RESEARCH FACILITIES AND PROGRAMS

Astron Device Begins Operating

An experimental facility based on the Astron concept has just been completed at the University of California's Lawrence Radiation Laboratory in Livermore.

The Astron concept, one of the four approaches to the controlled fusion problem (the others are the Stellarator, the mirror devices, and the pinch devices), employs high energy electrons to provide both the magnetic bottle for plasma confinement and to produce and heat the plasma to the temperature required for fusion.

The Astron idea was conceived in 1952 by Nicholas Christofilos. The idea was presented early in 1953 to a meeting of Sherwood scientists. However, an experimental program was deferred until some theoretical work could be done to clarify certain questions. By the end of 1956, theory was sufficiently advanced to justify the initiation of an experimental program at LRL. Christofilos, then at Brookhaven National Laboratory, was invited to direct the program at LRL.

In any controlled fusion approach there are two basic problems: (1) the production and (2) the confinement of a hot (10-KeV) plasma for a time long enough for the energy released by fusion of the plasma ions to exceed the energy required to produce and maintain the plasma. The Astron device uses high-energy electrons for production, confinement, and heating of the plasma up to fusion temperature. Energetic electrons are to be injected and trapped in an evacuated vessel where a magnetic field is established by external coils. The vacuum magnetic field is substantially parallel to the axis of symmetry of the evacuated vessel.

High-energy electrons are injected into the Astron device, where they gather as a thin layer of electrons which rotate and describe a helical path about the axis of symmetry. This electron layer, or "E layer" (shown in Fig. 1), acts itself as a solenoid generating a magnetic field which opposes the field of the external solenoids. By injecting and trapping more electrons, thus building up the E layer, it is expected that the self-field generated by the rotating electrons (within the cylindrical volume enclosed by the E layer) will become slightly stronger than the field established by the external coils. The combination of the external field with that of the E layer will then create a magnetic-field pattern with the lines of force closed within the chamber (shown in Fig. 1a). Since, in this field configuration, no lines of force escape the confining region, plasma particles cannot be lost by direct scattering, but only by diffusion across the lines of force. This feature permits an isotropic Maxwellian velocity distribution to persist within the plasma.

The plasma is to be generated by ionization of neutral residual gas by the rotating high-energy electrons. Thereafter the plasma will be heated up by Coulomb interactions with the E-layer electrons. Thus the E layer is expected to perform two basic functions:

(1) To establish a closed pattern of magnetic-field lines to provide plasma confinement.

(2) To generate the plasma by ionization of neutral particles and thereafter heat the plasma up to fusion temperature. The second condition can be met providing that the energy given by the electrons to the plasma exceeds the energy lost by the plasma because of its tendency to drift outwards across the magnetic lines. Furthermore, the plasma density and temperature depend on the electron energy. In the absence of instabilities, an electron energy of 50 MeV is required to generate and maintain a plasma at 10-20-KeV temperature and at a density a few times 10^{14} ions/cm^3. At this temperature and density the energy released by fusion reactions would far exceed the energy required to maintain the hot plasma.

It is possible to demonstrate the feasibility of the basic Astron principle (the trapping of enough electrons in the E layer to create the closed pattern of magnetic lines), with elec-

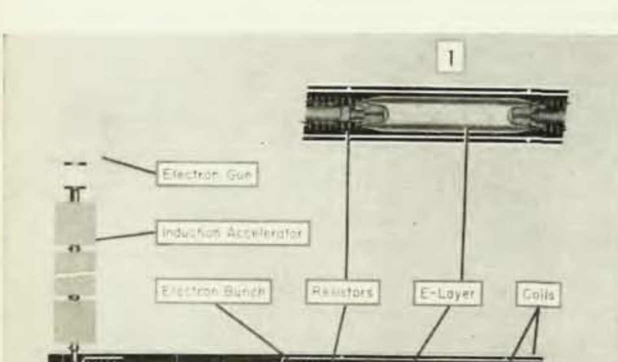

Fig. 1. Schematic drawing illustrating the electron layer and plasma configuration in the Astron device.

Fig. 2. Overhead view of the Astron induction accelerator (4 MeV, 150-ampere electron beam).

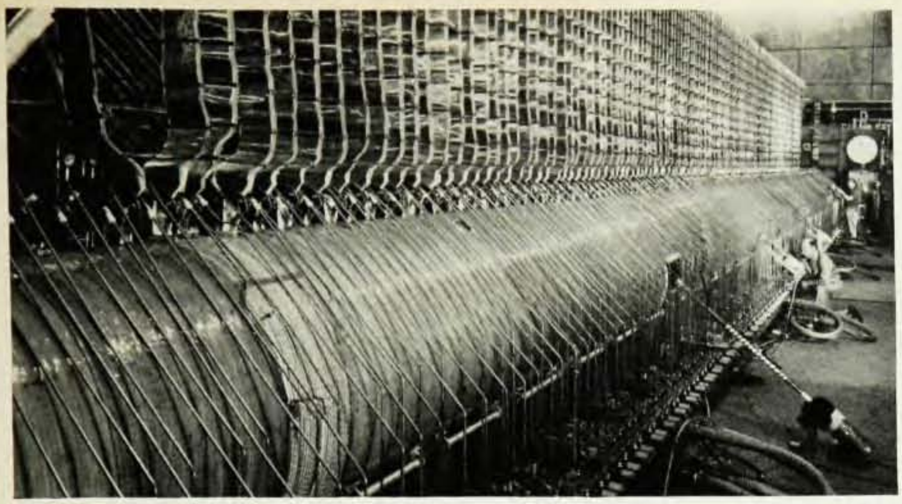

Fig. 3. View of the Astron tank from the west end.

trons of much lower energy. Thus, in the first experimental facility just completed, the electron energy is 4 MeV. The facility is expected to answer the most crucial question about the Astron concept: Is the E layer stable? Under certain conditions, the passage of a beam of high-energy particles through a plasma generates electromagnetic and/or plasma waves, resulting in fast energy exchange between the particle beam and the plasma. It is not known whether this will happen in the Astron; the geometry of the E layer and the electron-density distribution in the E layer are such that theoretical formulation of the stability problem seems to be impossible. The crucial question of the stability of the E layer has been the subject of much controversy among the Project Sherwood theorists during the last five years, but so far there is neither rigorous proof nor disproof of E-layer stability. Hence the question must be answered experimentally.

The first three years of the Astron project were devoted to the development of components for the electron accelerator and to the design of the first Astron model. The electron accelerator, shown in Fig. 2, has now been operating for almost a year. It is a linear machine, operating on the magnetic-induction principle, and it accelerates an electron beam of 150 amperes up to 4 MeV. The pulse length is 0.3 microsecond and the pulse rate is 5 to 50 pulses/sec. Thus more than 2×10^{14} electrons per pulse are accelerated. The relatively large number of electrons per pulse is required by Astron's particular method of trapping electrons. It is not possible to inject and trap charged particles in a magnetic field constant in time. Astron achieves trapping by sending the injected electrons through a large number of resistive rings, shown in Fig. 1 and 1a, before they arrive in the trapping region. As the electrons pass by the resistors, they lose some of their energy by inducing eddy currents in the resistors. This small energy loss of the electrons traps them in a magnetic potential valley. Since the magnetic field is stronger at the ends of the vessel than in the middle region, the electrons are trapped just as a car may be trapped in a valley between two hills if it comes downhill with the brakes applied. The energy loss per electron is proportional to the total number of electrons injected per pulse; therefore the number of electrons per pulse must be great enough to provide sufficient energy loss for trapping to occur.

The high-energy electrons are injected into a tank 90 feet long, with an inside diameter of 2.5 feet (Fig. 3). A long solenoid 4 feet in diameter placed outside the tank generates the vacuum field required to guide the injected electrons in forming a cylindrical E layer two feet in diameter and 40 feet long. Between the injector and the end of the E layer (which are 20 feet apart) the tank interior is filled with resistive rings which slow down the injected electrons.

The central part of the solenoid consists of 128 coils, each one-half foot long, which are energized independently by 64 power supplies. Thus any desired magnetic field shape can be formed. The field shape can be changed during the buildup of the E layer to conform with the field pattern required to maintain the E layer in equilibrium at the desired radius and length. This part of the facility has just been completed, and experiments aimed at trapping the electrons have begun.

The first phase of the experimental program is aimed at trapping a single electron pulse and studying its behavior under a variety of conditions. Following this phase the objective will be to build up the E layer in steps, to study its behavior, and to determine the necessary conditions to circumvent possible instabilities. Finally, the crucial step will be attempted: to build the E layer up to the point of establishing the pattern of closed magnetic-field lines and eventually to generate and confine a plasma. It is estimated that at least a year will be required before the question of E layer stability can be answered.

Meanwhile, the Joint Committee on Atomic Energy, in a report to the Appropriations Committee dated April 21, said: ". . . those approaches (toward controlled fusion) which are explored and prove unproductive should be abandoned. As an example, the AEC testified that ASTRON, an approach which is only now beginning to be tested, will prove its worth or lack thereof during the next fiscal year. If found unproductive, it should be dropped."

If the E layer proves stable, however, then a hot Maxwellian plasma may finally be produced and maintained in steady state. This would be a major achievement—one perhaps opening the door to controlled fusion.

The Farthest Quasar

The most distant object ever observed has been reported by M. Schmidt and T. A. Matthews of the Mount Wilson and Palomar Observatories. The