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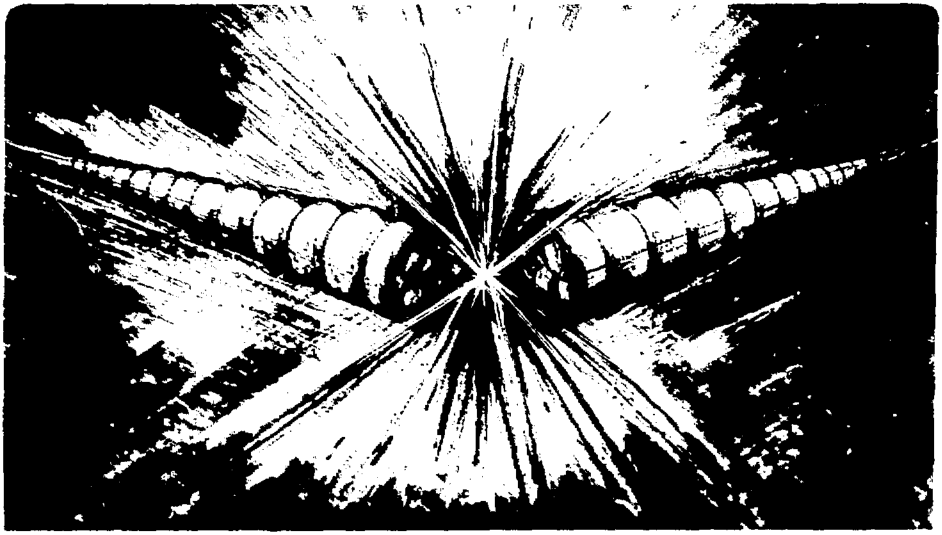

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HEAVY-ION-BEAM STUDIES AND IMAGING
WITH A MULTIPLANE, MULTIWIRE PROPORTIONAL CHAMBER*

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Abstract

A 16-plane multiwire proportional chamber is used to accurately measure intensity profiles of heavy ion beams at the Bevalac. An imaging capability has now been developed for the system, allowing for reconstruction of 3-dimensional representation of radiological objects using heavy ion beams.

Introduction

MEDUSA (MEdical Dose Uniformity SAmpler), a 16-plane multiwire proportional chamber has been constructed and used at the Biomedical beam area of the Bevalac[1]. The 16 chamber planes, each of which has 64 parallel wires placed 4 mm apart, are stacked with their wire directions staggered in such a way that they cover the 180 degree space (Figure 1). When ionizing radiation passes through the chamber, the resulting ionization electrons are collected in each signal wire and stored in the integrating capacitor connected to the wire. The voltage on the capacitor is therefore proportional to the beam intensity over the area of a strip which is centered on the particular wire and extends midway toward the adjacent two wires.

The data collected on the 64 wires of a plane are the line integrals along the wires of the beam intensity. In other words, the data represent the one-dimensional projection of the 2-dimensional beam intensity profile along the direction of the wires of the particular plane. Based on the 16 projections, each at a different angle, the beam intensity profile can be readily reconstructed. At the end of each data collecting cycle, usually one or a few Bevalac pulses, the capacitor voltages are sequentially sampled, digitized, and stored in a buffer memory under the control of an LSI-11 microprocessor. Upon command, the data in the buffer are serially transmitted to the host computer, a PDP 11/34 computer. The 1024 data points (16 planes of 64 wires) are used to reconstruct the beam profile, usually in a 64 x 64 array with 4 mm pixel size. The software developed for the reconstruction is based on the technique of back-projection with Fourier convolution[2]. The reconstructed image is color coded according to the intensities and displayed on a RAMTEK system which has a 512 x 512 pixel matrix with each pixel of 12-bit refreshable memory.

Beam Profile Studies

Uniform dose distributions of heavy ions in large volumes are required for the radiotherapy and radiobiology programs at the Bevalac[3]. For example, radiotherapy often requires a uniformity of doses with fluctuations less than a few percent over a 20 cm diameter field size. This lateral uniformity must persist over the full thickness of the treatment volume, which often spans 12 cm or more. Therefore accelerated heavy ion beam must be spread out both in its particle ranges as well as in lateral directions before it enters the treatment volume. The spread of the ranges of the stopping heavy ions, which defines the treatment volume thickness, is called the modified Bragg peak, and is achieved by inserting a variable thickness absorber such as a spiral ridge filter into the beam. The lateral spread of the beam is generated by transporting the heavy ion beams through a scatterer-occluding ring assembly[4,5]. The first scatterer located approximately 10 m upstream of the isocenter scatters the pencil beam and shapes it into a broad Gaussian distribution. The occluding rings and a central post, placed in a concentric geometry and centered on the Gaussian beam, remove excess particles from the central axis of the scattered beam. And multiple scattering by the second scatterer diffuses the beam into a wide field with the required flat dose distributions. The second scatterer and the occluding ring assembly is positioned about 5.5 m upstream of the isocenter.

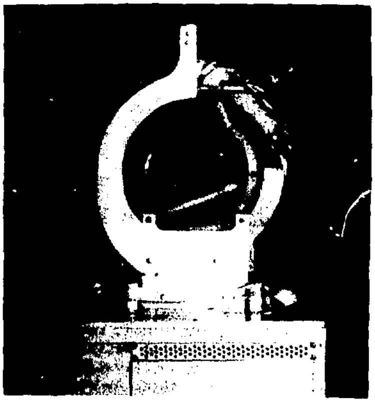

Figure 1. MEDUSA.

Some examples of the heavy-ion beam profiles are shown in Figure 2. The beam used for these examples is neon-20 with a kinetic energy of 670 MeV/amu. Figure 2a shows a wide and uniform beam generated using 1.11 cm of lead first scatterer, the spiral ridge filter for a 10 cm spread Bragg peak, and an occluding ring and post system. The spiral ridge filter and the copper plate that holds the occluding ring serve as the second scatterer. The beam, measured at the midpoint of the spread Bragg peak, is 20 cm in diameter and its uniformity is within ±2%. The beam profile depicted in Figure 2b shows an overcompensated beam. The occluding ring and the post were too large, so that their "shadow" is not smoothed out by the multiple scattering. Increasing the thickness of the second scatterer and decreasing the sizes of the occluding ring and post may produce more uniform dose distribution. An example of an actual therapy beam shaped by an irregularly shaped collimator to conform to the shape of the treatment volume is shown in Figure 2c. The range of the beam is adjusted to align the distal peak with the distal edge of the treatment volume by varying the thickness of a water absorber in the beam line. Finally the beam goes through the irregular collimator, which in this case is placed in front of MEDUSA located at the beam-delivery isocenter.

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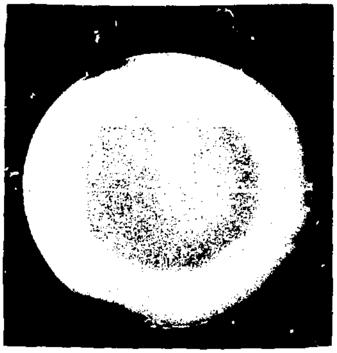

Figure 2a. The intensity profile of a 670 MeV/amu neon-20 beam.

Figure 2b. An overcompensated beam.

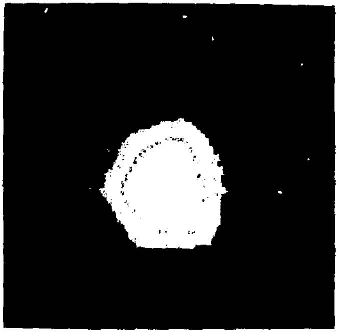

Figure 2c. An example of the radiotherapy beam shaped by an irregular collimator.

MEDUSA is used in the Biomedical facility of the Bevalac for routine beam profile measurements and for new beam development. It produces satisfactory images of beam profiles using one Bevalac beam pulse. In practice, however, three or more beam pulses with reduced intensities are used to average out the excursion of the beam from pulse to pulse.

Imaging With MEDUSA

MEDUSA was constructed primarily for measuring the intensity profiles of heavy-ion beams. As seen above, it performs these functions quite well, providing good images where spatial intensity variations are slow. However, the sharpness of the edges of the collimated-beam image (Figure 2c) indicates that this chamber might also be applied for the imaging of complex objects. Tests to be described below have borne this out.

By adjusting the thickness of an absorber, the unmodified Bragg peak can be placed slightly downstream of MEDUSA. When a wide, flat beam is sent into the device, it will reconstruct a wide, flat beam profile. If an object is introduced in the beam upstream of the chamber, the part of the beam impinging on the object will stop within the object and fail to go through the chamber, thus casting a "shadow" of the object. The images of such shadows are readily reconstructed. Figure 3 is an image of two laboratory tools reconstructed in MEDUSA using a 670 MeV/amu neon-20 beam (range in water is about 32 cm). The image is reconstructed in 384 x 384 pixels, or 6 pixels per 4 mm wire spacing. In the reconstructed image of an edge, the transition from 10% to 90% of pixel values from background to full "shadow" takes about 2 mm. A straight edge is reconstructed to an accuracy of about 1.4 mm, which is about one-third the wire spacing.

Figure 3. A projection radiograph of laboratory tools produced by MEDUSA using 670 MeV/amu neon-20 beam.

Heterogeneous 3-dimensional objects can be imaged using MEDUSA in the following way. If a heavy ion beam with a modified Bragg peak (spread by a spiral ridge filter, for example) is transmitted through a radiological object, only the particles in the portion of the peak that have excess energy after passing through the object will enter the chamber. If modified Bragg peak is shaped in such a way that the dose is a function of the position in the spread peak, then the measured dose downstream of an object in the beam can be translated into the integrated stopping power of the object along the path of the beam (Figure 4). In other words, the reconstructed image of a 3-dimensional object using a heavy ion beam with a suitable modified Bragg peak is a 2-dimensional projection radiograph of the object, each pixel of which gives the integrated electron density seen by the beam particles arriving at this pixel's coordinates.

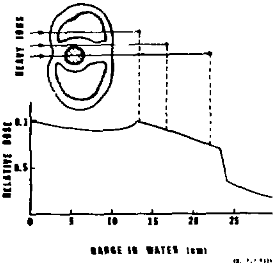

Figure 4. The relationship of integrated electron densities seen by the heavy ions and the dose on the spread Bragg peak in imaging by MEDUSA.

The simple phantom shown in Figure 5a represents the human body (lucite, density = 1) with lungs (air space cut out in the lucite), and a spinal column (teflon, density = 2.2). Imaging experiments were performed with the standard neon radiotherapy beam using a 12 cm spread Bragg peak. The phantom was rotated by an equal angular increment between exposures and 16 projections distributed uniformly over 180 degrees were obtained. The reconstructed image of the projection at one of the angles is shown in Figure 5b. Based on these 16 projections, a 3-dimensional reconstruction of the phantom is carried out. Figure 6a shows axial tomographic slices of the phantom. The reconstructed

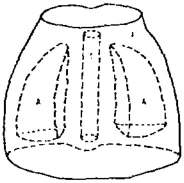

Figure 5a. A lucite phantom with two air spaces and a teflon rod.

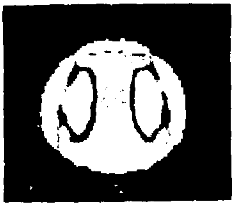

Figure 5b. An image of the phantom made in MEDUSA using a Bragg peak.

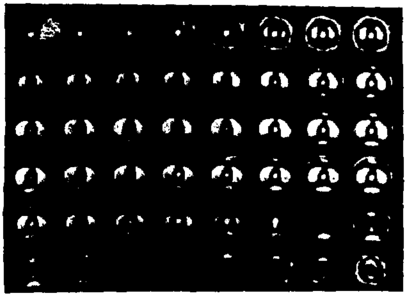

Figure 6a. Reconstructed tomographic sections of the phantom.

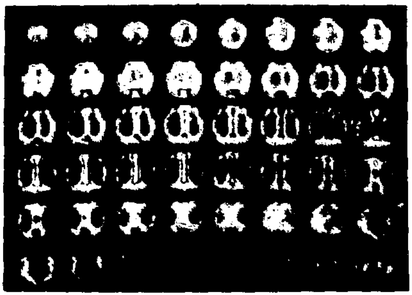

Figure 6b. Reconstruction of the phantom in coronal planes.

slices of the phantom in coronal planes are shown in Figure 6b. An attempt to reconstruct a 3-dimensional representation of the phantom is shown in Figure 6c, which show the teflon column and the two air spaces in the lucite. In these tests, the radiation dose required to produce the 3-dimensional reconstruction using 16 projections is estimated to have been about 2 rad.

These preliminary tests of imaging by MEDUSA were performed using a ridge filter designed for radiotherapy applications. The dose differential obtained using this filter over the spread Bragg peak is less than 40% of the dose at the proximal peak (Figure 4). Since the detection of the integrated electron density depends on the transmitted dose, the larger is the dose differential the better is the density resolution of the image. A filter with more suitable Bragg peak spreading for MEDUSA imaging is being developed. The sensitive area of MEDUSA is a circle of a radius of 25.6 cm, which is too small for most human patients. A larger chamber, and probably with finer wire spacings than the current 4 mm, may be useful for clinical applications. It will provide a 3-dimensional assessment of the patient anatomy with respect to the treatment beam when the patient is in the treatment position immediately before the treatment. Such information will be very valuable for therapy planning, verification of the plan, patient positioning, and the localization of the treatment volume.

Figure 6c. A 3-dimensional representatin of the air spaces and the teflon rod of the phantom produced by MEDUSA.

Conclusions

MEDUSA has proven to be a highly useful tool for heavy-ion beam tuning and verification. Its ability to image 3-dimensional objects is investigated for use in verification of radiotherapy patient setups and therapy plannings. Such a system will make it possible to assess the patient anatomy in relation to heavy ion beams with the patient in the treatment position at the time of treatment.

Acknowledgments

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