USNDP Astrophysics Task Force
Activity Report

November 2003

A number of efforts within the U.S. Nuclear Data Program (USNDP) either directly or indirectly help improve our understanding of a wide range of exciting astrophysical phenomena such as stellar explosions, the interior of our sun, Red Giant stars, and the early Universe. This work includes evaluations of particular nuclear reactions or the properties of specific nuclei, development of nuclear models to calculate unmeasured properties, and data processing and dissemination in formats requested by astrophysicists as well as in standard NNDC formats. There is also an effort to develop tools to facilitate evaluation processing and dissemination. The work done by members of the Nuclear Astrophysics Data Task Force spans the activities done within the USNDP Nuclear Reaction and Nuclear Structure Working Groups. A brief discussion of these research efforts is given below.

Compilations & Evaluations

At BNL, work continues on a project to compile and evaluate alpha-induced nuclear reaction cross sections, focusing on light- to medium-mass nuclei up to Z = 32 and alpha particles with energies up to ~ 20 MeV. A number of these reactions are of interest in astrophysics. This work is done in collaboration with scientists from the Former Soviet Union (Russian Federal Nuclear Center), and is funded by the US Civilian Research and Development Fund for the Former Soviet Union (CRDF). The compilation, optical model calculations, and evaluations will be used to generate improved alpha-nucleus potentials and thermonuclear reaction rates.

At LANL, the n-p capture reaction – crucial for studies of the early Universe – is being investigated with R-matrix theory. Fits with accuracy of 0.2 – 2.5 % have been obtained by combining N-N scattering, capture, and photodisintegration data. Calculations have also been made for the TUNL Energy Levels of Light Nuclei (A=5-7) evaluation. Additionally, LANL is collaborating with ORNL on R-matrix calculations on ORNL measurements of the ^{17}F(p,p), ^{17}F(p,p'), and ^{17}F(p,α)^{14}O reactions to determine an improved stellar ^{14}O(α,p)^{17}F reaction rate. This reaction is crucial for energy generation in X-ray bursts.

At McMaster University, a brand new effort has been funded to perform evaluations of reactions on radioactive isotopes important in stellar explosions. The emphasis will be on reactions that will be measured at TRIUMF's ISAC radioactive ion beam facility. Reactions of interest include ^{13}N(p,γ)^{14}O, ^{15}O(α,γ)^{19}Ne, ^{19}Ne(p,γ)^{20}Na, ^{18}Ne(α,p)^{21}Na, ^{21}Na(p,γ)^{22}Mg, and ^{25}Al(p,γ)^{26}Si.

At ORNL, an evaluation of the ^{18}F(p,□) and ^{18}F(p,□) reactions, important for understanding stellar explosions, has nearly been completed. A Ph.D. thesis was successfully defended on this work and a short paper published, with a longer paper is in preparation. Recent results from an ORNL Holifield Radioactive Ion Beam Facility measurement of the ^{18}F(d,p)^{18}F reaction are being incorporated into this evaluation, as well as new Thomas-Ehrman level shift calculations and an improved non-resonant reaction rate calculation. The new reaction rates will be put into formats requested by astrophysicists and distributed over the WWW. An evaluation is being made, in collaboration with LANL, of the ^{14}O(□,p)^{17}F reaction via R-matrix calculations on ORNL measurements of ^{17}F(p,p), ^{17}F(p,p'), and ^{17}F(p,□)^{14}O. Additionally, the levels in ^{34,35}Ar and ^{31}S relevant for proton capture reactions on ^{33,34}Cl and ^{30}P, respectively, are being assessed for studies of stellar explosions. This work is also coupled to future planned measurements with radioactive beams at ORNL.

At TUNL, the evaluation "Energy Levels of Light Nuclei: A=5-7" has been published in Nuclear Physics A, posted online, and incorporated into ENSDF. This work is important to astrophysics research because a number of reactions induced on light ions [e.g., ^{3}He(d,p)^{4}He and t(d,n)^{4}He] are dominated by individual resonances detailed in these evaluations. Additionally, a preliminary version of the A = 10 evaluation has been released.

Development of Evaluation and Processing Tools

At ANL, considerable effort was devoted to the issue of handling quantities that are positive definite and which have very large uncertainties – for example, the reaction rates used in calculations of stellar element synthesis. The lognormal distribution is the appropriate way to represent such quantities, and confidence intervals, rather than the traditional mean values and standard deviations, are employed. This work was done in collaboration with Hiram College. A collaboration led by ORNL is utilizing this new large-uncertainty formalism in simulations of the synthesis of nuclei in nova explosions.

At ORNL, a new computational infrastructure is being developed to facilitate the incorporation of nuclear physics evaluations into astrophysics models. The infrastructure consists of a suite of computer codes synthesized into an all-in-one, user-friendly, robust computational package accessible through a web browser. It will enable users, by a series of mouse clicks, to insert their latest evaluations into the reaction rate libraries used by astrophysicists. It will also enable users to create custom libraries tailored for their particular application, which can easily be reproduced by other uses wishing to perform consistency checks on, for example, element synthesis calculations. Also at ORNL, a novel effort is underway to gauge the influence of nuclear reaction rate uncertainties (such as those determined from detailed cross section evaluations) on element synthesis predictions in stellar explosions. This work is done in collaboration with ANL and utilizes lognormal distributions of reaction rates in a Monte Carlo approach to element synthesis studies.

Disseminations

At ORNL, the **www.nucastrodata.org** site was developed to link together all datasets relevant for nuclear astrophysics studies. Additionally, this site features the **RATEPLOTTER** program, which gives users quick, user-friendly access to over 60,000 thermonuclear reaction rates in the REACLIB library via a web browser. This program, as well as the above website, will be integrated into the computational infrastructure (discussed above) being developed for nuclear astrophysics studies.

Nuclear Theory

At LANL, improved global microscopic - macroscopic predictions of β decay with first-forbidden transitions have been carried out. The inclusion of first-forbidden transitions significantly improves the global agreement with measured β lifetimes. These new lifetime predictions were used in site-independent calculations of the rapid neutron capture process (r-process) believed to occur in supernovae, and resulted in a significant speed up of nuclear burning (matter flow) near the closed neutron shells. A collaborative study (with experimentalists) on the β decays of neutron-rich unstable nuclei $^{94-99}$Kr and $^{142-147}$Xe was completed. Additionally, a new study of fission barriers far from stability was carried out using a multimillion-grid-point 5-dimensional deformation space. This new model will help improve predictions of the fission of heavy neutron rich nuclei in unmeasured mass regions. This work may also help influence estimates of the age of the Universe through studies of heavy element abundances – the so-called cosmochronometers – because fission is ignored in many previous cosmochronometry studies.