NEUTRON MEASUREMENTS

It is rather remarkable that neutrons, which are responsible for both nuclear fission and production of radioisotopes and have thus made possible all the varied practical applications of atomic energy, are still among the particles most difficult to detect and measure. The difficulty, of course, arises from their absence of electric charge. Unlike the charged particles (electrons, protons or alpha particles) they themselves do not cause any ionization in the matter through which they pass; their presence is known only indirectly - from other particles which they hit and set in motion or from chemical and physical changes in materials in which they are absorbed.

The elusive character of the neutron was foreseen when, in 1920, Rutherford first suspected its existence. He visualized the existence of a particle without electric charge and realized that being uncharged it would be entirely unaffected by an electrical field and would easily pass through solid barriers. "It should be able", as he put it, "to move freely through matter ... and it may be impossible to contain it in a sealed vessel." It is not surprising that, when ten years later Bothe and Becker found evidence of some extremely penetrating radiation from beryllium hit by alpha rays they thought it to be a special form of gamma radiation. On this hypothesis, however, the interaction of this radiation with matter, investigated by Joliot and Irène Curie, did not fit in with known physical laws, and it was only when Chadwick interpreted this radiation to be composed of uncharged particles that the mystery finally disappeared.

It was 12 years after Rutherford's prediction that the neutron was discovered, but immediately after its discovery it became the most valuable tool for exploring the atom. It was discovered in 1932; by 1934 it had been used to produce radioactive isotopes of stable elements, by 1939 it had split the uranium atom in laboratory experiments, and by the end of 1942 it had been responsible for the first self-sustaining nuclear chain reaction and the controlled release of nuclear energy. Hardly ever has the discovery of a particle led to such revolutionary scientific progress in the space of a single decade.

In the last twenty years the neutron has been responsible for further advances in nuclear science and technology and applications of neutrons have increased enormously. This, in turn, has increased the need for methods by which neutrons can be readily detected and their densities and energies accurately measured. It is also necessary to establish the relationship between a given dose of neutrons and the effects it produces on various materials, and this requires an accurate assessment of the dose. This has become especially important in view of the biological hazards of neutron radiation. Since the radiation hazards associated with reactor operation are mainly due to the neutrons emitted in the fission process, neutron dosimetry (i.e. measurement of neutron doses) is now one of the primary safety requirements in atomic energy operations.

Main Principles

Methods of detecting and measuring neutrons, however, are not only complicated but still somewhat inadequate for the great variety of tasks in which accurate measurements are necessary. Most of the established methods are based on either of two main principles. In the first place, the creation of artificial radioactivity by neutron bombardment provides the basis for what are known as the activation methods of neutron measurement. Since neutrons produce radioactive isotopes when they are absorbed by stable elements, the amount of activity induced in a material can indicate the number of neutrons hitting the material. Besides, since the induction of radioactivity is associated with the energy level of the neutrons, this technique can also be used for measuring neutron energies.

In the second place, neutrons knock off protons (nuclei of hydrogen atoms) while passing through hydrogenous materials, and a count of the recoil protons gives a measurement of the neutron flux. This method, too, can be used for measuring neutron energies because, the two types of particles being of approximately equal mass, almost all the energy of the neutrons is transferred to the protons as a result of such collisions.

Being charged particles, the protons can be easily counted and their energy measured. This is done with the help of a variety of radiation detectors. To start with, there is a group of detectors based on ionization phenomena. Electrical pulses produced by ionizing events (caused by charged particles or electromagnetic radiation) are registered by electronic instruments and the pulses are counted and analysed to determine the amount and the energy of the radiation. Geiger counters and ionization chambers are well-known examples of this type of detector. The pulses can also come from flashes of light produced by ionizing radiation in certain materials. Here again, an electronic count of the scintillations (or rather of the pulses produced) is used for the detection and measurement of radiation.

The detector based on this principle is known as the scintillation counter. There are also a few other types of detector - for example, devices based on the damage caused by radiation in solids or those based on the effects of radiation on a sensitive emulsion.

Measurement of the flux (i.e. the number of particles passing through a given area per unit time) and measurement of the energy distribution (where the particles have different levels of energy) are the two main tasks in studying the characteristics of a neutron field. A somewhat different task is to measure the dose of neutron radiation delivered to a material. This is usually regarded as the energy imparted to the material by the neutrons; in other words, it is the absorbed dose. In biological studies in particular, it is the absorbed dose, and not the total neutron flux, that is of real consequence. Measurement of the absorbed neutron dose has lately assumed great importance, especially in view of reactor hazards, but the difficulties of accurate measurement have not yet been entirely resolved.

A major difficulty arises from the fact that neutron radiation is often accompanied by gamma radiation and measurement of the total dose does not readily indicate the contribution made by the neutrons. Since the effects of the two forms of radiation are often different, it is necessary to have measuring techniques which can discriminate against the gamma rays and specifically assess the neutron dose.

It has been widely felt for some time that there is an urgent need for improving the techniques and instrumentation for neutron measurements for the protection of atomic energy workers, especially reactor personnel, against neutron radiation, as well as for a better understanding of the dose-effect relationship. A few reactor accidents in recent years have shown the importance of effective methods of quickly identifying the persons exposed to neutron and gamma radiation and accurately assessing the radiation dose received; but while the techniques of measuring gamma ray dose are well established those for neutrons are yet to be adequately developed. This has been the subject of some concern among nuclear scientists and the need has been felt for the widest possible exchange of information on the current techniques of measurement as well as for an exchange of ideas on possible lines of improvement. In several countries, a great deal of research effort is now directed towards improving neutron measuring techniques and instruments, and the progress of this effort can be substantially accelerated by a comparative assessment of the experimental approaches. This would also be useful for the standardization of measuring techniques and instruments.

Symposium at Harwell

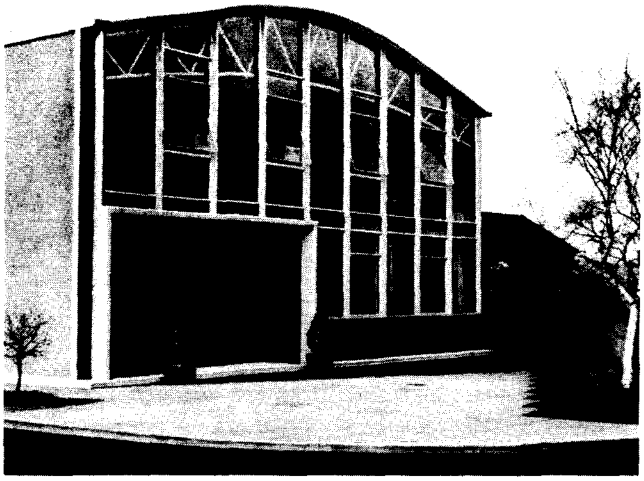
A symposium on Neutron Detection, Dosimetry and Standardization was held by the International Atomic Energy Agency from 10 to 14 December 1962 at Harwell, United Kingdom. It was attended by 280 scientists from 27 countries and 5 international organizations.

Welcoming the scientists attending the symposium, Dr. F.A. Vick, F.R.S., Director of the Atomic Energy Research Establishment at Harwell, said that the whole existence of the Harwell establishment rested upon applications of neutrons "which were discovered, or should I say invented, or imagined" thirty years ago by Sir James Chadwick, who was until recently a part-time member of the United Kingdom Atomic Energy Authority.

A reference to the discovery of the neutron and its subsequent role in the development of atomic energy was also made by Professor A. Sanielevici, Acting Director of IAEA's Division of Research and Laboratories, who addressed the opening session on behalf of the Agency's Director General.

Professor Sanielevici pointed out that measurements of high energy nuclear particles were assuming greater and greater importance in the peaceful applications of atomic energy. So far as the neutrons were concerned, the scope of their practical use in industry, biology and medicine, as well as in research work, had increased so rapidly that it had not been possible for the development of measuring techniques to keep pace with this advance, and this called for greater efforts to improve both the techniques and the necessary instrumentation. The symposium at Harwell, Professor Sanielevici said, was intended to provide a comprehensive picture of the present stage of development in the detection, dosimetry and standardization of neutron radiation as well as to determine the lines of further development. The meeting would cover all aspects of neutron dosimetry, but questions relating specifically to the biological effects of neutron radiation and the relationship between dose and effect had been left out of its scope. A symposium on the biological effects of neutron irradiation would be held by IAEA next October.

More than 100 papers were presented at the symposium. The topics of discussion were arranged under three broad headings, viz. measurement of neutron field characteristics, dose measurements, and calibration and standardization. There were nine sessions, presided over by the following scientists: A.H.W. Aten, Jr. (Netherlands), L.H. Bruner (USA), V.S. Crocker (UK), P. Delattre (France), G.V. Droste (Federal Republic of Germany), V.I. Ivanov (USSR), W.G. Marley (UK), A. Persano (Italy) and J. Thomas (Denmark).



Cockcroft Hall, Harwell, where the IAEA symposium on neutron measurements was held

The majority of papers were concerned with different aspects of measuring neutron field characteristics. They were subdivided into two groups, one relating mainly to flux measurements and the other concerning spectrometrical measurements, i.e. measurements of neutron energies and their distribution. A large number of papers discussed problems of measuring neutrons of high energy (fast neutrons), but some dealt with slow (thermal) and intermediate energy neutrons also. Fast neutron measurements are particularly difficult. So far as the biological effects are concerned, they are among the most dangerous of all atomic radiations. The recoil protons, carrying most of the neutron energy, become extremely powerful agents of ionization and, since neutrons can travel long distances before colliding with atomic nuclei and thus knocking off protons, fast neutrons can produce densely ionizing radiation deep within the irradiated material.

Flux Measurements

Some recent developments in instruments for detecting high energy neutrons were described in a paper by A. Goodings and D.L. Roberts (UK). They stated that ionization chambers had certain special advantages over other techniques for the measurement of neutron flux, because they provided virtually instantaneous readings with considerable operational convenience. The authors discussed recent work by the UKAEA on the development of new fission detectors, which measure the flux of neutrons from a count of nuclear fissions they cause.

Fission counters were also discussed in a few other papers, but the majority of papers on flux measurements discussed applications of the principle of activation. Since the induction of radioactivity in a given substance is dependent on the neutrons possessing a "threshold" energy, the use of the activation principle has led to the development of threshold detectors which can determine both the flux and the energy of neutrons. I. Heertje and A.H.W. Aten, Jr. (Netherlands) stated that for many purposes the use of threshold detectors still represented the most convenient techniques for the measurement of fast neutron fluxes. However, it required both a suitable method for measuring the total activity in the irradiated material and sufficiently accurate information on the cross-section as a function of neutron energy, i.e. the chance of the neutrons being absorbed by the material as far as it is dependent on their energy.

The choice of the substance to be irradiated - as a kind of foil against the passage of neutrons - is obviously of considerable importance and experiments with different materials were described at the symposium. W.G. Cross (Canada) discussed the use of magnesium, titanium, iron, nickel and zinc; the use of titanium in threshold detectors for fast neutron measurements was also described by W.L. Zijp (Netherlands). Two British scientists, N. Adams and J.A. Dennis, reported on new methods of using gold and indium foils in investigating radiation leakage from critical assemblies, while four Norwegian scientists (D. Grimeland and others) presented a paper on the measurement of neutron fluxes by activation of sodium iodide crystals. Sodium, it was pointed out, is very suitable for neutron density measurements.

A few novel methods of flux measurement were also suggested at the symposium. For example, two German scientists, R. Hosemann and H.F.H. Warrikhoff, put forward a theory of "neutron element" based on experiments with a new type of detector known as "gamma element". The so-called "radiation elements" represent a group of detectors which convert radiation energy directly into useful electrical energy, and the electricity generated provides a basis for measuring the radiation. The electricity consists of the charged particles ejected from the atoms hit by the radiation. The detector is based on a two-electrode system in a vacuum cell, the two electrodes yielding different numbers of charged particles when exposed to radiation. If, for instance, the yield of charged particles (e.g. electrons released by gamma radiation) of one electrode is higher than that of the other, there will be a net transfer of electrons between the two, causing the system to be charged. It has been suggested that this principle can also be used for a neutron detector in which the charged particle (e.g. protons) yield of one electrode, when exposed to neutrons, will be considerably higher than that of the other. As the coating material for the electrodes, it is possible to use boron, which gives off alpha particles when hit by neutrons, or some hydrogenous substance that will give off protons.

Another possible type of detector, discussed by G. Perriot (France), is based on the variations in the electrical resistivity of solids subjected to neutron bombardment. In preliminary experiments a number of solids have been selected which could be used as detectors.

The methods and instrumentation for flux measurements now in use at important reactor centres were also described. A. Charbonnel (France) described the detecting equipment and counting techniques used in the Department of Large Experimental Reactors at Saclay. U. Farinelli (Italy) gave an account of techniques used in the Ispra-2 reactor, while five other Italian scientists (M. Bresesti and others) described fast neutron measurements by threshold detectors in Ispra-1 and Avogadro reactors.

Neutron Energies

A number of papers dealt with spectrometrical measurements, i.e. measurements of neutron energies and their distribution in a given field. Recent developments in fast-reactor neutron spectrometry techniques were described in a review paper presented by a group of French and Belgian scientists. Spectrometrical techniques were also reviewed by R. Wallace (USA) and E.L. Stolyarova (USSR).

K.W. Geiger (Canada) described a method for measuring neutron spectra by a proton recoil telescope and discussed its advantages over the established method of measurement from the tracks made by recoil protons in a nuclear emulsion. The nuclear emulsion method can be used for the detection and measurement of any ionizing radiation because of the tracks left in the emulsion by charged particles or electromagnetic radiation, in the same way as light affects the emulsion on a photographic plate. Mr. Geiger said that because of the tedious and time-consuming procedure involved in analysing the proton recoil tracks in the emulsion, a proton recoil telescope had been built for use as a neutron spectrometer. In this device, the recoil protons pass through a counter telescope and are eventually absorbed by a scintillation crystal. The proton energy released in the scintillator is measured by electronic instruments.

The use of nuclear emulsions for measuring fast neutron spectra was discussed in a paper by S. Passe (France).

A. Narath and P. Koeppe (Germany) suggested that the considerable time and effort spent on visual microscopic examination of neutron films could be saved by the use of automatic equipment for scanning and counting, and described an experimental model of an automatic scanner.

As indicated earlier, a special problem in neutron measurements arises from the fact that neutron radiation is often accompanied by gamma radiation. The principal method of differentiating between the two is spectometrical analysis - for example, by separating the pulses produced by the two types of radiation. G.C. Doroshenko and E.L. Stolyarova (USSR) described a method of pulse separation in a scintillation detector, based on the principle that scintillations produced by different types of exciting particles have different decay times. V.I. Ivanov, also of the USSR, described another method by which the pulses caused by recoil protons (resulting from collisions with neutrons) and those caused by electrons (ejected from atomic orbits by gamma ray photons) are channelled along different paths in the electronic circuit.

E.F. Bennett (USA) gave a paper on methods of discriminating against gamma rays in a proportional counter (which is essentially based on the ionization principle). Discrimination is possible because of the difference in the path length of an electron (ejected by gamma radiation) and that of a recoil proton (produced by a neutron), the former being considerably greater. As a consequence, ionization from the recoil proton is created in the form of a bunch with small spatial extension, whereas the radial projection of the ionization from the electron track is likely to have a much larger dimension. This, in turn, produces different types of pulse and the difference can be seen in the electronic reading.

B. Brunfelter, J. Kockum and N. Starfelt (Sweden) discussed techniques of discrimination based on the different shapes of scintillation pulses from neutrons and gamma rays. In another paper from Sweden (G. During, R. Jansson and N. Starfelt) it was pointed out that the organic scintillator, employing pulse-shape discrimination to eliminate gamma ray background, presented a possibility of measuring neutron spectra above energies of about 0.5 MeV.

Dose Measurements

During the discussion on neutron dose measurements, G.S. Hurst and R.H. Ritchie (USA) presented a generalized concept for radiation dosimetry. They pointed out that the main basis of radiation dosimetry had hitherto been the measurement of the total energy absorbed per gram of material occupying the sensitive region of the radiation detector. This principle has been successfully employed to measure the absorbed dose in various kinds of matter for ionizing radiations over a wide range of energy. However, with the present large-scale application of different types of radiation and the more stringent requirements for the protection of man against these radiations, it is desirable to characterize the interaction of radiation with matter in several days. This is particularly necessary in the increasingly sophisticated field of radiation biology. Mr. Hurst and Mr. Ritchie said that new advances in radiation physics now made it possible to approach the problem of dose determination in many more ways than previously. They presented the theoretical formulations for dealing with various aspects and phases of the transfer of energy from radiation to the irradiated material.

In a paper on practical neutron dosimetry, four other American scientists (C.C. Gamertsfelder and others) described a dosimeter for use in locations where nuclear accidents are possible. The dosimeter consists of indium and gold foils located at the centre of a paraffin cylinder. They also described a procedure for quickly identifying persons exposed to substantial neutron doses from a nuclear accident. The procedure consists in detecting radiation from activated sodium in the body by holding an ordinary Geiger counter against the abdomen of the exposed individual and having him then bend over the counter. It was stated that this technique had been found useful in identifying exposed personnel following a recent criticality accident at Handford.

The routine personal monitoring of fast neutrons at AB Atomenergi in Sweden was described by S. Hagsgård and C.C. Widell. This is done by counting tracks in a nuclear emulsion with the help of a microscope and a projection screen. Large neutron doses are monitored by a field activation dosimeter consisting of a cadmium-shielded phosphorus foil, a cadmium-shielded gold foil and an unshielded gold foil.

D. Nachtigall (Germany) described battery-operated instruments for routine measurements of local dose rates and pointed out that, while these instruments are quite sensitive, their response is not proportional to the dosage. He discussed how this difficulty could be overcome.

Two Romanian scientists, J. Apostol and M. Oncescu, presented a paper on the measurement of neutron doses from sources used in the oil industry. They said that in this work the problems arising from mixed radiation fields could be solved by measuring gamma doses by means of conventional battery-powered dosimeters and establishing a relationship between neutron and gamma doses.

H.H. Rossi (USA) pointed out that, because of their simplicity and reliability, ionization chambers were regarded as very convenient instruments for radiation dosimetry. In particular, the tissue-equivalent chamber, in which some of the material to be irradiated resembles body tissue in its reaction to radiation, may be used for absorbed dose measurements over a wide range of radiation and dose levels. However, because of their universal response, these instruments provide no significant discrimination between doses due to individual radiations in mixed fields; while they can be used singly in relatively pure radiation fields, they must be supplemented by other devices for a satisfactory assessment of a mixed radiation field.

W. Abson and R.P. Henderson (UK) said that in radiological monitoring systems for the control of exposure of personnel to mixed neutron and gamma radiations, the ideal measurement is one which indicates the maximum rem (Roentgen-equivalent man) dose to a human body exposed to the same radiation as the measuring instrument. Ionization chambers with tissue-equivalent walls and gas filling can be used for the measurement of a "first collision dose in tissue" due to fast neutrons, but this does not correspond to the maximum rem dose in the body since the latter depends on multiple collision processes and on the r.b.e. (relative biological effectiveness) appropriate to the nature and energy of the secondary ionizing radiations produced in the body by fast neutrons. The authors said that other types of ion chambers could be designed that would have a neutron response matching fairly closely these requirements for rem dose indication. They gave design details and radiation characteristics of a high-pressure hydrogen-filled chamber for this purpose.

Certain problems relating to the energy dependence of a proportional counter neutron dosimeter were described by W.B. Beverly, R.S. Caswell and V. Spiegel, Jr. (USA). A proportional counter dosimeter with polyethylene walls and ethylene gas filling is widely used for neutron dosimetry in the presence of gamma rays. Large pulses due to recoils from neutrons are accepted and measured while small pulses due to secondary electrons from gamma rays are rejected. The authors suggested ways of improving the accuracy of these measurements.

Review and Standardization

Apart from the papers discussing specific problems or individual methods and instruments, several review papers giving a broad account of present practice were presented at the symposium. The work of the EURATOM Dosimetry Working Group was described by P. Delattre and A. Prosdocimi. Dosimetry work at the SORIN Nuclear Research Centre in Italy was discussed in a paper by A. Rossi and SORIN staff. Y. Droulers gave an account of methods of measuring fluxes and doses of neutrons and gamma rays evolved from in-pile experiments at the Centre d'études nucléaires, Grenoble, France, while an account of neutron dosimetry at the Reactor Protection Research Service at Fontenay-aux-Roses was given by R. Beaugé. Fast neutron measurements in civil power reactors in the United Kingdom were discussed in a paper by L.K. Burton and A.E. Souch. J. Romanko and W.E. Dungan (USA) discussed current analytical and experimental techniques used at a typical nuclear facility in defining and measuring neutron spectra.

The last session of the symposium was devoted to methods of calibrating neutron measuring instruments and standardizing neutron sources. A method of calibrating equipment for neutron dosimetry, discussed in a paper by four French scientists (E. Calvet and others), is based on measuring the heat generated in a material as a result of neutron absorption; since this provides a precise measurement of the energy imparted by the neutrons to the absorbing material, the instruments ordinarily used for dose measurements can be calibrated by checking the measurements against the readings from a microcalorimeter (an instrument capable of measuring extremely small increases in heat).

Calibration and measuring equipment would help in standardizing the measurements. Another way of doing this would be to standardize neutron sources; if the strength of a source is precisely known it can be used to check the accuracy of measurements made with a particular instrument. The preparation of standard sources, the neutron emission rate of which is accurately known from what is called absolute measurements, is therefore an important task. Several papers on methods of absolute measurement, preparation of standard sources, and intercomparison of measurements were presented at the symposium.

This is a field in which international collaboration is essential. Standardization of radiation measurements is one of the main scientific activities of the International Atomic Energy Agency and forms an important part of the work done at the Agency's laboratory at Seibersdorf.

At the end of the symposium at Harwell, the Agency organized a meeting of a panel of experts on the standardization of neutron measuring instruments. The panel, which met under the chairmanship of R.H. Ritchie, of the Oak Ridge National Laboratory, USA, and included scientists from Canada, France, the USSR and the United Kingdom as well, reviewed the present situation in respect of standardization of neutron sources and of flux and dose measurements, and made certain proposals for the establishment of intercomparison centres for the calibration of neutron measuring instrumentation. The recommendations of the panel will help the Agency in determining further steps to standardize neutron measurements at nuclear centres in different member countries.

EXPERTS AND EQUIPMENT FOR ATOMIC DEVELOPMENT

An Outline of the IAEA Programme for 1963

Thirty-seven countries will this year receive technical assistance from the International Atomic Energy Agency in the form of services of experts and equipment for their atomic energy programmes. The Agency will send out about 80 experts and provide more than $450 000 worth of equipment.

The Agency's 1963 budget provides for an expenditure of $864 000 for this form of assistance to its Member States. This is part of a total operational programme (including exchange and training of scientists) of a little over 2.2 million dollars, to be financed almost entirely out of voluntary contributions to the Agency's General Fund. The contributions made or pledged so far, however, fall short of the target, which was set at $2 million, and consequently the allocations for various parts of the programme will have to be reduced.

It is expected that $713 000 will be available for the provision of experts and equipment out of contributions to the General Fund. In addition, the Agency's share in the approved United Nations Expanded Programme of Technical Assistance (EPTA) on 1 January 1963 provided nearly $573 000 for experts, visiting professors and equipment for this year. The total value of this kind of assistance to be given by the Agency this year will therefore be of the order of $1 286 000.

The experts will represent various branches of nuclear science and technology, and the equipment, too, will be varied, the nature of the projects for assistance being determined by the specific needs of individual Member States. This can be seen from the following brief account of the assistance to be given to each country. (For the sake of convenience, the countries have been arranged in a few geographical groups.)

Latin America

The Argentine National Atomic Energy Commission, which has been engaged in reactor research