developments in radiation detection

The effectiveness of a radiation-protection programme must be checked by an adequate monitoring system. A recent symposium organized by the IAEA reviewed developments in radiation detectors that can be used to measure different types of radiation and in biological indicators of radiation dose which could become of real value.

The programme of the symposium was very comprehensive. Papers were presented, during eight working sessions, on calibration methods and techniques, intercomparison of detector characteristics and the choice of suitable detectors for particular radiation monitoring purposes, and on developments in so-called "biological dosimeters," such as the use of chromosome aberration analysis in assessment of radiation dose. About 160 scientists from 29 countries and four international organizations took part in the week-long discussions.

At the opening session Prof. Ivan Zheludev, Deputy Director General, Department of Technical Operations, recalled that the Agency had taken a leading part in the organization of other symposia — on personnel dosimetry for radiation accidents, the assessment of radioactivity in man and the handling of radiation accidents — in 1964, 1965 and 1969.

The Department of Research and Isotopes is now engaged in helping Member States to improve their dosimetric procedures, through an intercomparison service operated jointly by the IAEA and the World Health Organization; more than 200 institutions in more than 45 Member States are taking part in this work. Secondary reference laboratories are being set up as a joint project with WHO in a number of countries.

Experimental intercomparison work was reviewed in a paper presented by Dr. G.A. Dorofeev, of the IAEA Division of Health, Safety and Waste Management, prepared jointly by him and Dr. S. Somasundaram, of the Bhabha Atomic Research Centre, Bombay, India and formerly on the Agency's staff. They pointed out that the problem of measuring radiation and monitoring radiation exposure of personnel at nuclear energy establishments is very important from the point of view of ensuring radiation safety, and that to carry out reliable and precise measurements it is necessary to calibrate instruments accurately — to determine the relation between the reading given by a measuring device, and the actual measured quantity.

Relative methods of measurement are used widely in science; but in radiation protection work measurements are made in terms of absolute units of dose, concentration, flux density and so on. Measurement results are recorded. Special means may be used to reproduce accurately quantities to be measured, and thus to calibrate the measuring instruments to be used in practice.

Participants in the Symposium, photographed during the opening session. *Photo: Schikola*

Dr. Dorofeev and Dr. Somasundaram pointed out that in most developing countries there are no centres at which instrument and source calibration can be carried out. These countries must seek the help of centres in other places in order to obtain calibration of secondary standards for both instruments and sources, then use these standards for the calibration of laboratory and field instruments.

In order to assess the accuracy and reliability of the radiation protection measurements made in laboratories in Member States, it was decided to invite a number of them to take part in an intercomparison experiment. Each laboratory was sent a set of five luminescent glass dosimeters, and was asked to irradiate two to about 500 mR each under different conditions (different distances from the source or with different sources or with different secondary standard instruments), and two others to about 1 R each, again under different conditions. The fifth dosimeter was not to be irradiated, but was to be kept together with the others in order to monitor background conditions in the laboratory and during transportation. After irradiation, all five glasses were to be returned to the Agency to be read out.

It proved that most results (presented in graphical form in Figure 1) were close to the stated exposures. Some large deviations could be due to mistakes during irradiation, or uncertainties in the measurement of exposure rates of the gamma fields used; others might also be explained by scratches on the glasses or by broken edges, in which cases a large contribution to measured dose could result from scattered radiation. In later work the experimental procedure might be altered and measurement accuracy increased. This experiment could, however, be regarded as a first step toward achieving greater standardization.

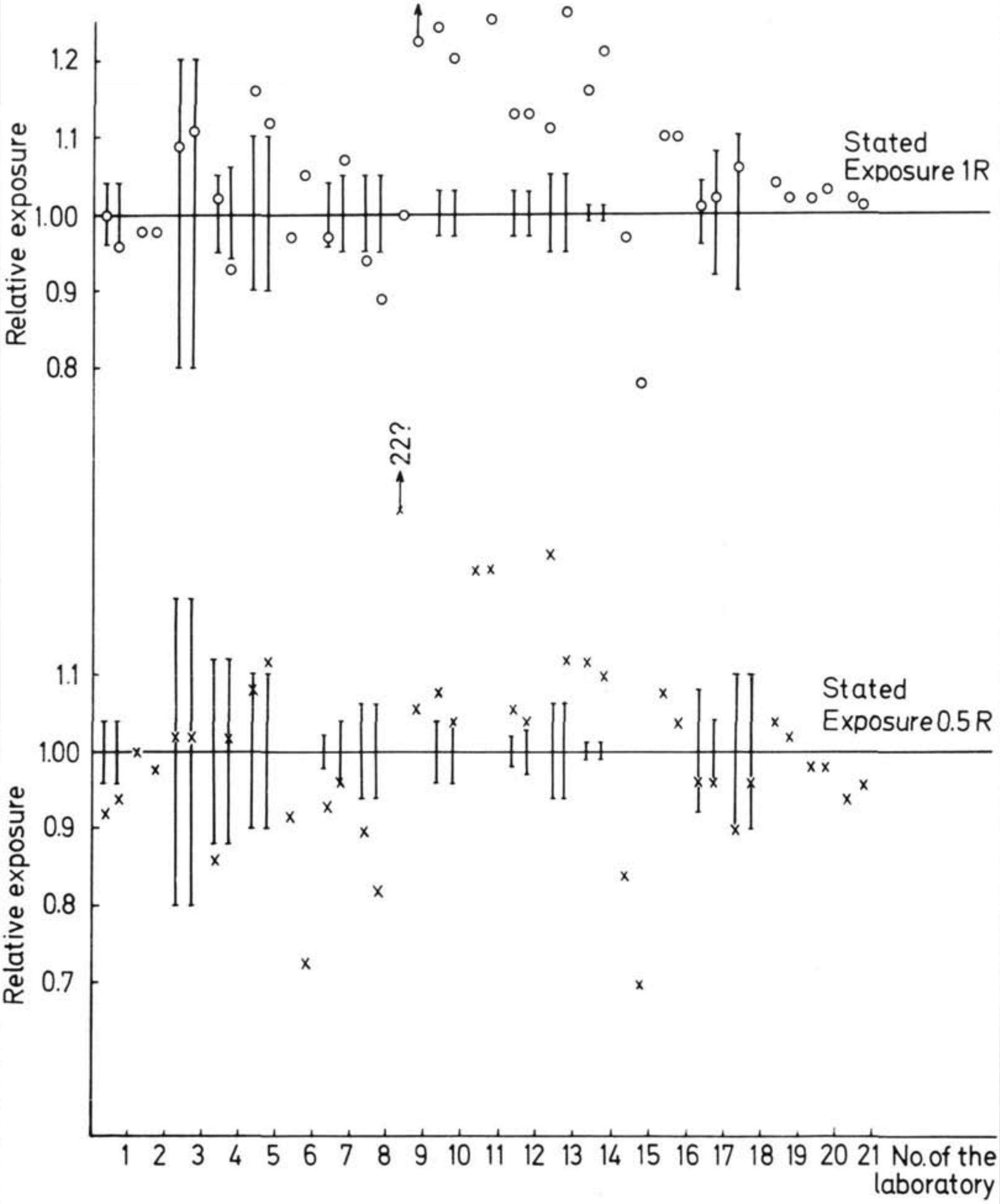
The Physics of Measurement

Participants described and discussed a very wide variety of devices which may be used in dosimetry, and their calibration, during the first four days of the symposium. One personal view which seemed to attract wide support was expressed in a paper presented by Dr. H. Brunner, assistant head of the Health Physics Division of the Eidg. Institut für Reaktorforschung, Würenlingen, Switzerland.

"Radiation monitoring," he said, "is no longer only a fascinating hobby where we have time to play with new toys, but has become an ordinary profession. We have to consider radiation detection devices as tools that have to be developed according to precise specifications and have to be used for precisely defined monitoring tasks, with the aim of getting data that can be interpreted either in terms of radiation protection regulations, or of exposure of persons.

"There exist suitable solutions for most routine problems. Good international co-operation between health physicists, manufacturers and authorities, and feedback of routine problems into research and industry as well as better economy of the available means, will help us to reach our fundamental objective: adequate radiation protection under all conditions."

This was not to deny the value of fundamental research on new types of radiation detectors. Interest was expressed, for example, in a silicon



Results of the experiment

"avalanche" detector described by G.C.Huth and P.J.Moldofsky, of Space Technology Products, General Electric Co., and developed under a US Atomic Energy Commission contract. This detector, analogous to a proportional counter, could in their view pave the way for use of previously unusable low energy radiation-emitting isotopes, and make possible clinical and experimental work not feasible until now. Incident ionizing radiation induces electron-hole pairs in the 'drift' or proportional region of the semi-conductor, and the resulting avalanche of charges across the PN junction has the effect of amplifying the deposited charge by a factor of 100 to 300.

Dr. Huth pointed out that, if such a detector were used, incident 22 keV gamma radiation from a Cadmium-109 source would produce an output equivalent to 2.2 MeV (assuming a gain of 100), so that radiation which would otherwise be below the output noise level by about a factor of two would be above the noise level by a factor of 50. Similarly, incident 3.31 keV Calcium-41 X-rays which would be below the noise level in other room temperature solid-state detectors would produce an output equivalent to that from 331 keV X-rays incident on a non-amplifying silicon detector.

Measuring body burdens

"Thus, low energy isotopes formerly not useful *in vivo,* where cryogenic cooling cannot be used to lower detector noise, can now be detected far above the noise," said Dr. Huth. "Betas as low as 5 keV and gammas and X-rays as low as 1 keV are detectable with typical detectors, and experimentally the avalanche detector has been used to detect 380 eV X-rays."

Such a detector could be useful in studies of inhaled plutonium in the lungs, where the maximum permissible burden was 16 nCi and low background counting was a necessity. This extremely radiotoxic element was measured by detection of daughter uranium L X-rays of 13.6, 17.4 and 20.5 keV; typical isotopic compositions of plutonium produced recently emitted only four to eight of these low-energy X-rays for each 100 alpha particles.

From long-term studies on dogs, it appeared that inhaled particulate $^{239}PuO_2$ moved from the lungs to the thoracic lymph nodes in such a way that 60 per cent of the body burden was in these nodes after ten years. This suggested to Dr. Huth and his co-workers that a means of internal measurement of activity in the tracheobronchial and mediastinal lymph nodes would be useful, and they therefore fabricated prototypes of an avalanche detector to be placed in the esophagus near to them. This allowed the source-detector distance to be as little as one centimeter, and made it possible to measure low-energy radiation which would not penetrate tissue appreciably for measurement externally.

An example of the clinical application of the avalanche detector could be taken from a study of the effects of hormones and chemotherapy on malignancies of the breast by measurement of uptake of phosphorus-32 as a function of time after the beginning of therapy, said Dr. Huth. It was hoped that useful therapy might be chosen more quickly on the basis of ^{32}P investigation than had been possible previously, with smaller administered doses of ^{32}P than had been necessary in the past. He and his fellow workers hoped that availability of a detector of the capacity he described would create interest in low energy, low count rate clinical work, allowing reduction of doses to patients, and in isotopes not used previously for lack of a suitable detection system.

Thermoluminescent and other detectors

By far the greatest number of papers presented during the symposium dealt with developments relating to exo-electron or thermoluminescent detectors, semi-conductor devices such as that described above, proportional and scintillation counters and other physical means of measurement of radiation dose. One author pointed out that, among phosphors used in thermoluminescent devices, lithium fluoride is "clearly in the lead" — about half of all relevant publications listed in Nuclear Science Abstracts in 1969 dealt with this material. He attributed this to the fact that lithium fluoride, lithium borate and beryllium oxide approximate human tissue in atomic number, and no shielding was therefore required to avoid over-response to gamma rays below 100 keV; and LiF had other desirable characteristics.

The last morning was devoted to developments in biological dosimetry. In the first paper on this subject, Professor H. J. Evans, of the Medical Research Council Clinical and Population Cytogenetics Unit of the Western General Hospital, Edinburgh, UK, recalled that the first critical evaluation of the relationship between chromosome aberration yield and dose was made by Karl Sax some 30 years ago. "There is no question," Prof. Evans went on, "...that for any particular cell type in any particular species uniformly exposed to a known quality of radiation, under well-defined and controlled conditions, there does exist a very strict relationship between the incidence of induced aberrations and the absorbed dose. It is this relationship ... that is such an essential prerequisite for any biological dosimeter."

Chromosome aberrations as an indicator of dose

During the past decade studies on radiation-induced chromosome aberrations in human lymphocytes, exposed either *in vivo* or *in vitro,* have been carried out by a large number of groups, and a considerable amount of information on the response of these cells has been gathered. A number of groups have attempted to make practical use of the system to estimate dose in cases where individuals were accidentally exposed to radiation.

If this is to be possible, said Prof. Evans, "we have to be able to extrapolate from the yield of aberrations that we determine from cells taken from an exposed individual, to a known aberration yield obtained experimentally — in other words, we have to have a dose curve for calibration. Secondly, we know from work on other species that the frequency of aberrations is very much influenced by a variety of physical and biological factors.

"Despite all the variables" (including age of the subject, the time after irradiation when a sample is taken, and culture conditions in the laboratory) "we can detect aberrations with doses as low as 10 rads from conventional X-rays, and within a given laboratory in which the culture conditions are standardized and the variables are fixed, we can get very good repeatability. So for uniform whole-body irradiation I am optimistic."

Prof. Evans noted, however, that this optimism did not extend to cases in which an individual received only partial body exposure.

"If the distribution of aberrations between cells were random, showing a Poisson distribution; if the aberrations increased linearly with dose; if there were no differential cell selection or differential rates of development of unirradiated and exposed cells in culture; and if there were a continuous rapid and thorough cell mixing of lymphocytes within the body, then it would be possible to obtain reasonable estimates of equivalent whole body doses in cases of grossly non-uniform and partial body exposure," he said. "Unfortunately, only one of these requirements, that of random distribution of aberrations between irradiated cells, is met."

Making the tally

Two other authors, G.W. Dolphin and R.J. Purrott, of the Health and Safety Branch of the Radiological Protection Division of the UK Atomic Energy Authority, Harwell, UK, described in a joint paper what amounts to another practical limitation upon this form of dosimetry. Cells are scored for chromosome aberrations after *in vitro* culture; the number scored under the microscope depends both on the manpower available in the laboratory, and the importance of the particular case. These authors stated that a competent scorer could average only 50 cells a day over a long period of time; this work must therefore be allocated carefully among other work in hand. In 26 investigations made in their laboratory during the past two years the number of cells scored had never been less than 100, and in two cases it had been 1000.

But, even at this stage of the development of this technique, it has proved to be of value to at least one radiation worker. Drs. Dolphin and Purrott described a case in which it was suspected that a man had been over-exposed to radiation — he had radiation burns on his fingers — at a time when he was not wearing a film badge. The question to be answered was "Should this man continue as a radiation worker from the point of view of total body exposure?" The answer, derived from an analysis of chromosome aberrations, was that he could safely do so. It was felt that this form of dosimetry could thus be valuable in reassuring people in similar situations.

This article cannot survey all the papers presented, or even all the subjects discussed. It is expected, however, that the "Proceedings" of the symposium will be published in a few months.