



Annual Report for FY2008

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USNDP Annual Report for FY2008

Summary of the U.S. Nuclear Data Program Activity for 2008

I. Introduction (Report FY2008)

The USNDP Annual Report for FY2008 summarizes the work of the U.S. Nuclear Data Program (USNDP) for the period of October 1, 2007 through September 30, 2008 with respect to the work plan for FY2008 that was prepared in February 2006. The work plan and final report are prepared at the direction of the DOE Office of Science, Office of Nuclear Physics for the nuclear data program. 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 28.4 FTE scientific, mostly at NNSA laboratories, to be compared with 19.2 FTE scientific (permanent + temporary) at USNDP laboratories funded by the DOE Office of Science, Office of Nuclear Physics. Since it is often difficult to differentiate 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.

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 FY2008. Then, we proceed with the detailed status of work done in FY2008.

Total staff assigned to USNDP activities during the year represented 23.6 FTE. There is continuing gradual loss of permanent scientific staff in USNDP activities, 14.3 FTE in FY2008 compared to 14.9 in FY2007, partly offset by increased temporary scientific staff.

Fiscal year 2008 is the 10th year during which the Nuclear Data Program has operated under a work plan developed by the program participants. As the following sections illustrate, the nuclear data program is successfully carrying out important work in direct support of DOE missions. 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 convenient manner.

The program metrics requested by DOE are included below. Tab. 1 summarizes the USNDP metrics for the years that such metrics were reported. Tab. 2 shows the breakdown of the metrics for this fiscal year by laboratory and compares them with the previous fiscal year. The tables are followed by a description of the meaning of each metric.

Tab. 1 shows that the FY2008 budget increased by modest 2.2%. This was far less than solid 14.6% increase in FY2007 that was preceded by substantial drop by -6.6% in FY2006. This

illustrates that the USNDP continues to cope with an unfortunate record of volatile budgets in last several years.

Table 1: Summary of the USNDP metrics in FY01- FY2008, for definitions see next page.

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

In addition, Tab. 1 shows the USNDP metrics, with more details to be found in Tab. 2. The metrics show that compilations decreased somewhat but there is an increase in the two most important categories, evaluations and dissemination, and also an increase in the remaining three categories:

1. **Compilations.** Compilations include NSR, CSISRS and XUNDL databases, showing certain overall decrease. This is caused by considerable drop in papers published in Nucl. Phys. A and Eur. J. Phys. A, and corresponding reduction of bibliography entries to NSR.
2. **Evaluations.** There is an increase in the evaluations, up by 5% compared to FY2007. We note that the top performance in evaluations, reached in FY05, was exceptional due to evaluation of large number of super-heavy nuclides (63 nuclides, A = 266-294).
3. **Dissemination.** This indicator continues in a steady increase. In FY2008 we reached the milestone of 3 million (2,996,000) data retrievals from the USNDP databases. Most notable is sharp increase in the use of NucAstro web system maintained at ORNL. At BNL, the most popular product continues to be NuDat which contributes almost 60% data retrievals.
4. **Reports.** There is some increase in the number of published reports, though the level is approximately constant over the last three years.
5. **Papers.** The number of papers published in refereed journals has increased and reached the record level since 2001.
6. **Invited Talks.** The number of invited talks continues to grow over several last years. We reached record level, impacted by large number of lectures of USNDP lecturers given at the IAEA Workshops.

Table 2: USNDP metrics in FY2008, numbers for FY2007 are shown for comparison.

Lab	Compilations		Evaluations		Dissemination ³		Reports		Papers		Invited Talks	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
BNL ¹	4962	4592	142	150	1380	1961	21	12	9	21	6	17
LANL	-	-	40	60	233	384	2	3	12	14	17	11
LBNL	-	-	39	52	376	315	2	8	5	7	3	10
ORNL	-	-	18	11	176	264	4	7	6	4	9	10
ANL	-	22	22	6	13	15	2	3	17	16	7	10
LLNL	-	-	7	6	8	7	6	10	3	4	6	8
University ²	393	490 ⁴	98	100 ⁵	53	50	3	5	2	6	3	2
Total	5355	5104	366	385	2239	2996	40	48	54	72	51	68

1) BNL compilations in FY2008 consist of 3,532 NSR papers and 1,060 CSISRS reactions.

BNL evaluations in FY2008 consist of 96 nuclides for ENSDF and 54 reactions for ENDF.

2) TUNL, NIST, McMaster; 0.4FTE of McMaster funding comes from Canada.

3) Data retrievals in thousands. LBNL scaled in accord with retrievals/hits ratio observed at BNL.

4) In addition 90 nuclide masses updated on www.nuclearmasses.org.

5) 98 nuclides for ENSDF plus 2 astrophysical reaction rate data sets.

Definitions

- *Compilations:* The sum of the new entries added to the USNDP bibliographic (NSR - papers) and experimental databases (CSISRS - 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 (Report FY2008)

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 many of the other program participants are also involved in the coordination and dissemination activities.

National and International Coordination

The NNDC, while serving as the secretariat for the program, has prepared the program work plan for FY2008 in conjunction with the members of the Coordinating Committee. The NNDC Head serves as chair of the USNDP Coordinating Committee, which consists of the Principal Investigators from each of the participating groups, and he chairs the annual meeting of the program held at Brookhaven National Laboratory. LANL chairs the Nuclear Reaction Data Working Group, and LBNL the Nuclear Structure Working Group. ORNL chairs the Astrophysics Task Force and LLNL chairs the Homeland Security Task Force.

In February 2008 the DOE Office of Nuclear Physics conducted its annual Budget Briefing. Pavel Oblozinsky, Coral Baglin, Toshihiko Kawano as well as F. Kondev, R. Firestone and M. Herman represented the USNDP and made the case for the FY2010 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).

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. The NNDC hosted the CSEWG annual meeting in November 2007. The major topic of the meeting was the performance of the ENDF/B-VII.0 library.

Several USNDP participants attended the June 2008 meeting of the NEA-sponsored Working Party on International Evaluation Cooperation (WPEC) in Tokai, Japan. The US has the lead responsibility for several projects sponsored by this activity.

In June 2008 the NNDC organized major Workshop on Neutron Cross Section Covariances held in Port Jefferson, NY. The Workshop was attended by 53 scientists, 37 being from the United States and many of them related to USNDP.

USNDP Databases

The NNDC operates five Dell servers running 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. This NNDC web system continues to operate without interruptions and provides stable service to US nuclear data users.

The NNDC maintains seven nuclear physics databases for the USNDP. These databases have been updated continuously in FY2008 with new and revised information from efforts of the NNDC, the 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 FY2008, retrievals from the USNDP databases as offered by the USNDP laboratories reached 3 million data retrievals (2,996,000). The use of our services continues to grow, in some areas the growth by far exceeding our expectations about forthcoming slowing down in growth.

Major Publications

The USNDP continues to publish monthly the refereed journal *Nuclear Data Sheets*. 11 issues were devoted to nuclear structure data and one issue to nuclear reaction data. In general, citation of published papers is good. For example the “big paper” on the new ENDF/B-VII.0 library, published in December 2006 issue, reached 85 citations in 2 years according to SCOPUS (78 according to Web of Science).

III. Nuclear Structure and Decay Data (Report FY2008)

The Working Group's priorities emphasize the evaluation of nuclear structure and decay data, either for entire mass chains or for individual nuclides, and the entry of these results into the Evaluated Nuclear Structure Data File (ENSDF). ENSDF is of particular importance because it provides the source information for various other databases and applications such as NuDat, Nuclear Wallet Cards and MIRD as well as contributing much valuable structure and decay data information needed for ENDF/B.VII. Most ENSDF evaluations will also appear as publications in *Nuclear Data Sheets* or *Nuclear Physics A*. In addition, working group members participate in several international collaborations or coordinated research projects designed to provide nuclear data tailored to meet the specialized needs of various research and user communities. Frequently-accessed web sites maintained at several data centers continue to disseminate nuclear structure and decay data in a variety of user-friendly forms; 1.1M data retrievals were recorded from NuDat alone in FY2008.

Evaluations for ENSDF

USNDP nuclear structure and decay data evaluation groups in the US and Canada were involved in 247 nuclide evaluations (or 76%) out of a total of 325 nuclide evaluations that were submitted during FY2008 for inclusion in the ENSDF database. The USNDP evaluators have also provided peer review for 15 mass-chain evaluations, and the NNDC routinely performs additional checks prior to publication. The eleven issues of the journal *Nuclear Data Sheets* (published by Elsevier) that were devoted to nuclear structure and decay data contained 17 mass chain evaluations; these publications also included work by evaluators from Argentina, Brazil, China, France, Japan and Russia. The publications of two additional mass chains completed in FY2008 await journal space but the evaluations are already accessible from ENSDF.

Compilations for XUNDL

The XUNDL database facilitates prompt access to unevaluated nuclear structure information from the most recently published papers. The McMaster group prepared 430 new and 60 updated data sets for the XUNDL database during FY2008 and ANL and the University of Jordan contributed an additional 32 datasets; all of these were incorporated into the database by BNL. Approximately 50 private communications were obtained from authors concerning some of the data entered into XUNDL during the year; these serve to resolve data-related inconsistencies and/or provide additional data details, and they are forwarded to NNDC annually so that ENSDF evaluators also can benefit from the information they contain. A potential new function for the database emerged this year; the authors of one Physical Review Letters publication arranged for their detailed data to be added to XUNDL, then referred readers of their publication to XUNDL for those (unpublished) data.

Compilation of New Atomic Mass Measurements

A large number of precision mass measurements have been made in the last five years, and advances in experimental techniques and facilities (especially for nuclei far from stability) suggest this trend will accelerate in the future. Unfortunately, Georges Audi, the leader of the

2003 Atomic Mass Evaluation, has retired from mass evaluations, and the future of this effort is still unclear. Because nuclear masses are utilized in a wide range of basic and applied nuclear science research, it is important to compile as many of the new mass measurements as possible for any future mass evaluation effort. To this end, McMaster University has initiated an effort to compile the published results of new mass measurements. The dissemination is currently being handled through the nuclearmasses.org web service, created at ORNL via non-USNDP funding. This service contains visualization and analysis tools for experimental, evaluated, and theoretical masses. It enables users to quickly compare the latest measured masses with different theoretical models and previous evaluations.

Nuclear Science References Database (NSR)

This bibliographic database expanded by 3,532 references during FY2008 and now contains at least 194,350 citations; web queries for the year totaled 192K. Oversight and much of the keywording for this database are provided from NNDC but, in addition to the keywording of articles from three major European journals provided by collaborators at the IAEA, additional keywording assistance was provided this year by a McMaster undergraduate student and several other people. This has enabled the database to keep pace with the published nuclear science literature this year.

USNDP Contribution to Decay Data Evaluation Project (DDEP)

The international DDEP collaboration includes several USNDP evaluators as well as non-ENSDF evaluators from France, Germany, Romania, Russia, South Korea, Spain, and the United Kingdom; it prepares evaluations for radionuclide decays of importance in applied research. LBNL continues to coordinate this project, to provide general editorial oversight and, in FY2008, reviewed all evaluations submitted to the project, without cost to the US nuclear data program. Also, during FY 2008, USNDP participants in the DDEP prepared one radionuclide evaluation.

USNDP Evaluator Participation in IAEA CRPs

Two USNDP nuclear structure evaluators are currently participating in IAEA Coordinated Research Projects (CRP). One project is the “Updated Decay Data Library for Actinides”, and it involves both data evaluations and measurements; these have already resolved some existing data inconsistency problems and will ultimately benefit the ENSDF database. The other is titled “Reference Database for Neutron Activation Analysis”; its purpose is to provide evaluated k_0 /cross section data for use by the neutron activation community and those data will ultimately benefit the existing database (EGAF) which contains evaluated discrete-line prompt-photon data from thermal neutron capture. Both projects are scheduled for completion in 2009.

Structure Data Evaluator Training Efforts

Five US evaluators served as lecturers and laboratory instructors during the fourth two-week long *Workshop on Nuclear Structure and Decay Data: Theory and Evaluation* that was cosponsored by the IAEA and ICTP in Trieste in April/May 2008. This was a particularly successful Workshop, drawing 25 participants and 7 ICTP Associates or Affiliates from 20 countries, including 4 recently-recruited USNDP nuclear structure evaluators. In addition to

providing valuable training for the new USNDP evaluators, this activity has the potential to develop a pool of young nuclear scientists from outside the US and Canada who may ultimately become involved in structure data evaluation work, thereby broadening the international contribution to this enterprise.

Modernization of Drawings in *Nuclear Data Sheets* Publications

Recognizing the need to improve the quality and legibility of level scheme drawings in *Nuclear Data Sheets* mass-chain publications, NNDC contracted in December 2006 for new drawing preparation software to address this problem. The original contractor failed to complete the project, but McMaster has developed his incomplete codes to the point where they could be used to provide much clearer band drawings for one of the FY2008 *Nuclear Data Sheets* mass chain publications and several subsequent ones. More work will be needed to streamline the merging of these drawings with the old *Nuclear Data Sheets* production software output, however.

“Island of Inversion” Topical Evaluation

In response to a request from the research community, a collaborative effort is under way to provide up-to-date evaluations for nuclei in or near the so-called “Island of Inversion” near $N \sim 20$. In FY2008, 21 of these nuclides were evaluated by LBNL and McMaster and added to ENSDF, and a new web page was designed at BNL for their dissemination. The nuclides covered will now be expanded to encompass $Z=9-14$ and $N=16-24$, and it is anticipated that this work will lead to the publication of a review article on this topic.

IV. Nuclear Reaction Data (Report FY2008)

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 NNDC has compiled 106 papers (33 papers with neutron-induced reactions, 70 charged-particles and 3 photonuclear, containing data for total of 1,060 different reactions) for the experimental nuclear reaction database, CSISRS. The NNDC maintains ENDF/B-VII.0 library and collects all the deficiencies reported. In addition, it maintains ENDF/A database as repository of new evaluations that represent candidates for inclusion in the ENDF/B-VII.1 version of the library scheduled for release by the end of 2010.

BNL, LANL, ORNL, and ANL have a cooperative project on the covariance data evaluation for a large number of nuclei in the evaluated nuclear data files, primarily for the criticality safety study, but also important for many nuclear energy applications. We have produced numerous new covariance data estimates including light elements, structural materials, fission products, and actinides. These activities aim at quality assurance of the ENDF/B-VII database, especially for the next release of the general purpose file, which should include the covariance data for major nuclei, possibly ~100 materials for AFCI applications.

The activity to supply nuclear data for Homeland Security continues in the framework of the Task Force that holds a special session during each annual USNDP meeting. LANL developed a new method to calculate the prompt-neutron fission spectra based on the Monte Carlo technique, which allows us to obtain more microscopic information in the chain of fission fragments decay. LLNL continues the development of FREYA, its microscopic event-by-event fission simulation tool. FREYA is being used to produce a new fission neutron spectrum for plutonium. It was reported recently that the prompt-neutron fission spectra have significant impact on criticality benchmark testing, because it modifies the average energy of neutrons inside the system. The issue addressed will be one of the main goals of nuclear reaction data study in near future both in the theoretical and experimental aspects.

LANSCE produced new experimental data of prompt fission neutron spectra for ^{239}Pu and ^{235}U , with the FIGARO detector for incident neutron energies from 1 to 50 MeV. Neutron capture data for ^{75}As , ^{89}Y , ^{143}Nd , ^{149}Sm , $^{151,153}\text{Eu}$, ^{175}Lu and $^{241,242,243}\text{Am}$ were obtained with the DANCE detector. The fission cross section measurements were performed for plutonium isotopes, $^{239-242}\text{Pu}$. The $^6\text{Li}(n,\alpha)$ reaction cross section in the MeV region was improved. The analyses of these data are underway at LANL by using the Hauser-Feshbach statistical model combined with the direct reaction theory.

Model Code Highlights

Several new features were added to the nuclear reaction calculation code EMPIRE. The resonance module, developed by BNL/KAERI collaboration, takes resonance parameters from ATLAS then put them into a compact format by considering thermal cross section uncertainties and statistical properties of resonance parameters. The EGSM (Enhanced/EMPIRE Generalized Super-fluid Model) level densities are updated to reproduce compiled s-wave average resonance spacing values. The microscopic level densities were upgraded to the RIPL-3 version with parity distribution. The new fission module allows utilizing any arbitrary fission barriers calculated with microscopic models and accounts for multi-hump barriers with absorption in unlimited number of wells.

Fission physics is one of the biggest challenges in nuclear physics in view of its complicated dynamics and poor predictive power of current nuclear reaction codes. In FY2008, USNDP made a remarkable progress in the fission study, which includes microscopic-macroscopic fission potential surface calculations at LANL, experimental efforts and theoretical development of the prompt fission neutron spectrum at LANL and LLNL. Using the event-by-event modeling code at LLNL, FREYA (Fission Reaction Event Yield Algorithm), uncertainties in the fission spectrum were estimated by analyzing sensitivities of the model parameters. FREYA is currently being employed to produce a new LLNL fission neutron spectrum for plutonium.

At LLNL, an important toolset was developed to evaluate the EGAF thermal neutron capture-gamma data. The toolset automates the evaluation process and facilitates a more scientific evaluation methodology. This will be used to incorporate the high-precision measurements of gammas following thermal neutron capture on all elements of importance to homeland security applications. These tools will enable detailed tests of the RIPL and ENSDF databases and the final evaluations will be included in a future ENDF library release.

A new version of the R-matrix code SAMMY code at ORNL was released. New options added in this release are an energy dependent nubar (average number of neutrons per fission), variable target thickness for transmission, a revised self-shielding and multiple scattering module, a Gaussian width can be a linear function of energy, and a new input method of resonance parameters to avoid numerical errors near threshold energies. It was pointed out that data covariance matrices separated into data and data-reduction components require much less storage and CPU-time than explicit data covariance matrices.

The TUNL program on pre-equilibrium phenomenology is no longer funded through the DOE USNDP program. Work continues at a very-much-reduced pace and this year projectile break-up was studied.

Nuclear Standards Highlights

A new evaluation of the neutron cross section standards was recently completed, with results published in October 2007 in the IAEA report. The evaluation, which was led by NIST, was largely performed by an IAEA Coordinated Research Project (CRP) with support, primarily experimental in nature, through the NEA Working Party on International Evaluation Cooperation

(WPEC) of the Nuclear Energy Agency and CSEWG. The evaluations were produced by combining R-matrix calculations with experimental data using the GMA code.

Measurements of the H(n,n)H angular distribution, by detecting the recoil proton, by a NIST collaboration at the neutron incident energy of 14.9 MeV have been completed and a paper is being written for journal publication. A measurement of the n-³He coherent scattering length using both a polarized neutron beam and a polarized target has been completed. New measurements of angular distributions of scattered neutrons from the H(n,n)H reaction; and the ⁶Li(n,t) and ¹⁰B(n,α) cross sections are planned. In the MeV region, the ⁶Li(n,t) reaction was studied at LANSCE. An IAEA data development project on maintenance of the standards, "Maintenance of the Neutron Cross Section Standards," has begun its activities that should allow continual improvements to the standards.

Nuclear Astrophysics Highlights

Work continued on the evaluation of several nuclear reactions important for astrophysics modeling at ORNL [¹⁷F(p,γ), ¹⁵N(d,p), ³¹P(p,α)] and at McMaster [²¹Na(p,γ), ⁴⁰Ca(α,γ)]. LANL continued in the theoretical development of the fission barrier of heavy elements that determines the end-point of r-process in nucleosynthesis. New nucleosynthesis calculations were performed at LANL, which includes improved weak interaction rates and multiple-neutron emission rates calculated with the Hauser-Feshbach model. The paper was published in Physical Review Letters.

The first direct measurement of the gamma width of the crucial ¹⁸Ne state that dominates the ¹⁷F + p fusion rate in stellar explosions was made at ORNL HRIBF with a radioactive ¹⁷F beam. This measurement was coupled with data assessment and element synthesis calculations to determine the impact for nuclear science and exploding stars. Progress was made at ANL on determining ¹⁸⁷Re level properties to help understand the ¹⁸⁷Re / ¹⁸⁷Os cosmochronometer. Finally, at McMaster University, the ⁴⁰Ca + alpha and ²¹Na + p reactions were evaluated, important for element burning in massive stars and in novae, respectively.

V. Accomplishments (Report FY2008)

This chapter was prepared for the **third** time, in response to a request by DOE-SC, Office of Nuclear Physics. Following this request, in this chapter we summarize our most significant accomplishment(s) in FY2008/FY2009 (anticipated).

In the past two years we reported ENDF/B-VI.0 library release and two million data retrievals from the USNDP databases. For the purposes of the present document we report one accomplishment.

Three Million Retrievals from the USNDP Databases

In FY2008, retrievals from the USNDP databases as offered by the USNDP laboratories reached three million retrievals (2,996,000). This achievement reflects the collective work of USNDP in maintaining and improving the databases as well as its web services.

Tab. 3 illustrates the rapid growth in the use of nuclear data produced and offered by the US Nuclear Data Program. We show years 2001-2008, the period of time when this statistic has been systematically maintained. One can see that in last four years the usage of data more than doubled. The relative slowing down in growth seen in 2006 (annual growth 13%) was replaced by somewhat unexpected vigor in 2008 (annual growth 34%).

The contribution from the NNDC increased sharply after major database migration and web service upgrade was completed in 2004. In FY2008 the NNDC service supplied almost 2/3 of retrievals. There is a relative slow down in several USNDP laboratories caused by limited funding in last couple of years. In addition to traditionally strong services provided by NNDC, LANL and LBNL, in 2006-2008 the new NucAstro web system at ORNL started to make significant contributions.

Table 3: Data retrievals from the USNDP databases in FY2001-FY2008; shown in thousands is the sum over all USNDP laboratories and the NNDC contribution. Also shown is relative growth on annual basis.

FY	2001	2002	2003	2004	2005	2006	2007	2008
USNDP	667	799	966	1,212	1,642	1,863	2,239	2,996
USNDP	-	+20%	+21%	+25%	+35%	+13%	+20%	+34%
NNDC	257	281	330	478	778	1,089	1,380	1,961
NNDC	-	+9%	+17%	+45%	+63%	+40%	+27%	+43%

Table 4: USNDP Staffing Table for FY 2008

Annual Report FY 2008	ANL		BNL			LA NL	LBNL		LL NL	McMaster		NI ST	OR NL		TUNL		Program Total			
	Sci Per	Sci Tem	Sci Per	Sci Tem	Tec Adm		Sci Per	Sci Tem		Sci Per	Sci Tem		Sci Per	Sci Tem	Sci Per	Sci Tem	Sci Per	Sci Tem	Tec Adm	Total
I. NNDC Facility Operation	0.00	0.00	0.35	0.00	1.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	1.65	2.00
Management			0.35														0.35	0.00	0.00	0.35
Secretarial/Administrative Support					0.55												0.00	0.00	0.55	0.55
Library					0.25												0.00	0.00	0.25	0.25
Computer Operations					0.85												0.00	0.00	0.85	0.85
II. Coordination	0.10	0.00	0.65	0.00	0.00	0.40	0.30	0.00	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.00	1.50	0.00	0.00	1.50
National Coordination			0.35			0.10	0.30		0.05				0.05				0.85	0.00	0.00	0.85
International Coordination	0.10		0.25			0.30											0.65	0.00	0.00	0.65
III. Nuclear Physics Databases	0.00	0.00	1.05	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05	0.00	1.50	2.55
Nuclear Science References, NSR			0.10		0.70												0.10	0.00	0.70	0.80
Exper. Nucl. Structure Data, XUNDL			0.05														0.05	0.00	0.00	0.05
Eval. Nucl. Structure Data, ENSDF			0.20		0.65												0.20	0.00	0.65	0.85
Numerical Nuclear Data, NuDat			0.15														0.15	0.00	0.00	0.15
Reaction Data Bibliography, CINDA			0.05														0.05	0.00	0.00	0.05
Experimental Reaction Data, CSISRS			0.10														0.10	0.00	0.00	0.10
Evaluated Nuclear Data File, ENDF			0.30														0.30	0.00	0.00	0.30
Database Software Maintenance					0.15												0.00	0.00	0.15	0.15
Future Database System Develop.			0.10														0.10	0.00	0.00	0.10
IV. Information Dissemination	0.00	0.00	0.95	0.00	0.25	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.60	0.00	1.75	1.50	0.25	3.50
Nuclear Data Sheets			0.10		0.15												0.10	0.00	0.15	0.25
Customer Services			0.15		0.10												0.15	0.00	0.10	0.25
Web Maintenance & Development			0.70			0.10	0.10							1.50	0.60		1.50	1.50	0.00	3.00

Table 4: USNDP Staffing Table for FY 2008, cnt'd

Annual Report FY 2008	ANL		BNL			LA NL	LBNL		LL NL	McMaster		NI ST	OR NL	TUNL		Program Total				
	Sci Per	Sci Tem	Sci Per	Sci Tem	Tec Adm		Sci Per	Sci Tem		Sci Per	Sci Tem		Sci Per	Sci Tem	Sci Per	Sci Tem	Sci Per	Sci Tem	Tec Adm	Total
V. Nuclear Structure Physics	0.85	0.20	2.30	1.30	0.00	0.10	1.70	0.40	0.20	1.35	0.00	0.00	0.00	0.30	0.85	0.50	7.35	2.70	0.00	10.05
NSR Abstract Preparation			0.70	0.10													0.70	0.10	0.00	0.70
Compilation of Exper. Structure Data	0.05									0.20							0.25	0.00	0.00	0.25
Eval. of Masses & Nuclides for ENSDF	0.50	0.20	1.25	1.20			1.25	0.40		1.13				0.30	0.45	0.25	4.58	2.35	0.00	6.93
Ground & Metastable State Properties			0.15														0.15	0.00	0.00	0.15
Radioactive Decay Data Evaluation	0.20		0.05							0.02							0.27	0.00	0.00	0.27
Thermal Capture Gamma Data Eval.							0.35	0.00	0.20								0.55	0.00	0.00	0.55
Light Mass Eval. for Nucl. Physics A														0.40	0.25		0.40	0.25	0.00	0.65
Nuclear Structure Data Measurement	0.10					0.10	0.10										0.30	0.00	0.00	0.30
ENSDF Evaluation Support Codes			0.15														0.15	0.00	0.00	0.15
VI. Nuclear Reaction Physics	0.05	0.00	0.95	0.50	0.00	1.60	0.00	0.00	0.18	0.00	0.00	0.20	0.20	0.20	0.00	0.00	3.33	0.70	0.00	4.03
Experimental Data Compilation			0.10	0.45													0.10	0.45	0.00	0.55
<i>Neutron Data</i>			0.05	0.10																
<i>Charged Particle Data</i>			0.05	0.30																
<i>Photonuclear Data</i>				0.05																
ENDF Manuals and Documentation			0.15														0.10	0.00	0.00	0.10
ENDF Evaluations			0.40	0.05		0.30			0.18								0.88	0.05	0.00	0.93
Nuclear Reaction Standards						0.10						0.20					0.30	0.00	0.00	0.30
Nuclear Model Development			0.30			0.60											0.90	0.00	0.00	0.90
Nucl. Reaction Data Measurements						0.20											0.20	0.00	0.00	0.20
Astrophysics Nuclear Data Needs	0.05		0.05			0.40				0.25			0.20	0.20			0.85	0.20	0.00	1.05
Reaction Data for RIA Target Design						0.00											0.00	0.00	0.00	0.00
	ANL		BNL			LANL	LBNL	LLNL	McMaster	NIST	ORNL	TUNL	Program Total							
DOE-SC Nucl. Data Funded Staff	1.00	0.20	6.20	1.80	3.40	2.10	2.10	0.40	0.43	1.60	0.00	0.20	0.25	2.00	1.45	0.50	14.33	4.90	4.40	23.63
Staff Supported by Other Funds		0.80	0.40	1.20	0.20	14.40	0.15	0.80	7.50	0.40		2.80					25.65	2.80	0.20	28.65
TOTAL STAFF	1.00	1.00	6.60	3.00	3.60	16.50	2.25	1.20	7.93	2.00	0.00	3.00	0.25	2.00	1.45	0.50	39.98	7.70	4.60	52.28

Detailed Status of the Work Plan (Report FY2008)

I. NNDC Facility Operation (Report FY2008)

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 their 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:

- Scan and remediate regularly vulnerabilities on NNDC servers and clients to ensure compliance with DOE cyber security requirements.
- Provide computer support to the NNDC staff and its visitors as necessary.
- Move the secondary database server powering up the NNDC web site to ITD central computing facility to enhance services reliability.
- Improve the NNDC computer room and its operating environment by upgrading air conditioning system.

Status:

- Cyber security vulnerabilities were regularly addressed and resolved ensuring compliance with DOE cyber security rules and regulations.
- Computer support to the NNDC staff and to about two dozen of the NNDC visitors was provided.

- Secondary database server has been moved to ITD already in FY2007. Also air conditioning system in the NNDC computer room has been upgraded in FY2007.
- Dell Linux cluster, purchased in 2006 for ENDF/B-VII.0 phase 1 testing, was upgraded from 11 to 75 CPU cores to enhance capabilities of covariance data processing and sensitivity matrix calculations.
- The NNDC network was upgraded from 100 Megabits/sec to 1 Gigabits/sec.
- New Linux working server, providing faster processing speed and more advanced functionalities to NNDC staff, was installed and configured.

II. Coordination (Report FY2008)

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 Measurement and Basic Physics Committee of the Cross Section Evaluation Working Group.

ANL Planned Activities:

Organize and chair the CSEWG Measurement and Basic Physics Committee.

Status:

- ANL organized and chaired the Measurement and Basic Physics Committee at the November 2007 CSEWG Meeting.

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

BNL Planned Activities:

Prepare FY2009 work plan for USNDP in time for spring 2008 FWP submittals.

Organize and chair CSEWG Meeting at BNL in November 2007.

Organize and chair USNDP Meeting at BNL in November 2007.

Edit and publish summary reports of the CSEWG and USNDP meetings.

Edit and publish USNDP Annual Report for FY2007.

Maintain CSEWG and USNDP websites.

Status:

- FY2009 work plan for USNDP was prepared in February 2008.
- CSEWG Meeting was held at BNL in November 2007.
- USNDP Meeting was held adjacent to CSEWG Meeting in November 2007.
- Summary report of CSEWG-USNDP 2007 meeting was published on-line in December 2007.
- USNDP Annual Report for FY 2007 was published on-line in February 2008.
- CSEWG and USNDP web sites were regularly maintained, with considerable improvements regarding reaction data retrieval capabilities.

LANL -- Chair U.S. Nuclear Data Program's Nuclear Reaction Working Group and help coordinate nuclear reaction data work at different labs to advance USNDP; chair Evaluation Committee of the Cross Section Evaluation Working Group.

LANL Planned Activities:

Organize and chair CSEWG Evaluation Committee meeting at BNL, November 2007.

Organize and chair Nuclear Reaction Working Group meeting at USNDP meeting in November 2007, and help coordinate Homeland Security, Astrophysics, and RIA Task Forces.

Status:

- Organized and chaired the Evaluation Committee at the November 2007 CSEWG meeting.
- Organized and chaired Nuclear Reaction Working Group meeting at USNDP meeting in November 2007.
- Homeland Security and Astrophysics data needs were investigated. New theoretical developments for Homeland Security and Astrophysics data were made. RIA Task Force was terminated in 2007.

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:

Organize and chair Nuclear Structure and Decay Data Working Group meeting at USNDP meeting, November 2007.

Serve on USNDP Coordinating Committee.

Status:

- Organized and chaired USNDP Nuclear Structure and Decay Data Working Group meeting in November 2007.
- Served on USNDP Coordinating Committee.
- Helped organize the LLNL Capture Gamma Library project and participated in DOE NA-22 Review of the LLNL Neutron Capture Gamma Library Project. This is new activity added since the last report.

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

LLNL Planned Activities:

Organize and chair the CSEWG Task Force on Nuclear Data Needs for Homeland Security.

Status:

- Seven LLNL participants attended the FY2008 CSEWG meeting in November 2007.
- LLNL prepared the Task Force on Nuclear Data Needs for Homeland Security report for CSEWG.
- Organized the Compound Nuclear Reactions (CNR*) conference in October 2007.

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:

Summarize USNDP efforts in nuclear data for nuclear astrophysics at USNDP Meeting in November 2007.

Communicate current efforts and future plans with researchers in nuclear astrophysics data.

Represent USNDP nuclear astrophysics efforts at international collaboration meetings on nuclear astrophysics data.

Initiate collaborative research projects to raise the visibility of nuclear data projects directed at astrophysics applications.

Discuss future plans in nuclear astrophysics data with DOE, with USNDP/NNDC, and with other agencies.

Status:

- USNDP efforts in nuclear data for nuclear astrophysics summarized in an oral presentation for USNDP meeting in November 2007.
- Gave an invited presentation on nuclear astrophysics data efforts at ORNL and other USNDP institutions at the Session on Nuclear Astrophysics Data at the Nuclei in the Cosmos X Meeting in Mackinac Island, Michigan in July 2008.
- Explored prospects for joint research / data projects in nuclear astrophysics involving multiple USNDP sites and international collaborators, including Beihang University of Aeronautics and Astronautics in Beijing, China.

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:

Participate in IAEA CRP on “Updated Data Library for Actinides”.

Status:

- ANL staff continues participating in the IAEA-CRP on “Updated Decay Data Library for Actinides”. He chaired the third IAEA-CRP meeting that was held at the IAEA Headquarter in Vienna in September 2008.
- Two lectures were prepared and presented at the IAEA/ICTP organized workshop on “Nuclear Structure and Decay Data: Theory and Evaluation” that was held in Trieste, Italy, April 2008.
- Three lectures were prepared and presented at the DDEP training workshop that was held in Bucharest, Romania, May 2008. ANL staff served as a member of the Scientific Advisory Committee of this meeting.
- ANL hosted and mentored a scientist from the Kolkata, India NSDD center (Dr. G. Mukherjee) as a nuclear structure data evaluator.

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:

Participate in the IAEA-sponsored NRDC meeting in 2008.

Participate in NEA WPEC annual meeting in 2008.

Serve as coordinator of the WPEC Subgroup 24 on fast neutron cross-section covariances.

Provide lecturer to the IAEA/ICTP workshop on nuclear reaction data (if organized).

Status:

- M. Herman participated in the meeting of the Network of the Nuclear Reaction Data Centers (NRDC) organized by the IPPE, Obninsk, Russia in September 2008. He presented status report on the NNDC activities in reaction data (compilation, evaluation, dissemination).

- M. Herman, on behalf of P. Oblozinsky, led the US team at the NEA Working Party on International Evaluation Cooperation (WPEC) meeting in Tokai, Japan in June 2008. He presented a talk on the status of the ENDF/B library and reported on the activities of WPEC Subgroup 24.
- M. Herman served as the coordinator of the WPEC Subgroup 24. The subgroup continues to study and compare different approaches to produce covariances in the fast neutron region. The subgroup was extended for an additional year.
- The nuclear reaction workshop organized by the IAEA was predominantly experiment oriented and BNL participants were not involved in it.
- J. Tuli and A. Sonzogni delivered a series of lectures at the IAEA sponsored Workshop on Evaluation of Nuclear Structure Data at ICTP Trieste, Italy in April 2008.

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:

- Participate in NEA-WPEC 2008 meeting.
- Participate in relevant IAEA CRP meetings (RIPL-3).
- Make latest version of NJOY data processing code available to the international community.
- Host a couple of international visitors to LANL to collaborate on the evaluation of reaction data.

Status:

- LANL staff members participated in WPEC meeting in Tokai, Japan in June 2008.
- Participated in IAEA Technical Meetings on fusion nuclear data library, RIPL-3 library, and prompt fission neutron spectra.
- Upgrades to NJOY were released to the international NJOY data processing community.
- NJOY, which includes a covariance processing module, ERRORJ, has been tested. Talk was given at the covariance workshop in Port Jefferson, NY in June 2008.
- Hosted a PhD student from Kyushu University to perform data analysis of prompt fission neutron spectra.
- Invited a scientist from CEA, France, as a long-term visiting scientist.

LBL – Participate in IAEA-sponsored training workshops, planning meetings and coordinated research programs on nuclear structure and decay data.

LBL Planned Activities:

Continue participation in IAEA CRP on “Reference Database for Neutron Activation Analysis”.

Participate in IAEA/ICTP nuclear structure and decay data evaluation training workshop if one is scheduled during FY2008.

Status:

- Led preparations for the IAEA CRP on “Reference Database for Neutron Activation Analysis”, to be held in November 2008.
- Presented four lectures at the IAEA/ICTP organized “Workshop on Nuclear Structure and Decay Data: Theory and Evaluation” that was held in Trieste, Italy, April/May 2008.

McMaster – Continue participation in new evaluators training program.

McMaster Planned Activities:

Participate in the discussions of spin-parity assignment rules and other policy matters related to the NSDD network.

Participate in training/mentoring of new ENSDF evaluators through collaborative work, as needed and as the opportunity arises.

Status:

- As action item from 2007 NSDD meeting, systematics of M1 transition rates has been reviewed and RUL proposed in different mass regions. A report was presented at USNDP-2008 meeting.
- Work with evaluator from ORNL on A=58 is continuing.
- Preliminary work started with a new evaluator Dr. Abu-Saleem from Jordan University on A=71. He is scheduled to visit McMaster in Jan 2009.

III. Nuclear Physics Databases (Report FY2008)

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:

Database distributed to collaborators monthly.

Status:

- Database was updated on a weekly basis with newly published references. Quality control was performed on all new entries, with special attention given to entries produced by IAEA Vienna and McMaster University.
- Database updates were distributed monthly to external contributors.

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:

Update database as input is received from McMaster.

Status:

- Database was updated as required, 452 new (430 from McMaster, 22 from ANL) and 60 updated files were included.
- Database was distributed to the NSDD network once.

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:

Database distributed to collaborators twice a year.
Process evaluations received from NSDD evaluators.

Status:

- The ENSDF database was distributed in October 2007 and March 2008.
- 25 mass-chains, additional 63 nuclides and 2 data sets were received, processed and added to ENSDF in FY2008. Processing includes file checking, review and post-review checking.

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:

Update NuDat database as necessary, about 10 times a year.

Status:

- The NuDat database was updated regularly.
- Retrievals from the NuDat database were up by 47.5% and reached 1.1 million.

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:

Contribute to CINDA by compiling experimental cross section data to the CSISRS database (200 compiled papers expected).

Status:

- 106 new references were added following the new entries compiled to the CSISRS (EXFOR) database of experimental nuclear reaction data.

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:

Update CSISRS with EXFOR compilations from cooperating centers (500 expected).

Status:

- The CSISRS database was regularly updated using input from the cooperating data centers (619 new compilations/entries, corresponding to 4,098 reactions/subentries; this includes the NNDC compilations of 106 entries and 1,060 subentries).

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 the ENDF/A web interface.

BNL Planned Activities:

Maintain ENDF discussion list to facilitate validation of new ENDF/B-VII.0 library.

Collect and maintain new evaluations submitted for future release of the ENDF/B-VII library.

Perform phase1 testing of all new evaluations for the ENDF/B-VII.1 library.

Status:

- The ENDF discussion list, endf@lists.bnl.gov, was regularly maintained.
- Reported deficiencies and suggested improvements for files in the ENDF/B-VII.0 library have been stored on a continuing basis.
- Newly submitted evaluations were verified (phase1 testing), collected on the ENDF/A web site and made available for validation. These evaluations are considered to be candidates for ENDF/B-VII.1 library expected to be released by the end of 2010.
- Validation of the new ENDF/B-VII.0 library continued and the results have been collected on the NNDC web site.

H. Database Software Maintenance

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

BNL Planned Activities:

Re-write the selector generation program for NSR.

Status:

- Completion of this task has already been reported earlier and no new work was performed during FY2008.

I. Database Systems Development

The multi-year effort to migrate the USNDP databases to a LINUX/SYBASE environment was completed in FY2004. 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 astrophysics. 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:

Continue development of journal tracking database in support of NSR compilation.

Maintain new CSISRS web interface for users without specialized knowledge of ENDF.

Maintain and improve Sigma web interface for users without specialized knowledge of ENDF format.

Status:

- The NSR journal tracking system was extended to cover additional journals.
- Development of java-base publication software for ENSDF was pursued under external contract. Basic features for band plotting code have been implemented, but further work is needed to complete the project.
- No new development was necessary as far as CSISRS retrieval is concerned; recent extensions and modifications to the existing CSISRS web interface made it more friendly to non-ENDF users.
- The new version (2.0) of the easy to use ENDF retrieval and plotting interface, Sigma, was released in April 2008. This version extends plotting capabilities to angular distributions, and double-differential cross sections. It allows also for direct plotting of covariances and for operations on evaluated cross sections.

J. Evaluated Gamma Activation File (EGAF)

Note: This item was not included in the official FY2008 Workplan and was added at the time when the present Annual Report was written.

The LBNL Isotopes Project is responsible for EGAF, a database of neutron capture gamma-ray cross section data required for Prompt Gamma-ray Activation Analysis (PGAA), Neutron Activation Analysis (NAA), and other nuclear applications. The work is coordinated with the IAEA by the Isotopes Project. The EGAF file contains gamma-ray cross sections for prompt and delayed gamma-rays from neutron capture and total radiative neutron capture cross sections. The data are stored in the ENSDF and tabular format. The database is published in *Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis, STI/PUB/1263, 251 pp.; 14 figures; 2007, ISBN 92-0-101306-X*, which is currently available on-line at <http://www-pub.iaea.org/MTCD/publications/PubDetails.asp?pubId=7030>. These data are also being incorporated into ENDF format in collaboration with the LLNL Neutron Capture Gamma Library Project.

New evaluations for the next release of the library, EGAF-2, are being produced and tested and are made available to users through the IAEA and LBNL websites.

LBNL Planned Activities:

No activities were mentioned in the official FY2008 Workplan.

Status:

- An EGAF database update is in progress based primarily on new measurements at the Budapest Reactor.

- A new activation file is under development in collaboration with the IAEA CRP on a “Reference Database for Neutron Activation Analysis”.

IV. Information Dissemination (Report FY2008)

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 four 2.8 GHz dual-processor Dell servers running on the Linux operating system and using the Apache Tomcat and Sybase server software. This solution was made public in April 2004 and has proved to be secure, fast and have minimum downtime. Most of the databases were redeveloped to take advantage of the new hardware possibilities as well as new programming technologies, such as the use of the Java and Java scripts languages. In FY 2005 this system was upgraded from a single web server to dual web server system. This upgrade significantly increases reliability of the system. The NNDC also maintains the Atomic Mass Data Center web site. Other USNDP members also offer nuclear physics information through their web sites. These services require resources to maintain currency and improve performance.

ANL Planned Activities:

Maintain and upgrade the ANL/NDM report series web site.

Maintain and upgrade Experimental Resources for Nuclear Data web site.

Maintain and upgrade the ANL Nuclear Data Information web site.

Status:

- The three web sites were maintained and periodically upgraded.

BNL Planned Activities:

Improve NSR and ENSDF web interfaces.

Maintain web interface to the ENDF database.

Improve web interface for double-beta decay.

Improve reliability and cyber security of its web services by installing the latest version of Apache/Tomcat servers and mod-jk2 connector software for a new dual web server system.

Maintain currency of the CSEWG, USNDP and the NNDC web sites.

Investigate Google search to support compilation of NSR.

Explore possibility for a nuclear astrophysics webpage in collaboration with JINA.

Status:

- The NSR and ENSDF web interfaces were maintained.
- The existing web interface for the ENDF database was maintained.

Extension of ENDF retrieval and plotting system, Sigma2.0, was developed and launched in April 2008. It allows for plotting of angular distributions, and certain class of covariance matrices. The innovative extension is a possibility to perform operations on evaluated cross sections.

- NuDat continues to be by far the most popular product of the NNDC web service. In FY08, NuDat was responsible for as much as 56% data retrievals out of total of 1,961K retrievals served by the entire NNDC web service system.
- The web interface for double-beta decay was maintained.
- No investigation of Google search to support compilation of NSR has been performed.
- The currency of the CSEWG, USNDP and the NNDC web sites was maintained.
- No collaboration on nuclear astrophysics webpage with JINA too place.

LANL Planned Activities:

Include access to new reaction and structure data evaluations, supported by DOE/Nuclear Physics, via the T-16 web site.

Provide actinide ENDF/B-VII data via LANL web site for criticality data testing, together with other LANL evaluations (e.g., light nucleus reactions).

Status:

- The server was renewed to provide faster and more secure services to the users.
- The latest LANL evaluations were made available via our web site. This has been particularly important for the integral data testing community that is validating the preliminary ENDF/B-VII evaluations.

LBNL Planned Activities:

Maintain existing web pages and support the Isotope Explorer 2 and 3 software previously developed by LBNL.

Status:

- Updated existing web pages as needed and disseminated Isotope Explorer 2 and 3 and NSR search software.
- Limited maintenance and no new dissemination effort.

LLNL Planned Activities:

Maintain LLNL Nuclear Data and Atomic Data Viewer.

Add search capability to the Nuclear and Atomic Data Viewer.

Extend the Nuclear and Atomic Data Viewer as per user requests.

Maintain and upgrade LLNL Computational Nuclear Physics web pages.

Status:

- The Nuclear and Atomic Data System was maintained.
- The Computational Nuclear Physics web pages were maintained.

ORNL Planned Activities:

Development and maintenance of our online software suite to convert nuclear data to astrophysical reaction rates and plot, manipulate, and share results online is at severe risk of termination.

Efforts to regularly update nuastrodata.org web pages are at risk of termination.

Status:

- The **Computational Infrastructure for Nuclear Astrophysics**, online at **nuastrodata.org**, is serving as the software backbone for data processing and dissemination of a new international collaboration in nuclear astrophysics data. New workflow management tools have been developed for this effort and are now undergoing testing. These tools have utilization in the nuclear data community beyond research in nuclear astrophysics.

TUNL Planned Activities:

Continue to improve the TUNL web site and provide access to new information on $A = 3 - 20$ nuclei.

Continue to prepare new PDF and HTML documents of the most recent TUNL reviews.

Continue to provide PDF and HTML documents for FAS reviews for the $A = 3 - 20$ series.

Continue to provide General Tables to accompany the most recent TUNL reviews of the $A = 3 - 20$ series.

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.

Status:

- PDF and HTML files are online for *Fay Ajzenberg-Selove and TUNL reviews* for 1959-present.
- Re-creation of PDF files for *Fay Ajzenberg-Selove and TUNL reviews* to provide the most current NNDC reference keys and to correct all errors found since the articles went to press is in progress. This year we re-created $A = 3 - 20$ (1959-1980).
- Energy Level Diagrams are online for *Fay Ajzenberg-Selove and TUNL reviews* for 1959-present.
- Compiled information on Thermal Neutron Capture data for $A = 2 - 20$ nuclei is online.
- Compiled information on beta-decay data for $A = 3 - 20$ nuclei is online.

- An effort to provide compiled information on beta-decay data for $A = 4 - 20$ nuclei is essentially completed.

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:

Effort required to provide technical support to users as necessary.
Extend Comments/Questions option for all reaction databases.

Status:

- The use of the NNDC web service continued to grow. In FY2008, the growth was 42% compared to previous year and the service provided total of 1,961K data retrievals.
- The NNDC staff responded to user inquiries by phone, email and web.
- Comments/Questions option was maintained for the reaction databases, CSISRS and ENDF, also for the whole NNDC web service as well as Nuclear Wallet Cards.

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:

Prepare twelve issues of Nuclear Data Sheets for publication.
Investigate a publication of adopted levels and gammas of all nuclides in ENSDF in electronic form (web and CD-ROM).

Status:

- Twelve issues of Nuclear Data Sheets were published. Eleven issues were dedicated to ENSDF mass-chain evaluations and one issue was dedicated to evaluation of neutron cross sections.
- The project to publish all adopted levels and gammas in ENSDF was discontinued in 2006.

V. Nuclear Structure Physics (Report FY2008)

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 approximately 30% of the keywords. These will be checked and edited by BNL as necessary before being added to the database.

BNL Planned Activities:

Prepare entries for 4,100 new references with keyword abstracts for 2,200 of them.

Check and edit approximately 1,000 key-worded abstracts (Nucl. Phys. A, Eur. Phys. J. A, and Phys. Lett. B) prepared at the IAEA Nuclear Data Section.

Status:

- 3,532 references, 1,908 of them with key-worded abstracts, from almost 80 journals and several conference proceedings were added to the NSR database. This includes contributions from the IAEA and McMaster University.
- IAEA timely contributed 255 key-worded references.
- There has been a considerable decline in a number of articles published in Nucl. Phys. A and Eur. Phys. J. A (672 papers less), which explains difference between planned and actual number of compiled entries.

McMaster Contribution to NSR Abstracts:

- Two undergraduate students under subcontract with NNDC were trained and supervised at McMaster for preparing keywords of about 1,000 current papers, primarily from Physical Review C.

B. Compilation of Experimental Structure Data

This activity involves compilation of recently published or completed experimental nuclear structure data for inclusion in XUNDL.

ANL Planned Activities: (*new task added during FY2008*)

Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database.

Status:

- Since April 2008 ANL staff compiled 22 data sets that were published in the journals Phys. Lett. B and J. Phys. G. Data were coded into ENSDF.

BNL Planned Activities:

Compile BE(2) experimental data.

Compile $\beta\beta$ -decay experimental data.

Status:

- 23 new entries for 21 different nuclides were added to the BE(2) database.
- 13 new entries for 3 different nuclides were added to the $\beta\beta$ -decay database.

McMaster Planned Activities:

Compile data sets (in ENSDF format) for current experimental nuclear structure publications on high-spin and low-spin physics.

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. On a timely basis send a copy of all such private communications to NNDC for archival and distribution purposes.

Train a new undergraduate student in early 2008 for XUNDL compilation work.

Status:

- 430 new data sets from current journal publications in experimental nuclear structure (high-spin and low-spin) were compiled and sent to NNDC. Another 60 data sets were updated based on new papers from the same groups or authors as in data sets from earlier papers.
- 32 compiled data sets were received this year from other data centers which were reviewed and edited at McMaster.
- Throughout the year there were active communications with the original authors of the papers to resolve data-related problems and to obtain additional details of data that are useful to include in XUNDL and/or ENSDF databases.
- Scott Geraedts was trained through 2007-2008 to work during the year on XUNDL compilations. He will continue part-time work until about April 2009.
- New experimental mass measurements for about 90 nuclides extracted from papers published during Jan-July 2008 were compiled and made available at the nuclearmasses.org online service. The measured values were compared with those from AME-2003.

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 nucleus or group of related nuclei to deduce recommended values from the measured data and prepare a file in ENSDF format that will be the basis for a publication “*Nuclear Data Sheets*” and will be 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:

2 equivalent mass chains will be evaluated and published.

At least two mass chains will be reviewed.

Collaborate with scientists from new NSDD data centers on evaluation projects.

Complete the horizontal evaluation on nuclear K-isomers and initiate drafting of a final publication.

Status:

- Two mass chains (A=202 and 206) were revised and published in *Nuclear Data Sheets*.
- Work is near completion on evaluation of all nuclides within A=204; evaluation of A=177 and 209 mass chains is continuing.
- Work on the horizontal evaluation on K-isomers is continuing in collaboration with scientists from Australia, but the progress is slow due to time constraints.
- Collaborations with evaluators from NSDD centers in India, Bulgaria and Australia are continuing.

BNL Planned Activities:

At least 6 equivalent mass chains will be evaluated.

At least 6 mass chains will be reviewed.

Continue mentoring of new ENSDF evaluators.

Status:

- Includes subcontracted part-time evaluators: C. Reich – Idaho; N. Nica - Texas A&M; E. Browne – LBNL, and D. de Frenne – NPL, Gent, Belgium
- 8 mass chains were evaluated and submitted, the NNDC share being 96 evaluated nuclides:
 - Nuclides (5 nuclides by Burrows and Gupta)
 - A = 72 (6 nuclides by Sonzogni)
 - A = 97 (14 nuclides by Nica)
 - A = 102 (14 nuclides by de Frenne)
 - A = 145 (16 nuclides by Browne and Tuli)
 - Nuclides (1 nuclide by Tuli)
 - A = 147 (16 nuclides by Nica)
 - A= 154 (15 nuclides by Reich)
 - A = 229 (8 nuclides by Browne and Tuli)
 - A = 240 (1 nuclide, collaboration with Browne)

- 3 mass chains were published in Nuclear Data Sheets plus one included in the ENSDF:
 - A = 45, 49, 137, 230 (in ENSDF)
- 11 mass chains were reviewed:
 - A = 107,108,111,214 (Tuli)
 - A = 127,147,169,182 (Reich); 206 (Browne); 78,81 (de Frenne)
- Mentoring of new evaluators continued (N. Nica – Texas A&M, D. Abriola – IAEA Vienna, and S. Basu - India).

LBNL Planned Activities:

Evaluate the equivalent of at least 4 mass chains, including a minimum of one from the A=26-30 region. In the course of this, an attempt will be made to identify specific needs of the nuclear structure community and tailor some evaluation activities to meet those needs (*e.g.*, specific isotope evaluations in neutron-rich regions).

Review mass-chain evaluations, as requested.

Status:

- Submitted A=25 (Firestone), A=93 (Baglin), A=179 (Baglin), A=214 (Wu) – total of 44 nuclides.
- Isotope evaluations: ^{170}Os , ^{170}Ir , island of inversion isotopes ^{28}Ne , ^{29}Ne , ^{29}Na , ^{30}Ne , ^{30}Na , ^{30}Mg – total of 8 nuclides.
- Published A=24, 137 (with NNDC), 166, 169, 214 (in ENSDF only), 230 (with NNDC, in ENSDF only).
- Mass chains under revision: A=25, 30, 81, 93, 145 (with NNDC), 179, 184, 187, 229 (with NNDC) and 240 (with NNDC and McMaster).
- Reviewed one mass chain.

McMaster Planned Activities:

1.5 equivalent mass chains (including the A=31-44 region) 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.

This activity will partially replace our updating of SD structures in nuclei where not much new data are now reported.

Collaboration with a new center/evaluator as part of mentoring process, as needed.

Status:

- Five full-length mass chains (A=31, 78, 85, 89, 240) and 49 individual nuclides were evaluated and sent to NNDC for inclusion in ENSDF and mass-chain publication in Nuclear Data Sheets. A=78 was done in collaboration with the group in Kuwait and A=240 with LBNL group.
- A=25 and 187 mass chains from LBNL center were reviewed.

- Collaborative work with evaluator from ORNL on ENSDF evaluation of A=58, as a part of mentoring activity is still continuing. New evaluator at McMaster for ENSDF work underwent training through collaborative work on A=31 mass chain. Preliminary work started on mentoring a new evaluator Dr. Abu-Saleem at University of Jordan through collaborative work on A=71.

ORNL Planned Activities:

Complete evaluation of structure information for nuclei with A=245 and 152.

Review one mass chain evaluation.

Continue evaluation of A=58 in collaboration with McMaster University.

Status:

- A=152 evaluation in progress.
- Review of A = 58 completed (M. Martin).
- A=58 evaluation revised (C. Nesaraja in collaboration with McMaster).
- Murray Martin has continued his training of post-doc Caroline Nesaraja in A-chain evaluations.

TUNL Planned Activities:

Prepare the ENSDF files corresponding to new publications in the “*Energy Levels of Light Nuclei*” series.

Status:

- Work on A = 11, 12, and 13 ENSDF files is underway.

D. Ground and Metastable State Properties

The NNDC maintains a database of nuclide properties for the Nuclear Wallet Cards.

BNL Planned Activities:

Update database as new information becomes available.

Status:

- The database was updated twice during FY 2008.

E. Radioactive Decay Data Evaluation

Decay data for nuclides of importance for metrology are evaluated in an international collaboration. When complete, these evaluations will be entered into the ENSDF format, merged into the ENSDF database and made available to ENSDF evaluators. In the United States, E. Browne (LBNL) coordinates this project at no cost to the US Nuclear Data Program.

ANL Planned Activities:

Evaluation of two radionuclides will be carried out as a part of the ANL contribution to the IAEA CRP on “Updated Decay Data Library for Actinides” and the DDEP collaboration.

Reviews of selected nuclides will be performed.

Status:

- Evaluation of ^{206}Hg was completed.
- One nuclide (^{139}Ce) was reviewed.

McMaster Planned Activities:

Evaluate decay datasets for one or two radionuclides.

Status:

- Decays of two nuclides were reviewed for DDEP.

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 will constitute a valuable resource required for updating the ENDF database. Additionally, delayed photon data need to be added to EGAF. The k_0 -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 k_0 values then need to be integrated into EGAF and, ultimately, made available to ENSDF evaluators.

LBNL Planned Activities:

Continue the following activities outlined in the FY2007 Work Plan with a view to maintaining and developing the EGAF database:

- (i) Continue collaboration with LLNL (see also Section VI. B, LLNL entry) to perform statistical-model calculations of quasi-continuum γ -ray cascade information; in FY2007, these calculations will be extended to the heavier elements. This project also includes supervision of a doctoral student at LLNL who is generating ENDF-format capture γ -ray datasets for use with MCNP and other transport-code calculations.
- (ii) Add to EGAF the neutron-capture decay data produced in the course of participating in the IAEA CRP on “Reference Database for Neutron Activation Analysis” (FY2009 completion date for CRP); in FY2007, the initial evaluation of k_0 values will have been presented to the CRP.

- (iii) Add any new thermal (n, γ) data that become available, along with any total radiative-capture cross sections derived from them.

Status:

- Published paper Phys. Rev. C77, 054615 (2008) in collaboration with LLNL describing statistical model calculations for the Pd isotopes.
- A preliminary comparison of k_0 , σ_γ , and s_0 data from all sources was presented at the November 2007 meeting for the IAEA-CRP on “Reference Database for Neutron Activation Analysis”. These data will be incorporated into EGAF.
- Update of the EGAF database is in progress.
- ENDF format datasets for isotopes with $Z=1-17$, 64, 74 have been prepared. Automation of statistical calculations is in progress.

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

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

TUNL Planned Activities:

Prepare “*Energy Levels of Light Nuclei, A = 11 - 12*” and “*Energy Levels of Light Nuclei, A = 3*” manuscripts for publication in *Nuclear Physics A*.

Evaluate nuclei in the $A = 13 - 15$ mass region in preparation for a future “*Energy Levels of Light Nuclei, A = 13 - 15*”.

Status:

- Evaluation of $A = 12$ nuclei is underway.
- Evaluation of $A = 11$ nuclides is complete, updates are being carried out as work on $A=12$ continues; preprints for $A=11$ and 12 will be released simultaneously.
- Evaluation of $A = 3$ nuclides is complete; preprints for $A=3$ will be released in early 2009.
- The TUNL post-doc is making progress in the evaluation of $A=13$ nuclides.

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.

ANL Planned Activities:

Complete decay data measurements on ^{243}Cm , ^{233}Pa , ^{237}Np as a part of the ANL commitment to the IAEA-CRP on “Updated Decay Data Library for Actinides”.

Participate in the development of the Argonne Total Absorption Spectrometer (ATAS) and the corresponding infrastructure at ANL for analysis, compilation and evaluation of decay data for neutron-rich fission products.

Status:

- Decay data measurements of ^{233}Pa , ^{243}Cm and ^{237}Np were completed and data analysis is ongoing. A talk was presented at the PHYSOR08 conference and a full paper was published in the proceedings.
- Participated in activities aimed at developing of ATAGS and the corresponding infrastructure at ANL for analysis, compilation and evaluation of decay data for neutron-rich fission products. Hosted and mentored a student from ANSTO/ANU Australia who worked on the project at no cost to ANL NDP.
- Participated in collaborative nuclear structure and decay data activities at the Argonne ATLAS facility with notable contributions to studies of K-isomers in heavy nuclei near $A=250$ and in deformed nuclei in the $A\sim 180$ region. This work complements the evaluation activities of K-isomers that are carried out by the ANL nuclear data staff. Maintained important collaborative connections with FRIB and GRETINA research communities because of their vital importance to nuclear science in US.

LANL - LANL/LANSCE maintains a small program to measure nuclear decay information.

LANL Planned Activities:

Examine prompt gamma-ray emission data from neutron reactions on Xe and Kr isotopes, and photo-induced reactions on ^{56}Fe to search for previously unobserved transitions in these and other, nearby residual nuclei.

Interact with mass chain evaluators on the nuclear structure of these nuclei.

Status:

- Data have been taken for ^{130}Te , ^{100}Mo , $^{70,72,74}\text{Ge}$, ^{140}Sn , and ^{138}Ba .
- Lifetimes and structure of isomeric states of $^{203,205}\text{Tl}(n,2n\gamma)$ residuals were studied, and submitted to Phys. Rev. C.

- Data analysis was completed on isomer production in neutron reactions on $^{191,193}\text{Ir}$ and ^{197}Au .
- Interaction with the evaluators for these nuclei continues.

LBL - 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:

Participate in local nuclear structure experiments with an emphasis on topical issues and data needs such as AFC-related measurements or nuclear structure experiments on nuclei far from stability.

Status:

- Measured (3He,t) charged particle transfer reactions as a surrogate for neutrons with energy between 10-20 MeV.
- LBNL Director's funds have been allocated for a third and final year of support for S. Basunia to continue his surrogate reaction measurements.

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:

Maintenance and upgrades for format changes as required.

Continuing development of ENSDF editor as well as Java versions of LOGFT, ALPHAD and FMTCHK.

Status:

- Maintenance and upgrades were done on regular basis.
- No development of ENSDF editor and Java versions of LOGFT, ALPHAD and FMTCHK were performed.

VI. Nuclear Reaction Physics (Report FY2008)

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:

Compile data from 200 charged particle and neutron reaction publications.

Status:

- Experimental cross section data from 106 publications were compiled (30 neutron, 70 charged-particle reaction papers and 3 photon-induced reaction papers). This translates into 1,060 compiled individual reactions, to be compared to 566 reactions compiled in FY2007.
- The NNDC compiler left BNL in August 2007 and the compilation activity has been outsourced (S. Hlavac – highly experienced experimentalist, SAS Bratislava and O. Schwerer – retired EXFOR database manager, IAEA Vienna).

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 ensure 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 FY2006. 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.

ANL Planned Activities:

No work planned for FY2008.

BNL Planned Activities:

- Respond to user needs for evaluated nuclear reaction data.
- Collect and address users' feedback related to the ENDF library.
- Work with LANL on upgraded evaluations for future release of the ENDF/B library (version VII.1).
- Improve methodology for providing covariance data, in the fast neutron energy region, to the next release of ENDF.

Status:

- New/revised evaluations submitted for the ENDF/B-VII.1 release were collected and made available to the library developers at the ENDF/A web site (27 materials).
- Users' feedback on the ENDF library continues to be collected and stored under the Validation section of the ENDF/B-VII.0 web page.
- The improvement of the covariance methodology focused on generation of covariances in the resonance region using Atlas of Neutron Resonances database. In addition, work on improving covariance methodology in the fast-neutron region continued.
- Improved covariance methodology was used to produce covariance data for several user groups:
 - Extensive set of covariance estimates (^{19}F – ^{209}Bi) was contributed to low-fidelity covariance project for the US Nuclear Criticality Safety Program (NCSP).
 - Covariance evaluations were performed for 55-Mn (with ORNL) and 90-Zr in the full energy range for NCSP.
 - Starter set of covariances for GNEP users has been prepared. It includes 108 materials (3 light nuclei from LANL, 5 new actinides LANL/ORNL, 9 ENDF/B-VII.0, 14 minor actinides revised by BNL, 2 new BNL and 74 low-fidelity estimates produced/revised by BNL).
- Support activities for covariance data evaluations were provided:
 - New covariance data in ENDF/A (19-F, 55-Mn, 90-Zr, 233,235,238-U, 239-Pu) were processed.
 - 108 files for the GNEP covariance starter file were processed.
 - Graphical representation of covariances (MF=33) within web retrieval and visualization system SIGMA has been implemented.

LANL Planned Activities: (work mostly supported from other sources)

- Upgrade the LANL ENDF evaluations for U, Pu, Am, Np isotopes that perform well in criticality benchmarks, considering new LANSCE experimental data.
- Provide upgraded ENDF evaluated data files for charged-particle reactions having $A \leq 10$, including covariance data. Continue to

study a problem on oxygen, which is reported by criticality benchmarks.

Re-evaluate Ti data, for which problems in the criticality benchmarks are reported.

Submit the covariance data for several important actinides, as well as for light elements, in the fast energy region (this is supported by many projects including AFCI, criticality safety, and also a WPEC collaboration).

Provide new delayed neutron data that include neutron spectra, yields, and delayed gamma-ray data.

Status:

- New ^{237}Np and ^{241}Am capture cross section data were evaluated, and compared with the LANSCE/DANCE experimental data. The results were published in Phys. Rev. C. Preliminary calculations were performed for $^{240,242}\text{Pu}$ and compared with the DANCE data too.
- The covariance data of light elements were estimated, and they were converted into the ENDF-6 format.
- Covariance data for important actinides, including ^{233}U , ^{235}U , ^{238}U , and ^{239}Pu in the fast neutron region were produced and provided to GNEP, criticality safety, and WPEC collaborations.
- New delayed neutron energy spectra were provided for homeland security studies. A delayed-gamma simulation code using the Monte Carlo technique was developed, and it was combined with transport simulation codes.
- New Ti evaluations for all isotopes were made. Benchmark tests that include the new Ti data were performed. The overestimation problems reported were resolved by the new evaluations.

LBNL – *This item was not part of the official FY08 Workplan and was added at the time when the present report has been written.*

LBNL is collaborating with LLNL to incorporate EGAF capture gamma-ray data into the ENDF file. This effort follows research leading to the PhD. thesis *Improved Neutron Capture Data and Evaluation with Statistical Nuclear Structure Models for Transport Libraries* by Brad Sleaford, which was performed under the direction of Richard Firestone of the Isotopes Project and completed in FY2008. The LLNL effort is supported by DOE NA-22.

LBNL Planned Activities:

No activities planned in FY08 Workplan.

LLNL Planned Activities: (work mostly supported from other sources)

Perform new evaluations as per customer requests and submit these and other LLNL generated evaluations into ENDF.

Produce ENDF files with the discrete and quasi-continuum gamma-ray spectra in collaboration with LBNL using data in EGAF database.

Add capability to FETE code to translate ENDF covariance data and propagate these data into calculations of benchmark quantities using Monte-Carlo techniques.

Test LLNL translation and processing codes that use new structure rich nuclear data format. Extend format to include elements of ENDF evaluated data format.

Status:

- LLNL evaluations submitted to ENDF/A: ^{240}Am , ^{237}U , ^{47}Ti (bugfix).
- LLNL evaluations completed during FY2008, but not yet submitted to ENDF/A: $^{57,60,61}\text{Co}$, $^{56,57,63,65,66,67}\text{Ni}$, $^{64,66,67,68}\text{Cu}$, $^{63-72}\text{Zn}$, $^{68,70,72}\text{Ga}$, $^{76-78}\text{Kr}$.
- LLNL partial evaluations for the Hoffman RadioChemistry Library (currently in ENDF/A) “filled-out” to full evaluations (144 out of 497 completed in FY2008) but not yet submitted to ENDF/A.
- Development continues at LLNL of a structure-based (XML) data representation for deterministic and Monte-Carlo processed data, the processing codes and access routines. The access routines are being tested in the GEANT4 transport code by the GEANT collaboration and locally in LLNL transport codes. Many of the ENDF parameterized types are currently implemented.
- The FREYA code for simulating fission fragment formation and decay is being developed in a LLNL/LBNL collaboration. This model is discussed in Section VI.E below.
- In collaboration with LBNL, discrete and quasi-continuum gamma-ray spectra from the EGAF database have been added to the ^{19}F , ^{182}W , ^{183}W , ^{184}W , ^{186}W and ^{207}Pb ENDF evaluations. These evaluations have been submitted to ENDF/A. This effort has spun off into a larger project funded by NA-22 at DOE with the goal of automating all ENDF evaluation updates over the course of a few years. The automation toolset is described in Section VI.E below.

C. ENDF Manuals and Documentation

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:

Maintain ENDF-6 formats manual that is available on the web and prepare major update of the manual. This format is used for the ENDF/B-VII release.

Status:

- The new LaTeX version of the ENDF-6 Formats Manual has been undergoing extensive review and numerous corrections were implemented. Many of these corrections address issues that were present in the original (Word) version of the manual and should make the ENDF-6 format better defined. The retrospective description of the format was added by N. Holden.

D. Nuclear Reaction Standards

Nearly all nuclear reaction data measurements are made relative to some reaction standard such as the hydrogen elastic cross section. Maintaining accurate current values for the standard cross sections is the objective of this task, which can be accomplished only through international cooperation. A new international evaluation of the neutron cross section standards was done to provide the improved standards that are needed. This evaluation was largely performed by an IAEA Coordinated Research Project (CRP) with support, primarily experimental in nature, through the Working Party on International Evaluation Cooperation (WPEC) of the Nuclear Energy Agency and CSEWG.

ANL Planned Activities:

No work planned for FY2008.

LANL Planned Activities:

Participate in the international effort to reevaluate the light-element standard cross sections with LANL leadership for H, Li and B, and investigate the nature of output covariance data from R-matrix analyses of systems containing the light-element standard cross sections.

Incorporate the cross section standards into the new ENDF evaluations, and perform validation tests with integral measurements.

Measure cross sections for the standards reaction ${}^6\text{Li}(n,\alpha)$ from 1 to 5 MeV to provide improved data for R-matrix analysis.

Study covariance data evaluation for the standards in a different technique when the R-matrix analysis gives extremely small uncertainties.

Status:

- New experimental data of ${}^6\text{Li}(n,\alpha)$ were taken, and the R-matrix fit was performed. The resulting reaction cross section after including the new data is higher than the ENDF/B-VII.0 evaluation in the 2 MeV region.

- Cross sections reported as a ratio to the standards were modified by using the final standards evaluations.
- Absolute fission cross section measurement in design stage with LLNL and others.
- A simple estimate of covariance data for light elements outside the standards energy range was made. This is important for data processing with NJOY.

NIST Planned Activities:

Participate in the IAEA data development project on maintenance of the neutron cross section standards so that standards will be available for future cross section libraries.

Finish detailed documentation for the standards evaluation process.

Continue the documentation of changes to EXFOR files based on the corrections obtained from the files of Poenitz and new information obtained from the CRP investigations.

Continue to recommend new measurements and perform examinations of the data from them for use in future evaluations of the standards. Encourage measurements by submitting standards for the WPEC High Priority Request List.

Submit for publication the collaborative measurements with Ohio University and LANL on the measurements of the hydrogen elastic scattering angular distributions. Consider additional standards work with the collaboration.

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.

Continue work on a measurement of the ${}^6\text{Li}(n,t)$ cross section standard at ~ 4 MeV neutron energy using improved fluence determinations based on calorimetry, nu-bar of ${}^{252}\text{Cf}$ and α - γ coincidences with the ${}^{10}\text{B}(n,\alpha\gamma)$ reaction.

Continue efforts to improve the ${}^3\text{He}(n,p)$ standard cross section using spin-dependent n- ${}^3\text{He}$ coherent scattering length work.

Status:

- An IAEA Consultants Meeting on the data development project on maintenance of the neutron cross section standards was held. This project was initiated as a result of a proposal from NIST. The NIST delegate chaired the meeting and gave a report on an update of the standards database. Also work was done on investigating the prospect of an inelastic scattering cross section standard; considering adding additional standards energy ranges for the $\text{Au}(n,\gamma)$ cross section; proposing updates for the evaluations of the ${}^{252}\text{Cf}$ spontaneous fission neutron spectrum and the ${}^{235}\text{U}$ thermal neutron-induced fission neutron spectrum; and developing a procedure for improving the smoothing process for the $\text{Au}(n,\gamma)$ cross section.

- A detailed IAEA Technical Report that describes the standards evaluation process was completed and published (IAEA report STI/PUB/1291) This provides a complete source of documentation for the standards evaluation. A discussion on the covariances obtained from the evaluation process was the topic of a paper given at the recent workshop on neutron cross section covariances hosted by the NNDC. Also an invited talk was given on the status of the neutron cross section standards at the 13th International Symposium on Reactor Dosimetry.
- Work has continued on the documentation of changes to data files made by Wolfgang Poenitz. It appears that it will not be possible to obtain more of Poenitz's files of corrections that were made to datasets used in the evaluation process.
- We continue to recommend new measurements and monitor the progress being made on standards experiments. Work has been completed on the ${}^6\text{Li}(n,t)$ cross section at LANL and work at NIST on that cross section continues; ${}^{10}\text{B}(n,\alpha)$ cross section work at Peking University and IRMM continues; new measurements have been made and additional work is planned by two separate groups at n-TOF of the ${}^{238}\text{U}(n,f)/{}^{235}\text{U}(n,f)$ cross section ratio. Measurements of fission cross section ratios have been made at LANL. New collaborative (LANL, LLNL) very accurate fission cross section measurements are planned using a TPC.
- A near final draft has been completed on the collaborative work with Ohio University and LANL on the measurements of the hydrogen elastic scattering angular distribution at 14.9 MeV. It should be submitted for publication in 2008. A new experiment has been designed in which the recoil neutron, rather than the recoil proton, will be detected. This allows angular distribution data to be obtained to much smaller angles. The experiment is nearly ready for extensive diagnostic measurements.
- The National Repository for Fissionable Isotope Mass Standards continues to monitor samples and make them available for loan in physics experiments.
- Work continues at NIST on a measurement of the ${}^6\text{Li}(n,t)$ cross section standard at ~ 4 MeV neutron energy. A paper on this work using neutron fluence determination based on α - γ coincidences with the ${}^{10}\text{B}(n,\alpha,\gamma)$ reaction was given at the ISRD-13 meeting in May 2008. The very small uncertainties planned for this work ($\sim 0.25\%$) have required a large amount of time to understand and reduce the various uncertainty components.
- Measurements have been completed of the spin-dependent n - ${}^3\text{He}$ coherent scattering length that will improve the ${}^3\text{He}(n,p)$ standard cross section. This work has been submitted for publication.

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 GNASH (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-3 to improve accuracy and reliability of input parameters used in nuclear reaction calculations.

ANL Planned Activities:

No work planned for FY2008.

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 for homeland security applications. Close collaboration with LANL will continue focusing on validation of the fission models in EMPIRE and GNASH. Major effort will be 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 developed and tested.

BNL Planned Activities:

Release new version of the code EMPIRE with above-mentioned improvements.

Develop the improved version of the covariance module in EMPIRE for fast neutrons.

Implement and test the new resonance module allowing utilization of information from Atlas of Neutron Resonances.

Status:

- The EMPIRE-2.19 version (originally released in March 2005) was continuously updated and retrievable through the CVS repository. This version gradually became EMPIRE-3.0 (not yet available through the EMPIRE web interface). An extensive paper on EMPIRE-3.0 was published in Nuclear Data Sheets (NDS 108, December 2007).
- New parameterization of EMPIRE-specific (EGSM) level densities has been developed and implemented in EMPIRE-3.0.

- Work continued on the improvement of the physics description of the fission channel. New approach to calculate transmission through multi-hump barrier was developed by EMPIRE developers R. Capote (IAEA Vienna) and M. Sin (University of Bucharest).
- Implementation of Atlas-Empire-Kalman chain, the backbone of the EMPIRE covariance module, has been improved. Extensive paper on EMPIRE covariance methodology has been published.
- Theoretical study of uncertainty minima in optical model cross sections has been undertaken.
- Consistency between thermal cross sections and resonance parameters has been partially implemented in the resonance module of EMPIRE.

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 due to the decrease in operating experimental facilities throughout the world. The LANL GNASH code has proved to be an important tool, and we will continue development of a new version of this code, McGNASH, to provide a state-of-the-art capability to predict reaction cross sections. This also involves a close collaboration with experimentalists at LANSCE to interpret new measurements using the GEANIE and DANCE gamma-ray detectors, as well as (n, charged-particle) data. These data will result in advances in our understanding of nuclear reaction mechanisms, and improvements in our modeling codes. Also, largely under DOE/DP support, we will continue modernization of our R-matrix EDA code (used for light nucleus calculations and data evaluations) and explore implementation of exact particle-exchange formalism.

LANL Planned Activities:

- Calculate and interpret gamma-ray reactions measured with GEANIE at LANSCE. A FY2008 area of research centers on neutron reactions on fission products including the noble gases, xenon and krypton.
- Collaborate with LANSCE experimentalists on the interpretation of new FIGARO measurements of neutron inelastic scattering.
- Perform radiative capture calculations on Gd and Eu isotopes in support of DANCE detector capture measurements, and provide the Maxwellian averaged cross section to s-process study.
- Perform radiative capture calculations for fission products, in collaboration with CEA (France).
- Perform neutron inelastic scattering and fission neutron spectrum measurements with the FIGARO array.
- Develop a code to calculate the delayed neutron spectrum including Los Alamos micro-macroscopic nuclear mass model, which allows beta-decay from isomer states.

Develop a theory and method to calculate compound reactions when strongly coupled-channels exist. This is crucial to study reaction cross sections for actinides.

Modern nuclear structure models, such as Hartree-Fock, will be applied to calculate nuclear reaction cross sections to reduce phenomenological model parameters.

Study ^{238}U neutron inelastic scattering at low-excitation energies where theoretical calculation underestimates experimental data.

Status:

- The calculation and interpretation of the $^{150}\text{Sm}(n,n')$ reaction have been completed. A soft-rotator model was employed to calculate the neutron transmission coefficients. The coupled-channels method is found to be crucial to obtain a reasonable total neutron emission cross section near 5 MeV, which reproduces the GEANIE data.
- Measured fission neutron spectrum and multiplicity for incident neutrons from 1 to 200 MeV on ^{235}U , ^{238}U and ^{237}Np to test models including the Los Alamos Model. Average energies were obtained from the experimental data, and the model calculations were performed.
- Radiative capture data of DANCE for ^{241}Am in the unresolved resonance region were analyzed by using deformed Hauser-Feshbach model calculations, and a Phys. Rev. C paper was published.
- New method to calculate the radiative capture cross sections on deformed nuclei was developed, in which the coupled-channels method is combined with the Hauser-Feshbach statistical theory. The method was applied to analyze DANCE ^{241}Am and ^{237}Np data. This is also crucial for deformed target important in the s-process network simulation.
- Hartree-Fock-BCS model was applied to calculate the inelastic scattering process on both spherical and deformed targets. The model developed is a fully quantum-mechanical one, without any adjustable parameters.
- A new code to calculate the delayed neutron spectra was developed.

LLNL – *Note: This item was not part of the official FY2008 Workplan and was added at the time of writing the present report.*

LLNL's nuclear reaction modeling efforts are focused on fission studies, *ab initio* methods to study light ion reactions and tool development for mass production of ENDF libraries.

LLNL Planned Activities (*not included in FY2008 Workplan*):

Finalize the plutonium neutron spectra evaluation up to the threshold for second-chance fission.

Status:

- FREYA is currently being tuned to agree with the available plutonium data on the fission neutron spectrum and the average neutron multiplicity. Once complete, the new evaluation will be made available and the covariance matrices for the spectrum will be reported. FREYA is a work in progress with J. Randrup of LBNL. A paper for Physical Review C is in progress.
- In collaboration with LBNL, LLNL has developed a toolset for evaluating EGAF data, incorporating the Monte Carlo gamma cascade code DICEBOX from Charles University, Prague. This toolset allows systematic evaluation of the EGAF thermal neutron capture data and complements the experimental EGAF data with DICEBOX calculations for the unresolved quasi-continuum. These model calculations can then be extended to higher neutron incident energies to build complete ENDF libraries. The toolset automates this process and facilitates a more scientific approach to the evaluation methodology.
- LLNL has been developing an *ab initio* framework to describe both the low-lying structure of light nuclei and their reactions. This effort promises to provide a truly microscopic theory for reactions involving light nuclei with broader capability than other competitive methods. Current efforts are based on a groundbreaking effort to couple the *ab initio* no-core shell model (NCSM) to the resonating-group method (RGM) technique, obtaining a completely new *ab initio* approach that is capable of simultaneously describing deeply and weakly bound states; clustering effects; resonance states; and reactions on light nuclei. The first milestone of this approach was achieved in 2008 with completion of the formalism for a single-nucleon projectile, i.e. for an *ab initio* description of nucleon-nucleus scattering.
 - Phase shift results for neutron scattering on ^3H , ^4He and ^{10}Be and proton scattering on $^{3,4}\text{He}$ using realistic nucleon-nucleon potentials were published in Phys. Rev. Letters.
 - A long paper for Physical Review C, with all the technical details, will be submitted soon.
- Preceding the the above fully *ab initio* reaction theory described above, a combined *ab initio*/potential-model approach with microscopic bound-state wave functions and potential-model scattering wave functions was developed. This approach was used to calculate the S-factors of the d-t reaction and capture reactions important for astrophysics.

TUNL – Ongoing work involves the development of preequilibrium nuclear reaction models, as well as the improvement and benchmarking of the computer code PRECO. The unique strengths of this program are its ability to describe reactions with complex particles in the exit and/or entrance channel, and the comprehensive nature of the state densities, which contain the effects of shell structure, the pairing interaction and isospin conservation.

TUNL Planned Activities:

DOE funding for this activity has been discontinued.

Status:

- DOE funding for this activity was discontinued. PRECO-2006 was released to the public.

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.

BNL – We are responsible for compilation of nuclear reaction data within the USNDP. It is very important for compilers to maintain an active contact with data producers so that they have up-to-date knowledge of measurement procedures and techniques including their advantages and drawbacks along with understanding of data uncertainties. This goal can be best achieved by taking part in nuclear data measurements. BNL will do so by devoting a relatively small effort, 0.1 FTE, to collaboration primarily with the LANSCE data measurement program at LANL.

BNL Planned Activities:

Participate in $(n,n'\gamma)$ and fission neutron spectrum measurements at FIGARO at LANSCE.

Participate in the Lead-Slowing-Down Spectrometer measurements on ultra-small targets at LANSCE.

Status:

- This activity was cancelled as the NNDC staff left BNL in August 2007.

LANL -- Nuclear data for fission products are important for a number of applications. This task is related to the evaluation activity described in Section VI.B.

LANL Planned Activities:

Measure and analyze prompt neutron emission following interactions of fast neutrons with fission products such as strontium and barium

isotopes. These measurements are gated on gamma rays from (n,n'γ) reactions.

Measure the gamma-ray output from neutron-induced fission of ^{235}U , ^{238}U , and ^{239}Pu for neutron energies from 1 to 100 MeV.

Collaborators include scientists from CEA (France).

Complete analysis of gamma-ray production for neutrons on fission products ^{100}Mo and ^{130}Te with the goal of deducing partial reaction cross sections.

Complete measurement of gamma-ray production from neutrons on natural Pb and Te to provide data for background assessments in neutrino-less double beta-decay experiments (with University of South Dakota, LBNL, and LLNL).

Measure the neutron capture cross-section of $^{242\text{m}}\text{Am}$ at DANCE for neutron energies less than 200 keV.

Measure the neutron capture and fission cross sections of ^{243}Am and ^{239}Pu at DANCE for energies less than 200 keV.

Measure the neutron capture cross-section at DANCE for at least one radioactive isotope of importance to nuclear astrophysics.

Status:

- Neutron emission from iron, molybdenum and barium isotopes was measured at LANSCE/FIGARO in coincidence with gamma rays to deduce (n,n') emission spectra from isotopes.
- Measured fission neutron emission spectra for ^{239}Pu and $^{235}\text{U}(n,f)$ and with CEA (France) scientists at LANSCE/FIGARO. Incident neutron energy from 1 to 200 MeV. Data analyzed for incident neutron energies of 1-50 MeV.
- Experimental data on ^{100}Mo and ^{130}Te acquired at LANSCE/GEANIE.
- Gamma production cross sections on Pb and Te were measured, and the analysis in progress for backgrounds in double beta-decay experiments.
- Measured neutron capture cross sections of $^{242\text{m},243}\text{Am}$ for neutrons below 200 keV at LANSCE/DANCE.
- Measured $^{152}\text{Eu}(n,\gamma)$ cross section for astrophysics at LANSCE/DANCE. Data being analyzed.

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 will lead 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.

LBL 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.

LBL Planned Activities:

- Continue to perform (n, γ) cross section measurements at thermal energies in collaboration with the Budapest Research Centre.
- Complete measurements (begun in FY2007) of (n, γ) cross sections using thermal and 2.5 MeV neutrons from the LBNL neutron generator (in collaboration with NRC Negev, Israel).

Status:

- Continued measurement and analysis of thermal neutron cross sections on separated-isotope targets of H, D, Li, B, C and N at the Budapest reactor.
- Measurements performed in collaboration with NRC Negev, Israel were presented at 2007 Nuclear Science Symposium and Medical Imaging Conference in Honolulu, October 27-November 3, 2007.
- Concluded LBNL D+D neutron generator research program.

LLNL – The LLNL Physics division performs measurements in support of various laboratory applications with NNSA and other funding. Most of this work is done in collaboration with other laboratories (e.g. LANL, LBNL and TUNL) and with university collaborators supported through the Stockpile Stewardship Academic Alliance program (e.g. Yale, Univ. Richmond, etc.). The evaluation activity discussed in Section VI.B is grounded in these measurements.

LLNL Planned Activities (work completely supported from other sources):

- Neutron induced reaction measurements on one or more isomer targets.
- Perform surrogate (n,n'), (n,2n), (n, γ) and (n,f) measurements on several nuclei with programmatic and/or astrophysical importance.
- Perform neutron capture measurements with DANCE array at LANSCE in collaboration with LANL.
- Perform fission cross-section measurements with the lead slowing down spectrometer at LANSCE in collaboration with LANL.

Status:

- $^{234}\text{U}/^{236}\text{U}(\alpha,\alpha'f)$ surrogate reactions for $^{233}\text{U}(n,f)/^{235}\text{U}(n,f)$ direct reactions as a benchmark for the surrogate technique in the actinide region.
- Produced the $^{239}\text{U}(n,f)$ cross section using the two neutron ($^{18}\text{O},^{16}\text{O}$) transfer reaction on ^{234}U and ^{238}U targets and the surrogate ratio method. $^{234}\text{U}(2n,f)$ and $^{238}\text{U}(2n,f)$ are surrogate reactions for $^{235}\text{U}(n,f)$ and $^{239}\text{U}(n,f)$ respectively.

- Published measurement of the $^{241}\text{Am}(n,2n)$ reaction cross section from 7.6 MeV to 14.5 MeV in Physical Review C. Measurement of $^{241}\text{Am}(\gamma,n)$ reaction cross sections have been carried out at TUNL/HIGS to complement the (n,2n) work.
- Published measurement of ^{241}Am neutron capture cross section in Physical Review C.
- Fielded the $^{242m}\text{Am}(n,\gamma)$ cross section measurement using DANCE at LANL.

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:

Complete work on ^{186m}Re that is of relevance to the $^{187}\text{Re}/^{187}\text{Os}$ cosmo-chronometer, including modeling of the production and destruction cross-sections of the ^{186m}Re isomer and the analysis of the $^{187}\text{Re}(n,2n)^{186m}\text{Re}$ data (in collaboration with TUNL).

Assess the nuclear structure and decay data needs for astrophysical modeling work in collaboration with scientists within USNDP Astrophysics Task Force and JINA.

Status:

- Studies of structure of states above the long-lived isomer in ^{186}Re that are of relevance to the $^{187}\text{Re}/^{187}\text{Os}$ cosmo-chronometer are continuing.

BNL Planned Activities (largely done by guest scientist not funded by USNDP):

Perform systematic evaluations of neutron capture cross sections in the energy region of interest for nuclear astrophysics (neutron unresolved resonance region). Produce Maxwellian averages of these data.

USNDP support to this work will be limited to including the evaluations in appropriate databases and to providing data dissemination.

Produce Maxwellian averages for neutron capture cross sections using the ENDF/B-VII.0 library.

Status:

- ENDF/B-VII.0 Maxwellian averaged cross sections were compared with the existing evaluations by Bao et al. The differences were analyzed and independent computations were performed.

- The related web interface that includes comparison with other evaluated libraries was completed.

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:

- Continue N-N analysis to energies above 50 MeV and provide evaluated n-p capture cross-sections, rates, and covariance data.
- Complete neutron-rich fission barrier calculations, using new and improved multidimensional macro-micro fission model.
- Improve neutron capture models to provide capture cross sections for nucleosynthesis network calculations.
- Provide neutron capture cross sections on important s-process branching point nuclei.
- Provide direct/semi-direct capture cross sections on important r-process waiting point nuclei.

Status:

- Extension of the N-N analysis up to 200 MeV was not completed, but covariance data including the capture cross section were prepared in the ENDF-6 format.
- New fission barrier calculations completed. The data were published.
- New capture reaction modeling for deformed nuclei was developed.
- More than 1500 neutron capture cross section data were provided for nucleosynthesis network calculations. These data are supplementary to the nuclear reaction rate database currently available.
- Direct/semi-direct neutron capture model with the BCS theory was developed. The calculated DSD capture cross sections were included in the nucleosynthesis nuclear database.

LLNL – LLNL has a strong combined theoretical and experimental effort to determine nuclear data for various astrophysical processes.

LLNL Planned Activities:

None stated in FY2008 USNDP plan.

Status:

- The low energy nuclear experimental group (Burke, Sheets, Szielzo) has carried out three experiments this year, all with strong astrophysical relevance, namely the radiative width of the triple-alpha reaction, $^{40}\text{Ca}(\alpha,\gamma)^{44}\text{Ti}$, and $^{152}\text{Gd}(n,\gamma)^{153}\text{Gd}$. The first,

coupled with $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$, is the crucial reaction that determines the C/O ratio in stars. The second is the principal production mechanism of the radioisotope ^{44}Ti , a diagnostic of core collapse conditions in SNII. The last is an important s-process branch point. To determine the low-energy (n, γ) cross section we utilized the surrogate reaction technique via inelastic scattering of protons on ^{154}Gd to generate the desired $^{154}\text{Gd}^*$ compound nucleus. The validity of this approach is confirmed by reproducing the directly measured ^{155}Gd and ^{157}Gd (n, γ) cross sections.

- Hoffman, Pruet, and Fisker continued their research on nucleosynthesis in the early proton-rich neutrino wind, making an extensive survey of the nuclear uncertainties affecting ^{92}Mo synthesis. They showed that if the vp-process is responsible for the solar $^{92}\text{Mo}/^{94}\text{Mo}$ ratio and ^{92}Mo is co-produced with the other light p-nuclei of Sr, Ru, and Pd, the ^{93}Rh proton separation energy must be 1.64 +/- 0.1 MeV (within the current uncertainty range, but a factor of five more precise). Three groups (ANL, Jyvaskyla, and GSI) have now measured the critical masses affecting $^{92,94}\text{Mo}$ synthesis using Penning Traps and find very nearly the same value ($S_p(^{93}\text{Rh})=2.00$ +/- 0.08 MeV) as in the semi-empirical mass survey (2.05 +/- 0.5 MeV, Audi & Wapstra 2003), leading to the realization that proton-rich neutrino winds cannot be solely responsible for the current solar abundance ratio. The work was recently published in Ap. J. Letters. Fisker was a co-author on the two mass measurements.
- Hoffman has studied the theoretical uncertainties in the statistical model calculation of $^{59}\text{Fe}(n,\gamma)^{60}\text{Fe}$ and $^{60}\text{Fe}(n,\gamma)^{61}\text{Fe}$ which affect the stellar production of ^{60}Fe and the observed $^{26}\text{Al}/^{60}\text{Fe}$ ratio. Hoffman's cross section, 10.6 mb at 25 keV, is in excellent agreement with the first measurement of $^{60}\text{Fe}(n,\gamma)^{61}\text{Fe}$. A comparison with the two previous capture cross section calculations and the impact on ^{60}Fe synthesis was also discussed. Results are being submitted to ApJ.

McMaster -- Pending the approval of a submitted (in December 2006) DOE grant (for 2007-2010) proposal, the evaluation of nuclear astrophysics data is expected to complement the on-going experimental program of direct measurements of radiative capture cross sections and particle-transfer experiments using radioactive ion beam facilities at TRIUMF, NSCL, RIKEN and ANL.

McMaster Planned Activities:

Specific reactions planned for evaluation in FY2008: $^{19}\text{Ne}(p,\gamma)^{20}\text{Na}$
and $^{30}\text{S}(\alpha,p)^{33}\text{Cl}$.

Status:

- We had originally anticipated new data on the two reactions above, but the radioactive ion beam development required for these experiments is still pending. In the last fiscal year, our efforts have focused on evaluating the $^{21}\text{Na}(p,\gamma)^{22}\text{Mg}$ and $^{40}\text{Ca}(\alpha,\gamma)^{44}\text{Ti}$ reaction rates, in light of the availability of recent new data from both reaction studies and mass measurements. These reactions are important in models of novae and supernovae, respectively.
- Both evaluations have been completed and papers have been published containing the new evaluations of these reaction rates. These have also been submitted to Nuclear Astrophysics database at ORNL for inclusion in www.nuastrodata.org. It is expected that these submissions will be reviewed in FY2009.

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

ORNL Planned Activities:

Complete evaluations of proton capture on ^{17}O and the $^{17}\text{O}(p,\alpha)^{14}\text{N}$ reaction for novae and red giant stars; this will form part of a PhD thesis.

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 ORNL's Holifield Radioactive Ion Beam Facility.

Extract spectroscopic information (excitation energies, spectroscopic factors, spins, parities, ANCs) on nuclei near the N=82 closed shell – ^{131}Sn , ^{133}Sn , ^{135}Te - from transfer reaction measurements on radioactive Sn and Te nuclei. This information is important for modeling the r-process in supernovae.

Status:

- Work on $^{18}\text{F}(p,\alpha)^{15}\text{O}$ and $^{18}\text{F}(p,\gamma)^{19}\text{Ne}$ continuing, with a new round of experiments and associated evaluations, to improve our understanding novae and X-ray bursts.
- First direct measurement of gamma width of crucial ^{18}Ne state that dominates the $^{17}\text{F} + p$ fusion rate in stellar explosions made at ORNL HRIBF with a radioactive ^{17}F beam. Work coupled with data assessment and element synthesis calculations. Paper submitted for publication.
- Spectroscopic factors determined for ^{16}N levels from measurement of $^{15}\text{N}(d,p)$ at ORNL, important for red giant star element synthesis. Paper published on this work.
- New information -- angular distributions, excitation energies, and spectroscopic factors -- extracted from (d,p) measurements on ^{130}Sn , ^{132}Sn , and ^{134}Te ; papers in preparation.

- New information – spin-parity and widths – determined for levels in ^{26}Si and ^{34}Ar crucial for explosive burning in novae and X-ray bursts; assessments are under way and will be part of a Ph.D. thesis.

H. Reaction Data for RIA Target Design

Rare Isotope Accelerator facility design needs high-quality nuclear reaction data for target design. LANL will collaborate in order to provide key reaction cross-sections using theory calculations and measurements to evaluate the data.

LANL Planned Activities:

We aim to maintain important collaboration connections with the RIA community because of its importance in nuclear science, but effort is limited because of budget restrictions. However, we will continue to maintain a presence in the RIA planning community via participation in RIA meetings and workshops.

Status:

- Because this activity was modest, our effort in FY2008 was very limited.

Appendix A

Nuclear Data Activities Funded from Sources outside the Nuclear Data Program (Report FY2008)

ANL – Additional support for the nuclear data work at Argonne (funding of a part-time post-doc) comes from ANL LDRD project entitled “Development of Argonne Total Absorption Gamma-ray Spectrometer for Advanced Fuel Cycle Applications”. This is a collaborative project with scientists from the ANL Physics Division that will expire at the end of FY2009.

BNL – Additional support for the nuclear data work at the National Nuclear Data Center comes from three sources:

1. Elsevier supports the production of computer-generated photo-ready copy of manuscripts for the Nuclear Data Sheets.
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.
3. The GNEP Data Adjustment project, funded by DOE-NE, supports the NNDC work on development of neutron cross section covariances for fast advanced burner reactors.

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.

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.

2. Advanced Fuel Cycle (AFC). This supports the development of improved nuclear data important for transmutation in the fast neutron energy region, as well as high-energy spallation models important for describing processes in the spallation target. Recent focuses have been improved ENDF data on minor actinides (ATW fuel), and lead and bismuth (target/coolant), as well as better intra-nuclear cascade codes for modeling neutron production and radionuclide production in the spallation target. This program also supports experimental nuclear reaction measurements at LANSCE for both fission and capture cross sections.
3. Nuclear criticality safety. This funding supports improved nuclear data important in criticality safety studies, such as uranium isotopes, as well as data on chlorine, aluminum, etc. Data testing using critical assemblies and NJOY processing code development is also funded by the program.
4. LANL LDRD. There are 3 LANL LDRD projects that support nuclear reaction data measurements.
5. 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.
6. SciDAC (Scientific Discovery through Advanced Computing). This funding supports advanced nuclear reaction modeling based on microscopic nuclear structure theory (universal nuclear energy density functional).

LBL – LDRD funding for a project on the measurement of cross sections for advanced fuel cycles provided partial support for one of our structure evaluators, enabling retention of evaluation capability while addressing laboratory research priorities. Analysis of $^{238}\text{U}(^3\text{He},\text{tf})$ cross section data measured in collaboration with LLNL and University of Richmond was completed, and LBNL provided the lead author on the resulting paper submitted to Phys. Rev. C. This reaction serves as a surrogate for the $^{237}\text{Np}(n,\text{f})$ reaction which is of relevance to Advanced Fuel Cycle data needs. The work benchmarked the experimental procedures at LBNL using a previously-measured reaction, with a view to employing the surrogate reaction technique to obtain vital (n,f) cross section data for cases where direct experimental measurements are not feasible. USDOE Low-energy Nuclear Physics funds provided about 0.3 FTE support for ENSDF mass chain evaluation already mentioned in this report.

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/DP/ASC funds data validation and verification efforts, development of *ab-initio* structure and reaction methods and development of theory supporting the surrogate measurement campaign for unstable actinides.
2. NNSA/DP/SC funds experimental campaigns for unstable actinides, including development of the Time Projection Chamber at LLNL for new ^{239}Pu fission cross section measurements.
3. NNSA/NA-22 and DHS fund experimental work on the structure of Pu and U, including the recent discovery of strong electromagnetic resonances in these nuclei and the development of methods of improved calculations of neutron-capture spectra.
4. DHS funds fission-multiplicity experiments and theory development.
5. Two separate SciDAC grants support (i) reaction theory development and (ii) nuclear astrophysics.
6. LDRD supports experiments for an improved measurement of the triple alpha reaction, development of nuclear experimental techniques on laser implosion platforms, experiments to measure $^{40}\text{Ca}(\alpha,\gamma)$, and *ab-initio* reaction theory.

McMaster – The nuclear data effort receives 0.4 FTE support from the Canadian research agency to evaluate A-chains/nuclides for ENSDF and to train/supervise summer students for compilation of experimental nuclear structure data for XUNDL.

NIST – A variety of sources support nuclear data activities:

1. The Nuclear Data Verification and Standardization program has funding through the Commerce Department (NIST). This provides about half of the total support for the program.
2. NIST provides 1 FTE for interferometry work, which has yielded coherent scattering lengths (which provide scattering data) needed for neutron cross-section evaluations.
3. NSF provided 1 FTE for a graduate student to work on the interferometry experiments cited above.
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.

Appendix B

USNDP Organization (Report FY2008)

Coordinating Committee

1. P. Oblozinsky, BNL, chair
2. C. Baglin, LBNL, *chair - Structure WG*
3. D. Brown, LLNL
4. A. Carlson, NIST
5. A. Chen (B. Singh), McMaster
6. R. Firestone, LBNL
7. T. Kawano, LANL, *chair - Reaction WG*
8. J. Kelley, TUNL
9. F.G. Kondev, ANL
10. M. Smith, ORNL

Working Groups

- Nuclear Structure and Decay Data (chair C. Baglin, LBNL)
- Nuclear Reaction Data (chair T. Kawano, LANL)

Task Forces

- Nuclear Data for Astrophysics (chair M. Smith, ORNL)
- Nuclear Data for Homeland Security (chair D. Brown, LLNL)

