Progress Reports from the US Nuclear Data Program: Nuclear Reaction Data 4/98 — 4/99

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Abstract

This document compiles informal progress reports from laboratories participating in the US Nuclear Data Program, and focuses on nuclear reaction data work from April 1998 - April 1999.

I. LANL Group T-2: Chadwick, Hale, MacFarlane, Young, Madland

A. Nuclear Astrophysics

We have continued evaluations of light-element cross sections important in astrophysics. From R-matrix analyses at Los Alamos of the ^{5}He, ^{16}O, and ^{17}O systems, new evaluated cross sections have been obtained for the reactions ^{3}He(d,p)^{4}He, ^{12}C(α,γ)^{16}O, and ^{13}C(α,n)^{16}O. We also recently restarted an analysis of low-energy N+N scattering with deuteron photodisintegration data added, in order to obtain an improved evaluation for n+p capture in the region of importance for big-bang nucleosynthesis.

We have also developed a capability to model photonuclear reactions with the GNASH code, which utilizes Hauser-Feshbach theory, for the prediction and analysis of photonuclear cross sections in astrophysics. We are chairing an IAEA Coordinated Research Program on this subject.

B. Radioactive Ion Beam (RIB) Applications

Group T-2 hosted two 2-day workshops on "The CINDER'90 Code and Nuclear Data for Radioactive Ion Beam Applications", which were attended by researchers from ANL, ORNL, and LBNL. New Radioactive Ion Beam facilities that are being designed will require detailed simulations of the radioactivity produced in the target, beam-line, and beam-stop. The Los Alamos CINDER code, linked with an intranuclear cascade code, can be used for these simulations. CINDER incorporates an extensive database of nuclear decay properties, allowing the time-dependence of the induced activity to be determined.

Nuclear reaction data are needed in the design of RIB targets. Specifically, excitation functions are needed for the production of various proton- or neutron-rich nuclides. In most cases, no measurements exist, and therefore predictions are needed based on theory. We have worked with RIB researchers at ANL and ORNL to determine priority production cross sections that are needed. To address these needs, we have : (1) generated an extensive database of all production excitation functions, for incident protons and neutrons, on over 600 targets. This utilized the newly developed Hybrid Monte Carlo Simulation preequilibrium model we developed, with Blann, included in the HMS-ALICE code; (2) For specific high-priority reactions, we performed detailed calculations with the GNASH reaction code, with guidance from measurements where available, producing 33 new ENDF evaluations. These evaluations are being included into the Brookhaven NNDC databases.

An important ingredient in the above RIB calculations is the optical model, used to calculate particle emission transmission coefficients. We have made progress in developing global potentials, in the 20-2000 GeV, paying close attention to isospin dependencies that allow the potentials to be used far from stability — an important consideration for RIB.

C. Level densities, isospin effects, and GEANIE

Nuclear level densities play an important role in the calculation of nuclear reaction data. We have continued our collaboration with Haight and Grimes at LANSCE/WNR to analyze newly obtained ^{28}Si(n,z) and ^{58,60}Ni(n,z) experimental data (z representing charged-particle ejectiles). The reactions were interpreted in terms of Hauser-Feshbach, and preequilibrium emission mechanisms, and the data allowed us to infer the magnitude of the total level densities in the targets, and in the residual nuclear systems. The data also provided interesting information on the role of isospin conservation in nuclear reactions. This work has been submitted to Phys. Rev. C for publication.

We have also collaborated with experimentalists at LANSCE (including Becker, from LLNL) on the interpretation of new g-ray data measured using the GEANIE detector. Our principal progress has been on the interpretation of nuclear reaction mechanisms in the actinides, in the presence of fission. This is leading to improved cross section data for reaction channels that were previously poorly-understood.

D. Nuclear data for medical radiotherapy applications

Nuclear reaction data on biologically-important materials are needed for improved simulations of energy deposition, and relative biological effect, in proton, neutron, and photon cancer therapy. Through chairmanship of an International Commission on Radiation Units and Measurements (ICRU) report committee, we have developed nuclear reaction databases for these applications, and have completed a new ICRU report, to be published this year. The databases will be archived at the NNDC.

E. Light nuclei data

We continued our collaboration with Tilley, Weller, Ludwig, and others at TUNL on nuclear structure and data analyses. Resonance parameters from our analyses of ^{5}He and ^{5}Li are reported in the latest A=5 “Energy Levels of Light Nuclei” Nuclear Physics A paper (in press).

F. Nuclear reaction modeling codes

Nuclear reaction modeling codes have played a key role in the evaluation of nuclear reaction data. At Los Alamos, the GNASH code has been particularly useful, together with the EDA R-matrix code. We have embarked on a project to rewrite the GNASH code using FORTRAN90, with modern coding practices, and to include various additional reaction theory calculation capabilities. We are also collecting together other useful reaction codes, such as Blann's new HMS-ALICE, and Kalbach's preequilibrium codes, to provide an archive for interested users.

G. WWW dissemination and NJOY data processing

We have maintained our support and development of the NJOY data processing code, and recently participated in the NJOY User Group Meeting in Paris.

The T-2 Nuclear Information Service WWW site has been expanded to include access to, and graphical representation of, many new data compilations.

II. Duke University, C. Kalbach

The following progress has been made:

Included simple model (Kalka '89) for strong collective states in PRECO-E
Started some work on looking for systematics in parameters for these states.
Study of the relative surface effects in n- and p-induced reactions

This last is important in the long-playing question of finding a preequilibrium model that will fit all four (N,N) channels with a consistent set of input.

Future priorities include:

Complete work on surface effects and write it up for publication
Extend studies to the 60-200 MeV range looking for behavior of the preequilibrium damping matrix element Consider looking for systematics in E_λ and β_λ for the collective states in case these are needed for systems well off the stability line.

III. NNDC, BNL, V. McLane, *et al.*

Issued release 5 of ENDF/B-VI.
We continue entering CPND data. As of Feb. the CSISRS library contains more than 3.3K references for CPND data and almost 600K data points. Total for all data is more than 12K references and approaching 5 million data points.
We have had 4 visitors to help with the data compilation: 2 from Russia, 1 from Ukraine, 1 from Hungary.
We have upgraded all systems to handle the Y2K problem. Programs have been distributed to data centers which use our codes (at IAEA, in Russia, Ukraine and China).

IV. NIST, A. Carlson

Our evaluation efforts this past year have been focused on the re-evaluation of the neutron cross section standards. I am looking at the database for the standards which involves looking at the literature, reading the papers and examining them so that I can prepare the data for use in the upcoming evaluation. We have additional people who are willing to help on this. We have the programs and database used for the simultaneous evaluation portion of the ENDF/B-VI evaluation. I have sent them to Shibata who will be working on that part of the evaluation. We still need to fully update the database before that evaluation can be completed. As you know Gerry Hale will do both the hydrogen and boron R-matrix analyses when the experiments on those standards have been completed. I am still concerned about the combination process. I got Bob Peelle's program which was used for the ENDF/B-VI evaluation but a fair amount of work will be needed before it can be used. It is possible that an alternate approach will be considered. Cadarache has offered to do data testing once the process is completed. I would like to have more people involved in the evaluation.

The analysis of the hydrogen scattering measurement at 10 MeV (the LANL-OU-NIST collaboration) is in progress.

V. ORNL Nuclear Data Project, M.S. Smith, et al.

A. Overview

We have a new program of evaluating and disseminating nuclear datasubsection of vital importance for studies in nuclear astrophysics. Research programs in nuclear astrophysics address some of the most fundamental questions in nature: What are the origins of the elements that make up our bodies and our world? How did the solar system, the sun, the stars, and the galaxy form, and how do they evolve? Measurements in the nuclear laboratory form the empirical foundation for the sophisticated theoretical models of these astrophysical systems. In many cases, however, new nuclear physics measurements are not rapidly disseminated to the research community nor rapidly incorporated into astrophysical models. For this reason, progress in many fundamental problems in nuclear astrophysics can be significantly aided by more effectively utilizing nuclear data. The ORNL effort addresses this problem by providing new evaluations of important reactions and disseminating them to the research community in user-friendly formats that are easily incorporated into astrophysics models. Our evaluation work is focused primarily on capture reactions on radioactive isotopes on the proton-rich side of stability - reactions that are important for understanding the element synthesis and energy generation in stellar explosions. We are also working on reactions that are important for understanding Red Giant Stars and the Solar Neutrino Problem. Our work utilizes the latest advances in Internet- and WWW-based information services to disseminate evaluated data to the astrophysics research community.

Additionally, M.S. Smith chairs an Astrophysics Task Force which submitted a proposal to the DOE for a coordinated U.S. Nuclear Astrophysics Data effort involving 5 national laboratories (ANL, LBNL, LLNL, LANL, ORNL) and one university (University of California at Santa Cruz). A funding decision on this proposal is still pending. Previous efforts in organizing nuclear

astrophysics data activities led by ORNL have included an extensive documentation of the overlap of expertise of the nuclear data community with the needs of the nuclear astrophysics community. This information is posted on our nuclear astrophysics data website [1].

Lists of nuclear astrophysics data projects for the period April 1998 to April 1999 follows.

B. Nuclear Astrophysics Data Projects 4/98 - 4/99

1. Evaluation of the $^{17}O(p,\alpha)^{14}N$ Reaction Rate

This reaction is very important in determining the relative abundance of oxygen isotopes in the envelopes of Red Giant stars, which can be used as a tracer of the convection process occurring in these stars. This reaction is also important for interpreting oxygen isotope anomalies observed in meteorites. A recent measurement of this rate [2] changed the previous rate estimates by more than a factor of 10 at certain temperatures. Our work, still in progress, will give a complete expression for the current $^{17}O(p,\alpha)^{14}N$ rate incorporating all recent experimental information in a format that can be easily incorporated into astrophysics models. The final rate and plots will be posted at our WWW site.

2. Evaluation of the $^{18}F(p,\alpha)^{15}O$ and $^{18}F(p,\gamma)^{19}Ne$ Reaction Rates

We have recently started to evaluate two reactions that are very important for understanding of stellar explosions such as nova and X-ray bursts: $^{18}F(p,\gamma)^{19}Ne$ and $^{18}F(p,\alpha)^{15}O$. These are among the so called "explosive hydrogen burning reactions" that were identified by the Astrophysics Data Steering Committee in 1996 as being a high priority to evaluate. These two reactions in particular are important because they help determine the amount of stellar material that can be processed from the mass $A \geq 20$ region to higher masses. Our evaluation work will provide reaction rates which incorporate all the recent indirect measurements and the newest direct measurements with radioactive ion beams.

3. Solar Fusion Reaction Rate Assessment

A new evaluation of the cross sections for the 19 reactions of greatest importance to the study of the solar interior has recently been made by Adelberger *et al.*[3] We will convert these cross sections into reaction rates in an analytical format easily input into astrophysics models, compare the analytical approximations with the rates derived from numerical integration, determine the rate uncertainties from the cross section uncertainties, and examine the differences between these new rates and other rate assessments.

4. Improvements to the WWW posting of the Caughlan and Fowler Reaction Rate Collection

We extended the usefulness of our posting of one of the most important reaction rate collections, by Caughlan and Fowler [4], by completing a graphical user interface based on the chart of the nuclides to allow users to search for rates of interest. This collection is a central part of the nuclear astrophysics data that we have posted at the Oak Ridge URL address of http://www.phy.ornl.gov/astrophysics/data/data.html. This new improvement is in addition to improvements made in early 1998 of adding GIF and Postscript plots of each of the rates, along with a technique to automatically regenerate plots if future modifications are needed. We have also calculated the temperature derivatives of these reaction rates, important for coupling nucleosynthesis calculations to hydrodynamics simulations to provide more accurate modeling of stellar explosions. These very complex rate derivatives were posted online in a text format, along with a downloadable fortran subroutine. Members of the research community have informed us that this online rate compilation has been very useful to their work.

5. WWW Posting of Big Bang Nucleosynthesis Rates

Evaluations of the 12 reactions of greatest importance to the synthesis of isotopes in the early universe [5] were posted WWW for the first time, in a format that can easily input into astrophysics models.

6. Nuclear Astrophysics Bibliography

A Nuclear Astrophysics Bibliography has been produced and posted on our WWW site. This is a useful resource for producing evaluations of nuclear reaction and structure information important for astrophysics. This bibliography includes references to astrophysical journals and reports which are outside the normal scope of Nuclear Science References. The first phase of this project, which includes over 1200 references, has recently been completed. It is anticipated that this bibliography will grow steadily in time.

References:

[1] M.S. Smith et al., U.S. Nuclear Reaction Data Network Astrophysics Task Force Report (1995): http://www.phy.ornl.gov/astrophysics/data/task/taskforce_report.html
[2] J.C. Blackmon et al., Phys. Rev. Lett. 74 (1995) 2642.
[3] E.G. Adelberger et al., Rev. Modern Phys. 70, Part 2 (1998) 1.
[4] G.R. Caughlan, W.A. Fowler, At. Data Nucl. Data Tables 40 (1988) 283.
[5] M.S. Smith, L.H. Kawano, R.A. Malaney, Astrophys. J. Supplement 85 (1993) 219.

ANL, D.L. Smith

Analysis of neutron activation cross sections from 16-20 MeV that were measured in 1996 at the IRMM Van de Graaff facility in Geel, Belgium, has been completed and a paper has been submitted for publication. A new set of measurements was performed at the IRMM facility during May-June 1998 as part of an on-going collaboration between Argonne, IRMM, and JAERI. Experimental and evaluated data for neutron-induced hydrogen production reactions on

vanadium have been compiled and critically examined. This investigation led to a recommendation that ENDF/B-VI evaluations for the (n,np+pn) and (n,t) processes be revised. These revisions lead to a reduction by a factor of $\approx$3 in hydrogen production from vanadium at 14 MeV neutron energy. The compilation of (p,α) and (p,γ) cross-section and resonance-parameter data for several isotopes of sulfur is now in progress. This information will be published in an Argonne report and posted on the World Wide Web to guide the evaluation of cross sections relevant to stellar hydrogen burning. They are used in the nucleo-synthesis network calculations for astrophysics.

A. Neutron Activation Cross-Section Measurements from 16-20 MeV

Data analysis for an experiment performed in 1996 at Geel, Belgium, in collaboration with IRMM and JAERI has been completed. A manuscript entitled “Neutron Activation Cross Section Measurements from 16 to 20 MeV for Isotopes of F, Na, Mg, Al, Si, P, Cl, Ti, Mn, Fe, Nb, Sn, and Ba" has been submitted for publication to Nuclear Science and Engineering. Cross-section data for 22 distinct reactions have been acquired through this investigation. Detailed comparisons with existing experimental data and evaluations from the literature are included in this paper along with a detailed analysis of experimental errors.

A new set of neutron activation measurements was carried out at IRMM during May-June 1998 as part of the continuing collaboration between ANL, IRMM, and JAERI to investigate cross sections for reactions leading to short-lived radioactive byproducts. The emphasis continues to be on the energy range 16-20 MeV. This work utilized in part a new sample transport mechanism that permitted measurements to be made for reactions involving products with half lives as short as 3 seconds. Use was made of isotopically enriched sample materials obtained on loan from JAERI. The neutron activation data acquired at IRMM during this period will be analyzed in the months ahead. Additional measurements are also needed to finish this project and they will be carried out following completion of the facility refurbishment project at the IRMM Van de Graaff accelerator laboratory.

B. Hydrogen Production in Vanadium

The status of neutron cross section data for hydrogen production from 14-MeV neutron interactions with vanadium (99.75% ^{51}V) has been examined. It was found that exclusive use of ENDF/B-VI cross sections for these processes leads to an over-prediction of hydrogen production by a factor of 3, with important consequences for the analysis of radiation damage of vanadium structures found within fusion reactors. The problem was traced to an excessively large evaluated (n,np+pn) cross section in ENDF/B-VI. A new evaluation of the hydrogen producing reactions in vanadium has been performed. It recommends preserving the ENDF/B-VI values for (n,p) and (n,d). The ADL-3 (Russian) evaluation for (n,np+pn) was found to be in reasonable agreement with recently located experimental data so it is recommended for future use. Finally, nuclear-model calculations were performed with code GNASH to provide the (n,t) evaluation. A paper is being prepared on this work.

C. Production of ^{26}Al in Fusion Reactors

The production of long-lived radioactive ^{26}Al in fusion reactors has been investigated. The processes considered were the ^{27}Al(n,2n)^{26}Al reaction occurring in trace quantities of aluminum and the ^{28}Si(n,np+d)^{27}Al(n,2n)^{26}Al sequential reaction processes in silicon carbide, a compound which is presumed to qualify as a low activation candidate structural material for fusion reactors. It was decided that the cross section data for ^{28}Si(n,np+d)^{27}Al are very uncertain whereas the values for ^{27}Al(n,2n)^{26}Al are much better known due to recent work at IRK, Vienna. It has been concluded that until the pertinent data for the silicon reactions are improved it will not be possible to perform reliable estimates of ^{26}Al production from silicon carbide residing in a fusion neutron environment.

Data Compilation for Astrophysics

Information on level properties, resonance parameters, and cross sections have been compiled for the ^{33,34,36}S(p,γ) and ^{32,33,34,36}S(p,α) reactions in preparation for a detailed evaluation of these processes for applications in nuclear astrophysics. Most of this work was performed by a student from Hiram College, Ohio, through the Argonne National Laboratory Student Research Participation Program.

In the next stage of this project, the compiled data for ^{33,34,36}S(p,γ) and ^{32,33,34,36}S(p,α) will be organized. Summaries of the references and tabular information will be issued in Argonne reports and this information will also be made available on the World Wide Web. Procedures will be developed for calculating the direct proton capture strength associated with (p,γ) and (p,α) reactions on A = 30-50 nuclei. A search will be made for possible missing low-energy proton resonances through consideration of more complex transfer reactions such as (^{3}He,d). Knowledge of the existence of these resonances is needed in order to produce reliable evaluations of the hydrogen burning reactions which are required for nuclear astrophysics applications.

LANL LANSCE/WNR, R.C. Haight

Work completed in the past year:

^{27}Al(n,xγ) from 3 to 400 MeV (Pavlik, *et al*.). Published in Phys Rev C.

Silicon(n,z) from threshold to 60 MeV, submitted to Phys Rev C.

Total neutron cross sections from 5 to 600 MeV (Werner Abfalterer et al. -- report will be available in about 2 weeks, PRC article is in preparation and might be done by then, PRL article on H and D published in 1998).

^{9}Be(n,α)from threshold to 50 MeV (Not completely finished. Might be by April).

^{16}O(n,xγ) (Report being finished by Ron Nelson, Andre Michaudon and Darrell Drake).

Report on radioactive products of 800 MeV proton spallation by John Ullmann (nearly finished).
There has been a lot of work on GEANIE, but the only final numbers to my knowledge are for ^{196}Pt(n,xγ) in the PRC article by Lee Bernstein (PRC 57, R2799 (1998)).
Continuation of (n,γ) studies on radioactive nuclei. Design of the DANCE detector (capture on radioactive targets for astrophysics) is continuing full speed.
Neutron-proton Bremsstrahlung: In progress.

VIII. Ohio University, S.M. Grimes and T.N. Massey

During the past year, work focused on research in the areas of neutron sources, total cross sections and spectroscopy of light nuclei.

Measurement of the stopping target (d,n) spectra from ^{9}Be(d,n), ^{11}B(d,n) and ^{27}Al (d,n) have been made at 2.5, 5 and 7.5 MeV. These cross sections are fairly smooth as a function of outgoing energy at 60^{o}, even though the structure is complicated at 0E. Measurements at the top energy were done with a fission chamber to obtain absolute cross sections. These spectra were then remeasured with a lithium glass detector, which allowed the determination of the efficiency of this detector. The lithium glass detectors were then used to make the measurements at 2.5 and 5 MeV.

The neutron spectra for the ^{9}Be(p,n) reaction are of interest in planning neutron irradiations for cancer treatment. We have completed measurements at 3.4, 3.7 and 4 MeV with stopping targets over the angular range 0 to 150 degrees. Similar studies are also underway for the ^{9}Be(d,n) reaction between 3 and 7 MeV.

Two papers have been published within the last year reporting on applications of the Ramsauer model to parameterizing the neutron total cross section of a number of elements up to 120 MeV. A further study on extending these fits to 600 MeV is underway.

A paper reporting the parameters of an excited state in ^{7}He has recently been submitted for publication.

A comprehensive comparison of the level densities of nuclei with $20 \leq A \leq 41$ with the predictions of a model including two-body interactions has recently been completed. This work has been submitted for publication.

Neutron-proton elastic scattering at 10 MeV is being studied in collaboration with LANL and NIST and cross sections for (n,z) on silicon are being measured in collaboration with LANL.