SEP 30 1966

CFSH PRICES

BNL 10585

CONF-661014-2
CN-23/39

H.C. \$ 1.00; MN 50

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IN NUCLEAR SCIENCE ABSTRACTS

Activities of the Cross-Section Compilation and Evaluation Centers at the Brookhaven National Laboratory

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1. INTRODUCTION

The Brookhaven National Laboratory has traditionally played a key role in the measurement, compilation and evaluation of neutron cross-sections. At a time when new information centers are being proposed and when "centers of excellence" are supposed to spring up Minerva-like into instant maturity it may be well to reflect on the major reasons for these past accomplishments; the presence of strong staffs of both nuclear and reactor physicists, of the required tools such as advanced research reactors, accelerators and computers, and last but not least the steady support of the USAEC and its advisory bodies.

We last reported on Brookhaven's activities in cross-section compilation and evaluation at the AEC-ENEA sponsored seminar of last May [1]. We assume that the papers which were presented at this Conference are generally available and shall therefore concentrate on developments since that time.

2. THE SIGMA CENTER

During the past year, the compilation and evaluation efforts at the Brookhaven National Laboratory have been accelerated. We shall discuss first the status of the publications of supplements to BNL-325 since these are of worldwide interest. In May, 1965 we were able to report that a comprehensive three-volume second supplement was in preparation. Volume I, Z=1-20 had already appeared and Volume III, Z=88-96 was distributed during

* Work performed under the auspices of the United States Atomic Energy Commission

† Preprint of paper to be presented at the IAEA Conference on Nuclear Data - Microscopic Cross Sections and Other Data Basic for Reactors, Paris, France, October 17-21, 1966.

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the summer of 1965. The rapid increase in cross-section data for medium weight elements has made it necessary to publish Volume II in three parts, each consisting of about 400 pages, in our new book-size format. The formal work on this volume was completed in August, 1966. At that time, Volume II-A, Z=21-40 had been published and distribution had been started. Volume II-B, Z=41-60 was in press and distribution is anticipated in October. The final volume of the series, Volume II-C, Z=61-87 is expected to be in print about the end of this year.

With the completion of these supplements there will be a lull in formal BNL publication activities. As M. Goldberg has pointed out [2], the next edition of BNL-325 will certainly run to several volumes. We are therefore anxious to learn whether a new ten-volume set of BNL-325's will be as well-thumbed as the older editions. Some speed-up in our methods of processing and publishing data will also be required and we are concerned lest the quality of the work suffer on this account. During the next year we shall be gaining experience with fast computer-based, graphical plotters. A modern Cal-Comp plotter and associated equipment has recently been acquired by the BNL Applied Mathematics Department. As these facilities become operative, an attempt will be made to supplement BNL-400, the angular distribution compilation, entirely by computer.

The storage and transmittal of cross-section data at the BNL Cross-Section Compilation Center has for some time been accomplished by use of a magnetic tape data library known as SCISRS [3], the Sigma Center Information Storage and Retrieval System. The rapidity with which the SCISRS tape can grow is indicated by the fact that it contained only 230,000 individual data points when Goldberg reported on its use in March, 1966 at the Conference on Neutron Cross-Section Technology [2]. In August 1966, it contained over 600,000 data points. Much of this growth is attributable to the digestion of data contributed by the Nevis group at Columbia and to the transfer of all data contained in BNL-400, the "Angular Distribution" compilation, onto tape. A similar large increase in data storage is expected as the recent Los Alamos bomb test cross-section data arrives and is digested.

To date no problems have arisen in the rapid storage and transmittal of data via SCISRS and relatively modest blocks of machine time are required for this purpose. As an example, the bulk of the recent Columbia data was rapidly transferred to tape by arranging for block time on the IBM-7094 computer. A block time of two hours per night (during which up to 20,000 data points can be processed) is found to be more than ample to keep up with the current rate of data acquisition and no requirement for an order of magnitude increase in machine time is anticipated in the future.

While SCISRS is therefore satisfactory for the internal needs of the Center, it is realized that it cannot, in its present form, satisfy the needs of all users. Recommendations for the specifications of a second generation SCISRS has therefore been undertaken by a subcommittee of the NCSAG (Neutron Cross Section Advisory Group) for the USAEC Division of Research. As of this date, the required SCISRS-II specifications have not yet been defined but every effort will be made to coordinate the Sigma Center compilation work with that of its many diverse groups of users.

3. THE CROSS-SECTION EVALUATION CENTER

An important group of users of the Sigma Center compilations is the USAEC Division of Reactor Development and Technology (DRDT). This Division maintains the Cross-Section Evaluation Center at Brookhaven. In contrast to the work of the Sigma Center, the work of the Cross-Section Evaluation Center is primarily that of systematic evaluation of neutron cross-section data. However, the operations of the two Centers are linked and their personnel have always worked in close proximity which results in considerable mutual benefits. The work of this group has been previously described [1] and the recent individual evaluation efforts of its members will be discussed in a companion paper by D. Goldman and K. Parker.

We shall therefore confine our discussion of the Cross-Section Evaluation Center's work to group efforts. First, it is worth mentioning that the optical model code ABACUS-2 of E. H. Auerbach has received worldwide interest and distribution. Recognition of the rapidity and flexibility of this code has led to a continuing series of requests for its listings, master deck or other components from universities and major nuclear research laboratories both in the United States and abroad. The international appeal of such codes as ABACUS-2, THERMOS, etc. points out the importance of this work. It is clear that the field badly needs an improved optical model code for neutron cross-sections of similar flexibility and convenience. In the same vein, we badly need satisfactory calculational models for multilevel fits of neutron cross-sections both for compilation and for evaluation work. For some time the Cross-Section Evaluation Center directly supported the application of the Adler and Adler multilevel formalism to fissionable isotopes. Some work of this type is now supported directly by the DRDT Division of the USAEC.

In addition to the work of its Centers, members of the Reactor Physics Division at Brookhaven have frequently published reports which contain correlations of nuclear data with integral experiments [1]. Discrepancies that have been noted between differential cross-section measurements and integral measurements have frequently led to the correction and improvement of the techniques for both types of experiments. As an example, the discrepancy in the epithermal value of alpha of ^{235}U which was the subject of a special panel discussion at Gatlinburg in 1965 [4] has now been considerably clarified. Similarly, the analysis of critical experiment data for thermal reactor assemblies in the U. K. had led G. Tyror and J. R. Askew to recommend a substantial reduction in resonance integrals for ^{238}U , a recommendation that requires serious further investigation of these supposedly firm numbers.

Cross-section accuracies of about $\frac{1}{2}\%$ are frequently requested and can be justified for several nuclides. However many cross-section measurers feel that accuracies of 1-3% are probably ultimate limits. On the other hand, criticality data (and associated material tolerances and quality control) to $\frac{1}{2}\%$ appear feasible. With techniques for integral experiments improving to the point where measurements of detailed neutron spectra are becoming feasible, it appears that integral and critical experiments for thermal as well as fast spectra should continue to be important for many years.

4. THE ENDF FORMAT

Various systems for storing and retrieving evaluated nuclear data have sprung into being at individual laboratories in response to their specific requirements. The need for a flexible standard format was recognized some years ago by H. Honeck at Brookhaven. Under the sponsorship of the Reactor Mathematics and Computation Division of the American Nuclear Society, he developed the punched card/magnetic tape system called the ENDF or Evaluated Nuclear Data File. Details of the system are contained in various BNL reports [5,6] and Cross-Section Evaluation Center Newsletters. The latter are issued whenever major changes or additions to the ENDF Master Library are made.

As shall shortly be made clear the ENDF system has recently been split into two systems ENDF/A (Evaluated Nuclear Data File, Version A) and ENDF/B. Version A contains evaluated point data and is intended for use by individuals actively engaged in evaluation work. Thus it may contain multiple evaluations of the same data. It may be fragmentary in the sense that the entire energy range may not be covered or a complete set of partial cross sections may not be given. On the other hand, it uses the original, highly flexible format.

Version B is intended as direct input into multigroup and Monte Carlo codes. It will contain one complete set of data for each material and a relatively simple format. The data on Version B will serve as a reference cross-section set for user groups. Where Version A is a continuously growing library, it is expected that ENDF/B will be changed only occasionally, possibly on an annual basis.

The library ENDF/A presently contains an updated version of the Aldermaston/Winfrith Data File. An entirely tape-to-tape Fortran II program was written to convert the data to the ENDF/A format. About 15 minutes of IBM-7094 time were required to convert the first such tape received, dated July 1, 1964, which contained 23,964 BCD card images in the A/W format. In addition, ENDF/A contains a recent KAPL evaluation of fast neutron cross-sections of oxygen and recent GA evaluations of thermal neutron scattering kernels for graphite, beryllium and water. As similar careful evaluation efforts are completed and sent to S. Pearlstein at the Cross-Section Evaluation Center they will be placed in the ENDF/A Library at the Brookhaven National Laboratory.

5. THE CROSS-SECTION EVALUATION WORKING GROUP (CSEWG)

The limitation of the original ENDF system was that it was open-ended. There remained the need to close the loop for reactor designers by putting the data into a format of immediate use to the largest or the smallest user. The splitting of the ENDF system into two parts was a step in this direction. Additional links are however still required. There are shown schematically in Fig. 1.

The circles in Fig. 1 may be thought of as data libraries, while the boxes are computer codes designed to process the data. The links designated as SCORE and ENCØRE are complex and do not yet exist. Since SCORE forms the link between SCISRS and ENDF/A, it is part of the problem

currently under consideration by the NCSAG. Some steps in the development of SCORE and ENCORE have also been taken by the DRDT Division of the USAEC, but it is clear that it will take considerable time before these steps are fully implemented.

For these reasons, the DRDT Division of the USAEC on the advice of its Advisory Committee on Reactor Physics (ACRP), has decided to concentrate on the early completion of an ENDF/B library and its associated programs. The ENDF/B tapes can serve as direct input to existing Monte Carlo codes or the MC² code which is being designed by the Argonne National Laboratory for the design of fast breeders. For other applications, further processing of ENDF/B data is required. The code ETOM (ENDF to MUFT) is currently being developed to process the data into multigroup sets for thermal codes such as MUFT. Finally, FLANGE has been developed to obtain thermal neutron scattering kernels from the scattering laws contained on ENDF/B. All of these codes are expected to be operational during the Fall of 1966.

The evaluation of the data required for the first ENDF/B tape is being carried out by a working committee (CSEWG) composed of representatives of USAEC laboratories and contractors having direct responsibilities to the DRDT Division of the USAEC, plus representatives from the AEC, the Advisory Committee on Reactor Physics and laboratories in the Naval Reactors Branch. The effort is focused in the BNL Cross-Section Evaluation Center with S. Pearlstein as its Chairman. The goal is a complete set of cross-section data for some fifty reactor materials and isotopes from hydrogen to curium-244 by November, 1966. Once the data has been placed on ENDF/B, distributed to reactor designers and processed into multigroup forms, it will be tested against integral measurements obtained from critical and exponential experiments. The total experience gained from using the data plus new cross-section data can then be combined in an attempt to generate an improved ENDF/B tape. With time it is expected that formats and codes will also be improved and the list of isotopes expanded.

At the CSEWG meeting of June 9-10 at Brookhaven, members of the committee agreed to the following standards in their evaluation of data for individual isotopes: Data submitted for inclusion in the ENDF/B library should be documented even if in minimal form. The source of the data, whether by report or personal communication should be indicated. In addition comments about the methods, experimental or theoretical, used in deriving the data are requested. Participants are urged to provide as complete a documentation as possible. The CSEWG committee itself is composed of a strong group of nuclear and reactor physicists most of whom have had experience in reactor cross-section evaluation. Many previous data evaluations are available to them. Thus, in spite of time limitations, it is hoped that the first ENDF/B library, after thorough checking, will become a widely used tool.

6. INTERNATIONAL COOPERATION

By international agreement, the Sigma Center at BNL services the United States and Canada in the compilation of measured neutron data. Similar Centers now exist in Saclay, Vienna and Obninsk. By agreement with the ENEA, the SCISRS data are routinely sent to the Neutron Data Compilation Center (CCDN) at Saclay. The second CCDN newsletter (CCDN-NW2) contains a complete listing of their SCISRS master tape as of June, 1966. During the first eight months of 1966 some 450,000 data points were sent from the Sigma Center to the Saclay Center. In addition, the Sigma Center cooperated in the training of personnel for both the Saclay center and the IAEA Nuclear Data Unit at Vienna although formal cooperative agreement for regular exchange of large blocks of data with the latter Center has not yet been established. However, some fission cross-section data, published in BNL-325, were sent to the IAEA Center for their use at this Conference.

The return flow of cross-section data from Saclay to Brookhaven is still sporadic. In part, this is due to computer problems and to the strong effort being made there on the CINDA System. We have found the CINDA system useful, particularly in cross-section evaluation. The system still has some weaknesses, chiefly the lack of completeness of its references and lack of documentation behind some of its cited references. The latter problem could be avoided if minimum standards were adopted for cross-section evaluation, while the former problem can be overcome with time and a strong staff of CINDA readers.

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SCHEMATIC OF THE FLOW OF NUCLEAR DATA FROM COMPILATION TO REACTOR CALCULATION.

FIG. 1