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CSEWG SYMPOSIUM

"A CSEWG Retrospective"

35th Anniversary
Cross Section Evaluation Working Group

November 5, 2001
National Nuclear Data Center
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CSEWG SYMPOSIUM

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Monday, November 5, 2001
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*Paper not included in this document

Introduction

This publication has been prepared to record some of the history of the Cross Section Evaluation Working Group (CSEWG). CSEWG is responsible for creating the evaluated nuclear data file (ENDF/B) which is widely used by scientists and engineers who are involved in the development and maintenance of applied nuclear technologies. This organization has become the model for the development of nuclear data libraries throughout the world. The data format (ENDF) has been adopted as the international standard. On November 5, 2001, a symposium was held at Brookhaven National Laboratory to celebrate the 50^{th} meeting of the CSEWG organization and the 35^{th} anniversary of its first meeting in November 1966.

The papers presented in this volume were prepared by present and former CSEWG members for presentation at the November 2001 symposium. All but two of the presentations are included. I have included an appendix to list all of the CSEWG members and their affiliations, which has been compiled from the minutes of each of the CSEWG meetings. Minutes exist for all meetings except the 4^{th} meeting held in January 1968. The list includes 348 individuals from 71 organizations. The dates for each of the 50 CSEWG meetings are listed. The committee structure and chairmen of all committees and subcommittees are also included in the appendix.

This volume is dedicated to three individuals whose foresight and talents made CSEWG possible and successful. They are Henry Honeck who lead the effort to develop the ENDF format and the CSEWG system, Ira Zartman, the Atomic Energy Commission program manager who provided the programmatic direction and support, and Sol Pearlstein who led the development of the CESWG organization and the ENDF/B evaluated nuclear data library.

Charles Dunford
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A Short History of Nuclear Data and Its Evaluation

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ABSTRACT

This paper reviews both neutron and non-neutron nuclear data over the past century, especially those data of relevance to the USDOE (formerly the USAEC) Cross Section Evaluation Working Group, CSEWG. Among the topics whose history will be examined are neutron cross sections, charged particle cross sections, neutron resonance integrals and neutron fission product yields. Other topics discussed include isotopic composition of the elements, nuclear spins and parities, radioactive half-lives, nuclear magnetic dipole moments and electrical quadrupole moments, alpha particle energies and intensitites, beta-ray energies and intensities and gamma-ray energies and intensities. The status of automation of these parameters into data files will briefly be discussed.

INTRODUCTION

In 1966, the Division of Reactor Development and Technology (DRDT) of the United States Atomic Energy Commission (USAEC) was concerned about the problems involved in the evaluation and processing of nuclear data for reactor calculations. The DRDT's plan for the development of the necessary methods for the processing of the data and for obtaining data for immediate use in reactor calculations involved a long range goal of developing automated methods for processing nuclear data, as well as a short range goal of providing reactor designers with a reference set of data that they could use for their current projects. For the short term goal of obtaining a reference set of nuclear data, the DRDT sponsored the Cross Section Evaluation Working Group (CSEWG), a co-operative evaluation effort aimed at providing reactor designers with a good set of evaluated nuclear data. The proposed long range goal was to be addressed by CSEWG over time. Although the initial effort focused on neutron cross section data primarily, over time, CSEWG added other categories of nuclear data to their automated files of information.

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This paper will review the status of the evaluation of nuclear data beginning with the time that radioactivity was first discovered and nuclear data first became available in the late nineteenth century. It will conclude with the time that CSEWG began operation and held its first meeting at the Brookhaven National Laboratory's (BNL's) Cross Section Evaluation Center on June 9th and 10th, 1966. An overal general history of various categories of nuclear data will be followed by a review of the evaluations of specific types of data.

PRE-HISTORY

Our history of nuclear data begins at the end of the nineteenth century with the discovery of uranium rays (radioactivity) in February 1896 by Henri Becquerel[1]. The early part of that century saw the proposal of the atomic theory of matter and the concepts of atomic weights of the elements by John Dalton[2]. Later in the century, Lothar Meyer and Dmitri Mendeleev studied the physical and chemical properties of the chemical elements, respectively, and by using these properties, they arranged the atomic weights of the then known chemical elements in a periodic fashion, the so-called Periodic Table[3].

Toward the end of the nineteenth century, Issac Newton's laws explained the behavior of both objects in motion and of gravity. From the work of James Clerk Maxwell and Heinrich Hertz, it was known that light, electricity and magnetism are interrelated and they were explained by a few simple equations. Everything was thought to be under control. Physicists thought that they had matters in hand. The first American Nobel Prize winner, Albert A. Michelson, in an 1894 speech at the University of Chicago, lamented that "the most important fundamental laws and facts of physical science have all been discovered. These are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote. Our future discoveries must be looked for in the sixth place of decimals."

Within three years of this speech, x-rays were discovered, the electron was discovered and radioactivity was discovered.

THE NUCLEAR PROCESS BEGINS

Nuclear data began with the discovery of so-called uranic rays by Becquerel and with the work of Marie and Pierre Curie, who tried to determine whether other substances besides uranium also emitted these rays (Marie Curie was the first to refer to this phenomenon as radioactivity[4]). The understanding of radioactivity was aided by the work of the New Zealand physicist, Ernest Rutherford, and the English chemist, Frederick Soddy on the atomic transformation law, for which Rutherford received the Nobel Prize in Chemistry. This award prompted Rutherford to quip that the quickest transformation he had ever witnessed was his change from physicist to chemist[5]. The radioactive decay rate was found to be proportional to the number of atoms which were undergoing decay. Mathematically, this led to an exponential form for the decay and to a characteristic decay constant (reciprocal life-time or half-life) associated with each radiation energy.

Although data was to be found in the early publications of the Curies and Rutherford, the first major review of these radioactive data was published in 1931 by the International Standards Radium Commission[6] and contained tables of the lifetimes and the radiation energies of the natural radio isotopes. This report was published simultaneously in four other journals around the world; Phys. Zeitschr., J. Am. Chem. Soc., Phil. Mag. and J. Phys. Radium.

In this age of radioactivity at the beginning of the century, many radioactive substances were being found with various atomic weight values. In 1911, Frederick Soddy used his displacement law for α-particle decay (reduce the atomic mass number by four and the atomic charge by two) and β transitions (no mass change and increase the charge by one) to show the chemical identity of meso-thorium (^{228}Ra) and radium (^{226}Ra)[7]. In 1913, he concluded that there were chemical elements with different radioactive properties and different atomic weights but with the same chemical properties, so they occupied the same position in the Periodic Table. He coined the word "isotope" (Greek for in the same place) to account for these radioactive species[8].

In 1897, the English physicist, J. J. Thomson, discovered the electron[9]. In 1912, he studied the rare gas neon by sending electrons through neon gas, creating neon ions, which he accelerated toward his detector (a photographic plate[10]). Using electric and magnetic fields operating at right angles to each other to deflect these ions, Thomson found darkening at two separate locations on the photographic plate, corresponding to positions for the ^{20}Ne ion and for the ^{22}Ne ion. Relative intensity of darkening on the photographic plate was 90% and 10%, respectively, for the two ion beams. Given that the atomic weight is equal to the average mass of the element, this could now account for neon's non-integral atomic weight value of 20.2. This was also the first time that isotopes of a stable chemical element had been found, in contrast to all previous isotopes for the radioactive elements. One of Thomson's students, Francis Aston, using a mass spectrograph (a variation of Thomson's instrument), began measuring the percentage of each element's isotopes, or the chemical element's isotopic composition. These percentages of an isotope in a chemical element are now referred to as isotopic abundance values. Aston's first compilation of isotopic abundance values was published in his book on "Isotopes" in 1922[11].

Using his mass spectrograph, Aston[12] observed small divergences of atomic masses from integral values. This led to the use of that instrument for the measurement of atomic masses. A difference between the isotopic mass and the mass number was called the packing fraction. It is related to the binding energy per nucleon in the nucleus. The binding energy of a nucleus is the difference between the combined masses of the nucleons in the nucleus and the mass of the nucleus itself. Measurement of various atomic masses indicated that the binding energy per nucleon varied as a mass number increased. A table of packing fractions appeared in Aston's book on "Mass Spectra and Isotopes" in 1933[13].

In 1924, Wolfgang Pauli[14] postulated the existence of a quantum number, I, of a nucleus (referring to the total nuclear angular momentum or nuclear spin) and the associated magnetic dipole moment, μ. Samuel Goudsmit and Ernst Back[15] experimentally verified Pauli's concept of nuclear spin and magnetic moment to explain observed hyperfine structure in spectral lines. In 1930, Linus Pauling and Goudsmit[16] produced the first table of nuclear moments in their book on line spectra.

THE NEUTRON ERA

As the 1930s began, the nucleus was thought to contain both protons and electrons to explain the beta decay of natural radio isotopes. In a 1921 public lecture, Ernest Rutherford[17] said that there must exist in nature a particle with the same mass as a hydrogen atom but with a zero electric charge, to explain the phenomenon of radioactivity. Frederick Joliot never bothered to read Rutherford's remarks because Joliot wrongly assumed that a public lecture would contain a display of oratory but no new ideas[18]. Theoretical work was never highly regarded in Marie Curie's laboratory, where Joliot worked. Curie once responded to a theoretical physicist's recommendation that a particular experiment be performed with a comment that they might even perform the experiment in spite of that suggestion[19]. Rutherford and his assistant, James Chadwick, spent ten years trying to find the neutron without success.

In 1930, Walther Bothe and H. Becker[20] observed the emission of a penetrating secondary radiation by various light elements bombarded with polonium α-particles and interpreted it in terms of high energy γ-rays. It was later proved by the same authors that this secondary radiation included a high energy γ-ray component and was due to residual nuclei being left in an excited state. In any case, their geiger point counter was not capable of detecting neutral particles.

Following up on Bothe and Becker's investigation in 1932, Frederick Joliot and his wife, Irene Joliot-Curie, reported that α particles from polonium bombarded beryllium and they produced radiation that knocked protons out of hydrogen atoms[21]. They thought that they had observed a γ-ray Compton effect but Chadwick determined that these γ-rays would require an energy in the range of 55 to 90 million-electron-volts (MeV). He proposed the elusive neutron as the solution and experimentally verified this assumption. Chadwick is now credited with the discovery of the neutron[22].

In 1934, Joliot and Joliot-Curie[23] determined that the product atom of an artificial disintegration need not always correspond to a stable isotope but could disintegrate with the emission of light particles with a definitive half-life. They had discovered artificial radioactivity. Ernest Lawrence observed the same phenomenon using his cyclotron. He found that his counters "mis-behaved" after the cyclotron was shut off. He "solved" this mal-function by automatically shutting off his counters, once the cyclotron was shut off and never realized that he had missed a fundamental discovery[24].

Joliot's production of artificial radioactivity using α particle bombardment only worked with the light chemical elements. The coulomb barrier prevented a nuclear reaction from occurring in a heavy nucleus. Enrico Fermi put together the ideas of the neutron and artificial radioactivity and produced neutron fission.

Most scientists knew that neutron sources were very much weaker than α particle sources. However, Fermi realized that neutrally charged neutrons would be much more effective than the α particles for the study of artificial radioactivity. He proposed irradiating all elements, even heavy ones with neutrons to study artificial radioactivity.

In a series of 1934 papers[25], Fermi's group reported irradiating all available elements up to uranium with neutrons and the resulting production of radiations with characteristic half-lives. He thought that they had created[26] element 93 and possibly 94, which they would call ausenium and hesperium[27]. Fermi sent preprints to 40 prominent nuclear physicists. At the time, Fermi was best known for his theory explaining β decay. Rutherford thanked Fermi for the preprint and he congratulated Fermi on his "escape" from theoretical physics[28].

Reports[29] began to appear in the literature claiming that Fermi's radiation might be protactinium (element 91) and not element 93. Lise Meitner, who had discovered protactinium, convinced her co-discoverer, Otto Hahn to investigate this problem[30]. In 1934, Ida Tacke Noddack, the discoverer of the element rhenium, published an article[31] stating that bombardment of heavy elements with neutrons might cause the nuclei to break into larger pieces, which are isotopes of known chemical elements but not neighbors of those irradiated. No one took this concept of nuclear fission seriously, since it was incompatible with the known laws of physics at the time. It was considered to be pure speculation. Finally in January 1939, the joint efforts of Meitner, Hahn and Fritz Strassman resulted in the publication of the discovery of neutron fission[32].

The reasons why the discovery of fission was delayed for five years is also an interesting story[33]. However, contrast the period from 1934 to 1939 from the time of the first detection of neutron fission until there was an understanding of what had physically taken place, to the much shorter time period from 1939 to 1942 between the actual discovery of neutron fission until the first application of fission in the operation of a sustained man made nuclear chain reaction, in the Chicago Pile (CP-1).

Many groups around the world began scientific work on neutron fission. In the year between the 1939 discovery of fission and a 1940 review article[34] by Louis Turner on Nuclear Fission, more than one hundred papers were published and about fifty radioactive fission products had been discovered and partially identified. By September 1939, the Second World War had begun and by 1941, many scientists in the USA, Canada and England imposed a voluntary censorship on their own publications of work in the field of neutron fission. The whole subject became "classified" and virtually disappeared from the literature[35]. This attempt not to alert the wartime opponents of the interest in nuclear fission was noted, at least by the Japanese, when the hotest scientific subject completely disappeared from the literature[36].

At the conclusion of the War, many of the previously classified papers were finally published in the open literature including a report[37] on the measured data on fission product yields for the neutron fission in ^{235}U. This report was the Plutonium Project Record of the Manhattan Project Technical Series. Studies had now been made directly or indirectly on nearly all of the 160 radioactive fission products then known. The results of the Plutonium Project were presented in tabular form. Nuclear fission product mass chains were divided into a light group (equal to or less than mass 117) and a heavy group (greater than mass 117). Nuclear fission yields were listed for the various mass numbers.

<u>DECAY DATA TABLES AND CHARTS</u>

There have been a number of tables of decay data presented in various formats over the years. In 1936 and 1937, Hans Bethe wrote a series of three articles on Nuclear Physics dealing with stationary states of nuclei, nuclear dynamics - theoretical and nuclear dynamics - experimental. In the later article[38], Bethe and Stanley Livingston presented tables of reactions and a table of induced radioactivities. In the radioactivity table, they listed nuclide, half-life, radiation and energy, method of production and the references. In 1940, J. J. Livingood and Glenn Seaborg[39] collected information on all nuclear species which were produced artificially, following the Livingston and Bethe's model. There was a separate table of stable nuclei with their isotopic abundances and a table of induced radioactivities with half-life, radiation, production methods and references. Later editions of this table included information on all nuclei in one table and was known as the "Table of Isotopes". The sixth edition of this Table[40] appeared in the year following the creation of CSEWG.

A member of Fermi's group, Emilio Segre, introduced a scheme for presenting data on all known nuclides in a chart form, where he represented the neutron number, N, in horizontal rows along the left side of the chart and the atomic number, Z, as vertical columns along the bottom of the chart. A revised edition of Segre's Chart from May 15, 1945 was published with classified data omitted[41]. In 1948, Gerhart Friedlander and Morris Perlman[42], at the General Electric Research Laboratory in Schenectady, New York, inverted Segre's chart and plotted the atomic number, Z, against the neutron number, N. This GE Chart of the Nuclides as it would be later called included information on isotopic abundances, radioactive half-lives, radiation type, energies, atomic masses and thermal neutron cross section values. The generation of data for this wall chart was moved to the General Electric's Knolls Atomic Power Laboratory, also in Schenectady and a ninth edition[43] of this GE Chart was published at the time of CSEWG's start.

Katharine (Kay) Way had been a member of the Manhattan Project effort working at the Clinton Lab (later renamed Oak Ridge National Lab). While at Oak Ridge after World War II, Kay Way began collecting information on nuclear data. In 1948, Way headed the Nuclear Data Project which was established at the US National Bureau of Standards (later renamed the US National Institute of Standards and Technology). A report[44] was published in 1950. The data included measured values with references of isotopic abundances, neutron cross sections, decay modes, conversion coefficients, energies of radiations, genetic relationships, radioactive half-lives, intensities of radiation and methods of production with some reaction energies. There were some decay schemes drawn but there were no recommended values and no errors presented.

In 1953, the Nuclear Data Project was moved to the National Academy of Sciences - National Research Council in Washington, DC. The published data[45] now also included coincidence measurements, mass assignments, neutron and proton separation energies, total disintegration energies and spins, magnetic and electric moments. Errors were now listed along with a single decay scheme for all isobars of a given mass number, A. These data were in the form of loose leaf pages called "Nuclear Data Sheets", one for each mass number.

In January 1964, the Nuclear Data Project moved again back to the Oak Ridge National Laboratory, where Kay Way had originally begun her efforts. The Nuclear Data Sheets were once again to be published in a book form by Academic Press, rather than the single sheets of data.

There were additional efforts, most of which were not as comprehensive as the Table of Isotopes, the Chart of the Nuclides or the Nuclear Data Project. These included work in the USSR by Dzelepov beginning in 1950 and later revisions[46], reviews of light nuclei energy levels by Tom Lauritsen[47] and various co-wokers, including Fay Ajzenberg, who continued this work after Lauritsen's death, and by Pieter Endt[48] and his co-workers at the State University of Utrecht, in the Netherlands.

ATOMIC MASSES AND ISOTOPIC ABUNDANCES

In Aston's 1933 book[13], the mass and abundance tables were made up of mass spectrographic measurements (utilizing a photographic plate for ion detection) of packing fractions and isotopic abundances. The atomic masses were determined by the "doublet method"; the mass difference between two atom or molecular ion fragments having the same mass number is determined, where the difference between the mass number and the atomic mass is related to the packing fraction.

At the beginning of the nineteenth century, the first standard for atomic weights[49] was hydrogen with a unit value. However, this standard led to the situation where the heavy elements, thorium had a mass of 230 and not 232 and uranium had a mass of 236, not 238. At the beginning of the twentieth century, the use of a standard of oxygen having a value of 16 corrected this problem. In 1929, the isotopes of oxygen were discovered[50,51]. Chemists continued to use the standard of atomic oxygen = 16, while physicists used a standard of $^{16}O = 16$. In 1935, Malcolm Dole[52] discovered the variation of the oxygen isotopes in air and in water. This led to a small variable mass difference between the chemist's mass stanard and the physicist's mass standard.

Chemists refused to accept the mass spectrometrists $^{16}O = 16$ standard because there were literally tens of thousands of chemical measurements in the literature with uncertainties quoted to better than two tenths of one percent (0.2%), which would be affected. Finally after two decades, Alfred Nier[49] provided an acceptable compromise for the standard of mass, that of $^{12}C = 12$. With all of the various hydro-carbon compounds available, ^{12}C had been a mass spectrometry secondary standard. This change in the standard to $^{12}C = 12$ involved a difference of only 0.004% and was acceptable to the chemists, since it hardly impacted any data in the chemical literature at the time. The International Union of Pure and Applied Physics (IUPAP) approved the mass change at their 1960 General Assembly meeting in Ottawa, Canada and the International Union of Pure and Applied Chemistry (IUPAC) also approved it at their 1961 General Assembly meeting in Montreal, Canada[53].

The new 1960 relative nuclidic mass table based on the $^{12}C = 12$ scale was published in 1960 by Josef Mattauch and Aaldert Wapstra[54]. The consistent set of nuclidic masses were computed with least squares methods from all significant experimental data for the mass numbers less than 200. There were not enough experimental data to perform a least squares fit for the data above A > 200. In addition, Al Nier[55] had just published his results for atomic masses in the heavy mass region at the same time and these data were available too late in the process to be incorporated into the 1960 mass table.

As a result in 1965, Mattauch and Wapstra[56] published the 1964 Atomic Mass Table using a new computer progress on the IBM-7090 calculating best values from a least sqaures fit of data and a χ^2 fit of adjusted values. This constituted the latest mass data at the time of the CSEWG meeting.

The original work on isotopic abundances of the elements was performed by Aston using a mass spectrograph and photographic plate detector. By the 1930's, use of the mass spectrometer with electronic detection of the ion beams, especially with those built by Al Nier, allowed Nier to detect minor isotopes for the first time, such as ^{40}K, ^{36}S, ^{46}Ca, ^{48}Ca and ^{184}Os. After the discovery of neutron fission, at Fermi's request, Nier separated ^{235}U from natural uranium, which allowed experimenters to determine that it was the ^{235}U isotope and not the more abundant ^{238}U isotope that was causing the fission of thermal neutrons.

In 1950, a report by Kenneth Bainbridge and Al Nier[57] provided a complete compilation of all isotopic abundance measurements with comments. Nier would later update tables of isotopic abundances.

NUCLEAR SPINS AND NUCLEAR MOMENTS

It was mentioned above that Pauli introduced the concept of nuclear spin to explain the hyperfine splitting of spectral lines in the time frame before the discovery of the neutron. The angular momentum is always conserved in nuclear transitions, so the vector difference between the initial value of spin and the final value must be possessed by a particle absorbed or emitted in the transition.

Parity of a system of particles has no simple analogue in classical mechanics but is a fundamental property of the motion according to quantum mechanics. In quantun mechanics, the absolute value of the wave function, $\psi\psi^*$, must be the same at the co-ordinate point (x,y,z) as at (-x,-y,-z). If the reflection of the particle through the origin does not change the sign of ψ, the motion of the particle is said to have even parity. If the reflection changes the sign of ψ, the motion of the particle is said to have odd parity. If the orbital angular momentum is even, the reflection does not change and the parity is even, while if the orbital angular momentum is odd, the parity is odd.

Data on the spin and parity of various nuclear ground states and excited energy states have been collected in the various Nuclear Tables, Nuclear Charts and Nuclear Decay Schemes that have been mentioned above.

Similarly, values of the magnetic dipole moment and electric quadrupole moment of nuclei have been collected in the various Nuclear Tables, Nuclear Charts and Nuclear Decay Schemes that have been mentioned above.

THE NEUTRON CROSS SECTION

Following the discovery of the neutron by Chadwick and the use of the neutron for causing nuclear reactions by Fermi, there were a series of measurements performed of the probability of a neutron to cause a particular reaction. This probability was called a cross section and the general size of the unit of cross section was 10^{-24} to 10^{-30} cm^2. Somewhere in the time frame of 1941 to 1942, physicists from Purdue University are credited with introducing the term "barn" (with the symbol b) for 10^{-24} cm^2, to describe cross sections that were relatively easy to measure ("as big as a barn")[58]. The term came into general use in the open literature around 1947. The subunits of milli-barns (mb) for a cross section of 10^{-27} cm^2 and micro-barns (μb) for a cross section of 10^{-30} cm^2 would also eventually appear in the literature.

The Manhattan District Project was the code name used during World War II to refer to all of the wartime work on the American attempt to produce an atomic bomb. A collection of neutron cross sections of the elements based on prewar and wartime work during the Manhattan Project was made by Hyman Goldsmith (BNL) and Herb Ibser (Wisconsin) and it was revised by Bernard Feld (MIT) and Goldsmith and published[59] in 1947. Katherine (Kay) Way and G. Haines published[60] a series of thermal neutron cross section review tables in the 1947 and 1948 timeframe. By the early 1950s, the first of a series of "barn books" of neutron cross sections were published by the USAEC Neutron Cross Section Advisory Group[61] with the designation AECU-2040 in 1952 to 1954. Brookhaven Neutron Cross Section Compilation Group published a series of neutron cross sections reviews, BNL-170, BNL-250 and finally BNL-325, from 1952 to 1955. Later editions of this barn book kept the designation BNL-325 in the 1957, 1958, 1960, 1964, 1965 and 1966 editions and supplements. In addition to compiling the experimental data points, there were hand-drawn best fit curves through the data points, as eye guides. The 1956 publication[62] of angular distributions of the cross sections were designated as BNL-400, which designation was also kept in later editions.

CENTRAL INTELLIGENCE, NUCLEAR DATA CORPORATION OF AMERICA

As mentioned above, during the World War II, the Manhattan District Project was formed to provide support for the building of the first atomic bomb. Hyman H. Goldsmith was the neutron cross section information coordinator for this Project. Goldsmith is reported to have continually traveled around the country visiting one laboratory of the Project after another and he provided inter-laboratory information exchange by carrying the latest neutron cross section measurement results on various pieces of paper in his pockets.

In 1956, Herbert Goldstein was working at the Nuclear Development Corporation of America (NDA) and he developed a scheme for keeping track of neutron cross section measurements in the bibliographic sense. He called[63] his IBM punched card index, “Central Intelligence - NDA”, or CINDA. These cards indexed both the published and the unpublished literature on microscopic neutron cross section measurements in a form so that searching for information, keeping the index up to date and providing periodic cumulations could be done quickly and mechanically.

By 1963, the lack of external financial support caused the index to become out of date. Goldstein[64] renamed his bibliographic effort “Card Index of Neutron Data” with the same acronym and he solicted external readers to cover the major journal publications and bring CINDA back up to date. With the eventual demise of the punched IBM cards for computer input, the same acronym has evolved to “Computer Index for Neutron Data” and is now performed via a four nuclear data center agreement.

DATA EVALUATION EFFORTS AT THE TIME OF CSEWG’S FORMATION

In 1951, the compiling of neutron data started at Brookhaven as a supplemental activity to the neutron measurment program in the Physics Department by Don Hughes, who had come from the Metallurgical Laboratory or Met Lab (later renamed Argonne National Laboratory) in Chicago. When Hughes died in 1960, the Neutron Cross Section Compilation Group (Sigma Center) was moved to the Nuclear Engineering Department. The Cross Section Evaluation Center, CSEC, was organized at this time and in 1967, the Sigma Center and CSEC were merged into the National Neutron Cross Section Center at BNL. In the early 1960s, a major effort was undertaken to place all of the data on magnetic tape in the Sigma Center Information Storage and Retrieval System, SCISRS. One major disadvantage of SCISRS was that it was written in machine language for use at BNL. This was not as useful to other labs who were interested in receiving the data but who did not use the same machine language.

In the mid 1960s, the situation of nuclear data compilation and evaluation was as follows. The next generation of main frame computers (faster calculational speed and larger memory capacity) were beginning to become available at the various reactor design laboratories around the country. The IBM 704, 7090, 7044 and 7094 computers were now being replaced by the Control Data Corporation’s (CDC) 6600 computer. This would be exploited in the near future.

At the 1961 Vienna Conference on the Physics of Fast and Intermediate Reactors, Ken Parker[65] (Atomic Energy Research Establishment, Aldermaston, UK) indicated some of the requirements for the neutron cross section libraries. These libraries had to specify all of the reaction processes available or else a zero value cross section would automatically be assumed by the computer program. There had to be a simple presentation of the data on punched cards, which would be easy to revise. However, the data could not be revised frequently because in that case the reactor designers would be unable to perform comparative calculation as they made their design revisions. There was a need to cross check the data for errors and the best data should provide reasonable answers for simple systems, such as bare reactor cores. Parker would make a distinction between the compilation of neutron cross section data and the evaluation of neutron cross section data.

At the 1964 Geneva Conference on the Peaceful Uses of Atomic Energy, John Story[66] (Atomic Energy Establishment, Winfrith, UK) stated that the uncertainties in neutron cross section data were larger than were being estimated at that time. He defined a cross section data file as a complete set of evaluated cross section data for a single material and a cross section data library as data files for a number of materials. He agreed with Parker that all cross sections must be represented over the full energy range but Story stated that the accuracy need not be the same for 1) all materials in the library, 2) for different cross section reaction types in the library, or 3) for different regions of the energy range in the library.

Story listed the procedure for a data evaluator to follow: 1) search the scientific literature for the cross section data; 2) study the references found in this search and put the cross section data into tables or on to punched cards and compare the resulting data with theory; 3) prepare a set of recommended cross section values on punched cards and check recommended data on the punched cards; and 4) document the details and justify the recommended data.

At the AEC-ENEA Seminar on Cross Section Evaluation at BNL (May 1965), Bob Howerton[67] (Lawrence Radiation Laboratory-LRL-Livermore) indicated that early (1957) neutron cross section data provided no associated experimental errors. For many elements and isotopes, there were no evaluated neutron cross sections over a defined range. By 1960, LRL would provide such evaluated data on magnetic tape.

Ken Parker[68] at the 1966 Washington Conference also commented on the very large amount of neutron cross section data that was then becoming available due to better machines to generate the data, more experimenters to perform the measurements and new techniques for automatic computer handling of numerical data. The data evaluators were being overwhelmed. The only solution was to increase the evaluators output by introducing computer mechanized evaluation of the cross sections. The majority of the effort of cross section data evaluation was devoted to the collection, the plotting and the tabulating of the experimental and theoretical data with a minority of the time on the actual evaluation of the data. The collection of all relevant numerical data on SCISRS tape was a start in the right direction but there was still the problem of the data being represented in machine language.

In 1964, Henry Honeck at Brookhaven began work on the Evaluated Neutron Data File (ENDF) as a vehicle to simplify the exchange of evaluated data. It would serve as a link between a data library and the processing codes. ENDF would allow data sets from different sources to be placed in a common format for use in neutronic calculations. Once it is created, CSEWG will generate and test new and revised data for the ENDF/B library.

In the early CSEWG days (1968), Herb Goldstein[69] would comment about the use of neutron transport programs that had built-in neutron cross section libraries that could not be modified. As a result, many neutron cross section measurers might be shocked to see the recent data that they had measured and which had been available for over a half decade could not be made use of by the reactor designers.

In 1966, Ken Parker[68] had commented that the rules for selection of data are either logical, in which case they could in principle be used by a computer, or else they are illogical, in which case they should not be used at all. However, by 1968, Herb Kouts[70] would comment that attempted machine made evaluation programs such as SCORE (from Atomics International) could not replace an experienced neutron cross section evaluator such as Joe Schmidt (Karlsruhe) in Kouts' estimation.

HISTORICAL CONCLUSIONS

From the above review of nuclear data evaluation over the past century compared to the situation in the present day, the vast amount of change that has been wrought by the work of the cross section evaluation working group can be seen in both the areas of nuclear data evaluation as well as the automation of the data files.

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Cross Section Evaluation Working Group History

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Background

Many people contributed to Cross Section Evaluation Working Group (CSEWG) in very significant ways and there is the distinct possibility in any recounting that someone would unfairly be left out. So, I point to The List prepared by Charlie Dunford of all those connected with CSEWG. I will mention a few names but emphasize the early history of what was done rather than who did it.

The story starts circa 1963 when several fairly detailed nuclear data libraries existed. Among the best known were the United Kingdom Nuclear Data Library (UKNDL), the library (KDK) for fast reactors at Karlsruhe, and in the U.S., the data libraries at Nuclear Development Associates in New York, Atomics International in Canoga Park, and at Livermore (ENDL). It was known that these libraries could give different answers when calculating the same reactor configuration but the dissimilarities in internal formats made it difficult to understand why the differences occurred. The principal thrust toward a universal format for evaluated data was made by Henry Honeck who credits a stimulating discussion with Al Henry of Westinghouse and George Joanou of General Atomic at the bar of the Colony Restaurant in Washington D.C. The Reactor Mathematics and Computation Division (RMC) of the American Nuclear Society supported the idea of placing all noteworthy libraries in the same format for easy comparison. In RMC sponsored meetings held in 1963 and 1964, representatives from about 20 laboratories worked to circulate and comment on a preliminary proposal on formats for evaluated data.

Evaluated Nuclear Data File (ENDF)

Henry Honeck, then at Brookhaven National Laboratory, undertook the job of developing the format. A format primarily based on the UKNDL format, started by Ken Parker, was started with some support from BNL staff. However, the new library format Evaluated Nuclear Data File (ENDF) would be mathematically rigorous, e.g. specified interpolation schemes between tabulated points, so that cross section integrals, products, and ratios would yield well defined and repeatable results. There were also code modules developed for the plotting, integration, multiplication, and other processing of cross sections that would be written in FORTRAN, for computer interchangability, and distributed to assist others wishing to use ENDF data. The formats for ENDF were documented and circulated in the hope that evaluated data sets would be placed in this common format to facilitate comparison.

However, shortly after this beginning, the next step was contemplated and momentum switched toward the final objective - a recommended evaluated data set for each material needed for analysis. The recommended data sets, in the ENDF format would be labeled ENDF Version B (ENDF/B), and alternate data sets in the ENDF format would be labeled Version A (ENDF/A). The requirements for ENDF/B were that the recommended data consist of only one set for each material and be complete in all data needed for analysis. The requirements for ENDF/A were less stringent. The data sets need not be complete over the energy range or reactions of interest nor be limited to one data set per material.

Clearly, the requirements for selection and completion of data sets for ENDF/B represented a massive effort. It would require measurers of nuclear cross sections who knew the strengths and weaknesses of existing experimental data and were knowledgeable about the prospects for new measurements. It would require measurers of integral experiments, e.g. criticality, reactivity coefficients, reaction ratios, who knew the strengths and weaknesses of these data. It would require theorists who could help bridge the gaps in experimental data space and also help select from among widely discrepant experiments. It would require reactor physicists skilled in the use of neutronic and radiation transport codes and knowledgeable about which data should receive priority because of their importance. It would require numerical analysts and code developers since comparisons with experimental results depended not only on input data but the tools used in calculations.

The principal sponsorship for ENDF/B came from the Division of Reactor Development and Technology (RDT) within the United States Atomic Energy Commission (AEC). The RDT was headed by Milton Shaw, who had previously been active in Admiral Hyman G. Rickover's nuclear data program. In 1966, thermal reactors were a commercial success and no longer depended on government support. Since there was not an immediate energy crisis, the AEC felt one of its roles was the long-range development of efficient nuclear energy sources, namely, breeder reactors. The development of evaluated data for a demonstration fast reactor useful to obtain breeding data became part of the AEC goals and ENDF/B appeared on the milestone charts.

At this time Henry Honeck was working in RDT and still active in the development of ENDF formats with the help of a programmer, Joan Felberbaum, at BNL. The question of how to jump start ENDF/B was solved by Honeck's manager Ira Zartman. Since it takes time for new projects to get formally included in the budget cycle, Zartman noted that several labs having the talent to contribute to ENDF/B already had funding for reactor development technology. He persuaded Milton Shaw to authorize the AEC laboratories to divert existing resources, identify their data requirements, and designate appropriate individuals to work toward ENDF/B. The effort would be coordinated by BNL with Sol Pearlstein as Chairman. Pearlstein was in a cross section compilation and evaluation group that was an outgrowth of the Sigma Center, a BNL group that originally collected experimental neutron cross sections from the world laboratories, superimposed the data on graphs and circulated the plots among laboratories. The graphs were circulated informally at first, then published at the first Geneva Conference in 1955, and later appeared periodically as the publication BNL-325. The BNL group had already obtained some recognition by hosting the 1965 Nuclear Energy Agency conference on evaluated nuclear data. Early in 1966 a small planning group composed of Henry Honeck (AEC), Harry Alter (AI), Bert Toppel (ANL), and Sol Pearlstein (BNL) met at BNL to plan how the ENDF/B would be started.

Cross Section Evaluation Working Group (CSEWG)

The group that would undertake to develop ENDF/B was called the Cross Section Evaluation Working Group, CSEWG. The first meeting was held at BNL June 9-10, 1966. The members attending are shown in Table I. In addition to the AEC labs and contractors, the Naval Reactor labs KAPL and BAPL were in attendance. The list of materials that had been submitted for which data were needed is shown in Table II.

At the meeting there was a tendency to discuss a wide range of issues that were not likely to be decided at one meeting. Instead, the group responded to the Chairman's call to concentrate on the main issue - the evaluation of data for ENDF/B. Two main approaches were discussed:

1. The evaluation of selected data for all materials by individual groups having expertise in that type of data, e.g. resolved resonance region, unresolved resonance region, angular distributions.

2. An individual or group would assume responsibility for the evaluation of the complete data needed for a material.

The advantage of the first approach was that the appropriate expertise for each type of data would be rendered but it was uncertain how the data would be merged into a complete evaluation and who would do so. The advantage of the second approach is that the responsibility for submitting a complete evaluation was clear but it was uncertain that the best technology would be used or the initiative taken to obtain it.

The issues became clearer as laboratories showed their degree of interest in the materials on the ENDF/B list. Some laboratories already had completed data sets for important materials. Those labs had a vested interest in adopting data that was similar to their data already in use. When KAPL offered to take responsibility for U-235, the pendulum swung to the second approach and labs eagerly volunteered to take responsibility for complete evaluations of materials important to their laboratory's programs. There was little concern that a single evaluated data set might be adopted en masse since a review process, yet to be determined, would ensure that competing versions of evaluations would be discussed. The initial list of responsibilities for ENDF/B evaluations is shown in Table III. Participants having unique data sources for a material were requested to send that information to the laboratory having responsibility for that material. In some cases, the laboratory having unique data sources that were financed privately considered that data proprietary and would not release the data.

To quell fears that the AEC would in effect legislate what data AEC contractors must use, the AEC issued the following statement at the June meeting. Excerpts from the statement follow:

"One of the long range goals of the Reactor Physics Branch of the Division of Reactor Development and Technology is the development of a set of basic nuclear data which can be used to accurately predict the behavior of neutrons in a nuclear reactor."…"The first reference set and perhaps several of the later sets may be deficient in many respects, and hence would not be immediately suitable for reactor design. It is not expected that reactor designers would discard their own proven methods and data in favor of a reference set until the reference set were shown to be equal to or superior."…"It is conceivable that an exception could occur in the case where several organizations submit to the AEC reactor designs to be compared."…"More meaningful comparisons can be made if certain select design calculations were made using the reference data. However, even in this case the comparison would not be meaningful if the reference set were not duly tested and shown to reproduce the essential physics."

The statement illustrates that from the beginning of the ENDF/B effort the AEC was sensitive to the concerns of contractors participating in CSEWG. I believe this sensitivity was helpful in securing the willing cooperation of CSEWG organizations.

In the CSEWG meeting that followed on November 14-16, 1966, considerable progress had taken place. Although material submitted in the ENDF format mostly consisted of evaluations previously evaluated some new evaluations were presented. The standardization of formats and checking codes enabled the BNL group to quickly prepare review kits for the CSEWG meeting. It was also clear that progress had been made to couple ENDF format to data library preparation codes for reactor physics calculations.

Subcommittees

At this meeting, several CSEWG subcommittees were started that would provide valuable guidance for the development of ENDF/B.

Codes and Formats Subcommittee, 1st Chairman, H. Honeck
To make all necessary revisions to assure compatibility of edit and retrieval codes with the ENDF/B and provide guidance for future code development. This Subcommittee, over the years, responded cautiously to requests for format changes. Mindful of the impact of changes on the cost and schedule of reprogramming codes, the Subcommittee's conservative response helped stabilize the ENDF/B effort.

Data Testing Subcommittee, 1st Chairman, P. Greebler
To initiate and coordinate a limited test program of the ENDF/B both microscopically and macroscopically, and to recommend modifications in future data tapes. This Subcommittee selected only a few integral critical assemblies to benchmark calculations. In this way the subtleties in benchmark material and geometry specifications, data processing numerical techniques, and neutronics codes could be explored in a meaningful way.

Normalization Subcommittee, 1st Chairman, D. Goldman
To ascertain that data contained in ENDF/B have been normalized in a logical and consistent way according to standards recommended by this Subcommittee and approved by CSEWG. This Subcommittee's activity was crucial toward the improvement of data libraries. Cross section measurements, many of which are made relative to standards, e.g. ^{10}B(n,α), ^{235}U(n,fission),that have changed over time, must be renormalized to standards recommended by this Subcommittee. Members of this Subcommittee are generally knowledgeable about measurement techniques and about statistical and systematic error analysis.

Resolved Resonance Region Subcommittee, 1st Chairman, S. Pearlstein. To investigate and suggest methods for improving the energy and temperature dependence of cross sections generated from resonance parameters. Accelerator groups were producing cross sections in the "resonance region" in great detail. The several resonance formalisms available were not always capable of fitting the data numerically or with physical significance. Procedures for entering resonance parameters and a smooth background where necessary were developed by this Subcommittee.

Shielding Subcommittee, Established but not staffed as yet.
To specify Shielding and gamma-ray production cross section needs, survey available data, and make recommendations to CSEWG.

Somehow, these subcommittees displayed wisdom beyond their experience. The objectives chosen were modest in scope. This approach enabled the subcommittees to explore problems in detail without over extending human resources thus building a rather solid foundation for the expansion of objectives that followed in later years. In time, the number of subcommittees increased adding expertise and specialized meetings as needed. CSEWG decided early on the stepwise approach. The ENDF/B would generally be issued in complete library versions and at the start, versions were timed to coincide with major milestones of the AEC breeder reactor program. Significant changes in data would be held for the next version in order to provide a measure of stability in reactor design methods. Often, format changes and data improvements in ENDF/B were very problematic and difficult to resolve. However, the subcommittees did not allow paralysis to occur and made decisions that allowed progress to continue. Eventually, additional agencies sponsored CSEWG participation and new subcommittees and additional data types were included.

Several accomplishments in the early years of CSEWG served to ignite a spirited effort that continues today. Many experts wanted to join CSEWG but the size of the group at meetings was kept at what was believed to be a workable number, generally about 45 members.

Technological Highlights

Contributing to the excitement of CSWEG was its involvement in early advances in technology.

Automation. Computers were instrumental in keeping pace with the large amounts of data formatted into ENDF and submitted to BNL. Computer codes to produce plots and listings indicating possible errors helped keep the review of submitted evaluations a manageable task.

Quality Assurance. The time and expense of preparing cross section libraries for neutronics codes made it prudent to remove clerical and physics errors from evaluations before further processing. Several levels of checking codes were used before submitting evaluations for further testing.

> CHECKER - Scanned data for format violations and points potentially out of range.

FIZCON - Checked internal consistency, integration normalizations, negative cross sections, etc. FIZCON was originally part of CHECKER.
PSYCHE - Checked energy balance with mass table, resonance parameters with known statistics, angular distributions with Wick's limit, etc.
PLOTEF, LISTEF - Could provide plots and listings of ENDF/B contents.

All codes were written in standard FORTRAN to facilitate implementation on different computers. After the correction of errors found by the foregoing codes, the data were tested in integral benchmark calculations to indicate the usefulness to be expected from ENDF/B.

Artificial Intelligence. Placed in computer programs were steps previously performed by eye and hand operations. For example, the determination from a plot of data as to whether a point among a group of data points is an outlier or not was simulated by computer. The probable range of a point was felt to be near or within a triangle formed by straight line extrapolation forward from the previous two points and extrapolation back from the next two points and the line joining the adjacent points. This automated scanning of the data tables indicated numerous order of magnitude clerical errors which greatly aided the review process. Also, the computer codes used to plot data were programmed to scan the data sets and determine useful scale limits and interpolation patterns without intervention, if desired.

Network Communication. The BNL group acquired a time-sharing computer for its data compilation and evaluation activities. Since 1975, the computer had had been used at selected professional meetings for online data retrievals over telephone lines. Evaluators began to make online retrievals of references and experimental data. Evaluators could transmit data to BNL but until high speed lines became available, only magnetic tapes was suitable for submitting the large ENDF/B evaluations.

Documentation. The formats, evaluated data, and editing codes for ENDF/B were documented to a high standard. The formats were carefully defined so that data could be entered with no confusion about what physics was intended and computer programs could be written to provide unique answers. The sources of evaluated data were documented both internally in ENDF/B itself and often in laboratory reports. This feature was a distinguishing feature compared to other data libraries and paved the way for ENDF/B to become the standard reference data library for nuclear applications and regulatory procedures. The computer codes used to edit ENDF/B were extensively commented within the source code to aid the understanding of their use and to facilitate adapting codes to individual needs.

Uncertainties. Most handbooks of data contain useful numbers but the probable errors for those numbers are seldom given because they are difficult to determine. Therefore, the range of confidence over which the numbers can be used is not known. CSEWG assigned uncertainties to ENDF/B in order to establish a range of accuracy for the file. The inclusion of data uncertainties and their correlations, to be discussed elsewhere in this symposium, required sophisticated use of physical statistics which significantly raised the scientific level of the CSEWG effort.

The foregoing ground breaking nature of the CSEWG effort contributed to the enthusiasm with which members participated.

Conclusion

In 1984, C. Dunford, a charter member of CSEWG then working at BNL, became the CSEWG Chairman. Today, the CSWEG effort continues to function despite much smaller funding levels compared to previous years. International cooperation has helped shore up the available resources. No one person has proved indispensable. Version ENDF/B-VI, issued circa 1990, has had a long life. The versions of ENDF/B are no longer tied to federal prototype designs but improvements in evaluations and new versions of ENDF/B are likely to continue.

TABLE I

ATTENDEES AT THE FIRST CSEWG MEETING

Laboratory	Representatives
Advisory Committee on Reactor Physics (ACRP)	D. T. Goldman
Argonne National Laboratory (ANL)	E. M. Pennington B. Toppel
Atomic Energy Commission (AEC)	H. Honeck
Atomic Power Development Associates (APDA)	T.A. Pitterle
Atomic International (AI)	H. Alter C. L. Dunford R. S. Berland
Babcock & Wilcox Company (BW)	W. A. Wittkopf D. Roy
Bettis Atomic Power Laboratory (BAPL)	D. Harris
Brookhaven National Laboratory (BNL)	J. Chernick S. Pearlstein T. E. Stephenson
Combustion Engineering (CE)	L. C. Noderer
General Atomic (GA)	M. K. Drake
General Electric (GE)	I. Wall
Knolls Atomic Power Laboratory (KAPL)	C. Lubitz
Los Alamos Scientific Laboratory (LASL)	R. J. LaBauve
Oak Ridge National Laboratory (ORNL)	C. W. Craven
Pacific-Northwest (PNW)	B. R. Leonard K. B. Stewart
Philips Petroleum Company (PP)	J. R. Smith R. Grimesey
Savanah River Laboratory (SRL)	J. E. Suich D. R. Finch
Westinghouse Atomic Power Division (WAPD)	R. A. Dannels N. Azziz

TABLE II

MATERIALS FOR WHICH DATA ARE NEEDED

MATERIAL	MATERIAL
H 1	Gd
H_2O	Dy 264
D 2	Lu 175
Li 6	Hf
Li 7	Ta 181
Be 9	W
Be 0	Au 197
B 10	Th 232
C	Th 233
CH_2	Pa 233
N 14	U 233
O 16	U 233 F.P.
Mg	U 234
A1 27	U 235
Ti	U235 F.P.
V 51	U 236
Cr	U 238
Mn 55	Np 237
Fe	Np 239
Ni	Pu 238
Zr	Pu 239
ZrH	Pu 239 F.P.
Nb	Pu 240
Mo	Pu 241
Xe 135	Pu 242
Sm 149	Am 241
Eu 151	Am 243
Eu 153	Cm 244

TABLE III

LABORATORY RESPONSIBILITY CHART

Laboratory	Prime Responsibility	Assistance
ANL	Mg, Ti, ^{51}V, Mo, Gd	
APDA	^{240}Pu	Na
AI	^{238}Pu, ^{242}Pu, ^{244}Cm	
B&W	^{232}Th, F.P.(^{233}U,^{235}U,^{238}U,^{239}Pu)	
BAPL	^{233}Pa, ^{233}U	
BAPL-KAPL	Zr, Hf	
BNL	Mn	
GA	H_2O, D_2O, Be, BeO, CH_2, ZrH, Nb, ^{234}U, ^{236}U, ^{241}Pu	^{232}Th,^{233}Pa,^{238}U
GE	Ta, W, ^{239}Pu	^{238}Pu,^{243}Pu,^{244}Cm
KAPL	C, O, ^{235}U	
LANL	^{6}Li, ^{7}Li	
ORNL	^{10}B, ^{14}N, ^{27}Al	
PNW	^{1}H, ^{2}D, ^{135}Xe, ^{149}Sm, ^{151}Eu, ^{153}Eu, ^{164}Dy, ^{175}Lu, ^{176}Lu, ^{197}Au	
PP	^{237}Np, ^{239}Np, ^{241}Am, ^{243}Am	$^{234-36}U$,$^{238-42}Pu$,^{244}Cm
SRL		Thermal data
WAPD	Cr, Fe, Ni, ^{233}Th	

Memories of CSEWG 1966 – 1968

Harry Alter
Atomics International and US Department of Energy

I recall the trip from California to New York City to attend a meeting in July 1965. As I walked from the taxi to the hotel entrance that evening, I was reintroduced to the 85 F temperature and 85% humidity, a typical July evening in NYC. The next day, the meeting participants thankfully gathered in an air-conditioned hotel room and finally came up with the concept that would become CSEWG. I consider myself fortunate to have participated in the beginnings of CSEWG. The mid 1960's were exciting times for civilian applications of nuclear energy.

The rapid growth of research and development applications in nuclear energy was hindered by the lack of a standard nuclear database from which multigroup constants could be developed. Evaluations of neutronic characteristics of competing nuclear power plant designs required energy dependent neutron cross sections. Without some level of data standardization, comparisons were difficult if not meaningless. The time was right for an activity such as CSEWG.

The CSEWG sponsor, AEC/RRD, recognized the need for the widest participation by organizations involved in nuclear research and development, i.e. industry, national laboratories and universities. To help overcome parochialism among organizations use of nuclear data, the sponsor had a powerful weapon-----FUNDS.

During the first few years, CSEWG meetings were held from BNL. Participants would normally stay at hotels in Patchogue, a short drive from BNL. At the first introductory meetings a total 23 organizations were represented: National Laboratories (10) ANL, BAPL, BNL, KAPL, LANL, LBL, LLNL, NBS, ORNL and SRL: Industry (10) AI, APDA, B & W, BNWL, CE, GA, GE ID, UNC and W; Universities (3) NYU, RPI and Stanford. The participants formed a number of committees covering activities relevant to the goals of CSEWG. The committee activities and their initial chairmen included: Data Testing (Paul Greebler), Codes and Formats (Henry Honeck), Resonance Region (Sol Pearlstein), Normalization (David Goldman), Shielding (Frank Clark) and Fission Products (Warren Wittkopf). Committees would meet during the CSEWG meetings focusing on their specific activities. They would report their progress or lack of progress to the CSEWG meeting. In later years, additional committees were formed to address activities not previously covered.

Meeting logistics were considerably improved when BNL built several multi-story dormitory styled buildings. When staying at one of the dormitories the key to maintaining cleanliness was to rise early so you could use the hot water before your friends did. The large number of early risers never ceased to surprise me. A few of us believe that this early rising and not the meeting content produced nodding heads and soft rhapsodies. A solution to this problem does not exist. Some of our finest heads have nodded in agreement.

Organizations prosper when there is a need for the product and/or services. The ability of CSEWG to provide both a product and services was primarily due to its internal staffing, at BNL, and support received from the outside user participants. People were the engine that drove CSEWG. During the early years, the BNL staff and the non-BNL groups merged to form a cohesive and focused organization.

The early CSEWG years have left me with lasting memories of the people with whom I interacted. They were a hard-working group, focused at the tasks on hand, competitively pushing their ideas, graciously (often begrudgingly) accepting ideas and concepts not their own, establishing a firm camaraderie and, perhaps most important, maintaining a sense of humor throughout. The CSEWG meetings, however, were not all work and no play. In particular, I remember the CSEWG poker games (not authorized by CSEWG). There were some excellent poker players and fortunately some who were not. Memory fails me as I try to remember who filled each category. However, I state for the record, that today I live in Las Vegas------ financially secure.

As I write this paper, I picture in my mind the faces of the people I interacted with during those early CSEWG years. They included: Chernick, Kouts, Pearlstein, Prince, Bhat, Cullen, Magurno, and Goldberg, BNL; Clark, Craven, DeSaussre, and Penny, ORNL; Daniels and Pitterle, W; Davey, Toppel and Pennington, ANL; Drake and Matthews, GA; Labauve, Dudziak, Moore, and Harris, LANL; Honeck, Suich and Finch, SRL; Goldman, NBS; Greebler, Hutchins and Henderson, GE; Grimacy and Smith, ID; Howerton, LLNL; Kalos, NYU; Leonard and Liikala, BNWL; Livolsi and Wittkopf, B&W; Lubitz, KAPL; Sher, Stanford; Hemmig, AEC; and of course Dunford, Berland, Hubner, and Lemke AI. There were others, of course, and I apologize for not remembering. Fortunately, you know who you are. You were my competitors and, of course, you were my friends and whether you have passed on or still here I will never forget you.

In conclusion, I present a toast to the memory of the CSWEG I knew (1966 –1973) and to the participants who filled the tables at BNL. An exciting, vigorous, vociferous, bickering, hard working, win imbibing, poker playing, results producing group who came together at the right time and the right place. To my many friends, who have provided me good memories that will last a lifetime, I say **L'CHAIM**

Some CSEWG Recollections

Charles Dunford
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The Cross Section Evaluation Working Group, which was founded in 1966, has a remarkable record for longevity and for success. I have had the opportunity of being involved with the organization from its inception. I cannot claim perfect attendance, having missed meetings in the period 1971-1974 and in 1994 and 1995 while working for the International Atomic Energy Agency in Vienna Austria. Since I cannot recall ever attending a meeting without Cecil Lubitz (Knolls Atomic Power Laboratory) present, I thought he might be eligible for the perfect attendance plaque. But he missed a number of meetings in the early 1980's. So there is no one with perfect attendance from 1966 to the present. This paper is an attempt to record my recollections of some of the important events and activities of CSEWG during its first 35 years and of some of the key players in the organization's success.

The Founding Fathers

Henry C. Honeck was the spiritual founder of CSEWG and the Evaluated Nuclear Data File (ENDF) system for evaluated nuclear data. Hank and I first crossed paths when I was a senior at the Massachusetts Institute of Technology taking courses in the Nuclear Engineering Department when he was completing his doctoral studies. Hank is renowned for his work in developing theory and computer codes to perform reactor lattice calculations. He became convinced that the increasingly sophisticated nuclear reactor design codes and the increasing amounts of fundamental nuclear data available required the development of a system for storage and exchange of evaluated nuclear data used in the design of nuclear reactors.

ENDF was not the first computer format for storage of evaluated nuclear data. Computerized files of evaluated nuclear data existed in the United Kingdom (Ken Parker, Aldermaston), West Germany (Joe Schmidt, Karlsruhe), and the United States (Bob Howerton, Livermore; Harry Alter, Atomics International; and Egan et. al. Hanford). These data files were mostly used either locally or at a limited number of institutions. Hank's concept was to develop an application-independent, well-documented, evaluated nuclear data library. The system would include numerous computer codes for quality control of the data included in the file and processing codes to prepare this data for use in nuclear design codes.

Hank organized a series of three meetings as chair of the Subcommittee on Evaluated Nuclear Data Files of the ANS Reactor Mathematics and Computation Division. Cecil Lubitz describes these meetings in his contribution to this seminar. Following these meetings, Hank distributed a preliminary format description in January 1965. The file format clearly showed the influence of the Aldermaston format. The ENDF format as we know it today with each physical record other than text records having 6 numeric fields, 11 characters wide, with trailing MAT, MF, MT and sequence numbers was not defined in this original document. The underlying strategy described in this document was to have two files, ENDF/A and ENDF/B. The data would be stored as data records, each data record containing the description for one function, of one reaction, of one material with descriptive header information. ENDF/A would contain data records using the full ENDF format. ENDF/B would allow only restricted formats for easier machine processing. A program would be written to convert from the ENDF/A to the ENDF/B. Among other things, the program would replace alphanumeric identifiers with pure numeric ones and covert to standard units quantities such as energies to electron volts and cross sections to barns.

In 1965 and 1966, Hank served as a detailee in the Reactor Physics Branch of the AEC. It was during this time that he was successful in convincing the AEC to support the creation of the ENDF system. In 1967, Hank left the AEC for the Savannah River Laboratory where he continued his interest in CSEWG, helping to produce the first ENDF/B library.

Ira Zartman was the Chief of the Reactor Physics Branch of the AEC's Division of Reactor Development and Technology (DRDT) when the CSEWG activity began. It was through his effort that funding was found to begin the work on ENDF/B-I. He realized the need to make the nuclear data evaluation effort in the US more efficient as the variety and amount of information, which would be needed for the design of fast reactors, was growing rapidly. DOE also believed that a common nuclear data library would facilitate the comparison of competing power plant designs. He convinced Milton Shaw, the head of DRDT, to order DRDT funded laboratories and companies to reprogram existing money to support CSEWG activities. Needless to say, not all of the contractors were happy about the directive. Most of the participants at the first meeting were DRDT contractors except for the two Naval Reactor laboratories, KAPL and BAPL.

In May 1965, one year before the first CSEWG meeting, the AEC and the European Nuclear Energy Agency sponsored a seminar on the evaluation of neutron cross section data at Brookhaven. Most of the scientists doing neutron reaction data evaluation in the US and Europe attended. The seminar conclusions were prepared by Ira Zartman and R. Perret of ENEA. The conclusions foresaw the creation of two major evaluation "centers", one in the US and one in Europe to exchange information and to coordinate the collection and evaluation of nuclear data in their respective regions. In the US, the formation of CSEWG and the National Neutron Cross Section Center (now NNDC) was the response to this recommendation. The ENEA Neutron Data Compilation Centre (now the NEA Data Bank) became the European counterpart of the NNDC. However, it was nearly two decades before the CSEWG counterpart, the JEF project, came into being.

It is impossible to imagine the nuclear field today without the infrastructure that was championed by Ira Zartman. If the proposal to create a CSEWG-like organization were made today, I suspect it would have little chance of being successful. He had the long-term vision to recognize the importance of having nuclear data and related expertise available for nuclear applications.

Sol Pearlstein is the person who should be credited with the successful implementation of Hank Honeck's vision. Sol volunteered to organize the United States evaluations effort. At that time, he was a member of the BNL data evaluation group. The task of organizing a cooperative evaluation activity and creation of a computerized reference library was given to him. Within two years, Sol was able to create the CSEWG organization and produce the first version of the ENDF/B library. He served as chairman of CSEWG from its inception until May 1984. Under his leadership, CSEWG produced five versions of the ENDF/B library, each representing a significant improvement over the previous version.

Sol realized that Brookhaven could not produce this library without significant outside help. At the second meeting, an organizational structure was put in place, which would last for thirteen years. He was willing to delegate responsibility for important aspects of the effort to CSEWG members from organizations other than Brookhaven. In a very short time, a tradition of multi-laboratory cooperation was established which continues to this day.

In 1967, the National Neutron Cross Section Center (NNCSC) was established with Sol Pearlstein as the head. Sol held this position until 1991. The new center combined the BNL evaluation group and the compilation group (SIGMA Center). A DEC computer was purchased for the exclusive use of the NNCSC. This computer provided the capability to collect, process, archive, and disseminate the new database from a central facility.

Some Key Contributors

There were many who have made significant contributions to CSEWG over the past 35 years. I realize that one takes risks when selecting specific individuals to mention while not selecting others. Of the more than 200 contributors to CSEWG, I believe that the following five individuals deserve special recognition.

<u>Bob Dannels</u> <u>(WNES)</u>

Bob attained almost mythical status as the second chairman of the Codes and Formats Committee. This was a period of rapid development of the ENDF format to improve the treatment of existing and to handle new data types. Bob imposed order on the process of selecting and implementing new formats by requiring that detailed proposals be submitted well in advance of the CSEWG meeting where the proposal would be considered. He also required that the cost of implementation be considered for the many computer codes that interface directly or indirectly to the ENDF format. Bob served as the acting head of the NNCSC and acting chair of CSEWG when Sol was on sabbatical leave in 1972.

The first format modification approved by his committee in 1969, Modification 69-000, reads

> *"... strongly recommends that the Procedures Manual revision of BNL-50066 have three round holes punched instead of the present* <u>*nineteen*</u> *rectangular holes."*

<u>Raphe LaBauve</u> (LANL)

Raphe was the ultimate team player and southern gentleman. He represented the DRDT program at LANL from the first meeting of CSEWG until his retirement in 1987. Whenever a problem occurred requiring emergency intervention, Raphe was the individual called on by the CSEWG chairman. He served as chairman of the Shielding Subcommittee from 1972 to 1976 and chairman of the Codes and Formats Subcommittee from 1976 to 1980. After the reorganization of 1980, Raphe served as chairman of the Formats Subcommittee until 1985 when he succeeded Bob Howerton as chairman of the parent Methods and Formats Committee. Raphe had a special talent for developing a consensus on contentious issues.

<u>Harry Alter</u> (AI)

Harry led the data evaluation group at Atomics International from 1964 until the group was dissolved in 1973. He participated in the CSEWG planning session of April 1964 and played a key role in the effort to establish CSEWG. AI had its own mature data library and processing programs which were not compatible with the ENDF system. He realized the advantages of a universal system for storing evaluated nuclear which would have the possibility of providing better nuclear data libraries at lower cost through reduced duplication of effort. The full resources of the AI group were devoted to supporting BNL in the production of the initial release of ENDF/B. Harry assumed the chair of the Data Testing Subcommittee in 1969. During his tenure ENDF/B-II and ENDF/B-III were released and ENDF/B-IV begun.

<u>Phil Young</u> (LANL)

If there was any single individual who personifies CSEWG, it was Phil. He was the consummate nuclear data evaluator. He combined knowledge of theory, experiments, computers and work ethic to be the most prolific evaluator in the history of CSEWG. In the 1980 reorganization, he was asked to chair the newly created Evaluations Committee. This new committee was given the ultimate responsibility for the contents of the ENDF/B data library, a responsibility that formerly resided with the Data Testing Subcommittee. Phil had responsibility for the production of the ENDF/B-VI evaluated data library and many of the "mods" to that library. As chair of CSEWG, I relied heavily on Phil for informed and unbiased advice. Even after his formal retirement from LANL and CSEWG in 1998, Phil continues to be an important contributor of evaluated data to ENDF. At 18 years, Phil's record of holding a key position in CSEWG exceeds even that of Sol Pearlstein.

Dick McKnight (ANL)

Dick has chaired the Data Validation Committee (formerly known as the Data Testing and Applications Committee) since 1985. This year he will tie Sol Pearlstein for longevity in a key CSEWG position. During Dick's chairmanship, the committee has been responsible for data testing of all releases of ENDF/B-VI. The role of this committee has been to analyze and document the performance of each library release in a wide range of reactor designs. In recent times, with automation of validation procedures, this committee does a pre-release assessment for the most important materials to insure that there is not a degraded performance from a new release. For all materials, the post-release validation process indicates areas for possible improvement. Dick and his committee were responsible for developing the ENDF Benchmark book which documents all of the reactor integral experiments used in ENDF/B validation. In this period of decreasing funding Dick has been able to marshal resources sufficient to provide a guide to the effectiveness of the ENDF/B library.

History of ENDF Versions

ENDF/B-I The first version of ENDF/B was released in 1968. The evaluations contained in the library were taken from existing evaluations and converted into the ENDF format. The emphasis was on the creation of the necessary infrastructure to support such a library. The evaluations submitted to the NNCSC were processed through checking and plotting codes developed at NNCSC and AI. The evaluations were reviewed by the Data Testing Subcommittee. Most of the testing done was to check for mechanical errors and for currency of the data used in the evaluation. ENDF/B-I contained evaluations for neutron interactions with 58 materials. Six of these evaluations were found to be deficient and in need of improvement.

ENDF/B-II The next version was released in 1970. Experience with the production of the first version resulted in improved checking of the individual evaluations (Phase I) and more systematic benchmark checking (Phase II). In this release, the capture and fission cross sections, and $\bar{\nu}$ were re-evaluated for the fissile and fertile materials. Evaluations for the structural materials, iron, nickel and chromium were upgraded. New evaluations for copper, rhenium, hafnium and zirconium were added. Evaluations for important neutron reactions with fission product nuclei were included in the new release as well as data for the various components of the energy released in fission. The ENDF utility programs, PSYCHE, INTER, LISTEF and PLOTEF were developed to improve the Phase I testing. Improved documentation for the ENDF formats and procedures was prepared in 1969. This work was published in 1970 as ENDF-102 in much the same form as today's format manual.

ENDF/B-III ENDF/B-III was released in 1972. While data testing clearly showed improvement of this library as compared to ENDF/B-II, further improvements to the fissile/fertile, structural and heavy actinide cross sections were indicated. For the first time, the "standard" cross sections for neutron-induced reactions were identified. A special purpose Standards Library was created and sent to the IAEA for worldwide distribution. A special purpose library for Dosimetry cross sections was also created by CSEWG. New fission product cross sections were added to improve decay heat calculations. Benchmark testing demonstrated that future versions of ENDF would need to include improved fission product yields and to add nuclear radioactivity data.

ENDF/B-IV Enclosure 3 of the minutes of the November 1972 CSEWG Meeting laid out an ambitions set of goals for ENDF/B-VI. There were 17 goals listed which included

1. development of delayed neutron yield data and spectra,
2. improved product yield and decay data,
3. gamma-production for many materials,
4. improved $\bar{\nu}$ and σ for the "Big 3 + 2" actinides,
5. errors for selected materials,
6. broadened benchmark testing,
7. improved documentation.

Distribution of the ENDF/B-IV was completed in July 1974, continuing the tradition of new releases of the ENDF/B library every two years.

ENDF/B-V The release of ENDF/B-V was originally scheduled for mid-1977. The general purpose library was released at the end of 1978 and the special purpose libraries shortly thereafter. For the first time, the Department of Energy placed restrictions on the distribution of an ENDF/B library. With maturity, it took more time to make improvements to the data which would warrant the release of a new version of ENDF/B. It would never again be released on a two-year cycle.

One fundamental concept introduced in this version of ENDF/B was to complete the evaluation of the standards early so that they could be used in the evaluation of other materials, for example, to get absolute cross sections from fission ratio measurements. In addition to improving the evaluations for many materials where new experimental measurements had been made, special emphasis was placed on having complete files for actinides, both cross sections and decay data. Decay data formats were expanded so that more information needed to improve decay heat calculations further could be stored in the library. Another goal was to expand both the quality and quantity of covariance information in ENDF/B.

ENDF/B-VI One of the great strengths of the ENDF/B library was its goal of being an application independent library. Before ENDF/B-VI, this meant to be applicable for both thermal and fast reactors. The goal of ENDF/B-VI was to extend the energy range of the file to higher energies to accommodate fusion reactors and other higher energy applications such as nuclear medicine. One of the motivations for this change in emphasis was the fact the sponsorship of CSEWG shifted from DOE's Office of Nuclear Energy to Office of Energy Research after the cancellation of the Clinch River fast reactor project. The responsibility for the development of fusion energy rested with Energy Research. ENDF/B-VI was completed and released in 1990. Phil Young will describe the production of ENDF/B-VI and the numerous revisions since its initial release

ENDF Goes International

Today, the ENDF format is the de facto international standard for storage and exchange of evaluated nuclear data. The inventors of the ENDF system and the ENDF format probably did not foresee the international impact of their work. The immediate problem was to unify all of the various libraries and formats in the United States into the ENDF system. This did not occur immediately or without problems. The initial version of ENDF/B did not have the support of the military programs except for the naval reactor laboratories. The first release of ENDF/B was generally available without restriction except for evaluations of Zr, Hf and ^{233}U that were supplied by naval reactor laboratories. By the time ENDF/B-II was released, alternate evaluations for these materials were available and included in the ENDF/B library. The military programs at Los Alamos and Livermore first send observers starting in 1967. However these laboratories continued to use their own library stored in the Aldermaston format. By 1970, they had become full participants in the CSEWG activities. Los Alamos adopted the ENDF system. However Livermore continued to maintain their separate evaluated data library and format. Eventually Livermore developed the ENDL format for their library with programs to translate from ENDF to ENDL and vise versa. The ENDL format and library continue to be used by Livermore to this date although they are planning to adopt the ENDF system in the future.

Outside the US, ENDF coexisted with local libraries and formats. The foremost of these were the Aldermaston library in the United Kingdom, the KEDAK library in Karlsruhe Germany and the BROND library in the Soviet Union. In the early 1980's Japan adopted the ENDF format for its JENDL library. Western Europe had yet to adopt a common format or library. This all changed with the decision of the US to restrict the distribution of ENDF/B-V to the United States and AECL Chalk River in Canada. From very early times, AECL had taken an active part in CSEWG and provided important data for the library. The decision by the United States to restrict ENDF/V was based on a dispute over the free exchange of data from integral experiments. ENDF/B-V evaluations could be released to a non-CSEWG organization only on a material-by-material basis with DOE approval. Processed nuclear data had the same restrictions. The NNDC had to lock the master tapes in a large safe, which now sits empty in the NNDC library. Very few such requests were granted. The world would not have access to the latest evaluations from CSEWG. The impact was greatest on Western Europe that had no unified library and greatly diminished resources. Under the sponsorship of the Nuclear Energy Agency, their member states decided to develop common evaluated nuclear data file to be called JEF for Joint Evaluated File, which used the ENDF format

The first truly international evaluated nuclear data library (FENDL) was proposed by the Nuclear Data Section in 1989. This was to be a library of materials in the ENDF format to support the IAEA's international fusion reactor design project INTOR. This project was followed by a Japanese-European-American project called ITER. Since the IAEA had no resources to evaluate nuclear data for this library, the contents had to be selected from the existing libraries, ENDF/B, JENDL, EFF and the Russian BROND library. The new US library, ENDF/B-VI, was sponsored by DOE's Office Energy Research whose policy was not to restrict its distribution. For the first time, participants from these projects and others, intercompared evaluations with the goal of selecting the "best" available evaluation for the new library. The approach was very similar to ones taken for the first versions of the ENDF/B and JEF libraries, but now on an international scale. Major contributors from CSEWG were Duane Larson, Fred Mann and Ed Cheng. One staff member from the IAEA, Valery Guolo, came to the NNDC for several weeks to prepare review "kits" for the evaluations proposed for inclusion in FENDL. These review kits were then analyzed by experts in a series of meetings in Vienna. For the first time, methodology and results were discussed in detail by the world's leading nuclear data evaluators. Once the materials were selected, an extensive benchmarking activity was undertaken. The project was completed with the release of FENDL-2 which included improvements suggested by the evaluation reviews and the benchmarking. The highlight of this phase was the fact that the improvements were reflected in the contents of the participant's evaluated data files.

At about the same time, with the strong support of the Nuclear Energy Agency Nuclear Data Committee (NEANDC), an effort was made to coordinate the evaluation effort of the NEA member states. John Rowlands (Winfrith, UK) and Alan B. Smith (ANL, USA) were the prime movers for this idea. In 1989, the chairs of the three evaluation projects, Massimo Salvatores (JEF), Sin-Iti Igarashi (JENDL), and I representing CSEWG, met in a small smoke-filled room at a hotel in Los Alamos. Many members of the NEANDC had gathered with us in that room. The smoke was courtesy of Alan Smith's pipe. The chairs of the three projects initially had somewhat divergent objectives. It was clear that resources continued to dwindle internationally. Max Salvatores with his experience in developing a multi-national evaluated nuclear data file proposed that JEF, JENDL and ENDF/B be merged into a single library. The chairs of the other projects felt that such a development would only lead to further reduction in their local resources and that the organization would not be responsive to the national needs of the US and Japan. By the end of the evening, we had agreed to the formation of the Working Party on International Nuclear Data Evaluation (WPEC for short) under the sponsorship of the NEANDC. The objective of the working party would be to organize scientists from the separate projects to work on the resolution of important problems in nuclear data evaluation. It was realized that such activity would naturally lead to having common evaluations for important materials in the three libraries. After about three years, the IAEA was invited to join this activity. In this way, the Russian evaluators (BROND) and the Chinese evaluators (CENDL) who also used the ENDF format could be included in the coordinated nuclear data evaluation effort. WPEC continues to be active to this day with ongoing responsibilities for coordinating nuclear reaction standards evaluations, nuclear data measurement activities, international input to ENDF format development, development of nuclear model codes and needs for new or improved nuclear data.

Two Little-Known CSEWG Projects

I was personally involved in two interesting projects sponsored by CSEWG. Unfortunately neither project ever saw the light of day and so are deservedly only footnotes to the history of CSEWG. The first was the SCORE project that started in 1968 and ended in 1972. The second project that I will describe is ENDF/C.

The original concept for ENDF was to have two data files. The first file was called ENDF/A. This file was to contain data sets describing the energy dependence of a single function such as the elastic angular distributions for neutrons on Fe. ENDF/B was designed to have complete representations for interactions of neutrons with a target material. As opposed to ENDF/A, the data for each function in ENDF/B would have numerical identifiers and would be represented in standard units. ENDF/B would be easily machine-processable. The code to convert ENDF/A to ENDF/B was called ENCORE. John Suich of Savannah River Laboratory was responsible for writing this program.

CSEWG supported a project to investigate the use of interactive techniques to perform nuclear data evaluation. I was given the responsibility for this project with the assistance of Bob Berland. At that time most computers were operated in a batch mode. Only one job at a time could be processed. Every desktop did not have a computer. I recall that a whole group might have only a single mechanical calculator. George Joanou formerly of General Atomic and a friend of Hank Honeck was working at the IBM Research Center at Palo Alto, California. This research center was closely linked to the Stanford Linear Accelerator (SLAC) facility. SLAC had an IBM 360-50 with a new product, an IBM-2250 attached. The 2250 was the first IBM interactive graphical terminal device. It had a light pen as well as a keyboard for user input. It was programmable using a special machine language. The 360-50 computer had a new IBM operating system, HASP, which could process TWO jobs simultaneously. Under George's direction, IBM agreed to provide a programmer familiar with the 2250 machine language to develop the graphical display package, which could be called from FORTRAN. The programmer Robert Creasy, had a degree in physics that proved to be very useful.

The initial concept was to use the data from a SCISRS tape containing experimental data from the Brookhaven data center as the basis for evaluation of a cross section. Programs written in Fortran would process the tape and display the experimental data on the screen of the 2250. The light pen could be used to select the experimental data to be included in the analysis. Then spline curves could be fit to the experimental data would be made and a file in ENDF/A format produced. At a later time, model calculations were to be added to the evaluation procedure. Within a period of about one year, the concept was demonstrated. The development continued in Idaho Falls with the collaboration of Mike Moore and Orville Simpson to add the capability to evaluate resonance region data. The Adlers, Felix and Donatella, also were involved so that an Adler-Adler analysis could be performed with SCORE. Before the project had been finished, I had left Atomics International. Phil Rose completed the project. The concepts we were investigating seem to be pretty primitive by today's standards. But at the time, the approach seemed to offer a better, more efficient way to evaluate nuclear data.

The project involved frequent trips from Los Angeles to Palo Alto on the world-renowned Pacific Southwest Airlines at about 14 dollars each way. The three of us would work on SCORE on the midnight to eight shift at the SLAC computing center for a week at a time. I got to know all of the great restaurants in San Francisco as at least once a visit we would have a night out in SF before going to work. And then the project moved to Idaho Falls. My fondest memory of Idaho Falls was that the airport was only ten minutes out of town.

The second project that I would like to mention is the ENDF/C project. During the planning for ENDF/B-V, it was recognized that evaluated nuclear data for other than neutron reactions needed to be included in ENDF/B. It was not clear whether the existing format could be modified for this purpose or whether a new format had to be devised. A committee was formed to investigate the question. The committee consisted of Bob Howerton, Bob MacFarlane, Francis Perey and myself. We met in Oak Ridge in 1974 to design a format that could accommodate a wide variety of the nuclear data that might be needed in the future. The main issue to be addressed was the structure of the file and the definition of the tags to be attached to a record to uniquely identify the contents of the record. The committee believed that the methods used to represent nuclear data in the file were adequate for representing existing and expected data types.

The changes proposed for ENDF/C are detailed in Enclosure 8 of the minutes of the May 1975 CSEWG meeting. Among the changes proposed were

1. Introduce unique unchanging MAT numbers to define the incident particle and the target material.
2. MF values would be used to specify the outgoing particle in secondary particle distributions.
3. MF=1 would only contain text records to provide documentation for the evaluation.
4. Fission neutron multiplicities would be stored as part of the secondary particle distributions instead of being stored in MF=1. The secondary particle probablitity tables would be replaced by multiplicity tables.
5. All information for the resonance region including smooth background would be stored in MF=2. The MT number would be used to distinguish different resonance region parameterizations.
6. Subsections would be permitted in MF=3 to describe cross sections for discrete final states in a nuclear reaction.
7. Isotopic cross sections would be included in evaluations of natural elements with more than one isotope. This was already possible for resonance parameters.
8. Formats would be defined for specifying nuclear levels and other nuclear structure quantities.

A computer program was written to convert ENDF/B to ENDF/C to test the concepts. The battle over migrating to ENDF/C raged on for more than four years. The resistance of those organizations whose data needs were satisfied by existing formats was fierce. The minutes of the November 1979 meeting contains a memo from Bill Henderson of the Westinghouse Power Systems Division to Raphe LaBauve who was chair of the Codes and Formats Subcommittee proposing that if the next version of ENDF were to be stored in ENDF/C format, NNDC should have a program to convert the file back to ENDF/B format. The conservatives won the day. The new data types were accommodated in ENDF/B-VI by extending the formats used for ENDF/B-V. The most important requirement for the ENDF/B library is that it needs to be available in a convenient form for users. There is great reluctance to invest resources in upgrading code systems when the new features of ENDF are not needed by the community paying for the code modifications. The ENDF/B library is not directly used in design calculations. It must be processed first by programs such as NJOY to get either multigroup or Monte Carlo libraries. The difficulty in introducing new formats is demonstrated by the introduction of correlated secondary energy-angle distributions (MF=6). The formats for this data were already adopted when the fast reactor program in the United States was cancelled. The only funds available for updating the processing programs came from the military program for NJOY. It took more than 10 years to get versions of the AMPEX (ORNL) and MC^2 (ANL) processing systems operational.

Conclusions

The CSEWG organization created in 1966 has continued to perform vital tasks for more than 35 years in support of the development and implementation of nuclear technologies. It has become the model for similar activities worldwide. It has demonstrated the ability of individuals from many disciplines and organizations to work together for many years to produce a vital product, ENDF/B. Of necessity, this paper mentions only some of the many activities and individual who made CSEWG such a success. The full roster of individuals and organizations who have participated in the work of CSEWG in the past 35 years is given in Appendix A of the proceedings of this seminar.

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Cross Section Evaluation Working Group Physics

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In 1966, when the Cross Section Evaluation Working Group (CSEWG) started, reactor physics analysis appeared to be in a state of disarray. Analysis systems were tailored to the energy range they covered. Different systems were used for thermal reactor design from those used to analyze fast reactors and higher energy applications. Even within an energy range, different approaches were used. For thermal energy applications, anywhere from 3-energy group cross sections to many group temperature dependent scattering kernels were used. In high-energy applications, several to many energy groups were used. To this day, the Hansen-Roach 16 energy group set still gives good answers in many applications but the details of how the data were selected and tweaked by its many users are not documented which is a deficiency for today's regulatory requirements. In 1966, the plethora of databases and neutronics codes made methods of analysis seem mysterious, more art than science. The ideal of a single universal data library from which the data for any application could be derived seemed a long way off. Even if detailed nuclear data libraries were available, the solution of neutronics equations was constrained by the limited speed and storage of computers and the limited precision of the computer code algorithms.

As detailed nuclear data libraries became available and comprehensive analysis systems were developed, these systems could be used to perform parameter surveys for a wide range of nuclear designs. The survey results might not be accurate on an absolute basis but could be accurate to the first order when normalized at a point to agree with an integral experiment.

Discrepancies Between Calculations and Experiments

There were seemingly irreconcilable differences between integral and differential data and calculated and measured results, e.g. ^{238}U resonance capture, ^{235}U α, so that the agreement sought between calculation and experiment was difficult to realize. A large number of critical experiments, where the multiplication factor K_{eff}~1.00, became available that were well documented and could be modeled to serve as benchmarks for calculations. Attention was drawn to the disagreements between calculation and experiments for these cases.

The specialists working in differential neutron cross section measurement and evaluation generally worked separately from those performing integral measurements. The evaluator of differential data hoped to obtain cross section detail throughout the spectral range for each material to an accuracy at best of a couple of percent. The measurers of integral experiments, e.g. criticality, could obtain results for a combination of materials averaged over a wide spectrum range to an accuracy of a few tenths of a percent. The fact that the uncertainties in differential data are an order of magnitude larger than the uncertainties in integral data led to the question - Are differential and integral data closely related?

Differential and Integral Data

A large number of criticality measurements over a wide range of fuel to moderator ratios constituted a database of integral measurements for many different neutron spectra. This provided a sort of broad energy band test of cross section data as a function of energy. Interest grew in using the cross section evaluations as trial functions and employing least squares fitting techniques to determine what energy dependent cross sections could fit integral experiments with the minimum deviation. When the cross sections fitting the integral experiments best lay outside the probable errors of differential measurements, this caused great concern. The measurer was puzzled as to how the measurements could be that much in error. The reactor physicist thought the cross section measurements were wrong and the adjustment procedure was a clever way to determine differential cross sections.

CSEWG Investigations

What could be the reason for the discrepancy between calculation and experiment for integral data? Was a new physics involved? As the capability of computers improved the methods of analysis also improved. With Monte Carlo transport methods and pointwise energy data the Boltzmann equation could be simulated in detail. As the reactor physics equations could be solved without compromise close examination of the discrepancies between calculation and experiment became possible. In addition to CSEWG meetings several symposia on special topics were held, some of which helped solve discrepancies. These are listed in Table I. For example, the second symposium in Table I led to a higher accuracy measurement of the capture widths in low energy resonance parameters for ^{238}U and an improved method for calculating resonance capture in extremely narrow resonances. These two remedies worked about equally to bring calculation into agreement with experiment. BNL seminars on the MeV range, were instrumental in intensifying the collection of such data and the use of nuclear models to fill in gaps in measurement space to complete ENDF/B files.

The evaluator must consider the time history of measurements. Very few measurements are made on an absolute basis. Usually, measurements are made relative to another cross section considered as a standard, e.g. carbon scattering cross section, ^{10}B(n,α) cross section, ^{235}U(n,f) cross section. The adopted standard has often changed with time. When measurements are renormalized to the current standard the discrepancy among the measurements is often reduced. The work of the CSEWG Normalizations and Standards Subcommittee contributed greatly to this work. R-Matrix theory was an important component of this work.

An early initiative taken by CSEWG was the simultaneous evaluation of key materials. The evaluations for ^{235}U, ^{238}U, and ^{239}Pu, called the Big 3, were evaluated by a special task force. As a result the calculations for benchmarks involving the Big 3 became more internally consistent than before. This is because experimental data considered in the evaluations consisted of cross section ratio measurements among these materials, which are obtained with smaller uncertainties than for cross section measurements.

Uncertainties and Sensitivities

If the evaluation of cross sections was to be considered a science instead of an art then the assignment of uncertainties to data was important. Errors in both differential and integral data must be carefully examined. What did a number e.g. 3, assigned to a cross section mean? Did a number 3.00 mean that the cross section was known to 2 significant figures? A number should be reported with the range of uncertainty, e.g. 3.1 ± 0.4 or 3.1 +0.3 -0.5, the uncertainties need not be symmetric.

The discussion of uncertainties within ENDF/B spurred a vigorous debate circa 1974. CSEWG members were heard to say "Uncertainties were too difficult to assign, and virtually impossible to assign over the complete range of data." "Even if assigned, uncertainties would never be used. There simply was not sufficient interest to justify the enormous expense to implement uncertainties in reactor physics codes".

The decision to proceed with uncertainties was helped by work(1) begun at Oak Ridge National Laboratory (ORNL) to develop a language and format for covariances and sensitivity coefficients. The covariances (uncertainty matrix) are application independent. The sensitivity coefficient matrix consisted of the relative change in a calculated result to changes in the cross sections. The sensitivity matrix is application dependent. The product of these two matrices was the predicted uncertainty in the result. The method could also be used to work backward from a required uncertainty in integral data to determine to what precision a differential measurement was needed. Differential data need not be known to as small an uncertainty as integral data because of data correlations (off diagonal matrix elements) many of which are negative in sign and reduce the calculated uncertainty compared to cases where data are uncorrelated (only diagonal terms). As resources became scarce it was not possible to work on all cross sections in the ENDF/B catalog of materials but only those having the most importance. Sensitivity analysis could be used to determine the cost benefit of individual data improvements. The foregoing and the matrix adjustment procedure(2) based on Bayes theorem provided a clear physical relationship between differential and integral data.

Systematic Errors

Both statistical and systematic uncertainties must be considered. The statistical errors arising in an experiment are easier to determine and depends mostly on the signal to background ratio for an experiment. Systematic errors can introduce a bias in the result. The determination of systematic errors is difficult and depends on measuring a parameter using different and independent measurement techniques.

As an example of the need for close examination of experimental data, a histogram(3) of the calculated effective multiplication factor for 800 critical experiments using a data library based on ENDF/B-IV is shown in Figure I. Overall, the calculations yield a mean k_{eff} = 0.9809 ± 0.0312 or about 2% low. A closer look shows two peaks, one with a $k_{eff} \sim 0.995$ indicating relatively good agreement with experiment and the other a $k_{eff} \sim 0.92$. The lower peak consists mostly of data for unreflected uranyl-nitrate solutions in simple geometries. At the time of this work, circa 1980, the calculations for solution experiments, ostensibly simpler to model, showed a systematic bias compared to other cases warranting a thorough study of the high energy ^{235}U fission cross section.

Conclusion

For the development of ENDF/B to continue, the successive versions had to improve the agreement between calculation and experiment. While CSEWG often knew what changes in differential data were desired, the tweaking of data was constrained to be consistent with measurements. In this way the resulting discrepancies between calculation and experiment remained a gadfly to spur greater understanding of the issues. CSEWG can take pride that each successive version of ENDF/B increased the applications for which the library could be used.

References

1. F.G. Perey, "Estimated Uncertainties in Evaluated Data", *Trans. Amer. Nuc. Soc.*, June, p. 337(1974).

2. J.B. Dragt, et al, "Methods of Adjustment and Error Evaluation Evaluation of Neutron Capture Cross Sections; Applications to Fission Product Nuclides", *Nuc. Sci. Eng.* **62,** 117 (1977).

3. R. Kiyose, et al, "Experimental Benchmark Needs for Criticality Safety", *Trans. Amer. Nuc.Soc.,* **39**,513(1981)

TABLE I

Cross Section Symposia

1. BNL-50387, "Multi-level Effects in Reactor Calculations and the Probability Table Method", Proceedings of the CSEWG Resonance Region Subcommittee, BNL, May 8, 1972.

2. BNL-NCS-50451, "Seminar on ^{238}U Resonance Capture", Ed. by S. Pearlstein, BNL, March 18-20, 1975.

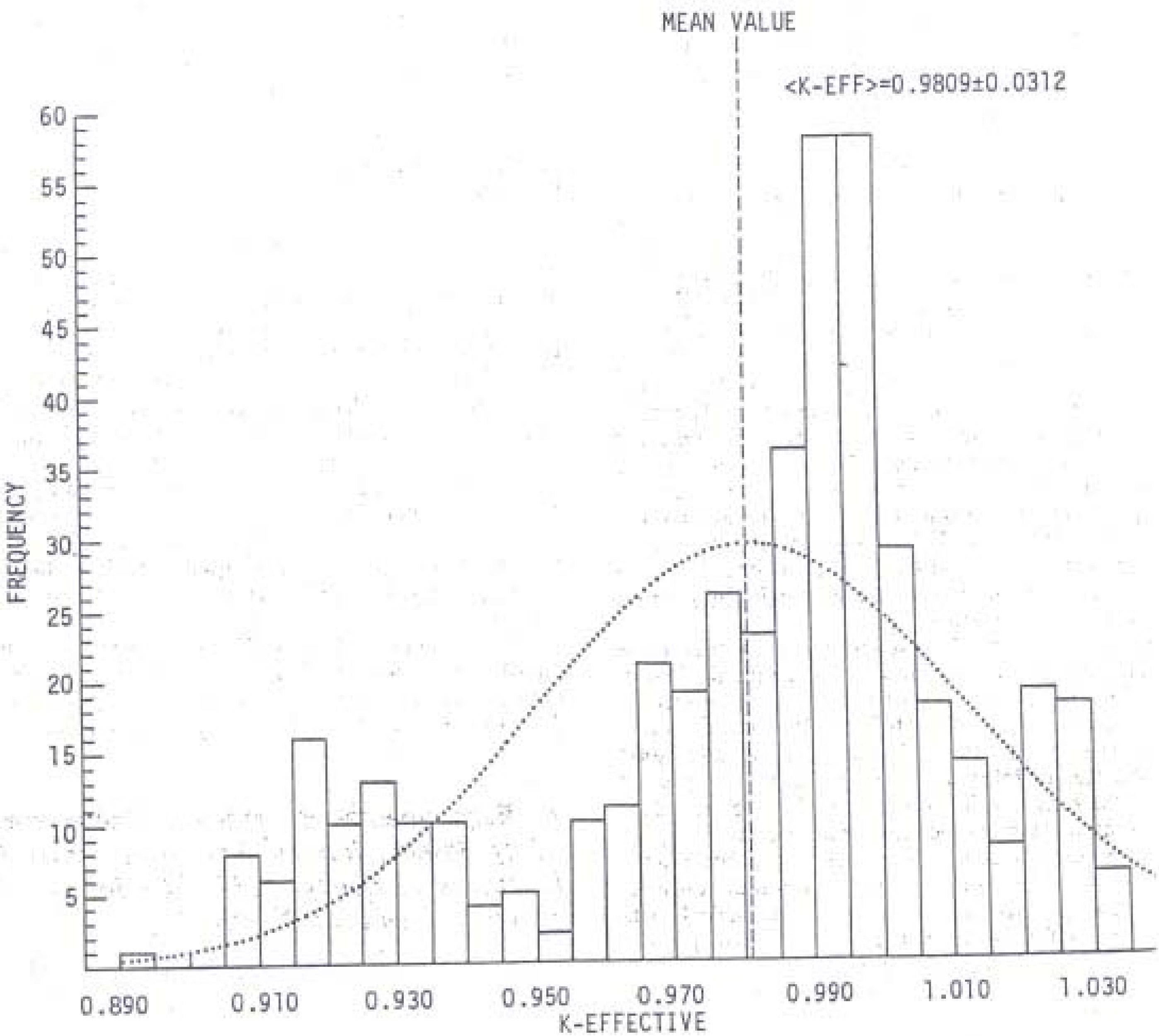
3. BNL-NCS-50681, "Symposium on Neutron Cross Sections from 10-40 MeV", Edited by M.R. Bhat and S. Pearlstein, BNL, May 3-5, 1977.

4. BNL-NCS-51245, " Symposium on Neutron Cross Sections from 10-50 MeV", Edited by M.R. Bhat and S. Pearlstein, BNL, May 12-14, 1980.

5. BNL-NCS-51363, "Proceedings of the Conference on Nuclear Data Evaluation Methods and Procedures", Ed. by B.A. Magurno and S. Pearlstein, BNL Sept. 22-25, 1980.

6. International Symposium, Nuclear Data Evaluation Methodology, Ed. by C.L. Dunford, BNL, Oct. 12-16, 1992. World Scientific.

FIGURE I



Histogram of the effective multiplication factors.

The ENDF/B Standards

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INTRODUCTION

The standards have had an interesting evolution going from ENDF/B-I to ENDF/B-VI. When ENDF/B was in its infancy, the number of standards, their energy ranges of applicability, and their accuracy were not well established. The need for better standards has led to significant improvements and very sophisticated evaluation procedures such as those that were used for the ENDF/B-VI standards evaluation. The desire for standards which are recognized internationally led to the ENDF/B standards being accepted by each of the major international evaluation projects. The ENDF/B standards were made available outside of America even for ENDF/B-V while other evaluations were not. A new evaluation of the standards is being started now which will be a cooperative effort with international involvement in order to make use of the resources available internationally.

ENDF/B-I

There was a Normalization Subcommittee, which became the Normalization and Standards Subcommittee, that was responsible for the standards for ENDF/B-I. This Subcommittee was first chaired by David Goldman. However, it was not possible to properly use the standards for this evaluation. The focus was on getting as many evaluations as possible that were of reasonable quality into the library. It was based on evaluations already in use at that time for which the institutions that supplied the funding for the evaluations were willing to release them. For the various evaluations, data were used which had been measured relative to standard cross sections. These standard cross sections had appropriate features such as having a smooth energy dependence, a large cross section and were easy to implement in appropriate detectors; but, different evaluators were not necessarily using the same values for the standard cross sections. Thus the term standard had a different meaning for that work compared with what it means now. It was rapidly recognized that proper and consistent standards must be used in the evaluation process. It should be emphasized that the evaluations for ENDF/B-I were basically used to check out the processing codes which had been written.

ENDF/B-II

Greater attention was given to the normalization of the data files for the evaluations in this version. The normalization was done in accordance with recommendations of a fertile-fissile task force which met at BNL on Aug. 11-12, 1969. The Version II library did not predict several integral benchmark measurements as well as the Version I library, even though much of the Version II data was believed to be appreciably “better” than the Version I data. Neither Version I or Version II was believed adequate for reactor design applications without major adjustments. This gave rise to a second task force which

Table 1

December 1972
Responsibilities of the Normalization and Standards Subcommittee

- Review and recommend all cross sections described as standards. Includes thermal cross section shapes, values and resonance integrals of all ENDF/B materials. Of particular importance are:
  - Cross sections classed as measurement standards by the USNDC.
  - Thermal cross sections for the primary fissile nuclei.

- Neutron dosimetry cross sections.

- Ensure that proper standards are used in the normalization of each ENDF/B file.

- Interact with other standards efforts outside of the CSEWG (USNDC, ASTM, IAEA, ANS).

- Interact with Data Testing Subcommittee by studying Phase II testing results that may indicate a need for modification of a standard cross section value. Recommend changes where appropriate.

- Interact with any other CSEWG Subcommittees when activities under their responsibility have an effect on standard cross section values.

- Maintain "Standard Reference and Other Important Nuclear Data" reports. (^{252}Cf ν, fission neutron energy spectra, thermal fissile parameters, cross section standards, delayed fission neutrons, α, fast neutron capture, $T_{1/2}$, other thermal cross sections & resonance integrals, decay schemes, isotopic abundances, energy per fission, specific discrepancies, inelastic scattering for fissile & fertile nuclei).

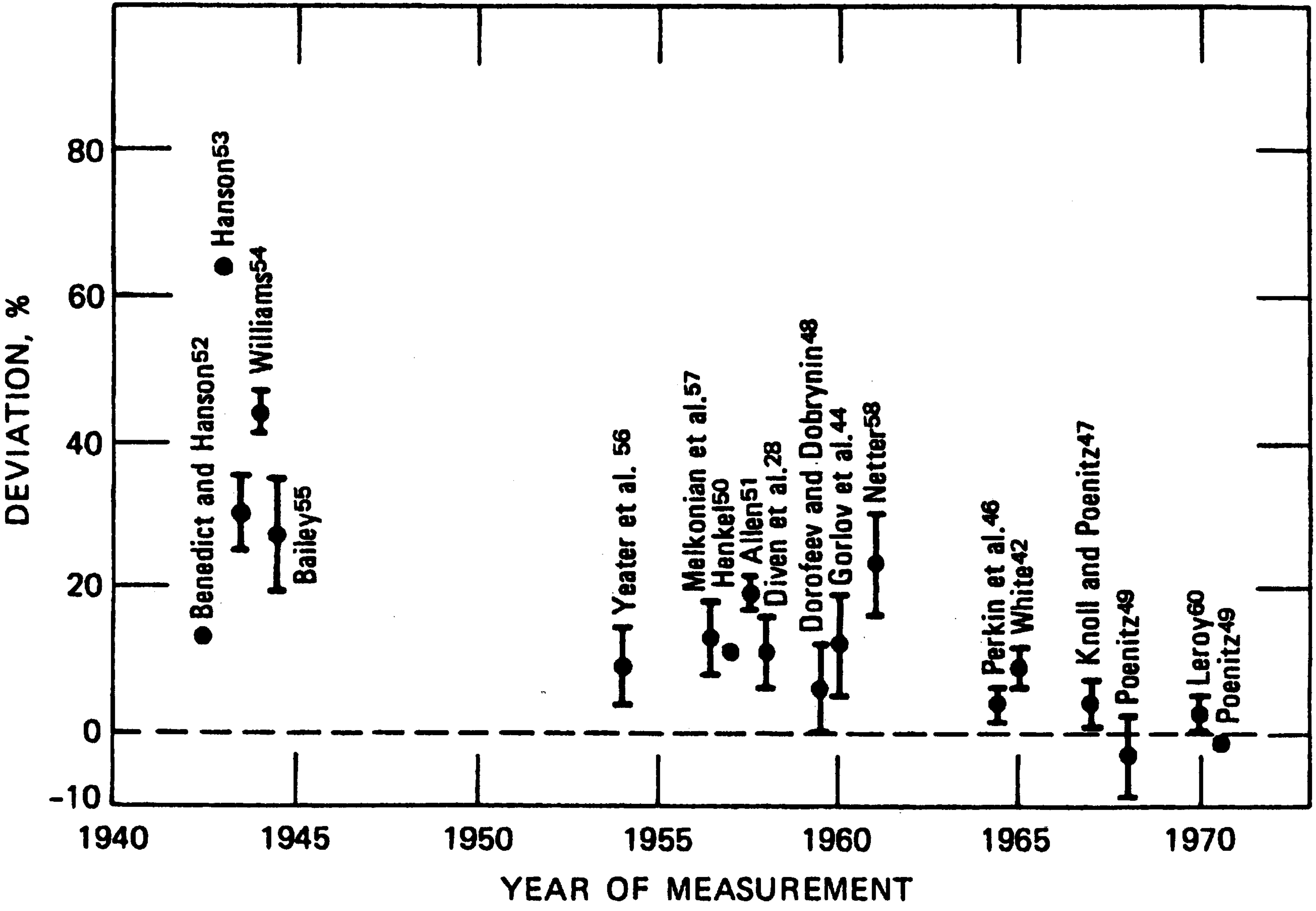

Fig. 1 Average deviation of different measurements of the $^{235}U(n,f)$ cross section, 20 to 1000 keV, from an evaluation by Poenitz.

Table 2
ENDF/B-III Neutron Cross Section Standards

Reaction	Energy Range	Evaluator
H(n,n)	σ_T 0.1 to 20 MeV $\sigma(\theta)$ 3 to 20 MeV	L. Stewart et al. (data taken from the Hopkins and Breit phase shift analysis)
^{3}He(n,p)	10^{-5} eV to 50 keV	L. Stewart and R. LaBauve
^{6}Li(n,t)	10^{-5} eV to 200 keV	M. Battat and R. LaBauve (data taken from the Uttley et al. resonance parameter fit)
^{10}B(n,α)	10^{-5} eV to 100 keV	R. LaBauve (data taken from the Sowerby et al., least-squares fit)
^{12}C(n,n)	10^{-5} eV to 2 MeV	N. Francis et al., R-matrix analysis
Au(n,γ)	10 keV to 5.4 MeV	F. Vaughn and H. Grench (best curve through the data)
^{235}U(n,f)	10^{-5} eV to 15 MeV	J. Smith et al.

Table 3
ENDF/B-IV Neutron Cross Section Standards

Reaction	**Energy Range**	**Evaluator**
H(n,n)	1 keV to 20 MeV	L. Stewart et al. (same evaluation as ENDF/B-III)
^{3}He(n,p)	10^{-5} eV to 50 keV	L. Stewart (same evaluation as ENDF/B-III)
^{6}Li(n,t)	10^{-5} eV to 100 keV	G. Hale et al., R-matrix analysis
^{10}B(n,α)	10^{-5} eV to 100 keV	G. Hale et al., R-matrix analysis
^{10}B(n,$\alpha_1\gamma$)	10^{-5} eV to 100 keV	G. Hale et al., R-matrix analysis
^{12}C(n,n)	1 keV to 2 MeV	F. Perey and C. Fu (R-matrix analysis, only minor modifications compared with ENDF/B-III)
Au(n,γ)	10 keV to 1 MeV, thermal	M. Goldberg and S. Mughabghab
^{235}U(n,f)	100 keV to 20 MeV, thermal	Task Force

convened at BNL on February 4 and 5, 1971. This task force led to adjustments, within the uncertainty of the available microscopic measurements. It was stated that the reality of the adjustments may be difficult to confirm.

ENDF/B-III

I joined the Normalization and Standards Subcommittee when the evaluation of the ENDF/B-III standards was nearing completion. At my first meeting of this Subcommittee, Bo Leonard, chairman, gave the scope of responsibilities of the Normalization and Standards Subcommittee. It was very broad! See the list in Table 1. Note this led to laboratories/individuals being responsible for items for which they have expertise and interest. I remember thinking that anything which was known relatively well had to have some sort of approval from the Normalization and Standards Subcommittee! Bo wrote very interesting Subcommittee reports. A number of us thought he often wrote the Normalization and Standards Subcommittee minutes before coming to the CSEWG meeting. We know he did not for one CSEWG meeting. At that meeting, he wrote in the minutes of the Normalization and Standards Subcommittee in which Leona Stewart was listed as an attendee, "L. Stewart primarily attended other Subcommittee meetings." Lee and Bo are the best of friends though.

Evaluations can be difficult. For the ENDF/B-III evaluation for the ^{235}U(n,f) cross section, the database showed a trend in which the cross section appeared to be decreasing with time. This is illustrated in Figure 1 which was taken from a paper by Wolfgang Poenitz given at the 1970 Neutron Standards and Flux Normalization Symposium. Actually the trend is not unreasonable. The earlier measurements were subject to large backgrounds which were difficult to remove completely. The presence of these backgrounds add signal (counts) to the apparent fission response, thus making the cross section appear too high. However, there have been many discussions with experimenters who were convinced that they had the "correct" values for the cross sections.

For ENDF/B-III, the standards were much better defined. There were a number of cross sections which were very seriously considered for standards but not accepted (e.g., ^{233}U(n,f), and a number of capture standards). The standards, their energy ranges, and their evaluators are listed in Table 2. For the first time an ENDF report providing summaries describing the standards was published.

ENDF/B-IV

In Table 3, the standards used in ENDF/B-IV are listed. There were changes in the energy ranges for some of the standards compared with ENDF/B-III. The ^{10}B(n,$\alpha_1\gamma$) cross section was added as a new standard. This is an important standard since it can be implemented by detecting the gamma-ray, which does not change in energy with the energy of the incident neutron.

There was a significant movement towards more objective evaluation techniques for the standards with this version of ENDF/B. However at that time these techniques were largely focused on the light-element standards with the use of R-matrix analyses. For the heavy-element standards older evaluation methods were used. I recall the process we followed for a portion of the evaluation of the ^{235}U(n,f) cross section. It was a "Task Force" evaluation. We had a very large piece of graph paper with all the measurements and their uncertainties plotted on it. We all stood around the table on which the graph paper was placed. We made our suggestions as to how we felt the curve should go, based on our understandings of the various experiments. It gave us freedom to favor (or discriminate against) certain data sets based on the quality of the work generally done by those groups. We all had our thoughts about the quality of the data from the various institutions and made them known as the curve was being drawn. Such evaluations are difficult to document and it is not clear how to determine meaningful uncertainties and covariance information. It was clear that a more modern objective procedure needed to be developed.

ENDF/B-V

The standards used in ENDF/B-V are shown in Table 4. The movement towards more objective evaluations led to a simultaneous evaluation of the ^{235}U(n,f) cross section by Poenitz. It was composed of an evaluation of the shape of the cross section and a separate evaluation of the normalization for the shape of the cross section. The members of the Normalization and Standards Subcommittee selected the experiments which were used for the determination of the normalization factor for the shape evaluation. This evaluation was a first step towards an evaluation process that would provide consistent sets of cross sections for all the standards.

ENDF/B-VI

For the ENDF/B-VI evaluation of the standards, considerable effort was devoted to improved evaluation procedures. In previous evaluations for ENDF/B, a hierarchical approach was followed. The lighter element cross section standards were generally considered to be better known. The H(n,n) cross section was considered the best known standard and was evaluated first and independently of the other standards. This standard is considered so well known that measurements relative to it are often called absolute measurements. The ^{6}Li(n,t) cross section evaluation was performed next. The only ^{6}Li(n,t) data which were used were absolute measurements or those measured relative to the H(n,n) standard which were converted to cross sections using the adopted hydrogen evaluation. Then the ^{10}B+n standard cross sections were evaluated. The only ^{10}B data which were used were absolute measurements and those relative to H(n,n) and ^{6}Li(n,t) which were converted using the new hydrogen and lithium evaluations. This process was continued for each of the standards. This method for using ratio measurements does not use all the information available. It does not include absolute and ratio data on the same basis as they were measured. For example, a ratio of the ^{10}B(n,α) to the ^{6}Li(n,t) cross sections would be used in the ^{10}B(n,α) cross section evaluation but not in the ^{6}Li(n,t) evaluation.

The difficulties with the hierarchical evaluation procedure and the success already realized using comprehensive objective data combination techniques in the ENDF/B-V standards evaluation led to the seeking out of a more global approach for ENDF/B-VI standards than had been used earlier. Least-squares methods should be used to combine the input data consistent with the experimental uncertainties. The method should be able

Table 4
ENDF/B-V Neutron Cross Section Standards

Reaction	**Energy Range**	**Evaluator**
H(n,n)	σ_T 1 keV to 20 MeV	L. Stewart et al. (same evaluation as ENDF/B-III and -IV)
$^{3}He(n,p)$	10^{-5} eV to 50 keV	L. Stewart (same evaluation as ENDF/B-III and -IV)
$^{6}Li(n,t)$	10^{-5} eV to 100 keV	G. Hale et al., R-matrix analysis
$^{10}B(n,\alpha)$	10^{-5} eV to 100 keV	G. Hale et al., R-matrix analysis
$^{10}B(n,\alpha_1\gamma)$	10^{-5} eV to 100 keV	G. Hale et al., R-matrix analysis
C(n,n)	10^{-5} eV to 1.8 MeV	C. Fu and F. Perey, R-matrix analysis
Au(n,γ)	200 keV to 3.5 MeV, thermal	S. Mughabghab
$^{235}U(n,f)$	100 keV to 20 MeV, thermal	W. Poenitz, simultaneous evaluation

to handle the full information content of the data base. Thus data should be evaluated simultaneously to assure proper use of the available information. Ratio measurements of standard cross sections should have an impact on each of the cross sections in the ratio. Correlations among the experimental data should be taken into account in the simultaneous evaluation. It was also important to retain fits to theory in the evaluation of the light element standards. This could be implemented with R-matrix analyses. Such analyses can provide coupling to reaction theory and give a smooth meaningful analytical expression for the energy dependance of the cross sections. Data in addition to angle integrated neutron cross sections such as differential cross sections, polarizations, and charged particle measurements involving the same compound nucleus can have a significant impact on the standard cross sections. In R-matrix analyses, different reactions leading to the same compound nucleus are linked by unitarity to the standard cross section. This condition imposes constraints on the standard cross section which are particularly strong near resonances.

The ideal way to perform this evaluation would be to develop a single fitting program that would use all the experimental data involving the standards. However the ideal way would be very difficult to implement (particularly with the computer capability available at that time). The single fitting program was not implemented. Bob Peelle determined that under proper conditions the equivalent of a global fitting procedure could be achieved by combining the output of a simultaneous evaluation using generalized least-squares with separate R-matrix analyses. An important condition was that there can not be any correlations between the database used for the simultaneous evaluation and the database used for the R-matrix evaluations. This procedure took advantage of the strengths of the two different analysis modes that can make use of separate classes of experimental information to impact on the evaluation of the standard cross sections. This then became the method used for the ENDF/B-VI standards evaluation. This led to a consistent evaluation in which correlations and ratio measurements were properly taken into account. To satisfy the correlation condition, the boron and lithium experimental data were separated into two uncorrelated groups, one for use in the R-matrix analyses and the other for use in the simultaneous analysis.

All the standards except the H(n,n), ^{3}He(n,p) and C(n,n) cross sections were evaluated using a simultaneous evaluation and R-matrix analyses. For the H(n,n) standard, the cross section was considered so well known that data on the other nuclides would have very little impact on it. This cross section was thus treated as absolute in the evaluation. For the ^{3}He(n,p) and C(n,n) cross sections, very few ratio measurements to other standards existed so little would be gained by putting them into the simultaneous evaluation and R-matrix analyses evaluation process. Separate R-matrix evaluations were performed for the H(n,n), C(n,n) and ^{3}He(n,p) cross sections.

The input data for the simultaneous evaluation was composed of two independent subsets. The first of these subsets was a large database of pointwise measurements, assembled by Poenitz. The database used for this evaluation is shown in Table 5. This database included many types of measurements, that are shown in Table 6. Total cross

Table 5

Simultaneous Evaluation Database

$^{6}Li(n,t)$

^{6}Li total cross section

$^{6}Li(n,n)$

$^{10}B(n,\alpha_0)$

$^{10}B(n,\alpha_1)$

^{10}B total cross section

$^{10}B(n,n)$

$Au(n,\gamma)$

$^{235}U(n,f)$

$^{238}U(n,f)$

$^{238}U(n,\gamma)$

$^{239}Pu(n,f)$

Table 6
Data Types Used in the Simultaneous Evaluation

Type	Data Type	Example
1	Absolute cross section	$\sigma_{nf}(^{235}U)$
2	Cross section shape	$c*\sigma_{n\alpha}(^{6}Li)$, c is unknown
3	Absolute cross section ratio	$\sigma_{nf}(^{238}U)/\sigma_{nf}(^{235}U)$
4	Ratio shape	$c*\sigma_{nf}(^{235}U)/\sigma_{n\alpha}(^{6}Li)$, c is unknown
5	Sum of cross sections	$\sigma_{tot}(^{6}Li)=\sigma_{nn}(^{6}Li)+\sigma_{n\alpha}(^{6}Li)$
6	Spectrum averaged cross section	$\sigma_{nf}(^{235}U)$ averaged over ^{252}Cf spontaneous fission spectrum
7	Absolute ratio of cross section/ sum of cross sections	$\sigma_{nf}(^{235}U)/\sigma_{n\alpha}(^{10}B)$, where $\sigma_{n\alpha}(^{10}B)=\sigma_{n\alpha_0}(^{10}B)+\sigma_{n\alpha_1}(^{10}B)$
8	Shape of Type 5 data	
9	Shape of Type 7 data	

section measurements for ^{6}Li and ^{10}B were contained in the database since the scattering and reaction data are interrelated in these measurements. $^{238}U(n,f)$, $^{238}U(n,\gamma)$ and $^{239}Pu(n,f)$ cross section data were included since they improved the quality of the standards. This is a result of accurate absolute measurements of these cross sections and many ratio measurements to the standards. Measurements of the ^{235}U and ^{239}Pu fission cross sections in the ^{252}Cf spontaneous fission neutron spectrum were also included in the database. These data had been obtained with high accuracy and were only weakly dependent on the uncertainties in the ^{252}Cf spontaneous neutron fission spectrum. They had an effect on the normalization of the evaluated cross sections.

The second subset which was used as input to the simultaneous evaluation was an evaluation of the thermal data for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu by Axton with the associated variance-covariance data. In addition to the $^{235}U(n,f)$ data, this evaluation included accurate cross sections which had been measured relative to the neutron cross section standards. Thus they would have an impact on the determination of the standards.

Evaluations of the ^{6}Li+n and ^{10}B+n cross sections were produced from R-matrix analyses by Hale. The ^{6}Li+n and ^{10}B+n analyses were done using a large database that is shown in Table 7. For the ENDF/B-VI standards evaluation process, a separate code written by Peelle was used to combine the simultaneous evaluation and R-matrix analyses and produce the final cross sections and covariances. Figure 2 shows schematically the standards evaluation procedure. Due to the nature of the R-matrix program, all experiments which are correlated and all ratio measurements (except those to the hydrogen standard) were put into the first data subset, which was used in the simultaneous evaluation. In the R-matrix analyses, the experimental data were weighted based on the quoted uncertainties and it was assumed that no correlations other than the overall normalization were present among the data from a particular experiment.

It was found that very unusual results can be obtained with discrepant correlated data. For example, combining two highly correlated discrepant data points can produce a result which is not between the two input values. In an attempt to remove problems associated with discrepancies, data greater than three standard deviations from the output results were down weighted in the simultaneous evaluation. This had the effect of reducing χ^2/(degree of freedom) to essentially 1. Unusually small uncertainties in the combined output of the evaluation were found even with this down weighting and increasing of the R-matrix uncertainties by a factor of the square root of χ^2/(degree of freedom). The greatest concern resulted from the observation that in some cases, the ENDF/B-V and ENDF/B-VI results did not agree within their uncertainties.

After an international review, these standards were accepted internationally to ensure that all evaluation projects were using the same set of standards. In Table 8, the neutron cross section standards used in ENDF/B-VI are listed. This evaluation is generally accepted as the best ENDF/B evaluation of the standards as a result of the improved evaluation

Table 7
R-Matrix Evaluation Database

^{6}Li Total		^{10}B Total	
^{6}Li(n,n)	Integral Data	^{10}B(n,n)	Integral Data
^{6}Li(n,n)	Differential Data	^{10}B(n,n)	Differential Data
^{6}Li(n,n)	Polarization Data	^{10}B(n,n)	Polarization Data
^{6}Li(n,t)	Integral Data	^{10}B(n,α_0)	Integral Data
^{6}Li(n,t)	Differential Data	^{10}B(n,α_0)	Differential Data
^{6}Li(n,t)	Polarization Data	^{10}B(n,α_1)	Integral Data
^{4}He(t,n)	Differential Data	^{10}B(n,α_1)	Differential Data
^{4}He(t,t)	Differential Data	^{7}Li(α_0,α_0)	Differential Data
^{4}He(t,t)	Polarization Data	^{7}Li(α,α_1)	Differential Data
		^{7}Li(α,n)	Differential Data

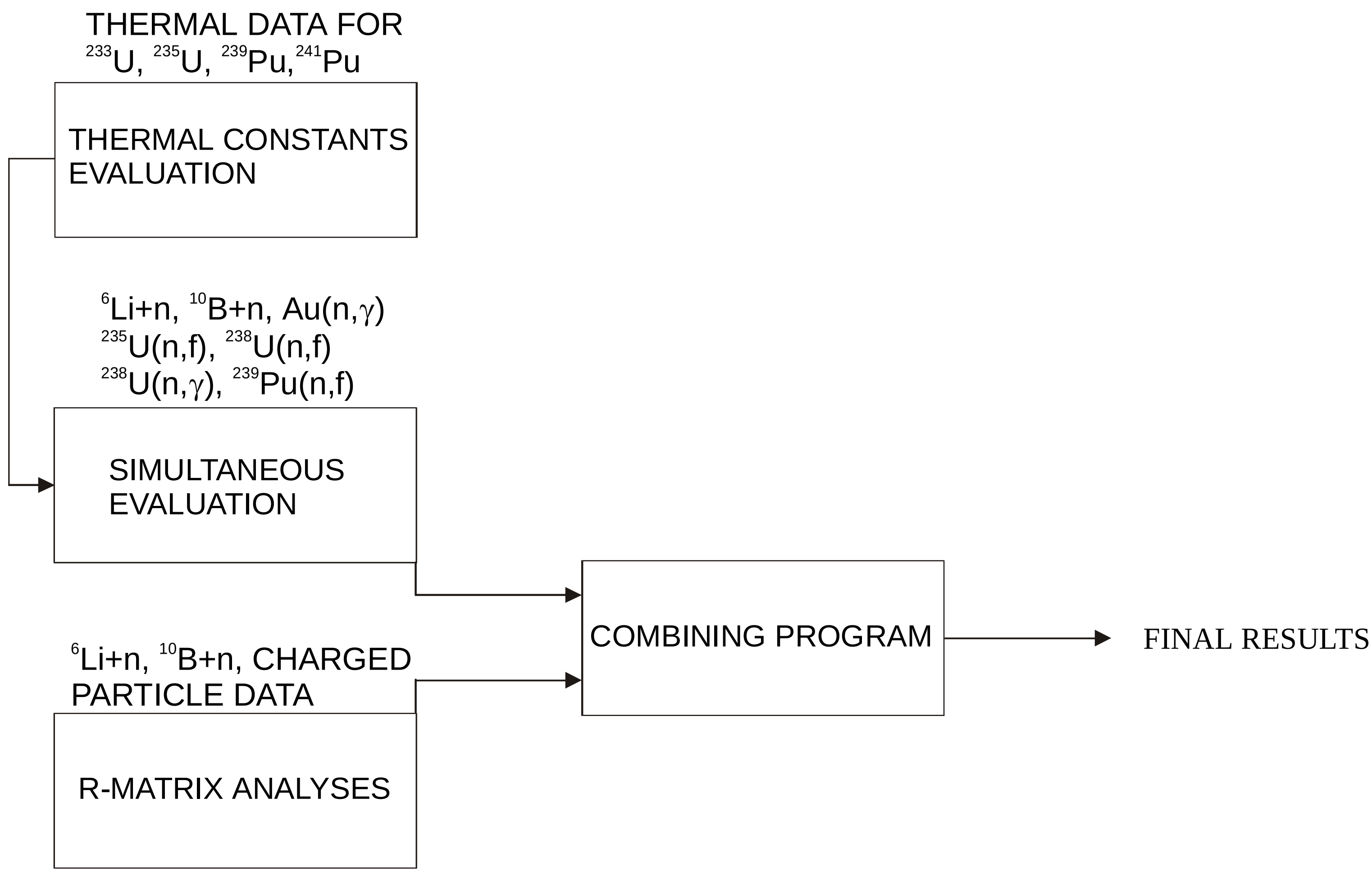

Fig. 2 The standards evaluation procedure for ENDF/B-VI

Table 8
ENDF/B-VI Neutron Cross Section Standards

Reaction	Energy Range	Evaluator
H(n,n)	10 eV to 20 MeV	D. Dodder and G. Hale, R-matrix analysis
^{3}He(n,p)	10^{-5} eV to 50 keV	G. Hale et al., R-matrix analysis
^{6}Li(n,t)	10^{-5} eV to 1 MeV	G. Hale* et al., combined R-matrix analysis & generalized least-squares simultaneous evaluation
^{10}B(n,α)	10^{-5} eV to 250 keV	G. Hale* et al., combined R-matrix analysis & generalized least-squares simultaneous evaluation
^{10}B(n,$\alpha_1\gamma$)	10^{-5} eV to 250 keV	G. Hale* et al., combined R-matrix analysis & generalized least-squares simultaneous evaluation
C(n,n)	10^{-5} eV to 1.8 MeV	C. Fu, R-matrix analysis
Au(n,γ)	200 keV to 3.5 MeV, thermal	W. Poenitz*, combined R-matrix analysis & generalized least-squares simultaneous evaluation
^{235}U(n,f)	100 keV to 20 MeV, thermal	W. Poenitz*, combined R-matrix analysis & generalized least-squares simultaneous evaluation

* These are the lead evaluators for these cross sections. However, the evaluations for these cross sections were done by combining R-matrix evaluations with generalized least-squares simultaneous evaluations.

techniques and databases used. A concern about this evaluation was the rather small uncertainties which resulted from the evaluation process.

FUTURE EVALUATION EFFORTS

The ENDF/B-VI standards evaluation was completed almost 15 years ago. Many important standards experiments have been done since that evaluation was completed. It is clear that significant changes will occur for some of the standards when a new evaluation is made which includes the new experimental data. Also there is a need for standards at energies above 20 MeV. Efforts to produce new evaluations of the standards have been slowed due to a number of factors. For ENDF/B there is a policy that the standards should not change for a given ENDF/B version since considerable confusion could occur if the standards, which are the foundation for evaluations, change. The anticipated development of ENDF/B-VII has removed this complication. Another important factor is the limitation of resources. It has been decided that, contrary to previous evaluations of the standards for ENDF/B, the evaluation will be done internationally so that full use of world wide capabilities will be available for the evaluation. The CSEWG formed a Task Force to investigate how to perform a new evaluation of the standards. The Working Party on International Evaluation Cooperation (WPEC) of the Nuclear Energy Agency Nuclear Science Committee formed a new Subgroup to promote international cooperation on the nuclear data standards. The International Atomic Energy Agency recently formed a Coordinated Research Program (CRP) focused on improving the standard cross sections, especially for the light elements, where the small uncertainty problem is most apparent. These groups are working cooperatively to update the previous work by including standards measurements made since the ENDF/B-VI evaluation was completed and to improve the evaluation process. With the international support of these groups an improved evaluation can be expected.

The Covariance Files of ENDF/B

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ABSTRACT

The following provides a personal perspective on the nearly 30-year effort to implement formatted data covariance files in ENDF/B. The members of CSEWG and the individual contributors to ENDF/B have provided international leadership by creating an entirely new technology to record, in computer processable form, the uncertainties and correlations of evaluated nuclear data. We conclude that the successes achieved in this pioneering effort constitute a real success, but that the work is far from finished.

User Requirements for Data Covariances

The construction, testing, storage and dissemination of large sets of recommended nuclear data are very expensive activities, and the costs can only be justified on the basis of tangible benefits delivered to end users of the data. This principle applies with special force in the production of evaluated data covariances (data uncertainties and their correlations), because the number of data covariances that need to be produced and distributed is, in principle, equal to the *square* of the number of data values. Because of this painful and unavoidable fact, the main theme of the history of covariance formatting and processing can be characterized as an effort to simplify and compress covariance information without, on the other hand, compromising the usefulness of the data in major applications. This fundamental limit makes the production of files of "application independent" covariance data an unreachable goal.

What, then, are the applications of data covariances that have been taken into consideration by evaluators in producing the covariance files of ENDF/B?

Four major uses of data covariances are listed below. Many of these "front line" applications make use of statistical inference techniques (generalized least squares). These techniques require valid data covariances (both data uncertainties and their correlations) as primary input, a point emphasized in the 1982 review by R. W. Peelle (Ref. 1).

(1) **data assessment:** estimating the accuracy of predictions of applied quantities (personnel dose, breeding ratio, etc.) due to the uncertainties in the basic data (also called "forward error propagation"); and

(2) **data adjustment:** refining the information contained in a general-purpose nuclear data evaluation by taking into account integral experiments of special relevance in a given field, such as reactor criticality;

(3) **reactor dosimetry:** using thin-foil activation measurements to infer the neutron spectrum at a given location in a fission or fusion reactor;

(4) **remote sensing:** using various nuclear measurements to infer the material composition of an inaccessible sample, such as in oil-well logging, baggage inspection or space exploration;

In at least one important area, data covariances are also needed for the internal work of the data evaluation community, specifically,

(5) **nuclear data standards:** in evaluating the uncertainties of important nuclear data determined mainly from ratio-to-standard measurements, the evaluator of the derived quantity becomes a "user" of the data covariances of the measurement standard, as produced by other data evaluators .

The following potential application of covariance data is a distant goal, but it places such large demands on the quality and completeness of the covariance files that it has not yet reached a practical stage.

(6) **planning of experiments:** When the existing data is found inadequate, as in Item (1) above, evaluated data covariances could be used as input to a process to select or design the optimum measurement program needed to reach accuracy goals in important applications (also called "the inverse problem").

While superficially appealing, the following potential use would place nearly impossible demands on the quality of the data. Thus it has not been endorsed by members of CSEWG.

(7) **automated updating of evaluated data:** The results of future experiments could be combined with an existing evaluation, using the methodology of data adjustment (Item (2) above), to produce a new evaluation of differential data without explicit re-consideration of the experimental database that led to the earlier file.

The Early Days

Most of the early history of ENDF/B covariances centers on the work of F. G. Perey, who designed the first approved data covariance format. His covariance format proposal was approved at the CSEWG meeting in May 1973 and modified in December 1973. Perey also served as the first Chairman of the CSEWG Data Covariance Subcommittee and wrote one of the most important pieces of software that employ data covariances in practice, namely the STAYS'L code (Ref. 2), still widely used in the field of reactor dosimetry.

In Ref. 3, Perey recalls "Until ENDF/B-IV the only method the evaluators had available to them for communicating [uncertainty] information was through the documentation. During the preparation of ENDF/B-IV a subcommittee was appointed to make recommendations in the area. The initial effort was directed toward a standardization of the reporting method in the documentation. It was only after considerable debate the concept of incorporating the information with the 'data files' on the tape was approved. There were two major factors, which influenced this decision. The first one was that the dominant features of the uncertainties are the correlations in the data and these are not easily handled in the documentation. The second one was that the uncertainty information needs to be processed together with the differential data to obtain the uncertainties in the quantities of interest."

In ENDF/B-IV, only three general purpose evaluations containing covariance files were released, namely, C from Oak Ridge and ^{14}N and ^{16}O from Los Alamos. However, much exploratory work went on in the US laboratories in the mid-1970s to investigate the potential usefulness of this kind of data, and much progress was made.

ENDF/B-V

By August 1978, Perey (Ref. 3) was able to publish a long list of materials and reactions containing covariance files available in the new ENDF-V format (^{1}H, ^{6}Li, ^{10}B, C, ^{14}N, ^{16}O, ^{19}F, ^{23}Na, ^{27}Al, Si, Cr, Fe, Ni, Pb, ^{232}Th, ^{233,235,238}U, ^{239,240,241,242}Pu, ^{241}Am and ^{237}Np). With the availability of covariances for these key materials, it became possible to perform quantitative data assessments in many important applications, involving both fission reactor cores and shielding materials such as concrete, water, stainless steel and lead.

Covariance Processing Tools

As mentioned above, the ENDF covariance formats were designed from the very outset to facilitate computer retrieval and processing. A noteworthy activity in the area of multigroup processing of covariance information has been the Los Alamos effort centered on the NJOY code system (Ref. 4). By the time of the 4th ASTM-EURATOM Symposium on Reactor Dosimetry in March 1982, the present author was able to report (Ref. 5) on the implementation of a full NJOY processing capability, including a tool for plotting covariance data and for the generation of multigroup covariance libraries in the compact BOXER format, which has proved convenient for input to dosimetry and sensitivity analysis programs.

ENDF/B-VI

In the 1980s, Perey was succeeded as Chairman of the Data Covariance Subcommittee by his Oak Ridge colleague R. W. Peelle. Peelle was largely responsible for overseeing the extension of the data covariance formats to meet a number of objections to the ENDF-5 format. As reviewed in Ref. 6, formats were added for secondary distribution uncertainties (File 34, File 35) and for uncertainties in radioactive decay data (File 40). Also, an attempt was made to add more realism to the resonance parameter formats (File 32). For example, in evaluators were given new tools to specify the correlations between the parameters of different resonances. In addition, the present author developed the File 30 format in order to permit evaluators to compactly describe nuclear data covariances that can be attributed to the uncertainties of a relatively small set of underlying parameters. The reader is referred to Chapters 30, 32, 34 and 35 of the ENDF-6 format manual (Ref. 7) for a full description of these new formats.

Unfortunately, these significant format improvements were made at a time when there were declining funds available for nuclear data evaluation activities in general. In this environment, US evaluators have been slow to make substantial use of the innovative features of the ENDF-6 covariance formats.

Another factor that has limited progress in the field of covariance evaluation has been the steady growth in the size and the overall level of detail in modern evaluations, two examples being the increased use of isotopic (as opposed to elemental) evaluations and the increased use of File 6 to more accurately describe the variation of emitted-particle energy spectra as a function of emission angle. Both of these changes clearly increase the physical correctness of the data evaluation and, thereby, make the work of the data evaluator easier. However, they obviously increase the number of evaluated data values per element.

This kind of "data splitting" operation is the opposite of "data combination" studies, where one tries to extract a small number of facts from a wealth of measurements. In building isotopic evaluations, for example, one takes a relatively sparse experimental database, which emphasizes measurements on natural-element samples, and tries to fill in an enlarged number of data slots, using systematics and nuclear theory as a guide. This can be done, of course, but one consequence is that the expanded data files will exhibit very strong cross correlations. The remark made at the outset about the size of covariance files varying as the square of the number of data values certainly applies here. Thus if one, for example, triples the number of data values in ENDF by such information splitting, then the number of data covariances will increase by a factor of nine! It appears that the data evaluation community has been more willing to accept a factor-of-three growth in the size of the main data files than it has a factor-of-nine increase in the size of the corresponding covariance data files.

Uncertainty of Neutron and Photon Emission Spectra

Thinking positively, it should be said that one of the recent format developments provides a very useful tool for addressing some of the concerns just mentioned. To further explain, we consider in some detail the problem of describing uncertainties in particle and photon emission spectra.

In the uncertainty analysis of advanced energy systems such as fusion reactors or accelerator driven systems, it will be necessary to modify a key assumption made by the authors of the earliest sensitivity analysis systems, namely, that one needs only to be concerned with <u>cross</u>

section uncertainties (as opposed to uncertainties of secondary particle emission spectra). While there is a clear need for improvement, it hardly seems practical, on the other hand, to include a full "covariance matrix of a transfer matrix" in the evaluated data file or even to use such a large matrix in practical applications.

This general dilemma has long been recognized, and it has been approached in the past by a variety of ad-hoc fixes such as the SED-SAD approach, which overlays an additional, arbitrary, very coarse multigroup structure on the problem (for example, see Ref. 8). Somewhat similar approaches are employed in the existing ENDF File 35 and a proposed File 36. It is difficult to see how a processing program can sensibly re-bin such coarse covariances into other, user-specified structures. The basic problem is that coarse-group covariance data are already integrated over energy and angle, and this integration cannot be undone by a code.

The new File 30 format provides a neat solution to this tough problem by permitting the factoring the "covariance matrix of a transfer matrix" into a triple matrix product involving two much smaller matrices. The middle portion of this "sandwich" describes the covariances of a relatively small number of underlying parameters, assumed to be responsible for the most important cross-section and emission-spectrum uncertainties. At neutron energies above a few MeV (where secondary angle and energy distribution uncertainties are expected to be most important), an appropriate choice of parameters might be a subset of the input parameters to a statistical nuclear model code. The number of important parameters for this purpose might be around 40. The other matrix contains the sensitivities of each element of the transfer matrix to each "uncertain" parameter. In a typical multigroup application, there are in the neighborhood of 100,000 distinct elements in the transfer matrix. Using these values, instead of storing a 100,000-by-100,000 matrix in a multigroup covariance library, one only would need to store a 40-by-40 matrix and a 40-by-100,000 one.

At the May 2001 specialists' meeting on nuclear data uncertainties at Aix-en-Provence, R. E. MacFarlane suggested that the approach followed in File 30 might offer similar benefits in other, quite different, areas of data covariance evaluation and processing.

Work Remaining

Although there is some remaining work to be done on the data formats (with the current emphasis being placed on new approaches to covariance data for resolved resonance parameters), it seems clear that the major items of work remaining to be done are all closely connected with the need to deliver covariance data in useful forms to the end users. For example, in the area of perturbation-theory based sensitivity analysis codes, work is needed to take full advantage of the factored form of covariances supplied in File 30, either as a way of building a very compact input data libraries, or in more fundamental ways. As was pointed at the end of the discussion of File 30 in Ref. 7, it appears both practical and desirable to use data in File 30 as the starting point for moving from a nuclear data uncertainty analyses based on *multigroup cross section* values to an uncertainty analysis based on *parameter* values. The mathematical transformations needed to implement this concept within a practical sensitivity analysis system seem relatively straightforward, but someone needs to do the actual work.

Another area where work is urgently needed is in the processing tools. The ERRORR module (Ref. 4) of NJOY currently processes all cross-section covariance data in File 33 format into a user-specified multigroup structure. A limited capability of processing of resonance-parameter covariances (File 32) is available, but only for the most commonly used File 32 option (namely, the ENDF-5 compatibility option). Peelle's new format for treating correlations between the parameters of different resonances is not yet handled. Other important new features of the ENDF-6 formats also are not yet handled, including File 30 as well as File 34, which the European Fusion File uses to describe ^{56}Fe angular distribution uncertainties. It appears that an investment in further development of the processing tools now would yield substantial benefits, especially in terms of stimulating new work by data evaluators in this field.

Conclusion

We conclude that the successes achieved so far in this pioneering effort constitute a real success, but much interesting and rewarding development work remains to be done.

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Progression of ENDF/B-VI: 1990 to 2001

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There is little question that the ENDF/□-VI file is the most important and frequently referenced evaluated nuclear database in the world. Why is this so? My answer is that a great deal of planning and work has gone, and continues to go, into it. In this paper I will review just a few facets of the development of ENDF/B-VI and very briefly sketch the progression that has occurred over the last 11 years. I will comment on what I regard are a couple of the key features of ENDF/B-VI and will quickly trace through the various data releases that have occurred since the first ones in 1990. And then I will finish with a few examples of recent improvements to the database and say something about our present evaluation activities.

Key Elements of ENDF/B-VI

I want to apologize at the very start for the many important areas that I will not cover due to time limitations and my own limited experience. Some of these are resonance parameter analyses, fission product yield and decay data, thermal data analyses, integral data and data testing, covariances, etc. Other people are far more qualified to discuss these areas.

I would also like to say at the start how informative it has been to go back and see what the CSEWG community has done over a broad period of time. In my view, ENDF/B-V.2 was a pretty good database for the time, and in fact, there are still a few areas that we have not greatly improved. However, there are a lot of other areas where dramatic improvements have been made, and most of all, we have greatly expanded the range and breadth of applicability of the file.

Two features, standards and formats, are obvious important reasons why ENDF/B-VI is the standard or reference evaluated database for the rest of the world. The idea of covariance analyses that include correlations in data had been around for some time. However, the scale of the simultaneous analysis of the standard cross sections that Wolfgang Poenitz, Allan Carlson, Bob Peele, and Gerry Hale pursued was certainly unique. And, of course, there was the analysis by Axton of the thermal standards. All the people at this symposium know just how much effort the standards evaluation really entailed At this point, however, I think we can say that it was certainly worth it. Of course, we now know of areas where improvements in the standard cross sections are needed, but the results of the simultaneous standards analysis have certainly served the CSEWG community well over the past 11 years.

A second major innovation that made ENDF/B-VI so successful was the greatly expanded platform for data evaluation provided by the ENDF-6 format. A great deal of the credit for the expanded format goes to Bob MacFarlane. Back in the mid 1980's Los Alamos was fortunate to have some support for missile defense, and Bob started thinking about what should be done to carry evaluated data up to higher energies. An important outcome was the present File 6 format. Not only does it handle correlated energy-angle data for all outgoing particles and photons, but also it provides for easy use of Kalbach systematics, discrete two-body scattering, charged-particle elastic scattering, and representation of N-body phase-space distributions. Of course, CSEWG had a File 6 before ENDF/B-VI, but anyone who ever tried to apply it realizes it was very restrictive and difficult to use. To my knowledge, no one ever succeeded in using it for an evaluation or, especially, in processing it. So Bob, with help from many others, came up with the very general format that we now use.

Of course, other important features are that the energy limits were removed for ENDF/B-VI evaluations, and incident particles and quanta other than neutrons were allowed. We now have a large number of neutron and proton evaluations extending to 150 MeV in energy. Additionally, there is at least one evaluation for incident deuterons, and there are several evaluations floating around Los Alamos for incident photons, although I do not know if any have made it into ENDF/B-VI yet.

Data Releases Between 1990 and 2001

I attempt below to give a thumbnail sketch of the various releases that have occurred for ENDF/B-VI over the past 11 years. There might be minor errors in it as I have mainly relied on old minutes from the Evaluations Committee, and sometimes there were unexpected delays that occurred after the meetings. But in any case, the essence is here.

Release 0 [1990]: Original ENDF/B-VI release of new evaluations for about 75 isotopes. Most major light element, structural material, and actinide evaluations were included. The standards data evaluation was released about a year or so prior to this.

Release 1 [1991]: Corrective revision. This release primarily fixed errors in the files that were undetected before Release 0 but which were found with processing and use. While very important, for the most part these were not major changes.

Release 2 [1992-1993]: New evaluations for approximately 24 additional isotopes. The list of new evaluations includes ^{14}N, ^{45}Sc, ^{59}Co, ^{63,65}Cu, ^{127}I and, most importantly, ^{238}U and ^{239}Pu, were re-issued with greatly improved resonance parameters.

Release 3 [1994-1995]: New evaluations for 11 materials. Some 4 of the new evaluations were extensions to 40 MeV - our first foray into higher energy evaluations. The list includes new resonance parameters for ^{241}Pu, a thermal data revision of ^{235}U, and a new evaluation of ^{241}Am.

Release 4 [1996]: Mainly corrective revision of Release 3 materials. This release also included two evaluations (^{152,154}Gd) that were approved for Release 3 but which we simply forgot to release!

Release 5 [1997-1998]: An oversight task force facilitated release of some 14 new evaluations. Included in this list were $^{28\text{-}30}$Si, $^{102\text{-}110}$Pd, ^{208}Pb, ^{243}Am and a major revision of ^{235}U. Also, two proton-induced files (^{12}C, ^{16}O) and a deuteron-induced file (^{3}H) were released.

Release 6 [1998-1999]: Major higher energy data release. The list included 33 evaluations with the neutron energy range extended from 20 to 150 MeV, plus 33 companion proton-induced evaluations to 150 MeV.

Release 7 [1999-2000]: New release of fission product as well as general-purpose evaluations. The release included 17 new evaluations of fission products plus neutron and proton-induced evaluations of ^{209}Bi to 150 MeV, as well as conventional evaluations for natural Zr, and $^{243,245,246}Cm$

Release 8 [2001]: Our most recent major release. It includes some 8 new evaluations as well as 33 evaluations that were modified to include new thermal-neutron photon-production data. The new evaluations are for ^{16}O, $^{35,37}Cl$, $^{121,123}Sb$, ^{232}Pa, ^{232}U, and ^{236}Np.

Recent Examples of Evaluation Advances

In this section I am going to describe briefly three recent evaluation efforts at Los Alamos that are part of Release 8 of ENDF/B-VI.

Thermal Neutron-Induced Photon Production (with S. Frankle and R. Reedy)

Frankle and Reedy carried out a very comprehensive compilation and evaluation effort for significant number of materials. The applications that drove this work were mainly oil well logging and planetary surface analysis using cosmic ray neutrons. Bob Reedy has been involved with the latter probably for two decades or so. The work involved compilation of isotopic spectra for elements from hydrogen through zinc as well as for $^{70,72,73,74,76}Ge$, ^{149}Sm, $^{155,157}Gd$, ^{181}Ta and $^{182,183,184,186}W$. Of course, evaluation of the data was required as well as conversion to elemental spectra, where needed. And the final step was melding the data into the existing ENDF/B-VI data files.

Evaluation of n + ^{35,37}Cl Cross Sections (with S. Frankle and A. Adams)

Applications such as oil well logging require cross section information on individual gamma rays. The previous ENDF/B-VI evaluation is for natural Cl. The actual evaluation work is vintage 1967, with additions of gamma-ray production for ENDF/B-V and an extension to 20 MeV for ENDF/B-VI. While it does contain information on discrete gamma rays, these data are only valid to about 8 MeV. Additionally, new isotopic JENDL-3.2 evaluations exist for both ^{35}Cl and ^{37}Cl, but, there are no photon production data in the evaluations. Therefore, as part of the thermal-neutron photon-production project mentioned above, we decided to perform completely new evaluations for the $^{35,37}Cl$ isotopes.

Our approach was to combine the new evaluations of thermal-neutron-induced photon multiplicities by Frankle and Adams with the resonance-parameter evaluations from JENDL-3.2 and with a GNASH-based analysis of neutron reactions on ^{35}Cl and ^{37}Cl. As usual, model parameters for the GNASH analysis were optimized to the available experimental data and were based on systematics otherwise. By using this approach, we were able to include a maximum of explicit information on discrete gamma rays. For example, in the case of ^{35}Cl, cross sections are provided for 90 discrete photons from (n,n') reactions, 102 photons from (n,p) reactions, 69 photons from (n,d) reactions, and 103 photons from (n,α) reactions. We used the criterion that only those photons are included that have cross sections greater than 1 mb at some energy.

^{16}O + n Evaluation (with G. Hale and M. Chadwick)

Finally, I want to briefly describe some of the work that went into a new evaluation of n + ^{16}O reactions. A great deal of discussion has already occurred within the CSEWG community concerning the new KAPL R-function and LANL R-matrix evaluations at incident neutron energies below 6 MeV, and impressive integral data comparisons will be presented at the regular CSEWG meeting this week. I will not discuss that work but will limit my comments to the data evaluation at neutron energies above 6 MeV.

The primary motivation for this work was the availability of extensive new photon-production data from LANSCE, measured by Nelson and Michaudon. Using the LANSCE white neutron source, Nelson and Michaudon measured angular distributions with 7 high-resolution detectors for 24 discrete photons at continuous neutron energies between 4 and 200 MeV. In our evaluation of these data, we only considered the data out to 30 MeV. By fitting each angular distribution with a Legendre expansion, we were able to extract integrated cross sections for photons from (n,n'), (n,p), (n,d), (n,t), (n,α), and (n,2n) reactions. Then, using known level branching ratios, we were able to infer level excitation cross sections for the same set of reactions.

Prior to the new LANSCE measurements, there were very few angular distribution measurements of ^{16}O gamma rays. Consequently, evaluators were forced to infer the integrated cross sections from measurements at 1 or 2 angles, using assumptions about the angular distributions that were often erroneous. We believe that the availability of the new experimental data has resulted in a quantum improvement in the data above 6 MeV. For the first time, we have reliable information on the energy-dependence of the discrete cross sections for the above list of reactions, as well as detailed angular distributions for the resulting gamma rays.

The evolution toward an improved ^{16}O evaluation is nicely illustrated by changes in the elastic cross section that occurred through various versions of ENDF/B evaluations. A comparison of experimental elastic scattering cross sections to the data in several versions of ENDF/B is included in Fig. 1.

On-Going Activities and Problems

Just in case anyone thinks we have solved all the problems, I want to mention in closing some of the new evaluation work that is currently in progress.

An effort is underway at Los Alamos to re-evaluate the available data for neutron reactions on the uranium isotopes. In particular, we are re-analyzing the neutron cross section data for the ^{232,233,234,236,237,239,241}U isotopes. We are using the ECIS coupled-channels optical model and the GNASH reaction theory codes to analyze the experimental data for each uranium isotope that has appreciable data. We are then using the systematic behavior of the nuclear model parameters to calculate nuclear data for the unmeasured isotopes. This effort has been in progress for a couple of years and should be completed in the next year or so.

A second major activity combines experimental and theoretical work from the Livermore and Los Alamos laboratories. This effort involves a new analysis of the ^{239}Pu(n,2n) cross section. In this work, gamma-ray cross sections from (n,2n) reactions were measured at the GEANIE facility. The experimental data were then analyzed with the GNASH reaction theory code in order to infer ^{239}Pu(n,2n) cross sections from the data. The results will be included in an upcoming update of the ^{239}Pu ENDF/B evaluation. A comparison of the GEANIE experimental data to previous measurements and to various evaluations is given in Fig. 2.

And finally, new evaluations of neutron-induced reactions on ^{235}U and ^{238}U are in progress. Several laboratories are participating in this work, which is aimed at solving some long-time problems with ^{238}U, primarily (n,n') reactions, and with perhaps improving the ^{235}U(n,f) cross section. There is an effort to re-assess the ^{235}U(n,f) standard cross section between 1-3 MeV and above 14 MeV. These will be discussed further at the regular CSEWG meeting this week.

Plans are currently being made by CSEWG for Version VII of ENDF/B. Therefore, none of the work described in this section will be included in the ENDF/B-VI data base. However, these efforts are logical extensions of work began for ENDF/B-VI and illustrate that we still have a dynamic system. The best wish that I can impart for the future of CSEWG is that ENDF/B-VII enjoys the same success as has ENDF/B-VI, and that it produces similar advances in evaluation methodology and quality.

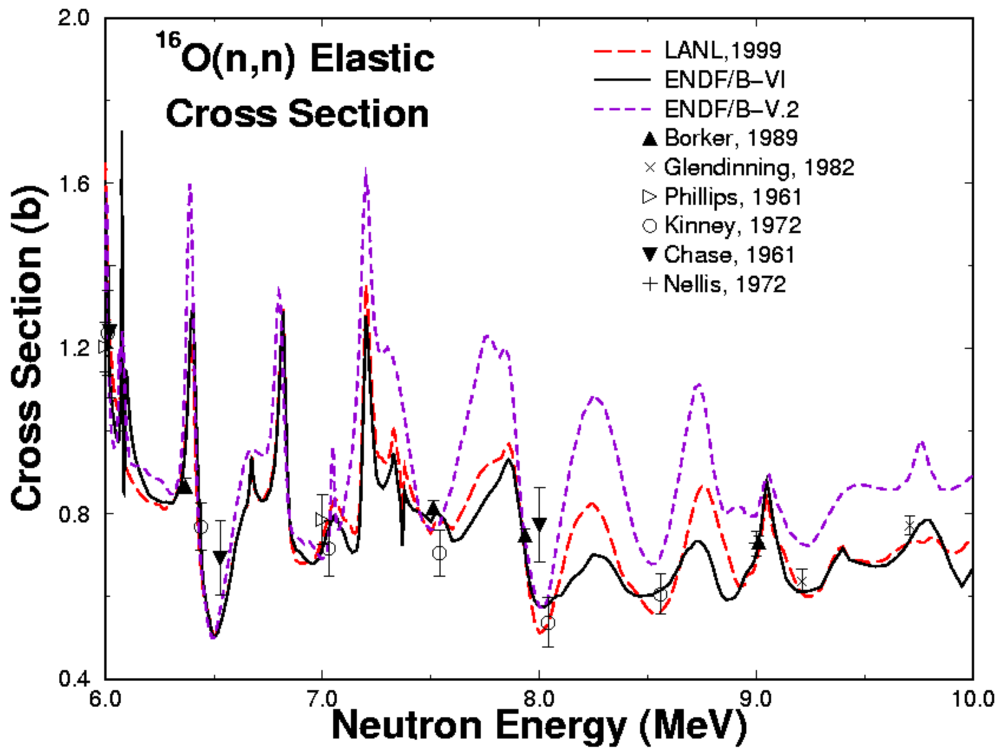

Figure 1. Elastic scattering cross section for n + ^{16}O from 6 to 10 MeV. The long dashed curve is the new Release 8 ENDF/B-VI evaluation.

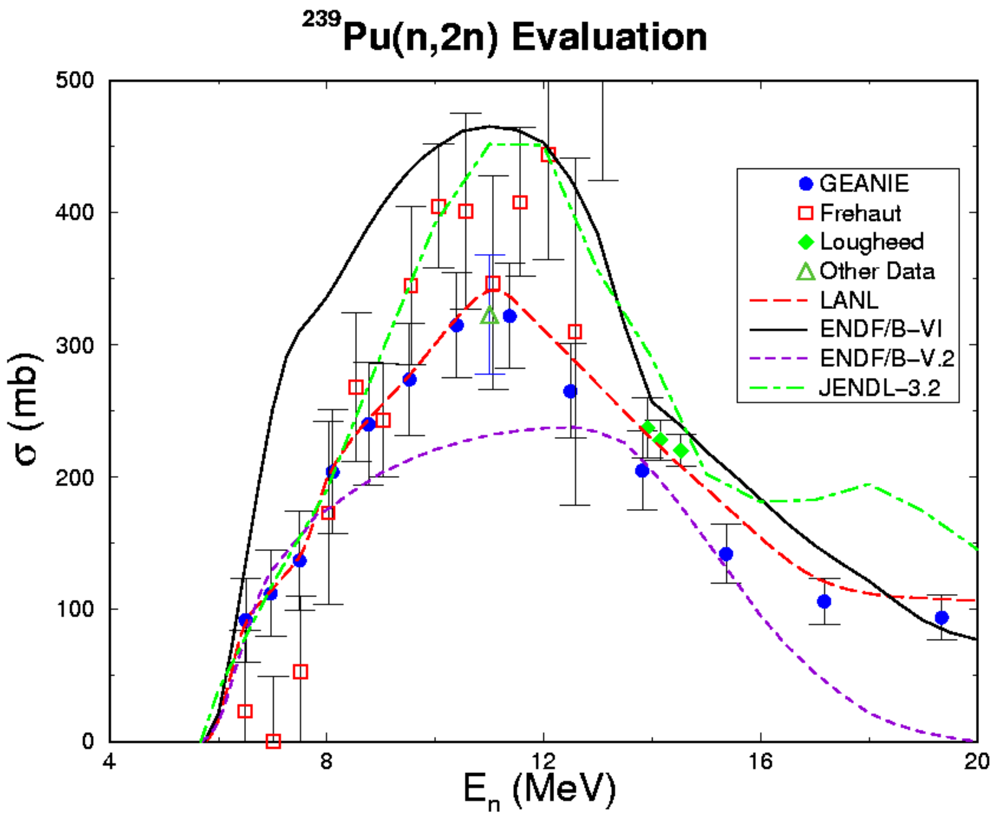

Figure 2. Evaluated ^{239}Pu(n,2n) cross sections from 4 to 20 MeV compared to various experimental data.

Appendix A
Summary of CSEWG Members, Committees, Meetings

This appendix has been written to document the CSEWG organization, its meetings and its participants. The information contained in this appendix has been extracted from the minutes of the CSEWG meetings, which are archived in the NNDC library.

CSEWG Participants

The first table contains a list of 348 individuals who have participated in one or more of the first 50 CSEWG meetings and the organization that they represented. The organizations are represented by codes. The full expansion of these codes is given in the CSEWG Participating Organizations List. The table also contains the first and last meeting in which the individual participated. The meeting range does not necessarily indicate continuous service. A meeting is identified by the year in the meeting was held, In case two meetings are held in a single year, the year is followed by (1) for the first meeting and by (2) for the second meeting.

CSEWG Committees and Subcommittees

The initial CSEWG committee structure was established at the second meeting. This table records the various committees and subcommittees that existed during the 35 years of its existence. The chairs of these committees are listed along with their dates of service. An → indicates a change in name of a committee or subcommittee. After the reorganization of 1980, a subcommittee structure was developed. Each subcommittee is listed along with its chairs and the period of time it existed. Subcommittee chairs are listed by order in which they served. Dates of service of the subcommittee chairs are not given. In 1995 the subcommittees were abolished.

CSEWG Meetings

Fifty CSEWG meetings were held between 1966 and 2000, two meetings were held each year from 1966 through 1981 except for 1967 and 1969 when one meeting was held. From 1982 through 2000, only one meeting was held per year except for 1989 when two meetings were held. All meetings have been held at Brookhaven National Laboratory except for 1994 which was held at Oak Ridge National Laboratory.

Due to a typographical error made on the 1980 minutes of the May 1980 meeting, both the October 1979 and the May 1980 meetings were called the 26th meeting. The CSEWG Meeting table has corrected for this mistake. Therefore the 2001 CSEWG Meeting is really the 51st meeting! The minutes of the January 1968 meeting are missing from the archives. However, the minutes of the September 1968 meeting refer to this meeting. The May 1984 meeting did not include an attendance list. Therefore anyone who attended only this meeting would not be included in the participant's table.

CSEWG Participating Organizations

Over time, organizations names have changed. Some no longer exist. I have chosen to use the organization name from the last meeting in which someone from that organization attended a CSEWG meeting. In the participant's table, if an individual has represented more than one organization, I have listed the organization represented for the longest time first.

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Adams	Amzie	LANL	1997	1997
Aline	Peter	GE-APO	1966(2)	1973(2)
Alter	Harry	AI	1966(1)	1973(2)
Anderl	R.	ID	1978(1)	1981(2)
Aronson	Arnold	BNL	1968(2)	1970(1)
Arthur	Edward	LANL	1981(1)	1986
Axton	Theodore	NPL	1986	1986
Azziz	Nestor	WNES	1966(1)	1967
Baer	William	BAPL	1968(2)	1971(1)
Barhen	J.	ORNL	1980(1)	1980(1)
Barrett	R.J.	LANL	1977(1)	1978(1)
Battat	Maury	LANL	1967	1968(2)
Baxter	Alan	GA	1988	1989(2)
Beck	C.	ANL	1977(2)	1977(2)
Becker	Martin	RPI	1971(2)	1982
Beer	Mendel	MAGI	1974(1)	1979(1)
Behrens	James	LLNL	1977(2)	1978(1)
Benjamin	Richard	SRL	1975(1)	1979(1)
Berk	Samuel	DOE	1982	1988
Berland	Robert	AI	1966(1)	1968(2)
Bhat	Mulki	BNL	1968(2)	1999
Block	Robert	RPI	1971(1)	1999
Blomquist	Roger	ANL	1997	1998
Bohn	Edward	ANL	1973(2)	1976(2)
Bohn	T.	ID	1978(1)	1978(1)
Bortz	A.B.	WARD	1976(1)	1976(1)
Boshoven	Jack	GA	1991	1991
Bowman	Charles	NIST	1972(2)	1977(1)
Bozorgmanesh	H.	Mich	1976(2)	1976(2)
Briggs	Blair	ID	1995	1998
Broadhead	Brian	ORNL	1980(1)	1994
Bunting	Roger	ID	1978(1)	1981(2)
Burke	John	KAPL	2000	2000
Burrows	Thomas	BNL	1981(2)	1990
Butler	Daniel	ANL	1968(2)	1969
Cabrilla	Dennis	DOE	1994	1997
Cahill	W.	LBL	1968(2)	1968(2)
Campbell	Joanne	LANL	1998	1998
Carlson	Allan	NIST	1972(2)	2000
Caro	Edmund	KAPL	1991	1993
Cavanaugh	G.	CE	1977(2)	1977(2)
Chadwick	Mark	LANL, LLNL	1994	2000
Chandler	J.R.	SRL	1982	1982
Chang	Jonghwa	KAERI	1999	1999
Chao	Yung-An	WARD	1996	1997
Cheng	Edward	TSI, GA	1982	2000
Chernick	Jack	BNL	1966(1)	1968(2)
Chiba	Satoshi	JAERI	1989(2)	1997
Childs	R.	ORNL	1978(1)	1978(1)
Chrien	Robert	BNL	1972(2)	1972(2)
Clark	Frank	ORNL	1967	1967
Cobb	R.	NAI, NFS	1972(1)	1974(1)
Collins	Peter	ANL	1976(1)	1978(1)

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Conde	Henri	Uppsala	1983	1983
Conner	J.	WNES	1973(2)	1975(2)
Conner	S.A.	WNES	1973(2)	1973(2)
Cowen	Charles	GE-BRDO	1970(1)	1987
Cox	S.	ANL	1973(2)	1973(2)
Craig	Donald	AECL	1979(1)	1988
Craven	Clyde	ORNL	1966(1)	1969
Crump	M.	CE	1983	1984
Cullen	Dermott	LBNL,BNL	1968(2)	2000
Dannels	Robert	WNES	1966(1)	1975(1)
Davey	William	ANL-W	1968(2)	1968(2)
Dean	Virginia	ID	1994	2000
Decher	Ulrich	CE	1991	1993
Derrien	Herve	CAD	1989(1)	1989(1)
DeSaussure	Gerard	ORNL	1971(2)	1972(1)
Dietrich	Frank	LLNL	1999	1999
Divadeenam	M.	BNL	1983	1984
Dos Santos	G.R.	ORNL	1997	1997
Doyas	R.	LBL	1969	1970(2)
Drake	Marvin	GA	1966(1)	1973(1)
Driscoll	Michael	MIT	1982	1982
Dudey	N.	ANL	1973(2)	1973(2)
Dudziak	Donald	LANL	1966(2)	1971(1)
Dunayeva	Svetlana	Sarov	1996	1996
Dunford	Charles	BNL, AI	1966(1)	2000
Dunn	Michael	ORNL	1999	2000
Durston	Colin	WNES, CE	1981(2)	1996
Eich	Walter	WNES, NAI	1968(2)	1976(2)
Eisenhauer	Charles	NIST	1975(2)	1975(2)
England	Talmadge	LANL	1973(2)	1993
Enz	Roy	DASA	1967	1967
Estes	George	LANL	1981(1)	1981(1)
Ewbank	Bruce	ORNL	1976(2)	1976(2)
Farrar	Harry	AI	1980(1)	1980(1)
Felberbaum	Joan	BNL	1966(2)	1967
Felty	James	SAI	1998	1998
Fiarman	Sidney	Stanford	1977(1)	1977(1)
Finch	Donald	SRL	1966(1)	1992
Finck	Philip	ANL	1997	2000
Fisher	Jack	NAI	1977(1)	1977(1)
Ford	Wendel	ORNL	1978(1)	1980(2)
Forsbacka	Matthew	DNFSB	1999	2000
Frankle	Stephanie	LANL	1994	1999
Fricke	Martin	GA	1971(2)	1972(1)
Fu	Peter	ORNL	1975(1)	1989(1)
Fujita	Edward	ANL	1997	1997
Fukahori	Tokio	JAERI	1989(1)	1998
Fuller	Everett	NIST	1972(1)	1973(2)
Garber	Donald	BNL	1973(2)	1974(2)
Gardner	Donald	LLNL	1974(1)	1981(1)
Gauld	Ian	AECL	1994	1994
Gohar	Yusry	ANL	1978(1)	1978(1)
Goldberg	Murrey	BNL	1968(2)	1968(2)

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Goldman	David	NBS, KAPL	1966(1)	1972(1)
Goldstein	Ruben	CE	1972(1)	1976(2)
Goulo	Valery	IAEA	1989(1)	1989(1)
Greebler	Paul	GE-APO	1966(2)	1967
Green	D.	APDA	1967	1967
Greene	Maurice	ORNL	1994	2000
Grimacy	Robert	ID	1966(1)	1987
Grundl	James	NIST	1971(2)	1975(1)
Guber	Klaus	ORNL	2000	2000
Guimaraes	Francisco	ORNL	2000	2000
Gundy	Michael	SRL	1992	1996
Gunst	S.B.	BAPL	1975(1)	1975(2)
Gwin	Reginald	ORNL	1976(2)	1977(2)
Haight	Robert	LANL	1992	1993
Hale	Gerold	LANL	1980(1)	1992
Hannum	William	DOE	1970(2)	1970(2)
Hardie	R.W.	HEDL	1974(2)	1975(2)
Harding	R.	CE	1969	1971(2)
Hardy	Judson	BAPL	1971(2)	1989(2)
Harker	Yale	ID	1972(2)	1977(2)
Harris	Donald	RPI, LANL, BAPL	1966(1)	1986
Harris	Joseph	SNL	1986	1986
Harris	L.	SAI	1975(1)	1975(1)
Heath	Russell	ID	1973(1)	1986
Hemmig	Philip	DOE	1968(2)	1992
Henderson	William	WNES, GE-NMPO	1966(2)	1985
Henryson	Herbert	ANL	1975(1)	1984
Hess	A.	ANL-W	1968(2)	1976(1)
Hetrick	David	ORNL	1988	1988
Hockenbury	Robert	RPI	1972(1)	1975(2)
Holden	Norman	BNL, KAPL	1969	1989(1)
Honeck	Henry	SRL	1966(1)	1968(2)
Horen	Daniel	ORNL	1975(2)	1979(1)
Howerton	Robert	LLNL	1967	1983
Hubbell	John	NIST	1969	1976(2)
Hubert	R.	BNL	1968(2)	1968(2)
Hubner	Robert	AI	1967	1968(2)
Hummel	Harry	ANL	1972(2)	1973(2)
Hunter	Hamilton	ORNL	1994	1996
Hunter	Ray	LANL	1973(2)	1973(2)
Huria	Harish	WARD	1996	1996
Hutchins	Bruce	GE-BRDO	1968(2)	1974(2)
Hwang	Richard	ANL	1996	1997
Ikeda	Yujiro	UCLA	1986	1986
Ingersoll	Daniel	ORNL	1987	1995
Irving	David	ORNL	1966(2)	1969
Jenkins	Douglas	ORNL	1970(1)	1972(1)
Jenquin	Urban	BNWL	1976(1)	1977(1)
Jonsson	Alf	CE	1985	1995
Kahler	Albert	BAPL	1989(1)	2000
Kalos	Malvin	NYU	1967	1974(2)
Kaul	Dean	SAI, DASA	1971(1)	1986
Kee	C.	ORNL	1974(1)	1974(1)

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Kellett	Mark	NEA	1998	1998
Kellman	S.	WNES	1969	1969
Kidman	R.	HEDL	1971(2)	1972(1)
Kinsey	Robert	BNL	1978(1)	1994
Knoll	Glenn	Mich	1976(2)	1977(2)
Knox	Harold	KAPL	1990	1990
Koning	Arjan	ECN	1997	1997
Kopecky	Jura	ECN	1989(2)	1989(2)
Koppel	Juan	GA	1968(2)	1968(2)
Kosako	K.	UCLA	1989(2)	1989(2)
Kouts	Herbert	BNL	1966(2)	1967
Kuhn	Edward	EEI	1973(2)	1973(2)
Kujawski	Edward	GE-BRDO	1975(2)	1978(1)
LaBauve	Raphael	LANL	1966(1)	1987
Lake	James	WARD	1980(2)	1982
Lancaster	Dale	WARD	1981(1)	1981(2)
Larson	Duane	ORNL	1977(2)	1995
Larson	Nancy	ORNL	1994	2000
Lazarus	Roger	LANL	1967	1967
Leal	Luiz	ORNL	1994	2000
Lederer	Michael	LBL	1974(2)	1974(2)
Lee	YongDeok	KAERI	2000	2000
Lemke	Barbara	AI	1966(2)	1966(2)
Leonard	Bowen	BNWL	1966(1)	1980(2)
Levine	Melvin	BNL	1968(2)	1968(2)
Lewellen	James	DOE	1974(1)	1980(2)
Liikala	Ronald	BNWL	1967	1968(2)
Lippencott	Ezra	HEDL	1974(1)	1980(1)
Little	Robert	LANL	1996	1998
Little	Winston	HEDL, BNWL	1969	1971(2)
Livolsi	Zizo	B&W	1966(2)	1974(2)
Lubitz	Cecil	KAPL	1966(1)	2000
MacFarlane	Robert	LANL	1974(1)	2000
MacGregor	Malcom	LLNL	1972(1)	1987
Madland	David	LANL	1977(1)	1977(1)
Maeck	William	ID	1974(1)	1974(1)
Maerker	Richard	ORNL	1971(2)	1978(1)
Magurno	Benjamin	BNL	1968(2)	1984
Mann	Fred	HEDL	1977(2)	1993
Marable	James	ORNL	1976(1)	1982
Mathews	Donald	GA	1966(2)	1987
Maynard	Charles	Wis	1972(2)	1977(2)
McCrosson	Joel	SRL	1968(2)	1975(2)
McElroy	William	HEDL	1971(1)	1977(1)
McFarlane	H.F.	ANL	1977(1)	1977(1)
McKnight	Richard	ANL	1976(2)	2000
McLane	Victoria	BNL	1982	2000
McNabb	Dennis	LLNL	1999	2000
McNeany	S.	ORNL	1975(2)	1975(2)
Meyer	Richard	DOE	1991	1995
Milgram	Michael	AECL	1987	1993
Moore	Michael	ID, LANL	1966(2)	1977(2)
Mosteller	Russell	LANL, NAI	1977(2)	1999

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Moxon	Michael	HAR	1992	1992
Mughabghab	Said	BNL	1982	2000
Muir	Douglas	LANL	1973(1)	1994
Neil	John	GA	1970(1)	1971(1)
Neuhold	Robert	DOE	1972(1)	1973(1)
Ng	R.	DOE	1980(2)	1981(1)
Nikolaev	Mark	Obninsk	1991	1991
Noderer	Lawrence	CE	1966(1)	1971(1)
Nordborg	Claes	NEA	1989(1)	1999
Nouri	Ali	NEA	2000	2000
O'Berg	D.	HEDL	1981(2)	1981(2)
Oblozinsky	Pavel	BNL	2000	2000
Omberg	R.	HEDL	1974(2)	1974(2)
Orphan	Victor	GA	1973(2)	1974(2)
Ottewitte	Eric	ID, AI	1969	1977(1)
Ozer	Odelli	EPRI, BNL	1968(2)	1986
Page	Earl	DE, APDA	1970(1)	1974(1)
Paik	Nam-Chin	WARD	1973(1)	1979(1)
Palmer	R.	ANL	1970(2)	1972(2)
Panini	Gianni	Bologna	1985	1985
Parish	Theadore	Texas A&M	1997	1997
Pearlstein	Sol	BNL	1966(1)	1999
Pearlstein*	Sol	BNL	1966(1)	1999
Peele	Robert	ORNL	1972(2)	1990
Pennington	Edwin	ANL	1966(1)	1979(1)
Penny	Keith	ORNL	1968(2)	1971(1)
Perey	Francis	ORNL	1971(1)	1979(1)
Perkins	Sterrett	LLNL	1984	1986
Perry	A.M.	ORNL	1973(2)	1973(2)
Philis	Claude	BRC	1989(1)	1989(1)
Pietrie	Lester	ORNL	1972(1)	1972(1)
Pitterle	Thomas	WARD, APDA	1966(1)	1972(2)
Poenitz	Wolfgang	ANL-W, ANL	1976(2)	1989(2)
Powell	R.G.	DASA	1974(2)	1974(2)
Prince	Augustus	BNL	1966(2)	1979(1)
Profio	Edward	GA	1967	1968(2)
Pronyaev	Vladimir	IAEA, Obninsk	1991	1999
Protsik	R.	GE-APO	1979(1)	1982
Ragan	George	ORNL	1972(2)	1972(2)
Rahn	Frank	Col	1972(1)	1972(1)
Ramchandran	S.	WARD	1972(2)	1972(2)
Rawlins	J.	WARD	1983	1983
Raymund	Malon	WNES	1970(2)	1977(1)
Rec	J.R.	CE	1977(1)	1980(2)
Reich	Charles	ID	1973(1)	1989(2)
Reid	J.	SAI	1974(1)	1975(1)
Resler	David	LLNL	1987	1998
Reynolds	Terry	KAPL	1970(2)	1970(2)
Ritter	Enloe	DOE	1975(2)	1975(2)
Romero	Juan	UCD	1996	1996
Rose	Philip	BNL, AI	1968(2)	1986
Ross	Alan	LLNL	1996	1999
Rothenstein	Wolfgang	Technion	1989(2)	2000

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Rothrock	R.	HEDL	1979(1)	1981(2)
Roussin	Robert	ORNL	1971(1)	1998
Roy	D.	B&W	1966(1)	1967
Ryskamp	John	ID	1988	1994
Sapir	Joseph	LANL	1988	1989(2)
Sayer	Royce	ORNL	1999	1999
Scheffel	Frances	BNL	1986	1986
Schenter	Robert	HEDL	1970(2)	1992
Schnitzler	B.	ID	1983	1983
Scoville	J.	ID	1971(1)	1971(1)
Seamon	Robert	LANL	1970(2)	1981(1)
Semler	T.	NASA	1972(1)	1972(1)
Shanstrom	Richard	GA	1967	1967
Sher	Rudolph	Stanford	1966(2)	1978(1)
Simons	G.	ANL	1975(1)	1975(1)
Singh	U.	CE	1981(1)	1983
Sirakov	Ivan	BNL	2000	2000
Smith	Alan	ANL	1972(2)	1989(2)
Smith	Donald	ANL	1993	2000
Smith	J.R.	ID	1966(1)	1981(1)
Smith	Michael	ORNL	1995	1995
Sowerby	Michael	HAR	1989(1)	1989(1)
Specht	Eugene	AI	1979(1)	1983
Speigel	V.	NIST	1976(2)	1977(2)
Spencer	R.R.	ORNL	1976(2)	1997
Stamatelatos	Michael	SAI, LANL	1974(2)	1978(1)
Steen	Norman	BAPL	1977(1)	1977(1)
Stehn	John	BNL	1970(1)	1987
Steiner	Donald	ORNL	1973(1)	1973(1)
Stephenson	Thomas	BNL	1966(1)	1970(1)
Stewart	Kent	BNWL	1966(1)	1972(2)
Stewart	Leona	LANL	1969	1986
Stuart	C.E.	GE-APO	1975(1)	1975(1)
Suich	John	SRL	1966(1)	1969
Sutton	Thomas	KAPL	1998	1999
Takahashi	Hiroshi	BNL	1973(1)	1999
Thom	Bruce	AWRE	1999	1999
Tomlinson	E.	ORNL	1977(1)	1977(1)
Toppel	Bert	ANL	1966(1)	1972(1)
Trkov	Andre	IAEA	2000	2000
Trubetzkoy	Eugene	UNC	1967	1970(1)
Trubey	David	ORNL	1968(2)	1970(2)
Trumpler	D.	CE	1980(2)	1980(2)
Uhl	Mario	IRK	1978(1)	1978(1)
Ullo	J.	BAPL	1977(2)	1978(1)
Valentine	Timothy	ORNL	2000	2000
Varlamov	Vladimir	Moscow	1991	1991
Vlasov	Mercury	KINR	1998	1998
Vonach	Herbert	IRK	1990	1990
Vondy	David	ORNL	1980(2)	1980(2)
Walker	William	AECL	1968(2)	1979(1)
Wall	Ian	GE-APO	1966(1)	1966(1)
Wasson	Oren	NIST	1989(2)	1994

CSEWG Participants

Last Name	First Name	Affiliation	Start Year	End Year
Watson	A.	CPL	1973(2)	1973(2)
Webster	Simon	NEA	1989(2)	1989(2)
Wehmeyer	David	APDA	1969	1969
Wehring	B.	Illinois	1975(1)	1975(1)
Weinman	James	KAPL	1996	2000
Weisbin	Charles	ORNL, LANL	1972(1)	1986
Wemple	Charles	ID	1993	1998
Werner	Christopher	LANL	1999	1999
Westfall	Michael	ORNL	1994	1997
Weston	Larry	ORNL	1975(1)	1994
Wheeler	F.	ID	1973(2)	1976(2)
Whetstone	Stanley	DOE	1976(2)	1992
White	John	ORNL	1975(2)	1999
White	Morgan	LANL	1999	2000
White	Roger	LLNL	1985	1996
Williams	Mark	LSU, ORNL	1979(1)	1997
Wilson	William	LANL	1978(1)	1998
Wittkopf	Warren	B&W	1966(1)	1978(1)
Wright	R.Q.	ORNL	1972(2)	1999
Wu	R.	HEDL	1980(2)	1980(2)
Yarbrough	M.	WARD	1980(2)	1980(2)
Yoon	Yu	ID	1991	1991
Yost	Karl	ORNL	1970(1)	1970(1)
Younes	Walid	LLNL	1998	1998
Young	Philip	LANL	1969	1997
Youssef	Mahmoud	UCLA	1988	1988
Yu	Hongwei	CNDC	1997	1997
Zhuang	Youxiang	CNDC	1987	1990
Zolotar	Bert	EPRI, ANL	1969	1973(2)

CSEWG Committees and Subcommittees

The CSEWG organization was created at the second meeting in November 1966. It consisted of five subcommittees. One of the five subcommittees, the Shielding Subcommittee, did not start work until the third meeting in May 1967. Some additional subcommittees were created in the following years. This structure lasted until the CSEWG meeting of May 1980.

CSEWG Chairmen

Sol Pearlstein	BNL	June 1966 to May 1984
Robert Dannels¶	WNES	November 1972
Charles Dunford	BNL	May 1984 to November 2000
Robert Roussin¶	ORNL	October 1993 and October 1994
Pavel Oblozinsky	BNL	November 2000 to date

Codes and Formats Subcommittee

Henry Honeck	SRL	November 1966 to September 1969
Robert Dannels	WNES	November 1969 to December 1973
Donald Mathews	GA	December 1973 to May 1976
Raphael LaBauve	LANL	May 1976 to May 1980

Data Testing Subcommittee

Paul Greebler	GE-APO	November 1966 to September 1968
William Davey	ANL	September 1968 to September 1969
Harry Alter	AI	September 1969 to December 1973
Bruce Hutchins	GE-BRDO	December 1973 to October 1974
Edward Bohn	ANL	October 1974 to May 1977
Charles Weisbin	ORNL	May 1977 to May 1980

Normalization Subcommittee → Normalization and Standards Subcommittee

David Goldman	NBS	November 1966 to September 1969
Bowen Leonard	BNWL	September 1969 to May 1980

Resolved Resonance Region Subcommittee → Resonance Region Subcommittee

Sol Pearlstein	BNL	November 1966 to September 1968
Thomas Stephenson	BNL	September 1968 to September 1969
Mulki Bhat	BNL	September 1969 to May 1973
Cecil Lubitz	KAPL	May 1973 to May 1980

Shielding Subcommittee

Frank Clark	ORNL	May 1967 to September 1968
Keith Penny	ORNL	September 1968 to March 1970
David Trouby	ORNL	March 1970 to May 1971
Marvin Drake	GA	May 1971 to May 1972
Raphael LaBauve	LANL	May 1972 to May 1976
Robert Roussin	ORNL	May 1976 to May 1980

¶ Acting CSEWG Chair

CSEWG Committees and Subcommittees

Evaluation Request Subcommittee

John Suich	SRL	May 1967 to January 1968

Fission Product Subcommittee → Fission Product and Decay Heat Subcommittee

Warren Witkopf	B&W	September 1968 to November 1972
Robert Schenter	HEDL	November 1972 to May 1980

Nuclear Model Code Subcommittee

Augustus Prince	BNL	October 1970 to May 1980

Error Quantities Subcommittee → Data Covariance Subcommittee

Marvin Drake	GA	May 1972 to December 1973
Francis Perey	ORNL	December 1973 to May 1980

Non-neutron Data Subcommittee

Edward Pennington	ANL	May 1972 to May 1973

Special Applications Subcommittee

Benjamin Magurno	BNL	October 1976 to May 1980

A major reorganization of CSEWG was approved at the November 1979 meeting. It took effect at the following meeting. CSEWG was organized into three technical and one administrative/policy committee. The administrative/policy committee is called the **Executive Committee** and is chaired by the CSEWG chairman. It included committee chairs and representatives of the major contributing organizations. The three technical committees were organized into subcommittees, which could be created or terminated as required. In 1993, the DOE Division of Nuclear Physics requested that CSEWG take over the responsibilities of the United States Nuclear Data Committee. In response, CSEWG created a new committee, the **Data Measurement and Basic Science Committee**. Responsibility for oversight of nuclear measurements related to nuclear data evaluation was assigned to this committee. In 1995, this committee was given responsibility for standards and the measurement request list. The subcommittee structure was abandoned in 1995 due to the reduced level of CSEWG activity. The committees began to meet as a whole. Individuals were assigned the responsibilities originally given to the subcommittees.

Evaluations Committee

Phillip Young	LANL	May 1980 to October 1998
Mark Chadwick	LANL	October 1998 to present

General Purpose (low Z) Subcommittee May 1980 to October 1994

Phillip Young(LANL)

CSEWG Committees and Subcommittees

General Purpose (medium Z) Subcommittee May 1980 to October 1994

Duane Larson(ORNL)

General Purpose (high Z) Subcommittee May 1980 to October 1993

Larry Weston(ORNL)

Standards Subcommittee May 1980 to October 1995

Allan Carlson(NIST)

Fission Products, Actinides and Yields Subcommittee May 1980 to October 1993

Robert Schenter(HEDL) & Tal England(LANL)

Charged Particle and Photonuclear Subcommittee May 1980 to October 1994

Leona Stewart(LANL), Roger White(LLNL)

Data Status and Requests Subcommittee May 1980 to October 1993

Mulki Bhat(BNL), Philip Rose(BNL), Duane Larson and Larry Weston(ORNL)

Special Applications Subcommittee May 1980 to October 1994

Benjamin Magurno(BNL), Fred Mann(HEDL)

Nuclear Medicine Subcommittee May 1990 to October 1995

Robert Schenter(HEDL)

Methods and Formats Committee → Methods and Processing Committee

Robert Howerton	LLNL	May 1980 to May 1985
Raphael LaBauve	LANL	May 1985 to May 1988
Robert Roussin	ORNL	May 1988 to November 1999
Maurice Greene	ORNL	November 1999 to present

Formats → Formats and Procedures Subcommittee May 1980 to October 1995

Raphael LaBauve(LANL), Robert Roussin(ORNL)

Evaluation Methods Subcommittee May 1980 to October 1981

Edward Arthur(LANL)

Processing Codes Subcommittee May 1980 to May 1983

Donald Finch(SRL), Raphael Labauve(LANL)

Utility Codes Subcommittee May 1980 to May 1985

Raphael LaBauve(LANL), Robert Roussin(ORNL)

CSEWG Committees and Subcommittees

Covariance Subcommittee	May 1980 to October 1994

Robert Peelle(ORNL), Douglas Muir(LANL)

Resonance Region Subcommittee	May 1986 to October 1995

Cecil Lubitz(KAPL)

<u>Data Testing and Applications Committee → Data Validation Committee</u>

Charles Weisbin	LLNL	May 1980 to May 1983
Robert MacFarlane	LANL	May 1983 to May 1985
Richard McKnight	ANL	May 1985 to present

Thermal Data Testing Subcommittee	May 1980 to October 1995

Philip Rose(BNL), Jud Hardy(BAPL), Mark Williams(LSU)

Fast Data Testing Subcommittee	May 1980 to October 1995

Richard McKnight(ANL)

Shielding Data Testing Subcommittee	May 1980 to October 1995

Robert Roussin(ORNL), Dan Ingersoll(ORNL)

<u>Data Measurement and Basic Science Committee</u>

Donald Smith	ANL	October 1993 to present

CSEWG Meetings

Meeting Number	Month	Days	Year	Notes
1	June	9-10	1966	
2	November	14-16	1966	
3	May	24-26	1967	
4	January	16-17	1968	No minutes
5	September	16-18	1968	
6	September	24-26	1969	
7	March	24-25	1970	
8	October	7-8	1970	
9	May	19-20	1971	
10	December	1-2	1971	
11	May	9-10	1972	
12	November	9-10	1972	
13	May	23-24	1973	
14	December	12-13	1973	
15	June	12-13	1974	
16	October	23-24	1974	
17	May	7-8	1975	
18	October	22-23	1975	
19	May	19-20	1976	
20	October	27-28	1976	
21	May	25-26	1977	
22	December	7-8	1977	
23	May	25-26	1978	
24	October	23-36	1978	
25	May	16-17	1979	
26	October	31-Nov 1	1979	
27	May	15-16	1980	CSEWG reorganized. Minutes counting error repeating 26, all meeting numbers off by one
28	October	22-23	1980	
29	May	13-15	1981	
30	October	21-22	1981	
31	May	19-21	1982	
32	May	12-13	1983	
33	May	9-11	1984	No attendance list in minutes
34	May	29-31	1985	
35	May	21-23	1986	
36	May	12-14	1987	
37	May	10-12	1988	
38	April	3-7	1989	
39	November	13-16	1989	
40	May	8-10	1990	
41	May	8-10	1991	
42	May	12-14	1992	
43	October	5-7	1993	
44	October	25-27	1994	Meeting at Oak Ridge
45	October	17-19	1995	
46	November	19-21	1996	
47	October	7-9	1997	

CSEWG Meetings

Meeting Number	Month	Days	Year	Notes
48	October	20-22	1998	
49	November	3-5	1999	
50	November	8-10	2000	This is the true 50^{th} meeting
51	November	7-9	2001	

CSEWG Participating Organizations

Organization	Organization Name
AECL	Atomic Energy of Canada Limited (Chalk River)
AI	Atomics International
ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory, Idaho Facility
APDA	Atomic Power Development Associates
AWRE	AWRE Aldermaston, UK
B&W	Babcock & Wilcox
BAPL	Bettis Atomic Power Laboratory
BNL	Brookhaven National Laboratory
BNWL	Battelle Northwest Laboratories
Bologna	ENEA, Bologna, Italy
BRC	CEN Bruyeres-le-Chatel, France
CAD	CEA Cadarache, France
CE	Combustion Engineering and its successors
CNDC	China Nuclear Data Center, CIAE, Beijing
Col	Columbia University
CPL	Carolina Power and Light
DASA	Defence Atomic Support Agency
DE	Detroit Edison
DNFSB	Defence Nuclear Facilities Safety Board
DOE	US Department of Energy and its predecessors ERDA and AEC
ECN	ECN Petten, Netherlands
EEI	Edison Electric Institute
EPRI	Electric Power Research Institute
GA	General Atomics and its predecessors
GE-APO	General Electric Atomic Power Organization
GE-BRDO	General Electric Breeder Reactor Development Organization
GE-NMPO	General Electric Nuclear Materials and Propulsion Organization
HAR	AERE Harwell, UK
HEDL	Hanford Engineering Development Laboratory
IAEA	International Atomic Energy Agency, Vienna, Austria
ID	Idaho Nuclear Engineering Labortory and its predecessors
Illinois	University of Illinois
IRK	IRK, University of Vienna, Austria
JAERI	Japan Atomic Energy Research Institute, Tokaimure, Japan
KAERI	Korea Atomic Energy Research Institute, Taejon, South Korea
KAPL	Knolls Atomic Power Laboratory
KINR	KINR, Kiev, Ukraine
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LSU	Lousiana State University
MAGI	Mathematical Aplications Group Inc.
Mich	Michigan State University
MIT	Massachusetts Institute of Technology
Moscow	Moscow State University, Russia
NAI	Nuclear Associates International
NASA	National Aeronautics and Space Administration
NEA	Nuclear Energy Agency, Paris, France

CSEWG Participating Organizations

Organization	Organization Name
NFS	Nuclear Fuel Services
NIST	National Institute of Science and Technology and NBS
NPL	National Physical Laboratory, UK
NYU	New York University
Obninsk	IPPE Obninsk, Russia
ORNL	Oak Ridge National Laboratory
RPI	Rensselaer Polytechnic Institute
SAI	Science Applications Inc.
Sarov	VIINF, Sarov, Russia
SNL	Sandia National Laboratory
SRL	Savannah River National Laboratory
Stanford	Stanford University
Technion	Texhnion University, Haifa, Israel
Texas A&M	Texas A&M University
TSI	TSI Research Corporation
UCD	University of California, Davis
UCLA	University of California, Los Angeles
UNC	United Nuclear Corporation
Uppsala	Uppsala University, Sweden
WARD	Westinghouse Atomic Reactor Division
Wis	University of Wisconsin
WNES	Westinghouse Nuclear Energy Systems