of structure information for two nuclei in A=241-249 region, or others assigned by NNDC. | In FY 2015, an A-Chain evaluation for ENSDF was completed for A = 41, the mass chain for A = 247 was published, the mass chains for 69Br and 69Kr were updated, and the mass chain for A=241 will be published in November. |
| Review one mass chain evaluation. | In FY2015, the mass chain for A = 87 was reviewed. |

| TUNL Planned Activities | Status |
|---|---|
| Prepare the ENSDF files corresponding to new publications in the "Energy Levels of Light Nuclei" series. | TUNL submitted an evaluation of A=3 nuclides, as well as, evaluations of $^{15,16,18}$Be, $^{17,18,19}$Na and $^{20}$Mg. |

## D. Ground and Metastable State Properties

| ANL Planned Activities | Status |
|---|---|
| Contribute to the development of the Atomic Mass Evaluation and NUBASE databases in collaboration with CSNSM and INP, Orsay and IMP, Lanzhou. | Continuing. Completed 70 evaluations for AME and NUBASE. |
| Unplanned activity. Complete evaluation of decay data for K Isomers in deformed nuclei | Completed. Evaluation of configurations and decay properties of K-isomers in deformed nuclei with A>100 was completed. Data were assembled in an ENSDF formated files. The results were published in At. Data Nucl. Data Tables 103-104 (2015) 50-105. |
| Unplanned activity. Review of metastable states in heavy nuclei | Continuing. At the request from the editorial board of the journal Reports on Progress in Physics, a review article on "Review of Metastable States in Heavy Nuclei" was completed and it is currently under review. |

| BNL Planned Activities | Status |
|---|---|
| Update the Nuclear Wallet Cards as new information becomes available. | Continuing activity, completed. |
| Atlas of Nuclear Isomers | B. Singh collaborated with A. Jain's research team at IIT, Roorkee, India to prepare a comprehensive compilation of all the known nuclear isomers of half-life greater than 10 ns. This work was recently published in Nuclear Data Sheets. |

## E. Non-ENSDF Decay Data Evaluations

ANL: compile and evaluate radioactive decay data for selected nuclei that are of relevance to nuclear structure physics and astrophysics, as well as to energy and non-energy (medical radioisotopes) related applications.

| ANL Planned Activities | Status |
| --- | --- |
| Evaluate at least one radionuclide in support of the IAEA-CRP on "Nuclear data for charged-particle monitor reactions and medical isotope production" | Continuing. 2 radionuclides (67Cu and 178Ta) were evaluated. A journal article on 67Cu is under preparation. |
| In collaboration with scientists from the Australian National University and under auspices of IAEA, develop new computational tools for improving data on Auger-electron emissions following radioactive decay, which are relevant to medical radioisotopes applications. | Continuing. Contributed to the development of computational tools aimed at improving data on Auger-electron emitting nuclides of importance to medical applications |
| Evaluate radioactive decay data produced at the CARIBU facility. | Continuing. Initiated evaluation of 156Pm 160Eu and 162Eu decay data. |

## F. Neutron-Induced γ-Ray Data Evaluation

The EGAF (Evaluated Gamma-ray Activation File) database, disseminated by the IAEA and maintained by LBNL, currently provides discrete-line prompt γ-ray information from thermal (n,γ) reactions in a format tailored to suit the needs of the neutron activation analysis community. However, it requires ongoing maintenance and development to make it more useful to the applied communities it serves. Statistical-model calculations can generate quasi-continuum photon cascade data to complement these experimental discrete-line data. Together, the experimental and calculated data could constitute a valuable resource required for updating the ENDF database. Additionally, delayed photon data need to be added to EGAF. The k0-value database currently used by the neutron activation analysis community needs to be assessed and compared with the corresponding decay information in ENSDF, and the resulting evaluated k0 values then need to be integrated into EGAF and, ultimately, made available to ENSDF evaluators.

| LBNL Planned Activities | Status |
| --- | --- |
| Continue to maintain and develop the EGAF database. Update EGAF prompt gamma-ray cross sections from new measurements. Add activation data to the EGAF file. Include improved nuclear stucture data for the RIPL library in EGAF datasets. | Continuing. FY2015 updates of 16,17,18O and 2H EGAF files. Submitted for publication in PRC. |
| Collaborate with Charles University (Prague) to perform statistical-model calculations of quasi-continuum γ-ray cascade information and generate ENDF-format capture γ-ray datasets for use with MCNP and other transport-code calculations. | Continuing. Collaborative visit - finalizing the papers for publication and statistical model calculation - Milan Krticka. |
| Collaborate with the University of Oslo to measure low-energy photon strength functions and level densities. | Continuing. Planning of experiment activities during Pader Sather workshop in Berkeley, Dec, 2014 and workshop in Oslo, May, 2015. |

## G. Evaluation of Light Nuclei for Nuclear Physics A.

TUNL evaluates additional data not included in ENSDF for publication in Nuclear Physics A and on its web site.

| TUNL Planned Activities | Status |
| --- | --- |
| Finalize any loose ends for publication of "Energy Levels of Light Nuclei A=12," and continue in preparation of the "Energy Levels of Light Nuclei A=13" manuscript. | Following publication of the review of A=12 nuclei in 2016, we will produce only the more focused ENSDF format nuclear structure data reviews for the light mass region. With serious reflection that considers both the great value of the breadth of information provided in the "Energy Levels of Light Nuclei" publications and the NSDD/ENSDF network expected 7-10 year periodicity for reviews of a given nuclear mass-chain, the only feasible direction for our future evaluations is to focus solely on ENSDF reviews to be published in the Nuclear Data Sheets. |

## H. Nuclear Structure Data Measurement

ANL - ANL will devote a relatively small effort (0.1 FTE) to participate through collaborative agreements in nuclear physics research activities related to nuclear data needs. The emphasis will be on data measurements aimed at providing answers to specific questions that arise from recent nuclear data evaluations and at improving the quality of existing databases in specific areas, such as (but not limited to) decay data of minor actinides and neutron-rich fission products. Maintain important collaborative connections with RIA and GRETINA research communities, because of their vital importance to the nuclear science in US.

| ANL Planned Activities | Status |
| --- | --- |
| Participate in nuclear physics research activities at ANL, MSU and other nuclear physics user facilities with main emphasis on decay studies of neutron-rich fission products of relevance to reactor decay heat and astrophysics applications, spectroscopy of heavy actinide nuclei and nuclei far from the line of stability | Participated in in-beam and decay experimental campaigns at ATLAS and CARIBU. Several articles were published in top nuclear physics journals. Led CARIBU experiments on decay properties of neutron-rich fission products (data analysis is continuing) and an ATLAS experiment on spectroscopy of the super-heavy 254Rf nucleus (results were published in Phys. Rev. Lett. 115 (2015) 132502) |
| Participate in research activities using the GRETINA spectrometer and in dissemination of produced data from those activities | Participated in Coulomb excitation experimental activities at ATLAS using CARIBU beams and the GRETINA spectrometer. |

BNL - BNL has spent a modest amount of time to participate in experiments relevant to isotope production and nuclear structure (Unplanned activity).

| BNL Planned Activities | Status |
|---|---|
| Participate in beta-decay measurements at Argonne's CARIBU facility with an emphasis on beta-delayed neutron emitters | Led CARIBU experiment on 92Rb decay relevant to reactor antineutrino spectrum calculations. Participated in TAGS experiments at ORNL aimed at reactor antineutrinos and decay heat. |
| Complete analyses of 152Eu and 154Eu decay data and publish results | Continuing. |
| Perform precision measurements of electromagnetic transition strengths in light nuclei as a guide for improved formulations of ab-initio theories | GRETINA experiment on 12Be has been analyzed and a paper is being prepared. |
| Unplanned activity | Per recommendations of the DOE Review panel, collaboration with BLIP was initiated. Two experiments were performed at Gammasphere on beta-decay of 82Rb (paper submitted) and 72As (paper in preparation. Several cross section measurements for high-energy protons on platinum were also explored. |

LANL: LANL/LANSCE continues to maintain a small program to measure nuclear decay data information.

| LANL Planned Activities | Status |
|---|---|
| Examine prompt gamma-ray emission data and gamma-gamma coincidence data from neutron reactions on fission-product nuclei to search for previously unobserved transitions in these nuclides. | Reaction on two xenon isotopes (124 and 136) were studued. The prompt gamma-ray emission study on Xe-136 was to investigate possible backgrounds in double beta-decay experiments. A paper on Ni-60, which examines multi-particle emission such as (n,2n+2p...), was published. |
| Interact with mass chain evaluators on the nuclear structure of these nuclei. | No particular interactions in FY2015. |

LBNL:– to promote a closer working relationship with the nuclear structure community, LBNL will devote a small effort (~0.1 FTE) to participation in local nuclear structure experimental work.

| LBNL Planned Activities | Status |
|---|---|
| Perform DICEBOX statistical model calculations to determine total radiative cross sections and elucidate nuclear level spins and parities. | Continuing. |
| Measure gamma ray cross sections at the Garching FRM-II and Budapest Reactors and produce improved (n,g) decay schemes and total radiative capture cross sections. | Continuing. |
| Investigate primary gamma ray photon strength functions and the contribution of the M1+E2 mixing ratio to nuclear statistical model calculations. | Continuing. |

## I. ENSDF Physics and Checking Codes

The NNDC maintains ENSDF checking and physics programs on behalf of the national and international evaluator networks

| BNL Planned Activities | Status |
|---|---|
| Maintain and upgrade ENSDF checking and physics programs for format changes as required. | Continuing effort. |
| Move codes off the Lahey compiler and make compatible with gfortran. | Continuing effort. |

# VI. Nuclear Reaction Physics

## A. Experimental Data Compilation

The NNDC, as part of a larger international cooperation, has responsibility for compiling experimental nuclear reaction data that have been produced in the U.S. and Canada. Incident neutron reactions have been well covered historically. NNDC thus concentrates on new measurements, but continues compilations of earlier publications that have not been included in the CSISRS database. Since incident charged particle data have not been completely compiled in the past, NNDC is compiling new charged-particle measurements. In addition, because of emerging needs such as astrophysics, the NNDC is compiling older data. Hence, there is a larger staff commitment to compiling this type of data.

| BNL Planned Activities | Status |
|---|---|
| Compile experimental data for neutron, charged particle, and photon induced reactions from 120 publications. | In FY2015 EXFOR group has produced 105 new, and 75 revised compilations. |
| Unplanned activity. Explore and update the missing and unobtainable data in EXFOR. | The volume of unobtainable data for U.S. and Canada has been reduced by 1/3. All unobtainable data of relevance to CIELO project ($^1$H,$^{16}$O,$^{56}$Fe,$^{235,238}$U and $^{239}$Pu) have been recovered. |
| Unplanned activity. Data recovery mission at the Oak Ridge National Laboratory. | In collaboration with Oak Ridge three groups of the previously published but unavailable in EXFOR data have been recovered. The group of recent data sets has been compiled. |

## B. ENDF Evaluations

Evaluated nuclear reaction data, for applications and for basic science needs, are stored in the ENDF database, which is maintained by BNL. As chair of the CSEWG evaluation committee, LANL staff works with BNL to insure quality control, particularly for new evaluations. New evaluations funded primarily from other sources are prepared for archival in the ENDF library. BNL, LANL, LLNL and ORNL provided neutron, proton and photonuclear reaction data evaluations for ENDF/B-VII released in FY2007. LLNL develops a computer code that translates LLNL evaluations in the internal ENDL format into ENDF-6 formatted data so that LLNL evaluations can flow back into the nuclear data community.

| BNL Planned Activities | Status |
|---|---|
| Respond to user needs for evaluated nuclear reaction data. | All user requests for reaction data were attended. Nuclear data needs by nuclear power, isotope production and homeland security were collected at the NDNCA Meeting at LBNL. |
| Collect and address users feedback related to the ENDF library. | User's feedback was collected it trackers maintained on the GForge server. |
| Work with CSEWG on upgraded evaluations for future release of the ENDF/B library. | NNDC is leading evaluation of iron for the international CIELO project and ENDF/B-VIII library. Beta0 version of the evaluation for 56Fe has been prepared and validated. Work continues. |
| Improve methodology for providing covariance data in the resonance region and in the fast neutron region to the next release of ENDF. | A new system for generation of covariances, advanced by S. Hoblit before his premature death, has been recovered from the Linux cluster and secured inside the EMPIRE code. |
| In collaboration with LLNL, coordinate the development of the Generalized Nuclear Data (GND) format as a proposed successor format for ENDF. | A requirements document for the new nuclear data structure is nearly complete and due in May 2015. Work has begun to draft the detailed format specifications. In parallel, the prototype format, GND, has advanced to version 1.7 and we are preparing for a new release of the FUDGE processing code. |
| Use the BNL-INL collaboration efforts on the assimilation of integral experiments to provide modifications to ENDF evaluations and cross-reaction covariances. | Activity has not been funded. |
| Provide production cross sections for medical isotopes. | Preliminary EMPIRE calculations have been performed to obtain cross sections for all possible reactions occurring when high-energy protons (up to ~200 MeV) interact with the various stable isotopes of Platinum. These are important quantities for drug development and or theranostic or radiotherapeutic applications in preclinical and clinical settings, in which a wide range of platinum isotopes is used. |

| LANL Planned Activities | Status |
|---|---|
| Upgrade the LANL ENDF evaluations for U and Pu isotopes that perform well in criticality benchmarks, considering new LANSCE experimental data. | New U and Pu cross section calculations performed, which include improved width fluctuation model when strongly coupled channels exist. The impact of this modeling was shown at several conferences and meetings. The final ENDF files have not yet produced. |
| Provide upgraded ENDF evaluated data files for light and medium mass elements, including covariance data. Perform criticality benchmarks. | Two copper isotope files upgraded, and criticality benchmark test performed. The new evaluations include upgraded model calculations as well as elastic scattering angular distributions. |
| Provide new evaluations and covariances of the prompt fission neutron spectra for major actinides, which include pre-fission neutrons based on the statistical model. | New prompt fission neturon spectra for Pu-239 at higher energies produced, and provided the nuclear data users at LANL, that include pre-fission neutrons. |
| Provide evaluated prompt fission neutron and gamma-ray spectra of 235U, 239Pu, and 252Cf to the user community, which are based on the Monte Carlo Hauser-Feshbach method. | The prompt fission neutron and gamma-ray spectra based on the Monte Carlo tecnique produced, but limited to low energies. Work continuued to extend the incident energy up to 20 MeV by including the pre-fission neutron evaporations. |

| LLNL Planned Activities | Status |
|---|---|
| Perform new evaluations as per LLNL customer requests and submit these and other LLNL generated evaluations into ENDF. | Continuing. |
| In collaboration with BNL, coordinate the development of the Generalized Nuclear Data (GND) format as a proposed successor format for ENDF. | Continuing. |

## C. ENDF Manuals and Documentation

The NNDC is responsible for maintaining the format and procedures manual for the ENDF system. We also produce the documentation supporting the contents of the ENDF/B library.

| BNL Planned Activities | Status |
|---|---|
| Maintain GForge version of the ENDF-6 formats manual up-to-date with CSEWG endorsed format changes. Issue official release of the manual. | All new format approved at the 2014 CSEWG meeting and 2015 spring "mini-CSEWG" meeting have been implemented. Work continues on various improvements to the manual. |
| Automate the generation and posting of the latest unofficial version of the ENDF-6 formats manual. | Continuing task. |

## D. Nuclear Reaction Standards

Nearly all neutron cross section measurements are made relative to a neutron cross section standard such as the hydrogen elastic cross section. Maintaining accurate current values for the standard cross sections is the primary objective of this task that can be most efficiently accomplished through international cooperation. A new international evaluation of the neutron cross-section standards is now underway. It is important to improve the standards database and procedures for evaluations in preparation for new evaluations of the standards. To assist in this, an IAEA data development project "maintenance of the neutron cross section standards" was initiated to ensure that we are prepared for the next evaluations of the neutron cross section standards. Historically the standards evaluation activity has included data other than the cross section standards, i.e. the thermal constants and the $^{252}$Cf spontaneous fission neutron spectrum. Recently the scope has been broadened, largely through the data development project, to include an investigation of possible inelastic scattering cross section reference standards; considering adding additional standards energy ranges for the Au(n,γ) cross section; and proposing updates for the evaluations of the $^{252}$Cf spontaneous fission neutron spectrum and the $^{235}$U thermal neutron-induced fission neutron spectrum.

| LANL Planned Activities | Status |
|---|---|
| Participate in the international effort to reevaluate the light-element standard cross sections with LANL leadership, and investigate the nature of output covariance data from R-matrix analyses of systems containing the light-element standard cross sections. | Once scientist participated in the IAEA meeting on the standards. Two major efforts on evaluating the standards continued; the light element standard cross section evaluation with the R-matrix, and the prompt fission neutron spectra. |
| Incorporate the cross section standards into the new ENDF evaluations, and perform validation tests with integral measurements. | New U-238 capture cross section calculation that includes new DANCE data was performed, and the result was compared with the standards. |
| Continue the search for suitable (n,xgamma) reactions as possible reference cross sections to complement or replace the $^{56}$Fe(n,x g = 847 keV) reaction, which has several experimental limitations. | We continue to work on this project, and communicate especially with IRMM (Belgium) in this work. |
| Continue to assess the feasibility of very high accuracy experiments on the H(n,n) angular distribution for improving this standard at several neutron energies for forward neutron scattering angles in the center-of-mass. This measurement follows the H(n,p) measurements that improved the data base at backward angles. We collaborate with researchers at Ohio University and NIST. | We continue to work with Ohio University and NIST in the design of this experiment. Our involvement this year has been to give advice on experiment design and MCNP modeling, which will be essential for the project's success. A LANSCE scientist visited Ohio University to give a seminar on LANSCE activities, and while there, had good discussions with the research faculty. |

| NIST Planned Activities | Status |
|---|---|
| Continue work on the IAEA data development project on maintenance of the neutron cross section standards. Prepare for the next IAEA Consultants' Meeting on this project and provide results on the updating of the standards database and its impact on the standards. | Continued work on the IAEA data development project on maintenance of the neutron cross section standards. Work continues on providing an update of the standards database that will be used for the standards evaluations. Preparing for the next IAEA Technical Meeting on this project when it is expected that final results for an international evaluation of the standards will be obtained. This work is a collaboration involving 9 countries. The meetings have been chaired by the NIST representative. |
| Prepare a publication on standards activities. | A publication was prepared for an International Symposium on Reactor Dosimetry that outlines the work being done on the standards. It should be published in 2016. A comprehensive report on the work done at the most recent IAEA sponsored Technical Meeting on the Current Status of Neutron Standards was recently finished. |
| Continue to recommend and encourage new measurements and perform examinations of the data from them for use in future evaluations of the standards. | Examined several new and corrected measurements under consideration for the standards evaluation. Continue to recommend and encourage new measurements and will perform examinations of the data from them for use in future evaluations of the standards. An example is work we encouraged on the $^{235}$U(n,f) and $^{238}$U(n,f) cross sections at energies above 200 MeV for which exploratory work has been done at the n_TOF facility. |
| Continue work on an experiment using neutron detection to measure the H(n,n) angular distribution. This work will lead to improved determinations at small center-of-mass angles. The focus will be on an experiment at 10 MeV. Work will also be done at 14.9 MeV. This work is done in collaboration with Ohio University, LANL and the U. of Guelma. | Continued work on an experiment using neutron detection to measure the H(n,n) angular distribution. This work will lead to improved determinations at small center-of-mass angles. The focus will be on an experiment at 10 MeV. Future work will also be done at 14.9 MeV. The effort recently is focused on looking at how to optimize the experiment using Monte Carlo calculations. This work is done in collaboration with Ohio University, LANL and the U. of Guelma. |
| Work on an experiment based on $^{252}$Cf nu-bar leading to an improved calibration of NBS-I, the U.S. national primary standard neutron source and determination of our bath efficiency. | Work continues on an experiment based on $^{252}$Cf nu-bar leading to an improved calibration of NBS-I, the U.S. national primary standard neutron source and determination of our bath efficiency. |
| Complete a measurement of the $^{6}$Li(n,t) standard cross section at ~ 4 meV neutron energy using an improved fluence determination based on alpha-gamma coincidences with the $^{10}$B(n,alpha) reaction. Study stability of $^{10}$B deposits for $^{10}$B(n,alpha)cross section measurements. If suitable targets can be made, cross section measurements will be initiated. | A measurement was completed of the $^{6}$Li(n,t) standard cross section at ~ 4 meV neutron energy using an improved fluence determination based on alpha-gamma coincidences with the $^{10}$B(n,alpha) reaction. Much investigation has gone into the uncertainty of this result resulting mainly from uncertainty in the $^{6}$Li mass. The initial value obtained was in excellent agreement with the ENDF/B-VII standards evaluation. It was recently found that the mass reported by IRMM was in error. Using the new mass value produces a cross section value with an uncertainty of |

| | 0.3% lower by 1% compared with the ENDF/B-VII value. |
|---|---|
| Continue to acquire and monitor samples in the National Repository for Fissionable Isotope Mass Standards. Also make these samples available for loan in physics experiments. | Continued to consider samples that can be acquired and monitor samples in the National Repository for Fissionable Isotope Mass Standards. Also made these samples available for loan in physics experiments. |

## E. Nuclear Model Development

This task covers activities such as development and validation of nuclear reaction models used for prediction of nuclear reaction cross sections. The two major codes are CoH3 (LANL) and EMPIRE (BNL). Measurements made by ANL and LANL along with other measurements made with DOE low-energy physics funds will play a crucial role in the validation of the models in these computer codes. BNL and LANL will also participate in the IAEA Coordinated Research Project RIPL to improve accuracy and reliability of input parameters used in nuclear reaction calculations

BNL - We are active in nuclear reaction model development focusing on the BNL code EMPIRE. The work in this fiscal year will concentrate on further extensions and improvements of its capabilities, including a new version of the level densities with appropriate parameterization. The work on validation of the code will be actively pursued, in particular in relation to emerging requirements of homeland security applications. Close collaboration with LANL will continue focusing on validation of the fission models in EMPIRE and CoH3. Major effort is dedicated to the development of capabilities for estimating covariance data for fast-neutron reaction cross sections. In response to the needs from many user groups (such as Gen-IV reactors, criticality safety, Advanced Fuel Cycle Initiative), BNL will collaborate with LANL and ANL on a methodology for nuclear data covariances. To this end, a covariance module in EMPIRE for fast neutron energies should be extended and tested.

| BNL Planned Activities | Status |
|---|---|
| Continue to improve reaction modeling in the EMPIRE code, maintain code's numerical integrity and enhance user friendly GUI. | 366 updates of the EMPIRE code were committed to the GForge server. Major improvements include (i) Moldauer width fluctuation factor, (ii) incident deuteron breakup (iii) preparation for the inclusion of the Engelbrecht-Weidenmueller transformation, (iv) extension of the Kalman fitting capabilities, (v) Kawano's formula for elastic enhancement factor and number of degrees of freedom. |
| Improve EMPIRE covariance capabilities for fast neutrons. | A new system for generation of covariances, advanced by S. Hoblit before his premature death, has been recovered from the Linux cluster and secured inside the EMPIRE code. The system will be made operational in the final phase of the iron evaluation. |
| Maintain GForge site with the current version of the EMPIRE code. | The GForge site was maintained and available to the users all the time through the year except a few hours needed to update GForge version. |
| Implementing continuous integration system ADVANCE for checking and validation of new EMPIRE versions. | New commits of the EMPIRE code were continuously checked by the ADVANCE system, including a branch with Engelbrecht-Weidenmueller transformation. |

LANL - Nuclear reaction theory calculations have played a crucial role in the evaluation of nuclear data, and will continue to play an important part in future evaluations. The LANL CoH3 code has proved to be an important tool, and we will continue development of advanced model codes to provide a state-of-the-art capability to predict reaction cross sections and to explore nuclear reaction physics in detail. This also involves a close collaboration with experimentalists at LANSCE to interpret new measurements using the GEANIE, DANCE, and CHI-NU detectors. These data will result in advances in our understanding of nuclear reaction mechanisms, and improvements in our modeling codes.

| LANL Planned Activities | Status |
|---|---|
| Apply a coupled-channels Hauser-Feshbach method to neutron capture process for deformed targets to study gamma-ray cascading, in support of DANCE and GEANIE measurements, and s-process nucleo-synthesis studies. | The coupled-channels Hauser-Feshbach model applied to more than 100 nuclides in the fission product region, as well as to the actinides. The M1 strength function was examined. A paper was accepted for publication by Euro. J. Physics. The calculated capture cross sections were compared with DANCE and GEANIE data. |
| Study neutron elastic and inelastic scattering angular distributions for some structural materials in the fast energy range, which have high sensitivities to the simulation for critical assemblies. | We produced elastic scattering angular distributions for the coppoer isotopes in the fast energ range, and performed criticality benchmark tests. A new method to estimate the elastic scattering anisotropy was developed in collaboration with NNDC/BNL, and a paper was published in J. Nucl. Sci. Tecnology. |
| Continue neutron inelastic scattering study for actinides in the fast energy range, to which theoretical calculations are essential, in collaboration with CEA, France. | The study on inelastic scattering on actinides continued. |
| Extend the Gaussian Orthogonal Ensemble and the Monte Carlo technique to calculate the width fluctuation correction factor for the deformed systems. | The random matrix method with the Monte Carlo tecnique applied to the width fluctuation correction, and a new parameterization for the compound reaction calculation was obtained. A paper was published in Nucl. Data Sheets to make these parameters avaialble to other Hauser-Feshbach codes. |
| Continue to develop Monte-Carlo Hauser-Feshbach code, CGMF, that can be used as an event generator in radiation transport codes | The development of CGMF continues. The code was extended for higher incident energies, which includes pre-fission neutrons before fission event. |

## F. Nuclear Reaction Data Measurements

The measurement of nuclear data is essential to provide data, which either cannot be calculated or cannot be calculated with sufficient accuracy for user applications. This activity is also essential to support and verify nuclear model development and application.

ANL: ANL has recently initiated a new program in collaboration with INL (Measurement of Actinide Neutronic Transmutation Rates with Accelerator mass spectroscopy - MANTRA), supported through ARRA funding from ONP/DOE, aimed at obtaining valuable integral information about practically all high mass actinides neutron cross sections that are of importance to advanced nuclear fuel cycles and to USNDP.

| ANL Planned Activities | Status |
|---|---|
| Participate in nuclear data activities at ANL using the Accelerator Mass Spectrometry technique and recently irradiated actinide samples at INL | Participated in the first experimental AMS campaign at ANL with irradiated samples from the INL-ATR reactor facility. A journal article has been accepted for publication in Nuclear Instruments and Methods. |

| LANL Planned Activities | Status |
|---|---|
| Analyze neutron inelastic scattering made with the GEANIE and FIGARO arrays. Correlate new data from GEANIE with data from FIGARO on targets near mass 60. | Data analysis of $^{60}$Ni GEANIE data completed, and a Phys. Rev. C paper was published. |
| Continue to improve the techniques to measure the fission-neutron spectrum for fission induced by neutrons of 0.5 to 200 MeV on $^{235}$U and $^{239}$Pu. The shape of the major part of the emission spectrum between 0.1 and 10 MeV will be determined in this experiment, performed in collaboration with LLNL researchers, and will be compared with the Los Alamos model prediction. The modeling includes the Monte Carlo prompt neutron emission technique and the microscopic quantum mechanical pre-equilibrium calculations. In FY15, we will begin measurements on the portion of the fission neutron spectrum below 1 MeV for spontaneous fission of $^{252}$Cf and neutron-induced fission of either $^{235}$U or $^{239}$Pu. | We have made production measurements of the prompt fission neutron spectrum (PFNS) measured with the lithium-glass detector array for neutron-induced fission of $^{235}$U. These are the first data in the energy range below 1 MeV for fast neutron fission, and we compare the results with data taken for thermal-neutron-induced fission. |
| Conduct proof-of-principle measurements of neutron inelastic scattering at the Chi-Nu facility at WNR with neutron emission below 1 MeV. | Studies have been made of scattering from one detector to another. For the $^{6}$Li-glass detector array, there is obvious scattering as seen when the full array of 22 detectors is populated relative to a reduced set of 7 detectors. The magnitude of this scattering was described well with the MCNP neutron transport code. A new scintillation material, $Cs_2LiYCl_6$ (CLYC), is being studied for use neutron emission measurements. |
| Complete the study of radiative strength functions in neutron capture on $^{167}$Er and $^{195}$Pt. The residual nuclei in their low-lying states are those characterized as a strongly deformed rotator ($^{168}$Er) and a transitional, soft-gamma nucleus ($^{196}$Pt). The gamma-ray cascades differ markedly for neutron capture in these two nuclear systems. (with Yale University) | This project has not made much progress this year. Instead, the LANL researchers have worked with Prof. Casten of Yale University to analyzed structure data relevant to Partial Dynamical Symmetries in rare earth and actinide nuclei. This structure work might have application to the interpretation of gamma-ray spectra from neutron capture. |
| Complete analysis of neutron capture-to-fission cross section ratio for $^{239}$Pu for neutron energies less than 200 keV. | Not complete yet. Data analysis still in progress. |
| Measure the neutron capture cross-section at DANCE for at least one radioactive isotope of importance to nuclear astrophysics. | We have measured neutron capture on radioactive isotopes of lutetium. |

LBNL: LBNL has recently initiated a new program to use surrogate reactions to deduce reaction cross sections which are of importance to Advanced Fuel Cycle (AFC) programmatic needs (a national priority). This is collaboration between the nuclear structure and nuclear reaction groups at LBNL and outside groups at LLNL and the University of Richmond that is currently funded from outside of the DOE Data Program. The LBNL group is leading a series of benchmarking experiments to test the applicability and accuracy of these new techniques for deducing cross sections of importance to AFC and the s-process. It is anticipated that this activity will provide nuclear reaction data measurements of importance to the Data Program. LBNL is collaborating with the Budapest Reactor Centre in the measurement, using isotopically-enriched targets, of selected thermal (n,γ) cross section data to supplement earlier elemental target measurements from which important information was either lacking (e.g., data from low-abundance isotopes) or discrepant.

| LBNL Planned activities | Status |
|---|---|
| Measure thermal (n,γ) cross sections using guided neutron beams in collaboration with the Budapest Research Centre and at the Munich Reactor. | Thermal neutron capture measurements on 93Nb, 16,17,18O and 2H targets were performed. Analysis of data are done. Submitted to PRC for publication (16,17,18O and 2H) |
| Investigate nuclear level densities and gamma ray strengths at the Budapest and Munich Reactors and the LBNL 88" cyclotron, and the UC Berkeley neutron generator laboratory. Develop improved statistical model calculations in collaboration with Charles University, Prague. | Continuing. 56Fe(n,n') measurements were carried out at 88-inch cyclotron. The study is being continued with additional measurements using GRETINA at MSU. |
| Measure nuclear cross sections in the plasma at the LLNL National Ignition Facility. | Discontinued. |
| Unplanned activity: 239Pu inelastic and (n,3n) measurements | Important 239Pu inelastic and (n,3n) gamma production data were made available to the nuclear data community through a nuclear-data-archaeologist, Naohiko Otsuka of IAEA. |
| Unplanned activity: Horizontal evaluation of (n,n'g) data from Baghdad Atlas. | Compilation of (n,n'g) data from Baghdad Atlas into a SQL database has been completed. Evaluation of these data is in progress. |

## G. Evaluation of Data Needed for Astrophysics

The objective of this activity is to support the nuclear data needs of the increasingly sophisticated simulations of astrophysical phenomena. The Astrophysics Task Force of the USNDP, presently chaired by ORNL, serves to improve communication and coordination of nuclear data evaluation activities relevant for studies in astrophysics.

| ANL Planned Activities | Status |
|---|---|
| Continue working on issues related to ground- and isomeric-state data (masses and decay properties) and their uncertainties of relevance to astrophysics applications, and r-process modeling in particular. | Continuing. Development of a suite of computer codes and corresponding libraries is continuing |

| BNL Planned Activities | Status |
|---|---|
| Continue work neutron capture and fission integral values and their uncertainties in the energy region of interest for nuclear astrophysics. | Computer codes have been transferred to a new machine, and maintained. |

LANL: Participate in the USNDP effort to develop high-quality data for astrophysics calculations of nucleosynthesis. Make new calculated and evaluated results available to the wider astrophysics research community via the USNDP Astrophysics Task Force.

| LANL Planned Activities | Status |
|---|---|
| Incorporate nuclear structure models into the neutron capture models to provide neutron capture rates off-stability to s and r-process hydrodynamics simulations. | Finite-Range Droplet Model (FRDM) incorporated into the neutron capture cacluation. This model is used for; (1) the single particle states for the direct/semidirect capture model, and (2) nuclear deformation for the coupled-channels model calculations. |
| Continue working on beta-delayed neutron emission rates in the astrophysical stellar environment, including explicit neutron and gamma-ray competition. | The model development continued. Calcuation of the beta-delayed neutron, as well as the gamma-ray competition, performed, and a Phys. Rev. C paper is under preparation. |
| Develop beta-delayed fission model for the r-process simulation. | The beta-delayed fission model development continues. The fission model is added to the beta-delayed neutron code, and some preliminary calculations were performed. |

ORNL: Evaluate capture reactions on radioactive proton-rich nuclei which are important for element synthesis and energy generation in stellar explosions.

| ORNL Planned Activities | Status |
|---|---|
| Continue assessments of capture reactions on p-rich unstable nuclides that are important for novae and X-ray bursts. The nuclei to be studied are those planned for measurements at radioactive beam facilities. | Levels of 18F+p in 19Ne were examined as a result of a measurement of 20Ne(p,d) with the JENSA gas jet target system at ORNL. The levels were used to determine a new 18F(p,alpha) rate and new nova nucleosynthesis, all within the framework of the Computational Infrastructure for Nuclear Astrophysics. This work has been submitted for publication. |
| Extract spectroscopic information (excitation energies, spectroscopic factors, spins, parities, ANCs) on nuclei near the N=82 closed shell – 81Ge, 127,129Sn, 135Te - from transfer reaction measurements on radioactive Ge, Sn, and Te nuclei. This information is important for modeling the r-process in supernovae. | Levels in 81Ge needed for 80Ge(n,gamma) were examined as a result of an ORNL measurement of 80Ge(d,p); this work is almost completed. Levels in 131Sn extracted from an ORNL measurement of 130Sn(d,p) were used to calculate a new 130Sn(n,g) cross section. This used a new approach that was benchmarked on nuclei where capture information already exists. This work has been published. |

## H. Covariances Development

Quantification of uncertainties and their correlations, mathematically represented as covariance matrices, became recently a focal point of the ENDF evaluation effort world-wide. A strong motivation for this revival is the role of covariances in guiding adjustment of the evaluations to the integral experiments to improve reliability and performance of the new libraries. Work in this field includes improvement of the methodology as well as development of actual covariance data. Major covariance activities are carried out at BNL, LANL and ORNL (the latter in the resonance region).

| BNL Planned Activities | Status |
|---|---|
| COMMARA-3, a library of covariances for the major reaction channels processed on a 33-energy grid, is to be based the reaction cross sections in ENDF/B-VII.1. Currently there is no funding for this project. Should funding be restored, the library will be reviewed and additional covariances included for the 1st Legendre moment for elastic scattering (mubar), average number of neutrons produced/fission (nubar), prompt fission neutron spectra (PFNS), and cross-material, cross-reaction covariances, where applicable. A preliminary beta version of this library was produced in FY2013 based entirely on covariance data in ENDF/B-VII.1. As time permits, additional beta releases may be possible by including processed covariances that result from integral data assimilation studies at the NNDC. | There has been no activity since the project has not been funded. |

## I. Reactor antineutrino spectra and decay heat calculations

The NNDC has been setting up methos to calculate antineutrino spectra decay heat from fissioning systems using the fission yield and decay data sub-libraries from ENDF-6 formatted libraries.

| BNL Planned Activities | Status |
|---|---|
| Setup methods and databases to calculate anti-neutrino spectra for major actinides. | An update to the ENDF/B-VII.1 decay data sub-library was performed. An article was published with the results of our calculations. A.A.Sonzogni, T.D.Johnson, E.A.McCutchan, Phys.Rev. C 91, 011301 (2015). We co-organized a workshop on the modelling of reactor antineutrino spectrum in Nantes, France, January 2015. We also worked on reviewing the ENDF/B fission yields for use in the calculation of the antineutrino spectra and an article is on preparation. |

## J. Verification and Validation

Quality Assurance (QA) of a nuclear data library requires that all files are checked for integral consistency and conformance with the adopted format. This part of the QA is called verification and is one of the fundamental functions of the National Nuclear Data Center. Furthermore, checking performance of the library against the integral experiments, known as validation, is an important step ensuring usefulness of the library for the end-users. The most extensive validation is performed by LANL and other CSEWG contributors funded with non-DOE-SC sources. The USNDP supports the ultimate validation effort carried out at BNL.

| BNL Planned Activities | Status |
|---|---|
| Establish automatic, real time verification and validation of the new/modified ENDF evaluations submitted to the NNDC GForge server. | In collaboration with a summer student, we installed and automated the running of LLNL's COG transport code. Work to integrate this into ADVANCE continues slowly as this activity is unfunded. |

## Appendix A
## Nuclear Data Activities Funded from Sources outside the Nuclear Data Program (Report FY2015)

| **BNL** |
|---|
| Additional support for the nuclear data work at the National Nuclear Data Center comes from the following sources:<br><br>1. Elsevier supports the production of computer-generated photo-ready copy of manuscripts for the Nuclear Data Sheets.<br><br>2. The US Nuclear Criticality Safety Program (NCSP), funded by DOE NNSA, supports the NNDC services in maintaining NCSP data submitted to ENDF/B-VII library as well as data development work on estimates/evaluations of neutron cross section covariances for criticality safety applications. |

| **LANL** |
|---|
| Most of the nuclear data work is supported from funds other than the nuclear data program. The effort is in support of the ENDF-related work of nuclear model development, nuclear reaction evaluation and ENDF processing.<br><br>1. Advanced Simulation and Computing (ASC program). This work supports the development of more accurate ENDF cross section databases for actinide fission fuels, light-nucleus thermonuclear fuels, and for reactions on important materials used for diagnostics (radiochemical reactions). Nuclear model code development, for both statistical and preequilibrium models, and for light R-matrix codes, is supported by this program, as is the development of the NJOY data processing code for providing data usable by Monte Carlo and deterministic transport codes in applications. The funding also supports physics research developments in nuclear reaction and structure theory (with a recent emphasis on nuclei and isomers away from stability), and fission theory. Data testing using integral benchmarks such as fast critical assemblies is used to validate the ENDF data.<br><br>2. Nuclear criticality safety. This funding supports improved nuclear data important in criticality safety studies, such as uranium isotopes, as well as data on structural materials. Data testing using critical assemblies and NJOY processing code development is also funded by the program.<br><br>3.LANL LDRD. There is one LANL LDRD projects that support nuclear reaction data measurements and nuclear reaction modeling for isomeric states.<br><br>4. Nuclear Weapons supports LANSCE measurements of fission output (neutrons and gamma rays), neutron capture on actinides and radchem isotopes, and neutron reactions relevant to radchem.<br><br>5. DOE/NNSA Correlated Data in Fission Events (NA22), supports Monte Carlo Hauser-Feshbach modeling for fission neutron and gamma-ray emissions, and relevant code development. |

| **LBNL** |
|---|
| Nuclear data group staff at LBNL/UCB are partially supported by external funds and three students from UCB, one from Air Force Institute of Technology supported by fellowships:<br><br>1. Na-22 for capture gamma-ray library evaluations in collaboration with LLNL - Husrt (LBNL).<br><br>2. LDRD at LLNL for photo strength function and level density studies - Bernstein (LLNL/UCB/LBNL). |

3. NSSC and SSGR fellowships for 56Fe(n,n'g) studies - Kirsch (UCB).

4. NSSC fellowship for 139La(n,g) photo strength study and EGAF update - Ureche (UCB).

5. NRC fellowship for production cross section measurements for medical isotopes - Voyels (UCB).

6. Domestic Nuclear Detection Office (DNDO/DHS) fellowship for thermal neutron capture gamma measurement and evaluation of 185,187Re - Matters (Air Force Institute of Technology, Wright-Patterson Base, Ohio).

### LLNL

NNSA Defense Programs, the Department of Homeland Security, and branches of the Office of Science outside the USNDP support most of the nuclear efforts at LLNL. Funding from USNDP is used to coordinate these efforts and process data for use by the larger community. Much of the Livermore experimental work is made possible by beam time and collaborations at TUNL, TRIUMF, LBNL and LANSCE. Sponsorship for different nuclear efforts includes:

1. NNSA/ASC funds data evaluation, validation and verification efforts, development of theory supporting the surrogate measurement campaign for unstable actinides, and optical potentials. Also funds part of the nuclear data formats and the processing of nuclear data.

2. NNSA/DP/SC funds experimental campaigns for unstable actinides, including development of the Time Projection Chamber at LLNL for new 239Pu fission cross section measurements.

3. NNSA/NA-22 funds the event by event fission modeling and the capture-gamma-ray evaluations.

4. OS/ARRA funds in part the generalized nuclear data efforts in tandem with ASC/IC.

### NIST

A variety of sources support nuclear data activities:

1. The NIST-DOE Neutron Cross Section and Fluence Standards program has funding through the Commerce Department. This provides about half of the total support for the program.

2.NIST provides 1 FTE for standard cross section work using ~4 meV neutrons and also for interferometry work, which has yielded coherent scattering lengths (which provide scattering data) needed for neutron cross-section evaluations.

4.NIST provided 1 FTE (75% experimental, 25% evaluation) for nuclear structure and decay data work. Much of this work also has applications in radioactivity standards and radiopharmaceutical studies.

### ORNL

The nuclear data work is partly funded by the DOE-SC Low Energy Nuclear Physics program.

### TUNL

The nuclear data work is partly funded by the DOE-SC Low Energy Nuclear Physics program through a TUNL/NCSU grant.