MEETING REPORT

SUMMARY OF THE INTERNATIONAL CONFERENCE ON NUCLEAR DATA FOR BASIC AND APPLIED SCIENCE, SANTA FE, NEW MEXICO, MAY 13–17, 1985

INTRODUCTION

Approximately 350 participants from 39 countries attended the 1985 International Conference on Nuclear Data for Basic and Applied Science. The overall objective of the conference was to review all aspects of nuclear data measurement, calculation, and usage in nuclear technologies. This meeting, like its predecessors, served as a forum for information exchange between theorists, experimentalists, and evaluators involved in basic nuclear activities, and scientists whose major interest is the utilization of nuclear data in applied nuclear technology.

The program consisted of 41 invited papers, 76 oral contributions, and ~190 contributed posters distributed among 12 major subject areas. Of these, some 60 to 70 papers either dealt directly with nuclear data for fusion reactors or were in related areas that impact nuclear data acquisition for fusion applications. The present report reviews the most significant aspects of these fusion-related papers.

ASSESSMENT OF NUCLEAR DATA NEEDS

A major review paper in the fusion area was given by Y. Gohar [Argonne National Laboratory (ANL)] and is particularly recommended for an overview of nuclear data needs for fusion reactors. A number of other papers dealt with more specific data needs, and several of these are highlighted below.

TRITIUM BREEDING AND FUSION BLANKET STUDIES

As summarized in Gohar's review, problems of the first wall and subsequent blanket elements have become critical elements in fusion reactor design. Nature has arranged the properties of materials such that it is difficult to design an efficient heat removal system that also provides a tritium breeding ratio (TBR) significantly greater than 1.0. New tritium production measurements in lithium assemblies were described in a review paper by Takahashi (Osaka University). Prominent among the experiments reported were tritium measurements in ^{6}Li and ^{7}Li carbonate pellets located in a 120-cm-diam natural lithium sphere that was irradiated at the center by 14-MeV neutrons from the OKTAVIAN facility at Osaka University. Also reported were similar measurements made in a 60-cm-thick Li_2O cylindrical assembly by Maekawa et al. [Japan Atomic Energy Research Institute (JAERI) Fusion Neutronics Source (FNS) facility], using $^{6}Li_2O$ and $^{7}Li_2O$ pellets. In both cases the measured values were compared to calculations using the ENDF/B-IV and JENDL-3PR1 evaluated data bases. Tritium production was overpredicted by ~20% in the ^{7}Li pellets using the ENDF/B-IV data, and by a few percent in the ^{6}Li pellets. For both ^{6}Li and ^{7}Li, calculations with the JENDL-3PR1 and preliminary ENDF/B-V data agreed better with experiment than did calculations with ENDF/B-IV.

Qaim et al. (Kernforschungsanlage, Jülich) reported on advances in both measurement and calculations of (n, charged-particle) reactions, in particular, tritium and helium production. Calculations of tritium breeding using ENDF/B-V-based multigroup libraries {Cheng [GA Technologies, Inc. (GA)] and Huang (Sichuan)} gave consistent results except for certain "leaky" blankets and systems that are not ^{6}Li dominated. In extensive calculations, the King Saud University group (Riyadh) studied a variety of integral neutronic properties for fusion-fission hybrid blankets in cylindrical geometry. The importance of ^{233}U production and the advantage of tritium production in $d + d$ plasmas were emphasized.

NEUTRON LEAKAGE SPECTRUM MEASUREMENTS

Recent measurements of neutron leakage spectra from lithium assemblies in Japan were summarized in Takahashi's review as well as in several contributed papers. Of particular interest were leakage neutron spectrum measurements from 40- and 120-cm-diam lithium spheres using 14-MeV neutrons in the OKTAVIAN facility, with measurements being made both external and internal to the larger sphere. Pulse-height unfolding and neutron time-of-flight (TOF) techniques were used for the leakage spectrum measurements. A similar experiment utilizing pulse-height unfolding was reported by Sekimoto et al. using a lithium fluoride rectangular assembly. Additionally, angle-dependent spectra of neutrons leaking from the central area of cylindrically arranged Li_2O blocks (from 5 to 40 cm thick) were measured by the TOF method by Maekawa et al. (JAERI, FNS).

Included in most of the above papers were calculational analyses of the neutron leakage experiments using the ENDF/B-IV and JENDL-3PR1 (or JENDL-3PR2) evaluated nuclear data libraries, and inferences were drawn regarding the status of the cross-section data, particularly neutron energy spectra resulting from ^{7}Li(n,$n't$) and ^{7}Li(n,2n) reactions. Calculations with both data evaluations were found to differ significantly from the leakage spectra measured for the thick assemblies, particularly at neutron emission energies below 3 MeV and between 5 and 11 MeV. Calculated spectra for thin assemblies agreed better with experiment, although the JENDL data were more consistent. In a paper by Shin and collaborators [University of California, Los Angeles (UCLA)], leakage spectra measurements with a 5-cm-thick Li_2O cylinder at the FNS facility at JAERI were calculated using the latest ENDF/B-V (revision 2) data file. The comparisons with experiment were much better than those using ENDF/B-IV data, although a need for additional improvements was noted.

Leakage neutron spectra measurements were reported by Kimura et al. for silicon and copper spherical piles, using the KURRI electron Linac and a lead target at the center of the piles as a neutron source. The measured spectra were compared with ones calculated from the ENDF/B-IV and JENDL-2 evaluated data bases.

The Swiss LOTUS facility for one-dimensional slab assemblies was also used by Haldy et al. to measure leakage neutron spectra from slabs of stainless steel, beryllium, lead, and graphite, using the pulse-height unfolding technique. Gross agreement with spectra calculated from neutron cross sections in the ENDF/B-IV library was reported, although significant differences are evident in the comparisons at some secondary neutron energies.

REACTION RATE MEASUREMENTS

Maekawa et al. (JAERI, FNS) performed reaction and fission rate measurements with the Li_2O cylindrical assembly configured to be 60 cm thick. Fission rates were determined for ^{235,238}U, ^{237}Np, and ^{232}Th using microfission chambers. The foil activation method was employed to measure reaction rates of the ^{27}Al(n,α)^{24}Na, ^{58}Ni(n,2n)^{57}Ni, ^{115}In(n,n')^{115m}In, and ^{115}In(n,γ)^{116}In reactions. Calculated reaction rates for ^{27}Al(n,α)^{24}Na with ENDF/B-IV gave somewhat better agreement with experiment than did calculations with the JENDL-3PR1 data base, with similar results for the ^{238}U fission rate.

NEUTRON MULTIPLICATION EXPERIMENTS

Because of the trend toward use of thermal blankets in fusion reactor designs, there have been new measurements of flux attenuation in thick lead layers and neutron multiplication factors for beryllium and lead, and some of these were described at the conference.

Neutron leakage spectra from lead shells (3 to 12 cm thick) were measured for 14-MeV source neutrons by the TOF method at the OKTAVIAN facility by Takahashi. Comparisons of the leakage spectra with ones calculated from the lead evaluation in ENDF/B-IV indicate the calculated values are significantly low at leakage neutron energies between 0.5 and 13 MeV, in agreement with the Swiss LOTUS results described above. By integrating the absolute leakage current spectra, overall leakage multiplication factors were obtained that could be compared to calculated values. It was found that the multiplication factors calculated with ENDF/B-IV were too low by 10 to 12%, whereas values calculated with ENDF/B-V agree within the errors of the experiment. A sensitivity analysis was used to infer a value for the Pb(n,2n) cross section at 14 MeV that was consistent with the measurements. Qualitatively similar results were obtained in Bulgarian measurements by Antonov et al. of the attenuation of 14-MeV neutrons in lead layers of varying thickness (2.5 to 12.5 cm).

BENCHMARK CALCULATIONS

In addition to the benchmark measurements described above, several calculations were presented that are candidates for computational benchmarks in fusion neutronics. In a presentation by Sawan (University of Wisconsin) and Cheng (GA), several candidate benchmark problems were proposed for nuclear data library comparisons, representing self-cooled 17Li-83Pb and helium-cooled lithium, Li_2O, and 17Li-83Pb blankets. Each of the blankets was modeled in one-dimensional cylindrical geometry with a uniform 14.1-MeV isotropic neutron source in the plasma zone. Calculations using different multigroup data libraries and codes were compared against continuous energy Monte Carlo results. The calculations indicate that the sensitivity of the TBR to group structure and weighting spectrum increases as thickness or ^{6}Li enrichment decrease, with up to 20% effects being found for thin, natural 17Li-83Pb blankets.

Calculational benchmark candidates were described by Youssef et al. (UCLA), showing the effects of Legendre order in neutron scattering cross sections, different multigroup libraries, differences between ENDF/B-IV and -V, and variations in results between various Monte Carlo and discrete ordinates codes. Discrepancies of up to 20% in tritium production from ^{7}Li were found for ENDF/B-IV and -V, and differences of ~4% were found due to the group structures of the particular libraries that were used. The MCNP and VIP Monte Carlo codes were found to give results in good agreement, but MORSE calculations were only consistent for high threshold reactions.

A calculational study of the LOTUS hybrid facility was presented by Pelloni and Cheng, showing the effect of self-shielding on tritium breeding and thorium capture for different designs, codes, and evaluated data libraries.

FUSION NUCLEAR DATA FOR CHARGED-PARTICLE REACTIONS

Charged-particle data (in this case where both the target nucleus and beam particle are charged) are of importance in several ways: for the basic fusion fuel reactions, for secondary charged-particle reactions in the plasma or first wall and breeding blanket, for diagnostic techniques, and for various auxiliary items such as the production of intense neutron beams for materials testing. The highlight of charged-particle measurements at the conference was the accurate work of Brown and coworkers [Los Alamos National Laboratory (LANL)] who measured absolute cross sections of the basic fusion reactions $^2H(t,\alpha)n$, $^2H(d,p)T$, $^2H(d,^3He)n$, and $^3H(t,\alpha)nn$ to accuracies of 1.4 to 4% for a bombarding energy range of 10 to 120 keV, roughly corresponding to a plasma temperature range of 1 to 30 keV. This work has resolved several previous discrepancies and is more accurate than will be needed in the foreseeable future. In combination with the R-matrix calculations of Hale and Dodder (LANL), cross sections for other energies or temperatures can be reliably predicted.

An example of the use of charged particles for fusion plasma diagnostics was given by Lovberg et al. (Princeton Plasma Physics Laboratory), who detected the 3-MeV proton from the $^2H(d,p)T$ reaction in the Princeton Large Torus to measure the ion temperature profile in a fairly thin plasma. The utility of the method is based on the strong temperature dependence of the $d + d$ reaction rate (T^4) and provides an attractive passive diagnostic method. As the density of plasma increases, this method will probably yield to the detection of neutrons and very high-energy gamma rays.

TOTAL AND DIFFERENTIAL NEUTRON CROSS-SECTION DATA

Several new measurements of elastic and inelastic neutron scattering and of gamma-ray production cross sections for structural and blanket materials were reported. Most of the data were reasonably well represented by accompanying optical and/or statistical model calculations.

D. Larson [Oak Ridge National Laboratory (ORNL)] presented high resolution gamma production cross sections for chromium, nickel, and iron for incident energies in the range $0.2 \leq E_n \leq 40$ MeV. He concluded that gamma production for even-even nuclides in this region comes mainly from de-excitation of the first excited 2^+ level, and emphasized determination of cross sections for tertiary reactions and total neutron inelastic scattering from the high resolution measurements. Similar measurements with lower resolution for tantalum and beryllium were reported by Gould [North Carolina State University (NCSU)] and collaborators, obtained with incident neutrons over a broad energy range at the Weapons Neutron Research (WNR) facility in LANL.

Hansen [Lawrence Livermore National Laboratory (LLNL)] reviewed measurements of nucleon scattering on a variety of targets from ^9Be to ^{239}Pu at energies up to 65 MeV that were analyzed with two local, microscopic optical potentials. Of particular interest for fusion were measurements at 14.6 MeV for some 16 targets. In general, the microscopic potentials are better able to follow variations in mass and energy than are global phenomenological potentials, with the potential of Jeukenne, LeJeune, and Mahaux giving overall a more satisfactory description of the data than that of Brieva and Rook. A topic raised in this review was covered in more detail in a contribution by Murphy et al. [Triangle Universities Nuclear Laboratory (TUNL)] on the success of the Lane model isospin-conserving term in the optical potential describing nucleon scattering and reactions on ^{10}B and ^{11}B.

Smith (ANL) and collaborators reported new measurements and evaluations for the fast neutron cross sections of niobium that differ significantly in some cases from those in ENDF/B-V. Marcinkowski and collaborators in Poland presented measurements and calculations of (n,p), (n,α), and $(n,2n)$ reactions on molybdenum isotopes at neutron energies between 13 and 17 MeV.

DOUBLE DIFFERENTIAL NEUTRON EMISSION DATA

Neutron emission spectra near 14 MeV for shielding and blanket materials are important nuclear data for fusion reactor designs. Several new measurements of double differential cross sections for fusion materials were reported at the conference.

Rather complete spectra at 6 angles for $^7Li(n,xn)$ reactions were given by Dekempeneer et al. (Geel). The results agreed well with the JENDL-3 evaluation, but not with version 1 of the Joint Evaluated File (JEF-1).

Drosg et al. (LANL) reported absolute double differential cross sections for ^{10}B and ^{11}B at 6 and 10 MeV, respectively, and for ^6Li, ^7Li, ^{10}B, ^{11}B, and ^{12}C at 14 MeV. Monte Carlo multiple scattering corrections using ENDF/B-IV cross sections revealed inconsistencies with the new measurements, especially for ^{11}B.

Antolković et al. (Zagreb) measured angular correlations in the $^{12}C(n,n')3\alpha$ reaction at 18 MeV in order to deduce angular distributions for steps of the sequential decay to three alphas through the 9.63-MeV level in ^{12}C, and for inelastic scattering to definite bins of excitation energy in ^{12}C. Alpha-particle spectra for the $^7Li(n,\alpha)$ reaction near 14 MeV were also reported from Zagreb in an experiment to locate the position and width of the ground state of ^4H.

Elastic scattering cross sections and neutron emission spectra for aluminum, copper, and lead at neutron energies between 3 and 14 MeV were given by Gul et al. (Nilore, Pakistan).

Data from an extensive program at Tohoku University, Japan, to measure double differential cross sections for fast neutrons on light elements were reported for ^6Li and ^7Li by Chiba et al., and for ^{10}B, ^{11}B, carbon, nitrogen, oxygen, fluorine, and silicon by Baba et al. The new measurements indicate some deficiencies in the present ENDF/B and JENDL evaluated spectra, pointing to the need for a new ENDF evaluation for ^{11}B, and a better accounting for energy-angle correlations than is allowed by the JENDL constant temperature representation. Spectra for the $Pb(n,xn)$ reaction shown by Iwasaki et al. did not agree with the ENDF/B-IV evaluation, but could be reproduced rather well by multistep Hauser-Feshbach calculations including precompound effects.

NEUTRON ACTIVATION DATA

Differential Measurements

A number of new measurements of activation cross sections were reported at the conference. Pepelnik et al. (GKSS Research Center, Federal Republic of Germany) described an extensive data set with measurements for ~50 different reactions being reported at 14.7-MeV neutron energy with accuracy ±5%. Similarly, some 20 reactions at this energy were reported measured by Meadows et al. (ANL), with uncertainties in the range of 2 to 5% and with evaluations being performed for most of the reactions. Included in these two experiments at 14.7 MeV were the following reactions and target isotopes:

(n,p): ^{27}Al, ^{41}K, ^{42}Ca, ^{43}Ca, ^{44}Ca, ^{46}Ti, ^{50}Ti, ^{51}V, ^{52}Cr, ^{53}Cr, ^{56}Fe, ^{59}Co, ^{65}Cu, ^{64}Zn, ^{68}Zn, ^{70}Zn, ^{90}Zr, ^{91}Zr, ^{92}Zr, ^{94}Zr, ^{110}Cd, ^{111}Cd, ^{114}Cd, ^{116}Cd

(n,α): ^{27}Al, ^{41}K, ^{44}Ca, ^{45}Sc, ^{51}V, ^{54}Fe, ^{59}Co, ^{90}Zr, ^{94}Zr, ^{93}Nb, ^{138}Ba

$(n,2n)$: ^{39}K, ^{48}Ca, ^{45}Sc, ^{50}Cr, ^{55}Mn, ^{59}Co, ^{65}Cu, ^{64}Zn, ^{90}Zr, ^{96}Zr, ^{127}I, ^{138}Ba, ^{238}U

(n,n'): ^{111}Cd, ^{136}Ba, ^{137}Ba

$(n,n\alpha)$: ^{51}V, ^{93}Nb.

In other experiments the (n,p) cross section on ^{59}Co was measured between 13.5 and 19 MeV to approximately ±5 to 7% accuracy (Hasan et al. and Williams et al.); the $(n,2n)$ cross section on ^{63}Cu and ^{65}Cu at 14.8 MeV to ~3% (Ghanbari and Robertson); and the $(n,2n)$ cross section on ^{58}Ni, ^{59}Co, ^{90}Zr, ^{93}Nb, and ^{197}Au between 13.5 and 15 MeV to ~5% (Ikeda et al.).

Greenwood (ANL) gave a summary description of measurements for 22 different reactions at the Rotating Target Neutron Source-II at LLNL, with neutron energies ranging between 14.5 and 14.9 MeV. The largest differences with ENDF/B-V evaluations were found for (n,p) reactions on ^{59}Co, ^{58}Ni, and ^{60}Ni; the ^{58}Ni$(n,2n)^{57}$Ni reaction; and the Ti$(n,x)^{47}$Sc reaction. Of particular interest were the measurements reported for the ^{27}Al$(n,2n)^{26m}$Al and ^{54}Fe$(n,2n)^{53}$Fe cross sections. Because these reactions have thresholds near 14 MeV, their rapidly rising cross sections can be used as sensitive measures of plasma ion temperatures in fusion devices.

Integral Tests of Activation Data

Revised evaluations of energy-dependent $(n,2n)$ cross sections for ^{58}Ni, ^{59}Co, ^{90}Zr, ^{93}Nb, and ^{197}Au based on measurements were tested by Ikeda et al. (JAERI, FNS) in reaction rate experiments in two different deuterium-tritium neutron fields and in a 60-cm-thick graphite assembly. The revised evaluations generally resulted in reaction rates that were improved over those calculated with ENDF/B-V or JENDL-2.

Activation Data Libraries

Mann (Hanford Engineering Development Laboratory) described extensive multigroup cross-section and decay data libraries. The libraries were formulated for use with the computer code REACT*2, which calculates activation and transmutation for neutrons and charged particles.

The cross-section library contains data for 338 isotopes and includes over 6000 reactions. Some 90% of the stable isotopes and all unstable isotopes with half-lives >5 yr and masses <220 amu are included. The library draws on the ENDF/B-V data file, the LLNL activation library ACTL-84, the LANL activation library, and the THRESH systematics computer code for the required data. The decay data library contains all isotopes that can be produced in the cross-section library, or that are daughters of such isotopes, and includes isomeric states.

NUCLEAR THEORY AND EVALUATIONS FOR FUSION DATA

Data of interest in fusion applications continue to be interpreted primarily through R-matrix methods for light systems and by optical and statistical model (including preequilibrium processes) calculations for medium to heavy nuclei. Fundamental to many of these studies is the understanding of nuclear level densities. The applications of these theories have been largely phenomenological of necessity, but microscopic methods are beginning to impact the field.

R-Matrix Methods

For light systems having resolvable resonances, R-matrix theory provides a convenient and powerful framework for describing reactions. Knox [Ohio University (OU)] discussed extracting the level parameters of the theory from shell model calculations, then adjusting them to give better fits to the data considered. He showed applications in which data for the $n + {}^6$Li and $n + {}^7$Li reactions were fairly well reproduced at energies up to $E_n = 8$ MeV. Hale (LANL) presented phenomenological fits for reactions in the ^{7}Li system that included peripheral channel overlap (deuteron exchange) effects in the ^{6}Li$(n,t)^4$He reaction. A description of SAMMY, a multilevel data fitting code that uses Baye's method rather than least-squares techniques, was given by N. Larson (ORNL).

Statistical and Optical Models

For medium to heavy nuclei at all but the lowest energies, the levels approach continuum distributions, and statistical methods are appropriate for describing the reactions. Although the distribution- (and energy-) averaged scattering matrix $\bar{\mathbf{S}}$ is presumed to come from the optical model, the averaged cross sections also depend on the width and energy distributions of the continuum levels, due to correlations in the presence of direct reactions. Fröhner [Kernforschungszentrum Karlsruhe (KfK)] presented an intriguing technique for obtaining distributions for the elements of $\mathbf{S}$ about their averages $\bar{\mathbf{S}}$ from the principle of maximum entropy, in analogy with what is often done to obtain thermodynamic distributions. This method is, in principle, a rigorous and general solution of the long-standing problem of obtaining averaged cross sections from the averaged scattering matrix elements given by the optical model. Mitchell (NCSU and TUNL) reported the first experimental evidence of correlations induced by direct reactions between reduced width amplitudes of resolved resonances in inelastic proton scattering on targets in the vicinity of mass 50.

Calculational tools for applying the usual statistical models were reviewed by M. Gardner (LLNL). She discussed the criteria for choosing optical model potentials, nuclear level densities, and gamma-ray strength functions that give reliable predictions of cross sections and spectra. A global, nonrelativistic spherical optical model for nucleon scattering from targets in the mass range $A > 53$ at energies 10 MeV $\leq E \leq$ 80 MeV was reported by Walter and Guss (Duke University and TUNL). The potential was determined from a large body of neutron cross-section and analyzing power data, with a modest amount of proton data included to constrain the coulomb correction terms. Additional aspects of accounting for neutron proton differences in statistical model calculations were pointed out by D. Gardner and M. Gardner.

Preequilibrium Emission

At incident energies near 14 MeV, the emission of particles before the compound system achieves equilibrium becomes increasingly important, and the usual equilibrium statistical treatments must be modified to take into account these preequilibrium components. Hodgson (Oxford) discussed various features of codes using the semiclassical exciton (EM) and geometry-dependent hybrid (GDH) models, as well as calculations based on the quantum-mechanical theory of Feshbach, Kerman, and Koonin. He concluded that, while the semiclassical models are computationally easier and less time consuming, they cannot account for measured features, especially in angular distributions, that are reproduced by the quantum-mechanical theory. Differences between the EM and GDH models were discussed in more detail by Akkermans (Utrecht), and a code system built around the EM code GRYPHON, which emphasizes consistency with equilibrium models, was described by Gruppelaar (Petten). Hetrick et al. (ORNL) reported calculations of 14-MeV emission spectra for neutrons incident on copper, nickel, and chromium, using the generalized Hauser-Feshbach code TNG. Similar calculations for titanium isotopes using the code STAPRE and the preequilbrium routine HYBRID were shown by Ivascu (Bucharest). Zhang (Beijing) discussed systematics of $(n,2n)$ and $(n,3n)$ cross sections over wide ranges of mass and energy in terms of a constant temperature evaporation model with a preequilibrium contribution.

Level Densities

Methods for calculating nuclear level densities that are required for statistical model and preequilibrium calculations were reviewed by Grimes (OU). He saw promising new information about level density systematics coming from microscopic Hartree-Fock and shell model methods, but felt that more experimental information was required to make further progress. Anzaldo Meneses (KfK and Mexico City) described level densities obtained from number theoretical methods containing temperature-dependent shell and pairing effects that differ significantly from Gilbert-Cameron and back-shifted Fermi gas (BSFG) formulas at temperatures below the Fermi energy. Calculations by Maino and Menapace (Bologna) using the microscopic Nilsson-BCS formalism showed that for medium mass nuclei ($51 \leq A \leq 66$), the parity probabilities are about equal at excitation energies >15 MeV, in agreement with experiments. Ivascu (Bucharest) reported that a merged BSFG and Ignatyuk level density model accounts well for isotopic effects in statistical model calculations of neutron cross sections for molybdenum.

Evaluations

Rowlands (Winfrith) described the status of the JEF project, which contains neutron cross sections for some 300 nuclides in ENDF/B format. The library, designated JEF-1, made up of U.S., European, and Japanese evaluations, has been satisfactorily benchmark tested, but work is under way on an improved library, JEF-2, that concentrates on data for primary actinides and structural materials. The procedure for obtaining the evaluated neutron standard cross sections for ENDF/B-VI was described by Carlson. It involves combining R-matrix calculations for the light element standards with the results of a simultaneous least-squares combination of data for all the standard reactions, where the data bases of the separate analyses have practically no overlap. Some of the fusion neutronics evaluation work for JENDL-3, using R-matrix calculations for the light element cross sections and statistical/preequilibrium model calculations for the structural materials, were discussed by Shibata (Tokai-mura).

NEW EXPERIMENTAL FACILITIES AND CAPABILITIES

Neutron Diagnostic Systems for Joint European Torus

Neutron detection techniques for plasma diagnostics at the Joint European Torus (JET) facility were described in a review paper by Lees. A summary was given of various neutron detection systems envisioned for JET, with particular emphasis on those under development by the Atomic Energy Research Establishment, Harwell. These latter systems are outlined below.

Pairs of ^{235}U and ^{238}U fission counters have been developed to measure the time response of the total neutron yield from JET. The associated electronics permit the simultaneous measurement of individual pulses (for low count rates) and total chamber current (up to 3 mA for high rates), thereby allowing the detectors to operate over a dynamic range of eight orders of magnitude in neutron flux. These fission yield monitors have been operational in JET for over a year with very few problems.

A time-integrated neutron yield monitor based on the activation technique is under development. Part of its appeal is, of course, that it will provide an absolute calibration and will be independent of possible electrical noise and interference. A fast transfer system for transporting irradiated foils to counting stations is nearly complete. Candidate reactions for the monitor include $^{115}In(n,n')^{115m}In$ (4.5-h half-life) for d-d neutrons and $^{109}Ag(n,2n)^{108}Ag$ (2.4-month half-life) for d-t neutrons.

The engineering design for a neutron yield profile measuring system has been completed. The system is designed for d-d neutrons, with 10-cm spatial resolution and a factor of 100 intensity dynamic range. A multicollimator system cast in concrete utilizes ten channels in the vertical profile monitor and nine in the horizontal profile. Each channel is viewed by an NE-213 liquid scintillator and photomultiplier tube, and a computerized tomography routine will convert detector output into spatial neutron distributions. Construction of this system will commence shortly, and it is hoped that it will be in use by the summer of 1986.

A number of d-d neutron spectrometers are planned or under development to facilitate determination of plasma characteristics (such as temperature) in JET from measured neutron energy distributions. Detectors for the spectrometers include a ^{3}He ionization chamber, an NE-213 liquid scintillator with pulse-shape discrimination, an in-line proton recoil device, a spherical ion chamber, and a neutron TOF device. Of these, only the ^{3}He ionization chamber has been extensively tested.

WNR/Proton Storage Ring Facility

The enhanced capabilities of the WNR facility at LANL were described in a review paper by Lisowski. In addition to the now-operational Proton Storage Ring (PSR), an additional target area is under construction for nuclear physics experiments that will take advantage of multiplexed operation and forward-angle scattering flight paths to greatly enhance the fast neutron flux. The new target area is expected to be in operation in 1986. The impact on nuclear data for fusion applications will mainly be a tremendous increase in neutron flux available at higher energies over existing white neutron sources. As an example, Lisowski presented a comparison with the Oak Ridge Electron Linear

Accelerator indicating that WNR/PSR would have approximately three orders of magnitude more flux of ~10-MeV neutrons. This increased neutron flux at higher energies will permit new measurements that are currently very difficult or even impossible to make.

Miscellaneous Developments

A postacceleration pulse compression system has been developed for the Geel Electron Linear Accelerator that permits higher resolution neutron TOF measurements to be made (Böckhoff et al.). The system was demonstrated with clearly resolved total cross-section measurements of two resonances in ^{16}O near 3.4 MeV that are separated by only 3 keV. This capability will be very useful in resonance studies where levels are closely spaced.

Liskien (Geel) described a new method for inferring angular distributions of inelastically scattered neutrons by analyzing Doppler-broadened gamma-ray lines. The technique was demonstrated for the previously unmeasured $^7Li(n,n')^7Li^*$ reaction to the 478-keV state. The method is applicable for levels with short half-lives in reasonably light nuclei.

CONFERENCE PROCEEDINGS

The complete Conference Proceedings will be published by Gordon and Breach Science Publishers (50 West 23rd Street, New York, NY 10010) and will appear in a forthcoming issue of the journal, *Radiation Effects.*

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