initial neutron pulse from the source and the time of opening of the individual "gate" to be "counted" by the detecting circuits. The neutron velocity—and hence the energy—may then be calculated, and the variation with energy of interaction with the nuclei of various elements may be inferred. For example, by placing substances in the path of the neutrons between source and detector, the extent to which the neutrons are absorbed in that substance may be investigated, over a range of neutron energies.

The results of such experiments are of fundamental importance in the design of nuclear reactors, since the choice of suitable materials (both reacting and structural) is severely limited by their nuclear properties.

Since the process of generating the neutrons in the heavy water target, as well as their absorption in samples, is a statistical process, the arrivals in each "gate" occur in a random manner, and, to achieve an accurate estimate of the rate of arrival (or counting rate), as many as possible must be counted. This means that the maximum possible number of electrons must be produced by the linear accelerator.

In this condition, the accelerator is generating harmful radiation at an intensity many thousands of times higher than is safe for exposure of the human body, and a very thick concrete shelter all around the machine is necessary, with only a small aperture for the emergent neutrons. All the electrical, as well as the vacuum pumping, apparatus is, therefore, remotely controlled from a safe point outside the shelter. Precautions are taken to ensure that no person may enter the shelter during operation or "see" the target from any distance less than that at which the intensity is reduced to a safe value.

The basic design of the accelerator was the work of the Harwell scientific staff, and the technical development and construction were carried out by the Mullard Electronic Research Laboratories, which have also cooperated in the design and manufacture of the detecting and "gating" circuits.

Technical Papers

Preparation of Radioactive Glass Beads

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There are many possible experimental uses for small, intensely radioactive sources that can, for example, be imbedded in living tissue. It occurred to us that approximately point sources might be made by incorporating isotopes of high specific activity into glass beads. It was found possible to prepare such beads containing Y^{91}, a pure β-emitter; Sr^{90}, a pure β-emitter that gives rise to an yttrium daughter (Y^{90}), also a β-emitter; and Ce^{144} which, with its praseodymium daughter (Pr^{144}), emits a more complex spectrum.

Use of a preliminary batch of Y^{91} beads imbedded in regenerating rat liver has been reported (*1*). By cutting microscopic sections through the point occupied by the bead, it was possible to obtain single tissue sections treated by a wide range of radiation dosages that were approximately calculable. Further development of the technique has enabled us to prepare beads with activities of the order of 1–2 mc/mg. Such beads are sufficient to produce a sharply demarcated area of liver necrosis within 48 hr, with the radiation dosage diminishing nearly to zero at the periphery of the organ.

Among possible methods for the production of radioactive beads are: (1) adsorption of the radionuclide onto powdered glass, followed by fusion of small quantities of the material to form beads; (2) incorporation of the radionuclide into the raw materials used in the manufacture of glass; and (3) precipitation of the radionuclide in the presence of powdered glass that can then be fused into beads. It was decided after a number of tracer studies (*2*) that the last method offered the most satisfactory means for the production of very small and highly radioactive beads. This is illustrated in Fig. 1*A* and 1*B*, in which the apparent activity is plotted for randomly chosen beads against weight and diameter cubed.

The method described here deals specifically with the production of beads containing yttrium[91], although beads of comparable activity were prepared with Ce^{144} and Sr^{90}, and, except for possible alteration in the chemical procedures, the technique may be applied to other radionuclides.

The solution of Y^{91} was received from the Oak Ridge Laboratory as $Y^{91}Cl_3$ containing 50 mc in 18.8 ml of weak HCl solution. To this solution were added 1 mg of yttrium carrier, 5 mg of powdered micro slide glass, and $Y^{91}(OH)_3$ precipitated by the addition of NH_4OH. In the case of Sr^{90} the carbonate was precipitated. After centrifugation, the supernatant was decanted and the precipitate slurried and partially dried in readiness for fusion into beads. The addition of 1 mg of yttrium carrier under these conditions gave recoveries of 95%–97%.

The amount of powdered glass added to the solution was determined by preliminary studies of the minimum

[1] The authors are indebted to A. S. Tracy for the photographs.

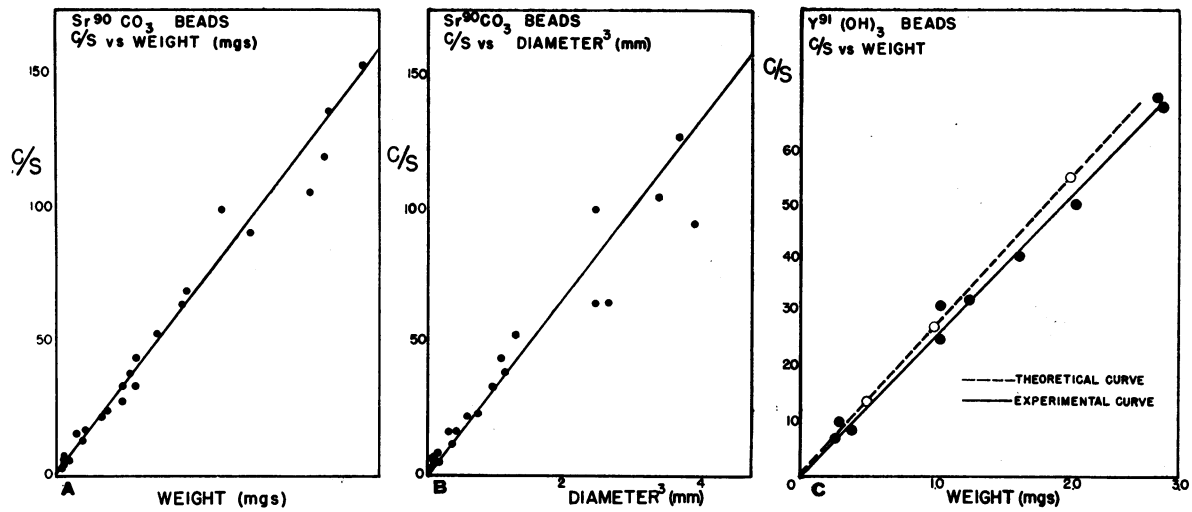

FIG. 1. *A, B*: Apparent activity of randomly selected radioactive glass beads plotted against weight and diameter cubed. *C*: A theoretical and experimental plot of counts per second against weight.

ratio of powdered glass to precipitate necessary to produce translucent and spherical beads. At a ratio of 5:1 (powdered glass to precipitate) relatively good beads were produced, and at the same time the conditions for minimum solids were fulfilled. Ratios of 20:1 will produce somewhat more perfect beads, but the specific activity will be lowered in the same proportion.

After the precipitate is obtained, it is stirred with a 1/16-in. stainless steel rod to mix the powdered glass and $Y^{91}(OH)_3$. The steel rod is also used as a plunger in a small-bore glass tube into which the slurried material is pipetted and dried for 15–20 min under an infrared lamp until it has hardened enough to be extruded in small fragments on a carbon block (about $3 \times 10 \times 15$ mm). The material on the carbon block is divided into smaller portions, the size of which will determine the size of the resulting beads, and then placed in the furnace until fusion of the radioactive beads occurs (20–30 min at 2,000° F). After fusion the carbon block is removed from the furnace and allowed to cool. The beads are then brushed into a glass vial, which is enclosed in a lead container.

The fusion furnace was designed to produce radioactive beads with minimal radiation hazard and to be replaceable at low cost because of the probability of radioactive contamination. It is constructed from a piece of Babcock and Wilcox K-30 insulating fire brick as shown in Fig. 2. The heating element consists of a coil of No. 18 Nichrome V wire composed of five turns wound on a ¼-in. × ½-in. bar stock form. Turns are spaced about ⅛-in. apart. The element is connected to the secondary of a 20-amp, 6.3-v transformer that is controlled through a variable transformer (Variac) for temperature control.

Because a variety of bead shapes and sizes results, a means of proper selection and calibration is necessary. Thus the vial containing the beads is placed in a transparent Lucite box, ½-in. wall thickness, which has a small adjustable opening at the top for remote-control manipulation of special hollow-tipped forceps. This assembly (Fig. 3) is then placed under a microscope, and proper selection of translucent and spherical beads can be made. A calibrated millimeter scale in the ocular piece facilitates measurement of the diameter of the selected beads, which are then stuck on black

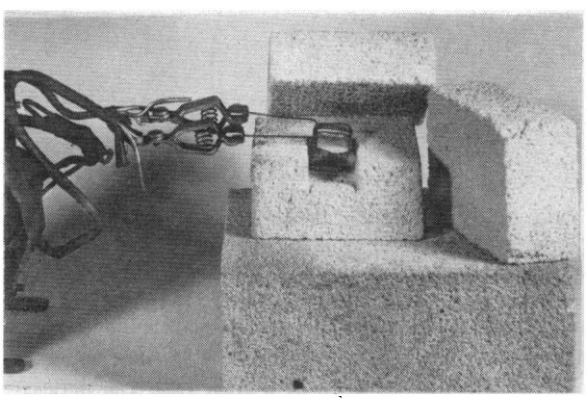

FIG. 2. Microfurnace used for fusion of radioactive beads.

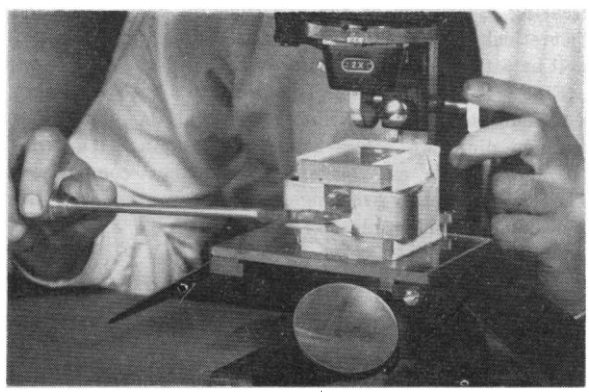

FIG. 3. Technique and assembly for selecting radioactive beads.

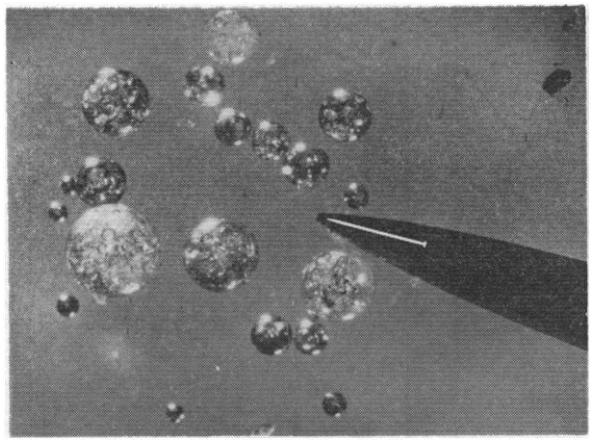

FIG. 4. Random sample of Y^{91}-containing beads and the point of a common pin (magnification × 35).

masking tape and transferred into individual capsules for measurements of radioactivity and for use.

In all these chemical and physical manipulations, radiation hazards must be considered. In most cases the work is done behind lead and/or Lucite shielding with the usual equipment necessary for semiremote-control handling (*3*).

Because of the high activity of the beads, the measurements are made with a Zeus α, β, γ portable ionization chamber that is mounted 10 in. above the measured capsules. The bead measurements are made by relative comparison with a series of Y^{91} standards ranging from 0.1 to 1.5 mc and prepared from a solution whose specific activity was originally determined by calibration against Ra DEF standards from the National Bureau of Standards. With these conditions of measurement, beads have been produced with specific activities ranging from 0.005 mc to 1.5 mc per mg, having diameters ranging from 0.05 mm to 1.0 mm, and weighing up to 1 mg.

The method of determining the radioactivity of the beads leaves some doubt of the validity of their millicurie content; however, under the conditions of measurement, and coupled with the knowledge of the expected theoretical activity of the precipitate (Fig. 1*C*), the error is probably not greater than 30%. The increasing divergence of the experimental curve from the theoretical curve with increasing bead weight might well be attributed to self-absorption.

Fig. 4 is a photograph (magnification × 35) showing a random sample of yttrium beads and the point of a common pin. An actual image of the pin is superimposed upon its enlargement for further comparison. The smaller beads are the ones that are selected for our experimental studies.

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Convenient Method of Mounting Sintered Glass Filters[1]

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The usual method of mounting ultrafine (UF) filters is to fit them by means of a rubber stopper onto a filtering flask with a test tube inside, or onto a test tube with a side arm. Both methods are somewhat cumbersome, and subsequent manipulations—taking the tube from the flask or transferring the filtrate into a test tube by means of a pipette—expose the filtrate to contamination. Besides, the side-arm test tubes are awkward to handle, and the breakage is usually high.

Fisher Scientific Company has put on the market a so-called shockproof condenser coupling (No. 7-702-C) to mount straight condensers for student use. These couplings proved to be very convenient for mounting medium-sized Pyrex sintered glass filters, particularly Corning Glass Company, UF30.

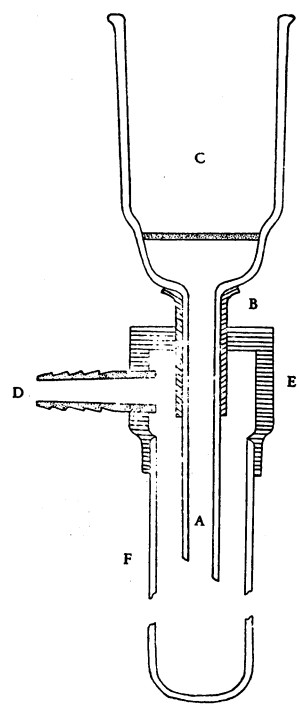

FIG. 1.

Fig. 1 shows how the device is assembled. The stem (*A*) of the UF30 filter is too narrow for the opening of the coupling; therefore a short piece (1 in.) of rubber tubing (*B*) of suitable size (5/16 in. × 3/32 in.) is first fitted on the stem and pushed sufficiently high to spread slightly at the joint of the body and the stem.

[1] This work was supported by a grant from The National Foundation for Infantile Paralysis.