Title

IMAGING WITH ACCELERATED HEAVY IONS IN SUPPORT OF CANCER DIAGNOSIS AND THERAPY

Author
Llacer, J.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Engineering & Technical Services Division

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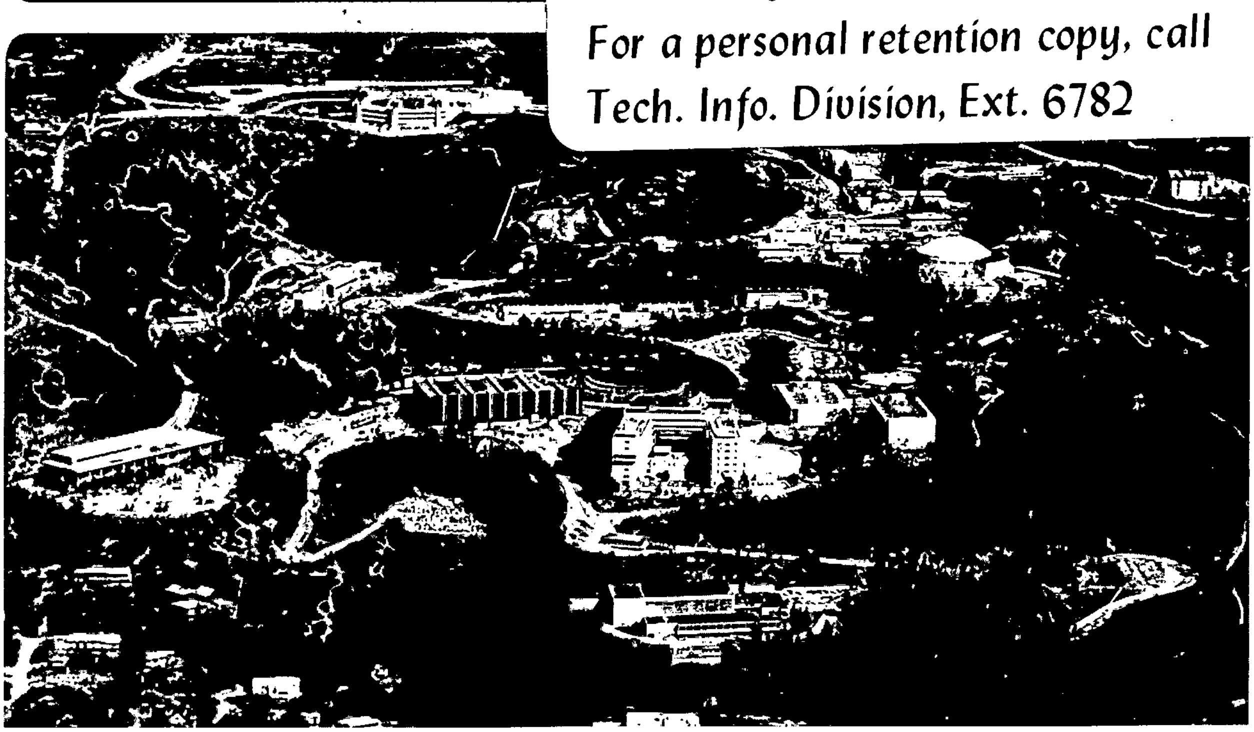

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DISCLAIMER

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Jorge Llacer
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
U.S.A.

Summary

Accelerated heavy ion beams (carbon through silicon) are being used in a variety of basic and applied Biomedical studies at the Lawrence Berkeley Laboratory. Using the BEVALAC accelerator,[1] those particles attain energies that allow them to penetrate deep areas of the human body, or to traverse it. As heavy ions lose energy in matter, their energy deposition per unit path length is relatively low until the end of their track. At that point it increases strongly, forming a sharp peak which, in water, is only a few millimeters wide. This sharply peaked depth-dose relationship is very favorable for the treatment of small cancer tumors in regions close to sensitive organs, in cases where surgery or chemotherapy are not effective or possible. Two other characteristics that make heavy ions excellent candidates for cancer therapy are their high Radiobiological Efficiency (relative efficiency in cell killing) and Oxygen Enhancement Ratio (effectiveness in cell killing for both oxygen-poor and oxygen-rich cells.)[2]

Cancer therapy using carbon and neon with energies up to 670 MeV/nucleon have been initiated at LBL after considerable experience and success with helium beam therapy. It is in support of the therapy activity and also as a future powerful diagnosis tool that imaging with accelerated heavy ions is being developed.

The fundamental characteristic of heavy ions that makes them into a desirable form of probing radiation for imaging is an energy loss mechanism that is proportional to electron density, rather than to a composite of photoelectric and Compton absorption coefficients for X-rays. This characteristic translate itself into a number of advantages:

a) A radiograph or tomograph obtained with heavy ions will result in information that is directly applicable to accurate treatment planning for therapy with the same kind of particles.

b) X-ray CT numbers, in conjunction with heavy ion CT numbers can be used to obtain considerably more detailed information about the composition of tissues than it is possible with only one of the techniques.

c) The dose with which useful plane or tomographic imaging with heavy ions can be obtained is much lower than that of conventional X-ray imaging.

Heavy ion imaging requires the measurement of position and range (or energy) of the particles which have tranversed a subject. There are two methods which, at present, can make this measurement with the necessary accuracy:

1) A stack of nuclear plastic sheet track detectors[3], and

2) Position sensitive, dE/dx silicon detectors before and after the beam traverses the subject, used in conjunction with a full absorption germanium detector stack, beyond the second silicon detector.[4]

The plastic track detectors record the stopping point of each heavy ion by the radiation damage that each sheet suffers at the end of the particle's track. After etching, a pattern of holes is made in each sheet of the stack. The pattern can be digitized by a video scanner, and computer processing gives a two-dimensional mapping of integrated electron density along the beam path.

This is the analog of a standard X-ray radiography. The information obtained is, however, quite different. Critical differentiation of soft tissues is very possible and the strong absorption of X-rays by bone is considerably softened in the case of heavy ions. By rotation of a subject, it has been possible to obtain enough information to demonstrate the tomographic capabilities of the method. A number of transverse images of anatomical structures have been obtained, and "in vivo" reconstructions of a human brain are being processed at this time.

The solid state detection method is considerably faster to use than the plastic track detector method, and can be as good or better in density discrimination and lateral resolution. Particle identification techniques afforded by the use of the two position-sensitive, dE/dx measuring detectors and the total absorption detector allow an effective discrimination against any particle that does not satisfy a stringent set of selection rules, so that the accuracy of the reconstruction can represent an improvement over plastic track detector images if a higher radiation dose is tolerable in the patient. A simple set of three detectors has been used to investigate the feasibility of the concept by reconstructing the image of a plastic disk of 7 cm. diameter with 7 one-millimeter copper pins along one diameter line and some voids. Data were obtained with a neon beam and the sample was rotated and translated past the beam and detector line in an initial experiment. The reconstructed image has proven the feasibility of the concept and has helped to identify some of the initial problems. The existence of the copper pins creates a number of artifacts which are part of the image reconstruction algorithm limitations, rather than to detector-electronics errors.

In closing, this paper discusses the application of two quite different technologies to the problem of obtaining radiographic and tomographic information for diagnostic and cancer therapy with heavy ions. The increasing worldwide interest in heavy ion radiation biology and medicine, with the possible construction of a number of dedicated accelerators, gives us the necessary impetus to continue our research work.

Acknowledgments

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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720