Future of Nuclear Data for Nuclear Astrophysics

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Abstract. Nuclear astrophysics is an exciting growth area in nuclear science. Because of the enormous nuclear data needs of this field, it has an exciting potential to boost nuclear data activities in the twenty-first century. Furthermore, the tremendous interest of the general public in astrophysics makes this area of work an excellent vehicle for wide exposure of nuclear data activities. Unfortunately, decreasing data evaluation manpower, the difficulty of processing nuclear data into formats compatible with astrophysical models, and a lack of a coherent future plan have brought about a crisis in nuclear data for nuclear astrophysics. It is imperative to take action now before the situation worsens - especially before new future facilities begin operation. A number of specific actions are proposed to help ensure that nuclear data is rapidly incorporated into astrophysical models in the future.

MOTIVATION

Nuclear astrophysics research addresses some of the most compelling 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? This area of research is one of the fastest growing in nuclear science. Measurements and theoretical descriptions of microscopic nuclear physics phenomena provide a foundation for sophisticated models of macroscopic astrophysical systems ranging from the Big Bang to the inner workings of our own Sun to the explosions of stars. These models are increasingly challenged by observations from space- and ground-based instruments that provide an incredibly detailed view of the Cosmos. The ability of astrophysical models to explain these observations strongly depends, in many instances, on the input nuclear data, and the latest models require more extensive and precise sets of nuclear data than ever before. In fact, progress in solving numerous astrophysical puzzles hinges on the availability of accurate, comprehensive sets of nuclear data that incorporate the latest laboratory measurements and theoretical results. Additionally, the enormous nuclear data needs in astrophysics coupled with tremendous interest of the general public make it an excellent vehicle for wide exposure of nuclear data activities.

Dedicated efforts in data compilation, evaluation, processing, and dissemination are needed so that nuclear physics results can be rapidly inserted into astrophysical simulations. Unfortunately, the manpower base for this work is eroding just as the rate of production of new results is increasing. Furthermore, the process of converting laboratory results into entries in a database is currently quite complicated and requires the use of numerous computer codes and multiple steps (often performed by numerous individuals). For these reasons, it is not uncommon for updates of vital nuclear datasets to take years (in some cases decades), and many of the best datasets are not freely shared within the community. The completion of future facilities such as the Rare Isotope Accelerator (RIA) will only exacerbate these problems by providing a surge of new data to evaluate. There is, unfortunately, neither sufficient manpower nor a plan to rectify this situation. If nothing is done, public databases will become hopelessly outdated, simulations using these databases will become untrustworthy, private proprietary databases will become the norm, and the community will be divided into those that have access to the latest data and those that do not. It will then become extremely difficult to compare simulations done by different research groups.

The field is in a crisis, and it is imperative to take action now before the situation worsens. There are, fortunately, a number of strategies that can enable a more effective utilization of nuclear physics information in astrophysics simulations. These include: increasing evaluation manpower in both the nuclear data and nuclear astrophysics communities; improving communication between ongoing evaluation centers and between evaluators and astrophysicists; streamlining the process of converting lab measurements into reaction rates; and developing a system to generate, manage, and visualize nuclear astrophysics datasets. Additionally, the future longevity of nuclear data work may require sweeping changes in the way that these activities are carried out and funded.
DATA EVALUATION STRATEGIES

There are a number of strategies that will improve the timeliness of nuclear data evaluations, including: boosting the available evaluation manpower within both the data and research communities; devising mechanisms to ensure that evaluations are focused on the highest-priority projects; and developing software to make evaluations easier to complete.

The highest priority is to reverse the decrease in evaluation manpower. In the US nuclear data community, 85% of the evaluators are currently over the age of 55, and there is no plan in place to transfer their collective knowledge to a younger generation of scientists before their retirement. This crisis could not come at a worst time, as scientists prepare for groundbreaking new facilities such as the Rare Isotope Accelerator (RIA). A major scientific goal of RIA is to explore the limits of stability by populating nuclei never before accessible in the laboratory—many of these of vital importance to astrophysics. The nuclear science community needs to build up its nuclear data evaluation infrastructure to prepare for the onslaught of information expected from RIA. Without devising and implementing a plan to boost evaluation manpower, the community will not be able to respond to this, or other, future developments in nuclear science.

Evaluation manpower can be boosted by attracting young scientists into data activities and retaining them. Three strategies to facilitate this are: coupling evaluations to research and to computer technology; mentoring with experienced scientists; and guaranteeing permanent positions for high performers. The Mentoring in Nuclear Information Technology (MINIT) initiative incorporates these concepts to rebuild and revitalize the evaluation capabilities within the US Nuclear Data Program (USNDP). The approach is to attract and retain a new generation of evaluators into the USNDP, who both benefit from the mentoring of senior evaluators and carry out active research programs. Furthermore, because of the importance of computer programming and information technology in carrying out evaluations and disseminating them to the research community, these evaluators need to be equally comfortable with Java as they are with HTML, as they are with Hamiltonians. We refer to this new breed of evaluators as Nuclear Information Technologists.

MINIT involves hiring, each year, a small number of new postdoctoral appointees for three-year terms. During their first year, the appointees would train with experienced evaluators and information technologists at the National Nuclear Data Center, where the USNDP is managed. During their second and third years, the appointees would be on assignment at a USNDP site, where they would be mentored by senior evaluators and involved in research projects related to their evaluation work. At the end of their third year, the best appointees would be retained as research staff at the USNDP site. Although some appointees may not choose to continue in nuclear data, their working familiarity with data evaluation techniques would greatly benefit the field in the future. The close coupling of research and evaluation activities that is central to MINIT will help attract appointees and keep them at the cutting edge of science, will be healthy for evaluation activities in the future, and has been strongly endorsed by external reviews of USNDP activities.

If pursued for even a few years, such a program would positively change the demographics of the USNDP evaluation manpower workforce. The major investment is in the commitment to promote appointees to staff positions upon completion of their third year. This commitment, which is absolutely crucial to attract young scientists to the data program, only requires a modest enhancement over current funding levels because of the impending retirement of almost all members of the US evaluation workforce. MINIT can revitalize the field by facilitating new projects that cannot now be pursued because of manpower limitations.

The nuclear data community cannot, however, provide all the evaluations needed for research in nuclear astrophysics: new evaluation efforts are needed from the research community. It is crucial to determine both which projects to focus on and how to best carry out these new data activities.

To determine evaluation priorities, calculations are needed to determine the sensitivity of astrophysical simulation predictions (e.g., element synthesis, energy generation) on input nuclear data (e.g., reaction rates, nuclear masses) [1, 2, 3]. It is also important to develop a mechanism to robustly propagate nuclear data uncertainties into reaction rate uncertainties, and then propagate these into astrophysics models to determine uncertainties in astrophysical predictions. Monte Carlo techniques can provide this last connection: utilized for over a decade in big bang nucleosynthesis [4], they are now beginning to be used in stellar element synthesis studies [5].

Advice from experts in the field are also invaluable for setting evaluation priorities. An ad hoc Nuclear Astro Data Steering Committee, with international representation, formed and met in 1996 for this purpose but has not been active since. It would be very beneficial for such a group to form now and lay out a plan for future evaluation studies. It would also be extremely helpful to create a high-priority or “wish” list for evaluations relevant for astrophysics. To formulate such a list, it will be necessary to overcome the natural tendency to keep such information proprietary in order to benefit the research community as a whole.

Programs to effectively carry out these new evaluation projects should be carefully devised. Rather than establishing one enormous project that would be hard pressed
to meet the needs of the entire community, it would be advantageous to launch a number of small, short-term, targeted evaluation efforts. These could more quickly respond to research needs, and would individually require less funding and management. To keep data activities focused on research needs, it is crucial to closely link evaluations with measurement and theory work. This coupling will also facilitate the recruitment of young scientists into data work – vital to the long-term vitality of this activity. While it is important to establish quality control and reasonable uniformity, the development of new “rules” for evaluations are probably not required as extensive guidelines already exist [6], and probably the most important rule for evaluators is to “do your best” [7]. It is also imperative to develop online computational tools to speed up evaluation and rapidly and properly process new evaluations for insertion into astrophysics simulations. Finally, it would be very beneficial to exploit the overlaps in expertise and interests between the nuclear data and nuclear astrophysics communities to avoid duplication of effort and to further studies in both areas.

In new evaluation activities, some features to avoid include: efforts with cumbersome organizational structures; efforts relying solely on volunteer efforts of researchers; efforts promising “complete” databases since one database will never fulfill all data needs; duplication of effort (except in certain cases); developing new data formats (unless absolutely necessary); not giving ample credit for evaluations comprising the databases; insisting on full ENSDF- or ENDF- style evaluations when streamlined evaluations tailored for astrophysical studies will suffice; perpetuating A-chain evaluation strategies that are rooted in history but are not appropriate for astrophysics; and charging for or otherwise restricting access to data generated with public funds.

There are two new evaluation efforts in nuclear astrophysics data. One is a collaboration between Konan University (Japan) and Universite Libre de Bruxelles (Brussels) [8]; a second is a collaboration of 7 Japanese institutes, lead by JAERI, with Los Alamos National Laboratory [9]. Additionally, there is a framework for an effort being investigated in the US [10] which features the establishment of a strong editorial board for oversight and quality control and the publication of evaluations in an online journal to give credit for evaluation work. However, current plans for this initiative call for a volunteer effort to carry out the evaluations.

**NUCLEAR ASTROPHYSICS DATA COORDINATOR**

The importance of improving communication between astrophysics modelers and evaluators and between different evaluation groups cannot be overstated. Advice from experts, as well as results from astrophysics sensitivity studies, must be transmitted back to evaluators to ensure that the highest priority evaluation projects are pursued. A serious effort to improve communication will require dedicated manpower, such as an **Astrophysics Data Coordinator**. Establishing such a position to improve communication, to publicize ongoing evaluation efforts, to seek out new collaborative and funding opportunities, and to recruit new evaluation help from research community would be extremely beneficial for the field. The Coordinator’s duties could also include: maintaining and updating a central WWW site linking relevant datasets; modifying datasets for compatibility with astrophysical codes; and improving data accessibility via the creation of indices, search capabilities, graphical interfaces, bibliographies, error checking, plotting tools, and other enhancements; encouraging and helping coordinate evaluation activities; establishing and maintaining a nuclear astrophysics email distribution list; and publicizing new nuclear astrophysics meetings, experimental results, evaluations and research articles. It would also be beneficial for the Coordinator to maintain an active research program to ensure the data activities truly fulfill research needs. The establishment of a Coordinator would, with only a modest investment, have a strong positive impact on nuclear astrophysics research efforts worldwide.

The success of evaluation efforts directed towards astrophysics research will, however, be difficult without an improvement the attitude of the research community towards data work. While the enhanced communications brought about by a Coordinator will help in this respect, a true attitude shift will require much more than the efforts of one individual. Some longer term solutions for change in the research community include: requiring evaluations of research results to be completed before follow-on funding is given for new measurements; developing strategies for giving credit for evaluation work; making evaluations a required part of research projects; and ending the unnecessary separation (in funding, language, and position descriptions) between “data work” and “research”. In the data community, an important long term solution is to hire scientists who do measurements (or theory) in addition to evaluations, following a natural transition away from “professional evaluators” to positions that equally emphasize research. Additionally, it may be advantageous to fund data activities (including data centers) along with, instead of separately from, measurements and theoretical work.
PROCESSING AND DISSEMINATION

The process of converting nuclear laboratory measurements and theoretical calculations into a format needed by astrophysics simulations is quite complicated and has generally required the use of numerous (often incompatible) computer codes and multiple steps. This contributes to the long delays for incorporating the latest nuclear results into astrophysics models. The development of software codes to rectify this situation is exemplified by a new computational infrastructure for nuclear astrophysics data [12] that is available at nucastrodata.org. This unique suite of computer codes utilizes a simple point-and-click interface to guide users to convert input nuclear structure and reaction information – the products of evaluation activities – into thermonuclear reaction rates in a variety of popular formats, including that of the widely-used REACLIB library [11] which contains over 62000 rates. It also facilitates evaluations and element synthesis calculations. A current list of features of this suite, which is continually being expanded, includes:

- normalize and extrapolate cross sections and s-factors
- combine experimental and theoretical cross sections
- store, manipulate, access, share, and plot cross sections and s-factors
- calculate reaction rates from cross sections or s-factors
- parameterize rates in REACLIB format or generate rates on a temperature grid
- plot rates and access and modify rate parameters
- insert rates into new or existing rate libraries
- create, store, merge, modify, manipulate, access, share, plot rate libraries
- share libraries with colleagues and the research community
- run, store, visualize, and compare element synthesis calculations [13]

This functionality readily facilitates the intercomparison of results from different astrophysics simulations. The host website nucastrodata.org features a comprehensive hyperlinked list of nuclear datasets important for astrophysics simulations available from around the world. The site helps users navigate through these datasets and publicizes them to the research community. Based on feedback from users, this site and its new infrastructure have become valuable assets for the nuclear astrophysics research community.

SUMMARY

Nuclear astrophysics studies rely on, and can bring wide public exposure for, nuclear data activities. However, current datasets for astrophysics are not incorporating new nuclear physics results in a timely fashion. It is imperative to take action now before current problems grow. A number of strategies can help ensure that future nuclear physics results are utilized in astrophysics studies. Astrophysics simulation sensitivity studies, and forming a panel of experts, are advocated to determine the highest priority evaluation projects. These can be addressed by a number of small, targeted, research community-based evaluation efforts combined with recruitment of a new breed of data scientists. The continued development of a new set of online software tools for processing nuclear results and disseminating them to the community is advocated, exemplified by those now online at nucastrodata.org. Also, the establishment of an Astrophysics Data Coordinator Position is advocated to improve communication between evaluators and astrophysicists. Finally, some long term suggestions are made to improve the attitude of the research community towards data work.

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