OFFICE OF BASIC ENERGY SCIENCES PROGRAM
TO MEET HIGH PRIORITY NUCLEAR DATA NEEDS
OF THE OFFICE OF FUSION ENERGY

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1983 REVIEW

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ABSTRACT

This review was prepared during a coordination meeting held at Oak Ridge National Laboratory on September 28-29, 1983. Participants included research scientists working for this program, a representative from the OFE's "Coordination of Magnetic Fusion Energy (MFE) Nuclear Data Needs Activities," and invited specialists.

* Participants are listed in Appendix A

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EXECUTIVE SUMMARY

The fourth coordination meeting of the Basic Energy Sciences' Program to Meet High Priority Nuclear Data Needs of the Office of Fusion Energy was held at Oak Ridge National Laboratory on September 28-29, 1983. This program focuses on the measurement of differential nuclear data of basic and long-range importance in the development of magnetic fusion energy. In attendance at this meeting were representatives from eight of the laboratories participating in the program, invited representatives from three other laboratories, a coordinator from the OFE program of Coordination of Magnetic Fusion Energy (MFE) Nuclear Data Needs Activities, and the chairman of the DOE-Nuclear Data Committee, which is the parent committee of this coordination meeting. Recent progress in the individual laboratory programs was reviewed, technical developments were discussed, and goals for the next two years were set. The output of the program was critically assessed against the current list of OFE nuclear data needs, and, in turn, this list received comments based on recent measurements and the capabilities of the nuclear science community to satisfy those needs.

The BES program is found to have made significant advances in meeting the OFE nuclear data needs. It is apparent that a large number of requests on the OFE's past and current lists for which the data measurement needs are now satisfied as a result of efforts within this program and elsewhere in the nuclear data community. Furthermore there has been active development at every participating laboratory of new techniques and new capabilities to address the more difficult measurements that remain and the new requests that will arise.

I. INTRODUCTION

In 1975 the Office of Basic Energy Sciences (BES) of the Department of Energy initiated a Program to Meet High Priority Nuclear Data Needs of the Office of Fusion Energy (OFE). This program now includes work at eleven laboratories. On September 28-29, 1983, representatives from eight of those laboratories met together with three invited participants and a representative of OFE's "Coordination of Magnetic Fusion Energy (MFE) Nuclear Data Needs Activities." The participants in the present meeting are listed in Appendix A. This meeting, held at Oak Ridge National Laboratory, follows similar meetings at Lawrence Livermore National Laboratory (1981), Triangle Universities Nuclear Laboratory (1979), and Oak Ridge National Laboratory (1976). At these meetings the progress of the individual laboratory programs is reviewed, technical developments are discussed, and goals for the next two years are set.

This BES program is unique in that it is a coordinated program among several laboratories to provide differential nuclear data specifically for the development of magnetically-confined fusion energy. Nevertheless, the Program has its limits: it does not attempt to satisfy all of fusion's nuclear data needs; it does not convert evaluated data into the processed cross sections required by many users; it does not address integral benchmark experiments including transport experiments, determination of kerma factors, and broad-spectrum-averaged data; and it is not expected to respond to certain immediate needs that are more properly supported by project offices in the OFE. Rather, the BES Program intends to provide measurements of differential nuclear data that are of high priority to OFE for intermediate- and long-range applications. Evaluated data are provided only as an extension of research in "applied theory".

The present meeting differed from past meetings in the increased number of participants and the broader range of research. The BES program has expanded since the 1981 meeting and now includes efforts in radioactive decay data, low energy fusion reactions for diagnostic purposes, and 14-MeV neutron cross section standards. The first of these three new directions was represented at the present meeting. In addition three U.S. measurement groups outside of the BES Program were invited to participate since their programs were considered to have relevance to nuclear data for fusion. Another significant addition since the last meeting was the presence of a representative (E. Cheng, GA Technologies) from the OFE's program of Coordination of Magnetic Fusion Energy (MFE) Nuclear Data Needs Activities. This program is an important step toward overcoming the problem, identified at previous meetings, of insufficient feedback from the users and requestors of nuclear data to the measurement community in general and the BES program in particular.

Current nuclear data needs of the Office of Fusion Energy are reviewed in Section II. Summaries from the participating laboratories and the goals of these laboratories for the next years are listed in Section III. We assess how well the program is meeting the OFE needs in Section IV. Some comments on the OFE request list are also given in this section. Section V summarizes our conclusions and recommendations. The programs of two non-BES-sponsored groups whose activities are relevant to fusion nuclear data needs are summarized in Appendix B.

II. CURRENT NUCLEAR DATA NEEDS OF THE OFFICE OF FUSION ENERGY

In response to our 1981 coordination meeting request,¹ the Office of Fusion Energy initiated a program at GA Technologies (GA) in early 1982 to establish communications between the fusion data developers and users. The 1982 GA report (GA-A16886)² represents the current statement of the nuclear data needed by the OFE Magnetic Fusion Energy (MFE) Program and will be updated as frequently as the progress of the program warrants.

In the GA report, general nuclear data needs and their priorities were determined according to the planned development of magnetic fusion energy. The priorities in order are (1) near-term development needs to demonstrate the scientific feasibility of magnetic fusion energy and to assess and make decisions on the engineering feasibility issues which are necessary to carry out the demonstration of engineering feasibility of fusion energy, (2) mid-term (or next generation) development needs to demonstrate the engineering feasibility of magnetic fusion energy and operate prototype demonstration and commercial D-T fusion power reactors, and (3) long-term development needs to operate the demonstration fusion power reactor utilizing advanced fusion fuel cycles.

The nuclear data needs to be emphasized for the MFE development program are given as follows:

- charged-particle nuclear and physics data
- neutron emission data
- tritium production data
- neutron activation and dosimetry data
- radionuclide decay data.

Charged particle production data that are of importance to radiation damage studies and nuclear heating calculations are also to be emphasized.

The specific nuclear data measurement needs (as opposed to needs for evaluated or processed data) were reviewed by the GA program² with input from the data developers and users. Tables 3-1 and 3-2 of the GA review summarize the requests for new data measurements.* The first lists the data requests for general fusion reactor development. The energy range of the incident particles (generally neutrons) in these requests extends up to 16 MeV. The second table gives the data requests for the Fusion Materials Irradiation Test Facility (FMIT). These data are requested primarily for the radiation damage studies and the operation of the FMIT facility. The energy range of the incident particle for these requests is, in general, above 15 MeV.

* These tables are reproduced in Section IV as Tables IV-1 and IV-2 with comments relating the requests to the BES measurement program.

III. INDIVIDUAL LABORATORY PROGRAMS

In this section, the programs of most of the participating laboratories are outlined briefly. Emphasis is given to recent results, any changes of program goals, and anticipated near-term results. Reported results generally cover the period since the last coordination meeting in October 1981; results prior to that meeting are summarized in the preceding report, "Office of Basic Energy Sciences Program to Meet High Priority Nuclear Data Needs of the Office of Fusion Energy: 1981 Review."¹ The present status of each program is then compared with that anticipated in October 1981. Any changes in the specific program goals are emphasized here. Finally new goals are set for the next few years. In the light of past performance, we expect a substantial number of these goals to be met on schedule and the results to be made available quickly.

New efforts in this program include work at Idaho National Engineering Laboratory (radioactive decay data), Colorado School of Mines (fusion gamma rays for plasma diagnostics), and the Universities of Michigan and New Mexico (standard cross sections). Only the first of these programs is outlined here; the others are very recent. We anticipate all to be summarized at the next coordination meeting.

BROOKHAVEN NATIONAL LABORATORY
NATIONAL NUCLEAR DATA CENTER

Our program has consisted of compilation and evaluation support activities in the area of charged-particle-induced reactions, development and improvement of model codes and parameters used in neutron evaluations, and general support activities including the U.S. Nuclear Data Committee Request List, the Symposia on fast neutron physics, and the Fast Neutron Newsletter.

RESULTS FROM 1981 TO PRESENT

The bibliography of Integral Charged-Particle Nuclear Data (BNL-NCS-50640) was terminated with the publication of the second supplement to the fourth edition in March 1982. We continue to coordinate the biennial review of nuclear data requests. This review includes fusion data requests along with those for other projects. We have also continued publication of the semi-annual Fast Neutron Cross Sections Newsletter, with the next issue going to press in August 1983.

The NNDC published the Proceedings of the Conference on Nuclear Data Evaluation Methods and Procedures as BNL-NCS-51363. Recently, the NNDC helped to organize and host the IAEA Advisory Group Meeting on Basic and Applied Problems of Nuclear Level Densities. The proceedings are in press and will be published as BNL-NCS-51694.

In addition to maintaining the Bibliography of Integral Charged-Particle Nuclear Data, the Center has been active since 1976 in other charged-particle activities which, in part, satisfy the charged-particle data compilation requests of the fusion community. These activities include participation in the Nuclear Reaction Data Centers Network which compiles and exchanges experimental nuclear reaction data and in the GSEWG Charged-Particle Nuclear Data Subcommittee. The Center also acts as a repository for other charged-particle libraries. These include the experimental data libraries of McGowan and Howerton and Hale's Evaluated Fusion Library.

A new cooperative effort in Western Europe with the goal of producing nuclear data evaluations for use in fusion research is being established. This effort called the European Fusion File (EFF) is being sponsored by EURATOM, and is only weakly connected to the JEF system sponsored by the Nuclear Energy Agency. The NNDC has begun to explore mechanisms for collaboration and data exchange with this group.

The Bologna set of model codes (PENELOPE) which includes precompound emission, angular distributions of the outgoing particles, and multi-particle emission has been implemented at the NNDC.

With the exceptions noted above, most of the anticipated results for FY1982 and FY1983 were not realized. This was caused by a combination of manpower and funding limitations which forced a reduction in staff and a shift in priorities.

ANTICIPATED RESULTS

FY1984

1. Continuing responsibility for the Data Request List and the Fast Neutron Newsletter
2. Investigate the possibility of producing a charged-particle index from Nuclear Structure References (NSR). This would be designed to satisfy the former users of BNL-NCS-50640.
3. Continue activities as a member of the Nuclear Reaction Data Center and participation in the CSEWG CPND Subcommittee
4. Evaluations of materials of interest to FMIT and the fusion community. These materials would be selected from the fusion data request list. The evaluations would use the new ENDF formats and include double-differential data.

FY1985

1. Continuing responsibility for the Data Request List and the Fast Neutron Newsletter.
2. If production of a charged-particle index from NSR is feasible and well-received, continue periodic publication of the index.
3. Continue activities as a member of the Nuclear Reaction Data Center and participation in the CSEWG CPND Subcommittee.
4. Continue evaluations initiated in FY1984.

NUCLEAR-DATA-RELATED ACTIVITIES AT INEL

The activities of EG&G Idaho at the Idaho National Engineering Laboratory (INEL) in the general area of Nuclear Data involve the measurement and critical evaluation of radioactive-nuclide decay data and low-energy nuclear-structure data important to various activities in Nuclear Science and low-energy nuclear physics. The decay-data measurements utilize state-of-the-art techniques of nuclear spectroscopy for the determination of decay properties of selected fission-product, actinide and activation-product nuclides relevant to the U.S. fission-reactor and fusion-energy programs. In the area of nuclear-data evaluation, there are two specific thrusts: (1) the evaluation of basic low-energy nuclear structure data for inclusion in the Nuclear Data Sheets; and (2) evaluation of radionuclide-decay data of fission-product, actinide and activation-product nuclides for inclusion in ENDF/B. A brief summary of activities in these areas is given below.

A. Decay-Data Measurement Efforts

1.) Transactinium-nuclide decay data. Over the past several years, we have been involved in the measurement of precise ($\leq 1\%$ standard deviation) values for the emission probabilities of prominent gamma-ray transitions from the decay of selected actinide nuclides identified as being important in various aspects of fast-reactor technology and its associated fuel cycle. This measurement activity represents a part of our laboratory participation in the IAEA Coordinated Research Program (CRP) on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data. This CRP is an outgrowth of an IAEA Advisory Group Meeting on Transactinium Isotope Nuclear Data, held in Karlsruhe in 1975, and involves participants from five laboratories around the world. Nuclides which we are studying in this effort include ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{232}U (and its daughters), ^{233}U , ^{235}U , ^{233}Pa and ^{229}Th .

2.) Delayed-neutron energy spectra. Delayed-neutron energy spectra of isotope-separated samples of fission-product precursor nuclides are being measured. These measurements are being carried out using the on-line isotope separator, TRISTAN, at the High Flux Beam Reactor at BNL. The energy spectra are being measured using a variety of proton-recoil detectors, which provide a good characterization of the neutron energy spectra in the important region from a few keV to several hundred keV. Thus far, spectral measurements have been made on isotope-separated samples of the precursor nuclides ^{93}Rb , ^{94}Rb , ^{95}Rb , ^{96}Rb , ^{97}Rb and ^{143}Cs , ^{144}Cs , ^{145}Cs . It is planned to carry out similar studies on all of the important fission-product delayed-neutron precursors, in a sequence determined largely by the elemental-extraction capabilities of the TRISTAN ion sources.

3.) Short-lived fission-product studies. We have recently placed into operation an on-line isotope-separator facility for the study of the decay properties of short-lived fission-product nuclides. This facility uses

spontaneous fission of ^{252}Cf as the source of fission products and a He-jet transport system to insert them into the ion source of the isotope separator. A program of measurement of decay properties of short-lived fission-product nuclides is being set up around this facility. In its early phases, this will emphasize direct determination of average beta- and gamma-decay energies, gamma-ray spectra and detailed beta-strength functions of selected delayed-neutron precursor nuclides.

4.) 4π beta-gamma coincidence measurements. A 4π beta-gamma coincidence system with unique high-counting-rate capabilities has been developed over a period of several years and applied to the measurement of gamma-ray emission probabilities of activation- and fission-product nuclides with half-lives ≥ 30 min. Source disintegration rates can be determined with accuracies of a few tenths of a percent at rates of $1\text{--}2 \times 10^5$ dis/s and $\sim 1\%$ at rates of $\sim 5 \times 10^5$ dis/s.

5.) Neutron dosimetry activities. For roughly the past decade, we have been involved in measurement and evaluation work related to reactor-neutron dosimetry. Through our participation in the Interlaboratory LMFBR Reaction Rate Program, we carried out precise gamma-ray disintegration-rate determinations on a number of radioactive nuclides produced through neutron activation and fission reactions in standard fission and dosimetry foils. These data were used to characterize the neutron fields in a number of fast-reactor critical facilities. At present, personnel at INEL are involved in neutron dosimetry for the TFTR Li-blanket program to characterize the neutron flux fields in the Li-blanket module of TFTR. They have the primary responsibility for specifying and conducting the experimental program in this area.

B. Nuclear-Data Evaluation

1.) Mass-chain evaluation. Basic low-energy nuclear structure data are being evaluated for publication in the Nuclear Data Sheets. This represents part of our participation in the work in International Nuclear Structure and Decay-Data Evaluation Network, and we are one of five groups in the U.S. involved in this work. The mass chains for which INEL has the evaluation responsibility lie in the region $153 \leq A \leq 162$.

2.) Decay-data evaluation for ENDF/B. For the past decade we have been involved in the evaluation of selected radioactive-nuclide decay data for ENDF/B. Within CSEWG, we had the initial responsibility for deciding which categories of decay data were to be included in ENDF/B and subsequently for preparing evaluated decay-data sets for a number of nuclides. In the most recent version of ENDF/B, Version V, INEL-evaluated decay data appear in the Fission-Product File (~ 320 nuclides), the Actinide File (~ 100 nuclides) and the Activation File (~ 70 nuclides). The present thrusts of this evaluation effort are to expand the number of nuclides in the Fission-Product File for which evaluated decay data are given, to upgrade the data in the Actinide and Fission-Product Files and to incorporate delayed-neutron energy spectral data for individual fission-product precursors.

Lawrence Livermore National Laboratory

Our program is to measure (n,p) , (n,d) , (n,t) and $(n,^3\text{He})$ and (n,α) reactions on materials of importance to the development of magnetic fusion energy. These reactions constitute the hydrogen and helium production by nuclear transmutation and are therefore important in assessing the effects of radiation damage by neutrons. By measuring the energy of the charged particles, we are also able to provide data on energy deposition (kerma factors) in materials by neutrons. These detailed cross sections, angular distributions and spectra provide especially useful tests of nuclear reaction-model calculations which in turn are used to provide comprehensive data in evaluated data libraries. To help interpret the microscopic data and to shed light on the reaction mechanisms, we also carry out related experiments on charged-particle induced reactions and direct measurements of kerma factors.

Previous results

Our results on $(n,\text{charged particle})$ reactions at 15 MeV have been published for ^{27}Al , $^{46,48}\text{Ti}$, ^{51}V , $^{50,52}\text{Cr}$, $^{54,56}\text{Fe}$, $^{58,60}\text{Ni}$, $^{63,65}\text{Cu}$, ^{89}Y , ^{90}Zr , ^{93}Nb and $^{92,94-96}\text{Mo}$ and for stainless steels 304 and 316. Results at 14.1 MeV for ^{12}C are submitted for publication and those for ^7Li , ^9Be , ^{11}B , N , O , ^{19}F and Si have been communicated at meetings.

To understand better the alpha-particle emission spectra, we have made precise measurements of the α -particle total reaction cross section as a function of energy for ^{48}Ti and ^{51}V . The optical model potential of McFadden and Satchler was found to be much better than that of Huizenga and Igo in accounting for these data. We have also taken and are analyzing data on particle emission spectra for $^{47,48}\text{Ti} + \alpha$ and $^{52,53}\text{Cr} + \alpha$.

Our results on carbon at 14.1 MeV imply a kerma factor lower than in present compilations. To verify this result, we have participated in a collaborative experiment with the University of Wisconsin where the pulse-height distribution from a carbon-wall proportional counter was measured and used to deduce the kerma factor. These new results are consistent with our previous data and therefore strongly suggest that the value of the compiled kerma factor should be reduced.

A rotating gas cell has been designed for neutron production using the increased beam ($> 10\mu\text{A}$) at the LLNL Cyclograff.

Comparison of present status with that anticipated in 1981 Review

The measurement program was altered due to (1) the unexpected result for carbon and (2) the need to know better the optical model potential for interpreting the (n,α) spectra previously measured. The purchase of a new ion source for the EN Tandem in FY1983 dictated that a new gas target be designed to use the much larger ($\geq \times 5$) beam currents available with this source.

Anticipated results

A. FY1984

1. Documentation of results on ${}^7\text{Li}$, ${}^9\text{Be}$, ${}^{11}\text{B}$, N, O, F and Si at 14 MeV.
2. Excitation function of $n + {}^{12}\text{C}$ reactions and scattering in the region $E_n = 13$ to 15 MeV. The (n,α) study will employ the electrostatic particle guide and the new rotating gas cell for improved neutron production at the LLNL Cyclograaff.

B. FY1985

1. More excitation functions of $(n, \text{charged particle})$ reactions on light nuclides.
2. Investigation of pre-equilibrium particle emission at $E_n \geq 20$ MeV.

LOS ALAMOS NATIONAL LABORATORY

The measurement program at Los Alamos is directed at obtaining neutron and gamma-ray emission spectra for important fusion materials and at precisely measuring fusion reaction cross sections and emission spectra for $d + d$, $d + t$, and $t + t$ reactions at low energies. The calculation program supports the measurements at Los Alamos and elsewhere by developing nuclear models and theory for application in nuclear data evaluations.

Results Since October 1981

A. Measurements.

1. Measurements of the $D(t,\alpha)$ reaction are complete. The integrated cross section was obtained at 16 energies from 8.3 to 78.1 keV (equivalent E_d), corresponding to plasma kT in the range of about 1 to 20 keV.
2. Measurements of differential and integrated cross sections for the $D(d,p)T$ and $D(d,^3\text{He})n$ reactions are complete for $E_d = 20$ to 117 keV.
3. Values of the $T(d,\gamma)$ cross section integrated over the 110-keV resonance have been obtained using a low energy deuteron beam and a stopping-length tritium gas target.
4. Measurements of the $D(t,\gamma)$ cross section at discrete steps across the 110-keV resonance using a thin target have been started. A BGO detector with active cosmic ray suppression spectrometer has been constructed.
5. Installation and check-out of a 5-detector BGO detector array at the WNR for measuring fast-neutron capture and neutron-induced γ -ray production cross sections is complete.
6. Initial studies have been made of an experiment to measure neutron production from 1 to 6 MeV triton and deuteron bombardment of the lithium isotopes.

B. Calculations.

1. Theoretical expansions for precise representation of charged-particle elastic scattering and a new Fokker-Planck treatment of small-angle slowing down that includes Coulomb-nuclear interference were developed. Charged-particle data libraries for d-t and d-d elastic scattering were derived for use in slowing down calculations (Proc. Antwerp Conference, 1982; LA-9841-PR, 1983).
2. Cross sections for d-t and d-d reactions with polarized particles were calculated with the Los Alamos EDA code and supplied to the Princeton Plasma Physics Laboratory for use in assessing the possible utilization of polarization effects in fusion reactors. (Pol. Fusion Fuel Workshop, Madison, March 1983; LA-1647-PR, 1982; LA-9841-PR, 1983).
3. We provided complete evaluations of neutron-induced reactions on ^7Li , ^{182}W , ^{183}W , ^{184}W , and ^{186}W for Revision 2 of ENDF/B-V, and completed a new evaluation of $D(n,2n)$ reactions that includes energy-angle correlated emission spectra (LA-9468-PR, 1982).
4. Initiated new R-matrix analysis of ^{10}B and began study of reaction theory parameterization for use in evaluations of ^{11}B , ^{14}N , and ^{16}O systems that will include covariance information on secondary energy distributions. (LA-9841-PR, 1983.)

Comparison of Present Status with that Anticipated in 1979

The measurement program is on schedule except that $D(t,\gamma)$ measurements were accelerated, resulting in a delay of the $t+t$ measurements. Emphasis on other fusion applications prevented us from completing the ${}^6\text{Li}$, ${}^{10}\text{B}$, and ${}^{11}\text{B}$ covariance analyses. However, reaction theory parameterizations were developed for light elements that should be directly applicable to these efforts. Additionally, unanticipated work was completed on fusion reactions utilizing polarized particles along with calculational methods for the more exact determination of charged-particle slowing-down.

Anticipated FY 1984 Results

- (1) Publish results of $D(t,\alpha)n$ and complete analysis and publish results of $D(d,p)T$ and $D(d,{}^3\text{He})n$ reactions.
- (2) Begin continuous flow tritium target operation on LEFCS and obtain initial data on $T(t,\alpha)nn$ and possibly $T(t,n)\alpha$ neutron spectra.
- (3) Continue work on $D(t,\gamma)$ thin target experiment..
- (4) Complete tritium and deuteron-induced neutron production experiment for ${}^6\text{Li}$ and ${}^7\text{Li}$.
- (5) Design experiment and complete initial studies of $(t, \text{charged particle})$ and $(d, \text{charged particle})$ reactions on the lithium isotopes. Initially the range of interest for these data will be 1-6 MeV.
- (6) Continue neutron capture γ -ray and neutron induced γ -ray production measurements at WNR.
- (7) Continue R-matrix studies for polarized fusion reactions, particularly for $A=4$ system; improve models for prediction of particle emission spectra.
- (8) Complete variance-covariance, reaction-theory analysis for ${}^{11}\text{B}$ -reactions; update ${}^7\text{Li}$ evaluation for new measurements; and expand our calculations of activation and other data for structural materials.

Anticipated FY 1985 Results

- (1) Complete $D(t,\gamma)$ and $t+t$ charged-particle and neutron reactions. Consider extension to other charged particle and gamma-ray diagnostic reactions.
- (2) Complete $(t, \text{charged particle})$ and $(d, \text{charged particle})$ reactions for the lithium isotopes to incident particle energies of up to 6 MeV. Begin similar measurements extending to higher energies.
- (3) Continue neutron capture γ -ray and neutron-induced γ -ray production measurements.
- (4) Update R-matrix calculations for $A = 4, 5$ systems; incorporate new LANL experimental data; expand Fusion Data File.
- (5) Complete variance-covariance, reaction-theory analyses for ${}^{14}\text{N}$ and ${}^{16}\text{O}$.
- (6) Complete calculations for structural materials of interest to fusion applications.

Oak Ridge National Laboratory

Measurements and model development at ORELA have continued with emphasis on high-resolution gamma-ray production cross sections and neutron and gamma-ray emission measurements. A low-level effort is continuing to develop a capability to measure neutron-induced charged particle spectra. Work has also continued on development of evaluation tools useful for fusion energy problems. Development of methods to deal with uncertainties associated with experimental data is continuing.

I. Results Since October 1981 Meeting

A. Measurements

1. High resolution (n,xy) measurements have been made using a Ge(Li) detector from $E_n \sim 200$ keV to 40 MeV for $^{56,57}\text{Fe}$, nat, ^{58}Ni , nat, ^{53}Cr and ^7Li . The ^{57}Fe data are published, and ^{56}Fe data reduction is underway. Our system is sensitive to gamma rays from ≤ 100 keV to ~ 10 MeV; however, few gamma rays have been observed above ~ 5 MeV.
2. Neutron emission and gamma-ray production measurements for Mo up to 20 MeV were redone due to a hardware failure during the original run. The (n,xn) data are now available (ORNL/TM-8863).
3. A new detector system has been designed and is being tested for the neutron and gamma-ray emission measurements. It will provide angular as well as energy information for the emitted neutrons and gamma rays. It consists of an 80-cm-long quartz tube filled with NE213, and position of detection techniques are used to obtain the angular information.
4. A number of studies have been made of flight paths, detectors, ORELA power variation, resolution functions, etc., in order to more accurately specify uncertainties and correlations associated with our measurements. A series of reports resulting from these studies is in preparation.
5. Several approaches have been tried in an attempt to develop a system for (n,charged particle) measurements, all of which appear to be impractical due to count rate limitation. Another system is under design which will approach a 4π detector and forego angular resolution in an attempt to get an adequate count rate.
6. A larger diamond was acquired for the $^{12}\text{C}(n,\alpha)$ and $^{12}\text{C}(n,n'\alpha)$ measurement attempt. A number of tries were made to get data from which useful (understandable) information could be extracted, but we were unsuccessful and this effort has been dropped.
7. Data reduction was completed on $^{63,65}\text{Cu}(n,xy)$ and the results published.

B. Model Code Development

1. Our TNG model code has been further improved. In particular, a consistent treatment of pairing corrections in the level density formulas used in compound and precompound reaction theories of the code has been developed. A width fluctuation correction capability was added for the continuum part of binary reactions.
2. The GLUCS code for simultaneous evaluation of correlated cross sections has been partially rewritten to handle a larger number of input data with the same computer. A smoothing capability for the input correlation matrix and a new format for concise representation of cross-material correlations have been developed. The new format (LB=6) has been submitted to CSENG and approved for use in ENDF/B-5 Mod 2.

3. Implementation of advanced level density theorems in TNG has been given priority over the documentation for calculating angular distributions of particles emitted in the precompound mode of reaction because the latter can be better presented after the former.

II. Comparison of Present Status With That Anticipated in the 1981 Review.

The major delay is in progress in the (n,xn) and (n,xy) measurements using NE-213 scintillation detectors, due mainly to the loss of the person doing the measurements. Also, inadequate ORELA intensity has hindered attempts to fully test our new detector.

III. Anticipated Results - FY84

A. Measurements

1. Complete data reduction for ^{56}Fe , ^{58}Ni high-resolution gamma-ray measurements, and report results.
2. Complete testing of new neutron (and gamma-ray) emission detector and its associated hardware and software, and measure Ni.
3. Continue development work on (n,c.p.) detector system.

B. Model Development

1. Pairing effects on the spin cutoff parameters of particle-hole level densities will be published.
2. TNG capability for calculating angular distributions will be further tested with both 14-MeV and 25-MeV (n,xn) data using the newly developed level density formulas.

IV. Anticipated Results - FY85

A. Measurements

1. Complete data reduction for nat, ^{53}Cr and natNi high-resolution gamma-ray measurements, and report results.
2. Measure neutron and gamma-ray emission from Cr using new detector.
3. Continue efforts on (n,c.p.) system.

B. Model Development

1. The method used in TNG for calculating angular distributions of particles emitted in the precompound mode will be published.
2. Model code development will continue, with possible emphasis on capture gamma-ray yields and spectra using a precompound model.

OHIO UNIVERSITY

Cross section measurements at Ohio University are made with neutron beams produced by a 9 MeV tandem van de Graaff accelerator. Current research is principally in the areas of neutron elastic and inelastic scattering and neutron-induced charged-particle-producing reactions. Studies of light nuclei have yielded cross sections for various neutron-induced reactions which have been analyzed with R-matrix theory. Hauser-Feshbach calculations have been used to interpret (n,p) and (n, α) cross section measurements on medium-weight nuclei.

Results for FY82-83

A. Neutron Scattering Measurements and Analysis

1. R-matrix analysis of ${}^7\text{Li}$ system for $E_n \lesssim 4$ MeV completed. (Nucl. Phys. A403 (1983) 205).
2. Measurements of the ${}^6\text{Li}(n,t)\alpha$ differential cross section at $E_n = 2.0, 2.5, 3.0$ and 3.5 MeV have been completed.
3. An extension of the earlier ${}^7\text{Li}$ R-matrix analysis (A.1 above) to $E_n = 8$ MeV is currently underway. This new analysis includes the neutron elastic channel, two inelastic neutron channels, the ${}^6\text{Li}(n,t)\alpha$ channels and also examines mechanisms of the ${}^6\text{Li}(n,d)$ reaction.
4. Measurements of $\sigma(\theta)$ for ${}^{11}\text{B}+n$ elastic and inelastic scattering as well as an R-matrix analysis of the ${}^{12}\text{B}$ system have been completed (Nucl. Phys. A394 (1983) 221).
5. An R-matrix analysis of the ${}^{13}\text{C}$ system for $E_n \lesssim 9$ MeV including the neutron elastic and inelastic channel has been completed (Nucl. Phys. A378 (1982) 503).
6. The R-matrix study of the ${}^{13}\text{C}$ system (A.5 above) has recently been updated to include ${}^{12}\text{C}(\bar{n},n){}^{12}\text{C}$ polarization data for $E_n < 2$ MeV. Predictions for ${}^{12}\text{C}+\bar{n}$ analyzing powers have been made for $E_n < 9$ MeV.
7. Measurements of the ${}^{13}\text{C}(n,n){}^{13}\text{C}$, ${}^{13}\text{C}(n,n'){}^{13}\text{C}^*$ (3.09) and ${}^{13}\text{C}(n,n'){}^{13}\text{C}^*$ (3.68 and 3.85) $\sigma(\theta)$ have been made at 55 incident neutron energies from $E_n = 4.5$ to 11 MeV.
8. Differential elastic and inelastic ${}^{18}\text{O}^*$ (1.98 MeV) cross sections for ${}^{18}\text{O}+n$ have been measured at 11 angles for 37 energies for $5 \leq E_n \leq 7.5$ MeV. An R-matrix analysis of these data is now underway.
9. The Ohio University R-Matrix Analysis Code has undergone two updates: the code can now predict polarization for the neutron elastic channel and has been expanded to allow up to six particle channels in an analysis.

B. (n,z) Program

1. A new (n,z) spectrometer has been developed. It has a much increased counting rate over the quadrupole, but does have higher background for protons.
2. Cross sections for (n,z) reactions on ${}^{60}\text{Ni}$ have been measured at 8, 9.4 and 11 MeV.

C. Shell Model Calculations and Code Development

1. A new shell model code has been written and is currently being tested.
2. Calculations of the level density of ^{28}Si have been completed and published (Phys. Rev. C27 (1982) 2893).
3. Calculations of the level scheme of ^{16}O have been compared with experimental values to determine appropriate values for single particle energies and two-body matrix elements.

Anticipated Results

FY84

1. Complete new ^7Li system R-matrix analysis for $E_n \lesssim 8$ MeV.
2. Begin measurements of $^6\text{Li}(n,t)\alpha$ differential cross section for $E_n > 4.5$ MeV.
3. Begin R-matrix analysis of ^8Li including the $^7\text{Li}(n,t)$ reaction.
4. Begin preliminary work on $^{10}\text{B}+n$ R-matrix analysis in the "few" MeV region.
5. Complete analysis of $^{13}\text{C}(n,n)^{13}\text{C}$, $^{13}\text{C}(n,n')^{13}\text{C}^*$ (3.09) and $^{13}\text{C}(n,n')^{13}\text{C}^*$ (3.68 and 3.85) differential data for $E_n = 4.5$ to 11 MeV.
6. Begin R-matrix analysis of $^{13}\text{C}+n$ scattering data.
7. Continue shell model calculations on ^{14}C , ^{19}O and other light nuclei using an existing code VLADIMIR at LANL and the improved code CRUNCHER we are developing here.
8. Complete $^{18}\text{O}(n,n)^{18}\text{O}$ and $^{18}\text{O}(n,n')^{18}\text{O}^*$ (1.98 MeV) R-matrix analysis for $E_n \lesssim 7.5$ MeV.
9. Complete analysis of ^{58}Ni and ^{60}Ni (n,z) data and publish the results.
10. Initiate measurements on $^{63}\text{Cu}(n,z)$ at 8 and 9.5 MeV.

FY85

1. Complete all $^7\text{Li}+n$ work, measurements and analysis.
2. Complete $^7\text{Li}+n$ R-matrix study.
3. Begin $^{10}\text{B}(n,n')^{10}\text{B}^*$ differential cross section measurements.
4. Begin $^{10}\text{B}+n$ R-matrix analysis.
5. Complete R-matrix analysis of $^{13}\text{C}+n$ scattering data.
6. Extend $^{18}\text{O}+n$ elastic and inelastic differential cross section measurements to include higher-excitation groups and/or for $E_n \lesssim 5$ MeV and $E_n \gtrsim 7.5$ MeV.
7. Perform $^{63}\text{Cu}(n,z)$ measurements at 11 MeV. Begin $^{65}\text{Cu}(n,z)$ measurements.
8. Complete level density calculations for ^{27}Al and ^{26}Mg and compare with measurements, including (d,n) and (p,n) measurements made here.
9. Extend shell model calculations to nuclei near ^{14}C and ^{19}O .

ROCKWELL INTERNATIONAL

The objective of Rockwell International's BES program is to measure the fast-neutron total helium generation cross sections of several separated isotopes and their associated pure elements by high-sensitivity gas mass spectrometry. The results are intended for use both in the selection and assessment of fusion reactor materials and as primary experimental data for cross section evaluations and theoretical cross section model testing. Measurements made to date have been for materials irradiated by 14.8-MeV T(d,n) neutrons at the Rotating Target Neutron Source-I and -II (RTNS-I and -II) facilities at the Lawrence Livermore National Laboratory. This program is complementary to a DOE-Office of Fusion Energy program, in which integral helium production cross sections of selected pure elements, separated isotopes, and candidate fusion reactor alloys are being measured in other neutron environments used for fusion materials testing, including mixed-spectrum fission reactors and the Be(d,n) neutron field.

Results Since October 1981

Since the last BES program review, total helium generation cross section measurements for 14.8-MeV neutrons have been completed for ^9Be , Nb , ^{10}B , ^{11}B , NC , NiO , NF , NSi , NTi , ^{55}Mn , ^{59}Co , ^{89}Y , Nag , NTa , Npt , and Npb , plus a series of NLi , ^6Li , and ^7Li analyses based on irradiated LiF crystals. Most of these results have been reported in DOE-OFE Damage Analysis and Fundamental Studies Quarterly Progress Reports (DOE/ER-0046), and our previous results have been summarized in J. Nucl. Mater. A more detailed paper, presenting all of our 14.8-MeV cross section measurements to date, is nearly complete and will be submitted for publication shortly.

The ^6Li and ^7Li cross section measurements, based on ^6LiF and ^7LiF samples irradiated in experiments at RTNS-I (including one experiment performed jointly with LLNL) and RTNS-II, exhibit some inconsistencies and large scatter, and are also generally higher than current evaluations. These measurements have relatively large uncertainties (~15%), due primarily to the uncertainties associated with subtracting the large helium contribution from fluorine. A new joint Rockwell-LLNL RTNS-I irradiation has subsequently been performed using lead-encapsulated ^6Li and ^7Li metal samples. Analysis of this experiment is now in progress.

Helium analyses have also been performed for most of the separated isotopes of Ti and Cr. Cross sections have not yet been determined from these results, however, pending a measurement of the oxygen content of each material. Oxygen impurities in these isotopes must be determined because of the large helium production cross section of oxygen (400 mb) at 14.8 MeV.

A new high-sensitivity constant-temperature furnace has been designed and constructed for the analysis of large samples with low helium concentrations. A few internal modifications shown necessary by initial furnace tests have been made, and further testing is in progress.

Comparison of Present Status with that Anticipated in 1981

The helium generation measurement program anticipated in 1981 has had some modifications, due largely to additional irradiation experiments to measure the lithium cross sections, and a longer than expected development period for the constant-temperature furnace. The analysis of several RTNS-II-irradiated separated isotopes of Sn, W, and Pb, and planned irradiations in a new neutron energy spectrum, have been delayed until the new furnace is completed. Cross section determinations for the Ti and Cr isotopes have been delayed because of the need to investigate oxygen impurities in those materials.

Anticipated Results

A. FY 1984

Anticipated results for FY 84 include (1) completion of helium analyses and cross section determinations for the ^6Li and ^7Li metal samples irradiated in RTNS-I, (2) completion of analyses of the separated isotopes of Ti, Cr, Sn, W, and Pb irradiated in RTNS-II, and (3) irradiation of selected materials in a new (~8-14 MeV) neutron energy spectrum. Add-on experiments at RTNS-II are also planned, to investigate selected light elements, including nitrogen.

B. FY 1985

Anticipated results for FY 85 include the completion of helium analyses and cross section determinations for the irradiation experiments initiated in FY 84, and the continuation of total helium production cross section measurements for selected materials in new neutron energy spectra.

Triangle Universities Nuclear Laboratory

The TUNL program focusses on measurements and analysis of elastic and discrete-inelastic scattering cross sections using polarized and unpolarized neutrons. Neutrons in the energy range 8 to 17 MeV are obtained from the $^2\text{H}(d,n)$ reaction. Target nuclei cover the whole range of the periodic table.

Information

Information gained from TUNL research efforts in polarized neutron scattering, (p,n) reaction studies, and proton and neutron radiative capture experiments is incorporated into reaction model analyses of the neutron scattering data. This contributes to improved parameterizations and evaluations of experimental results obtained here and elsewhere.

Previous Results

A. Measurements--Neutron elastic and inelastic scattering cross sections in the 8 to 15 MeV energy range have been published for $^6,^7\text{Li}$, ^9Be , $^{10,^{11}}\text{B}$, $^{12,^{13}}\text{C}$, ^{16}O , ^{40}Ca , $^{54,^{56}}\text{Fe}$, $^{63,^{65}}\text{Cu}$. Measurements in the same energy range have been performed for ^{14}N , ^{27}Al , ^{28}Si , $^{58,^{60}}\text{Ni}$, ^{89}Y , ^{93}Nb , $^{116,^{120}}\text{Sn}$, ^{208}Pb and results have been reported at meetings. We have recently performed measurements at 17 MeV for all of this latter group of nuclei, as well as for ^9Be and $^{10,^{11}}\text{B}$.

Cross sections for incident beams of polarized neutrons have been measured for the bulk of the nuclei listed above. These results, normally termed analyzing powers, have been published for ^{12}C , ^{40}Ca , ^{54}Fe , ^{65}Cu . Such polarization data are used to constrain optical model parametrizations and resonance parameters.

The $^3\text{H}(p,n)$ breakup neutron cross sections from 9 to 14 MeV and cross sections for the intense neutron source reaction $^1\text{H}(^7\text{Li},n)$ have been published. Nucleon capture cross sections have been measured for the mass 3 and mass 4 systems.

B. Analyses--A global spherical optical model analysis of the 1-p shell nuclei has been published. Lane model consistent analyses of ^9Be , ^{13}C and ^{15}N for (n,n), (p,p), and (p,n) scattering have been published. Spherical and deformed optical model calculations have been made for ^{12}C , ^{40}Ca ,

$^{54,56}\text{Fe}$, $^{58,60}\text{Ni}$, $^{63,65}\text{Cu}$, $^{116,120}\text{Sn}$ and ^{208}Pb . These analyses have included results of the polarization measurements. Mott-Schwinger scattering and more flexible form factors have been incorporated into the global optical model code GENOA.

Comparison of present status with that anticipated in 1981 review

All optical model and Lane model analyses have been performed or are in progress. Some scattering data at 17 MeV were obtained and are being incorporated into these analyses.

The VAX installation of the Monte Carlo code for reducing continuum neutron emission spectra was completed. However the large corrections for the $T(p,n)$ continuum neutrons combined with large multiple scattering corrections make it unfeasible for us to extract accurate neutron emission cross sections down to 1 MeV from our measured time-of-flight spectra. The $T(p,n)$ source reaction does not appear to be useful for accurate continuum cross-section measurements for incident neutrons above 10 MeV.

Anticipated results FY 84-85

1. Deformed optical model analysis of neutron scattering from 1-p shell nuclei.
2. Extend Lane model analyses for ^9Be and $^{10,11}\text{B}$ to include new neutron cross section and analyzing power data.
3. Publish (n,n) and (p,n) cross section data for 1-p shell nuclei at 17 MeV.
4. Complete measurements and analyses for ^{14}N and ^{27}Al neutron scattering from 11 to 17 MeV.
5. Publish spherical and deformed optical model calculations and cross-section and polarization data for ^{28}Si , ^{32}S , $^{58,60}\text{Ni}$, $^{116,120}\text{Sn}$, ^{208}Pb .
6. Complete measurements of 17-MeV cross-section and polarization data for medium weight nuclei and incorporate into analyses.
7. Continue development work on high-energy chopper in order to improve timing of beam pulses and subsequently, the system resolution.
8. Complete new detector efficiency measurements.
9. Initiate neutron detector array development.
10. Investigate feasibility of using cyclotron injector for higher-energy cross-section measurements.

IV. BES-FUNDED PROGRAM

In this section the activities of the BES-supported facilities that address the nuclear data requests of the Office of Fusion Energy are discussed. The nuclear data measurement requests for magnetic fusion energy development, as given in Chapter 3 of Ref. 2, are reproduced in Table IV-1. We note in comments and footnotes on that table the measurements and/or pertinent theoretical calculations underway at BES facilities and other U.S. laboratories and the availability of suitable existing data. Nuclear data measurements requested for the Fusion Materials Irradiation Test facility are reproduced in Table IV-2 and our comments are given in the footnotes to that table. Finally the requests for data on near-term fusion fuels are addressed in Table IV-3.

Magnetic fusion energy program nuclear data needs as outlined in the GA Technology report GA-A16886 are quite extensive. Some of these needs are not being addressed by existing BES programs. Others are technically difficult. The following list gives details of these two areas:

1. Plasma diagnostic reactions $[Ti(\gamma, p), D + e^-, T + e^-]$ involve incident particles not used by BES experimenters.
2. The measurement of neutron emission for incoming monoenergetic neutron with energies between 8 and 13 MeV is quite difficult and accuracy better than 20% is probably not attainable. However, some USA groups are using white neutron sources for these studies both within and outside the BES program.
3. BES programs are not currently measuring activation and dosimetry reactions (except when involving total helium production). However,

other groups, e.g. the ANL-FNG group, are measuring a number of pertinent reaction cross sections with short-to-medium-lived products. A different ANL group is starting a pilot program measuring reaction cross sections having very long-lived products. Also some relevant information can be inferred from ORNL measurements of (n, γ) reactions combined with nuclear model calculations.

4. Integral experiments (such as benchmarks), kerma factor experiments, and sensitivity studies are not presently within the province of BES.
5. Although BES does support the development of tools for the evaluation process, BES does not support the performance of evaluations.
6. The processing of evaluated data lies entirely outside the scope of BES.

Table IV-1
NUCLEAR DATA MEASUREMENT REQUESTS FOR MAGNETIC FUSION ENERGY DEVELOPMENT
(Table 3-1 of Ref. 2)

Nuclide	Reaction	Energy Range of Incident Particle (MeV)	Accuracy (%)	Priority	Footnote	Status
⁷ Li	n,n'α	3 to 16	5	1	a,e	New measurements completed or planned by ANL, LLNL, and Rockwell-LLNL that address most of energy range.
⁹ Be	n,2n	1.9 to 16	5	1	b,e	Measurements to ±15% completed at LANL for 6, 10, 14 MeV. Official ENDF/B evaluation should incorporate. Planned scattering measurements at ANL should indirectly yield results.
⁹ Be	n,γ	0 to 16	20	2	c	No measurements planned at BES facilities.
¹⁰ B	n,p	9 to 16	20	2	e	No measurements planned at BES facilities.
¹⁰ B	γ production	0 to 16	20	2		Measurement in progress at ORNL.
¹¹ B	γ production	2 to 16	20	2		Measurements in progress at LANL and ORNL.
¹² C	n,Nem(E;En';θ)	9 to 16	10	1		Measurement to 10 MeV planned at ANL; 20% accuracy at best.
¹³ C	n,α	5 to 16	20	2		Measurement of α-spectra to 11 MeV planned at Ohio U.
¹⁶ O	n,Nem(E;En';θ)	9 to 16	20	1		No measurements planned at BES facilities.
¹⁶ O	n,α	2.3 to 16	10	1		Alpha-particle emission measured at LLNL at 14 MeV.
¹⁹ F	n,Nem(E;En';θ)	9 to 16	20	2		No measurements planned at BES facilities.
²⁷ Al	n,2n	13.6 to 16	20	2		No measurements planned at BES facilities.
natTi	γ,p	10 to 20	50	1		No measurements planned at BES facilities.

IV-1 Continued

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Status
V	n,Nem(E;En';θ)	9 to 16	10	2		Measurements being considered at ANL, ORNL. 20% accuracy at best.
V	n,xp	9 to 16	20	2		Measurement completed at LLNL (15 MeV), ANL to 10 MeV and 14 MeV in progress.
⁵⁰ V	n,2n	11.3 to 16	20	2		No measurements planned at BES facilities.
⁵¹ V	n,α	7 to 16	20	2		Measurement to 10 MeV and at 14 MeV in progress at ANL.
Cr	n,Nem(E;En';θ)	9 to 16	20	2		Measurement to 10 MeV planned at ANL. 20% accuracy at best. Measurement planned to 20 MeV at ORNL.
⁵⁹ Co	n,γ	2.5 to 16	20	1	c	Measurements already available should be reviewed.
⁵⁸ Ni	n,α	5 to 16	20	1		Spectrum measurement complete at 8 MeV (Ohio U.) and at 15 MeV (LLNL). Cross section can be inferred from (n,xy) measurement at ORNL.
⁵⁸ Ni	n,d	9 to 16	20	1		Same comment as above.
⁵⁸ Ni	n,p	1 to 16	20	1		Reliable data already exist.
⁵⁸ Ni	n,γ	0 to 16	20	1	c	Substantial data exist at lower energies.
⁶⁰ Ni	n,2n	13 to 16	20	1		No measurements planned at BES facilities.
⁶⁰ Ni	n,p	1 to 16	20	1		Substantial data already exist.
⁶² Ni	n,γ	0 to 16	20	1	c	No measurements planned at BES facilities.
⁶⁴ Ni	n,2n	13 to 16	20	1		No measurements planned at BES facilities.

IV-1 Continued

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Isotope	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Status
⁶³ Cu	n,α	6 to 16	20	1		Substantial data already exist.
⁶³ Cu	n,p	2 to 16	20	1		Spectrum measured at 15 MeV (LLNL). ANL will measure activation.
⁶³ Cu	n,γ	6 to 16	20	1	c	No BES measurements planned.
⁶³ Cu	n,2n	11 to 16	20	1		14-MeV measurement in progress (ANL).
⁶⁴ Zn	n,p	9 to 16	10 to 50	1		Already measured to ±15%; 14-MeV experiment in progress (ANL).
⁹³ Nb	n,α	5 to 16	20	2	f	Spectrum measured at 15 MeV (LLNL) - model calculations can extrapolate.
⁹³ Nb	n,2n	9 to 16	20	1		Nb-92m production has been measured.
⁹³ Nb	n,p	4 to 16	20	1	f	Spectrum measured at 15 MeV (LLNL). Model calculations can extrapolate.
⁹³ Nb	n,γ	0 to 16	20	1	c	Existing data should be reviewed.
⁹² Mo	n,p	9 to 16	20	1	f	15-MeV spectrum measured at LLNL. Models can extrapolate.
⁹² Mo	n,γ	0 to 16	20	1	c	Existing data should be reviewed.
⁹⁴ Mo	n,2n	9 to 16	20	1		No measurements planned at BES facilities.
⁹⁴ Mo	n,p	9 to 16	20	1	f	15-MeV spectrum measured at LLNL. Models can extrapolate.
⁹⁵ Mo	n,p	9 to 16	20	2	f	15-MeV spectrum measured at LLNL. Models can extrapolate.

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Status
⁹⁸ Mo	n,γ	0 to 16	20	1	c	Existing data should be reviewed.
Ta	γ production	0 to 15	20	2		Measurements completed at ORNL.
Ta	n, Nem(E; En ⁻ ; θ)	5 to 16	20	2		No measurements planned at BES facilities.
¹⁸⁰ Ta	n, p	1 to 16	20	2	d	No measurements planned at BES facilities.
¹⁸¹ Ta	n, γ	0 to 16	20	2	c	Existing data should be reviewed.
W	n, xp	9 to 16	20	2	d	No measurements planned at BES facilities.
W	n, xα	9 to 16	20	2	d	No measurements planned at BES facilities.
¹⁸⁰ W	n, γ	0 to 16	20	2	c	No measurements planned at BES facilities.
¹⁸² W	n, 2n	9 to 16	20	2		Existing data should be reviewed.
¹⁸⁴ W	n, γ	0 to 16	20	2	c	Existing data should be reviewed.
¹⁸⁶ W	n, 2n	9 to 16	20	2		Existing data should be reviewed.
¹⁸⁶ W	n, γ	0 to 16	20	2	c	Existing data should be reviewed.
Pb	n, 2n	6.8 to 16	5	1		No measurements planned at BES facilities.
²⁰⁴ Pb	n, 2n	9 to 16	20	2		No measurements planned at BES facilities.
²⁰⁶ Pb	n, α	9 to 16	20	2		Measurement in progress at Rockwell for (n, He) at 14.8 MeV.
²⁰⁴ Pb	n, γ	0 to 16	20	1	c	No measurements planned at BES facilities.
²⁰⁶ Pb	n, 2n	9 to 16	20	1		No measurements planned at BES facilities.

IV-1 Continued

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Status
^{232}Th	n,2n	11 to 16	20	2		Measurements completed (LANL).
^{232}Th	n,3n	11 to 16	20	2		Measurements completed (LANL).
^{238}U	n,3n	11 to 16	20	2		Measurement completed (LANL).

- a Reaction should be (n,xt).
- b Reaction should be n,Nem(E, E_n', θ).
- c Highest priority should be for the energy range thermal-2 MeV. Higher energy range can be addressed on a longer term, lower priority basis.
- d The request itself should be reviewed because cross sections appear too small (<10 mb) for practical importance and/or lead to stable products.
- e Data of reasonable accuracy available from non-U.S. laboratories. See CINDA.
- f The statement, "model calculations can extrapolate," means that state-of-the-art calculations can extrapolate existing data probably to the accuracy required. For high priority requests, or where high accuracy is desired, additional measurements to test the calculational results are essential.

Table IV-2

NUCLEAR DATA MEASUREMENT REQUESTS
FOR FUSION MATERIALS IRRADIATION TEST FACILITY
(Table 3-2 of Ref. 2)

Nuclide	Reaction	Energy Range of Incident Particle (MeV)	Accuracy (%)	Priority	Footnote	Comment (from Ref. 2)
^3He	n, p	2 to 30	10	3	a	Dosimetry.
		30 to 40	20	3		
^3He	$n, n'p$	E_T to 30	10	3	a	Dosimetry.
		30 to 40	20	3		
^3He	$n, 2p$	E_T to 30	10	3	a	Dosimetry.
		30 to 40	20	3		
^6Li	n, α	0 to 25	10	2	b	Dosimetry and damage calculation.
		25 to 40	20	1		
^{10}B	n, α	0 to 25	10	2	b	Dosimetry.
		25 to 40	20	2		
^{11}B	n, α	E_T to 25	10	3	b	Dosimetry (track recorder).
		25 to 40	20	3		
^{23}Na	$n, \text{Nem}(E; E_n'; \theta)$	15 to 35	15	2	a	Dosimetry calculation.
^{23}Na	n, γ	0.5 to 22	10	2	a	Activation.
^{23}Na	$n, 2n$	20 to 30	20	2	a	Dosimetry.
^{24}Mg	n, p	4.9 to 20	10	3	a	Dosimetry.
		20 to 40	20	3		
^{27}Al	$n, \text{Nem}(E; E_n'; \theta)$	15 to 35	10 to 40	2		Damage.
^{27}Al	$n, 2n$	15 to 30	20	2	a	Activation.
^{27}Al	n, xp	9 to 15	10	3	b	Damage.
		15 to 35	20	3		
^{27}Al	n, α	9 to 15	10	2	b	Damage.
		15 to 30	20	2		
					a	Damage, activation.

IV-2 Continued

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Comment
natK	n,Nem(E;En';θ)	10 to 40	15	2	a	Dosimetry.
39K	n,2n	15 to 30	20	2	a	Activation.
41K	n,p	15 to 30	20	2	a	Activation.
natTi	n,Nem(E;En';θ)	15 to 35	10 to 40	2		Damage.
46Ti	n,p	15 to 40	10	2	a	Activation.
natV	n,Nem(E;En';θ)	15 to 35	10 to 40	2		Shielding, damage.
natV	n,xp	9 to 15 15 to 30	20 20	3 3	b	Damage.
natCr	n,Nem(E;En';θ)	15 to 35	10 to 40	1	a	Dosimetry, damage.
natCr	n,xα	15 to 35	20	1	b	Damage.
52Cr	n,p	15 to 35	20	2	a	Activation.
52Cr	n,2n	15 to 35	20	2	a	Activation.
53Cr	n,3n	15 to 35	20	2	a	Activation.
54Cr	n,4n	15 to 35	20	2	a	Activation.
55Mn	n,2n	15 to 30	10 to 20	2	a	Dosimetry.
natFe	n,xp	9 to 15 15 to 40	20 20	2 2	b	Damage. Damage.
natFe	n,xα	15 to 40	20	2	b	Damage.
54Fe	n,p	20 to 40	10 to 20	1	a	Dosimetry.
54Fe	n,α	20 to 30	10 to 20	1	a	Dosimetry.
56Fe	n,p	15 to 30	20	2	a	Activation.
59Co	n,3n	E _T to 40	10 to 20	1	a	Dosimetry.
59Co	n,4n	E _T to 40	10 to 20	1	a	Dosimetry.
59Co	n,p	20 to 28	10 to 20	1	a	Dosimetry.

IV-2 Continued

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Comment
⁵⁹ Co	n,α	15 to 25 25 to 40	10 20	2	*	b Dosimetry.
natNi	n,Nem(E;En';θ)	15 to 35	10 to 40	1		Damage.
natNi	n,xp	9 to 15 15 to 40	10 20	2 2	b	Damage. Damage.
natNi	n,α	15 to 40	10	1	b	Damage.
⁵⁸ Ni	n,2n	20 to 30	10 to 20	1	a	Activation.
⁵⁸ Ni	n,3n	20 to 40	10 to 20	1	a	Activation.
⁵⁸ Ni	n,t	15 to 40	20	2	a	Dosimetry and activation.
⁶⁰ Ni	n,p	2 to 50	10 to 20	2	a,b,c	Activation.
⁶⁰ Ni	n,t	15 to 40	20	2	a	Dosimetry and activation.
⁵⁸ Ni	n,p	15 to 40	20	2	a	Dosimetry and activation.
natCu	n,xp	9 to 15 15 to 30	20 20	3 3	b	Damage.
natCu	n,α	9 to 15 15 to 30	20 20	2 2	b	Damage and activation.
⁸⁹ Y	n,2n	20 to 30	10 to 20	2	a	Dosimetry.
⁸⁹ Y	n,3n	20 to 35	10 to 20	2	a	Dosimetry.
⁸⁹ Y	n,p	20 to 30	10 to 20	2	a	Dosimetry.
natZr	n,x	20 to 40	20	3	a	⁸⁹ Zr production needed for FMIF dosimetry.
⁹⁰ Zr	n,3n	E _T to 50	10 to 20	3	a	Dosimetry.

IV-2 Continued

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Comment
^{93}Nb	n, n'	10 to 30	20	1	a	Dosimetry.
^{93}Nb	$n, 2n$	20 to 28	20	1	a	Dosimetry.
^{93}Nb	$n, \text{Nem}(E; E_n'; \theta)$	20 to 35	10 to 50	3	a	Damage.
^{93}Nb	n, xp	15 to 30	10 to 50	3	b	Damage.
^{93}Nb	$n, x\alpha$	15 to 35	10 to 50	3	b	Damage.
^{103}Rh	n, n'	10 to 30	20	3	a	Dosimetry.
natSn	$n, \text{Nem}(E; E_n'; \theta)$	15 to 35	10 to 40	3		Shielding.
natSn	n, xp	9 to 15 15 to 30	10 20	3 3		Damage.
natSn	$n, x\alpha$	9 to 15 15 to 30	10 20	3 3	b	Damage.
^{169}Tm	$n, 2n$	8 to 25	10 to 20	2	a	Dosimetry.
^{169}Tm	$n, 3n$	15 to 30	10 to 20	2	a	Dosimetry.
^{169}Tm	$n, 4n$	E_T to 40	20	3	a	Dosimetry.
^{169}Tm	$n, 5n$	E_T to 50	10 to 20	3	a	Dosimetry.
natW	$n, \text{Nem}(E; E_n'; \theta)$	15 to 35	20	3		Damage.
natW	n, xp	9 to 15 15 to 30	10 20	3 3		Damage.
natW	$n, x\alpha$	9 to 30	20	3		Damage.
^{197}Au	$n, 2n$	20 to 25	20	2	a	Dosimetry.
^{197}Au	$n, 3n$	20 to 40	20	1	a	Dosimetry.
^{197}Au	$n, 4n$	25 to 40	20	3	a	Dosimetry.
^{197}Au	$n, 5n$	30 to 40	20	3	a	Dosimetry.

IV-2 Continued

Nuclide	Reaction	Energy Range (MeV)	Accuracy (%)	Priority	Footnote	Comment
^{197}Au	n,x α	15 to 30	10	2	a,b	Dosimetry.
^{235}U	n,f	14 to 40	10 to 20	1	a	Dosimetry (track recorder).

- (a) BES programs are not currently measuring activation and dosimetry reactions (except when involving total helium production). However, other groups are measuring reaction cross sections with short-to-medium-lived products. One particular ANL group is starting a small program to measure reaction cross sections having very long-lived products. Also some information can be inferred from ORNL measurements of (n,x γ) reactions combined with nuclear model calculations.
- (b) Measured data at ~ 14.8 MeV exist from LLNL, and/or Rockwell International, or at other energies from Ohio University.
- (c) Substantial data exist at low energies.

Table IV-3
Cross Sections for Near-Term Fuels

Reaction	Comment
$t(d,\alpha)n$	A state-of-the-art experiment from 8-80 keV with absolute errors ranging from 1.4 to 4.8% has been completed at LANL. Improved accuracy is not feasible at present.
$t(t,\alpha)2n$, $t(t,n)\alpha$	Measurements are planned for 10-130 keV at LANL. Accuracies for the (t,α) and (t,n) reactions are anticipated to be $\pm 5\%$ and $\pm 10\%$ respectively.
$d(d,^3\text{He})n$ and $d(d,p)t$	Measurements of both reactions are complete at LANL for the energy range 20 to 117 keV with absolute errors ranging from 2 to 4%.
$d(\alpha,\alpha)d$ and $t(\alpha,\alpha)t$	Facilities exist at LANL to obtain these data but direct measurements are not planned at present. Existing data and R-matrix analysis results should be reviewed.

V. CONCLUSIONS AND RECOMMENDATIONS

The task of this group, as in the past three meetings, was to assess the current OFE nuclear data requests from the perspective of basic nuclear data measurements. We find that progress continues to be made by BES-sponsored laboratories in meeting requests for measurements. This progress is summarized by laboratory in Section III and by reaction in Section IV. Relevant contributions are also being made by other U.S. laboratories and by foreign institutions. Measurements now exist which address many of the OFE data requests, and the measured data are available for the evaluation process. Several of the remaining data requests are experimentally difficult, and we are pleased to report that every participating laboratory reported new techniques and new capabilities to address these more difficult data needs as well as the new data-measurement requests which continue to be received.

There are some areas, however, that are not being addressed by the BES program, and these are also summarized in Section IV. Most of the problems not being addressed are either (a) considered to be outside the domain of BES (e.g., integral studies, evaluations), or (b) requests for measurements for which appropriate experimental facilities are not available at the BES laboratories.

For the first time, representatives of facilities funded by agencies other than BES were invited to attend this coordination meeting and report on non-BES nuclear data measurement work relevant to OFE needs being performed at their laboratories. Some of this work is outlined in Appendix B.

We are pleased to note that following a recommendation from the 1981 BES meeting, a dialogue has been established between OFE and BES through a program at GA Technologies which assesses and updates the Magnetic Fusion Energy

program Nuclear Data Needs. Data assessment work at the present meeting was therefore based on a GA document (GA-A16886, October 1982)² which is an extended and revised version of OFE lists used in previous meetings.

It was clearly pointed out at this meeting by the OFE-supported coordinator that measurement of a requested cross section does not necessarily meet the "OFE requirement" for that nuclear datum. This program has been successful in meeting requests for measured nuclear data, but its success may not be evident to the user of cross section data. The user requires evaluated and processed cross sections, which can be directly used in design codes. While the BES program provides theoretical models in addition to the measured data for evaluation work, the responsibility for the actual evaluation and processing of the data lies with other programs.

The evaluation and processing steps require further time and effort. ENDF/B and other cross section evaluations are normally performed on a multiple-year cycle (~5 years for ENDF/B), and the re-evaluations are performed mainly for the materials of highest current interest to the fast breeder program (the major sponsor of ENDF/B in the past). Evaluations of other materials are carried from one evaluation cycle to the next. Thus, new measurements can take several years to impact evaluated data files. A recommendation for OFE-sponsored evaluation and processing for materials important to their work was included in our 1979 and 1981 meeting reports, and we are pleased to note that OFE has initiated a program which will begin to meet these needs. We are encouraged that this program will enable the data measured by the BES program and elsewhere to reach the user in a more timely manner. An increase in the OFE evaluation/processing effort would further reduce the time lag between measurement of the data and their availability to the user.

We recommend that the future GA Technologies documents contain information on the status of a data request. Previous requests that were satisfied should also be included. This information would inform the user as to whether a measurement had been made, and if completed, whether it was incorporated in an evaluation, processed and ready for use. It should also reduce the problem of a measurement request appearing, being satisfied and removed from the list, and then reappearing because a user does not have the data in a usable form. Some members of the BES group are familiar with evaluation work as well as measurements and would be willing to assist in developing this status information.

In large part, the ability of BES-funded programs to meet OFE data requests in a timely fashion is a result of the fact that most of the facilities were already in existence and supported by other funding agencies before the BES Program began. The success of the present program depends on continued support of the existing experimental facilities, many of which continue to be funded mainly by these other agencies.

It is recommended that the fifth BES review meeting take place two years from now. For this meeting, we recommend that the OFE, working together with BES, establish a clear distinction between basic nuclear data needs and evaluation/processing requirements, and continue to strive for a close working relationship for the transfer of nuclear data requests and results.

REFERENCES

1. Office of Basic Energy Sciences Program to Meet High Priority Nuclear Data Needs of the Office of Fusion Energy, 1981 Review, October 27, 1981, Lawrence Livermore National Laboratory (unpublished).
2. E. T. Cheng et al., "Magnetic Fusion Energy Program Nuclear Data Needs, Annual Report for Fiscal Year 1982," GA-A16886, GA Technologies (1982).

Appendix A

DOE - BASIC ENERGY SCIENCES MEETING

September 28-29, 1983

ATTENDEES

Robert C. Haight	LLNL	- Chairman
Duane C. Larson	ORNL	- Scientific Secretary
Richard L. Walter	TUNL/Duke	
Phillip G. Young	LANL	
Frederick M. Mann	HEDL	
Chris Gould	TUNL/NCSU	
Stanley Whetstone	DOE/DNP	
Donald L. Smith	ANL	
Philip F. Rose	BNL	
Oren A. Wasson	NBS	
Dennis W. Kneff	Rockwell International	
E. T. Cheng	GA Technologies, Inc., San Diego	
Paul W. Lisowski	LANL	
Steven M. Grimes	Ohio Univ.	
Charles W. Reich	INEL	
Russell L. Heath	INEL	
J. Kirk Dickens	ORNL	
David M. Hetrick	ORNL	
Francis G. Perey	ORNL	

Appendix B

THE ANL FUSION NUCLEAR-DATA PROGRAM RECENT PROGRESS

For more than a decade the ANL nuclear-data effort has responded to fusion-data needs through a program of measurements, calculations and evaluations. This activity has yielded a large body of information, e.g., the initial resolution of the ^7Li tritium-breeding discrepancy, the generation of activation and reaction data, and the provision of a number of relevant ENDF evaluations. This coordinated measurement, interpretation and evaluation effort continues with current emphasis as follows:-

A. Energy-Averaged Neutron Total Cross Sections

These quantities are essential for evaluations, for model development, and for verifying the internal consistency of partial cross sections. Despite this importance they are frequently very uncertain or simply unknown over large energy regions. Therefore, energy-averaged neutron total cross sections are routinely measured by this Group in order to complement our determinations of partial cross sections and our evaluation effort. The experimental accuracy is nominally 1% and the energy range approximately 50 keV to 20 MeV, i.e., the region of major fusion interest. Recent results (ANL/NDM-80, in press) include: C, Sc, Zn, Cu, Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, In, Sn, Sb, Nd, Hf, Pt, Ta, Au, Th, ^{233}U , ^{235}U , ^{238}U , ^{239}Pu and ^{240}Pu . These values are now being employed in model interpretations and evaluations (e.g. ANL/NDM-74).

B. Fusion Activation Data

Many fusion-data needs are in the area of activation cross sections (E. Cheng et al., GA-A16886). Studies of such processes have long been pursued in a comprehensive manner by this Group, with particular attention to achieving good accuracies and quantifying the associated uncertainties. This effort is expanding. We are generally starting with precise determinations of 14 MeV values and then extending over the entire energy range of interest (threshold to 20 MeV). Illustrative reactions involved in this program are: $^7\text{Li}(n;n',t)\alpha$, $^{27}\text{Al}(n;p)^{27}\text{Mg}$, $^{27}\text{Al}(n;\alpha)^{24}\text{Na}$, $^{28}\text{Si}(n;p)^{28}\text{Al}$, $^{46}\text{Ti}(n;p)^{46}\text{Sc}$, $^{47}\text{Ti}(n;p)^{47}\text{Sc}$, $^{48}\text{Ti}(n;p)^{48}\text{Sc}$, $^{51}\text{V}(n;p)^{51}\text{Ti}$, $^{51}\text{V}(n;\alpha)^{48}\text{Sc}$, $^{52}\text{Cr}(n;p)^{52}\text{V}$, $^{55}\text{Mn}(n;2n)^{54}\text{Mn}$, $^{55}\text{Mn}(n;\alpha)^{52}\text{V}$, $^{54}\text{Fe}(n;p)^{54}\text{Mn}$, $^{56}\text{Fe}(n;p)^{56}\text{Mn}$, $^{59}\text{Co}(n;p)^{59}\text{Fe}$, $^{59}\text{Co}(n;2n)^{58}\text{Co}$, $^{59}\text{Co}(n;\alpha)^{56}\text{Mn}$, $^{58}\text{Ni}(n;p)^{58}\text{Co}$, $^{58}\text{Ni}(n;2n)^{57}\text{Ni}$, $^{65}\text{Cu}(n;p)^{65}\text{Ni}$, $^{65}\text{Cu}(n;2n)^{64}\text{Cu}$, $^{64}\text{Zn}(n;p)^{64}\text{Cu}$, $^{64}\text{Zn}(n;2n)^{63}\text{Zn}$, $^{113}\text{In}(n;n')^{113\text{m}}\text{In}$ and $^{115}\text{In}(n;n')^{115\text{m}}\text{In}$. All flux determinations are based on the ^{238}U fission cross section (INDC-36/LN). This work addresses an important tritium breeding reaction, $^7\text{Li}(n;n',t)\alpha$, with the aim of achieving accuracies consistent with stated fusion needs (M. Abdou, Antwerp Conf.). The $^{51}\text{V}(n;p)$ and $(n;\alpha)$ studies are particularly well along, and results to 10 MeV for $^{51}\text{V}(n;p)$ will be reported at the forthcoming APS Nucl. Phys. Div. Meeting. They should help to alleviate the uncertainties in present evaluations (e.g., S. Tanaka, JAERI-M-82-151) resulting from the absence of $^{51}\text{V}(n;\alpha)$ data below 10 MeV and $(n;p)$ data below 13 MeV. Both of these energies are well above the reaction thresholds.

C. Neutron Scattering and Emission

For approximately twenty years, this program has advanced toward higher energy: first to 1.5 MeV, then to 4-5 MeV, and now up to 10 MeV. This capability covers a large part of the total energy range of fusion interest. The measurement targets include the large majority of elements, and accuracies of a few percent or better with an energy mesh of 0.1 to 0.5 MeV are achieved. Attention is first given to direct processes (e.g. elastic and direct inelastic scattering), then to compound-nucleus inelastic-scattering cross sections, and finally to angle-energy continuum distributions. The current measurement program treats C, Ca, Cr, Fe, ^{58}Ni and Y targets up to 10 MeV and other elements are rapidly being added to this list. A comprehensive review of results to 4-5 MeV, covering a wide range of targets, is in press (Nucl. Phys.). Measurements have been made using the time-of-flight technique with 5-6 m flight paths. A "Stonehenge" system is now being installed, providing massively shielded flight paths of 18 m for selected high-resolution measurements. This new apparatus also has the potential for precise spectroscopy of the "exotic" fusion-fuel reactions (e.g. precise (p;n) studies), with resolutions previously not readily achieved.

D. Models and Calculations

Our experimental results are routinely interpreted using contemporary nuclear models. Recent endeavors have been directed toward the understanding of nuclear absorption effects in the regions near and between shell closures, and correlation with the "anomalous" absorption noted in (p;n) studies (to be published in Nucl. Phys.). Such interpretations are made possible by the availability of efficient optical, compound-nucleus, and coupled-channels codes in our Group which provide an excellent (and possibly unique), capability for direct fitting of experimental data (BAPS 28, 688 (1983)).

E. Evaluation

The experimental and calculational results are followed through to our evaluation effort in order to obtain contemporary versions of ENDF files suitable for direct utilization in fusion-system calculations. This Group bears a lead national responsibility of providing evaluations for several elements included in ENDF. At present, niobium and cobalt evaluations are in progress, and these make extensive use of recent experimental results from this Group. In these two cases, as well as for others, we are updating evaluations completed by this Group more than a decade ago. Throughout, careful attention is being given to quantitative uncertainty specification (ANL/NDM-62 and 67).

Applied Nuclear Physics Section, Applied Physics Division, Argonne, 9/83.

HANFORD ENGINEERING DEVELOPMENT LABORATORY

The program at HEDL, supported by the Office of Fusion Energy, is directed toward meeting immediate needs of the Fusion Materials Irradiation Test (FMIT) facility and of the Reactor Technologies Branch of the Office of Fusion Energy.

HEDL has supplied much of the data needed for the design of FMIT. The neutron emission data from $d + Li$ were measured using thick lithium targets. Activation reactions induced by deuterons on various thick elemental targets were also studied. Neutron emission data from $d + Cu$ and $d + Au$, transport cross sections, and activation cross sections have been supplied.

Data supplied in support of the Reactor Technology Branch include a $^{59}Ni + n$ evaluation, activation and transmutation reaction evaluations, as well as data processing.

Capabilities include operation of advanced nuclear model codes, evaluation of nuclear data, and processing of evaluations. Integral measurements of FMIT-related data should occur in FY84 or FY85.