emission regulator maintains the electron ionizing current at a constant value by controlling the temperature of the tungsten filament. Two identical ion current amplifiers are used, each amplifying the current to one of the two collectors. The amplifiers employ a unity gain circuit in order to meet the severe requirements with respect to dynamic range, sensitivity, and stability. The first stage, or preamplifier, of each amplifier is mounted close to the collector assembly and its components are carefully matched to the other to reduce the drift of the amplifiers with respect to each other.

The few controls and switches are mounted within easy reach of the operator. The most important of these are the decade dials and null indicating meter used in measuring the isotope ratio.

The resolution of the isotope ratio mass spectrometer is adequate for precise ratio measurements up to about mass 70. In the case of CO_2 the contribution of mass-44 ions to the mass-45 ion beam is less than 0.04% of the mass-44 ion beam intensity.

The dual collectors cannot be used for the simultaneous collection of hydrogen and deuterium ions because of the greater spatial separation of the two ion beams at the points of focus. Provision is made, however, for conveniently comparing their intensities by using a reference voltage as a standard.

TABLE 1

REPRODUCIBILITY OF SUCCESSIVE ISOTOPE-RATIO DETERMINATIONS

Reading No.	N_2 Mass 29 / Mass 28	CO_2 Mass 45 / Mass 44	H_2 Mass 3 / Mass 2
1	.007569	.011596	.000395
2	.007563	.011598	.000393
3	.007570	.011594	.000396
4	.007564	.011599	.000398
5	.007567	.011593	.000395
6	.007564	.011594	.000397
7	.007565	.011596	.000396
8	.007567	.011597	.000399
Mean	.007566	.011594	.000396
S. D.	.0000025	.000003	.000002

Only gas samples can be introduced into the instrument, so the products of an experiment must be converted to CO_2, N_2, O_2, or H_2-D_2, depending on the tracer used. The sample is bled into the evacuated introduction system from a suitable container through a system of stopcocks, and a Toeppler pump is provided for adjusting the sample pressure. Gas samples as small as 0.1 ml S.T.P. can be handled. To achieve maximum precision all related samples are compared to a standard sample, and this standard is run frequently in order to overcome the effects of long term drifts. The excess of rare isotope is computed with reference to the standard.

It is of great practical interest to know the maximum dilution which an enriched material can undergo and still be detected. This ultimate dilution can be computed from the enrichment of the tracer material and the minimum detectable excess of the rare isotope over its natural abundance in the dilutant. While the minimum detectable excess may be affected by natural variations of the normal material, it is the precision in measuring a change of isotope ratio at the normal abundance level which is considered here. With the mass spectrometer described, the ratio is read to six figures and is significant to about .000005, as illustrated in Table 1. Each column of this table represents eight successive measurements made within a short period of time on a single sample of the gas indicated.

With precision comparable to that shown in Table 1, 30 atom % enriched hydrogen, nitrogen, or carbon may be diluted to 1 part in 100,000 in normal material. For the great majority of applications, this precision is highly satisfactory; thus the isotope ratio mass spectrometer is a tool of outstanding value in the numerous scientific investigations involving stable isotopes.

References

1. NIER, A. O. *Rev. sci. Instr.*, 1947, **18**, 398.
2. WASHBURN, H. W. *U. S. Naval Medical Bulletin*, Supplement, March–April, 1948.

The Photographic Plate as an Instrument in Nuclear Research Autoradiography and Radiation Monitoring

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The photographic plate has become in recent years a very valuable tool for measurement of radiation from radioactive materials. Such radiations include charged particles of all types—electrons, protons, alpha particles, and ionized atoms, as well as electromagnetic radiation such as X-rays and gamma rays. Extensive applications of the photographic plate have been made in the fields of nuclear physics, autoradiography, and in radiation monitoring.

Nuclear physics. In 1945, following the tremendous expansion in nuclear physics during the war period, and the development of higher energy accelerators, physicists began to look seriously to the photographic plate as a means of registering the paths of high energy charged particles. For this purpose, the photographic plate resembles closely in action that of the Wilson cloud chamber. However, the silver bromide emulsion with its high stopping power (about 2,000 that of air), continuous sensitivity, and simplicity, gives it distinct advantages not possessed by the cloud chamber.

The Ilford Company in England pioneered in the field of producing the modern type nuclear emulsion and in 1945 produced a series of plates that far surpassed in sensitivity plates previously made. Subsequently, the Eastman Kodak Company in America, together with their British affiliate, Kodak Limited, started a program of

research which resulted in a series of plates that paralleled in quality and exceeded in sensitivity any previous plates. Plates are now commercially available that will record any type of charged particle, including electrons at the minimum ionization energy, with clear tracks, and low background fog.

Nuclear track plates differ markedly from the ordinary optical type emulsions, being distinguished by a high silver bromide-to-gelatin ratio, by extremely small and uniform grain size, and very great thickness. Whereas the optical type emulsion has a silver bromide-to-gelatin ratio of about 50: 50 and a thickness of 10 μ, the nuclear track emulsion has a silver bromide-to-gelatin ratio of 80: 20 and a thickness between 25 and 300 μ.

A charged particle on passage through a material medium loses energy at a definite rate per unit of distance, depending upon its charge and velocity and upon the number of electrons per cm^3 of the stopping material. The main portion of this energy loss goes into production of ions through the interaction of the particles with the electrons of the stopping atoms. The energy loss varies directly with the square of the charge on the particle and inversely as the square of its velocity. However, at velocities approaching that of light, the inverse v^2 relationship becomes constant and relativistic effects enter to cause the energy loss curve to pass through a minimum value and rise slightly at higher energies.

Photographic action of charged particles is closely linked with the energy loss rate curve described above and the sensitivity of an emulsion can be specified in terms of the highest energy particle that can be recorded. Low velocity particles have strong photographic action and high velocity particles have weak photographic action. Plates are now available that record particles at energies corresponding to the minimum of the energy loss rate curve and will thus pick up a background from cosmic ray electrons. The useful life of such plates is limited in this way to about three weeks, there being no practical means of shielding.

The factors of range in the emulsion, grain spacing in the track, and the scattering of particles passing through the emulsion are important to the research worker doing quantitative work in nuclear track photography. By a combination of these attributes, it is possible to draw conclusions about the mass, charge, and energy of the particles under observation.

Autoradiography. A very important application of the photographic plate in recent years has been in the field of autoradiography. This consists in the technique of locating and measuring the distribution of radioactive elements by means of photographic registration of the emanations from these elements. This means has been used for years in the study of naturally radioactive constituents of minerals such as radium and thorium. Limitation of radioactive elements to the few naturally occurring ones correspondingly restricted the field of autoradiography. With the advent of atomic energy and the atomic pile, it has now become possible to produce radioactive isotopes of practically all the elements of the periodic table in considerable quantities. The use of active isotopes in conjunction with the photographic plate has placed an extremely valuable tool in the hands of the chemist, metallurgist, biologist, and petrographer, whereby chemical elements can be traced in various substances, reactions, and processes peculiar to each of these fields of work.

The technique of autoradiography consists essentially in placing a photographic emulsion in contact with a given test sample of material and registering a self-portrait of that surface by means of "tagged" tracer atoms in or near the surface. The picture may consist of a series of smoothed-over density values, as obtained in an ordinary picture, the contour map of the densities indicating the intensity of radiation. If, however, the radioactive atoms are very sparse it may become necessary to make a microscopic survey of the developed emulsion to determine the concentration of radioactive atoms from track counts. This method, though tedious, permits almost unbelievable sensitivity, it being possible to locate concentrations of the order of 10^4 atoms with isotopes having a few days' half-life. Another feature of track-autoradiography is that it permits, under favorable circumstances, the exact location of the emitting atom through location of the start of the track. Measurements have been published showing the location of active atoms within a few microns.

Radiation monitoring. Photographic plates are being used extensively now as a monitoring instrument for the detection of health hazards. A small piece of photographic film in the form of a dental packet can be worn on the person of a radiation worker and used as a continuous integrating device for measuring either particle or gamma radiation. In monitoring for radiation, it is necessary to measure X-rays and hard gamma rays, since these are very penetrating and are frequently hazardous.

The fastest X-ray emulsions will register as little as 0.05 roentgen and cover a range to about 2.0. Emulsions are available covering the range of exposures from this low limit up to 5,000 r.

The materials used in a badge usually include a high speed film covering the range 0.05 r to 2 r and a second film covering the range 1 r to 10 r. In addition, a third film may be included to monitor for neutrons. The manner of operation is as follows: A piece of Cd 1 mm thick is placed over part of the badge. The Cd will stop slow neutrons, beta particles, and soft X-rays. Therefore, the unshielded films will register beta radiation and soft X-rays. Behind the Cd shield, the films register the hard X-rays and gamma rays. The bottom film is a nuclear track emulsion that will register proton tracks. Slow neutrons can pass through the films on the side unshielded by Cd and give use to the nuclear reaction $N^{14}(n, p)C^{14}$ by interaction with the N atoms of the emulsion. The fast neutrons penetrate the Cd shield and collide with hydrogen nuclei in the emulsion to give knock-on protons. It turns out that tolerance levels of fast and slow neutrons give convenient track counts in two weeks' exposure.