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Institut für Neutronenphysik und Reaktortechnik

# Neutron Nuclear Data Compilation and Evaluation
## - past, present and future -

J.J. Schmidt

GESELLSCHAFT FÜR KERNFORSCHUNG M.B.H.

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Abstract

Whereas in other physics domains the terms "compilation" and "evaluation" have about the same meaning and are almost interchangeably used, they have acquired quite different and distinct meanings in the field of neutron physics and nuclear data. This peculiar distinction in the case of neutron physics data comes about in the main not only because of the very great numbers of those data but also because the accuracy available, even now after years of extensive research, is still not adequate enough to the stringent needs of nuclear reactor technology and other applied branches of nuclear physics. As a consequence continuous centralized efforts of gathering the data are needed as an essential prerequisite of their effective comparison, evaluation and utilization.

Thus in the field of neutron physics compilation means the gathering of experimental references and of experimental nuclear data contained in these references for a certain neutron reaction with a given nuclide in a given energy range. Today it involves in addition the storage and organization of the compiled information in computer data files; for this purpose data storage and retrieval programs have to be prepared in order to satisfy various requests from the data files. Compilation also involves extensive extraction and documentation of information regarding experimental details (frequently unavailable elsewhere) and the publication of data compendia.

Evaluation denotes the comparison and critical assessment of the compiled experimental data and the selection by some appropriate averaging procedure of a complete and self-consistent set of preferred values. Much more than that, the requirement of completeness, particularly for reactor physics purposes, involves the necessity of using appropriately parameterized nuclear theories and considerations of nuclear systematics to fill in gaps and to help to remove inconsistencies in the available experimental information. Furthermore the effective utilization of the evaluated data necessitates, as a large part of the whole evaluation effort,

the development of computer libraries of evaluated data, together with a variety of associated computer programs for data checking and handling, which serve as input to program systems converting the evaluated data into forms suitable for use in nuclear reactor and other applied nuclear physics calculations. As a final indispensable laborious part, evaluation includes careful and comprehensive written documentation.

In response to the increasing demands of the nuclear community a worldwide organizational effort has developed particularly in the last ten years in the compilation and evaluation of all experimental information in the field of neutron nuclear data. Supraregional committees like the European American Nuclear Data Committee (EANDC) and its local subcommittees and more and more also the International Nuclear Data Committee (INDC) have made substantial contributions to the international organization and coordination of this effort. At present the task of getting the bibliographic and experimental information systematically compiled all over the world, stored and distributed to a variety of customers is subdivided primarily among four centres for neutron nuclear data at Obninsk in USSR (NDIC), at the IAEA in Vienna (NDU), through the ENEA at Saclay in France (CCDN) and at Brookhaven in the USA (NNCSC) with separate service areas. More and more these centres also provide for the storage and exchange of evaluated neutron nuclear data files originating from various laboratories all over the world.

# Neutron Nuclear Data Compilation and Evaluation -past, present and future- [x)]

Neutron nuclear data compilation and evaluation actually dates back as far as the Manhattan District Project during World War II. The Nuclear data needs for the development of the atomic bombs started and forced a rather ambitious program of measurement, compilation and evaluation of important neutron nuclear data for this project. Physicists as eminent as Enrico Fermi and Eugene Wigner were among the first nuclear data compilers and evaluators. At that time the data output of the experiments and thus the data handling problems were still rather small. In 1952 it was still possible for all information which had been gathered so far to be put together in one fairly small volume /¯1_7.

It was at Brookhaven National Laboratory, at the instigation of the USAEC Neutron Cross Sections Advisory Committee, where the information for the AECU-2040 report had been compiled and the first systematic neutron data compilation activities been set up in what was to become the well known Brookhaven Sigma Center under the vigorous guidance of Donald Hughes. Three years later in 1955 as an enlarged successor of the AECU-2040 report /¯1_7 the first edition of the well known BNL-325 work came out /¯2_7 just in time for the opening of the First Geneva Conference on Peaceful Uses of Atomic Energy and gained worldwide distribution and acknowledgement through this conference. Whereas data compilation in the USA before this conference had mostly responded to military purposes and demands, so from this conference on it became more and more directed towards peaceful applications. By the time of the Second Geneva Conference on Peaceful Uses of Atomic Energy in 1958 nuclear data information was almost completely released and in particular a second edition of BNL-325 was published /¯3_7.

This second edition of BNL-325 still represented a fairly comprehensive review of available neutron data measurements mainly in the form of graphs with a few tables. The graphical display of measured neutron cross sections as a function of neutron energy over the range from about 0 to 20 MeV for most elements, and many isotopes from hydrogen to americium, with eye-

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[x)] Manuskript eingereicht zum Druck am 14. November 1969 guide curves through the experimental data, highlighting the physical behaviour of the cross sections, found the particular interest of neutron experimentalists and reactor physicists throughout the world. At that time in the nuclear reactor field thermal reactor design was still predominant, and reactor physicists could find in BNL-325 tabulated best values of thermal neutron cross sections and fission parameters for the purpose of reactor physics calculations. Tables with resonance parameters for many isotopes were also given and served many fundamental and applied purposes in the nuclear community. However, the bulk of the neutron cross section data appearing in the graphs in BNL-325 were not generally well-documented, and were not yet available in tabular form outside the Brookhaven Sigma Center.

In 1958 R.J. Howerton from the Lawrence Radiation Laboratory, Livermore, published in three volumes the results of an extensive several year's work on compilation of experimental neutron cross section data /¯4_7. Complementary in a sense to BNL-325, this publication contained experimental neutron cross sections in tabular form as a function of neutron energy together with the experimental errors in energies and cross sections. This particular feature made it one of the widely used standard works on neutron cross sections in the years to come of particular usefulness to neutron data evaluators for various applied purposes and to reactor designers. As in BNL-325 the whole range of atomic weights was covered; neutron energies ranged from 1 keV to 14.5 MeV. In 1961 this work was complemented by a similar tabular collection of available neutron scattering angular distribution data /¯5_7.

As was indicated above, at the beginning of the nuclear reactor development in the fifties the interest was still centered on thermal neutron reactors and rather crude calculational methods; at that time only the rather limited amount of neutron nuclear data information in the range of thermal and low resonance energies was essentially needed. Since the second half of the fifties and the beginning of the sixties the situation has changed completely. Neutron nuclear data compilation and evaluation rapidly evolved into a large international effort going on amongst various laboratories and centres. This has been the consequence mainly of the fact that interest has become more and more focussed on the development of fast and intermediate reactors and thus on the much larger energy range between meV and MeV energies. Simultaneously the rapid computer development allowed and forced steadily increasing refinements of the reactor theory methods; these went parallel with and were also provoked by the increasing refinements of the measurement techniques of experimental reactor physics. These refinements in reactor theory and experiment opened the possibility of much more detailed and reliable predictions of reactor physical properties with almost the only condition that the neutron nuclear data involved be known to sufficient completeness, detail and reliability over the whole energy range of reactor neutrons. Since then it has become indispensable that compilation and evaluation of neutron nuclear data for a given element or isotope should cover in a much more comprehensive way the whole neutron energy range from almost 0 to at least 15 MeV and all possible neutron reactions occurring in that range. Moreover it has been increasingly recognized that the data must be available on punched cards or magnetic tape so that the computer can be used to prepare derived quantities (such as multigroup constants) needed for reactor calculations.

As a matter of fact the neutron nuclear data field is concerned with the following data types /‾6_7:

(a) microscopic cross sections for all neutron induced reactions between 0 and at least 15 MeV (for example, (n,f), (n,$\gamma$), (n,n), (n,n'), (n,p), (n,$\alpha$), (n,2n) and other threebody break-up reactions), together with quantities involving cross section ratios such as $\alpha = \sigma_{n\gamma}/\sigma_{nf}$ and $\eta = \bar{\nu}/1+\alpha$;

(b) angular distributions for elastically scattered neutrons and elastic scattering polarization data;

(c) angular and energy distributions for inelastically scattered neutrons;

(d) differential angular and energy dependent excitation data for outgoing neutrons, protons, α-particles, gamma-rays, etc., outgoing combination of these particles;

(e) number, energy spectra and angular distributions of prompt and delayed fission neutrons and the half-lives of delayed neutron precursors;

(f) resolved and statistical resonance parameters, statistical distributions of resonance partial half widths and level spacings;

(g) Legendre polynomial coeefficients of scattering angular distributions;

(h) nuclear temperatures and single particle level densities derived e.g. from neutron inelastic scattering to the "continuum" range of residual nuclear energy levels and similar physically significant parameters derived by experimenters from their measurements;

(i) fission product yields and cross sections;

(j) "clean" integral data having immediate application in experimental neutron physics and in evaluation. The principal types are average cross sections measured in well defined neutron spectra, such as thermal reactor and neutron fission spectra, together with so-called infinite dilution resonance integrals for neutron absorption and fission processes.

In the second half of the fifties and later on the requirement mentioned above of a comprehensive nuclear data basis for reactor calculations and other applied purposes and the increasing installation of large computers led to an increasing systematization of the evaluation efforts. Shortly after the edition of UCRL-5226 Howerton published a volume frequently used in later evaluation work of semi-empirical curves of the most important neutron cross sections for almost all elements in the neutron energy range 0.5 to 15 MeV which was based on the available still scarce experimental data and supplemented by inter- and extrapolations and by theoretical estimates [7].

Compilation and evaluation work was also going on in a number of the US laboratories; among these Los Alamos, Nuclear Development Corporation of America, General Atomic, Atomics International and Hanford should be mentioned in particular.

In Western Europe at about the same time pioneering work in neutron data compilation and evaluation was done by two closely collaborating British groups headed by H. Parker at the Atomic Weapons Research Establishment Aldermaston and by J.S. Story at the Atomic Energy Establishment Winfrith. At least in Europe these groups were the first to make comprehensive data compilations and evaluations and to establish an extensive computer library of evaluated neutron cross sections in the energy range from 0.025 eV to 15 MeV for a large variety of nuclides most important for further applications particularly in reactor calculations [8]. The work was shared between the two groups in the following way: Winfrith concentrated on thermal and resonance neutron cross sections, whereas Aldermaston was engaged in fast neutron cross sections. Somewhat later from 1960 on also in the German Nuclear Research Centre at Karlsruhe systematic compilation and evaluation work was started. Also Swedish and Italian research groups became engaged in evaluation work.

In the beginning of the sixties also the Institute of Physics and Power Engineering at Obninsk in the USSR entered the evaluation field. The results of this extensive work became widely distributed in the form of published tables of energy averaged group cross sections for many important nuclides (see for example [9] and [11]) and found useful application also in Western Laboratories.

In the first stages of all these developments the necessary literature references and the data information contained in these references had to be collected as of yore by very cumbersome manual procedures. Immediately huge gaps in the experimental information became apparent: for important nuclei the parameters of only few resonances were known, only few reliable data on neutron capture in reactor materials were available, the knowledge of inelastic level excitation cross sections was still very sparse, to give only a few typical examples. Simultaneously there was still no coordination between reactor evaluation, experimental and theoretical nuclear physicists: in particular the nuclear physicists were not well acquainted with the data needs of the reactor physicists.

Already in 1956 the fact that most nuclear data measurements were being performed in the USA, UK and Canada and the desire to coordinate more effectively the nuclear data efforts of these three countries led to the foundation of the Tripartite Nuclear Cross Section Committee (TNCC). With the increasing release of nuclear data information particularly from the USA beginning with the first Geneva Conference and with the increasing nuclear data efforts in Western Europe the need for collaboration with Western European Countries and laboratories became apparent. Thus in 1960, under the sponsorship of the ENEA, the European American Nuclear Data Committee (EANDC) was founded in which now all OECD countries participate[*] [12]. The EANDC meets at intervals of about nine months.

The primary responsibilities of the EANDC are the stimulation and coordination of nuclear data research within the OECD area. In order to achieve these aims, one of the continuing most important actions of the EANDC consists in the critical consideration of lists of requests for neutron nuclear data measurements, received from reactor and other applied nuclear physicists, which are compiled and sent to the EANDC by the various national and supranational data committees in the OECD area. These request lists specify the neutron nuclear data to be measured for given materials and energy ranges, and the desired experimental resolution, accuracy and priority according to the needs of the physicists involved in various national and supranational nuclear power development programs. Recently a joint request list has been produced and has been widely distributed among experimental physicists in the OECD member countries: it is called RENDA (Requests for neutron data measurements), and has been prepared by a computerized system which allows for rapid up-dating /‾13_7.

In order to help fulfil these requests the EANDC discusses and stimulates the development of measurement techniques and the establishing of new experimental groups and facilities. It advises on the allocation of enriched isotopes and other special samples needed for the requested measurements. It simultaneously encourages the coordination and distribution of the experimental work along various research lines and according to the experimental capabilities and experiences of the various laboratories. Upon the advice and recommendation of EANDC, Euratom established the Central Bureau for Nuclear Measurements at Geel/Belgium as the European counterpart of the American National Bureau of Standards and the British National Physical Laboratory. The Geel Centre is primarily concerned with nuclear standardization problems, precision measurements of neutron standard cross sections and data and the fabrication, assay and isotopic analysis of targets and samples.

Upon the recommendation of the scientific council of the International Atomic Energy Agency an international group of experts in the neutron nuclear physics data field with participants from Western, Eastern and Developing Countries was first convened in Vienna in 1963. This group, known as International Nuclear Data Scientific Working Group (INDSWG), met five times between 1963 and 1966 and explored the possibility of an extension of the scope of EANDC to a worldwide scale concerning particularly the free exchange of information on neutron nuclear physics experiments and facilities and of neutron nuclear data and bibliographic references amongst all countries concerned. A successful operation of the INDSWG evolved rather slowly and led in 1967 to the foundation of the International Nuclear Data Committee (INDC). According to its Terms-of-Reference this committee has "the dual purpose of serving as a means of promoting international cooperation in all phases of nuclear data activity of general usefulness to nuclear energy programs, and of advising the Director General of the IAEA in this field". In all those countries not directly represented in the INDC liaison officers are or will shortly be appointed to provide communication links between the data activities in their countries, the Nuclear Data Unit (NDU) of the IAEA and INDC.

Several large conferences have been held upon the recommendation and/or with the sponsorship of the EANDC and of the INDSWG. Particular mention may be made of the Conference on Neutron Time-of-Flight Methods at Saclay in 1961, the Conference on Automatic Acquisition and Reduction of Nuclear Data at Karlsruhe in 1964, the International Conference on the Study of Nuclear Structure with Neutrons at Antwerp in 1965 and the IAEA Conference on Nuclear Data for Reactors in Paris in 1966. A second IAEA Conference on Nuclear Data for Reactors will be held in Helsinki in June 1970; this will be the first Conference sponsored by the INDC. These conferences, which covered both fundamental and applied aspects of neutron physics measurements, compilation and evaluation, had many merits one of which was bringing nuclear physicists, compilers, evaluators and reactor physicists together and helping them to understand each other's problems.

As a primary result of all these international discussions and coordination efforts, particularly those of the EANDC during the last years, new experimental facilities, especially electron linear accelerators and Van de Graaff machines, were built in many laboratories, and the experimental capabilities, especially the energy resolution, were very much improved. The consequence of this great progress on the experimental side has been a very large increase in the amount and quality of neutron nuclear data produced. With a strong neutron source like a modern electron linear accelerator and high resolution experimental techniques like the neutron time-of-flight method of the order of a few hundred resonances in individual nuclei can be resolved. A single measurement series in the resonance range commonly yields about several thousand data points; for more important nuclei like $Au^{197}$ or $Pu^{239}$ quite a few of such measurements are available. One typical inelastic scattering experiment covers the cross sections for excitation of, say, ten different nuclear energy levels over a larger neutron energy range. One typical elastic scattering angular distribution measurement covers of the order of ten different angles at twenty or thirty neutron energies. This data explosion created a series of new problems such as the necessity of on-line conversion of the experimental raw data into cross section data or the computerized parametric analysis of neutron resonance measurements by the experimental physicists themselves. In particular new ways had to be found in order to make this vast amount of reference and data material available to the reactor physicists in a rapid and useful way.

It became rapidly apparent that the Brookhaven Sigma Center could not keep pace with the increasing production of neutron nuclear data both in Western Europe and in the US and Canada. Recognizing this fact the EANDC recommended in 1963 the creation of a centre for the compilation and dissemination of neutron cross section information and data in Western Europe and Japan /¯14_7. This recommendation was carefully explored and finally supported by a Study Group of experts convened by the European Nuclear Energy Agency (ENEA) and led in 1964 to setting up the Centre de Compilation des Données Nucléaires (CCDN) of the ENEA near the Centre d'Etudes Nucléaires at Saclay in France. In 1965 a cooperative arrangement was made between the ENEA and the US Atomic Energy Commission for the exchange of information between Brookhaven and Saclay.

In 1967 the Brookhaven Sigma Center, within the framework of the USAEC program, was enlarged to the National Neutron Cross Section Centre (NNCSC) comprising now in one large unit the formerly dispersed compilation, evaluation and programming efforts. Upon the recommendation of INDSWG in 1964 a Nuclear Data Unit (NDU) was created at the IAEA in Vienna with the particular objectives of compilation and dissemination of neutron nuclear data in non-OECD countries and of the exchange of such information between OECD and non-OECD countries. The increasing nuclear data measuring efforts in the USSR necessitated in 1964 the creation of a Nuclear Data Information Centre (NDIC) at Obninsk which serves similar purposes for the many laboratories in the USSR as does Brookhaven for North America and which communicates through the NDU of the IAEA with the Western centres. After improvements had been made in the regional organization of the compilation efforts and some restrictions to a free release and exchange of information and data particularly between Western and Eastern countries had been overcome, the international cooperation now proceeds in an increasingly satisfactory way and according to mutually agreed contracts between the four world nuclear data centres and their sponsors. The work of the centres is surveyed and guided respectively by local Centre Committees (NNCSC, CCDN, NDIC) and by the INDC (NDU). During the last few years Four-Centre meetings have become a regular custom on which items of common interest are discussed in order to strengthen and improve the cooperation among the four centres.

Concerning the technical tasks of the centres one of the basic purposes is the collection and dissemination of neutron nuclear data references. Originally many users of neutron data, in particular evaluators in various laboratories, had tediously built up their own reference indexes; much parallel and often not fully comprehensive work was done in this way. One of these indexing activities had a unique feature which later enabled it to be adopted and developed on a worldwide cooperative basis. This was the computerized reference index CINDA (Computer Index of Neutron Data) first started in 1956 by Professor H. Goldstein and his collaborators at the Nuclear Development Corporation of America (later absorbed by United Nuclear Corporation) in the USA. It was not until 1963 that this work gained international recognition and that a systematic and coordinated scanning of the literature all over the world was started and supported by a net of voluntary readers, individuals in many laboratories and other scientific institutions and in the centres themselves. The CINDA entries are collected and stored in the centres mentioned before, except that in the US the CINDA work is now centralized at the Division of Technical Information Extension (DTIE) at the Oak Ridge National Laboratory and not at Brookhaven. Each year a print-out of the whole content of the CINDA reference file is published and distributed to a large number of centre users in the whole world; in addition half-yearly supplements are published. The last edition of CINDA as of May 1969, CINDA 69 [15], contains about 60,000 entries corresponding to about 20,000 literature references; it also contains references to data evaluations and to theoretical articles and reports of interest in the neutron data field. For illustration the figure in the annex shows a typical page of the CINDA print out. Although coverage of the literature is not yet as complete as could be desired there has been a steady improvement with each edition, and CINDA is coming more and more into general use as a primary reference source particularly by evaluators and in the experimental laboratories. The real importance of CINDA is that the number of journals and report series considered containing neutron nuclear data is now so large that it is no longer possible for individuals to maintain private indexes covering the whole field.

The situation in the field of compilation of the data, being the second main purpose of the centres, is not yet so satisfactory. The data files in the centres contain now of the order of $10^6$ data points, but neither the back-coverage of data sets is complete, nor are the centres yet keeping pace with the current production of new information. There are several reasons for this: At the best a large amount of time and effort is required to establish the suite of programs needed for a computer based data storage and retrieval system in a fully operational way. In addition, historical reasons and the use of different computers at the four data centres have necessitated the development of separate sets of programs at each centre (NNCSC: SCISRS-I [16], CCDN: NEUDADA [17], NDU: DASTAR [18], NDIC: program without particular name known to the author [19]). For about two years a new improved data storage and retrieval system called SCISRS-II has been under development, with the main initiative and work coming from the NNCSC supported (for example, by attachment of staff) by the CCDN and NDU and with the particular emphasis on compatibility with various computer types. In order to facilitate the transmission of experimental data between the four centres, a computer format for the centre-to-centre exchange of experimental data and associated characteristic physical information has been developed in a joint effort of all four centres, the main characteristics of which have been fixed in the last Four-Centre-Meeting in Vienna in December 1968.

In February 1969 the IAEA convened a Panel on Neutron Data Compilation at Brookhaven with the principal objective of reviewing the capability of the four centres to meet the data demands of the nuclear community consisting of theoretical and experimental neutron physicists, evaluators, reactor physicists and other existing and potential users [10]. Recognizing the fact that with the present available manpower the centres could not compile the data in an encyclopaedic way, the Panel identified the following areas of data which are likely to be of special importance in the next few years and should therefore be covered most comprehensively /‾6_7:

a. data for fissile and fertile nuclides,
b. data relating to cross section standards,
c. data for reactor structural and coolant materials,
d. data for shielding materials,
e. data for transactinium nuclides produced during reactor operations.

It is hoped that the Panel can serve as a base from which to launch a vigorous campaign to promote effective use of the facilities that the four data centres can now provide. In the future these should be extended so that dissemination of information is as prompt and effective as possible by modern means and so that a variety of services can be provided which will give the best possible knowledge of, or comparison with, all existing information. The aim of these measures is to provide utmost incentive to all experimental neutron physicists for the immediate release to the data centres of all publicizable results.

For historic reasons the development of the CINDA reference file has been separate from the development of the various data storage and retrieval systems. Efforts are continuing in the data centres dealing with the general problem of correlating the contents of the data libraries with the appropriate entries in the CINDA reference file.

In the field of evaluation of neutron nuclear data, international coordination is still rather poor. As in the beginning most of the evaluation work is still performed in national laboratories in close contact to national reactor and other technological development programs. In order to keep pace with the steadily increasing amount of the available compiled data information, the evaluation effort in the last few years had to be much intensified in the already existing groups. In addition quite a few new groups were created which work partly in close bilateral cooperation or contract with the already existing groups. Such cooperations developed for example between a French group at Cadarache and the British groups at Aldermaston and Winfrith, between a group at the Technion Institute at Haifa in Israel and the German group at Karlsruhe. In the US the national evaluation effort has become better coordinated and is now concentrated in the Cross Section Evaluation Working Group (CSEWG). This group was founded in 1966, its work is directed by the Brookhaven NNCSC and its members come from about 15 different laboratories and industrial firms representing each small evaluation groups [20]. In the USSR the NDIC acquired a similar role: part of its functions is to coordinate the scientific work in the USSR on the measurement and evaluation of nuclear data [19].

Today many of the larger nuclear laboratories in the world have rather comprehensive computer libraries of evaluated neutron data. Formats which found particularly wide distribution are those developed at Aldermaston and Winfrith in the UK (UKNDL = United Kingdom Nuclear Data Library [21]), at Brookhaven in the US (ENDF/B = Evaluated Nuclear Data File B [22] and at Karlsruhe in Germany (KEDAK = Karlsruhe Evaluated Nuclear Data File [23]). The NNCSC, CCDN and NDIC have taken over the task to compile, store and distribute upon request evaluated data files in their respective service areas; exchange of evaluated data through the NDU at Vienna is only in its beginnings. It is to be hoped that, as already with experimental neutron data, the free exchange of evaluated data throughout the world will become possible.

Regarding evaluation work in the neutron data centres, so far larger efforts have only been undertaken by the NNCSC and by the NDIC. Less work, with an emphasis on neutron standard cross sections, has been performed by the NDU (review work on the 2200 m/sec constants for the main fissile nuclides [24] in collaboration with physicists from Canada, the UK and the USA) and by the CCDN (review work on the $Li^6(n,\alpha)$ cross section [25] in collaboration with some Swedish physicists).

Some of the evaluation work mentioned above has been extensively documented in tables, graphs and physical descriptions. A fairly comprehensive review of references for presently (1969) available neutron nuclear data evaluations may be found in Newsletter No. 9 of the Saclay CCDN which succeeded corresponding reviews in the Newsletters No.s 5 and 7 of the CCDN for 1967 and 1968, the first systematic survey being given by K. Parker et al. /¯26_7 in 1966. Particularly illustrative examples are given by the comprehensive documentation of the Aldermaston/Winfrith (see e.g. /¯27_7) and of the Karlsruhe /¯28_7 evaluations and data libraries. The most recent editions of the well known BNL-325 work mentioned already before /¯29_7 represent a substantial step towards a comprehensive documentation of compiled experimental data and involve also much data evaluation; they comprise as the earlier editions the whole range of atomic weights.

Computerized automatic evaluation is still in the beginning. Recently a group at Atomics International, in cooperation with IBM people, has begun to develop semi-automatic evaluation procedures in a program called SCØRE /¯30_7. This program uses graphical display units developed by IBM and allows continuous man-machine interaction during evaluation. The experimental data information stored in the computer can be made visible in tabular or graphical form on a screen and can be changed, deleted, corrected and averaged in least squares or spline fits by light pen or typewriter manipulation in desired, programmed ways. This procedure, although still expensive in its present form, promises to replace successfully the eye-guide curves drawn previously through experimental data sets and in addition in appropriate cases should speed up the evaluation process considerably.

In conclusion, the experience in the last decade has been that the evaluation task in the neutron data field is very hard by the large amount of data to be handled and the sheer quantity of work to be done which is still not satisfactorily counter-balanced by an adequate number of skilled people working on evaluation and by an effective coordination of the existing evaluation efforts. The evaluation task is made still harder by the large systematic errors and discrepancies encountered in many of the available, even modern, experimental data sets despite the great and continuing progress in the experimental techniques. On the other side the reliability requirements on the evaluated data by the data users in the reactor and other applied fields have been increasingly strengthened in recent years. While the bare calculational basic data input needs at least for the most important nuclides and neutron cross sections are satisfied to a fair degree by the existing main computer libraries of evaluated neutron data, the confidence level of theoretical design and prediction in the field of nuclear technology based on these evaluated data libraries, although certainly not exclusively due to data uncertainties, is still not be considered satisfactory and necessitates much more detailed investigations of particularly important neutron cross sections and standards. This involves that merits and defaults of individual experimental results are understood in greater detail and judged to a higher degree of confidence than was usually the case before. Certainly it is the experimental physicist himself who is genuinely suited for a critical assessment and comparison of his own results with those of his colleague and for the explanation of observed discrepancies, however difficult in individual cases these tasks nowadays might be. The evaluator, if it is not the experimentalist himself, is supposed to draw attention to and to comment critically and to the best of his knowledge on discrepancies in experimental results taking the assertions of nuclear theory and systematics into consideration. Nevertheless, while being in a worse position to resolve discrepancies than the experimentalist, the evaluator is expected to choose a sort of reasonable averages also in the case of conflicting data, to assign realistic errors and to complement and improve existing evaluated data files. In this situation a much closer cooperation and coordination of the efforts of experimental physicists, compilers and evaluators in close contact to and effective response to the needs of the nuclear community as a whole will be required over the next years. In this respect the four neutron data centres are supposed to play an increasingly important role in the future.

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| ELEMENT S A | QUANTITY | TYPE | ENERGY MIN | ENERGY MAX | DOCUMENTATION REF VOL PAGE | DATE | LAB | COMMENTS | SERIAL NO. |
|---|---|---|---|---|---|---|---|---|---|
| LI 007 | INELST GAMMA | EXPT-REPT | 3.4 6 | 7.5 6 | LA- 3765 | 6/67 | LAS | HOPKINS+ SCINT+TOF GAMMAS SEEN | 41391 |
| | 2 | | | | | | | SUPERSEDES BAP 12 893H5 8/67 | 41399 |
| LI 007 | INELST GAMMA | EXPT-PROG | 1.4 7 | | EANDC(E)115 U | 3/69 | GRE | BOUCHEZ, PROD OF 477KEV GAMMA | 553672 |
| LI 007 | N2N REACTION | EXPT-JOUR | 9. 6 | 1.4 7 | NP 38 300 | 0/62 | LPL | PENVENISTE+LSIG=10.2 AT 14MEV | 525535 |
| LI 007 | N2N REACTION | EXPT-JOUR | 1.0 7 | 1.4 7 | PR 129 1771 | 2/63 | LRL | LIC.SC-T ASHBY ET AL 10.2,14.1 4EV | 500111 DATA |
| LI 007 | N2N REACTION | EVAL-REPT | 8.3 6 | 1.5 7 | AWRE061/64 | 7/64 | ALD | PENDLEBURY DFN176 DATA UKAEA LIBRARY | 532953 |
| LI 007 | N2N REACTION | EVAL-REPT | TR | UP | UNC-5099 | 0/64 | UNC | COMPILED AND CALCULATED | 27116 |
| LI 007 | N2N REACTION | COMP-JOUR | 1.4 7 | | NP 65 257 | 3/65 | HAM | BORMANN. 1EXPT VALS.CFD SHELL EFFECT | 526487 |
| LI 007 | N2N REACTION | EXPT-PRIV | 1.4 7 | | *PU MATHER | 4/66 | ALD | MATHER+PAIN TO IMPROVE PREVIOUS XPT | 507591 |
| LI 007 | N2N REACTION | EVAL-REPT | 8.5 6 | 1.5 7 | LA-3695 | 3/67 | LAS | BATTAT+ SIG DATA IN ENDF/B FORMAT | 38823 |
| LI 007 | N3N REACTION | EVAL-REPT | 1.3 7 | 1.5 7 | AWRE061/64 | 7/64 | ALD | PENDLEBURY DFN176 DATA UKAEA LIBRARY | 532954 |
| LI 007 | N3N REACTION | EXPT-JOUR | 1.4 7 | 1.9 7 | NP A115 1 | 7/68 | TCK | FUJIKAWA+.UPPLIMIT SIG TRINEUTR.FORM | 549245 |
| LI 007 | N,GAMMA | EXPT-JOUR | THR | | NAT 158 482 | 0/46 | CAV | POOLE+.ACTIVATION REL IN.ABOUT 1MB | 509397 |
| LI 007 | N,GAMMA | EXPT-JOUR | THR | | PR 72 646 | 0/47 | ANL | HUGHES+. ACT.SUB-CADMSPEC..848SLI8BS | 500112 |
| LI 007 | N,GAMMA | EXPT-JOUR | THR | 2.8 5 | SPD 1 655 | 0/56 | CCP | KOLTYPIN. | 537322 |
| LI 007 | N,GAMMA | - | THR | 1. 3 | LMSD48353 | 1/59 | | ACTIVATION,40KEV RESOL, S PM20PC | 12191 |
| LI 007 | N,GAMMA | EXPT-JOUR | THR | 1.0 6 | PR 114 1037 | 5/59 | LOK | IMHOF+,40+-8MB THR 50-5MUB .04-1MEV | 32055 DATA |
| | 2 | | | | | | | SUPERSEDES BAP3 322H5 8/58,PPL2 442 5/59 | 32761 |
| LI 007 | N,GAMMA | EVAL-REPT | 1.0-3 | 1.5 7 | AWRE061/64 | 7/64 | ALD | PENDLEBURY DFN176 DATA UKAEA LIBRARY | 532955 |
| LI 007 | N,GAMMA | EVAL-REPT | 3.7-2 | 1. 6 | UNC-5099 | 0/64 | UNC | COMPILED AND CALCULATED | 27113 |
| LI 007 | N,GAMMA | EVAL-REPT | 1. -3 | 1.5 7 | LA-3695 | 3/67 | LAS | BATTAT+ SIG DATA IN ENDF/B FORMAT | 38822 |
| LI 007 | SPECT NGAMMA | EXPT-ABST | PILE | | HPA 34 483 | 8/61 | ETH | JARCZYK+FULL DESCRIPTION TBP IN NP | 545112 |
| LI 007 | SPECT NGAMMA | EXPT-PRIV | PILE | | *PU GILBOY | N/66 | ALD | CRYSTAL SPEC+LI-GE DETECTOR TBD | 521827 |
| LI 007 | N,PROTON | EXPT-JOUR | 1.4 7 | | NP 38 300 | 0/62 | LRL | BENVENISTE+L5MB | 525536 |
| LI 007 | N,PROTON | EXPT-JOUR | 4. 6 | 2.4 7 | NCS 3 4 1167 | 65 | FRK | XSECT,ANGDIST,ENERGY SPECTRUM,NDG | 519582 |
| LI 007 | N,PROTON | COMP-JOUR | 1.4 7 | | NUC 23 8 112 | 8/65 | IND | CHATTERJEE TABLE WITH REFS | 25373 |
| LI 007 | N,DEUTERON | EXPT-JOUR | 1.4 7 | | PR 89 80 | 1/53 | LAS | BATTAT+FROM HE6 PROD RATIO IN LI6+7 | 526557 |
| LI 007 | N,DEUTERON | EXPT-BOOK | 1.4 7 | | NEJTRONFIZ 249 | 61 | CCP | MIKHAJLINA.EMULSIONS. TOTAL SIGMA | 521230 |
| | 2 | | | | | | | ENGLISH TRANSL SPN(1961) PG 185 | 521250 |
| LI 007 | N,DEUTERON | - | 1.4 7 | | LA- 2643 ROSEN | 0/61 | | 9.8PM1.1MB CF PR89,80 | 12194 |
| LI 007 | N,DEUTERON | EXPT-JOUR | 1.5 7 | | JNE AB17 273 | 8/63 | ALD | BARRY. 14+-1.5MB REL U235 SIGF | 524123 |
| LI 007 | N,DEUTERON | COMP-REPT | 1.4 7 | | INDSWG-64 P.84 | 64 | CCP | MIKHAJLINA, CA 5 MB | 509398 |
| LI 007 | N,DEUTERON | EVAL-REPT | 8.9 6 | 1.5 7 | AWRE061/64 | 7/64 | ALD | PENDLEBURY DFN176 DATA UKAEA LIBRARY | 532956 |
| LI 007 | N,DEUTERON | COMP-JOUR | 1.4 7 | | NUC 23 8 112 | 8/65 | IND | CHATTERJEE TABLE WITH REFS | 25374 |
| LI 007 | N,DEUTERON | EVAL-REPT | 9. 6 | 1.5 7 | LA-3695 | 3/67 | LAS | BATTAT+ SIG DATA IN ENDF/B FORMAT | 38821 |
| LI 007 | N,DEUTERON | EXPT-PRIV | NDG | | DISS NEUCHATEL | 6/68 | NEU | NUSSBAUM TBP.E+ANGDIST,DS 0.8-1.8MEV | 544830 |
| LI 007 | N,TRITON | EXPT-JOUR | 1.4 7 | | PR 93 1086 | 3/54 | LAS | FRYE NUCL EMULS,55+-8MB,ANG DIST CRV | 42747 |
| | 2 | | | | | | | REPLACES AECU-2758 /53 | 42764 |
| LI 007 | N,TRITON | EXPT-BOOK | 1.4 7 | | NEJTRONFIZ 249 | 61 | CCP | MIKHAJLINA.EMULSIONS.13 CASES DETCTD | 521228 |
| | 2 | | | | | | | ENGLISH TRANSL SPN(1961) PG 185 | 521248 |
| LI 007 | N,TRITON | - | 1.4 7 | | LA- 2643 ROSEN | 0/61 | | 55PM8MB CF PR93,1086 | 12195 |
| LI 007 | N,TRITON | EXPT-ABST | TR | 1.5 7 | AERER-4131 P29 | 9/62 | ALD | BARRY AWRE ACTIVATION NDG | 527119 |
| LI 007 | N,TRITON | COMP-REPT | 1.4 7 | | INDSWG-64 P.84 | 64 | CCP | MIKHAJLINA, 50+-15 MB | 509399 |
| LI 007 | N,TRITON | EXPT-JOUR | 1.4 7 | | NP 60 581 | 0/64 | RBZ | VALKOVIC+ T-SPECTRUM,DISCUSSION,CURV | 533853 DATA |
| | 2 | | | | | | | CONTINUED NP A98 305 5/67,ALSO ANG-DSTRB | 533854 |
| | 3 | | | | | | | COMPARE 64PARIS 7/64 VOL.2 PAGES 244+936 | 533855 |
| LI 007 | N,TRITON | COMP-JOUR | 1.4 7 | 1.5 7 | NUC 23 8 112 | 8/65 | IND | CHATTERJEE TABLE WITH REFS | 25375 |
| LI 007 | N,TRITON | EXPT-ABST | 1.5 7 | | BAP 12 1140 13 | 0/67 | WWS | LINDSAY+2. OKS SEQUENTIAL DECAY | 42259 |
| LI 007 | N,ALPHA | - | 5. 6 | 1.4 7 | LA- 2643 ROSEN | 0/61 | | INC E+PHI DIST OF ALL RX PRODUCTS | 12198 |
| LI 007 | N,ALPHA | EXPT-JOUR | 1. 6 | 2. 6 | NP 38 300 | 0/62 | LRL | BENVENISTE+LNEGLIGIBLE FROM ANL4515 | 525537 |
| LI 007 | N,ALPHA | EXPT-JOUR | 1.4 7 | | PL 10 79 | 5/64 | BKB | POPIC+H4 NOT OBSERVED | 532792 |
| | 2 | | | | | | | CONTINUOUS IN 64PARIS II 243,764 | 532793 |