fusion between numerical mathematics, on the one hand, and nonnumerical reasoning, or symbolic logic, on the other. Machines that play games, machines that separate true combinations of statements from false combinations, other kinds of information-handling machines where emphasis is on logical competence rather than on mathematical competence, are already in existence. Symbolic logic, large-scale calculating machinery, and mathematics will continue to enrich one another in many significant ways.

The Traveling-Wave Linear Accelerator

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THE STUDY OF NUCLEAR PROCESSES commonly involves the bombardment of one nucleus with one or another of the fundamental particles. In many experiments, particularly early ones, the bombarding particles were those emitted by naturally radioactive substances, whereas in later work artificially accelerated particles have been extensively used. In experiments involving neutrons as the bombarding agent, production is normally a secondary process following the bombardment of a primary target either by a charged particle or by gamma radiation.

Familiar particle accelerators are direct current generators of, for example, the Cockcroft and Walton type, and cyclic accelerating devices typified by the cyclotron and betatron. In the former, particles are accelerated by passing through a single large-voltage gradient, whereas in the latter, energy is imparted to the accelerated particles by causing them to traverse a short intense gradient many times when constrained into an approximately circular path by a very strong magnetic field. For this purpose a large and expensive electromagnet is required.

Among the many electrical devices that have been made practicable by the great advances in radio technique of recent years is a new form of high-energy particle accelerator known as the Traveling-Wave Linear Accelerator. This machine has been fully described elsewhere, but a brief description of its mode of operation is, perhaps, not out of place here.

Electrons are introduced axially into a special form of evacuated radio wave guide, along which electric waves are made to travel so that their phase velocity increases steadily from a speed equal to that of the entering electrons up to nearly that of light. Most of the electrons are then constrained into "bunches" moving in constant phase relationship to the waves and are, therefore, accelerated with them.

In the accelerator recently installed at the Atomic Energy Research Establishment at Harwell in southern England, the final electron energy obtained may be as high as 3.2 mev with a mean current of about 120 μa. The electrons may be extracted from the machine by allowing them to emerge through a thin metal "window" at the end of the accelerating wave guide.

Use of magnetron valve. The radio waves are generated in a magnetron valve, such as was developed for radar use, at a wavelength of 10 cm. They occur in very intense pulses, 2 μs in length, and up to 500 pulses every second may be used. The current of electrons during the pulse is, therefore, of the order of 120 ma. If the large current of electrons from the machine is allowed to strike a heavy metal target, intense bursts of gamma rays are produced, and one use of the machine is to provide heavy doses for irradiation purposes.

This particular machine is, however, installed primarily as a neutron source. The gamma rays are converted into neutrons by photodisintegration in a target of heavy water. Some of the nuclei of the deuterium in the heavy water disintegrate and emit a neutron. Some of the neutrons emerge from the target and are available for experimental purposes. The machine will be used as a neutron source for time-of-flight measurements and, it is hoped, will prove a better source than has hitherto been available.

The linear accelerator is inherently suitable for this use since the neutrons are produced in bursts—corresponding to the pulses of radar waves from the magnetron. By a technique similar to that used for range determination in some radar equipment, it is possible to measure the time—which may vary in practical cases from a few microseconds to a few milliseconds—taken by neutrons to travel over a fixed distance from their origin in the source, to a detector (usually a proportional counter).

Calculating neutron velocity. A series of electronic "gates," opened in succession, allows only neutrons of velocities corresponding to the delay between the 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.