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HEALTH PHYSICS DIVISION

K. Z. Morgan, Director
F. Western, Associate Director

QUARTERLY PROGRESS REPORT

for Period Ending October 20, 1950

DATE ISSUED DEC 11 1950

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INSTRUMENT DEVELOPMENT

Personnel in this group previously engaged in physical research directed toward the development of components for radiation instrumentation have been transferred to a group newly organized within the Health Physics Division under the name "Physics of Radiation Dosimetry Group."

Constant Water Monitor. A scintillation counter was bread-boarded and tested. The low-energy beta activity was largely masked by the high efficiency for gamma counting; therefore the work on the scintillation counter was shelved.

A continuous-gas-flow proportional counter, 100 cm^3 in volume with an aluminum window 0.0005 in. in thickness, was tested. Preliminary measurements gave a background count of about 70 c/m over a 15-min interval, and 210 c/m when water having 440 $d/m/cm^3$ was under the counter window. This attack appears promising; the associated apparatus is being simplified and refinements are to be made.

Radio-frequency High-voltage Supply. A laboratory H-V supply to provide a regulated potential adjustable, from 500 to 2000 volts, maximum current drain 0.001 amp at regulated output and 0.0018 amp at short circuit for safety, is being packaged and drawings are to be made. The purpose of this H-V supply is to reduce the health hazard to Laboratory personnel.

Fast-neutron Survey Meter. The progress of development of proportional counters for various types of neutron measurements has been given in previous quarterly reports and is given below under "Physics of Radiation Dosimetry." A member of the Instrument Development Group is now considering the circuitry problems involved in engineering both a simplified fast-neutron survey meter and a fast-neutron dosimeter incorporating special designs of the fast-neutron proportional counter.

RADIOACTIVE WASTE DISPOSAL RESEARCH

The personnel, facilities, and basic program of the Waste Disposal Research Section have continued, with minor changes, as reported previously. Cooperation with other groups and agencies and the conduct of joint research projects have continued to receive emphasis.

Water and Liquid-waste Decontamination Processes. Continued studies of conventional water-treatment methods to determine their efficiency in the removal of various radioactive materials have included laboratory jar tests and operation of the small experimental water-treatment plant. The experiments were designed to approximate average conditions which might be encountered in water-purification plants. The data obtained thus far are incomplete and have not been fully analyzed, but they indicate generally the efficiencies that may be expected. Although certain radioisotopes are almost completely removed from water by these methods, the overall efficiency in the removal of mixed fission products is rather low (of the order of 50 to 80 percent) under usual conditions of operations.

Studies on the removal of radioisotopes from liquids by the process of precipitating calcium phosphate flocs from solutions of high *p*H have continued. It is hoped that chemical treatment methods will be found which will be useful as a means either of increasing the efficiency of water decontamination processes or of treating economically large volumes of low-level radioactive wastes. The research participant from the University of Texas Sanitary Engineering Staff, who completed his three months' assignment to this project on September 22, has assisted in these studies. Several phosphate coagulants and a variety of experimental conditions were tested with individual radioisotopes and with mixed fission products. It was found that high levels of removal were obtained if an excess of phosphate was used with a *p*H above 11.3 during precipitation. A preliminary report of the results of these studies was made at the meeting of the American Chemical Society in Chicago, September 7.

The graduate student assigned to studies of sewage trickling filters has completed his shakedown experiment and has begun a series of studies to determine their efficiency in removal of radioiodine. These studies are expected to be completed about the end of December.

Survey Studies of White Oak Drainage System and Clinch River. Most of the survey work has been in connection with the TVA-AEC Ecological Study of White Oak Creek (described in the two preceding quarterly progress reports, ORNL 695 and 786). Members of the TVA-AEC staff are conducting reconnaissance surveys of the entire creek and lake area below the ORNL site. The fisheries biologist has completed field collections for an estimate of the population and of the specific characteristics of fish in White Oak Lake; the botanist and the limnologist, assisted by the biological aide, are collecting, preparing, and preserving for present and future study hundreds of specimens from this drainage area and from other streams and pools. It appears that the flora and fauna of the White Oak Creek area are typical for this region.

The physical survey of the area, largely by TVA, ORNL, and USGS personnel, is well advanced. The installation of field location monuments, preparation of a large-scale map for field survey use, and a silt-depth survey of White Oak Lake have been completed. A systematic mud survey, consisting in the collection and radioassay of mud samples from the entire lake and marsh area, was performed by the Survey Monitoring Section during September. Water samples for physical, chemical, and radiological analysis are collected biweekly. The first of a series of measurements by TVA specialists to determine the time of water travel downstream through the creek and lake at various stages of stream flow has been completed. An intercepting sewer and weir-box installation to permit accurate measurement and monitoring of the effluent from the settling basin is nearing completion.

A series of laboratory experiments with controlled exposure of aquatic organisms to radioactive materials has been begun. Small fish now being kept in aquaria containing dilute solutions of radioactive cesium will be sacrificed at various time intervals for study of the concentration of the cesium. These specimens will also be used in work to improve the techniques for analysis of biological samples from the natural environment.

During September the logging of radioactivity in the test wells installed under the AEC Geological Survey Project was resumed, and measurements have been made on approximately half of the 51 test wells. This work is to be continued until records are complete. It will be repeated in the future with a semiautomatic cable reel and recorder mounted on a small trailer; these instruments are now being constructed and assembled.

Instrumentation and Techniques. Further work has been done on the development of mud probes to estimate the radioactivity from 1 to 18 in. below the surface of the mud in White Oak Lake and under various depths of water up to 12 ft. The instrument consists of a thick-wall stainless-steel G-M tube detector mounted on the end of a jointed aluminum tube and assembled with a portable survey meter adapted for this purpose. The instrument has been calibrated with a radium standard to give readings approximately in milliroentgens per hour and has a range of from 0.01 to 100 mr/hr on four scales. It has been field-tested and used to estimate the exposure received by organisms submerged in the mud below White Oak Dam. A newly designed gamma detector for this probe is being constructed. A beta detector has also been designed.

Progress has been made in the further development and testing of other instruments for use in the Ecological Study and other field survey projects. The fish probes are being calibrated by taking readings on live fish through the mouth and then sacrificing the fish for dissection and radioassay. A continuous proportional sampler of the "Trebler" type has been delivered and is being installed in the effluent weir box at the settling basin. Some tests have been made of the auger-type mud sampler, and work has been started to develop an underwater sampler for taking samples at the water-mud interface.

Two workers in this group, with advice from specialists in other groups, are working on methods for improving the efficiency of counting the disintegrations in samples containing unknown mixtures of radioisotopes of various energies. The approach adopted is, first, to determine the counting efficiency of beta particles as a function of the energy of the particles, and, second, to develop a method to determine a mean energy for a mixture of isotopes from which a mean counting efficiency may be obtained. A tentative method has been developed, and work will be continued in an effort to evaluate the factors that affect the accuracy of the method.

The fisheries biologist of the Ecological Study and a radiochemist of this Section have developed techniques for handling fish tissues through digestion and radiochemical separation procedures on a volumetric basis so as to eliminate all routine weighing of samples after the initial weighing. This procedure has been tested and outlined in detail and is being adopted for routine use on all suitable biological samples.

Further details of the waste-disposal studies in the Health Physics Division are given in the quarterly progress report of the Waste Disposal Research Section for the period July 1 to September 30, 1950.

THEORETICAL PHYSICS

Empirical Evaluation of Effective Atomic Number. Experimental values of the mass absorption coefficient for gamma and X rays, μ/ρ, have been tabulated by J. M. Allen.[1] If the mass absorption coefficient σ/ρ corresponding to the Compton effect as computed from the Klein-Nishina formula is subtracted, τ/ρ, the mass absorption coefficient for the photoelectric effect, is obtained.

Using least squares, these semiexperimental values of τ/ρ are fitted by the formula $\tau/\rho = kZ^p/E^q$, where Z is the atomic number and E is the energy. It is found that with $k = 6.4598 \times 10^{-9}$, $p = 3.2315$, and $q = 2.9881$ the computed values of μ/ρ are not in error by more than 20 percent for the range $5 \leqq Z \leqq 20$ and $0.01 \leqq E \leqq 0.2$ Mev. For the range $1 \leqq Z \leqq 16$ and $0.03 \leqq E \leqq 0.2$ Mev the error is within 11 percent, and it is within 6 percent over much of this range. Using the formula for τ/ρ, a formula for effective atomic number can be derived in the usual way.

A detailed report of this project is in preparation.

Calculation of Stopping Power at Intermediate Energies. The proposed methods described in previous quarterly reports have been used in determining the stopping power for protons in gold, silver, and aluminum within the energy range from 300 to 600 Kev. The results obtained differ from experimental data of Warshaw[2] by 12 to 19 percent. The project has been completed, and the results will be described in detail in a report to be issued soon.

Fast-neutron Tolerance Calculations. The life histories of 2000 neutrons of initial energy 10 Mev scattering in an infinite space of tissue have been computed by the Monte Carlo method. The collision density as a function of energy and position has been tabulated for the case in which the neutrons are normally incident on a slab of 30 cm thickness and for that in which they are normally incident on a half-space.

The corresponding energy loss per neutron has been tabulated for the slab geometry and indicates a peak at the boundary of 0.3 Mev/cm^3 and a second peak of nearly the same height at about 4 cm. The curve then falls off monotonically to 0.085 Mev/cm^3 at 30 cm. Preliminary statistical tests indicate an accuracy of about 10 percent in these figures, but further investigation is in progress.

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(1) In *Handbook of Chemistry and Physics*, 31st Edition, *pp.* 2031-2036, Chemical Rubber Publishing Co., Cleveland, 1949.

(2) Warshaw, S. D., "The Stopping Power for Protons in Several Metals," *Phys. Rev.* 76, 1759 (1949).

Using RBE (relative biological effectiveness) factors of 10 for the energy losses due to protons and 20 for energy losses due to the recoil of heavier nuclei, a dosage curve is obtained, the highest point of which indicates a maximum permissible flux of 14 neutrons/cm^2/sec based on a tolerance value of 0.06 rem per 24-hr day. These figures are to be regarded as provisional pending a more detailed analysis of the data.

This method takes into account multiple scattering as well as the finite thickness of the body. For comparison, the tolerance given by K. Z. Morgan for 10-Mev neutrons and based on first scattering is about 12 neutrons/cm^2/sec and assumes the RBE to be 10 for the processes considered above. Using an RBE factor of 10 throughout, our value would be 16 neutrons/cm^2/sec.

A detailed report on the problem will be issued after further analysis of the data. It is planned also to use the data to obtain tolerance values for beams of lower energies, but this project cannot be carried out until computing machines are available.

EXPERIMENTAL RADIATION MEASUREMENTS

Dispersal of Stack Gases. About 25 runs, each releasing roughly 200 curies of radioactive argon from the pile stacks, have been made during the past month. A thorough analysis comparing the data with meteorological conditions has not been completed.

Geological Surveys. During the past month, an aerial survey of regions in Wyoming and South Dakota was made for the purpose of discovering radioactive ore. Some anomalies noted in South Dakota will be investigated further. The equipment used in this survey consisted of 38 Geiger counters, each 2 in. in diameter and 10 in. long, connected in anticoincidence. Apparatus coupled to the radio-altimeter and using a cam arrangement to adjust the sensitivity of the recording rate meter to compensate for variation in height of flight above terrain was tried out and shown to be accurate within the statistical error of the recording.

Radiation Background Studies. A flight over the Arco area in Idaho is being considered to record the background of the area before operations are started. This is expected to take place next spring following the installation of scintillation counters, consisting of seven large sodium iodide crystals, each 4 in. in diameter and 2 in. thick, which will replace the Geiger Counters.

PHYSICS OF NUCLEAR RADIATION

Backscattering. Studies of backscattering with the use of an extrapolation chamber discussed in the last report have been continued. Partial collimation of beta rays was used in an investigation of the backscattering by a number of materials of atomic number ranging from that of beryllium to that of lead. The minimum deflection between the primary direction and the final direction varied between 71° and 86° while the maximum deflection possible was always 180°. For saturation backscattering the intensity was considerably reduced with increasing collimation. The ratio of backscattered radiation from material of high atomic number to that of material of low atomic number increases with increasing collimation.

The energy of the backscattered radiation was investigated using aluminum absorbers of increasing thickness. In agreement with previous investigations it was found that the average energy of backscattered radiation increases with the increase in atomic number of the backscattering material. A qualitative theoretical explanation of this effect can be given by combining Rutherford's or Mott's scattering formula with Bloch's energy-absorption formula for fast electrons.

Investigations of the growth of backscattering with thickness of material were continued to determine the mass per unit area of each material required to produce one-half of the saturation backscattering for that material. It has been found that these values decrease with increasing atomic numbers, as would be expected theoretically. The following values were found with partially collimated backscattering: Al, 32 mg/cm^2; Sn, 29 mg/cm^2; Pb, 21 mg/cm^2.

An investigation was conducted to determine the average energy distribution of the backscattered radiation with increasing thickness of the backscatterer. For lead and aluminum it was found that the average energy increased with increasing thickness. Further investigations with pressure chambers and different gases for backscattering are in progress. A detailed report of the results is being prepared.

Fast Neutron Monitoring. A series of tests has been run on ADP ($NH_4H_2PO_4$) piezoelectric crystals to evaluate any possible frequency change which may occur under fast-neutron bombardment. Since this compound has a high hydrogen

content, it was considered possible that recoil protons produced by fast neutrons would disrupt the crystal lattice sufficiently to modify the frequency characteristics to a measurable extent.

The crystals were obtained from Brush Development Company. Zero temperature cuts were not available. The temperature coefficient of frequency averaged -280 cycles/°C between 0°C and 23°C. The high coefficient made very close temperature control necessary, which was accomplished by use of a bath of melting ice in which the crystal holder was immersed when cycle frequency was being measured.

Reproducibility of frequency at ice temperature (0°C) could be attained only to within about 80 cycles, the frequency of the crystals used being about 1 megacycle. Any effect of n_f bombardment was less than this, though there was a tendency for a reading after bombardment by approximately 10^{12} n_f/cm^2 to be somewhat less than the reading just previous. At any rate, since weekly tolerance exposure is about 10^7 n_f/cm^2, this method is too insensitive for personnel monitoring even if the effect is real.

Although ADP crystals cannot, as yet, be made with zero cuts, inquiries are being made toward the procurement of ethylene diamine tartrate (EDT) crystals, which are also rich in hydrogen and can be made with zero cuts. While this does not promise much in the way of a method of personnel monitoring, it may be that, when temperature effects are eliminated, the crystals may furnish a method for catastrophe monitoring.

Some of Eastman's boron- and lithium-loaded nuclear plates have been ordered. Calculations show that if enough boron screening is used to give essentially a flat response to high-energy neutrons, the emulsion is not so sensitive as the Eastman NTA-emulsion H-recoil response, but it is proposed that tests be made with boron-wedge screens under different circumstances in order to see what can be deduced from alpha-track distributions.

Preliminary calculations indicate that a fast-neutron pocket meter may be feasible. This is being investigated.

RADIOCHEMICAL ANALYSIS

Exploratory Survey for Rare Earth Fission-product Activity in Urine of Personnel at ORNL. Among the beta-gamma-emitting radioisotopes to which laboratory employees are more commonly exposed, Sr^{90}, Sr^{89}, and Ba^{140} are considered to be among the most hazardous. Since Y^{90} and La^{140}, the decay products of Sr^{90} and Ba^{140}, are also radioactive and have short half-lives, there exists the possibility that the content of Sr^{90} and Ba^{140} in urine samples may in some cases be more advantageously determined by the measurement of these rare earth daughter products in radioactive equilibrium than by the direct determination of the parent isotopes. This possibility is especially attractive in the case of urine samples submitted for the determination of plutonium content. Since in the procedure currently used for plutonium determinations rare earths occurring in the samples are precipitated along with the plutonium, an indication of the possible activity of Sr^{90} and Ba^{140} in the urine sample may be obtained by the simple expedient of counting the beta activity of the plates already prepared for alpha counting, provided that the daughter products have sufficient time to reach transient radioactive equilibrium in the urine before the chemical separations are made.

A survey was begun February 1 and continued through August 15 in order to determine (1) to what extent the plutonium samples would have measurable amounts of beta-gamma activity and (2) how well the beta-gamma activity corresponds to Sr^{90} and Ba^{140}.

Two hundred and forty-two samples that had been prepared for plutonium determination were counted in a thin-mica end-window G-M counter with a geometry of approximately 25 percent. About 5.5 percent of the samples had activities higher than 5 c/m, the highest being 28 c/m. Decay studies of samples with the higher levels of activity showed the presence of Y^{90} in most cases.

Thirty-seven samples were studied by determining the beta-gamma activity of the rare earth fraction and analyzing the urine supernatant for strontium and barium. The results are shown in Table I.

TABLE I

NO. OF SAMPLES	BETA-GAMMA ACTIVITY ON Pu PLATE (c/m)	BETA ACTIVITY RECOVERED FROM URINE SUPERNATANT (c/m)	APPROXIMATE DISTRIBUTION OF ISOTOPES
18	< 3	< 3	
5	< 3	3 to 9	Sr^{89}
6	3 to 5	4 to 24	Sr^{89} and Sr^{90}
2	5 to 8	4 to 6	Ba^{140}
5	5 to 10	8 to 14	Sr^{90}
1	28	86	Sr^{90}

The results give no indication of the presence or absence of Sr^{89}, but this method is an easy one for survey of Sr^{90} and Ba^{140} in personnel who are not routinely checked but who may have ingested or inhaled such materials. It is not expected that this type of analysis will replace the procedure described in previous reports for gross fission products analysis in urine, but rather that it will supplement it.

PHYSICS OF RADIATION DOSIMETRY

During the last month of the quarter this new group was organized. It consists of a senior physicist, new to the Division, and two men, who, with their current program of research in neutron dosimetry, were transferred from the Instrument Development Group.

Neutron Dosimetry. The development of fast-neutron proportional counters of specialized design was discussed in the Health Physics Division's last three quarterly reports, ORNL 596, 695, and 786.

Tests on the response of a fast-neutron dosimeter designed to give a counting rate proportional to the neutron dosage in a collimated beam of fast neutrons have been extended into the energy range from 4 to 5.5 Mev, using the Van de Graaff generator of the Carnegie Institution of Washington. These tests, together with tests previously reported, confirm the theoretical design for energies ranging from approximately 0.3 to 5.5 Mev. It should be noted that the accuracy of this instrument is dependent upon the collimation of the beam.

The nondirectional integrating fast-neutron dosimeter using a proportional counter designed in accordance with L. H. Gray's principle of radiation dosimetry has received further tests at Carnegie Institution. In these tests, integration of pulse heights representing absorption of energy in units of various sizes was performed manually with the use of an A-1 linear amplifier, and measured energy absorption was found to be proportional to the computed dose. In application, an integrating electrical circuit designed and built by the ORNL Instrument Department is used with the proportional counter to measure the dose. The integrating circuit has been tested and found to be linear in its response. This assembly is presently being used in neutron shielding research currently in progress in the Physics Division.

CONSULTATION AND SPECIAL PROBLEMS

The chief effort of the group during the past quarter has been devoted to routine consideration of short-term problems related to radiation measurements and radiation protection and to studies of building design, from the point of view of radiation protection, in the current Laboratory building program.

One member of the group coordinated an investigation of clothing decontamination methods as applied to Army field laundry equipment. This investigation, a joint project of the Quartermaster Corps and the Chemical Corps, provided opportunity for a field test of a mobile radiological laboratory designed by the Army Signal Corps.

EDUCATION AND TRAINING

AEC Fellowship Program. The 11 NRC Fellows who came to the Division last fall completed their work September 15. Three of them returned to school for further graduate study, and the remaining eight have accepted positions in the health physics field in universities, in national laboratories and institutes, or in industry.

The new group of AEC Fellows in Radiological Physics registered in the graduate school at Vanderbilt University September 25. They will remain there until June, taking course work in biology, physics, electronics, and health physics. Members of the Laboratory staff will teach the courses in health physics at Vanderbilt during the second semester, which course work is now being planned. In June the Fellows will come to ORNL for field training and research.

Program for Military Personnel. A group of medical officers, following their year of study in radiation biophysics at Rice Institute, came to the Laboratory for eight weeks (July 31 to Sept. 22) of training in health physics.

Physics Course for Division Personnel. A course in atomic and nuclear physics at the college level has been instituted for a group of health physics surveyors who expressed a desire for such a course. It is given in the evening three hours a week.

At the request of the group conducting the TVA-AEC Ecological Study, a course of lectures in nuclear physics is being given, designed to assist them in the interpretation and analysis of their field data.

Orientation Lectures. The Education and Training Section has taken over the responsibility for that portion of the weekly orientation program pertaining to health physics.

Miscellaneous Activities. Members of the staff are assisting in other teaching activities in the Laboratory, particularly in the Apprentice Training School and in the Reactor School.