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IN REPLY REFER TO: H-9 FOR APPROVAL BEFORE DISPATCH

May 16, 1972

MES-200

Morton M. Kligerman, M.D., Director
Cancer Research & Treatment Center
University of New Mexico Medical School
Basic Sciences Building
Room B-15
Albuquerque, NM 87106

Dear Dr. Kligerman:

Enclosed please find copies of the mini-proposals from M. Raju and Chaim Richman.

Sincerely yours,

Thesa C. Britt

Thesa C. Britt, Secretary

tcb

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Enclosures (3) as stated above.

PHYSICAL PROPERTIES of the PION DOSE DISTRIBUTION and BEHAVIOUR of the BEAM in TISSUES

Chaim Richman

Objective: The purpose of these experiments is the following: 1) To determine the fractions of electron and muon contaminations of the therapeutic pion beam. 2) To determine the high LET dose in the plateau region of the beam. 3) To determine the distribution of the star dose in the peak region. 4) To study the attenuation of the beam in bone, muscle and fat. 5) To study the behaviour of the beam around tissue inhomogeneities. 6) To study collimation and field shaping of the beam.

Background: Experiments for the past ten years have shown that when protons are used to produce pion beams, muon and electron fractions are also produced. These can be small or large, depending on the geometry and magnetic parameters of the beam line.

The pion has one-sixth the mass of the proton and interacts strongly, both in flight and when it comes to rest. The physical products of these interactions determine eventually the biological responses of different tissues, and the scattering determines the behaviour of entire beams.

Methods of Procedure: The lithium-drifted semiconductor detector is a small probe which is well known to faithfully (linearly) respond to energies deposited by charged particles. Using the electronic modules which are available for the handling of logic and linear pulses, the system can be used to map a radiation field and to determine the high and low LET components of the field. This system will be used in different phantoms and with different configurations to lay the physical groundwork for therapy.

Significance: In preparation for both the radiobiological studies and the therapeutic uses of pions, it is not sufficient to measure the total dose with ionization chambers. One must know the detailed physical components of the beam: The fractions of low and high LET components produced by the contaminants, the elastic and reaction scattering of pions in tissues, and finally the nature of the star products. These phenomena will be somewhat different in different tissues and must be fully understood before therapy can begin.

M. R. Raju, H-9
May 10, 1972

SITE VISIT PRESENTATION

CELL BIOLOGY - PERSPECTIVE

I will give a brief summary on the work that was done on pion radiobiology and outline some of the characteristics of pion beams that necessitate extensive pretherapeutic pion radiobiology.

Radiobiology of pions at Berkeley was done mostly at the peak of depth-dose distribution. The beam had a contamination of 25% electrons and 10% μ^-. Tables I and II show the results of RBE and OER. The dose rate was about 0.5 rad/min. Hence some of these results are dose rate dependent. Besides these results being dose rate dependent, these numbers will not quite be the same for therapeutically useful beams but these results certainly give some idea of what to expect for therapeutic beams.

Let us consider a therapeutic situation such as a treatment volume of thickness 10 cm. The LET in the Region 1 is about 0.3 keV/μ and increases to about 3 keV/μ at the Region 2. Hence no significant changes in biological effects are expected in the intervening normal tissue Region 1 - 2. However, some of the recent calculations by Armstrong et al. from Oak Ridge National Laboratory indicate that a significant fraction of dose is deposited by nuclear interactions in the Region 1 - 2 and part of this dose is due to high LET. ~~OER~~ Radiobiological measurements so far did not indicate any significant increase in biological effects but this has to be carefully looked into.

The dose due to stars increases as we go from Position 3 - 5. Our previous RBE measurements correspond roughly to Position 5 and hence they are upper limits. When two opposed fields are used the variation in biological effects such as in RBE and OER gets reduced and nearly the same as in Position 4.

RBE decreases considerably and OER increases slightly with increasing width of the peak because with increasing width, the dose fraction due to stars gets reduced. This is illustrated in the figure. The biological effects are not expected to depend upon the depth at which these peaks are located.

The next slide illustrates schematically what to expect when biological systems are exposed at peaks of different widths to multiple doses.

Hence, radiobiological measurements with different systems have to be repeated for different peak widths corresponding to different thicknesses of treatment volumes for single and fractionated doses. Thus for pions pretherapeutic radiobiology is more involved than even fast neutrons.

M. R. Raju, H-9
May 10, 1972

SITE VISIT PRESENTATION

ABSORBED DOSE, DEPTH-DOSE AND ISODOSE MEASUREMENTS

The π^- beam will be monitored by using parallel plate ionization chambers. The absorbed dose in the region of interest will be measured by using a tissue-equivalent ionization chamber.

The composition of tissue equivalent plastic is not very critical at the plateau region as is the case for other charged particles such as electrons and protons, since the ionization in that region is mainly due to direct ionization in the gas rather than the contribution from the wall. However, in the pion stopping region the plastic composition is important and the dosimetry problems in the region are similar to that of fast neutrons because the π^- star components are quite similar to that of components arising out of fast neutron interaction. It is not possible to have the same amount of oxygen in any plastic material as there is in tissue. Hence, elements such as carbon have to be substituted for oxygen. Fortunately for π^- mesons, the star components and their energy distributions are quite similar in carbon, nitrogen and oxygen. A special plastic was made used by the late Dr. Shonka to experiment with pions, by taking pion interactions into consideration. This plastic contains less oxygen and more nitrogen than ICRU muscle. To see if there will be significant variations in depth-dose distribution of π^- mesons, depending on the type of plastic used as a material for an ionization chamber, depth-dose distributions were measured at Berkeley by using thimble-type ion chambers made out of TE 150 plastic which is tissue-equivalent for neutrons and the special plastic that is made. No significant differences in depth-dose distributions were found. We will repeat this experiment carefully at LAMPF and if these results are confirmed again, we will use muscle-equivalent plastic (A 150) material for ionization chambers (for neutrons).

It would be more convenient if we could use air in the ionization chambers rather than tissue-equivalent gas. Air introduces inhomogeneities in the chamber. However, Almond found no significant differences between neutron doses measured with chambers filled with air and with tissue-equivalent gas for neutrons produced by 30 MeV and 50 MeV deuterons on a beryllium target. We will do similar measurements for π^- mesons and if we do not find significant differences, then we will use air filled ionization chambers.

We will have our ionization chamber calibrated with ^{60}Co γ rays at NBS. The ratio of stopping powers for tissue and air for ^{60}Co (1.35) and for π^- mesons

of about 80 MeV energy (1.33) are within 2%. The relative mass stopping power for 8 MeV alpha particles and 1 MeV π^- mesons is about 1.2. Hence, errors due to changes in energy losses at the plateau and peak amount to about 7%. Reproducibility is the most important criterian we will use for the ionization chamber used in dose measurement. At the earliest opportunity our ionization chambers will be calibrated against absolute pion dose measurements in collaboration with NBS, Memorial Hospital and the M. D. Anderson Hospital. Collaboration with M. D. Anderson Hospital is particularly valuable because they are having a therapeutic program with fast neutrons. We will also plan to have intercalibrations with other pion facilities such as Stanford and Vancouver.

Pion depth-dose measurements will be carried out in a water phantom because of convenience. For pions water is a good approximation for tissue because as I mentioned before, π^- star products in oxygen are not very different from carbon and nitrogen. We will use depth-dose measurements in addition to beam diagnostic measurements as outlined by Arvid Lundy for optimizing various parameters for beam tuning such as magnet settings, wedge settings, etc., to get a desired beam.

Experimental depth-dose distributions were made mostly at Berkeley and CERN. Monte-Carlo calculations for pion depth-dose distributions were developed at Oak Ridge National Laboratory and they have compared with the experimental measurements at Berkeley and at CERN. The first slide shows the calculated results with experimental results at CERN. As you could see there is a reasonably good agreement. The second slide shows the theoretical calculations compared with experimental measurements at Berkeley. The agreement here also is good. It must be pointed out that no detailed beam diagnostic measurements such as energy and energy speed were available for both the pion beams used at Berkeley and at CERN and hence, in comparing with these experimental results with calculations, slight adjustments in energy spread and contamination in the beam were made. Hence we cannot conclude from these results, we have perfect agreement between theory and experimental results. We propose to do detailed verification of these calculations w ith experimental measurements for beams with precise information on energy and energy spread.

Dr. Hutson will be presenting to you on pion depth-dose calculations in detail both by Monte-Carlo methods as well as using relatively simple calculations that do not take too much computer time. After obtaining good agreements between calculations and experimental results, we also propose to provide extensive dosimetric information for all the radiobiological exposures in addition to the crucial experimental dose measurements.

The depth-dose measurements along with the radiobiological information become the input data for treatment planning and hence the depth-dose measuring apparatus will have direct computer entry through a CAMAC interface.

Other dosimetric systems such as miniature silicon diodes, thermoluminescent dosimeters, etc., will be investigated for their use with pions. LiF may have limited applications because of their LET dependence.

Isodose measurements for pions will be made by using probably commercial isodose mechanical devices. These measurements are very necessary for evaluating collimating systems, wedging techniques, beam blocks, etc. However, isodose measurements by themselves will not be very meaningful for treatment planning because of significant variation in biological effects as a function of depth.

Dr. Richman will be talking regarding other dosimetric work.