Title

A VISTI TO SEVERAL HEALTH PHYSICS DEPARTMENTS IN WESTERN EUROPE AND TO THE SYMPOSIUM ON SELECTED TOPICS IN RADIATION DOSIMETRY HELD AT THE INTERNATIONAL ATOMIC ENERGY AGENCY IN VIENNA JUNE 7 TO 11, 1960

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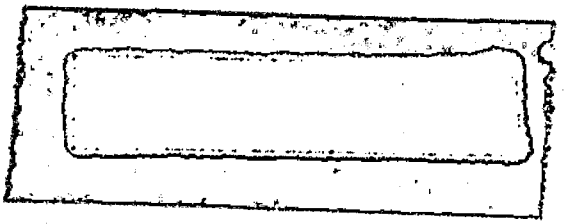

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ROME

On June 6, 1960 I visited the Physics Department of the Universitá Degli Studi-Roma Istituto di Fisica "Guglielmo Marconi," to talk to Mr. M. Rossi and Professor Mrs. A. Manfredini. Mr. Rossi is actively working on automatic scanning of nuclear emulsions but unfortunately does not speak English. Dr. Manfredini is closely related to this work but is not a co-author of the articles that have been published on the subject so far. However, she speaks English quite well and I spent most of my time talking with her.

There are two automatic scanning devices being used, the older one only counts tracks by having the image formed by a microscope focused on three slits which are arranged end to end. Each slit is one micron wide by 30 microns long when it is projected back onto the microscope slide. The light from the three slits is led to three photomultipliers by three light pipes and a count is made of the triple coincidences in the light decrease in the three channels.

The slide is moved at a rate of about 1 cm/sec by an automatic drive. The actual speed of the slide had not been measured, but this value is approximately correct. There is an automatic drive which allows a raster in the emulsion to be scanned either horizontally or vertically, or a volume can be scanned without any overlapping. The z axis of the microscope is not driven during a scan but only between scans. Apparently the photomultipliers are gated off when the z axis or the y axis is being moved. The photomultipliers are turned on only during the x motion.

When a comparison is made of the electronic coincidence count with a count made by a human scanner the angular distributions agree quite well for the 1×30-μ slit dimensions if the background is not too dense. The human scanner can ignore a very bad background, but the machine cannot make this distinction as easily. The accidental counting rate is found to be a power of the numerical track density, as it should be. The scanner is very good for measuring angular distributions for tracks lying in the plane of the emulsion. It misses those tracks with steep dip angles and includes them in the background. It would seem to me also to be instructive to measure the doubles counting rate on the photomultiplier as well as the triples to see how the dip is affecting the count.

There is a completely new device, which has been in operation for only a few weeks, for measuring the ionization density along a track. This employs a microscope which has one photomultiplier that scans for 40μ back and forth in a 1-μ-wide pattern by means of a rotating prism. The number of blobs seen by the photomultiplier is scaled and at the same time the prism drive turns a light-chopping wheel which interrupts a steady beam of light a known number of times during each 40-μ scan. The signal from this second photomultiplier is scaled in anticoincidence so that it counts the fraction of the 40-μ length that is obscured or, in the reverse sense, the fraction that is not obscured. This apparatus is sufficiently new so that no comparisons have been made with scanning by humans, and although Professor Manfredini was considerably more optimistic about its value than about the earlier apparatus merely for counting tracks, she was not yet able to say that it was a complete success.

Dr. Manfredini pointed out that Massilimano Ferroluzzi, a member of the automatic scanning group, is going to be in Berkeley working with the Alvarez group next year. I did not have an opportunity to meet him.

FRASCATI

During the afternoon of June 6, I went to the CNRN, the National Laboratories of Frascati. This laboratory is quite new and has an electron synchrotron which in many of its characteristics is quite similar to the quarter-scale Bevatron model at CalTech employed as an electron synchrotron. The laboratory is 18 kilometers southeast of Rome.

The accelerator has been in operation since 1959. The workmanship on the electron synchrotron itself is very nice . It looks as though great care has been taken in the design and fabrication of each part. The injector was made by the High Voltage Engineering Corporation, but the rest of the machine and associated equipment are of Italian design and construction. There are four external x-ray beams.

The shielding is a wall of concrete blocks with iron slugs as aggregate. The wall comes up about 3 feet above the median plane. The radiation level outside the shielding in the control room is apparently well below tolerance. There is no roof over the machine but it appears that none is needed. Professor Vincent Peterson of Caltech is doing work on the machine for a year similar to that done in Pasadena. The chief health physicist at Frascati, Dr . Ladu, was not in at the time of my visit so I was shown around by Mr. Capone of the Information Division.

VIENNA

The Conference was sponsored by the International Atomic Energy Agency, and was held in the Hofburg Palace in Vienna. The palace is now a government office building containing a good conference room with translation facilities. The International Atomic Agency is several blocks from the Hofburg Palace . The Conference was divided into sessions with headings as follows:

Considerations in General. There was an address by K. Z. Morgan, the principal Health Physicist in the United States.

The other sessions were on specific subjects. The second session was on Problems Related to Exposure Dose and Absorbed Dose. The third session, Recent Progress in the Methods and Instruments of Dosimetry, was divided into a part dealing with ionization chambers, one dealing with scintillation equipment, and one dealing with photographic dosimetry. The fourth session dealt with Chemical Methods, methods of using ionization chambers for determining neutron doses and dosimetry in solids in fields of neutrons and gamma rays. The fifth session was devoted to Special Methods of Dosimetry Around Accelerators and Reactors . The sixth session was devoted to Dosimetry of Critical Assemblies.

Most of the papers were made available to the participants at the beginning of the meeting in rough-draft form. The Russian papers were not available nor were their titles included in the program, but were all postdeadline papers. This made them considerably less effective than they would otherwise have been. The Czech and Hungarian papers were available in advance.

There were about 130 participants in the meeting. The USSR sent 4, the U. S., 13, the UK 18, Sweden 8, Poland 6, Italy 8, the Netherlands 8, Germany 15, France 16, Belgium 12, Switzerland 7, and Austria 17. In addition, there were small delegations from Brazil, Bulgaria, Canada, Czechoslovakia, Denmark, Finland, Greece, Hungary, India, Japan, Mexico, New Zealand, Norway, Pakistan, and Yugoslavia. Several organizations sent one or two observers, the CERN organization sent 1, Euratom 2, the Organization of European Economic Cooperation 2, and the World Health Organization 1. The representative of the World Health Organization, Lowry Dobson, is a member of the Lawrence Radiation Laboratory on leave.

There were several papers of interest which I will try to comment on. The abstracts of all papers were available at the time of the meeting and about half the papers were handed out in complete form. The entire proceedings will be published in the relatively near future.

A very simple portable scintillation dosimeter was reported on by R. Boulenger from CEN (Centre d'Etudes Nucléaires) in Mol Belgium. This dosimeter used the property of the logarithmic response of a photomultipler when the anode current is kept constant. This greatly simplifies the circuitry, and with a few transistors it is possible to produce a small portable instrument with a rather low battery drain that is suitable for some types of personnel protection.

There was a theoretical paper by J. Neufeld of Oak Ridge on the dosimetry of heavy charged particles. Using a theory suggested by Knipp and Teller and new experimental data, Neufeld has calculated the energy dissipated by heavy charged particles in tissue. This method takes into consideration the change in the charge of heavy ions as they slow down. The calculations result in higher LET values for heavy charged particles than have previously been used. Neufeld again pointed out how important it is to secure new experimental biological information on the effects of heavy charged particles in tissue. (As an aside, this would point to the desirability of construction by Donner Laboratory of the new accelerator, to provid heavy ions of high charge of sufficient energy to perform biological experiments.)

A very sensitive local calorimeter was described by P. Milvy of Sloan-Kettering in New York. This calorimeter is capable of detecting temperature differences of 10^{-6} °C, and has a volume of 0.9 cm^3. It is useful in determining w values.

An interesting new method for calculating doses due to environmental contamination was described by K. A. Mahmoud of the United Nations Scientific Committee on the Effects of Atomic Radiation. He showed how, by using the rate of deposition of fallout, doses can be calculated by this new method that are relevant to genetic and somatic effects. This method applies both to fission products and to carbon-14.

Rolf M. Sievert, of the Radiofysiska Institutionen in Stockholm, described a small portable instrument to be used by radiation workers for the determination of dose rate. Up to the present, films worn by occupationally employed personnel have been the principal method of dose determination, but these give only the integrated dose; the dose rate in general is unknown. Since the harmful effects of ionizing radiation may depend on the dose rate, it would be useful to measure this variable. The doses are recorded on a disk 24 mm in diameter which rotates at a slow rate but still provides a time resolution of about 1/10 to 1/2 minute. The sensitivity of the instrument is from 10 microrads to several hundred rads. The total instrument is 6X9X1.7 cm and weighs 200 grams. It is actuated by an ion chamber. A mere glance at the record shows whether the dose rate has changed significantly. If an accurate reading is required the record is observed by a microscope.

Another portable instrument was described by R. Walstam, also of the Radiofysiska Institutionen Stockholm. This instrument is a pocket dosimeter containing four ion chambers which provide extended coverage in sensitivity. Hundreds of these instruments are now in use at Nadiumhemmet for personnel protection. The sensitivity range covered varies by a factor of a hundred between the four ionization chambers. These instruments are designed to be read automatically. Knut Gussgard of Statens Råd for Strålehgieniske Skorsmål, Oslo, pointed out in his paper that the condenser in condenser ion chambers is sometimes subject to radiation effects due to discontinuities in the conducting condenser layers. If an uncharged condenser is irradiated an electric charge is induced in the system, which means that on subsequent charging and irradiation there will be an additional discharge through the condenser in addition to the discharge that occurs through the ion chamber. The extra discharge can even be of the same order of magnitude as the discharge through the ion chamber. As a result the reading can be rather erroneous in certain cases. This effect occurs even down to doses as small as 0.1 r of x-rays.

In a paper by K. V. H. Lidén of the University of Lund, Sweden, the errors introduced in dosimetry by the finite size of ion chambers in depth dose measurements are discussed. This is a very useful piece of information. Chambers of three different diameters were used in this work and four different energies of x-rays were employed. It was found that a dose measured with the large chamber could be as much as 6% above that measured with the small chamber. The chambers range from about 3 to 12 mm in diameter. This effect can be accounted for theoretically.

Robert Loevinger of Stanford University discussed ionization chamber recombination in high-intensity fields. A simple theory was presented which makes it possible to set the upper limit of radiation intensity that can be used with a given ion chamber.

A paper by N. Chassende-Baroz from Saclay, France, described a new type of photographic emulsion that makes it possible to measure doses as high as 50,000 roentgens, and other emulsions that make it possible to measure 10^8 rotengens. Both of these doses are far out of the range of presently available commercial dosimetry film. This experiment is being carried out in conjunction with Kodak-Pathé. There were several papers from various countries on pocket film dosimeters, describing the different types of filters used, the energy ranges, the type of processing, the type of particles that could be detected, and the accuracy with which they could be measured. A great deal of this work has been done in the United States and no significant improvement was noted in the work reported over that which is available in the several laboratories within the AEC.

There were several papers on the subject of chemical dosimetry. This technique, using ferrous solutions is still largely limited to doses of more than several hundred roentgens. The most interesting new development of chemical dosimetry, which is mainly academic at this point, was mentioned by W. Minder of the University of Bern, Switzerland, in which he pointed out that it is possible to also measure the polarization of gamma rays and x-rays in a chemical dosimeter. A paper presented by S. C. Sigoloff, of Edgerton, Germeshausen and Grier, Inc., Goleta, California, he pointed out that the tetrachloroethylene system makes it possible to measure doses as small as 5 rads and as large as 5 million rads. This system has certain advantages over the ferrous solutions in that it is linear and rate- and temperature-independent, and in addition, is insensitive to fast neutrons. Although the insensitivity to fast neutrons is its main advantage, another advantage is that it is possible to detect the radiation-induced change in the solution by a variety of different methods--for example, titration, conductivity charge, or change in pH -- as well as by colorimetric measurement.

A very interesting paper was delivered by Gunnar Ahnström of the University of Stockholm, Sweden, on the yields of free radicals produced by different types of ionizing radiation. Free radicals released by gamma rays x rays, and fast neutrons have been determined by electron spin resonance. At high LET values, the yield of free radicals is somewhat reduced, apparently owing to local recombination. Heavy recoil nuclei, under certain conditions, produce essentially 100% recombination and thus the remaining free radicals are solely those produced by the gamma-ray component of the dose. This is another possible way of separating gamma-ray doses from the dose due to heavy ions. This effect is especially pronounced in hydrogen-free materials, such as magnesium oxide. The method, although somewhat complicated, is capable of remote indication by electrical means, making it useful in high neutron fields where one wishes to measure a small gamma component.

There was a detailed review article by J. Moteff of General Electric on threshold detectors for spectral measurements of fast neutrons. A very thorough method of processing foils made of many different materials which makes it possible to measure neutron spectra in a large number of locations and reduce the data in a reasonably convenient way was described. In the case of reactors it is possible to use this method of neutron spectral measurements and to compare it to theoretically predicted spectra quite satisfactorily. Several of the foils are not sufficiently sensitive for personnel dosimeter purposes, but the method is a reasonably reliable one suitable for use around accelerators in regions where the radiation field is reasonably high.

F. J. Davis, of the Health Physics Division of the Oak Ridge, described further advances in the use of Au, Au + Cd, Pu^{239}, B^{10}, Np^{237}, and S^{32} threshold detectors. It is now possible to secure dose-rate measurements as well as total neutron doses and neutron spectra from these foils. He described the use of gold-silicon surface-barrier detectors in the dose-rate measurements with sulfur. The main advantage of the foils, of course, is that they are sensitive solely to neutrons. It is somewhat more difficult to secure detectors that are completely insensitive to neutrons and sensitive only to gamma rays, but two such detectors have been mentioned earlier in this report.

There was a paper by G. S. Hurst, of Oak Ridge, in which he outlined methods for using counting techniques rather than ionization techniques for separating neutron and gamma-ray doses. Balanced ion chambers, which have been used by many workers, are especially weak when it comes to measuring a small number of neutrons in a large background of gamma rays, since the subtraction of gamma rays involves the difference between two large numbers and it is entirely possible to get a negative neutron dose. On the other hand, when there is a large neutron component and very few gamma rays present, there is an appreciable neutron response of the gamma-sensitive chamber, consequently with both extremes there are large errors present. Hurst has shown that, by using a small proportional counter lined with polyethylene with a filling of ethylene gas, setting the bias voltage, and making proper corrections for loss of counts under the bias voltage, he is able to easily separate 100 r/hr of Co^{60} gamma-rays from 1 mr/hr of PoBe neutrons. This excellent separation apparently is not the limit of his system, but even higher adverse ratios may be separated with considerable precision.

Hurst also described a method of using a commercially available G-M tube as a gamma-ray dosimeter. The neutron response is essentially eliminated by the construction of the cover for the Geiger tube. The Geiger tube so covered is approximately energy-independent for radiation above 150 kv, and neither thermal neutrons nor fast neutrons produce a response.

L. Treguer, of Saclay, discussed the use of a large liquid scintillator for neutron spectroscopy. He is using the recently developed technique for discriminating against gamma rays by identifying pulse shapes. This technique has received wide application in the last year since the discovery that neutron and gamma-ray pulses in some scintillators have different shapes which can be distinguished electronically. The method is certainly a very powerful one, and changes our whole concept of the possibilities of doing neutron spectroscopy in connection with radiation protection.

J. Dennis at AERE, Harwell, has constructed a polyethylene-lined proportional counter, with a series of washer-shaped disks which intrude into the sensitive volume of the counter, in such a way as to try to eliminate the sensitivity to direction which is characteristic of proportional counters. The counting rate for this proportional counter rather closely follows the curve recommended by the ICRP for the variation in neutron dose for a fixed rem value. A similar approach to this problem was described by Ingvar Ö. Andersson, Aktiebolaget Atomenergi, Stockholm, Sweden. He has constructed a very interesting proportional counter which is quite similar to counters that we employ at the Lawrence Radiation Laboratory. By varying the thickness of the polyethylene walls at various points in the counter he has adjusted the sensitivity in such a way that the counting rate is proportional to the rem dose.

There were several papers dealing with glass dosimeters. Most of the glasses are sensitive only to very high radiation levels and must be viewed by irradiating them with ultraviolet light. However, Robert Ginther, of the U. S. Naval Research Laboratory, Washington, D. C., has produced Ce-activated scintillating glasses having light outputs that are about 10% of that of NaI. These glasses appear to be promising detectors for time-of-flight measurements, but their sensitivity is still considerably below that of other scintillators that are readily available.

There was one paper by J. Schulman, U. S. Naval Research Laboratory, Washington, D. C., on thermoluminescent dosimeters. This is a rather new technique which offers considerable promise. It is now possible to produce a dosimeter whose response is linear over a range from a few milliroentgens to 10,000 roentgens and whose response is independent of dose rate from 10 mr/min to 7000 r/min. This dosimeter can be made energy-independent from 40 kv to 1-1/4 Mev for gamma rays. This type of detector will also measure the dose rate at the same time that it measures the dose.

There were a few papers on the subject of criticality accidents, and there were numerous papers describing how dosimetry was performed in various laboratories in a routine manner.

In general, the Conference was quite valuable in that several new techniques were described. It would appear that new developments were confined mainly to the large laboratories in England, France, Sweden, and the United States.

BERN

On June 14, I visited Professor Houtermans at the University of Bern. Professor Houtermans has pioneered the work on photoluminescence and has visited Berkeley and has spoken on this subject. There have been some major improvement in the technique since his visit to Berkeley. He has moved into temporary quarters pending the completion of a new physics building and this move seems to have greatly curtailed the experimental work in the field of photoluminescence.

Recently, Professor George Kennedy of the Geophysical Department at UCLA has built one of Houtermans's devices. He is interested in dating porcelain and ceramics of Mexican origin by their radiation dose. In addition, Dr. Michael Schön at the Institute for Applied Physics at the Technical Hochschule in Munich has done a good deal of work on this subject. He has used artifical fluorides and natural fluorides quite effectively to measure doses down to 10 milliroentgens. Professor Houtermans feels that the lowest dose that can be measured by the photoluminescent technique is about 0.3 mr.

A firm in Belgium makes a radiation dosimeter for military use which measures from 10 r to 10,000 r, but it would be easy to push this down to 1 r in a commercial instrument. To go down to 0.3 mr requires a delicate laboratory setup, but the 1-r level would be easy to achieve.

Professor Houtermans pointed out that the dose can be secured by two different means in the photoluminescent process. One is the filling of existing traps by the incident radiation and the second method is the creation of new traps by the radiation itself, and their subsequent filling. The creation of new traps depends on the material used, of course, but represents another approach which has not been thoroughly investigated. What at first was felt to be an unfortunate nonlinearity in the dose measurements is now viewed by Professor Houtermans as a possible asset which will allow a greater flexibility in this method.

At any rate, he feels that the number of traps formed is directly proportional to the dose. The filling of these traps may be nonlinearly related to the dose. In addition to the dose itself, the dose rate and maximum temperature achieved by the sample since irradiation are measured by the process of thermal luminescence.

Professor Houtermans demonstrated the apparatus to me. There are two types of equipment that he uses. In the older form the mineral is powdered to about 75 to 100 mesh and then is stuck on the center of a stainles steel strip shaped like a letter "H", with a small dab of silicon grease. The stainless steel strip is then placed under the photomultiplier and an electric current passed through it in such a way as to raise its temperature linearly with time. The resulting light output can be easily seen by the partially dark-adapted eye as a bright blue glow; a great deal of light is produced and the signal is quite strong in the photomultiplier.

The newer and more sensitive apparatus heats the sample very slowly. The material is placed on a copper heating element and no separate stainless steel planchet is used. The heating rate is measured in hours instead of in seconds and the resulting light output is recorded on a recorder of the Leads and Northrup type. This arrangement gives much greater resolution than is possible with the fast heating method, and some of the results are now available in unpublished form. Unfortunately, I do not have a copy of the results yet but expect to receive one soon. Professor Houtermans points out that the relationship between radiation dose and the light glow is a changing function of temperature along the glow curve, so that, in principle, by measuring with a known material that has been calibrated one can unfold the dose rate from the data and secure all the facts of the radiation history of the material. The Houtermans figure based on his meteorite measurements for the flux of cosmic-ray protons in outer space is 0.6 particles/cm^2.sec sterad greater than 300 Mev.

A theoretical explanation of this work has been started by Curie and Schön. An interesting application of the technique has been made by Earl Engle at La Jolla, who has investigated the temperature history of a lead-ore body from Leadville, Colorado which shows the heating caused by the intrusion of the ore body into the surrounding rocks. It has been suggested that the technique holds great promise for geologists in investigating processes at elevated temperatures, since an irradiated sample loses its thermal luminescence as a function of temperature and the highest temperature achieved can be determined from the glow curves. Schön, at Munich, has done some additional work with neutrons in thermal luminescence and on dE/dx measurements with thermal luminescence.

In addition to the thermal luminescence work, Houtermans has a great variety of experimental activity going on with respect to the age of the universe and the ages of various rocks. His low-level counting facilities are highly developed. At present Houtermans is working diligently on krypton-80 which has a half life of 250,000 years, and which he feels will allow him to determine the constancy of cosmic rays over the last 400,000 years. This is certainly quite important to many other fields, and he seems to be getting results that indicate that cosmic rays have been constant for the last 400,000 years.

In the last year Houtermans and his collaborators have been working at CERN with external protons from the new AG accelerator. One of his associates, George Cvijanovich, an American, has discovered that there is a focusing of protons from a target which occurs quite naturally about 90 meters from the target, giving 10^4 protons per cm^2/sec of parallel proton flux of 25.2-Gev/c protons. These protons lose about 300 Mev in the walls of the vacuum tank. So far all the experiments have been with nuclear emulsion. The beam is polarized and elastic scattering diffraction patterns have been observed.

Houtermans himself received hand radiation burns in an accident in the twenties and has had difficulty with his fingers ever since, so he is a classic case of beta and gamma skin burns.

CERN, Geneva

On June 16 and 17, I visited the Health Physics Department at CERN, which is under the supervision of B. M. Wheatley. The health physics equipment at CERN is all of very high quality and is rather more elaborate than we are familiar with. Permanent area-monitoring ion chambers are installed at a variety of locations around the accelerator and the signals are brought to the control room where they are displayed and recorded. In the circuits of these ion chambers there are alarm devices operating at two different levels in such a way that a radiation excursion would cause the main accelerator to be shut off.

There is a large expense involved and I was quite surprised to find that this method is used not only at CERN, but also at several other accelerators in Europe. At CERN tissue-equivalent ion chambers of the type employed by Rossi are used. No attempt is made to measure the average neutron energy. A balanced ion chamber is employed to try to make a measurement of gamma rays independent of the gamma-ray response of the tissue-equivalent

chamber. It is assumed that the neutron spectrum around the accelerator is similar to the PoBe neutron spectrum. This is different from our experience, and in some areas around the AG machine the method even shows a negative neutron flux. As a result rather large RBE's are assumed in every circumstance. The value of 10 is universally used at CERN in all cases.

High-pressure-hydrogen ion chambers are used where neutron energies of a few Mev are present and gamma rays are also present. For measuring build-up curves under paraffin, they use indium-cathode Geiger counters. These are rather convenient but somewhat more expensive than our technique. They plan to measure the average neutron energy by the method that we use. Much of their work is in the preliminary stage and has not actually been carried out to experimental results giving radiation fields around the machines. They also plan to use threshold detectors in the future work.

B. M. Wheatley is trying to organize, through the International Atomic Agency, an intercomparison of neutron standards and neutron calibration facilities so that neutron doses may be placed on a basis that will allow different laboratories to be certain of the absolute values of their neutron fluxes.

I had a long talk with Ansel Citron at CERN. Citron made the calculations on which the present CERN 28-Gev shielding is based. He does not work in the Health Physics Group, however, and is no longer interested in this type of work. However, he used techniques similar to ours, and his results are very closely in agreement with our feeling on the subject of shielding of high-energy machines. Citron considered only neutron attenuation in concrete; he did not consider the skyshine problem, since it was planned from the very beginning of its design to put an adequate cover over the accelerator.

My general impression of CERN was that the Health Physics Department was provided with every possible piece of equipment and convenience. Some of the facilities seem to be rather luxurious. They did not seem to have a research or development program under way at this time, but planned to start such a program in the future. At present they are concentrating on a rapid expansion of their program to cover the radiological safety of their two accelerators. The cyclotron, of course, is fairly well in hand at this time. The 28-Gev machine is well shielded so that it does not present an acute radiation problem, but they plan to learn a great deal more about its radiation field then is now known, especially on external beams.

Their shielding is very highly engineered. The main shielding of the accelerator ring is, of course, dirt and concrete, and constitutes a very complete cover. The shielding in the target area near the machine consists of large concrete blocks which can be moved on tracks by a specially designed small engine. The shielding placed around specific experiments and external beams is not as completely engineered and must be moved by rigging methods.

STOCKHOLM - Atomic Energy Company

I next went to Stockholm, arriving on Monday, June 20. First I visited the Swedish Atomic Energy Company, which is owned 60% by the government and 40% by private industry. This company duplicates only part of the activities of the AEC, mainly the reactor program. There is a separate organization for the design and perhaps eventual production of nuclear weapons, called the National Defense Establishment.

I visited Ingvar Ö. Andersson, at the Atomic Energy Company, Drottning Kristinas Vag 47, Stockholm. The Health Physics Organization of the Atomic Energy Company is divided into five parts; Reactor Safety, Health Physics, Instrumentation, General Physics, and Waste Disposal. Andersson works in the General Physics Division under Dr. Josef Braun. Andersson is in charge of the development of instruments and control electronics for health physics purposes. The entire Health Physics Division of the Atomic Energy Company is being gradually transferred to the new Atomic Energy Laboratories at Studsvik, which is about 60 miles south of Stockholm on the Baltic. This new laboratory is perhaps half completed at this time and will be very extensive and modern in every respect. Many of the scattered activities of the Atomic Energy Company which are now located around Stockholm are to be concentrated at Studsvik. There will still be much activity of the company in Stockholm even after Studsvik is completed.

Andersson, in part of his work on instrument development, has put a great deal of effort into the He^3 type of neutron spectrometer. His experience has essentially paralleled ours. He has used a glass system throughout and has avoided some of the problems of metal systems, but basically his difficulty has been similar to ours. He has also experienced the very large apparent breakdown pulses which seem to occur when helium is used in a proportional counter. Andersson has worked on these breakdowns sufficiently to convince himself that his difficulty lies in the insulators. I learned later during my visit to Aldermaston how to solve this problem.

Andersson's instrument division has designed and constructed a human-body 4π counter which is based on the use of a large NaI crystal located at a controlled position relative to the subject who sits in a reclining chair with the NaI crystal between his head and knees. The patient and the NaI crystal are enclosed in a very heavy shield. A pulse-height analysis is made of the NaI crystal pulses by a Phillips 99-channel analyzer. A similar analyzer is used in conjunction with the time-of-flight to pulse-height converter used for neutron spectroscopy with the reactor.

There is a very excellent glass-blowing and counter-production laboratory associated with Andersson's work. He makes glass BF_3 counters and many types of proportional counters and Geiger counters, both for health physics measurements and for reactor control equipment. There are 14 people employed in the instrument development branch.

Andersson has done a lot of work on a proton-recoil proportional counter, very similar to the ones we use in Berkeley. However, he interprets his results in a slightly different way than we do. He has tried to tailor the response of the instrument in such a way that the counting rate is proportional

to the dose rate in rem. The counter consists of a 0.1-mm-thick polyethylene ribbon wrapped on a cyclindrical grid. One-fourth of the cylinder is covered with 1-mm-thick polyethylene. The resulting polyethylene cylinder is 35 mm in diameter and 410 mm long. The filling gas is 190 mm of methane and 30 mm of carbon dioxide and 410 mm of argon. This produces a response which corresponds to the recommendations of the ICRP of 1954 on neutron RBE. The paper that Andersson presented at the Vienna conference shows a relation between the theoretical response and the required response for this particular polyethylene configuration. The two curves differ by less than 20% over the energy range from 1/2 Mev to 15 Mev. He also shows how the RBE values in NBS Handbook 63, which differ somewhat from the 1954 ICRP values, can be fitted by a similar arrangement.

Argon is added to the gas mixture to reduce the proton ranges so that fewer protons hit the opposite wall, and carbon dioxide is added to improve the counting properties of the gas. Above 10 Mev some protons still pass through the counter and the sensitivity is subsequently lowered. The carbon and argon recoils are responsible for a slight increase in sensitivity at 15 Mev amounting to about 10 to 15%. The counter was calibrated from 0.2 to 2 Mev by using a tritium p,n reaction from a Van de Graaff generator. The d,d reaction was used at 2.65 and 3.90 Mev, and at 14 Mev neutrons from the d,t reaction were used for the top calibration point. The counter was calibrated both with and without methane gas, and there is a very satisfactory shift in the response curve with energy when methane is introduced, which demonstrates that the response of the counter is duplicating the RBE values.

The angular response of the counter has been checked with 1.6-Mev neutrons, and it has been found that the isotropic resonse is 10% lower than the response to neutrons incident normal to the axis of the detector. This is similar to our experience with proton-recoil proportional counters. The angular response was measured with the counter containing no methane. An error less than 10% is also expected in the methane-filled counter for an isotropic flux relative to a monodirectional flux. The rejection of gamma rays is quite thorough with a bias setting that still allows the neutron pulses to be readily counted.

Some of these counters have been filled for two years with no measurable determination in counting characteristics. The counters are used both in portable transistorized instruments and in fixed installations.

The National Defense Laboratory

The next morning, July 20, I went to the National Defense Laboratory to see Nils Starfelt. He is at Ulvsundavägen 180, in temporary quarters near the Bromma airport.* Starfelt is in charge of about 15 young physicists. The organization has a history of about two years. They have a Van de Graaff generator with which they do neutron cross section measurements. They also carry on work at the Nobel Institute with a Cockcroft-Walton with 14-Mev neutrons. They are deeply involved in civil defense. They also have much time to work on basic problems. They plan to make extensive neutron measurements in air at various distances from weapons and other types of sources. They also plan to make calculations by the Monte Carlo method of similar situations.

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Starfelt has also worked on a He^3 neutron spectrometer and has had difficulties similar to those reported by others and experienced by us. However, he feels that the future of neutron spectroscopy lies in the direction of the solid-state work now being carried on at Harwell, about which he was most enthusiastic, and which I will describe later on in this report.

He has made numerous approaches to the problem of the pulse-height-inverting spectrum obtained with a NaI crystal. He has worked on similar inversions of neutron pulse-height spectra obtained with various detectors. He now has a mathematician working on this problem. He is not very optimistic about the outcome of this work. He feels that there are fundamental limitations to the results that one can obtain by inverting a pulse-height spectrum. He has used 20-by-20, ten-by-ten and six-by-six matrices. He has worked on the subtraction method and points out that the subtraction method automatically gives a bad start in any inversion process, since the statistics at the high-energy end are usually poor and immediately cause the build-up of oscillations in the inverted data. He has tried another method in which a wider and wider interval on the pulse-height axis is taken as the high-energy end of the spectrum is approached, thus gradually de-emphasizing the poor statistics. This process gives better results but still leaves much to be desired.

In general, Starfelt feels that it is important in any inversion process to take much wider intervals then one would wish to ultimately end up with in order to kill unfortunate oscillations arising from the statistics. Starfelt had some of his men working on the separation of neutron and gamma-ray scintillations in liquids and crystals, and in addition he is beginning to work with plastic scintillators purchased from Nuclear Enterprises Limited in Great Britain. The plastic is designated NE 150. The address of Nuclear Enterprises is Mrs. D. F. Sharp, Bankhead Midway, Sitehill Edinburgh 11, Scotland, U. K.

Starfelt indicated that automatic scanning of nuclear track emulsion (perhaps of interest to us) is being carried on by Professor Von Freesen and by K. Krisstiansson at Lund. Similar automatic scanning work has been done by Professor Ekspong at the University of Stockholm, who was formerly at Uppsala. Starfelt spent considerable time describing with great enthusiasm the Harwell work by Dearnaleyon solid-state detectors. He plans to use one of these detectors in a manner rather different from that at Harwell. He is going to put a small piece of lithium between two of the detectors and detect both the alpha and the triton and thus secure the high-energy resolution characteristic of the solid-state detectors. The lithium iodide detector should behave better if it is cooled to liquid nitrogen temperature. However, he reminded me that this must be done quite carefully--he unfortunately broke his last crystal with thermal shock. In addition to Starfelt, I talked with two of his assistants, Gustav During and Rolf Jansson.

The afternoon of July 20 I went to Studsvik. The car was supplied by the Atomic Energy Company as arranged through I. Ö. Andersson. Studsvik is about 50 miles south of Stockholm and is directly on the Baltic. It is a very new installation. There is no town at the site of the laboratory but there is a small town a few kilometers south, in the opposite direction from Stockholm. The laboratory is perhaps half completed at this time and is well built, and the offices and laboratories are luxurious by our standards.

At Studsvik I spoke with O. W. Bergstrom and Karl O. Widell. At Studsvik they use a neutron badge (their security badge) which contains an aluminum foil to improve the neutron response according to the method suggested by Joseph S. Cheka of Oak Ridge. The rem-dose neutron instruments made by Ingvar Ö. Andersson are used here for area surveys.

Andersson and his entire neutron detection laboratory will move from Stockholm to Studsvik in a few months when their new offices and laboratory are complete. The laboratory at Studsvik will include a reactor and a well-equipped Van de Graaff. The laboratory has low-density walls and floors to provide a minimum of backscattering. The film badges at Studsvik are changed both biweekly and quarterly so that each badge contains two sets of film. There is an IBM program which directly gives the neutron rem dose and the neutron flux from the counting rates of the various polyethylene-lined detectors which are distributed around the laboratories at Studsvik. I did not have a chance to go into this refinement but I was amazed by such an elaborate procedure.

Also at Studsvik there is some rather remarkable air-monitoring equipment which they use continuously to monitor air which automatically provides for the decay of radon. This equipment seemed to be unusually well made and very precise. The dust and air particles are collected by electrostatic means rather than by the usual filter-paper technique. In addition to the fine air-monitoring equipment, they have a projection microscope for looking at NTA personnel badges. They use 100X10 power with oil immersion and a projection system. There is an electric guide motor which moves the emulsion and it takes 5 minutes to scan a square millimeter at all depths in 25-μ film. They routinely scan 3 mm^2 per film.

On the morning of July 21 I went to the Biochemical Institute at 63 Odengatan in Stockholm to see Gunnar Ahnström, whom I had met originally in Vienna. The reason I visited him was to find out about the rumor I had heard in Vienna that Lars Ehrenberg, Ahnström's collegue, and also Snyder at Oak Ridge feel that it is possible that some biological processes may have RBE's higher than 10.

Ehrenberg is mainly interested in the fine details of radiation processes in biological systems. He tries to measure small-scale effects on free radicals. He has also done work on chromosome breaks and aberrations. The chromosome breaks and aberrations are proportional both to biological damage and to the dose. However, he does not know whether mutations are directly related to chromosome breaks and chromosome aberrations and therefore whether mutations are proportional to the dose. In his experiments the number that is counted is the number of chromosome breaks per cell.

Ehrenberg produces free radicals by an electrolytic process which he believes is identical with the process by which they are produced by radiation. He measures the free radical concentration by means of electron spin resonance and the production of free radicals at different LET's. He has observed higher rates of recombination of free radicals with high LET's, due, he feels, to the higher effective temperature along the track where the LET is large. In the future he plans to work with enzymes and bacteriophage. He would like to be able to have 10^5 rad per hour of neutrons, but at present he does not have a source of neutrons that will do this.

He discussed the role of chemical protectors which can be introduced to offset the effect of free radicals, and he feels that the chemical protectors must be present in the biological system before the free radicals are formed. There are methods by which he can stabilize the free radicals and thus allow better measurements to be made. Since he does not have an adequate neutron source in his work on neutron RBE's, he uses deuterons of 5 to 100 kev in order to reproduce the type of dE/dx that would be expected from neutron recoils.

Some of his work has been done with barley seeds, and RBE values as high as 30 have been observed with a modified neutron spectrum that has a cadmium ratio of 35. (By cadmium ratio he means that sodium carbonate is exposed both bare and with a cadmium cover. Then the sodium carbonate is dissolved in water and a Geiger tube is submerged in the solution and the counting rate taken.) Neutrons giving RBE's up to a theoretical limit of about 50 are, generally speaking, below 50 kev in energy. Lars Ehrenberg points out that barley seeds are unusually good radiation dosimeters from about 50 to 1500 rads, specially for neutrons. Ehrenberg has done a considerable amount of work on neutrons--for example, the effect of neutron dose on plant height. He has also worked on the biological effect of x rays at low temperature. In the radiation of seeds by x-rays it has been found that chemical protection is possible, especially when liquid air temperatures are used.

Ahnström cautions that the water content in seeds is very critical whenever they are used as radiation dosimeters, and either this must be carefully controlled or at least the effect known. There is also a question whether or not seeds are germinating at the time of exposure. A germinating seed is six to seven times as sensitive to x rays as a dormant one, in addition to the possible difference in water content at the various stages of development. Seeds are found to be twenty to thirty times as sensitive to neutrons as to x rays. However, the neutrons, surprisingly, do not give as large an enhancement of effect in germinating seeds as x rays do. In addition, the chemical protector used for seeds with x rays, namely hydrogen sulfide, does not seem to protect against fast-neutron damage. Oxygen pressure, which is known to have a considerable effect on the x-ray sensitivity of the seeds, does not seem to affect their neutron sensitivity.

He feels that the difference between the neutron dose and the x-ray dose to seeds lies in the fact that the x rays affect the seeds' growth by an indirect process, whereas the neutrons affect the growth by direct processes. Therefore the direct action of the neutrons can not be influenced by chemical protectors or by the water content, whereas the x-ray effect can be influenced by these factors. In work at low temperatures it is found that x rays are less injurious at liquid nitrogen temperatures than at room temperature. This appears to be due to the elimination of the indirect processes of radiation damage. Ehrenberg feels that the RBE for fast neutrons for the production of lethality, growth retardation, chromosome rearrangements, sterility, and prevention of germination is about 20 for dormant or germinating seeds of barley. He has published several papers on this subject.

His most famous paper, of course, is Gonad Temperatures and the Spontaneous Mutation Rate in Man (Nature 180, 1433 (December, 1957)).

This is a most thought-provoking article, and I highly recommend it to all those interested in radiation problems.

The radiation protection work at the Institute of Organic Chemistry and Biochemistry at the University of Stockholm has largely taken the form of trying to discover methods of scavenging free radicals from an irradiated substance in order to reduce the ultimate radiation damage. Nitrogen dioxide has been used for this in plant seeds, for example. For directly measuring the dose of neutrons the Institute uses barley, and finds the neutron dose from 50 to 1500 rads is easily measured by this technique.

UPPSALA

On the afternoon of June 23 I went to Uppsala to see Borje Larsson. He showed me the cyclotron and the Medical Physics installation at the University. The cyclotron beam has been adapted to medical purposes largely in the field of neurosurgery. The beam can be scanned over the sample which is being irradiated by two electromagnets which are driven by a rather ingenious but simple power supply in such a way that the beam describes a rectangular Lissajous figure. This allows a rather well-focused beam to be spread over any preselected rectangular area. In addition, the beam can be scanned in range by a carefully made water absorber into which water can be pumped or withdrawn very rapidly. These two beam-scanning facilities make it possible to radiate a volume in a sample quite intensely, leaving the surrounding tissues rather unaffected.

This technique has been applied to a variety of biological experiments. At present the entire installation is undergoing some major improvements while the machine is turned off for the summar vacation. In addition to the investigation of techniques for neurosurgery with protons, work has been done on direct irradiation of carcinomas in various animals. Some of these results have been encouraging, but in general I would classify the work at Uppsala as very intensive in the direction of developing the possibilities for surgery with accelerator beams, with only a small part of the effort in the direction of application to immediate cures. It is of interest that the work at Uppsala is supported to a considerable extent by grants from the American Air Force.

HARWELL

I went to England and visited Harwell on June 28. I first saw Pearson in the Health Physics group at AERE, Harwell, who had arranged for my entire visit. I again saw Herd and Dennis, whom I had met in Vienna. In addition, I talked to Abson from the Electronics Department and J. W. Smith and P. O. Holt, both from Health Physics. I saw George Rolands, who had done some theoretical work on neutron diffusion through shields. He is a theoretical physicist and has given up this work to join the group working on thermonuclear energy problems. However, he is still interested in the shielding, and we had a long discussion about his methods. He feels that the diffusion theory is not sufficiently good near a boundary to allow the calculation of the neutron flux outside the boundary, though this is something that Hess, Canfield, and Lingfelder have done at Livermore. Roland's calculations apply mainly to critical assemblies, and involve an effort to predict the neutron energy spectrum on the inside and outside of a homogeneous

shield. He became interested in the Hess work on neutron diffusion in the atmosphere and wrote to us asking a few questions about the calculational technique. The accuracy that he feels is possible is about 10%. Also the calculational technique used by Rolands is limited to large volumes of shielding. Rolands has used both an analytic and a purely numerical method. The latter method is the one he prefers.

On the morning of June 29 I went to see A. W. Batchelor at the Medical Research Council facility, which is immediately next door to AERE but outside their fence. The financing of these laboratories is through different channels. The Medical Research Council and the Rutherford High Energy Laboratory are apparently completely unrestricted. There is no guard or any other control of the access to these laboratories, and photographs may be taken at will and apparently all the research is unclassified. A. L. Batchelor is a physicist who works for Neary, who is also a physicist. (Please note that A. L. Batchelor is not to be confused with R. Batchelor, whom I saw later at Aldermaston.) Both of them have become interested in biological work. Neary does a considerable amount of work on neutron irradiation of bean roots. Other members of the group include Frank Williamson, who operates their Cockcroft-Walton and d, d neutron sources. Munson has a small group working on the effect of x rays on bacteria.

Batchelor himself has been running an experiment on chronic neutron exposures, using the Gleep reactor, for the last ten years or so. The radiation doses run a few rad per week. The neutron flux from the pile is moderated so that the average energy is somewhere in the neighborhood of 700 kv. There is already a book written on the subject by G. J. Neary, R. J. Munson, and R. H. Mole entitled "Chronic Radiation Hazards: An Experimental Study with Fast Neutrons". New experiments are going to be undertaken with goats and the BEPO reactor, using a converter plate and fluxes of several r per hour. This new experiment on goats will not start until the summer of 1961.

A. L. Batchelor will be involved with the physics of the goat experiment, which apparently will be quite extensive. He is also engaged in the measurements of w for heavy ions. His detection equipment is quite routine. He uses magnesium,argon-filled,ion chambers for measuring gamma rays to about 1000 rads per hour. He also uses polyethylene and bakelite with C_2H_2 gas for neutron detection ion chambers. These ion chambers are concentric in design and contain 10 to 50 cm^3 of gas. There is an extensive DD generator available which can produce 300 microamperes of deuterium on D_2O or 600 microamperes on a lithium deuteride target. The targets are about 1/2 in. in diameter and water-cooled. The neutron spectrum given by the target is fairly broad, compared with the direct d, D_2O reaction. The average energy given by the lithium deuteride target is the same as that from d, D_2O. At their standard exposure distance of 17 cm from the target the doses run from 5 to 6 rads per minute of neutrons.

There was an interesting feature in their Cockcroft-Walton accelerator. The gas supplied to the ion source enters through a small nylon tube under pressure of about 80 lb/in^2. This gas proceeds up to the ion source, the nylon tube taking the voltage gradient. The pressure of 80 lb is sufficient to prevent discharge down the nylon tube, and by means of this method the gas in the ion source can be changed at will when the voltage is taken off the

Cockcroft-Walton. The change-over from one type of gas to another can be accomplished much more quickly than by the conventional method of letting the system down to air. Care, of course, must be taken so that the high voltage is not turned on before the pressure in the nylon tube has been brought back up to 80 lb.

The Cockcroft-Walton also has a unique type of personnel-protection procedure which consists of a series of photoelectric tubes up and down a stairway leading in to the bombardment area. There is no access gate. The photoelectric tubes are connected to a scaling unit which counts the number of people who go in and come out of the bombardment area. The accelerator can be turned on only when this total is zero. It is stated that in the two years of operation of the machine there has never been a mistake.

For neutron dosimetry at the Cockcroft-Walton two small ion chambers are used, one filled with argon and the other with methane. There is an electrical subtraction made right at the ion chambers so that a single cable leads out from the ion chambers, giving the neutron response directly. Both these chambers are of the gas-flow type. Considerable work has been done at the Medical Research Council on neutron dosimetry with roots and seeds. H. John Evans has worked on bean roots. Batchelor pointed out that they have had considerable difficulty using seeds for dosimeters, since the water content of a seed has a large effect on the result. The water content is fairly difficult to control. A dry seed has about 4% water and the radiation damage to such a seed is higher than to a moist seed. The main question in seeds is whether the cell division that is observed after radiation, which is used as the criterion for radiation dose, is the first mytosis or not. It is the first mytosis that counts as far as radiation is concerned.

In addition to the moisture problem there is also the question of the storage of dry seeds. It is found that the longer they are stored after radiation before they are germinated the greater the radiation damage. Batchelor felt that the bean root is a far superior biological dosimeter in that the question of water content, storage, and the order number of the particular cell division which is being observed is not in doubt. There is no question, of course, that the use of seeds as a dosimeter in spite of their drawbacks is tempting. If the humidity and the time of storage are controlled, then all one needs to do is to radiate the seeds, then sprout them and measure the heights of the resulting sprouts. However, there needs to be standardization in every step of the process.

In the bean-root dosimeter there are three types of damage that can be observed and can be related to the dose: (a) chromosome breaks, (b) inhibition of mytosis, and (c) reduction in root growth. The RBE for each effect separately is about 10. However, the relationship of each effect to the dose is of some interest. All three effects are linear with the neutron dose; however, effects (a) and (b) are proportional to the square of the gamma-ray dose, whereas effect (b) is linear with gamma dose. It appears that the neutron dose is a direct effect and therefore linear, whereas the γ dose in the case of chromosome breaks and root growth is produced. by a secondary reaction and therefore is a two-hit effect and thus is nonlinear.

Considerable effort is now being made to check gamma-ray dose effects at low levels. It is difficult to reduce the dose rate and still get reliable experimental results, because of the confusion in cell division which occurs. It is also possible that gamma-ray effects may be nonlinear owing to the short length of the region of heavy ionization. It may be that one such region is not sufficient to produce results and therefore the accidental coincidence of two or more ionization zones is necessary to produce the effect. RBE's up to 50 have been measured in Tradescantia, and RBE's up to 100 seem to be theoretically possible.

I next talked to Dearnaley and Paul about their work with surface-barrier charged-particle detectors. The detectors that they use differ somewhat from those being developed here in Berkeley. They are gold-germanium and gold-silicon p-n surface barriers. They can be thought of as solid-state ionization chambers. The gold-to-crystal junction is made by gluing a gold foil to the crystal and the lead to the gold foil is then glued on also with a conducting glue. This technique is used instead of welding or soldering in order to prevent heating of the junction, which would destroy some of its desirable properties. With the gold-silicon detector 50-kv proton recoils can be seen, and at 100 kv the energy resolution is 0.3%. When germanium is used the crystal must be cooled to liquid nitrogen temperatures; however, silicon may be used at room temperatures. The crystal is allowed to oxidize in the air and then the gold is glued to the oxide.

Carriers last about 1000 times as long in the cold process detectors made by the Harwell techniques as in the type of diffusion junction which is produced by diffusion heating. There is also more noise in the junctions produced by heat diffusion. It is possible to make the gold junction 1 in.^{2} in area; however, this produces a rather large electrical capacity. The largest silicon junctions so far made have had a 2-cm diameter. The silicon used at Harwell is supplied by Dr. A. A. Shepard of Feranti Ltd., Shadow Moss Road, Wythenshawe, Manchester.

The crystals supplied have been lapped and etched. There is a production technique described in a report which I received. Briefly, the crystals are washed in distilled and demineralized water; then 100μg/cm^2 of gold is evaporated onto the crystal. The gold is placed only in the center of the crystal and the bare crystal left around it. A silver paste is used to glue a gold conductor onto the back. Usually the conductor used is a flat piece of galvanometer wire. The silver paste is type FSP-36 made by Johnson, Matthey and Company, Ltd., 73 Hatton Garden, London. The other contact lead, which is a silver-gold galvanometer wire, one mil by ten mils in size, is glued on with the same silver paste. Galvanometer lead wire is used to get a good contact area because of its flat shape. The silver paste is baked for one hour at 60°C. This temperature is said not to be sufficient to produce the imperfections which cause the reduced resolution in the conventional barrier detector.

When it is desired to detect fission fragments a much thinner barrier is necessary to minimize the size of the electron pulses relative to the fission-fragment pulses. In this case, the crystals are mounted on Kovar instead of on gold. The sheet of Kovar metal has a dimple placed in the middle of it. This dimple retains a puddle of silver paste in the heating process and prevents it from leaking around the sides of the crystal. The same process

performed on germanium gives deeper barriers and therefore higher-energy protons may be detected in the linear region. The resolution of such a detector is a compromise between three factors ; leakage current, capacity, and energy released. The current versus voltage of such a detector may vary from day to day owing to a change in surface contamination.

The rise time of the detector is of the order of 1 mμsec. The decay time is related to the capacity of the detector feeding into the cable. The cable is the main load on the detector. The decay time usually observed in the Harwell setup is about 7 mμsec. They use two 100-Mc amplifiers, each with a gain of ten in series ahead of their scaler. There is a fairly good voltage plateau with such a detector, occurring above 5 to 10 v, above which the pulse height from a given type of pulse is relatively constant. The capacity of the detector is reasonably constant for voltages above about 25 v. The pulse height for a silicon detector is quite linear with the energy of the protons to about 4.5 Mev. This is, of course, a function of the direction of the proton track and the thickness of the layer. When americium alpha particles are used with the energy of 5.48 Mev the pulse height has a full width at half maximum of about 0.38%. The maximum proton energy for linear response is a function of bias voltage, and this energy can be adjusted to some extent within the range of reasonable voltages.

This type of detector represents a considerable improvement over previous methods of measuring proton energies in the energy range below 10 Mev. Consequently, it offers distinct possibilities in neutron spectroscopy. At present Dearnaley and his associates are trying to produce a very small proton recoil spectrometer. This detector will consist of a thin hydrocarbon film produced by the flotation of zapon on water which will be placed over a lead collimator consisting of a bundle of parallel capillary tubes separating the hydrogenous radiator from the detector by a fraction of a centimeter. This unit, which will be less than 1 cm^3 in size, will be inserted into a reactor in an effort to measure the neutron spectrum in a small hole. The very high energy resolution of the detector--less than 1% for protons--should make it possible to produce a spectrometer with a greatly improved resolution. In fact, it is felt that from the experimental evidence available for randomly directed neutrons producing proton recoils in a hydrogenous film over such a detector, the resulting pulse-height distribution will truly be rectangular (as it should be in theory), which will offer great improvements over the presently available detectors, which do not produce a truly rectangular shape. If this is borne out by experience it will be possible to measure the energy spectra of neutrons approaching from any direction and to perform the necessary differentiation without much loss of resolution. Of course, the solid-state detectors suffer from their low sensitive volume. There are many situations in which there is not sufficient sensitive volume to offer a good counting rate, but the substantial improvement in resolution certainly makes them very attractive new detectors.

On the afternoon of June 29 I visited Snowden at the Rutherford High Energy Laboratory. Snowden is the Chief Health Physicist at the Laboratory; however, he is also a senior member of the staff and has many other operations under his control. For example, he is responsible for the rf system on the new Bevatron-type accelerator now being constructed and he is also in charge of design and eventual construction of their bubble chamber. One of his most

difficult problems is that in many English installations when an outside contractor is brought in to do work in the laboratory, the personnel employed by the contractor are considered to be nonoccupationally involved and therefore must be protected from radiation levels which we consider to be occupational.

William Burrells is Snowden's health physicist on the new accelerator. He has had many years of experience in radiological work; however, he has recently spent most of his time checking out the magnets for the accelerator which have now been delivered to the site. Around the accelerator, after completion, they plan to employ hydrogen- and argon-filled high-pressure ion chambers outside the shielding for routine monitoring purposes. These will be permanently installed and recordings will be made of their output. They will also have less sensitive models of the hydrogen and argon chambers, which will be portable. There will be a system of interlocks which will shut down the main machine on any radiation excursion that may be observed by these ion chambers. In addition to this rather elaborate fixed installation there will be, of course, a complete radiation survey made by equipment such as we use.

There is also a large proton linear accelerator at the Rutherford High Energy Laboratory which has been in operation for some time. Careful surveys have been made of this machine to investigate its skyshine and it is found that the measured values agree quite well with those calculated in the paper by Lindenbaum.

The large accelerator at the Rutherford Laboratory is remarkably like the Bevatron. It differs mainly in that the shielding is quite extensive and the entire machine is covered by a roof supported by a single large column in the center. The experimental areas are arranged in one quadrant. There is a provision for a possible second quadrant for experimental facilities. There is a large earth barrier on one side of the machine which presumably will protect the offices and shop from the radiation coming through the shielding in the experimental area. Part of the experimental area will not have a roof so the beams let out into the experimental area can scatter over the top of the earth barrier. This is a possible weakness in the design. However, it would seem that in general the shielding is very well designed and adequate, and barring extraction of a large fraction of the beam into the experimental area, the situation is well in hand. Their provisions for handling shielding blocks in the experimental area are rather unique. No extensive crane facilities are provided. Instead there is a very good system of tracks and little cars which make it possible to move the shielding blocks quite easily. Recently an investigation has been made of the possibility of floating the shielding blocks on compressed air. It is possible that the floor may be ground smoother than it is to make this more feasible. Some experiments have been run and it appears that with proper design, concrete blocks can be floated on a film of air, without unreasonably requirements on their geometric tolerance.

ALDERMASTON

On June 29 I went to Aldermaston to see Robert Batchelor. Batchelor wrote the first paper on He^3 neutron spectroscopy and it was in order to talk about this that I went to see him. David West at AERE, Harwell, is carrying on the He^3 work. Batchelor realized in the early stages of this experiment that the purity of He^3 was quite critical and that he must limit the tritium content to less than one part in 10^8. He originally tried purification with calcium. The vapor pressure of calcium tritide is about 10^{-5}. He hoped to reduce the contamination to one part in 10^{10} by the use of calcium. The impurity limit of $1/10^8$ is based on the avoidance of tritium-decay β pulse pile-up. The individual tritium pulses are very small, of course, compared with the desirable pulses from the $He^3+n = T+p$ reaction, but they are so numerous that pile-up is a serious limitation. Dr. Wilkes at the Clarendon Library at Oxford did cryogenic separation of tritium from helium and he got purities T/He^3 of $1/10^9$ to $1/10^{10}$.

The second counter that was produced used 750 cc of He^3 plus krypton. At present work on the neutron spectrometer is centered on the use of He^3-filed ion chambers rather than proportional counters. In this manner many difficulties are avoided. The present goal is to use such a spectrometer to measure the neutrons produced by thermonuclear reactions. For 2.5-Mev neutrons the proportional counter has a limited proportionality. The ion chamber used is a cylindrical one. The present He^3 purification technique that seems to be best is to dilute it with hydrogen and then pass it over pyrophoric uranium. Repeated operations of this type seem to produce purities of the order T/He^3 10^{-10}. After a few dilutions, further dilution produces no additional increase in purity, since some of the tritium adheres to the walls of the vacuum system and this tritium is not eliminated by dilution.

In the early days of the project, Batchelor observed large breakdown pulses in the helium proportional counter. These breakdown pulses have been observed by many others who have worked with such instruments. In order to eliminate these breakdown pulses he mixed carbon dioxide or methane with the He^3 in addition to eliminating the breakdown pulses. These gases produced an improved drift velocity. Less then 1% of carbon dioxide was used instead of methane in order to avoid the hydrogen recoils that would come with the methane.

The purity of the carbon dioxide should be very high and at first it was difficult for Batchelor to get sufficiently pure carbon dioxide. The carbon dioxide was frozen several times to improve its purity by passing it through a trap filled with dry ice and acetone. Eventually it was found that the ideal way to purify carbon dioxide was to introduce it into a bulb in which sodium had been evaporated in such a way that the entire inner surface of the bulb was covered with a sodium mirror. The carbon dioxide is allowed to stand for several days in the bulb and is then found to be remarkably pure. The sodium mirror bulb is a very simple method by which gas is purified and it has many applications.

The exact process by which carbon dioxide eliminates breakdown pulses is not immediately obvious. However, it is related to the Ramsauer effect by which carbon dioxide speeds up the electron collection time. The carbon dioxide concentration was kept less than 1%, since this was found to be sufficient to suppress spurious discharges and to improve electron collection time, while larger amounts would have affected the resolution of the spectrometer.

Robert Batchelor's work at Aldermaston is the counterpart of Jack Peterson's work at Livermore. He is in charge of fast-neutron physics. There are three accelerators available, one at 6 Mev, one at 3 Mev, and a tandem Van de Graaff giving 10 Mev. There are two sections to the Physics Department at Aldermaston, one dealing with fast-neutron physics and the other with charged-particle physics. The 6- and 3-Mev accelerators were made by High Voltage Engineering Co. The work divides itself into two types; there are time-of-flight neutron spectroscopy and inelastic scattering work. There is also work with a large liquid organic scintillator which is spherical in shape. This detector was made by the Nuclear Enterprises Corporation and they are gadolinium-loaded. The 220-liter spherical model costs about 4000 £ total and has twelve 5-inch tubes viewing it. There were quite a few difficulties in the early days of its operation but now it seems to be quite satisfactory.

There is an elaborate arrangement for moving a large liquid scintillator about a target in an arc. Both the time-of-flight work and the large liquid scintillator installation are associated with the 6-Mev Van de Graaff. All the work of these machines is on neutrons at present. There is a Chemical Section (also under Batchelor), directed by Perkins, which does activation work and heavy-ion work. There is also a project for measuring fission cross sections to about 1% accuracy, and in addition work on measuring the number of neutrons emitted per inelastic event.

One detector, which Batchelor was quite proud of, is a small energy-insensitive counter. This counter consists of a photomultiplier on top of which is placed a small hollow plutonium sphere about 1 to 2 in. in diameter. The plutonium sphere is filled with xenon to make a gas scintillation counter. The probability of a count is quite flat from about 10 kv to about 6 Mev. This detector is, of course, isotropic as well as energy-insensitive. The xenon is frozen and pumped on; no other purification is used. Indium seals are used in the xenon gas system and the most important advantage of this detector is that it has a very high speed. There is about 20 mg/cm^2 thickness of plutonium in the sphere. There is an interesting experimental setup on the tandem Van de Graaff, which consists of a large tank, approximately 10 feet in diameter and 10 feet high, in which there are 24 magnetic channels at 15-degree intervals entirely around a target. At the end of each magnetic channel there is a provision for a photographic emulsion. This spectrometer makes it possible to measure an angular distribution at 15-deg intervals simultaneously.

As a matter of interest, I was not allowed to eat in the lunch room at Aldermaston because it is felt that people discuss their work at lunch and as a result foreigners are generally required to eat in town or in a special, private lunch room.

PARIS

On July 11 and 12 I visited Saclay and Orsay. I first went to see P. Bonet-Maury at the Radium Institute at the Sorbonne. He is in charge of health physics at the University and his work is largely biological. Bonet-Maury's work is quite similar to ours in many ways with the exception of his biological interest. He is academically inclined and the work is all unclassified. The work with the accelerators is carried out at Orsay, which is about 1 kilometer from Saclay. His main office, however, and some more laboratories are in Paris near the Sorbonne in the Institute du Radium.

Bonet-Maury provided me with a report which describes their experience with induced activities at their synchrocylotron and gives neutron intensities at various places around the cyclotron. Their experience is quite similar to ours in both these categories. The dosimetry work at Orsay, supervised by Bonet-Maury, is carried out by Mlle. A. Deysine, who is in charge of physical dosimetry. She makes measurements of neutron flux and also of induced activities, etc. At 1 minute after the cyclotron has been turned off, the induced activity has a half life of about 5 minutes. After 10 minutes the half life becomes much longer and the data do not indicate what that new period is. When the cyclotron is turned off the radiation level is about 1 r per hour inside the machine at the entrance to the magnetic channel. The cyclotron accelerates protons to about 150 Mev. Outside the vacuum tank gamma rays of a few Mev are the chief radiation problem. After the cyclotron was off for two months following a 6-month steady running period, there were a few hot spots inside the vacuum tank near the dees, giving readings of about 200 mr/h. After the 2-month shutdown the radiation level in the vault was about 10 to 50 mr/h, consisting of a few Mev gamma rays. The internal circulating current is 2 to 3 ma.

Bonet-Maury explained that in the last few months a health physics society called "The Societé du Radio Protection" has been organized in France. The President of the society is Jamet, the secretary is Duhamel, the head of Saclay's Health Physics Group, and the treasurer is Bonet-Maury. The French feel that it is too difficult to attend meetings of the Health Physics Society in the United States, even though this is intended to be an international organization, and that they need their own local society. However, they will closely affiliate with the Health Physics Society in some unspecified way.

At Orsay there is a 2-Bev electron linear accelerator rather similar to the Stanford one, which is partially completed at this time. It is intended gradually to extend this machine by adding to the low-energy end. The shielding of the machine is rather complete. The experimental area is very extensive and it appears that this machine is well constructed; at present it is operating up to about 600 Mev. At several places along the machine there are health physics monitors, which are ion chambers with a connection to a recorder in the main control room. Each ion chamber has built into it two remotely-operated gamma sources which can be moved from the storeroom, so that it is possible to check on the operation of any ion chamber quickly without leaving the control room or turning off the main accelerator. In addition to the large accelerator there is a 150-Mev cyclotron, and a 4-Mev dc machine which is under construction. There are two Cockcroft-Walton accelerators, one of 300 kev, and one of 600-kev and one cyclotron of 15 Mev.

Affiliated with Orsay is a national committee called with CNAS whose purpose is to design accelerators for France. They have money to do research and development work solely for the purpose of new accelerator design.

For neutron detection Bonet-Maury uses zinc sulfide spheres which were designed at Harwell for his biological work up to a few hundred rads. He also uses an iron sulfide chemical dosimeter. He has some graduate students working on proton dose measurements who use, in addition to chemical dosimeters, aluminum activation and C^{11}-activation in plastic. Ion chambers with small central electrodes are also used.

Much of the biological work consists of measuring the RBE in mice, goldfish, or bacteria. Bonet-Maury uses goldfish frequently for biological work since they are cheap and easy to use and they have the advantage that they are always immersed in water, and in this condition the dose can be made quite uniform throughout the goldfish without the variation that is characteristic of a dry animal, with varying thicknesses of animal structure.

On July 12, I also visited Saclay. At Saclay I was shown around by Mlle. Ann Duchateau, who is a translator in the Health Physics Information Division. The Health Physics Division has about 600 people in it in all of France, of which one third are at Saclay. S. G. Duhamel is in charge of this group, which is known as Service de Controle des Radiation et de Gene Radioactif. The group has its own information division and a large amount of translation is done by the Information Division itself. This is the reason for Mlle. Duchateau's activity. Her specialty is making rapid technical translations of about ten languages into French or into English, a rather unusual ability compared with our Health Physics activity. I had a talk with G. Soudain, Guirlet, Benezech, and Alec Stirling. All of this was done through translators except for Stirling, who spoke excellent English. Unfortunately, the translation made it difficult for them to say very much in view of their numbers, but I gathered that they work for Duhamel.

They use the Chekka-type film badge which has aluminum included in the film badge packet by Eastman, it isn't an external piece as is the case in some badges. At Saclay, generally speaking, they handle high-energy neutron protection as we do in Berkeley. Their attitude toward detectors is the same as ours, and with certain exceptions. They have not yet produced a polyethylene-lined proportional counter. They do have little bakelite boxes in which they put dental-x-ray-size K-5 emulsions to provide approximately tissue-equivalent surroundings in some of their film badges. However, I saw many film badges that did not have this feature. Their personnel dosimetry films have three different emulsion stripes on them, one sensitive from 10 to 600 mr, the next sensitive from 500 mr to 20 r, and the third from 10 to 800 r.

In monitoring the radiation level in an experimental setup at the Saclay large accelerator (Saturne), the technique used is a rather interesting one. A radiation survey is made near experiments by methods that are conventional in Berkeley. After the field pattern is known the experimental run is monitored by a two-scintillator telescope which is aimed at the target of the experiment, since the ratio between the biologically significant detectors and the scintillation telescope has been established. Fast electronics is used in the monitor telescope. By "fast electronics" they mean millimicrosecond coincidences.

I was shown around the Saturne Synchrotron by Alec Stirling, who is the Health Physicist in charge and who has made all the radiation surveys and guided the shielding work. Alec Stirling provided me with several Health Physics reports on the accelerator and, in addition, described his gradual improvement of the shielding situation. A roof has been added to about two-thirds of the area over the machine, which has greatly reduced the radiation levels outside. Stirling has made measurements which give him the nonisotropic and the deviation from isotropy of fast neutrons around the machine. He finds that at a distance of about two machine diameters the neutrons approaching from the machine are about 2-1/2 times as intense as those coming toward the machine from the other directions, and the neutrons approaching at 90 deg to the radius line to the machine are somewhat intermediate. He has made attenuation measurements in the heavy concrete roof above the machine for fast neutrons. There are extensive surveys included in the written reports which show the fast-neutron flux at various locations around the building. Neutrons of energy from 100 kv to 5 Mev have been measured in one series of experiments and greater than 20 Mev in another series.

There is a series of measurements showing the result of gradually putting the roof on the Saturne accelerator. The measurements of the radiation field around the accelerator have shown that the tangent tanks are the weakest barriers as far as shielding is concerned, and as a result extra shielding is placed over the tangent tanks, a conclusion identical to the one we reached in Berkeley.

The health physics program in Saclay is in its early stages of development, owing to numerous reorganizations in the past few years. A large fraction of the health physics work in the French Atomic Energy Commission is carried on at the Centre d'Etudes Nucléaires de Fintenay-Aux-Roses (CENFAR). This is a new laboratory located about half way between the center of Paris and Saclay, on the road to Saclay. Jaffe is the head of Health Physics at Saclay, whereas Duhamel is in charge of health physics in all of France. The information division of Health Physics, which arranged my tour through the laboratory and supplied the translator, is under Duhamel and serves all of France, rather than being restricted to Saclay, although physically it is located at Saclay.

The French are building a large new laboratory on the Riveria at Cadarache, which is near Aix en Provence. This laboratory will be the largest in France and will be restricted to low-energy physics and reactor work.

In summing up the visit to Western European High-Energy Health Physics installations I would say that the laboratories at which problems quite parallel to ours exist are the Rutherford Laboratory at Harwell, the Saclay and Orsay laboratories near Paris, and the CERN organization at Geneva. With regard to the development on instrument and counting techniques, the Swedish work of the Atomic Energy Company and the National Defense Organization are quite significant. Probably the most interesting single development of the trip was the discussion which I had at AERE, Harwell, about the solid-state detectors with low-temperature-produced junctions to measure proton-recoil energies. The second most interesting development is the work carried on in Sweden by Anderson on the polyethylene proportional

counter which can be adjusted to fit a variety of neutron RBE curves. This instrument should have a wide application in many different high-energy accelerator applications.

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