The First Two Electron Linear Accelerators in South Africa

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SUMMARY

The electron linear accelerator is considered by many leading radiotherapy centres throughout the world as the most suitable equipment for the treatment of cancer. There are good reasons for this opinion, and some physical aspects are summarised here.

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The linear accelerator has been specifically designed to meet the unique requirements of precision radiotherapy. It provides a substantial extension of the physician's ability to maximise tumour dose while minimising the dose to healthy tissue. Conversion of the accelerator to the electron therapy mode is an easy and rapid procedure. It has been proved beyond any doubt that electrons, when using optimal treatment conditions for various schemes, give superior radiation effects and in many cases better treatment results than X-rays.

The first electron linear accelerator—the Mevatron VIII — was taken into operation at the beginning of August 1969. The second electron accelerator—Mevatron VI — was taken into operation on 28 August 1972. There is actually a structural difference between these two models.

The concept of a linear accelerator originated with Ising in Sweden in 1924. He suggested the use of a spark-gap oscillator and transmission lines to accelerate particles in a straight line. In 1928, Wideröe in Germany successfully applied the resonance principle to accelerate potassium ions to 50 kV with an applied voltage of 25 kV. Technical advances resulting from the development of radar during World War II made possible the concept of the travelling-wave linear accelerator. In 1949, the first klystron-powered linear accelerator was successfully operated at Stanford, achieving an energy of 35 MeV in a 14-foot-long waveguide. By the middle of the 1950s, it was apparent that the linear accelerator showed great promise by its inherent capability to produce intense electron beam currents at high energies.

PRINCIPLE OF OPERATION

The basic microwave linear electron accelerator system consists of a power supply providing high voltage direct current power to the modulator, which converts direct current to high-peak pulses. This drives the power source, which is a high power amplifier tube (magnetron). In the Mevatron VIII, in addition, an amplitron amplifies the output of the magnetron tube with a factor of 6. Pulses of microwave frequency power from the tube are coupled to the acceleration waveguide, which is designed to propagate a travelling microwave field. Electrons are injected into this field by the electron injector—a heated cathode with associated pulsing, focusing the pre-acceleration components.

The system is equipped with an ion pump which maintains the electron injector and acceleration waveguide under proper vacuum conditions. A good vacuum is required to prevent electrical breakdown in the accelerating waveguide, and to prevent poisoning of the cathodes in the electron injector. Energy, current, pulse characteristics, vacuum, cooling and protective interlocks are all monitored and controlled remotely from the central control console.

Electrons are emitted from the injector at moderate energies. The injector system operates at pulse repetition rates up to several hundred pulses per second, with pulse lengths of a few microseconds. Injector systems bunch the electrons so that they are injected into the waveguide in the proper phase relationship with the microwave power.

The accelerating section consists of disc-loaded cylindrical waveguides. The accelerator may comprise only one such section or several in series, depending on the desired electron energy. Microwave frequency power is fed from the amplifiers to the waveguide at the beginning of each section. The electrons gain energy by absorbing energy from the microwave fields as they travel through the accelerator.

The synchronisation of power tubes and electron injector is accomplished by means of trigger pulses originating from a single master timing oscillator. These trigger pulses are precisely adjustable to provide the proper sequence.

In operation, electrons will be bunched about a narrow phase compared to the microwave cycle, and the power into each accelerating section will be coherent. However, when the electron beam passes from one accelerating section to another, it is necessary that the proper phase relationship between the bunched electrons and the microwave power in the new section be achieved. This is accomplished by remotely operated phase shifters for each section.

THE ELECTRON LINEAR ACCELERATORS

Advantages

Skin sparing effect. When using 250 kilovolt-peak-maximum or 3-mm Cu HWL X-rays, the maximum dose falls

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on the entrance skin; with ^{60}Co gamma rays the peak value occurs 0,46 cm below the skin, and with 6 MeV X-rays this approaches 1,5 cm, and with 8 MeV it is 2,0 cm below the skin. The deeper the point of maximum build-up occurs in the tissue, the less skin reaction will be encountered for a given dose.

Equal bone and tissue absorption. The 6 and 8 MeV X-rays are absorbed equally in bone, muscle and soft tissue.

Lower volume dose. Due to the higher energy of the 6 and 8 MeV X-rays compared to lower energy radiation, there is less side scatter outside the geometric confines of the shaped beam. For a given tumour size the total dose to the body is reduced, and vital organs lying adjacent to the main beam will suffer less damage.

Small focal spot. The electron beam striking the X-ray target is focused to a 3-mm diameter spot. This results in sharply defined X-ray beams with minimal penumbra.

High output. The linear accelerator with an output of 200 to 300 rads per minute X-rays or electron at 100-cm focus skin distance helps to avoid prolonged treatments.

Beam defining system. The Mevatron produces flattened, symmetrical X-ray fields, continuously variable in size from 0,5 × 0,5 cm up to 35 × 35 cm at isocentre.

Motorised retractable beamshield and isocentric rotation. The high output, combined with the retractable beamshield and large field size, is ideal for whole body irradiation. In addition to fixed and multiple field capabilities, the Mevatron incorporates arc and full rotation operation as a standard feature. In the arc therapy mode the output of the accelerator is continuously variable from 0,5 to 5 rads per degree.

The Mevatron VIII

The Mevatron VIII is mainly used in the 8 MeV X-ray mode. Any energy between 3 and 10 MeV can be push-button selected. This accelerator can also be used in the electron mode with 4,7 or 10 MeV electrons. The Mevatron VIII can also be used for research work. The machine is tilted through 90° and by means of a drift tube the electron beam can be guided to an adjacent room. The dose rate can be as high as 6 000 rads/sec.

The Mevatron VI

The Mevatron VI has just been installed and the necessary acceptance tests performed.

Comparison of Depth Dose Curves

The depth of the 50% X-ray dose with various energies, and percentage doses at depths of 10 cm and 30 cm for a 10 × 10 cm field, are given in Table I.

TABLE I. SUMMARY OF DOSAGES AT VARIOUS DEPTHS FOR DIFFERENT ENERGY SOURCES

Energy MeV	Depth cm of 50% dose	Percentage dose at 10 cm	Percentage dose at 30 cm (exit dose)
^{60}Co 80 cm FSD	11,5	55,6	13,5
6 MeV 100 cm FSD	15,0	67,0	23,0
8 MeV 100 cm FSD	17,0	71,0	26,5
10 MeV 100 cm FSD	18,0	73,0	28,5

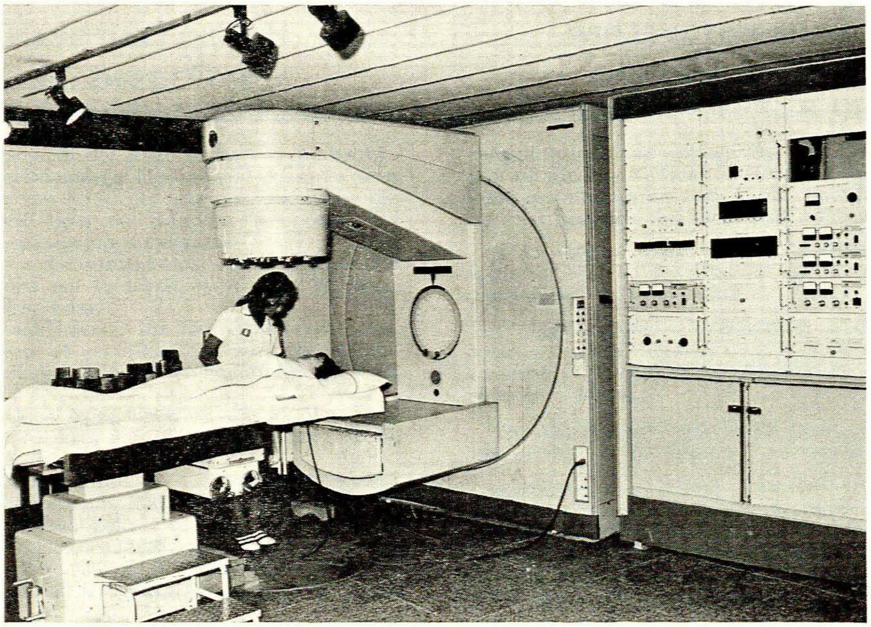

Fig. 1. The Mevatron VIII.

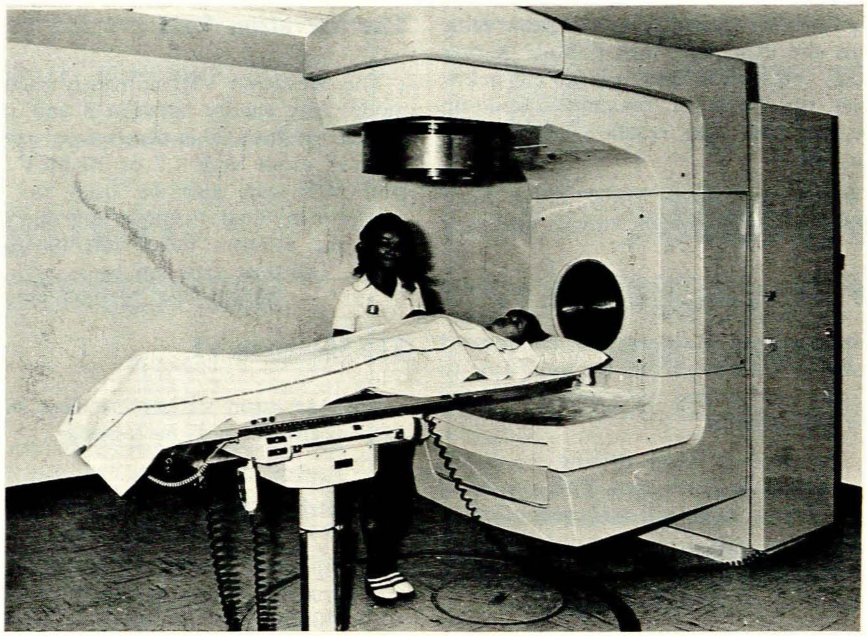

Fig. 2. The Mevatron VI.

CONCLUSIONS

The technical means for treating deep-seated, and in some cases superficial, lesions are now highly perfected. To have an electron and an X-ray mode with preselected energy facilities on the same console in one machine is truly an advantage. Taking all the advantages of the electron linear accelerator into account, this machine is indispensable in any modern therapy centre.

REFERENCES

1. *Operation Manual* from Applied Radiation, Walnut Creek, California, USA.
2. Cohen, M., Jones, D. E. A. and Green, D. (1972): Brit. J. Radiol., suppl. 11.