electron dose rates is that the x-ray production via bremsstrahlung as well as beam flattening requires a much larger primary electron beam current (about 3 orders of magnitude greater) than that required for the electron therapy beam.

The availability of medium energy linacs with high x-ray dose rates, large field sizes, and electron therapy energies up to 20 MeV, has given the linacs a considerable edge in popularity over the betatrons. Moreover, many radiotherapists regard the small field size and dose rate capabilities of the betatron as serious disadvantages to the general use of the device. Thus, a significant increase in betatron installations in this country, paralleling medical linacs, seems unlikely.

4.5 MICROTRON

The microtron is an electron accelerator which combines the principles of both the linear accelerator and the cyclotron (Section 4.6). In the microtron, the electrons are accelerated by the oscillating electric field of a single microwave cavity (Fig. 4.9). A magnetic field forces the electrons to move in a circular orbit and return to the cavity. As the electrons receive higher and higher energy by repeated passes through the cavity, they describe orbits of increasing radius in the magnetic field. The cavity voltage, frequency, and magnetic field are so adjusted that the electrons arrive each time in the correct phase at the cavity. Since the electrons travel with an approximately constant velocity (almost the speed of light), the above condition can be maintained if the path length of the orbits increases with one microwave wavelength per revolution. The microwave power source is either a klystron or a magnetron.

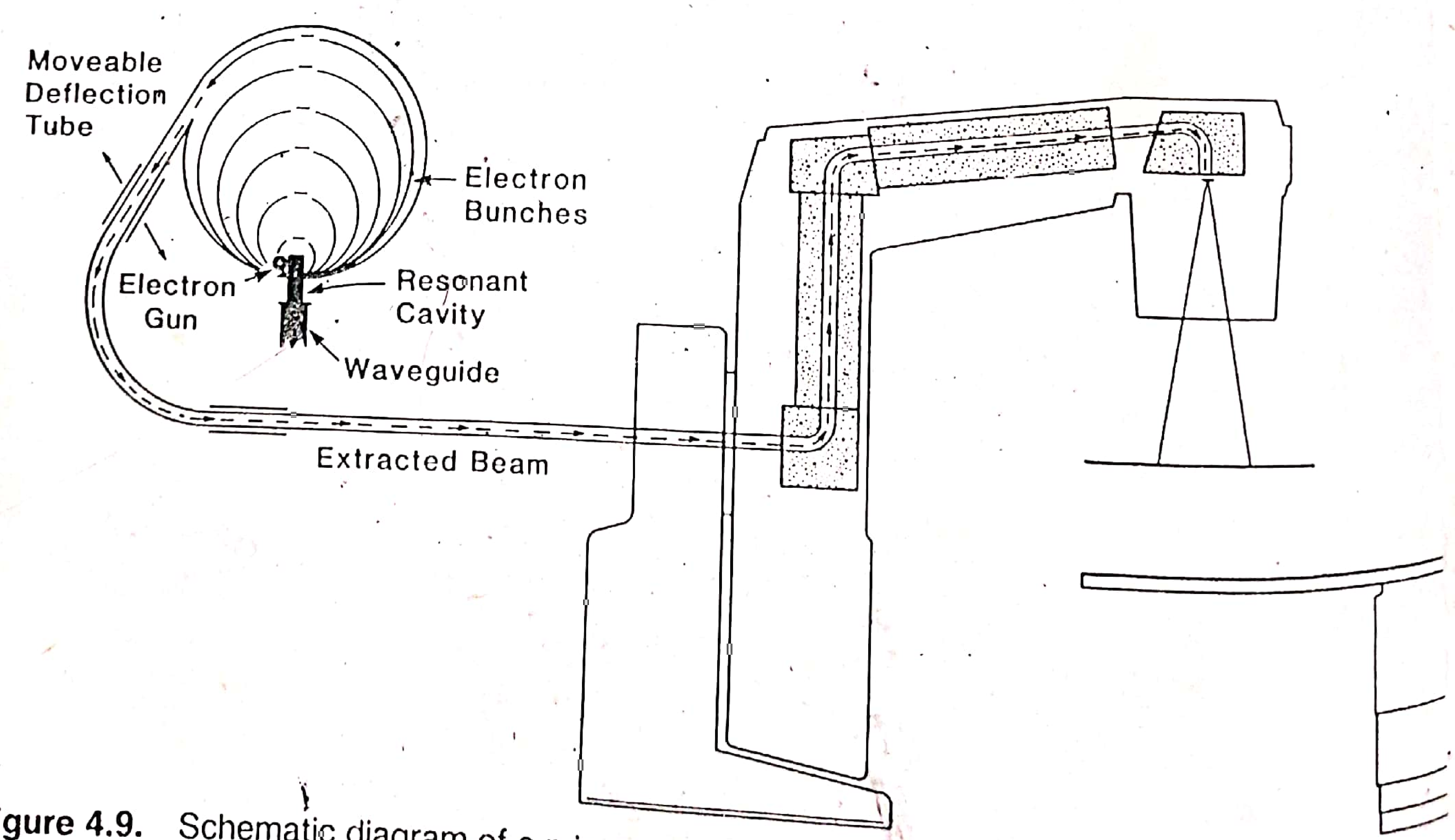

Figure 4.9. Schematic diagram of a microtron unit. (Reprinted with permission from: AB Scanditronix, Uppsala, Sweden.)

The extraction of the electrons from an orbit is accomplished by a narrow deflection tube of steel which screens the effect of the magnetic field. When the beam energy is selected, the deflection tube is automatically moved to the appropriate orbit to extract the beam.

The principal advantages of the microtron over a linear accelerator of comparable energy are its simplicity, easy energy selection, small beam energy spread, and a smaller size of the machine. Because of the low energy spread of the accelerated electrons and small beam emittance (product of beam diameter and divergence), the beam transport system is greatly simplified. These characteristics have encouraged the use of a single microtron to supply a beam to several treatment rooms.

Although the method of accelerating electrons used in the microtron was proposed as early as in 1944 by Veksler (5), the first microtron for radiotherapy (a 10-MeV unit) was described by Reistad and Brahme (6) in 1972. Later a 22-MeV microtron (7) was developed by AB Scanditronix and installed at the University of Umeå, Sweden. This particular model (MM 22) produced two x-rays beams of energy 6 or 10 and 21 MV and 10 electron beams of 2, 5, 7, 9, 11, 13, 16, 18, 20, and 22 MeV.

4.6 CYCLOTRON

The cyclotron is a charged particle accelerator, mainly used for nuclear physics research. In radiotherapy, these machines have been used as a source of high energy protons for proton beam therapy. More recently, the cyclotrons have been adopted for generating neutron beams. In the latter case the deuterons ($^2_1H^+$) are accelerated to high energies and then made to strike a suitable target to produce neutrons by nuclear reactions. One such reaction occurs when a beam of deuterons, accelerated to a high energy (~15–50 MeV), strikes a target of low atomic number, such as beryllium. Neutrons are produced by a process called stripping (Section 2.8D). Another important use of the cyclotron in medicine is as a particle accelerator for the production of certain radionuclides.

A schematic diagram illustrating the principle of cyclotron operation is shown in Fig. 4.10. The machine consists essentially of a short metallic cylinder

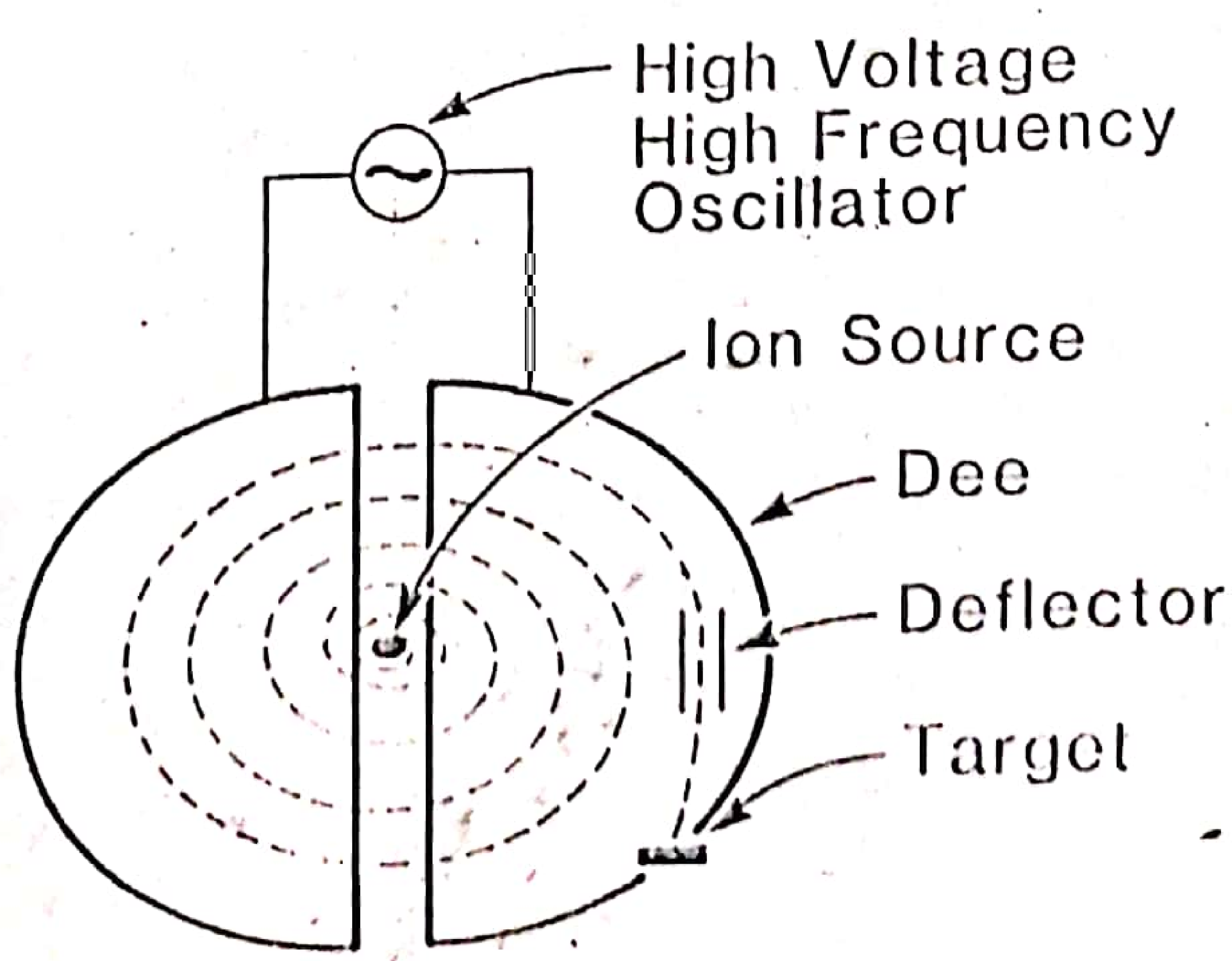

Figure 4.10. Diagram illustrating the principle of operation of a cyclotron.

divided into two sections, usually referred to as "Ds". These Ds are highly evacuated and placed between the poles of a direct current magnet (not shown) producing a constant magnetic field. An alternating potential is applied between the two Ds. Positively charged particles such as protons or deuterons are injected into the chamber at the center of the two Ds. Under the action of the magnetic field, the particles travel in a circular orbit. The frequency of the alternating potential is adjusted so that as the particle passes from one D to the other, it is accelerated by the electric field of the right polarity. With each pass between the Ds, the particle receives an increment of energy and the radius of its orbit increases. Thus, by making many revolutions, the particle such as a deuteron achieves kinetic energy as high as 30 MeV.

There is a limit to the energy that a particle can attain by the above process. According to the theory of relativity, as the particle reaches high velocity (in the relativistic range), further acceleration causes the particle to gain in mass. This tends to slow down the particle which can then get out of step with the frequency of the alternating potential applied to the Ds. This problem has been solved in the synchrotrons where the frequency of the potential is adjusted to compensate for the decrease in particle velocity.

4.7 MACHINES USING RADIONUCLIDES

Radionuclides such as radium-226, cesium-137, and cobalt-60 have been used as sources of γ rays for teletherapy.[3] These γ rays are emitted from the radionuclides as they undergo radioactive disintegration.

Of all the radionuclides, ^{60}Co has proved to be the most suitable for external beam radiotherapy. The reasons for its choice over radium and cesium are higher possible specific activity (curies per gram), greater radiation output per curie and higher average photon energy. These characteristics for the three radionuclides are compared in Table 4.1. In addition, radium is much more expensive and has greater self-absorption of its radiation than either cesium or cobalt.

A. Cobalt-60 Unit

A.1. SOURCE

The ^{60}Co source is produced by irradiating ordinary stable ^{59}Co with neutrons in a reactor. The nuclear reaction can be represented by $^{59}Co(n,\gamma)\,^{60}Co$.

The ^{60}Co source, usually in the form of a solid cylinder, discs, or pallets, is contained inside a stainless steel capsule and sealed by welding. This capsule is placed into another steel capsule which is again sealed by welding. The double welded seal is necessary to prevent any leakage of the radioactive material.

The ^{60}Co source decays to ^{60}Ni with the emission of β particles ($E_{max} = 0.32$ MeV) and two photons per distintegration of energies 1.17 and 1.33 MeV

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[3] Teletherapy is a general term applied to external beam treatments in which the source of radiation is at a large distance from the patient.