EULIMA BEAM DELIVERY

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The beam delivery system planned for EULIMA will use a small spot which will be scanned over the tumour volume. The spot will be sufficiently small that the edge can be defined sharply enough without adding collimators. Inside the tumour the dose can be varied from point to point as required to build up an overall dose uniform throughout the desired volume.

An important feature is the use of one or more beam splitters to divide the beam from the accelerator into many independent beams. This will enable the number of patients treated per day to be increased in proportion to the number of beams, and limited only by logistic and clinical considerations. This can be accomplished by splitting the beam as often as necessary, using a standard technique, which is already in use at LEAR [1]. The beam intensity required for each room is 2.10^8 particles/sec, compared with 5.10^9/s produced by a synchrotron and many more available from a cyclotron. Therefore in principle 16 or more sub-beams could be made available.

For the cyclotron a more efficient beam splitter can be based on the 70 MHz bunch structure of the ejected ion beam. A cavity resonating at 35 MHZ and synchronized to the cyclotron radiofrequency, has been designed to give an oscillating electric field of ± 25 KV/cm. The particles pass through when the field is at its peak value and are deflected up or down through 4 mR. They then pass cleanly into the main splitter magnets a few meters down stream, without hitting the magnetic septum. The power required for the RF splitter is about 25 kilowatts.

A fast on/off switch will be needed on each sub-beam, primarily to turn it on or off [2]. By using proportional control, with feedback from an ionization chamber, the switching magnet can also be used to control the intensity of each sub-beam. We anticipate a response time of order 50 μsec.

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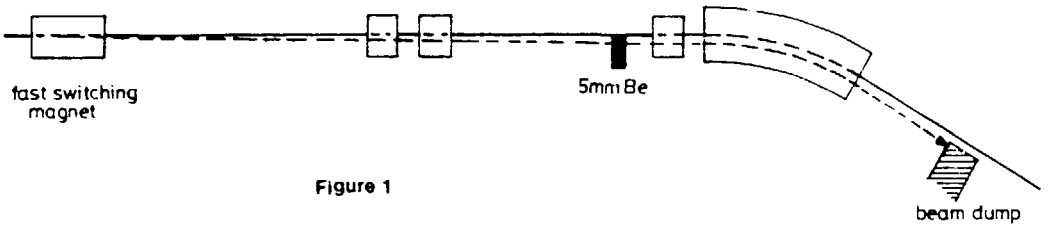

Figure 1

In the typical design, shown in Fig 1 the beam is lost in a two stage process to obtain clean switching. The beam is first deflected onto a primary slit (Carbon, 10 mm thick) at which it loses energy. This is followed by a fixed bending magnet, such that the unwanted beam falls 2 cm inside the graphite beam dump, while the wanted beam passes through without deterioration. By varying the current in the switching magnet the intensity of the beam can be controlled smoothly from zero to maximum. The beam intensity will be controlled by feedback from a fast ionization chamber downstream of the switch, so that the beam current matches the current requested by the beam control computer.

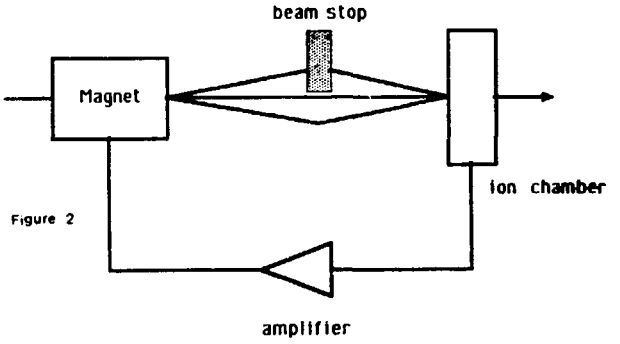

Figure 2

The ion collection time can be reduced by using a thin layer of gas (≈ 5 mm), high electric fields (≈ 10 kV/cm) and using the appropriate gas (helium). Collection times as short as 20 μsec appear to be attainable. Such a chamber can be the measuring element in a control loop, as shown in Fig 2, to adjust the switching magnet until the beam intensity is at the desired level. The level required would be specified as a demand signal injected into the control loop. As the demand is varied from zero to maximum the beam intensity would automatically be matched to the requirement with a delay of 50 μsec or less. At the scanning speeds proposed this would correspond to a position error of only 0.2 mm.

This intensity control, acting separately on each beam, will have many functions :

a) compensate for fluctuations in the accelerator

b) vary the intensity as required at different parts of the tumour to compensate for the plateau dose already received.

c) turn off the beam whenever the Bragg peak would fall outside the tumour

d) turn off the beam whenever an error condition is detected.

e) Initiate and terminate the treatment. For access to the room a secondary mechanical beam stop will also be used.

If we are to operate with multiple beams each must have an independent range control : energy control at the accelerator itself would affect all beams equally, so they would not be independent. Therefore range-changing absorbers (degraders) are included in the current designs. The two main alternatives are to put the variable degrader (a) before or (b) after the scanning magnets.

A detailed study of the loss of beam quality in a degrader has been reported [3]. In brief, to slow down an oxygen beam from 20 cm to 4 cm range in water it is necessary to focus the beam onto the degrader with an optimum convergence. At the output the angular spread (standard deviation) is 10 mR and the momentum spread is ± 1 %. In order to refocus such a beam onto the target plane, after passing through the scanning magnets, sextupole correcting magnets are included in the design. The final image size is 2.3 mm including second order aberrations.

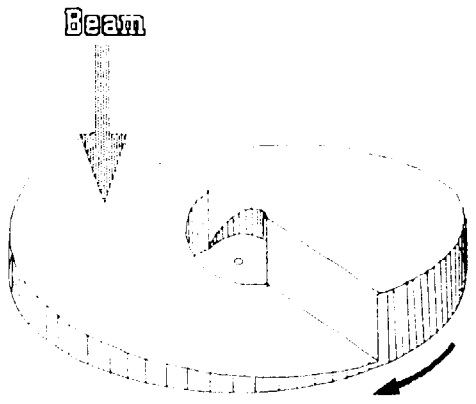

Figure 3

We have also considered the alternative of placing the variable degrader after the scanner, just in front of the patient. In this case the range could be modulated by a rotating wheel with a linearly increasing thickness, as indicated in Fig 3. The wheel would be mounted in a protective cage. It would have a diameter of about 90 cm and would rotate at 600 rpm, giving a complete range scan of 15 cm water equivalent in 50 msec. This would be the most rapid scan direction. During each range sweep the fast beam switch would be used to adjust the beam intensity to fit the required dose profile. In particular the beam would be turned off whenever the Bragg peak fell outside the tumour volume.

The advantage of this arrangement is that the lateral (magnetic) scans are much slower and consume less power. This simplifies and saves expense on the electronics. The principal disadvantage is that fragments created in the degrader will go into the patient.

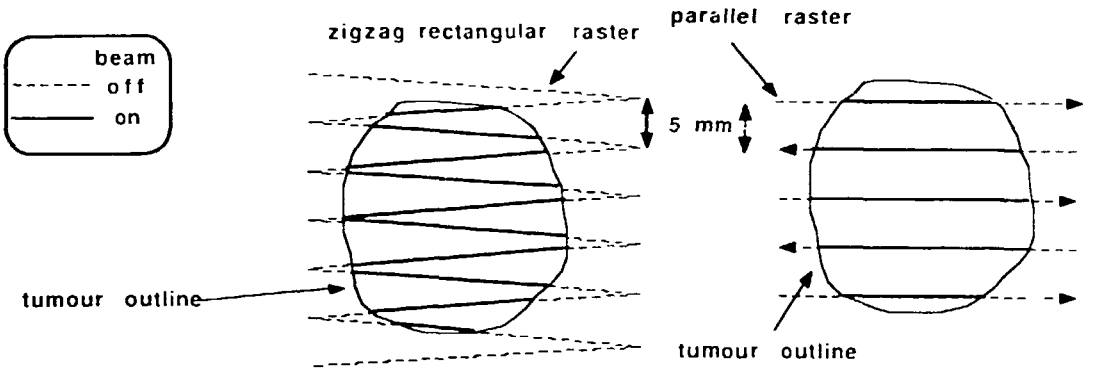

Figure 4a

Figure 4b

Lateral scanning : because each beam will be equipped with a fast switch, capable of regulating the beam intensity, it is permissible to use a continuous raster scan at uniform speed. The turning points would be outside the tumour where the beam will in any case be switched off. The scanning pattern for each range slice could be either a zigzag raster as in Fig4a, or a set of parallel lines as in Fig4b. On balance, option (b), the horizontal raster, will be the more economic. Secondly it will be conceptually easier for physicians to determine the dose required at each point if the raster is made up of horizontal lines. Thirdly, with the parallel scan one can move down to the next line as soon as the beam is outside the tumour. In contrast, with the zigzag one must complete the full scan to ensure equal line spacing ; more time is wasted outside the designated area.

In summary for a lateral scan area 10 x 10 cm^2 each range slice would be scanned in 1 second. Allowing 20 range slices (each 5 mm thick) a 1 litre tumour would be scanned in 20 sec ; it could be scanned 10 times in 200 sec. A 30 x 30 cm^2 window would take 9 times longer to scan, so depending on the time available one would only scan it once or twice. However, if the edge definition can be more blurred one can always broaden the spot, and scan with a cruder raster, so as to complete the scan more rapidly.

Designs of several complete beam delivery systems incorporating the above features were presented by way of example.

REFERENCES

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