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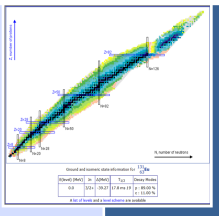

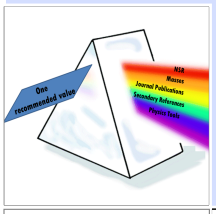

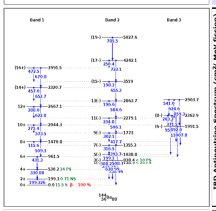

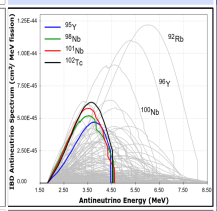

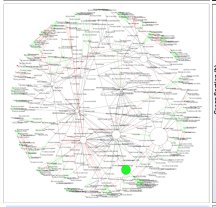

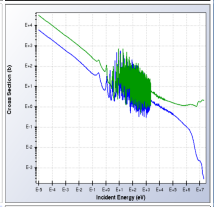

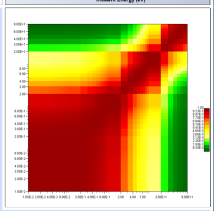

United States Nuclear Data Program

Annual Report for FY2021

This document describes the activities including related metrics performed by the US Nuclear Data Program members during Fiscal Year 2021.

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www.nndc.bnl.gov/usndp

BNL

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Shaofei Zhu

It is with infinite sadness that we write about Shaofei Zhu's passing on Monday, November 1, 2021. At the time of his death, Shaofei was a physicist working at the National Nuclear Data Center at Brookhaven National Laboratory, specializing in nuclear structure and decay, in particular, gamma-ray spectroscopy and evaluation of nuclear data.

Shaofei was born in China, obtained his B.S. degree from the University of Science and Technology of China in 1992. He came to the US for graduate school, obtaining a Ph.D. in physics from the University of Notre Dame in 2004. During the 2004-2019 period, Shaofei worked at Argonne National Laboratory, first as a post-doc and then as staff. Shaofei joined Brookhaven National Laboratory in May of 2019.

Shaofei was a dedicated professional and fantastic team player who always found time to help and mentor colleagues. His upbeat and friendly personality was cherished by all who were lucky to have known him at the professional and personal level.

I. Introduction

The US Nuclear Data Program (USNDP) Annual Report for Fiscal Year 2021 (FY21) summarizes the work of USNDP for the period of October 1, 2020 through September 30, 2021, with respect to the Work Plan for FY21 that was prepared in 2019. The Work Plan and Final Report for USNDP are prepared for the DOE Office of Science, Office of Nuclear Physics. The support for the nuclear data activity from sources outside the nuclear data program is described in the staffing table and in Appendix A. This leverage amounts to about 3.24 FTE scientific, to be compared with 25.095 FTEs at USNDP units funded by the DOE Office of Science, Office of Nuclear Physics. Since it is often difficult to separate accomplishments funded by various sources, some of the work reported in the present report was accomplished with nuclear data program support leveraged by other funding.

FY21 was the 22nd year in which the USNDP has operated under a Work Plan developed by the program participants. The program continued to carry out important work in support of the DOE mission. The work balances the ongoing collecting, analyzing, and archiving of nuclear physics information critical to basic nuclear research and to the development and improvement of nuclear technologies with the electronic distribution of this information to users in a timely and easily accessible manner. The present section of the report consists of activity summaries for the major components of the USNDP. This is followed by an updated staff level assignment table that reflects the final distribution of effort among the tasks carried out during FY21. Then, we continue with the detailed status of work performed during FY21.

In terms of personnel changes, the USNDP has undergone several changes in FY21:

- L. Bernstein transferred from LBNL to a joint UC Berkeley/LBNL appointment,
- D. Brown became the NNDC Head and now chairs both the USNDP and Cross Section Evaluation Working Group (CSEWG),
- Elizabeth McCutchan became the NNDC Deputy Head,
- A. Lauer-Coles joined the NNDC as a post-doc in May 2021,
- R. Lorek left the NNDC to join NASA as a post-doc in July 2021,
- D. Mason became a junior staff member at the NNDC in August 2021,
- C. Morse joined the NNDC as scientific staff in March 2021,
- A. Sonzogni was promoted from NNDC Head to the Chair of the Nuclear Science and Technology Department at BNL,
- P. Vincente-Valdez graduated from UC Berkeley with a Ph.D. in Nuclear Engineering, and
- S. Zhu passed away in November 2021 (in FY22)

Table 1 summarizes the USNDP metrics since 2001. Table 2 shows the breakdown of the metrics by laboratory for the reported fiscal year and comparison with the previous fiscal year. The tables are followed by a definition of each metric and any comments pertaining to the metrics.

Table 1: Summary of the USNDP funding and metrics.

Fiscal year	USNDP funding ($K)	Change (%)	Compilations	Evaluations	Disseminations	Articles	Invited talks
2001			7,139	334	667	25	22
2002	4,890		6,159	300	799	40	22
2003	4,932	+0.9	4,975	260	966	40	23
2004	5,015	+1.7	6,241	276	1,212	36	43
2005	5,437	+8.4	6,623	422	1,642	59	42
2006	5,099	-6.6	4,936	318	1,863	60	48
2007	5,841	+14.6	5,355	366	2,239	56	51
2008	5,967	+2.2	5,104	385	2,996	72	68
2009	6,267	+5.0	4,047	400	3,294	61	56
2010	6,549	+4.5	4,662	395	2,843	83	51
2011	6,534	-0.2	4,662	479	3,252	96	67
2012	6,785	+3.8	5,221	209	3,013	90	48
2013	6,249*	-7.9	4,925	282	3,447	84	79
2014	7,032*	+12.5	3,738	166	3,411	107	81
2015	7,381*	+5.0	4,949	271	4,246	98	50
2016	7,597*	+2.9	3,936	375	4,655	82	72
2017	6,953	-8.5	3,684	404	4,730	95	51
2018	8,496[a]	+22.2	4,097	221	4,722	79	58
2019	8,797[b]	+3.5	3,663	203	5,148	67	60
2020	9,344[c]	+6.2	3,603	159	5,678	63	49
2021	9,435[d]	+0.99	5,380	273	7,297	71	59

*: It includes $500K of Early Career Award (LANL).

a: It includes the following (a) FIRE collaboration funding $100 (LLNL), (b) LAB17 call funding: $325K (ANL), $220K (LANL), (c) LAB18 call funding $26K (ANL), $282K (BNL), $120K (LANL), $75K (LBNL), $100K (LLNL), $372K (ORNL).

b: It includes the following (a) FIRE collaboration funding $100 (LLNL), (b) LAB17 call funding: $325K (ANL), $220K (LANL), (c) LAB18 call funding $27K (ANL), $289K (BNL), $120K (LANL), $75K (LBNL), $50K (LLNL), $373K (ORNL), (d) WANDA organization: $25K (ORNL).

c: It includes the following (a) FIRE collaboration funding $100 (LLNL); (b) LAB calls funding: $354K (ANL), $619K (BNL), $120K (LANL), $75K (LBNL), $50K (LLNL) and $375K (ORNL); (c) WANDA organization: $150K (ORNL) and $20K (LLNL).

d: It includes the following (a) FIRE collaboration funding $100 (LLNL); (b) LAB calls funding: $884K (ANL), $717K (BNL), and $173K (ORNL).

Table 2: USNDP metrics in the last two fiscal years, numbers from the previous fiscal year are shown for comparison.

Laboratory	Compilations		Evaluations		Disseminations (in thousands)		Articles		Invited Talks	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
ANL	0	0	13	13	-	-	16	14	5	6
BNL*	3,493	5,291	88	181.1	5,138	5,426.5	32	22	21	16
LANL	-	-	3.4	0.71	-	-	8	8	9	13
LBNL	0	0	0	24.5	-	7.5	14	19	4	12
LLNL	-	-	0.1	0	-	-	1	1	2	6
MSU	61	50	26.5	20	-	-	2	4	2	1
ORNL	-	-	9	8	460[&]	1,979.5[+]	4	4	6	5
TAMU	-	3	17	17	-	-	3	5	0	0
TUNL	47	36	2	3	80	40	1	1	0	0
Total	3,603	5,380	159	273	5,678	7,453.5	63	71	49	59

*: BNL compilations consist of (a) 4,590 NSR articles, including keywords for 2,872 of them; (b) 434 articles for EXFOR; (c) 267 articles encompassing 552 XUNDL datasets. BNL evaluations consist of (a) 172 nuclides for ENSDF and 9.14 for ENDF/B. For the remaining groups, all compilations are for XUNDL, while all evaluations are either ENSDF (ANL, LBNL, MSU, ORNL and TAMU) or ENDF/B (LANL, LLNL).

&: A considerable increase in web traffic was observed at the ORNL web site, which is not reflected in this number.

+: The sizeable increase in ORNL web transactions represents the addition of several new features, including improved handling of large numbers of input nuclear data files and the capability to run Monte Carlo astrophysical simulations with these libraries.

Metric definitions and comments:

1. **Compilations**: The sum of the new entries added to the USNDP bibliographic (NSR - articles) and experimental databases (EXFOR - reactions, XUNDL - structure data sets). The compilation activities are on a healthy situation, and these databases are updated regularly with newly published material.
2. **Evaluations**: The sum of new evaluations submitted or accepted for inclusion in the USNDP evaluated nuclear databases. For ENSDF, it is the number of evaluated nuclides, while for ENDF, it is the number of evaluated reactions/covariances. There were 263 ENSDF evaluations and 9.14 ENDF/B evaluations submitted. The number of ENSDF evaluations remains well below the number needed, about 340, to evaluate each of the ENSDF nuclides on average every 10 years.
3. **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 accessed is not tallied. The number of database retrievals has increased significantly from last year's value due to new features available from ORNL's webservices.
4. **Articles**: The number of articles published in refereed journals. The number of articles per FTE has remained relatively constant in the last few years, but the number of FTEs in the USNDP has grown. A selected list of articles published is given in the Appendix C.

5. **Invited talks**: The number of presentations given at the explicit invitation of the organizers of conferences, symposia, workshops, and training courses. The number of invited talks has not changed significantly from last year's value.

II. Network Coordination and Data Dissemination

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

National and International Coordination

The NNDC, while serving as the secretariat for the program, has prepared the Work Plan for this fiscal year in cooperation with the members of the Coordinating Committee. The NNDC Head serves as the chair of the USNDP Coordinating Committee, which consists of the Principal Investigators from each of the participating group and chairs the annual meeting of the program held at BNL. A representative from LANL chairs the Nuclear Reaction Data Working Group, and a representative from TUNL chairs the Nuclear Structure Working Group. ORNL chairs the Astrophysics Task Force.

On February 9, 2021, the DOE Office of Nuclear Physics conducted its annual Budget Briefing. Lee Bernstein, David Brown, Jun Chen, Lynne Ecker, John Kelley, Filip Kondev, Hye-Young Lee, Elizabeth McCutchan, Ninel Nica, Michael Smith, Alejandro Sonzogni and Ian Thompson represented USNDP and made the case for the FY23 funding.

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

The NNDC continues to chair the Cross Section Evaluation Working Group (CSEWG), which produces the ENDF/B evaluated nuclear data library for nuclear science and applied nuclear technology use. Due to the ongoing COVID-19 pandemic, the 2020 CSEWG meeting was held virtually but hosted by BNL. The major topics of the CSEWG meeting was feedback on the recently released ENDF/B-VIII.0 library and next release of the VIII.1 version, now scheduled for February 2024. Additionally, there were presentations about the fission yield evaluation project funded by NA-22.

The USNDP also continues to play a leading role in the annual Workshop for Applied Nuclear Data Activities (WANDA) conference series, with the inaugural workshop held in Washington, DC in 2019 organized by LBNL. WANDA 2021 was held virtually with several USNDP members serving as speakers and session organizers.

USNDP Databases

The NNDC operates several Dell servers running the Linux operating system to support its compilation, evaluation, database maintenance, and information dissemination functions. These computers archive and serve the nuclear data produced by USNDP and the data obtained by other national and international collaborations. In addition, the NNDC maintains the collaboration GitLab server that facilitates data and

codes development and keeps track of changes. The NNDC maintains seven nuclear physics databases for USNDP, which were updated continuously this fiscal year with new and revised information from efforts of the NNDC, USNDP and international collaborators. Distributions of all or parts of these databases have been made to national and international collaborators as scheduled.

Data Dissemination

There were 7,297 million database retrievals this fiscal year, about 29% higher than the number of retrievals in the previous year, reflecting increased traffic to ORNL. Most of the retrievals, 72%, were from the NNDC web site, with NuDat as the most popular product.

Major Publications

USNDP continues to publish the refereed journal Nuclear Data Sheet: eight issues were published this fiscal year with seven dedicated to ENSDF evaluations, and one issue devoted to nuclear reactions.

III. Nuclear Structure and Decay Data

The nuclear structure working group emphasizes the evaluation of measured nuclear structure and decay properties for all isotopes. These data are maintained at the NNDC in the Evaluated Nuclear Structure Data File (ENSDF). Production of ENSDF is an international effort operating under the auspices of the IAEA Nuclear Structure & Decay Data (NSDD) network. ENSDF is an important source of information for derivative databases and applications, including NuDat, Nuclear Wallet Cards, RIPL, MIRD and ENDF/B. Evaluations are published as peer-reviewed articles in the Nuclear Data Sheets. The Nuclear Science Reference (NSR) and Experimental Unevaluated Nuclear Structure Data List (XUNDL) databases have been kept current. The combination of ENSDF and XUNDL databases represents a nearly complete literature coverage of experimental nuclear structure data, which is a salient feature of these databases.

In August 2021, a breakout session related to Nuclear Data was part of the Low-Energy Community Meeting; the session featured several presentations from researchers associated with the USNDP and others who are active in the low-energy nuclear physics community.

Status of ENSDF

ENSDF evaluations submitted to the database increased considerably over the previous year, with 263 nuclide submissions compared with 159 in FY2020. The evaluations were a combination of nuclides resulting from mass chain evaluations (13 mass chains in total) along with single nuclide submissions.

All evaluations were received from USNDP-funded centers, marking a second year with no contributions from the international community. Per the USNDP Nuclear Data Advisory Committee (NDAC) recommendations, USNDP leadership reached out to International Union of Pure and Applied Physics (IUPAP) and presented a case for more international involvement in ENSDF at their annual meeting.

A Nuclear Data Inter-Agency Working Group (NDIAWG)-funded effort to modernize the ENSDF database was initiated in FY21. The first year is mainly devoted to developing the new structure database and converting the previous 80-column ASCII format. Two dedicated workshops were held to gather input: a 4-day meeting in April 2021 with just ENSDF evaluators and a 1-day workshop tied to the Low-Energy Community Meeting in August 2021 to gather feedback from the user community.

Status of XUNDL

Based on regular scanning of nuclear physics journals, 686 datasets were compiled from 353 articles. The project to compile and carry out physics checks on the data from nuclear structure manuscripts submitted to Phys. Rev. C and European Physical Journal A continues.

Status of NSR

In FY2021, 4,590 new articles were added to the NSR database. USNDP contributions are from B. Pritychenko (manager), J. Totans, B. Singh, D. Symochko (NNDC) with international input from V. Zerkin and L. Vrapcenjak (IAEA), and A. Rodionov and G.I. Shulyak (PNPI/Leningrad). The database is current and in good shape. The number of NSR web retrievals was 334,383.

Horizontal Evaluations and Other Data Related Activities

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

- IAEA-CRP evaluation of fission yields: A. Sonzogni, A. Mattera, E. McCutchan, B. Pritychenko, T. Kawano, F. Kondev – continuing.
- IAEA-led activities on improving ENSDF codes: J. Chen, F. Kondev, B. Singh – continuing.
- IAEA-ICTP organized workshops: S. Basunia, E. McCutchan, F. Kondev, B. Singh.
- The Atomic Mass Evaluation (AME) and the evaluation of basic nuclear physics properties for ground states and isomers (NUBASE): F. Kondev – continuing with release of AME 2020 and NUBASE2020.
- Update of r0 radius parameter and revision of ALPHAD-radD analysis code: B. Singh. ALPHAD and ALPHAD-RadD codes available in November 2020; even-even r0 parameter evaluation published in NDS (2020Si16).
- IAEA-led decay data library for monitoring applications: J. Chen, F. Kondev, B. Singh, J. Tuli – continuing.
- Compilation of current papers on mass measurements on a yearly basis and make data file available on nuclearmasses.org: B. Singh, M. Smith – continuing.
- IAEA-CRP on Delayed Neutron Emission Probabilities: Reference database at IAEA-NDS: B. Singh, E. McCutchan, A. Sonzogni – completed, two articles published in NDS. Updates for new papers in August 2020 to present in progress: B. Singh.
- X-ray/γ-ray coincidence database – LBNL/DTRA: A. Hurst – continuing.
- WalletCraft: Object-oriented database for ground and long-lived isomeric properties: A. Hayes, E. McCutchan, B. Shu, A. Sonzogni – continuing.
- Atlas of Isomers project**:** B. Singh – update of 2015Ja04 Atlas has been completed with the addition of new isomers in literature from 2015 to 2021 and re-evaluation of half-lives and isomer energies. A paper is in preparation for submission in February 2022.
- Update of 1998Si17 Review of log *ft* values: B. Singh – all the beta decay schemes in the December 2021 version of ENSDF and significant portion of newer literature updated for AME-2020 Q values and 2021 literature. All the files have been run through new BetaShape code for log *ft* values. Filtering codes developed at Dresden have been executed. A paper is under preparation for submission in March 2022.
- Update of 2000Am02 magnetic dipole rotational bands: B. Singh – this work has been completed. A paper is under preparation for submission in February 2022
- B(E2) project for first 2+ and 4+ states of all the even-even nuclei: B. Pritychenko and B. Singh. Work on the first 2+ states was published in 2016Pr01: ADNDT. The on-going project is an update of the 2016 work as well as first evaluation of B(E2) values for the first 4+ to first 2+ states.
- Gamma-ray transition probabilities for all experimentally known multipolarities for all the nuclei: J. Chen and B. Singh – update of Endt's work of the 70's. This project has started recently and will take two-three years to complete.

Status of ENSDF Codes

Jun Chen continues developing new analysis and utility codes used by ENSDF evaluators, and he is implementing modern programming for legacy codes.

Updates continue for the McMaster-MSU JAVA-NDS code that has been used both to produce print-ready documents for the Nuclear Data Sheets and for retrievals of ENSDF data sets at the NNDC website.
The Java toolkit ConsistencyCheck has been developed and completed to ensure evaluation consistency and facilitate evaluation process, and updates and improvements for this code continues.

Java-RULER, a replacement for the legacy FORTRAN RULER program, has been developed. The utility code is used for calculating transition strengths. Updates include an improved Monte Carlo approach for error propagation for large and asymmetric uncertainties.

A new Java code called GLSC (Gamma to Level Scheme Computation) has been developed to replace the legacy GABS and GTOL codes. The Java code has improvements and offers new interactive features for fitting gammas in a level scheme, for calculating level feedings, and for calculating absolute gamma emission probabilities within decay datasets.

The AME-NUBASE viewer has been developed to provide easy and customized retrieval of AME (Atomic Mass Evaluation) and NUBASE (evaluation of ground-state and isomer properties) entries and also to automatically update all Q records in the adopted datasets and all parent Q values in the decay datasets in an input ENSDF file with the latest AME values.

Other new utility and analysis codes that have been implemented and released are: KeynumberCheck for checking NSR keynumbers in ENSDF datasets and Excel2ENSDF for converting an Excel table to an ENSDF dataset. Discussions during the USNDP meeting have motivated updates in the codes and the process for code distribution. New developments are underway.

IV. Nuclear Reaction Data

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

In FY21, the continued effort on improving nuclear reaction modeling has provided the unified, consistent description of the couple-channel formalism and statistical Hauser-Feshbach nuclear reaction theories, which, in particular, impacts strongly deformed target nuclei. This improved calculation on the inelastic scattering cross section of ^{238}U was demonstrated by better agreement with available experimental datasets. Regarding the long-standing problem of "too soft Prompt Fission Neutron Spectra (PFNS)" when compared with experimental data, we found two important components in the Hauser-Feshbach Fission Fragment Decay (HF^{3}D) model. Incorporating the wider fission fragment distribution than the experimentally reported data produced more consistent results on not only PFNS, but also other fission observables, such as cumulative fission product yields, the prompt neutron multiplicity, and the beta-delayed neutron multiplicity. The other discovery was the impact of the non-statistical nature of the spin distribution in low-lying levels hinders the outgoing neutron emission at high energies.

The experimental differential cross sections on ^{16}O(n,α)^{13}C reaction were finalized based on the measurements performed using LENZ (Low Energy NZ instrument) at the Los Alamos Neutron Science Center (LANSCE). Based on this work, angular distributions on reaction channels of (n,α_0) and (n,α_2+α_3) were deduced up to 12 MeV in neutron energy. The (n,α_0) cross sections agree well with ENDF/B-VIII.0 up to 6 MeV, and above this the current angular distributions suggest a new evaluation in particular by including newly available experimental datasets from ^{13}C(α,n) reaction studies.

The two software packages to support the USNDP and its community were released as open source by LANL. One is the ENDF-6 data interface and nuclear data evaluation assist code, DeCE (https://github.com/toshihikokawano/DeCE) and the other is to convert ENSDF into other application-specific formats, such as RIPL, CENS (https://github.com/toshihikokawano/CENS).

Finally, the USNDP was quite active in providing new evaluations. The article "Newly Evaluated Neutron Reaction Data on Chromium Isotopes" was published in the Nuclear Data Sheets, Volume 173, March–April 2021, Pages 1-41, detailing the new evaluations of stable chromium isotopes, led by Gustavo Nobre, in a collaboration between BNL, ORNL, IAEA, and JSI. Chromium is an important structure material present in stainless steel. This set of evaluations, ranging from thermal energy up to 20 MeV, consisted of updates to the thermal values, together with an improved R-matrix analysis of the resonance parameters characterizing the cluster of large s-wave resonances for ^{50,53}Cr isotopes, were performed. This dramatically improved a long-standing issue seen in some critical benchmarks sensitive to chromium. In the intermediate- and high-energy range up to 20 MeV, the evaluation methodology used statistical nuclear reaction models implemented in the EMPIRE code within the Hauser-Feshbach framework to evaluate the reaction cross sections and angular distributions. A significant improved performance in comparison with previous evaluations was also seen in the Oktavian shielding benchmark used to judge deep penetration performance with a 14-MeV D-T neutron source. Additionally, in an effort led by Matteo

Vorabbi, a new evaluation of ^{86}Kr was developed. The ^{86}Kr isotope is used as a diagnostic tool to measure the neutron flux produced by fusion reactions at the National Ignition Facility at LLNL. Being chemically inert, the krypton isotope can be implanted directly into the fuel capsule, and the reaction products can be measured to determine the flux of fusion neutrons. In this work, experimental data on the neutron production, radiative capture, inelastic scattering, and total cross sections of ^{86}Kr were used in conjunction with the fast region nuclear reaction code EMPIRE and a new resonance-region evaluation to produce a new evaluation of neutron-induced reactions on ^{86}Kr. With the reaction models and corrections to the structure of ^{86}Kr, the evaluated cross sections matched the experimental data. An article detailing this work, "Evaluation of Kr Cross Sections for Use in Fusion Diagnostics," has been submitted to the Nuclear Data Sheets for publication (manuscript found at arXiv:2109.08178). Both chromium and krypton evaluations have been submitted to the ENDF library to be reviewed and considered for inclusion in the upcoming ENDF/B-VIII.1 release in 2024.

Nuclear Astrophysics Highlights

The ENDF/B-VIII library of evaluated cross sections was used by BNL to generate thermonuclear reaction rates, which can be used in simulations of the synthesis of heavy elements via the slow neutron capture process. These s-process abundances can, by subtraction from solar abundances, be used to infer the contribution to heavy solar abundances synthesized via the rapid neutron capture process in supernova and neutron star mergers. This work was published in FY2021 in the Journal of Physics G Letters.

Neutron capture on 16O was studied theoretically using input from a global RMF-based nuclear structure model. This approach may be useful for global predictions of neutron capture cross sections needed for studies of the r-process (published in Eur. Phys. J. A). In another study, an analysis of levels in 21Na was used to determine an improved astrophysical rate for the 17F(alpha,p)20Ne reaction at X-ray burst temperatures (published in Phys Rev. C).

Additional Highlights

NuDat3 Is Live!

NuDat is a web application that allows users to search and plot nuclear structure and nuclear decay data interactively. NuDat was developed by the Nuclear Data Center (NNDC) at Brookhaven National Laboratory in the early 2000s. It provides an interface between web users and several databases containing nuclear structure, nuclear decay, and some neutron-induced nuclear reaction information. It is by far the most used application of the NNDC web services, with over four million retrievals in FY21.

Despite its high usage and popularity among many user communities, NuDat was still making use of 15-year-old web technology. In January 2021, the NNDC began a project to modernize NuDat, led by a BNL intern Donnie Mason. The project continued through the summer, with the internship converting to the DOE-funded Science Undergraduate Laboratory Internship (SULI) program. A beta version of NuDat3 was released at the end of FY21 along with Donnie Mason being hired as a Technology Analyst at the NNDC.

New web technology gives NuDat3 a host of new features as shown in Figure 1. For the interactive chart of nuclides, some additions include: (i) smooth pan and zoom using intuitive gestures, (ii) a movable current nucleus display with a search field and a zoom to slider, (iii) added ability to filter by ground and isomeric state properties, (iv) synchronized 1-D plots adjacent to the current chart view, and (v) options to export data, such as CSV, PNG, or a shareable link.

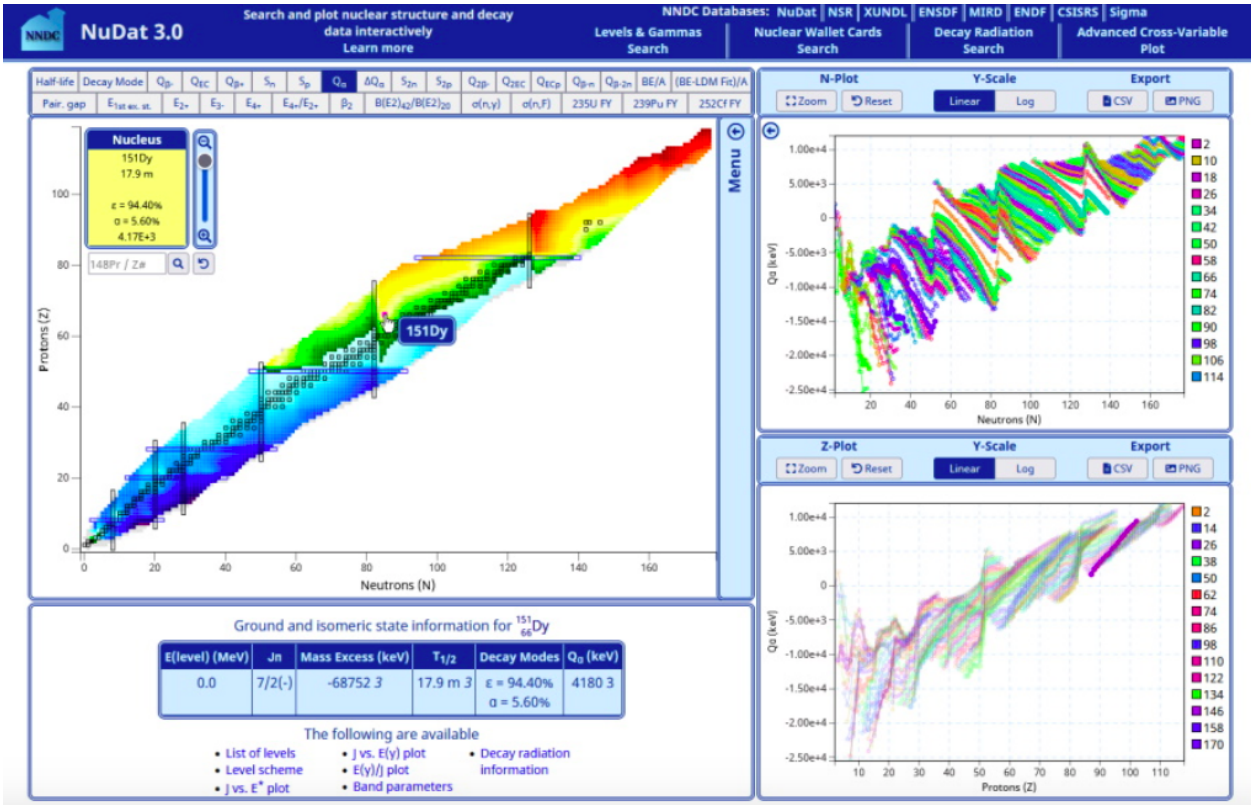


Figure 1: Screenshot of NuDat3 showing the interactive chart of nuclides (top left), current nucleus display (bottom left), and two plots synchronized to the main chart of nuclides (top & bottom right).

AME2020 and NUBASES2020

The mass of the nucleus provides the nuclear binding energy, a fundamental property that is indispensable for the study of nuclear structure, stellar nucleosynthesis and neutron-star composition, as well as atomic and weak-interaction physics. Together with other basic nuclear properties for the ground and isomeric states, such as excitation energies (for excited isomers), quantum numbers, half-lives, decay branches and their intensities, these carefully crafted nuclear data are important to both the basic nuclear science program and to many practical applications, and they are crucial input to the main USNDP databases, such as ENSDF and ENDF, which is excellent testimony to their relevance. The new evaluations of atomic masses (AME2020) and basic nuclear physics properties for ground states and isomers (NUBASE2020) were published in March 2021 (https://iopscience.iop.org/issue/1674-1137/45/3).

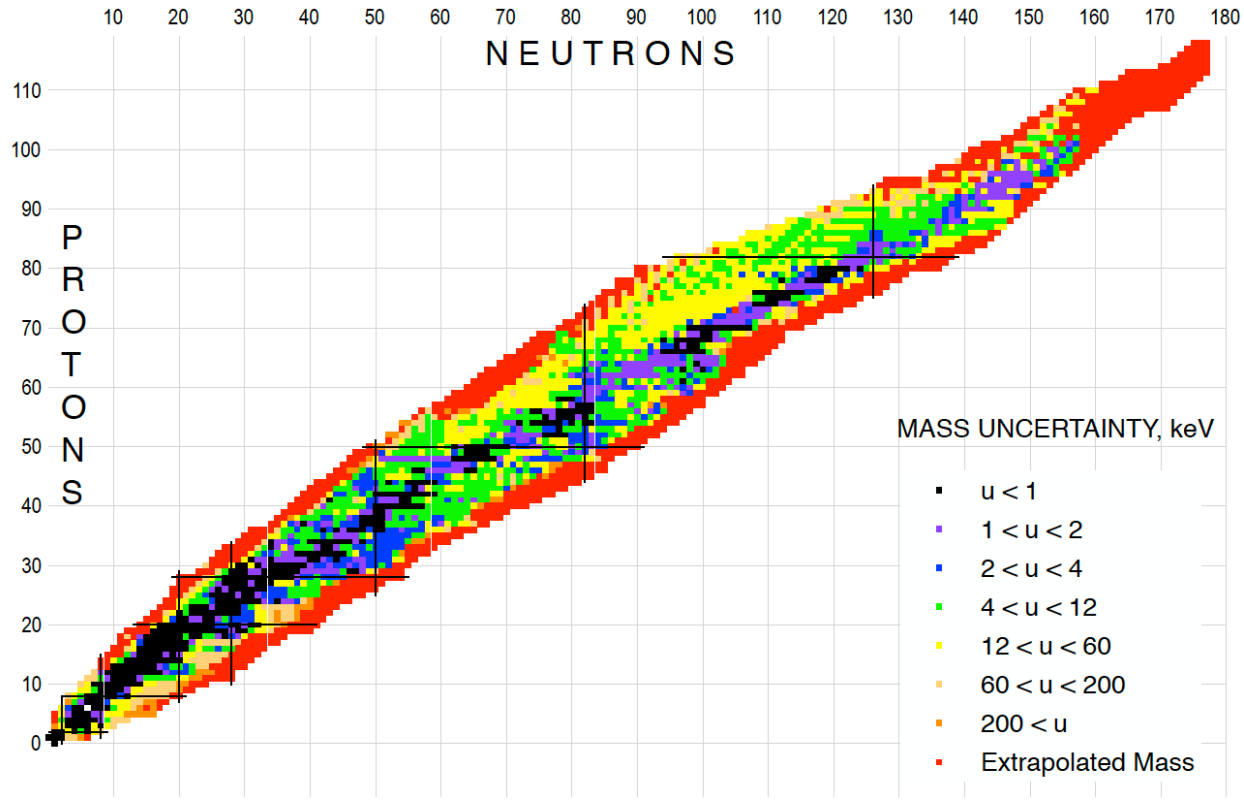


Figure 2: Nuclear chart displaying the mass-excess uncertainties for all (3340) nuclei in their ground state.

NNDC Designated as a PuRe Data Resource

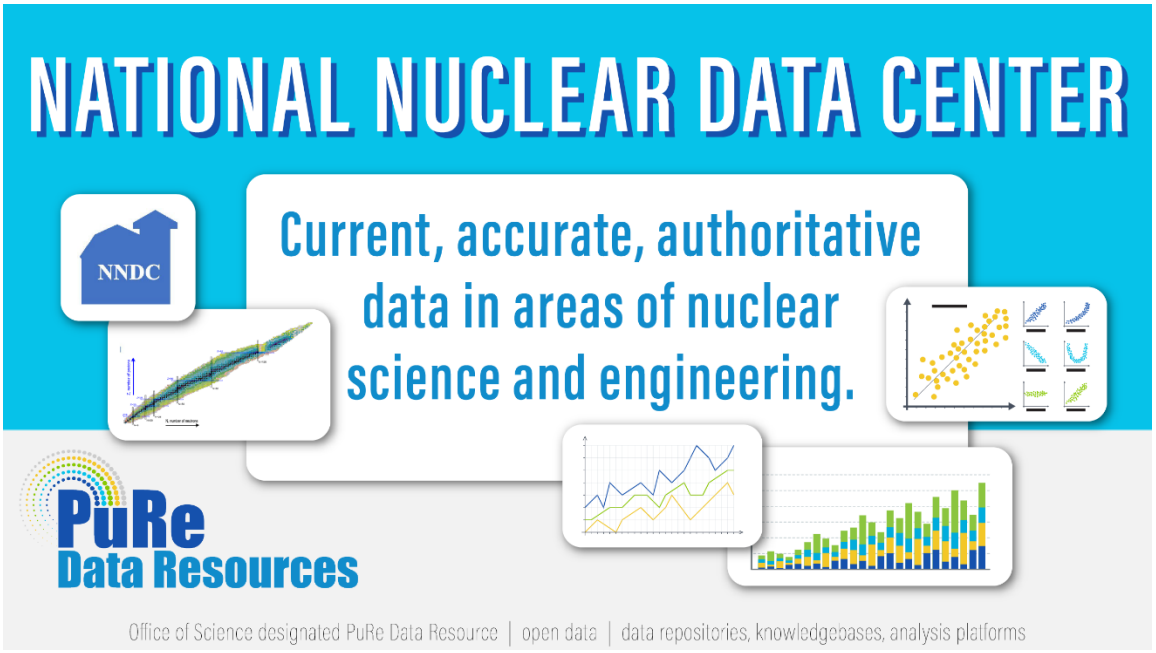


Figure 3: Banner announcing the designation of the NNDC as a PuRe Data Resource.

In April 2021, the NNDC was designated by DOE as a PuRe Data Resource. PuRe is a designation for key data repositories, knowledge bases, analysis platforms, and other activities that strive to make data publicly available to advance scientific or technical knowledge. By designating the NNDC as a PuRe Data Resource, the DOE recognizes the importance of these and carries the weight of scientific data stewardship. DOE's Office of Science manages these resources under an oversight model with high standards for data management, resource operations, and scientific impact. The inaugural list of PuRe Data Resources is given at https://www.energy.gov/science/office-science-pure-data-resources. As a requirement of the PuRe designation, the NNDC must abide by several conditions, including adding Document Object Identifiers (DOIs) to all datasets for which they are appropriate, including ENSDF, ENDF and EXFOR data, and developing robust data preservation and backup systems.

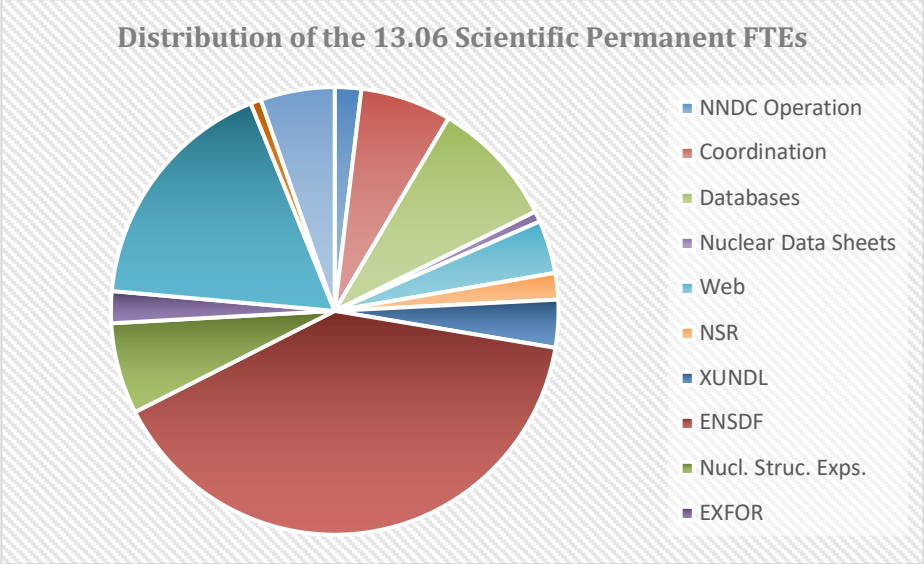
USNDP Staffing Table FY21

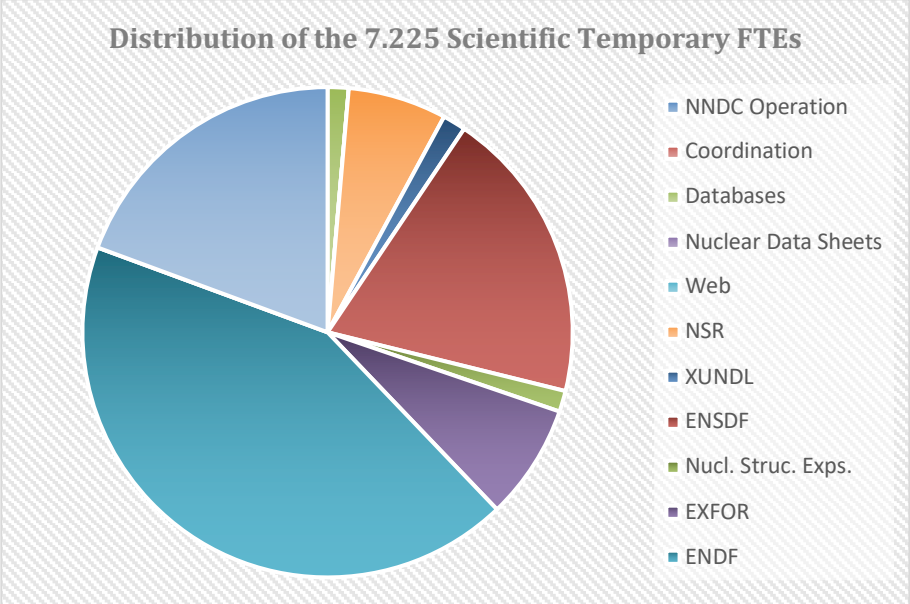
The table below gives the FTE distribution for each USNDP group according to activity. The values in this table and following plots are for the based funding only. In this table, PhD P means PhD Permanent; PhD T means PhD Temporary, which includes post-docs and scientists working under contract; T/A means Technical and Administrative; and GS means Graduate Student.

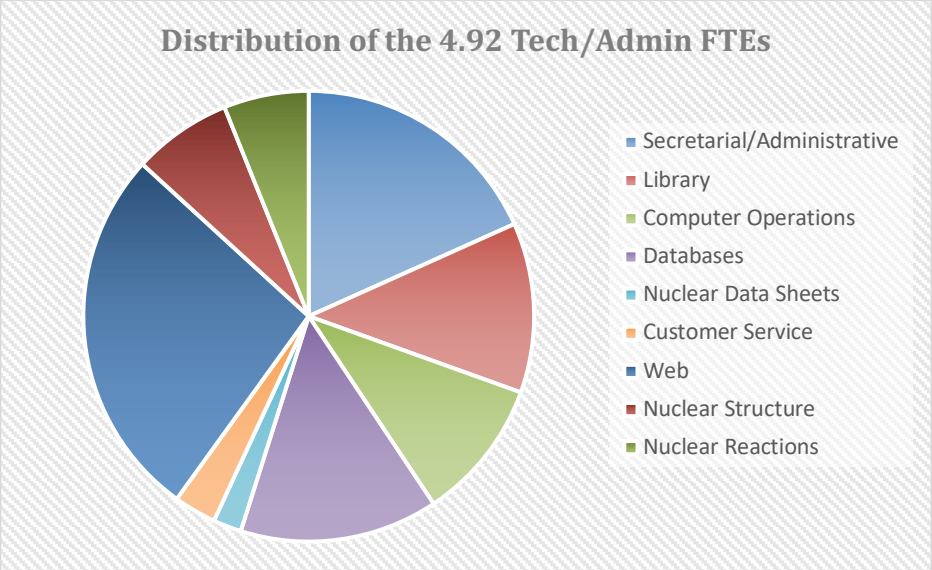
Activity	ANL	BNL			LANL		LBNL		LLNL	MSU	ORNL			TAMU	TUNL			
	PhD P	PhD P	PhD T	T/A	PhD P	PhD T	PhD P	PhD T	PhD P	PhD P	PhD P	PhD T	GS	PhD P	PhD P	PhD T	T/A	Totals
I. NNDC Facility Operation	0	0.25	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2.25
Management		0.25																0.25
Secretarial/Administrative Support				0.9														0.9
Library				0.6														0.6
Computer Operations				0.5														0.5
II. Coordination	0.05	0.28	0	0	0	0	0.48	0	0	0	0	0	0	0	0.05	0	0	0.86
National Coordination		0.26					0.48								0.05			0.79
International Coordination	0.05	0.02																0.07
III. Nuclear Physics Databases	0	0.8	0	0.7	0	0	0.4	0.1	0	0	0	0	0	0	0	0	0	2
Nuclear Science References, NSR		0.25		0.6														0.85
Exper. Nucl. Structure Data, XUNDL		0.19																0.19
Eval. Nucl. Structure Data, ENSDF		0.2																0.2
Numerical Nuclear Data, NuDat		0.05																0.05
Experimental Reaction Data, CSISRS		0.06																0.06
Evaluated Nuclear Data File, ENDF		0.04																0.04
Database Software Maintenance				0.1														0.1
Future Database System Develop.		0.01					0.4	0.1										0.51
IV. Information Dissemination	0	0.45	0	1.17	0	0	0.05	0	0	0	0.1	0	0	0	0	0	0.4	2.17
Nuclear Data Sheets		0.1		0.1														0.2
Customer Services				0.15														0.15
Web Maintenance & Development		0.35		0.92			0.05				0.1						0.4	1.82
V. Nuclear Structure Physics	0.7	2.4	1.1	0	0	0	1.1	0.7	0	1	1	0.2	0	1	0.7	0.1	0.4	10.295
NSR Abstract Preparation		0.25	0.47															0.72
Compilation of Exper. Structure Data		0.2	0.11							0.15					0.1		0.1	0.66
Eval. of Masses & Nuclides for ENSDF	0.4	1.32	0.53				0.85	0.625		0.65	1	0.15		1	0.6	0.1	0.25	7.475
Ground & Metastable State Properties	0.2																	0.2
Radioactive Decay Data Evaluation	0.08									0.01								0.09
Thermal Capture Gamma Data Eval.																		0
Light Mass Eval. for Nucl. Physics A																		0
Nuclear Structure Data Measurement	0.06	0.6					0.2	0.1										0.96
ENSDF Evaluation Support Codes										0.19								0.19
VI. Nuclear Reaction Physics	0	1.63	2.04	0.3	0.65	1.3	0.75	0.3	0.25	0	0.1	0	0.2	0	0	0	0	7.52
Experimental Data Compilation		0.3	0.55															0.85
ENDF Manuals and Documentation		0.01																0.01
ENDF Evaluations		0.65	0.4		0.4	0.2												1.65
Nuclear Reaction Standards			0.4															0.4
Nuclear Model Development		0.12	0.09				0.1		0.15									0.46
Nucl. Reaction Data Measurements					0.25	1.1	0.45	0.3										2.1
Astrophysics Nuclear Data Needs											0.1		0.2					0.3
Covariances development		0.1																0.1
Reactor anti-neutrino & decay heat calc.		0.1	0.6															0.7
Verification and Validation		0.35		0.3			0.2		0.1									0.95
DOE-SC Nucl. Data Funded Staff	0.79	5.78	3.15	4.17	0.65	1.3	2.73	1.13	0.25	1	1.2	0.15	0.2	1	0.75	0.1	0.75	25.095
Staff Supported by Other Funds	0.21	1.01	2.02															3.24
TOTAL STAFF	1	6.79	5.17	4.17	0.65	1.3	2.73	1.13	0.25	1	1.2	0.15	0.2	1	0.75	0.1	0.75	28.335

USNDP FTE Plots FY21

The plots below give the FTE distribution for Scientific Permanent, Scientific Temporary and Tech/Admin FTEs, in pie charts according to activity.






Distribution of the 4.92 Tech/Admin FTEs
Secretarial/Administrative
Library
Computer Operations
Databases
Nuclear Data Sheets
Customer Service
Web
Nuclear Structure
Nuclear Reactions

Detailed Status of the Work Plan – Fiscal Year 2021 Report

I. NNDC Facility Operation

A. Management

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

B. Library

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

C. Computer Operation

The NNDC operates seven servers and a high-performance cluster running Red Hat Enterprise/CentOS Linux in support of its compilation, evaluation, database maintenance, quality assurance and information dissemination functions. In addition, each staff member has a Windows PC, iMac desktop or a Linux workstation that provides an interface to these Linux servers and supports administrative functions, such as word processing and email. Furthermore, the BNL Information Technology Division provides centralized backup, printing and file serving for the PCs. This task includes system and application software upgrades for cyber security compliance, hardware and software procurements, machine operations and internal user support for the Linux, MacOS and Windows platforms.

BNL Planned Activities	Status
In collaboration with ITD, ensure continuous availability of mission-critical Web services through full compliance of NNDC's computers with DOE cyber security requirements.	Completed. All servers up to date with operating system patches and application software updates.
Provide technical computer support to NNDC staff, visitors and external collaborators to enable them to effectively and securely use NNDC computing resources as well as procure computer hardware, software and support services to meet NNDC's computing requirements.	Completed. A significant number of aging units were replaced. The 2008 Linux cluster was retired, and all HPC activities moved to the new cluster. The 2010 GForge server was decommissioned, and all collaboration activities moved to the GitLab server.
Manage NNDC/NE cluster.	The new cluster was upgraded from 240 to 432 cores and further hardware upgrades are planned.

II. Coordination

A. National Coordination

National coordination is required for activities under the USNDP as well as CSEWG. This is mostly performed by the NNDC, with contributions from other laboratories (USNDP Working Groups and Task Forces as well as CSEWG Committees).

BNL Planned Activities	Status
Prepare and organize USNDP budget briefing.	Completed
Prepare USNDP and FY2022 work plan.	Completed.
Organize and chair CSEWG Meeting at BNL in November 2020.	Completed.
Organize and chair USNDP Meeting at BNL in November 2020	Completed.
Edit and publish summary reports and proceedings of the CSEWG and USNDP meetings.	Completed. Summary published as BNL report BNL-221549-2021-INRE.
Maintain CSEWG and USNDP websites.	Ongoing and completed.
Organize mini-CSEWG meeting in the summer if needed.	Held virtually 16-19 August 2021. Summary published as BNL report BNL-222130-2021-INRE.
Host and help organize NDAC meeting.	Didn't take place due to Covid-19.

LANL Planned Activities	Status
Organize and chair CSEWG Evaluation Committee meeting at BNL.	CSEWG Evaluation Committee meeting organized.
Organize and chair CSEWG Covariance Committee meeting at BNL.	CSEWG Covariance Committee meeting organized.
Organize and chair Nuclear Reaction Working Group.	Chair of Nuclear Reaction Working Group served and gave a talk at CSEWG.

USNDP Unplanned Activities	Status
Help organize WANDA meeting.	WANDA 2021 was held as a virtual meeting on January 25-February 3, 2021. Cathy Romano (LBNL/IB3 Global) coordinated the event with Kay Kolos (LLNL) and Vlad Sobes (UTK) as workshop chairs. Many USNDP members participated as plenary speakers or session organizers. The workshop report was prepared in the form of a journal article, edited by Ramona Vogt (LLNL) and Michael Smith (ORNL), and submitted for peer-reviewed publication.
Help organize a workshop on nuclear data relevant to the interpretation of reactor antineutrino measurements.	The WoNDRAM meeting was held virtually June 21-24, 2021 with staff from BNL/NNDC and LBNL/UCB acting as speakers and session organizers.

Perform outreach to NASA and other relevant federal agencies regarding nuclear data needs for space exploration.	Staff from BNL/NNDC (Brown) and LBNL/UCB (Bernstein), together with Prof. Dan Cebra from UC-Davis, worked to make the case for targeted measurements nuclear data at E/A > 10 GeV/A using the RHIC fixed target station. The three of them gave a presentation at a BNL seminar on August 17, 2021. In addition, Bernstein and Catherine Romano (who is a contractor for the USNDP through Berkeley) have been engaging in outreach activities with other federal agencies with nuclear data needs related to space and aerospace exploration, including the Defense Threat Reduction Agency and the Missile Defense Agency.
Organize and participate in the Nuclear Data Working Group (NDWG).	Dr. Catherine Romano (LBNL/IB3 Global Services) has been acting as the leader for the Nuclear Data Working Group (NDWG) under contract through LBNL since FY2021. Drs. Brown, Bernstein and Kondev also serve on the NDWG. This work is ongoing.
Setup and maintain the NDWG website.	(BNL) Ongoing as of FY2021.

ORNL Planned Activities	**Status**
Coordinate and outreach USNDP Nuclear Astrophysics activities.	Outreach of USNDP activities in nuclear astrophysics to researchers in South Korea at Sungkyunkwon Univ. and at Institute for Basic Science Center for Exotic Nuclear Studies. Result was recruitment of graduate students and faculty for assessments of two thermonuclear reactions needed to understand X-ray burst nucleosynthesis.

TUNL Planned Activities	**Status**
Organize and chair USNDP Nuclear Structure Committee.	Continuing.

B. International Coordination

ANL Planned Activities	**Status**
Participate in IAEA-sponsored nuclear data activities.	Participated in the 2021 NSDD meeting and the IAEA-led project on “Evaluated Decay Data Library for Monitoring Applications.”

BNL Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Active participation in the INDEN collaboration completing the Cr evaluation effort.
Participate in NEA WPEC annual meeting.	Chaired WPEC GNDS Expert Group and organized several expert group meetings. Participated in WPEC SGs 43, 49, 50 virtual meetings in May 2021.
Participate in IAEA CRP and technical meetings.	Participated in the INDEN meeting on actinides, structural materials and AI/ML in December 2020. Participated in NSDD meeting April 2021.
Continue to participate in training/mentoring of new ENSDF evaluators through collaborative work.	New evaluator Christopher Morse was trained in ENSDF policies and procedures.

LANL Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Participated the Consultants Meeting of INDEN on Light Elements in March 2021 Participated the Meeting for the International Nuclear Data Committee in April 2021 Final Evaluated Photonuclear Data Library report was published as IAEA-NDS-232 (2020).
Participate in NEA WPEC annual meeting.	Attended the WPEC meeting.

LBNL Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Work on an ongoing basis with Arjan Koning to improve pre-equilibrium reaction mechanism modeling in support of high-energy proton reaction evaluation.

LLNL Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Participated in INDEN-LE meeting on Light Elements, IAEA meetings on Codes, on (Alpha,n) reactions.
Participate in NEA WPEC annual meeting.	Attended the WPEC meetings on GNDS.

MSU Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Participated IAEA-led project on “Evaluated Decay Data Library for Monitoring Applications.”

ORNL Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Attended NSDD meeting, gave presentation on ORNL efforts in nuclear structure evaluations and reviews, wrote status report of ORNL nuclear structure data activities, and updated and

	presented ENSDF Evaluation Guidelines (M. Martin).

TAMU Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Ongoing. 24th Technical Meeting of the NSDD network, IAEA Vienna, May 25, 2021, presented "TAMU NSDD Evaluation Center Report 2021."

TUNL Planned Activities	Status
Participate in IAEA-sponsored nuclear data activities.	Participated in discussions related to IAEA Nuclear Structure and Decay Data network activities.

III. Nuclear Physics Databases

A. Nuclear Science References (NSR)

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

BNL Planned Activities	Status
Distribute database to collaborators.	NSR database was distributed to the IAEA monthly.
Perform database updates and maintenance.	NSR was updated 181 times, and cybersecurity updates were implemented.
Continue joint project with the NRDC network to transfer missing nuclear reaction references to NSR.	Ongoing task. Goals for the year were completed.
Study in depth the possibilities of using AI and ML techniques in NSR, in collaboration with LBNL.	Prepared the NSR Modernization Proposal in collaboration with the BNL non-proliferation, LBNL and Stony Brook. Coordinating with LBNL's NucScholar project.

LBNL Planned Activities	Status
Develop NucScholar Natural Language Processing system for nuclear physics literature.	Ongoing Task. Coordination with BNL staff.

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 NNDC coordinates this work and updates the database as new/revised data sets are received from collaborators.

BNL Planned Activities	Status
Perform weekly update of the database using input received from compilers.	Completed.
Distribute database twice a year to the NSDD network.	Completed.

C. Evaluated Nuclear Structure Data File (ENSDF)

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

BNL Planned Activities	Status
Maintain ENSDF database, includes continuous updating.	Completed.
Process evaluations received from NSDD evaluators.	Completed.
Distribute ENSDF database to collaborators monthly.	Completed. ENSDF is archived and made available through the NNDC website.

D. Numerical Nuclear Data (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), and atomic and nuclear radiations derived from ENSDF. Additionally, NuDat contains an interactive Chart of Nuclides and interactive level schemes.

BNL Planned Activities	Status
Update NuDat database as necessary.	Completed.

E. Experimental Reaction Data File (EXFOR)

The NNDC is responsible for maintaining the EXFOR database at BNL. This database contains experimental nuclear reaction data for incident energies below 1 GeV, including neutron-induced, charge particle, and photonuclear reactions and spontaneous fission. Many groups worldwide compile experimental data and send it to the central database in Vienna in the EXFOR format. Then, each group is responsible for updating its own database. The effort described here includes quality control, file update and data transfer activities. The NNDC database is updated, as compilations are exchanged, and checked from the compiling centers. The compilation activity is given under Nuclear Reaction Physics.

BNL Planned Activities	Status
Update EXFOR database with compilations from cooperating centers (500 entries expected). The NNDC compilation work can be found under Nuclear Reaction Physics, Section V of the present document.	Completed. EXFOR database was updated 40 times. A project to produce a JSON output of fission yield data started, jointly funded by NA-22.
Participate in WPEC Subgroup 50 on creating a critically reviewed version of EXFOR.	Investigated nuclear reaction data outliers in EXFOR. Started to develop a new Java code for identification of deficient data. Prepared the USNDP EXFOR Modernization proposal in collaboration with LANL, LBNL, and Naval Nuclear Laboratory.

F. 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 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 in the 1960s 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 U.S. and the exchange of libraries internationally. New evaluations for the next release of the library, ENDF/B-VIII.0, are assembled, tested and made available to users through NNDC's Web servers and GitLab collaboration server at git.nndc.bnl.gov.

BNL Planned Activities	Status
Maintain and improve Sigma database and web interface for users without specialized knowledge of ENDF-6 format. (See also information dissemination, Section IV).	Not completed due to lack of personnel.
Maintain and extend ADVANCE, the ENDF continuous integration system that continually checks for modification to the ENDF database then runs all available tests on the changed data files.	Ongoing. The ADVANCE server was set up as the master node of a Kubernetes cluster of Docker containers which will become the new platform for nuclear data quality assurance.

G. Database Software Maintenance

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

BNL Planned Activities	Status
Fix software bugs and develop enhancements for the nuclear physics databases maintained by NNDC.	Completed.
Upgrade the Linux/MySQL server software to fix bugs, provide new functionalities, and improve the system's performance, security, and reliability.	Completed.

IV. Information Dissemination

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

A. Nuclear Data Sheets

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 journal published by Elsevier and various versions of the Nuclear Wallet Cards.

BNL Planned Activities	Status
Prepare issues of Nuclear Data Sheets for publication.	Completed.
Work on a new version of Nuclear Wallet Cards.	Ongoing.
Work on a new version of Handbook of Radioactive Nuclei.	Ongoing.

MSU Planned Activities	Status
Continue development of software for Nuclear Data Sheets publication.	The McMaster-MSU JAVA-NDS code has been updated constantly and distributed to NSDD evaluators regularly.

LBNL Unplanned Activities	Status
Development of a new website for dissemination of data regarding exotic nuclei that undergo beta-delayed particle emission.	The Berkeley Group is developing a website for the dissemination of beta-delayed particle emission data. This work builds on the recent publication Batchelder (ADNDT Vol. 132, (2020) 101323) and will continue to be updated regularly as new results are published. This work is ongoing.

B. Customer Services

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

BNL Planned Activities	Status
Provide technical support to nuclear data end-users as necessary.	More than 200 requests for articles were received by our librarian. Additionally, more than 100 emails were answered with different types of data requests.

C. 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 website. Other USNDP members also offer nuclear physics information through their websites. These services require resources to maintain currency and improve performance.

BNL Planned Activities	Status
Solicit user suggestions on enhancements to the ENSDF, NSR, NuDat and Sigma web interfaces and be responsive to those needs. Expand search and plotting capabilities of ENSDF data.	NuDat3.0 – a completely redesigned application was released in September 2021.
Maintain web interfaces for ENDF and EXFOR databases.	ENDF and EXFOR database web interfaces were updated in collaboration with the IAEA.
Maintain currency of the CSEWG, USNDP and the NNDC websites, proactively respond to the users' requests.	Completed.
Maintain the NNDC web services availability on a 99% and higher level.	Successfully kept NNDC web services downtime at a maximum of only eight hours for the entire year (~99.9% uptime).
Strictly follow all BNL and DOE cybersecurity rules and regulations during the web application design, development, and implementation. Address issues that arise during BNL scans.	Completed.
Upgrade GitLab server software to provide more powerful and advanced functionalities in the NNDC collaboration services.	Completed.
Make progress with modernization of the website, enhancing capabilities and follow industry best practices.	Ongoing.
Continue development of mobile applications targeting highly used databases.	Ongoing.

ORNL Planned Activities	Status
Incorporation of new mass compilations and new rate libraries into online collections.	Worked with McMaster to get the next installment of their collection of mass measurements posted at nuclearmasses.org; compilation number 14 was posted, covering masses from November 1, 2019 to November 27, 2020.

TUNL Planned Activities	Status
Provide access to present and past evaluations of Energy Levels of Light Nuclei for A=3-20 nuclides, including associated figures and energy-level diagrams and tables.	Continuing.
Provide access to compiled and evaluated data on light nuclei related to p-, alpha- and n-capture reactions, and ground-state decays.	Continuing.
Provide access for TUNL dissertations collection.	Continuing.

V. Nuclear Structure Physics

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. 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. Similar contributions from other external collaborators are expected. These will be checked and edited by BNL as necessary before being added to the database.

BNL Planned Activities	Status
Prepare entries for about 3,100 new references, and keyword abstracts for 2,000 of them. Provide coverage for more than 80 major journals, including complete coverage of Physical Review C and Nuclear Physics A.	Completed. 4,590 new references were added, and 2,872 references were keyworded.

B. Compilation of Experimental Nuclear Structure Data

This activity involves compilation of recently published or completed experimental nuclear structure data for inclusion in XUNDL. The compilation is managed by the NNDC.

ANL Planned Activities	Status
Compile and review datasets for recently published experimental nuclear structure data for	None requested by the XUNDL coordinator.

inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results.	

BNL Planned Activities	**Status**
Compile new B(E2) experimental data. Continue work on a B(E2) evaluation project in collaboration with McMaster University.	Ongoing activity.
Compile new double-beta decay experimental data. Start working on a data project with Kyiv Institute for Nuclear Research.	Ongoing activity.
Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results.	552 datasets from 267 articles were compiled in FY20.
Review compiled datasets submitted by other data centers prior to inclusion in the XUNDL database. Work with Phys. Rev. C and Eur. Phys Journal A to check and compile data prior to publication.	A total of 689 datasets from 356 articles were reviewed and incorporated in the database.
Compile new mass measurements and submit data file to nuclearmasses.org webpage at ORNL (McMaster University).	Continuing.

LBNL Planned Activities	**Status**
Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results.	No requests were received.

MSU Planned Activities	**Status**
Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results.	93 datasets from 50 articles were compiled (including 27 articles for PRC and EPJA data checking) in FY21.
Review compiled datasets submitted by other data centers prior to inclusion in the XUNDL database. Work with PRC and EPJA to check and compile data prior to publication.	56 datasets from 27 articles were reviewed and compiled; checking reports were prepared in FY21.

TUNL Planned Activities	Status
Compile and review datasets for recently published experimental nuclear structure data for inclusion in the XUNDL database. Interact with the authors for requesting additional experimental data or for further clarification of the published results.	41 data sets from 36 articles were compiled.

C. A-Chains and Nuclides Evaluations for ENSDF

USNDP evaluates nuclear structure and decay data for inclusion in the ENSDF database. This effort includes the critical analysis of all available experimental nuclear structure and radioactive decay data for a nuclide or a group of related nuclei to deduce recommended values from the measured data and prepare a file in ENSDF format that is the basis for publications in the Nuclear Data Sheets and is used to update the contents of the USNDP nuclear structure and decay database, ENSDF.

ANL Planned Activities	Status
Evaluate at least one mass chain from the ANL region of responsibility.	One mass chain was evaluated.
Review mass chain evaluations, as requested.	Reviews were not requested.

BNL Planned Activities	Status
Evaluate at least four mass chains or their equivalent nuclides.	Seven mass chains were evaluated.
Review at least four mass chains or their equivalent nuclides.	Six mass chains were reviewed.
Update ENSDF for the identification of new nuclides and for the first publication on the findings of the excited states of nuclides.	Completed.
Edit all evaluations submitted for publication, including checking their format and physics content.	Completed.
Continue mentoring new ENSDF evaluators.	Mentoring for new hires Shaofei Zhu, Andrea Mattera, Adam Hayes and Christopher Morse continues.

LBNL Planned Activities	Status
Evaluate the equivalent of at least two mass chains (20 nuclides), including a minimum of one from the A=21-30 region. Emphasis will be placed on evaluating data of current interest to the nuclear structure and nuclear application communities.	Submitted A=24 (8 nuclides) – M.S. Basunia, A. Chakraborty; A=213 (12 nuclides) – M.S. Basunia and A=231 (9 nuclides, joint with McMaster) – B. Singh (4.5), J. Tuli (4.5)
Review mass chain evaluations as requested.	Reviewed two mass chains: M.S. Basunia (1) and J.C. Batchelder (1)

MSU Planned Activities	Status
Evaluate the equivalent of at least two mass chains.	Three mass chains were evaluated, 50/50 shared with Balraj Singh.
Review one mass chain evaluations as requested.	One review was completed.

ORNL Planned Activities	Status
One equivalent mass chain and the data for new nuclides will be evaluated.	A = 249 was submitted; A = 242 post-review edits submitted; A = 137 post-review edits in progress; A = 216 is in progress; new updated Guidelines for Evaluators (Murray Martin) was completed.
Review mass chain evaluations as requested.	A = 48 review submitted.

TAMU Planned Activities	Status
At least one mass chain or their equivalent nuclides will be evaluated.	One mass chain was submitted.
Review mass chain evaluations as requested.	One review was completed.

TUNL Planned Activities	Status
Evaluate about one to two A-chains per year for publication in Nuclear Data Sheets and inclusion in the ENSDF database.	Evaluation of A=13 is progressing.
Evaluate and update ENSDF for A=2-20 near drip-line nuclides, especially for first observations or when ENSDF has no previous dataset.	Updated 13F, 17O and 18N in ENSDF.
Update various reaction datasets in ENSDF, such as for beta-decay and beta-delayed particle emission.	Continuing.

D. Ground and Metastable State Properties

ANL Planned Activities	Status
Compile and evaluate atomic masses and complementary nuclear structure data for the Atomic Mass Evaluation and the NUBASE evaluation of basic nuclear physics properties.	Completed and published the new AME2020 and NUBASE2020 evaluations.

BNL Planned Activities	Status
Develop new database for ground and metastable state properties (WalletCraft).	Ongoing.
Begin evaluation process to provide recommended ground and metastable state properties.	Ongoing.

E. Non-ENSDF Decay Data Evaluations

ANL Planned Activities	Status
Contribute to the IAEA-led project on "Evaluated Decay Data Library for Monitoring Applications."	Continuing.

BNL Planned Activities	Status
Contribute to the beta-delayed neutron emitters IAEA CRP.	CRP article published in March 2021.

LBNL Planned Activities	Status
Work with researchers at Pacific Northwest National Laboratory on the development of a numerical database with complete Gamma-ray/X ray coincidence data in a joint effort with the Defense Threat Reduction Agency. The database will be benchmarked against existing decay data from ENSDF as well as recently published datasets not yet included in ENSDF. These efforts will be coordinated with the ENSDF modernization initiative led by BNL.	Continuing. 35 decay datasets processed to date.

MSU Planned Activities	Status
Contribute to the IAEA-led project on "Evaluated Decay Data Library for Monitoring Applications."	Completed.

F. Neutron-induced γ-Ray Data Evaluation

LBNL Planned Activities	Status
Continue updating the Inelastic Scattering of Reactor Fast Neutrons Database (e.g., the "Baghdad Atlas") with modern ENSDF data as a validation database for (n,n'gamma) as well as with additional sources of energy differential (n,n'gamma) data from GELINA at Geel, nELBE at HZDR, and the GENESIS array at LBNL. Extract information from ENDF needed to produce flux-weighted partial gamma-ray cross sections and comparing the result to values in the Atlas.	Continuing.
Start benchmarking reaction modeling codes, including TALYS and EMPIRE. This work will be performed in collaboration with researchers from the IAEA and Naval Nuclear Laboratory.	Continuing.

Explore the role of quasi-continuum contributions through collaboration with researchers from LLNL and the University of Oslo.	Continuing.

G. Nuclear Structure Data Measurements

ANL Planned Activities	Status
Participate in nuclear physics research activities at ANL, MSU, and other nuclear physics user facilities with the main emphasis on decay studies of neutron-rich nuclei, spectroscopy of heavy actinide nuclei, and nuclei far from the line of stability.	Continuing.

BNL Planned Activities	Status
Precisely determine decay schemes of relevant medical isotopes using state-of-the-art gamma-ray spectroscopy.	Decay of 186Ir was measured using the Gammasphere array at ANL.
Participate in beta-decay measurements at facilities, such as Argonne's CARIBU, with an emphasis on nuclei relevant to decay heat, antineutrino spectra and delayed nu-bar.	Experiment using TAGS at CARIBU/ANL was attended.
Perform gamma-ray spectroscopy experiments with GRETINA to remedy data deficiencies uncovered during ENSDF evaluations.	Analysis ongoing.
Setup new gamma-alpha coincidence station.	Task performed using alternate funding (BNL Program Development).

LBNL Planned Activities	Status
Perform targeted decay-data measurements to address inconsistencies in decay data using light-ion and neutron activation and the Fast Loading and Unloading Facility for Fission Fragment Yields (FLUFFY) combined with a local array of single-crystal and Clover HPGe detectors. Results from these experiments will be published and updates presented to the ENSDF database manager.	The 283 keV to 656 keV γ-ray emission ratios of 61Cu decay from seven experiments and a variety of detectors and detection geometries were analyzed to resolve the issue of the recommended values with observed data. A manuscript was published in Appl. Rad. Isot. 170 (2021) 109625. Continuing experiments using the FLUFFY facility at the 88-inch cyclotron are planned.

H. ENSDF Physics and Checking Codes

BNL Planned Activities	Status
Maintain and upgrade ENSDF checking and physics programs for format changes as required.	Completed.
Work on the development of the next generation ENSDF format and develop applications that apply Machine Learning techniques to the new format.	Ongoing.

LLNL Planned Activities	Status
Collaborate with BNL in the development of the next generation ENSDF format and develop applications that apply Machine Learning techniques to the new format.	A NDWIAG FOA-funded project to modernize ENSDF has been funded starting in FY21.

MSU Planned Activities	Status
Maintain and improve the ENSDF utility and analysis codes in Java developed at MSU: JAVA-NDS, ConsistencyCheck, Java-RULER, GLSC, AME-NuBase retrieval tool, Excel2ENSDF, and KeynumberCheck.	Ongoing, with all codes updated constantly.
Develop new Java codes to replace the legacy ENSDF codes in Fortran that lack maintenance; for example, the Gamma to Level Scheme Code (GLSC), with all functions of the GTOL and GABS Fortran codes and more.	Ongoing, with the GLSC code completed in FY21.
Develop new tools for data evaluation.	Ongoing.

V. Nuclear Reaction Physics

A. Experimental Data Compilation

The NNDC, as part of a larger international cooperation, has the responsibility for compiling experimental nuclear reaction data that have been produced in the U.S. and Canada.

BNL Planned Activities	Status
Compile experimental data for neutron, charged particle, and photon-induced reactions from 120 publications.	131 new entries were compiled, 303 existing entries were corrected.
Explore possibilities of recovering previously unobtainable reaction data and proactively respond to users' needs.	Ongoing activity.

B. ENDF Manuals and Documentation

The NNDC is responsible for maintaining the format and procedures manual for the ENDF system as well as producing the documentation supporting the contents of the ENDF/B library.

BNL Planned Activities	Status
Maintain the GitLab version of the ENDF-6 formats manual current with CSEWG-endorsed format changes. Issue official release of the manual.	One format proposal was made in FY21 and shepherded through the ENDF-6 format proposal process. The process completed during FY22 during the 2021 CSEWG meeting.
Automate the generation and posting of the latest unofficial version of the ENDF-6 formats manual.	Ongoing.
Chair the WPEC Generalized Nuclear Database Structure (GNDS) Expert Group meeting and maintain the format specification for the GNDS, the successor format to ENDF-6.	The draft GNDS-2.0 specifications are complete and will be approved at the November 2021 WPEC meeting and (hopefully) finalized for the May 2022 WPEC meeting.

C. ENDF Evaluations

Evaluated nuclear reaction data, for applications and 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.

BNL Planned Activities	Status
Respond to user needs for evaluated nuclear reaction data.	Targeting fusion diagnostic applications, we successfully developed and completed a new reaction evaluation for 86Kr isotope. Also, collected requirements from the community to set up review process, in preparation for the next ENDF/B release, ENDF/B-VIII.1, aimed for 2024. Ongoing.
Collect and address users feedback related to the ENDF library.	Received, organized, and processed evaluated files contributed by the community to the ENDF/B library, logging and fixing errors. These were staged for review and ultimate approval. Ongoing.
Complete evaluations for Cr isotopes in the frame of the INDEN project, the successor project to CIELO. Work with CSEWG on upgraded evaluations for future release of the ENDF/B library.	Revised and published ("*Newly evaluated neutron reaction data on chromium isotopes,*" Nuclear Data Sheets, 173 (2021)) the evaluations for 50, 52, 53, 54Cr isotopes. Files are available through NNDC and IAEA websites. Completed.
Improve methodology for providing covariance data in the resonance and fast neutron region to the next release of ENDF.	Status unchanged from FY20: Covariance generation hampered by both missing resonances and resonance quantum number misassignment. We began an AI/ML project with SULI students to

	correct these issues before attempting to generate covariance data.
Update the Decay Data Sublibrary as new data for neutron-rich nuclides become available.	Completed.
Maintain the Atlas of Neutron Resonances electronic files in preparation for a future update of the Atlas of Neutron Resonances. Continue working on the use of ML techniques to better determine resonance properties, in possible collaboration with LBNL.	Status unchanged from FY20: Under NCSP funding, an API for the Atlas electronic files was developed. This has enabled identification and correction of numerous errors in the Atlas. We are considering future work in the context of various USNDP database modernization projects.
Participate in the Fission Yield evaluation CRP at the IAEA.	Status unchanged in FY21. No meetings held in FY21.

LANL Planned Activities	**Status**
Upgrade the LANL ENDF evaluations for major actinides as well as some other structural materials that perform well in criticality benchmarks, including new theoretical development of statistical model for deformed systems. Close collaboration with international nuclear data library activities at the IAEA and OECD/NEA.	New evaluations for tantalum-181 were performed to be included in the ENDF/B-VIII.1 library, and the validation test with the integral criticality measurements is planned. Once the validation on Ta-181 is finalized, the rest of Ta isotopes will be reevaluated using the same selection of models and consistent set of overlapping parameters as used in the case of Ta-181.
Provide upgraded ENDF for light- and medium-mass elements and perform criticality benchmarks.	Due to budget limitations, this task was performed with funding from another source.
Provide new evaluations of the prompt fission neutron spectra for major actinides, based on the Monte Carlo technique as well as the deterministic method, including pre-equilibrium emissions at high energies.	The investigation on the long-standing problem of "too soft Prompt Fission Neutron Spectrum" using the Hauser-Feshbach Fission Fragment Decay (HF^3D) model has found two important components; one is the primary fission fragment distribution needs to be slightly wider than experimentally reported data and the other is the nonstatistical nature of the spin distribution in low-lying levels at higher outgoing neutron energies. This work improved the agreement between calculations and experiments. Final results were published by T. Kawano et al. in Phys. Rev. C 104, 014611 (2021).
Improve photon production data for neutron capture and inelastic scattering, which will be used in prompt gamma-ray spectroscopy.	Gamma-ray production from neutron inelastic scattering off ^{238}U produced, which includes the quantum mechanical pre-equilibrium process. The final effort was published as "Unified description of the coupled-channels and statistical Hauser-Feshbach nuclear reaction theories for low energy neutron incident reactions" in Eur. Phys. J. A 57,

	16 (2021) by T. Kawano. To incorporate the most updated ENSDF data into the photon production calculations, an ENSDF convertor program CENS was written and released as open source software (https://github.com/toshihikokawano/CENS).
Improve angular distributions and energy spectra for neutron-induced charged-particle reactions.	Improved angular and energy distributions for structural materials are produced in collaboration with LANSCE and KAERI. In FY21, we made progress on Fe and Ni isotopes to complete angular distributions of discrete states and continuum and energy spectra for (n,z) reactions.

LLNL Planned Activities	**Status**
Perform new evaluations as per LLNL customer requests and submit these as well as other LLNL-generated evaluations into ENDF.	Continuing; in particular, patching gamma and charged-particle distributions missing in ENDF.
Perform R-matrix fits for proton and alpha particles incident on selected medium-mass nuclei ($4 < A < 50$) to accurately describe low-energy resonances and make candidates for future ENDF/B-VIII evaluations.	Continuing.

D. Nuclear Reaction Standards

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

BNL Planned Activities (Allan Carlson)	**Status**
Continue work on standards evaluations through involvement in the IAEA data development project, “Maintenance of the Neutron Cross	Ongoing. The Standards and the ENDF/B-VIII evaluations are in excellent agreement, but there is a trend

Section Standards." Checking the literature and other sources for possible measurements related to standards.	toward lower values at small CMS angles [N.V. Kornilov, A High-Precision Tagged Neutron n-p Scattering Measurement at 14.9 MeV, Nucl. Sci. Eng. 194, 335 (2020)].
Continue involvement with nuclear data groups as: • A member of the program committee of the International Symposium on Reactor Dosimetry's 17th International Symposium on Reactor Dosimetry (ISRD-17). Due to concerns about the virus, the ISRD-17 meeting will be held May 2022 (instead of November 2021) in Lausanne, Switzerland. I attended a meeting of the members of the Program Committee on February 2021. The agenda included updates on the meeting in May, issues concerning future symposium papers, the location of the meeting in 2023 (in the USA), and assignments for various positions (workshop, poster session and technical chairs) for the 2023 meeting. • A member of the International Advisory Committee of ND-2019. We are nearing the end of this work, reviewing contributions for inclusion in the proceedings of the conference. • A member of the International Advisory Board for the 5th International Workshop on Nuclear Data Covariances (CW2020).	Preparation for all meetings is ongoing. There are still lingering concerns about the meetings due to the virus. Abstract reviews for ND2022 are complete and it will be likely held virtually. CW2022 (formerly CW2020) is still planned for an in-person meeting.
Work will continue on both ^{6}Li(n,t) and ^{235}U(n,f) measurements at NIST with sub-thermal neutrons.	At the NIST Neutron Center for Neutron Research, a measurement was made of the ^{6}Li(n,t) cross section standard. This is the first direct and absolute measurement of this cross section in this neutron energy range using monoenergetic neutrons. • A primary effort was focused on measuring the neutron fluence accurately. It was determined with an uncertainty of 0.06%. • There is concern about the IRMM mass determination of the sample. That value yields a cross section value with an uncertainty of 0.3%, that is 1% lower than the ENDF/B-VIII value. • Most of the uncertainty is from uncertainty in the ^{6}Li mass. A better determination of the mass must be made.
Prepare for a virtual IAEA Consultants' Meeting	Preparation ongoing, meeting occurs in FY22.

on Neutron Data Standards October 12-16, 2021. At this meeting, the focus will be on updates to ^{239}Pu(n,f) cross section data based on the results from the templates work on this cross section and how to merge these data into a future version of the standards. Also some work will be done on updates to the ^{235}U(n,f) covariances in the GMA database using templates of expected uncertainties in fission cross sections. I plan to propose a discussion of a time scale for the next standards evaluation. It is important that some recent work on hydrogen scattering and ^{235}U(n,f) cross sections be completed before a new evaluation is considered.	

E. Nuclear Model Development

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

BNL Planned Activities	**Status**
Develop a new coupled-channels code using modern coding techniques for use in future evaluation work.	The general structure of the coupled-channels equations has been implemented. This structure allows the treatment of any kind of reaction, such as elastic, inelastic, and so forth. So far, the code was tested for nucleon-nucleus and nucleus-nucleus elastic scattering, and the results were found to match those obtained with other available codes, such as Fresco and EMPIRE. The simplest rotor model to describe the inelastic excitation of the target has also been implemented and it is currently under testing.
Model (n,g) spectra to address a major shortcoming in the ENDF library as noted in WANDA 2020.	Effort transferred to NA-22 funded project "Gamma Rays Induced by Neutrons."

LANL Planned Activities	**Status**
Continue to develop a microscopic description of the fission process in the fast energy range, which includes Class-I and Class-II coupling as well as penetrability calculations through arbitrary fission barrier shapes. Implement the theory into the	Modeling for fission penetration through arbitrary fission barrier shapes was made and implemented into CoH3. The actual fission cross section calculation under preparation.

Hauser-Feshbach code to facilitate actinide evaluations.	
Continue to develop a coupled-channels Hauser-Feshbach method for better prediction of neutron-induced reactions on deformed nuclei, with particular emphasis on fission, capture, and inelastic scattering channels.	The coupled-channels Hauser-Feshbach code development continued. We reported a consistent description of the nucleon-nucleus interaction for the deformed systems, which consists of the generalized transmission coefficients and the Engelbrecht-Weidenmuller transformation.
Continue to develop the Monte Carlo Hauser-Feshbach code, CGM, for evaluating major actinides, which has a unique capability to produce prompt fission neutron and gamma-ray spectra.	Development of Monte Carlo Hauser-Feshbach technique continued, and prompt fission neutron and gamma-ray spectra calculated. The results of the Hauser-Feshbach Fission Fragment Decay (HF^3D) model calculations made better agreement with recent measurements on Prompt Fission Neutron Spectra (PFNS).
Develop a semi-microscopic model based on the Gaussian Orthogonal Ensemble (GOE).	The semi-microscopic level density model based on GOE developed, and effective interaction of M3Y potential tested.

F. Nuclear Reaction Data Measurements

LANL Planned Activities	**Status**
Perform the precision measurement on the prompt fission-neutron spectrum for fission induced by neutrons of 0.5 to 200 MeV on ^{235}U and ^{239}Pu. With the high-energy neutron detector array, the measurement will be extended to the outgoing neutrons up to 12 MeV.	The high precision measurements on Prompt Fission Neutron Spectra (PFNS) for ^{239}Pu were performed at LANSCE using the ChiNu arrays, and the final results of PFNS from 10 keV to 10 MeV induced by neutrons of energy 1-20 MeV was published in Phys. Rev. C 102, 034615 (2020).
Perform transmission experiments on oxygen or neon isotopes at neutron energies from 1 MeV to 200 MeV in the interest of the Dispersive Optical Model potential investigation and some level information near particle thresholds.	The final analyses and results were reported in Phys. Rev. C (2020PR10).
Perform the precision measurement on the $^{16}O(n,\alpha)$ reaction cross section at LANSCE.	Measured differential cross sections on the 16O(n,a) reaction at LANSCE were finalized and ready for journal submission. The angular distributions showed a good agreement with the current ENDF/B-VIII.0 up to 7 MeV neutrons within experimental resolution functions. Above 7 MeV, further full evaluation is suggested based on our data and other recent 13C(a,n) reaction datasets.
Measure energy-dependent reaction cross sections on $^{35}Cl(n,p)$ and (n,α) reactions for improving insufficient experimental data.	Using a diamond detector as an active target, new, multiple reaction cross sections, such as 12C(n,a0), 12C(n,p0), 12C(n,d0+d1), and

	13C(n,a0), were deduced at LANSCE. By comparing the measured yields with Geant simulations, the current data could be used to validate neutron scattering cross sections as demonstrated in the report. The work was published in Phys. Rev. C 104, 014603 (2021) by Kuvin, Lee, et al.
Perform double-differential cross sections of ^{54}Fe(n,p) reaction in respect to incoming neutron energies and outgoing particles angles for the neutron energy range of 0.5 - 20 MeV.	Final angular distributions on ^{54}Fe(n,p) were deduced for discrete states and continuum, and the new evaluations are under way using these new results. In addition, total cross sections on (n,d) and (n,a) reactions were obtained from LENZ measurements up to 30 MeV. The work is ready for journal submission.

LBNL Planned Activities	**Status**
Study the ^{56}Fe(n,n'gamma) and ^{238}U(n,n'gamma) reactions using the Gamma Energy Neutron Energy Spectrometer for Inelastic Scattering (GENESIS).	Continuing. Data production experiments were performed on both targets in FY21. Analysis is in progress.
Perform energy-dependent measurements of short-lived fission fragments on ^{235,238}U using the Fast Loading and Unloading Facility for Fission Yields (FLUFFY).	Continuing. See similar task in nuclear structure measurements.
Measurement of the decay of ^{68m,g}Cu populated via ^{nat}Zn(n,px) using FLUFFY. This experiment will run "piggyback" on the ^{235,238}U(n,f) measurements mentioned above.	Continuing. Measurements planned for the second half of FY22.

LBNL Unplanned Activities	**Status**
Improve modeling of high-energy proton-induced reactions for spherical nuclei through stacked target foil activation experiments.	Continuing. This effort is being performed jointly with the Isotope Program, which is supporting the experimental measurements. The first results were published in Phys. Rev. C, vol. 103, no. 3, p. 034601, March 2021). Additional measurements were performed on ^{75}As, ^{nat}Sb and ^{nat}Tl. Additional results were published by A.S. Voyles et al., Eur. Phys. J. A, 57 (3), (2021).
Measurements of fast neutron-induced reaction cross sections on ^{23}Na, ^{35}Cl and ^{37}Cl.	In August 2021, the Berkeley group performed measurements of fast neutron-induced reactions cross sections on NaCl targets using a combination of activation and in-beam studies using a CLYC detector as an active target and a NaCl target using the GENESIS array. This work is being performed using support from both the DOE-Nuclear Energy

	University Program and the USNDP. This work is ongoing.
Measurements of photon- and electron-induced excitation of isomeric states in bromine and yttrium nuclei using the BELLA laser system.	The Berkeley group is preparing for experiments using photons and electrons produced via laser wakefield acceleration at the LBNL BELLA laser facility, which will constrain models of photon strength in the quasicontinuum of bromine and yttrium nuclei. This work is being supported by a grant by Google Project X and the USNDP.

G. Astrophysics Nuclear Data Needs

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.

BNL Planned Activities	**Status**
Work on neutron capture and fission integral values and their uncertainties in the energy region of interest for nuclear astrophysics.	Completed. Results for solar system ENDF/B-VIII.0 r-process abundances were published in J.Phys.(London) G48, 08LT01 (2021).
Evaluate nuclear astrophysics potential of EXFOR library.	Ongoing activity. Work on Karlsruhe MACS updates for the EXFOR project Area #1 are finished, and updates for the Area #2 are in progress.

LANL Planned Activities	**Status**
Continue improvement of neutron capture, beta-delayed neutron and fission modellings for s- and r-process hydro-dynamics simulations.	Improvement of astrophysical reaction rates continued. For the r-process, both neutron-induced and beta-delayed fission processes were included.
Develop a Monte Carlo simulation using Geant4, to be implemented for radioactive nuclear reaction analysis at Time of Flight facilities, in the interest of providing direct reaction cross sections for better understanding of heavy element productions.	Further progress was made to validate the Geant4 modeling against MCNP and LENZ experimental data. The final results with great agreement between MCNP and Geant are ready for journal submission.

ORNL Planned Activities	**Status**
Continue assessments of capture reactions on p-rich unstable nuclides that are important for novae and X-ray bursts. The nuclei to be studied are those planned for measurements at radioactive beam facilities.	Progress was made on converting central thermonuclear reaction rate values with uncertainties in the STARLIB and NACRE II collections into the REACLIB parameterized format. Temperature-averaged uncertainties (over hydrodynamic profiles) were generated for

	use in astrophysical simulations. Improvements for REACLIB were proposed that would enable the incorporate of rate uncertainties. Continuing work on assessments of ^{42}Ti(p, γ), ^{59}Cu(p,γ), and ^{59}Cu(p,α) reactions at high temperatures for X-ray burst nucleosynthesis.

H. Covariances Development

BNL Planned Activities	Status
Develop low-fidelity fission yield covariances consistent with the ENDF decay sublibrary and with measured yields. This project would allow us to develop expertise for the upcoming Fission Yields CRP.	Activity funded by another sponsor (NA-22).

LBNL Planned Activities	Status
Continue to develop an experimentally driven fission covariance database.	A manuscript containing Fission Product Yield covariances was published in Atomic Data and Nuclear Data Tables (ADNDT Vol. 140, July 2021, 101441) and is being disseminated on the LBNL group website (https://nucleardata.berkeley.edu/FYCoM/index.html). Work began under USNDP funding, now transitioned to NA-22.

I. Reactor Antineutrino Spectra and Decay Heat Calculations

BNL Planned Activities	Status
Improve our methods and databases to calculate antineutrino spectra for major actinides.	Continuing working on the use of cumulative fission yield correlations.
Perform decay-heat calculations in collaboration with experimental groups.	No requests were made.
Possibly participate in relevant experiments.	Participated in experiment at ANL using the MTAS setup.

J. Verification and Validation

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

contributors funded with non-DOE-SC sources. The USNDP supports the ultimate validation effort carried out at BNL.

BNL Planned Activities	Status
Maintain automatic, real-time verification and validation of new/modified ENDF evaluations submitted to the NNDC GitLab server.	Ongoing task. A new server replaced an older, less capable one.

Appendix A – Additional Funding Sources

ANL

Additional support for the nuclear data work comes from two LAB 18-1903 funded proposals (DOE/SC/NP and DOE/NNSA/NA-22) and two LAB 19-2114 funded proposals (DOE/SC/NP).

BNL

Additional support for the nuclear data work at the National Nuclear Data Center (NNDC) comes from the following sources:

1. The US Nuclear Criticality Safety Program (NCSP) supports the NNDC services in maintaining NCSP data submitted to the ENDF/B library as well as data development work on evaluations of neutron cross section covariances for criticality safety applications.
2. The Fission in Rapid Process Elements (FIRE) collaboration.
3. Evaluation of energy dependent fission product yields, funded by NA-22.
4. NA-22 Intentional Forensics Venture, a project to develop a tagging system for nuclear fuel.
5. DOE-NE's Nuclear Energy University Program (NEUP) to serve on thesis committee of RPI student developing Pb evaluations for ENDF.
6. High precision decay measurements of isotopes relevant to nuclear forensics, funded by NA-22.
7. Brookhaven National Laboratory Program Development funds used to establish in-house capabilities for decay data measurements.
8. Three NDWIAG FOA-funded proposals:
   - Modernization and optimization of the Evaluated Nuclear Structure Data File
   - High precision decay measurement of isotopes relevant to nuclear medicine
   - Perform total absorption gamma spectroscopy (TAGS) measurements of fission products
   - ^{238}U(n,n'g) evaluation using neutron-gamma coincidence (in collaboration with LBNL and LANL)

LANL

Additional supports for the nuclear data project are as follows:

1. Advanced Simulation and Computing under NNSA.
2. The US Nuclear Criticality Safety Program (NCSP).
3. Evaluation of energy dependent fission product yields, funded by NA-22.
4. Fission in R-Process Elements (FIRE) collaboration.
5. LANL-LDRD to develop transmission measurement capability for studying radionuclides at LANSCE.
6. Science Campaign support under Office of Experimental Sciences by NNSA.

LBNL

Additional supports for the LBNL nuclear data project are as follows:

1. DOE-NE's Nuclear Energy Advanced Modeling and Simulation Program (NEAMS) for the 238U and ^{56}Fe(n,n'g) measurement program using GENESIS funded through the FY18 NDIAWG FOA.
2. DOE-NE's Nuclear Energy University Program (NEUP) for measurements on ^{35}Cl for fast reactor design improvement.
3. DOE Isotope Program under 4 grants: (i) The Tri-Laboratory Effort in Nuclear Data (with LANL-IPF and BNL-BLIP); (ii) Production of ^{229}Th (with ORNL); (iii) Isotope production using secondary neutrons from thick target deuteron breakup; and (iv) Production of ^{236g}Np (with LANL, funded through the FY17 NDIAWG FOA).

4. Google Project X faculty support grant for exploring the use of energetic photons and electrons to transmute nuclear waste through photoexcitation.
5. Defense Threat Reduction Agency (DTRA) for the development of a gamma-ray/X-ray coincident database for nuclear forensics (with PNNL).
6. NNSA/NA-22 for the measurement of fission product yields at the LBNL 88-Inch cyclotron funded through the FY18 NDIAWG FOA.

LLNL

Additional supports for the LLNL nuclear data project are as follows:
1. Advanced Simulation and Computing under NNSA.
2. The US Nuclear Criticality Safety Program (NCSP).
4. ENSDF modernization project.

MSU

Data activities are supported by U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No. DE-SC0016948.

ORNL

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

TAMU

Data and experimental activities supported by U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No. DE-FG03-93ER40773.

TUNL

The nuclear data work is partly funded by the U.S. Department of Energy, Office of Science, Low Energy Nuclear Physics program through a TUNL/NCSU grant.

Appendix B – Non-USNDP funded nuclear data work

This appendix was added to voluntarily capture additional nuclear data work performed at USNDP sites.

Brookhaven National Laboratory

BNL scientists are engaged in a number of non-USNDP funded nuclear data activities, most notably with the continued support of the National Criticality Safety Program (NCSP) and the Defense Nuclear Nonproliferation (NA-22) Program. Currently the NCSP partly funds the operation of the Evaluated Nuclear Data File library project, in conjunction with the USNDP. The NCSP also funds development of analytical methods for thermal neutron scattering data and unresolved resonance probability distribution generation and a neutron resonance spingroup assignment machine learning project. NA-22 funds several projects as a direct result of the Nuclear Data Interagency Working Group proposal process. These projects include measurements of decay data relevant for non-proliferation, library development to support active neutron interrogation, and data work supporting the intentional forensics mission.

Lawrence Berkeley National Laboratory

LBNL Leveraged Activities	Status
Dissemination of the "Baghdad Atlas" database of Gamma-ray emission from the inelastic scattering of reactor fast neutrons.	This work began with USNDP funding and is now being carried out under NA-22 funding.
Dissemination of the Curie Data Analysis Software Package. Curie uses data from EXFOR, TENDL and ENSDF decay data to facilitate the analysis of activation data.	Distribution of the Curie package is carried out using github (https://jtmorrell.github.io/curie/build/html/index.html)
Development of a new Database of gamma-ray/X-ray coincidences.	The Berkeley group is working with PNNL using both DTRA and USNDP support to produce a JSON-formatted database of decay data for select nuclei of interest for nuclear forensics applications. This work is ongoing.

Lawrence Livermore National Laboratory

Livermore Laboratory has had a program for nuclear data for almost 60 years, and this has been often independent of the national ENDF library format. In that time, LLNL has made its own ENDL libraries in format designed for punched cards, and it has its own groups of evaluators leading to revisions about twice per decade. In the 70s the ENDL libraries were described by a comprehensive series of 20 descriptive volumes published under the label of UCRL-50400.

Because this original ENDL format was less flexible than the ENDF format, in the recent decade we have had some incentive to make more modern data structure, and this led us to designing, coding and translating the new Generalized Nuclear Data Structure (GNDS). This GNDS method is now maintained internationally by WPEC, and it is used internally at LLNL for all stages of the nuclear pipeline from decay models, data storage, translation, testing and processing for transport codes. It is the most comprehensive method for interchange of nuclear data and is becoming widely adopted as the preferred future standard.

The nuclear data that LLNL uses comes from a variety of sources. We examine existing libraries to determine which provides the best description of nuclear cross sections, and often use our own models for neutron reactions and decay processes. We have optimized our own Hauser-Feshbach models for neutron reactions on a wide variety of fission fragments and other nuclides of use for radiochemistry. As one of the first labs to comprehensively transport both neutrons and charged particles (isotopes of hydrogen and helium) we have a comprehensive library of low-energy charged-particle evaluations, with particular attention to exothermic reactions on targets up to lithium isotopes.

In the last 15 years the experimental groups at LLNL have been using the indirect 'surrogate' method to measure cross-sections for which direct detection is unavailable, and the results have been made into GNDS evaluations to determine the effects of the new cross-sections. We test all evaluations by comparison with the standard database of critical-assembly measurements and also by comparison with the pulsed-sphere measurements once performed at LLNL. New critical assemblies are being created, measured and modeled. The national collaboration to use a Time Projection Chamber to measure actinide and standard cross-sections is being led by LLNL experimentalists. We have used both ENDL and ENDF processed libraries in transport codes for programmatic work.

The USNDP provides a small contribution to the LLNL nuclear data team to enable the sharing of in-house data products with the national community. Our GNDS work is funded outside USNDP and has provided thorough checks of the ENDF libraries submitted by various groups.

Appendix C – Fiscal Year 2021 Articles authored by USNDP staff

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