# The ORNL Controlled Fusion Atomic Data Center

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**Abstract**

The principal mission of the Controlled Fusion Atomic Data Center is the collection, evaluation, and dissemination of atomic collision data relevant to fusion energy development. With the advent of the widespread use of the World Wide Web, the data center's resources are being placed on-line to facilitate their use by end-users (cf. `http://www-cfadc.phy.ornl.gov/`). As this development continues, initially disparate, individually compiled resources will be transformed into integrated tools for retrieving recommended data, or displaying and manipulating the information available. The data center's present capabilities, recent data production/evaluation efforts, and goals for future development are highlighted here.

## 1 Introduction

Since its inception at Oak Ridge National Laboratory in 1958 and formal establishment in 1963, the Controlled Fusion Atomic Data Center (CFADC) has published indexed compilations of bibliographical information and recommended numerical data regarding atomic, molecular, and particle-solid collisions of interest in fusion energy research. Rather than attempting to provide here an exhaustive history of the CFADC and its activities, we briefly summarize the resources available through the data center, primarily through the World Wide Web [1].

## 2 The "Redbooks"

In order to provide convenient recommended sets of atomic, molecular, and particle-solid collision data to the fusion energy research community, the CFADC has periodically published collections containing numerical and graphical data. Owing to their red bindings, these series of volumes have become known in the community as the "Redbooks." Usually a small group of experts has surveyed the existing experimental and theoretical works within a given range of reactions, and determined and catalogued recommended reaction cross sections. The latest series of such collections of recommended cross sections, rates, and numerical fits is entitled "Atomic Data for Fusion" [2]. Since only 500 copies of each volume were originally printed and distributed, the number of users to which these collections have been available was limited. Therefore, we have recently scanned the two most requested volumes and made them available through an indexed set of hypertext links on the data center Web site [1]. Users can view, print, or download the graphical and tabular data of interest directly from the Web.

Furthermore, the recommended data contained in the Redbooks have been recorded in the ALADDIN format, for ease of exchange within the fusion energy research community (see below). In the near future, hypertext linkages of the Redbook pages will allow the user-viewable graphs and tables to be directly linked to these separately organized ALADDIN data entries, and ultimately to

other resources. For example, when a CFADC bibliographic search is performed through the Web interface, Redbook graphical, tabular, and fit coefficient data will be returned in addition to the bibliographic listing. The existence of the Web-based version of the Redbooks will allow them to be updated in the future without the necessity of re-distributing new editions. That is, as data of improved accuracy or for new reactions becomes available which lead to modifications or extensions of the Redbook recommendations, new pages can easily be placed on the Web site.

## 3 The CFADC Bibliography

Another principal product of the CFADC has been a series of published bibliographies. Access to such information is a crucial first step in the process of providing critically evaluated data for applications like fusion energy research. After a long series of publications beginning in the 1960's, the semiannual CFADC bibliographic updates have recently been published along with contributions from other foreign data centers through the International Atomic Energy Agency (IAEA) in volumes entitled "International Bulletin on Atomic and Molecular Data for Fusion." Convenient cumulative indices to the bibliographic entries were published in 1980 and 1987 through the IAEA as well [3].

The ever increasing number of collected entries has lead to a succession of computer-based databases for archiving and organizing this information. Presently, the CFADC makes available entries dating from 1978 to the present (about 30,000 entries) over the Web [1]. This method of dissemination is quite effective in that it allows users unlimited direct access to the full, current database. Efforts are also underway to place the CFADC archival entries (dating from c. 1950 to 1977 and numbering approximately 40,000) on the Web-based system, and to link the bibliographic search engine with other resources such as the Redbooks and ALADDIN. For the benefit of the reader, we also mention that a group lead by the Laboratoire de Physique des Gaz et des Plasmas at the Université Paris-Sud maintains a completely independent general atomic and molecular bibliographic database which can also be searched via the Web (see `http://gaphyor.lpgp.u-psud.fr/`).

## 4 The International ALADDIN Network

Coordinated through the IAEA Atomic and Molecular Data Unit, the CFADC participates in an international network of atomic data centers whose missions involve the support of fusion energy research. Among this data center network's primary activities is the maintenance of a standard format of atomic and molecular data exchange called ALADDIN (A Labeled Atomic Data INterface). Originally developed by Russell Hulse of PPPL, ALADDIN was adopted in 1988 by the network. Almost two dozen collections of recommended or evaluated atomic collision data and particle-surface interaction data exist in this format, representing data for hundreds of individual reactions. This data provides a primary resource for atomic and molecular data for fusion energy research, often directly linked to plasma modeling codes. Furthermore, ALADDIN possesses a FORTRAN interface code through which searches of the data files for individual reaction data can be made, and tabulations from the fitted data coefficients can be outputted.

The data files, computer code, associated evaluation functions, and dictionaries have been distributed from the IAEA A+M Data Unit or the CFADC to interested parties, and are now available through the Web [1] for direct viewing and downloading. Preliminary linkage of the CFADC bibliographic search engine and the ALADDIN files has been recently accomplished and ALADDIN can be run directly over the Web. The IAEA maintains an Internet linkage to ALADDIN and is planning a Web interface. Web-based interfaces will also hopefully lead to flexible, updatable methods of maintaining and enhancing this valuable resource.

## 5 The Atomic Data and Analysis Structure

Developed in collaboration between Strathclyde University and the Joint European Torus (JET) principally by Hugh Summers, the Atomic Data and Analysis Structure (ADAS) is a collisional-radiative modeling suite designed to aid in the interpretation of the spectra of radiating plasmas. Its primary application has been fusion plasma diagnostics for JET, but has also recently been employed to aid in interpreting observations by the Solar and Heliospheric Observatory satellite. A consortium, of which the CFADC is a member, has also recently been formed to allow access to this powerful set of computer codes and data collections for a wider user community. A detailed description of the ADAS suite can be found on-line at Strathclyde University or mirrored at the CFADC (see the "links" hyperlink on the CFADC Web site [1]).

## 6 The ORNL Multicharged Ion Research Facility

An important aspect of the ORNL atomic physics for fusion program in addition to the CFADC is the Multicharged Ion Research Facility (MIRF). This facility has a long history of providing atomic data for electron-ion, ion-atom, and ion-surface collisions. Experiments in each of these areas are actively ongoing and utilize a state-of-the-art Caprice Electron Cyclotron Resonance ion source. Descriptions of the MIRF experiments are available through the CFADC Web site [1] as are indexed tabulations of certain portions of the data measured there. For example, the data obtained over the past three decades regarding electron impact ionization of atomic ions has been collected and organized into a hyperlinked Web resource. Similar work has been initiated for the ion-atom merged beams experiment, and linkages between these data collections and the bibliographic search engine will be made in the future.

## 7 Data Projects

Another aspect of the CFADC's mission is to provide whenever possible new calculations and/or evaluations of data which is urgently needed in fusion energy research. To this end, we have recently concentrated on the production of data for use in charge exchange recombination spectroscopy by computing large collections of state-selective charge transfer cross sections. These have been considered for a range of ions including those of Be [4] (owing to its low atomic number and consequent low induced radiation losses, it has been a primary plasma-facing component material candidate), Ne [5] (due to its introduction into the divertor to beneficially enhance radiation losses for energy exhaust), and Ar (due to its introduction as a diagnostic species) colliding with primary plasma components (H, $H_2$, and He).

Also, due to the need to model the momentum transport in the divertor plasma in present and next-step fusion devices, we have computed and tabulated the elastic and related transport cross sections for collisions among the isotopic variants of $H^+$ + H, $H_2$, and various other reactions of interest [6]. Work on production of both charge transfer and transport cross sections is ongoing. Some of these tabulations are available on the Web site under the "eprints" hyperlink, and future plans are to more systematically include them in data collections linked to the bibliographic search engine.

## 8 Towards the Future

Even though the needs of fusion and other applications for collected, evaluated, and recommended atomic data persist and in fact intensify, the human resources available for such activities continues to dwindle. Thus, an effective leveraging of these human resources by utilization of the World Wide Web as a means for disseminating data produced or collected at the CFADC, and across other sites maintained by other data centers, will be a dominant trend in the future. Linkages will be made between the disparate, individual data collections and resources. This will improve users' ability to find the required information, and will form a powerful aid for data evaluation. For example, combining in a single graphically oriented Web tool the ability to display existing recommended data, results from well-established scaling laws, new basic data from linked data collections, and data contained in other resources even across the Web, will facilitate efforts to carry out projects to recommend data and provide centralized, updatable files for access by users. Also, recognizing that the atomic data needs of a wide range of applications are in essence similar, the CFADC has initiated a program of production and collection of data of importance in astrophysics, an another important leveraging of resources. These data efforts are complimented by ongoing state-of-the-art modeling of astrophysical environments such as those present in later epochs of supernovae explosions.

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