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External Beam Focusing System - Argonne 60-Inch Cyclotron

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The external beam can consist of either deuterons, helium ions, or molecular hydrogen (H_2^+). The deuteron beam energy is 21.6 Mev with nominal deflected beam currents of 200 μa for deuterons, and 100 μa of D^+ and 180 μa of $_4He^{2+}$ have been attained. The experimental machine requirements have established a range of beam operation from the nominal quoted currents down into the region of 1×10^{-11} amperes.

The deflector system of this machine is a conventional type d-c system. The material of construction is copper; graphite was originally used with a minimum of success. This system has been in service for approximately seven years with a minimum of maintenance. Further deflector information is given in the ANL report 5907, "Argonne 60-Inch Cyclotron."

The beam that leaves the deflector system and enters the target chamber is about 10 cm in the radial direction; its full width at half height is about 3/4 centimeter (Figs. 262, 263, and 264). The total energy spread is about one percent.

The stability of the beam energy has been quite good. Long term energy stability is about 30 kev. In referring to long term, one means a period of several days. Short term stability, periods of a few hours, is 5 to 10 kev.

Referring to Figure 264, the particle energy is determined by absorption techniques at the target box. The measuring device is an eight-stepped absorber wedge which horizontally traverses a 3-mm segment of the beam. The wedge and associated instrumentation plots either the transmitted or stopped absorber current. By this technique, the beam energy can quickly be characterized for any given focused beam irradiation.

The beam focusing system (Fig. 265) extends from the target box into a room known as the Experimental Tunnel. To efficiently use the focusing system and to contain the unacceptable particles near the machine, a collimating aperture is inserted prior to the target box. This collimator passes 10 to 15% of the total deflected beam, which then traverses the remainder of the system with an efficiency of about 100 percent.

The beam passes through a fringing field of about 5 kilogauss at the target box to a zero field at the first quadrupole. The resultant effects are vertical and horizontal divergence of about $\pm 0.2^\circ$ and $\pm 1.2^\circ$, respectively.

The first quadrupole set consists of two lenses, each 8 in. long. The aperture size of the lens system is 5 centimeters. With the first lens set, the beam can be focused just beyond the switching magnet on the 0° or the $\pm 25^\circ$ ports. In this region, targetry for radiation chemistry, solid state physics, nuclear activation, and recoil studies can be located. For high density irradiations in this area, a 10-μa helium ion beam can be readily focused into an area of 1 by 2 mm. Figure 266 shows a typical contour of the beam as it enters the first quadrupole set, and the focus obtained.

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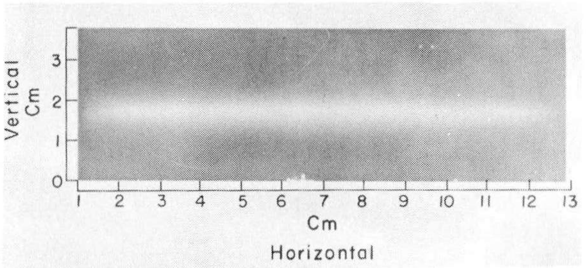

Fig. 262. Cross section of deflected beam, at target box.

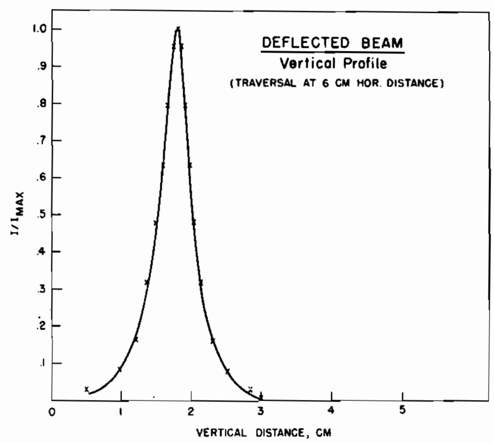

Fig. 263. Vertical profile of deflected deuteron beam, shown in previous figure.

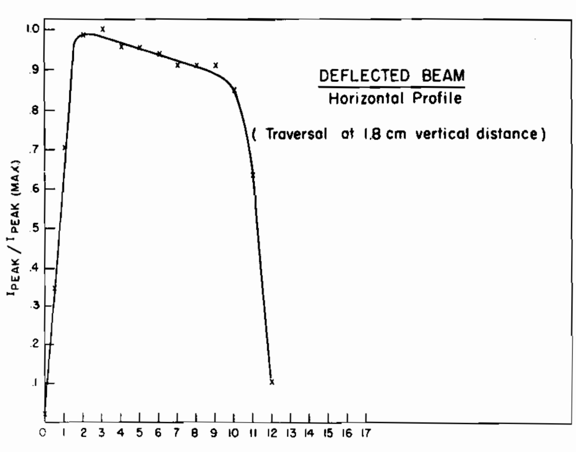

Fig. 264. Horizontal profile of deflected deuteron beam, shown in previous figure.

To facilitate the spatial positioning or sweeping of the focused beam, a cylindrical steering magnet is used. This magnet provides a uniform vector field which can be varied both in magnitude and direction. The magnitude can be varied from 0 to 1 kilogauss and the vector orientation can be varied through 2π radians. When this unit is used for beam sweeping to obtain uniform particle density over a target area of 3 to 4 cm^2 a particle uniformity to within $\pm 0.5\%$ can be obtained.

To continue with the focusing system, the beam normally follows the zero trajectory port, passes through a second quadrupole set, and enters the 7-ft vault shielding wall at an angle of 25.5° to a perpendicular erected to the wall. After the wall, the beam passes through a double collimating system consisting of two 3-mm dia apertures spaced 1 meter apart, and it then enters the 60-inch scattering chamber. One can consistently obtain 0.3 to 1 μa of current at the scattering chamber for 70 μa of beam deflected from the machine. The scattering chamber is located in the Experimental Tunnel, a room about 28 x 36 feet, 14 ft high.

The remainder of the focusing system provides multiple-irradiation ports. The switching magnet, circular-type pole tip, is used to switch the beam ± 25 degrees about the zero axis trajectory.

The operation of the quadrupole lenses has been quite good and experience has proven that current stabilities of 1 part in 500 to 1000 are quite adequate.

The entire vacuum plumbing of the focusing system couples together with quick-operated toggle-clamp couplings which facilitates the changing of the entire plumbing in a matter of minutes. For example, the tubing to the scattering chamber can be completely

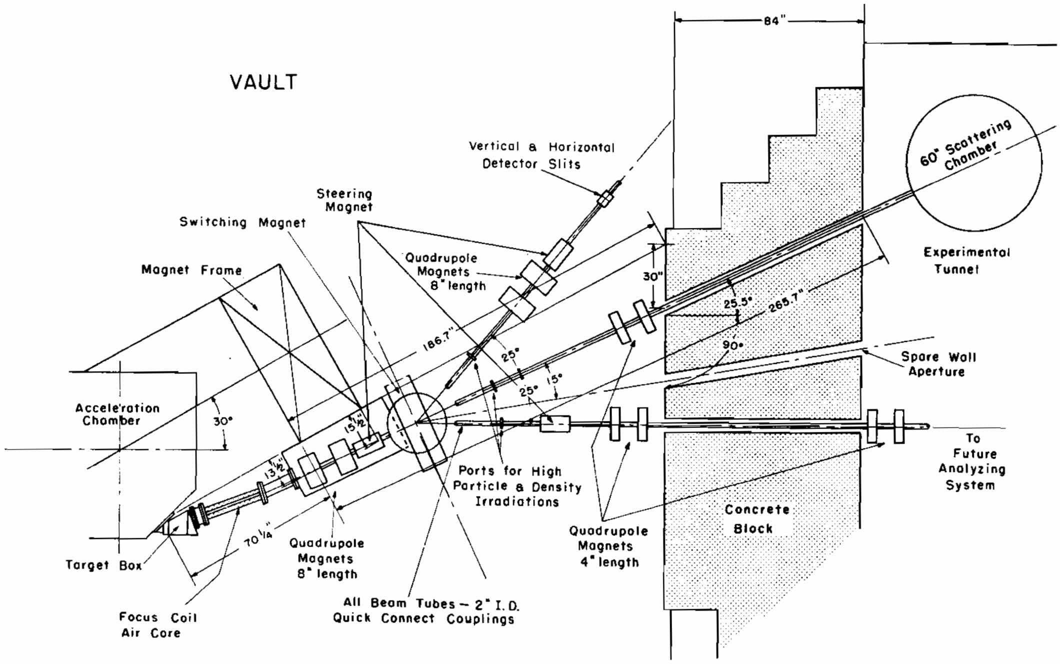

Fig. 265. Focusing system, Argonne cyclotron.

disassembled, reconnected, and a beam obtained in the chamber within 60 minutes.

Within the last week, although not well characterized at this time, experimental work was initiated to obtain a variable-energy cyclotron by using degradation techniques with the beam focusing system. The degradation system, remotely controlled, was located immediately after the switching magnet on the 25° port to the Experimental Tunnel. A set of 8-in. quadrupoles was close coupled to the degrader, and the remainder of the system is as given in Figure 265. A 21.6-Mev deuteron beam was degraded to 6.6 Mev and a 43.8-Mev helium ion beam to 8.8 Mev. Two questions immediately arise, first, the particle number available and second, the beam homogeneity after degradation. In regard to particle number, for a deuteron beam of 6.6 Mev, 10% of the beam entering the absorbers was obtained in the Experimental Tunnel. The focused beam size was about 1 cm^2, as compared with a 21.6-Mev focused beam of 1/2 cm^2 in area. The homogeneity of such a beam cannot be too bad considering the filtering qualities of the lens system, but at this time the exact homogeneity of the beam is now known.

YAVIN: What are the dimensions of the steering magnet? I am especially interested in the maximum deflecting radial and vertical angles you can achieve.

RAMLER: The steering magnet uses the principle that a sinusoidal current distribution on a conducting cylinder will result in a uniform field within the cylinder. This is the design principle. It is 12 in. long with an aperture of 5 centimeters. It has an effective field length of about 12 in., and one can obtain a field of about 1 kilogauss. The over-all diameter is about 10 inches. The magnitude and direction of the vector field is obtained by two similar coil sets, spaced 90° apart. As to the precise angles, I cannot give them, but you can determine them from the constants given.

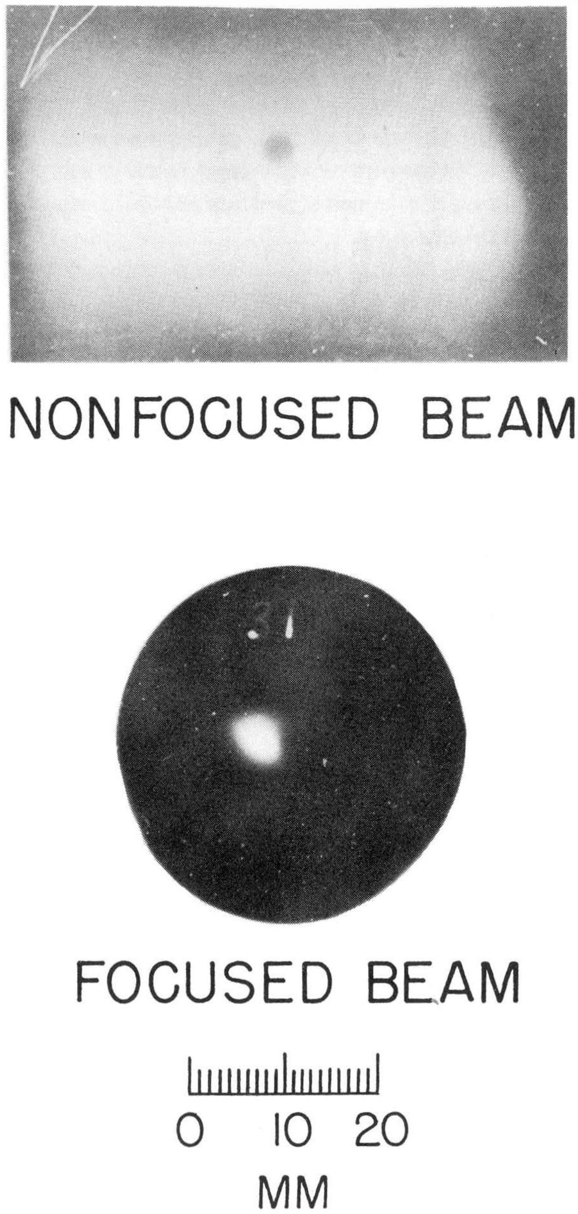

Fig. 266. Beam contour, before and after first quadrupole set.

SCHMIDT: If I understood your numbers correctly, the beam decreased by a factor of 6 when you degraded the energy with the foil.

RAMLER: It decreased by a factor of 10, from 10 to 1 percent. I cannot remember the particle numbers for the helium ions but a helium-ion beam was degraded from 44 to 8.8 Mev., and the particle number loss was similar to that for the deuterons.

YAVIN: What did you use for degrader?

RAMLER: We used aluminum foil, water-cooled. The foil changer has a possibility of 81 positions, remotely controlled.