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TITLE: MESON FACTORIES, PI MESON DELIVERY, AND PI MESON DOSIMETRY FOR CANCER THERAPY

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MESON FACTORIES, PI MESON DELIVERY, AND PI MESON DOSIMETRY FOR CANCER THERAPY

Within one or two months tests will start on a magnetic collection channel for pi mesons at the Los Alamos Meson Physics Facility. This channel will make available to the medical community for the first time, therapeutically interesting beams of pions for biomedical research and for the therapy of cancer. Some time in the next few years several other facilities of a similar nature will become operational around the world, and an active world wide program of research in the radiobiology, dosimetry, and therapeutic behavior of pion beams will be carried on. Why this sudden interest in pions for therapy of cancer? It is only now that this application of pions has been possible, due to the advent of a new class of physics research accelerators, the meson factories.[1] These accelerator installations are characterized by the very high current proton beams that they accelerate and the copious quantities of pi and mu mesons that are produced in targets which are introduced into these primary beams. In fact, these accelerators are designed to provide secondary beams of pi and mu mesons of such intensity that the nuclear physics studies done with them may approach in accuracy the studies done up to now in the primary beams of accelerators themselves. It should be made clear that it is not necessary to have such a sophisticated accelerator for the production of pi mesons if the only application is to be cancer therapy. It would be possible to reduce the cost of the Los Alamos Facility by a very

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[1]Rosen, L., "Meson Factories," Physics Today, Vol. 19, no. 12, Dec. 1966.

large factor if the system were to be optimized for cancer therapy alone. In fact, it can be demonstrated rather convincingly[2] that, if pion therapy is spectacularly successful, it need not be merely a laboratory curiosity. Reasonably priced accelerator systems which would be compatible with the hospital environment are quite feasible.

In the case of the Los Alamos Meson Factory, a beam current which is more than adequate for the therapy job is to be available, and a rather conventional magnetic channel for the collection and focusing of the pions has been designed.[3] We strongly felt that for the first trial with pions we should not get too involved with very complex magnetic systems, but that a rather straightforward system would let us concentrate on the formidable problems associated with delivery and dosimetry. However, if the trials are successful, it will be necessary to go to very high acceptance channels, using either superconducting technology or pulsed focusing techniques. Figure 1 shows the pion channel designed for the therapy facility at Los Alamos. In principal the system works as follows: pions originate at a production target located in the main proton beam line, where up to 1 ma of 800 MeV protons are focused. The target material will probably be carbon, but other materials are possible. The choice of target and production angle is dictated by a trade-off between meson flux and electron contamination, the latter being lower with lower Z materials in the target. A beam with a rather wide momentum spread (more than

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[2] Knapp, E. A., "Possible Pion Sources for Radiotherapy," to be published in the Proceedings of the 2nd Meeting on Fundamental and Practical Aspects of the Application of Fast Neutrons in Clinical Radiotherapy, The Hague, Netherlands, Oct. 3-5, 1973.

[3] Lundy, A., R. Hutson, E. Knapp, L. Rosen, "Status and Plans for the Negative Pion Radiotherapy Facility at the Los Alamos Meson Physics Facility," Paper presented at the 3rd International Conference on Medical Physics, Göteborg, Sweden, August 1972.

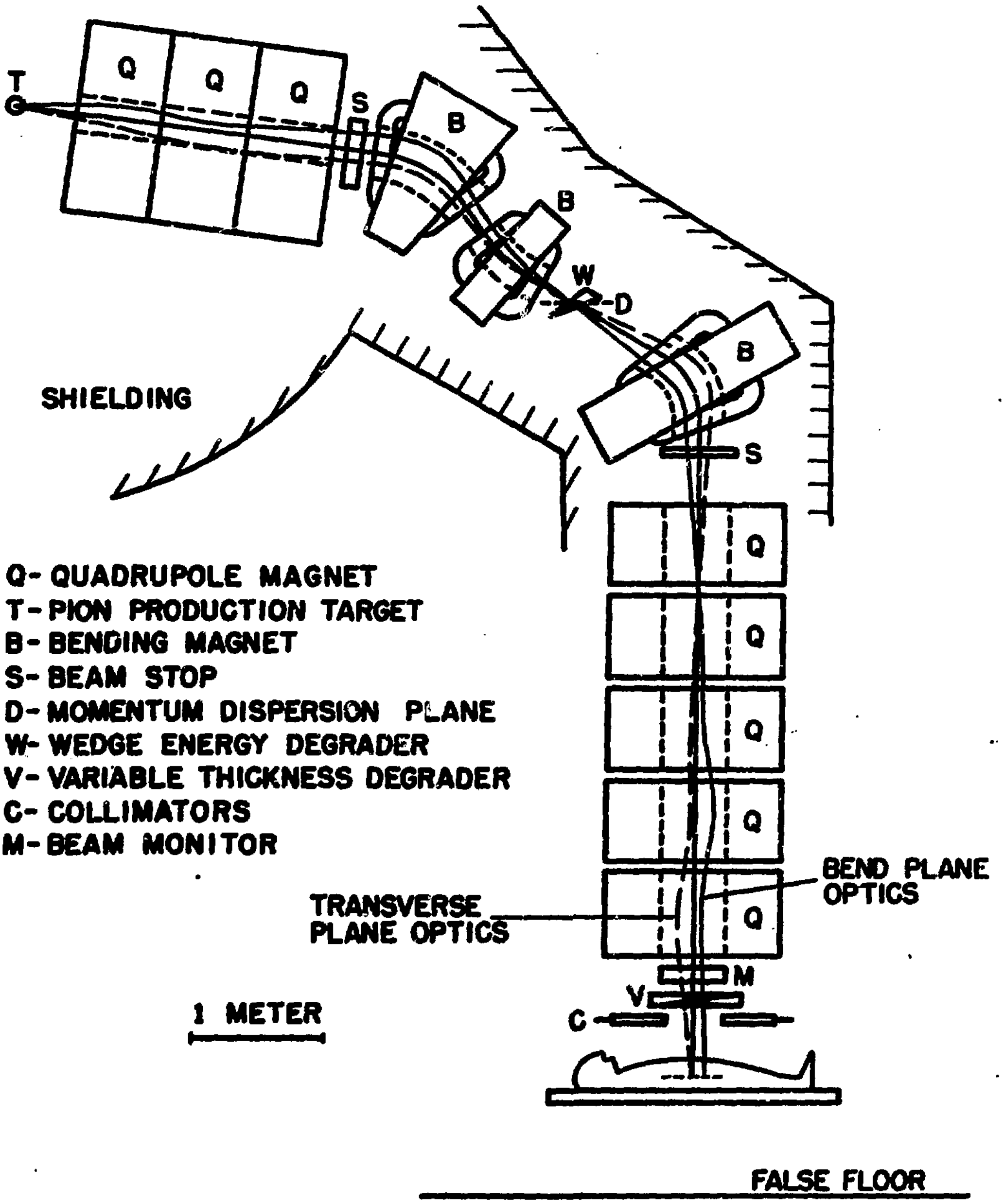
16%) is focused upon a wedge degrader, which serves to reduce the energy of the most energetic particles to that of the lowest energy ones, thus approximately monochromatizing the beam. In our studies of the beam optics made during the design of this channel we found it almost impossible to tailor the momentum spectrum to achieve the required precision of the dose deposition without a trick of this type. The monochromatized beam is then focused by use of five quadrupole magnets into a line focus about 1 meter from the end of the last magnet. This line focus is adjusted to fall at the end of the range of the pions, and in this line they come to rest and produce the star radiation which is their characteristic. For each star there is about 140 MeV of energy released in the form of heavy fragments, protons and neutrons, with the source at the position of the star. This process can be seen in Fig. 2, where the stopping line of pions is illustrated. We next will spread the beam of pions out (up/down) over the volume of the tumor by modulating the energy of the entering pion at the entrance to the body. This is accomplished by placing a variable thickness absorber between the last magnet and the patient. By varying the speed with which the absorber changes thickness the intensity of pions stopping as a function of depth can be varied. Alternatively a "ridge filter" can be employed to approximate the action of a varying thickness absorber. The "ridge filter" is a plate with a corrugated surface which provides different thicknesses to particles with different positions in the incoming beam; the dose distribution is then smoothed by the particle multiple scattering in coming to rest. Problems of tissue inhomogeneity can be minimized by employing no abutting field techniques. The skin to tumor dose ratio is so favorable that probably little additional gain can be obtained using multiport techniques, unless there is a dose rate gain, which has yet to be established. As can be seen in the graph, the pions show a clear advantage in localizability over any other form of radiation being considered, including protons, which give the best field shape for the heavy ions (even though they don't have a high LET). In conclusion, the problems in delivery, which we will have, involve the production of a converging beam of pions which can be controlled precisely as to energy and focus. These problems appear to be well in hand.

In dosimetry, we then determine how the dose should be distributed in order to obtain the best possible distribution of biological effect. This will be one of the most complex dosimetry problems with which medical physicists have ever had to deal. The radiation field is extremely mixed, being composed of pions, muons, heavy fragments, alpha particles, protons and x rays and electrons. The mixture of these components strongly varies as a function of position within the star region as well as in the "plateau region." To visualize this, consider the mixing ratio of radiations at the front and at the back of the stopping region, as shown in Fig. 3. This ratio will be drastically different, because all of the incoming pions must pass through the closest edge of the star region, but only the star products themselves contribute at the far edge of the peak.

The program in dosimetry will consist of a series of physical and biological experiments which we hope will determine the correct pion stopping distribution which achieves a uniform biological effect throughout the peak region with minimal effects in the surrounding regions, independent of treatment volume. As we progress we will determine quantities related to radiation quality, such as LET, as a function of depth and correlate this theoretically to the observed biological results. Some work has already started along these lines with theoretical models developed at Oak Ridge National Laboratory. Experimentally we expect to use ionization and multiplication chambers, Rossi-type proportional counters, solid state detectors, and any other tools which will aid in understanding this very complex radiation field.

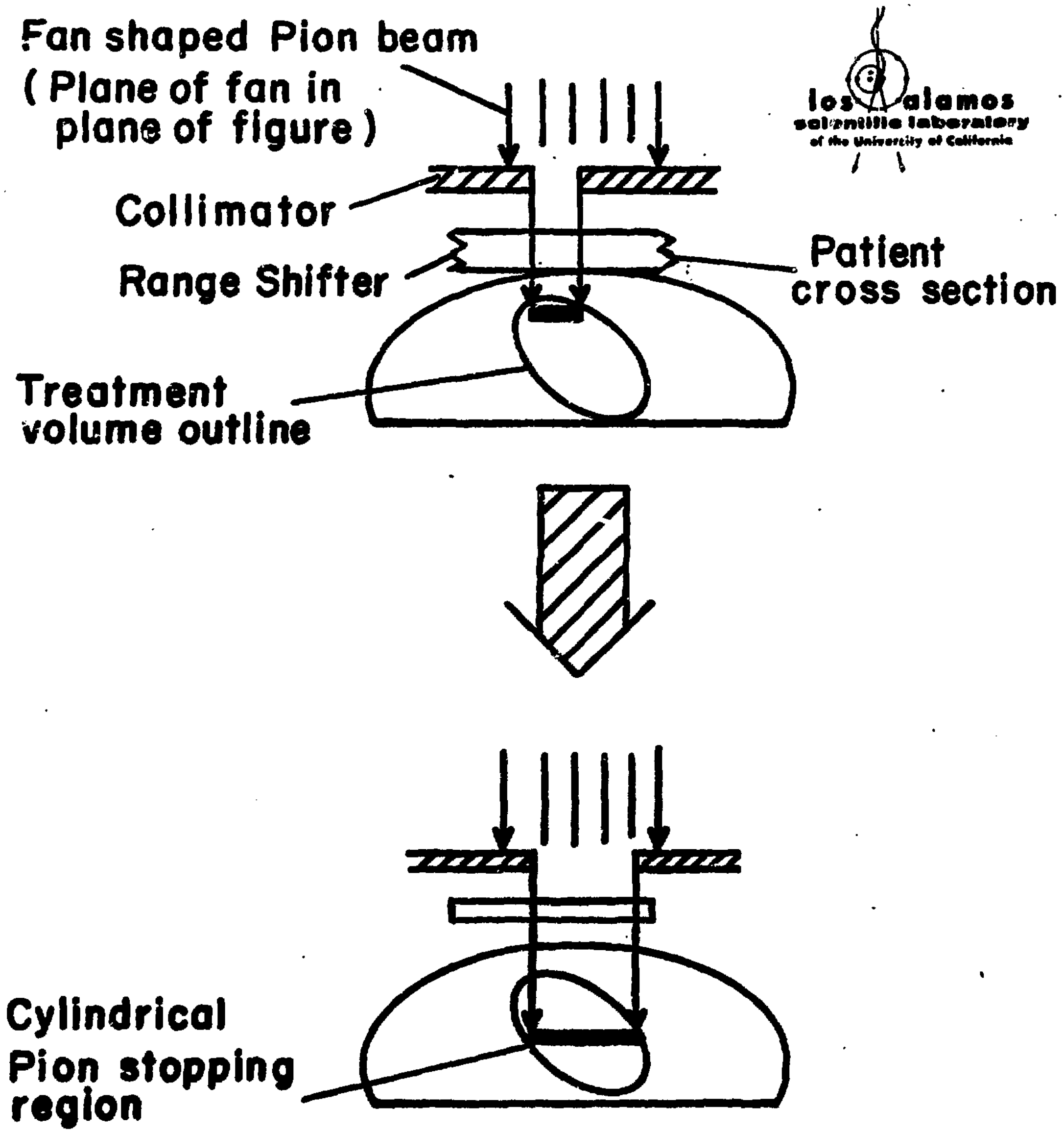
As the pions come to rest and then produce stars they emit characteristic radiations. These may be useful for the purpose of mapping the stopping region during irradiation. We will be developing apparatus to view and localize these radiations, with the goal of being able to map the treatment volume during an irradiation to observe immediately changes in characteristics of the beam if they occur and to verify the corrections made for tissue inhomogeneities. If possible the intercalibration of our measurement of dose with methods used elsewhere will be achieved by close cooperation with the other centers involved in high-LET radiation research. In addition, calorimetric intercalibrations will be attempted.

In conclusion, meson factories have given the radiation therapist his first opportunity to investigate the effects of pi meson radiations on cancer. We have constructed a meson delivery system which provides therapeutically useful beams of pions in a precisely controlled manner, and will begin the testing of the system within the next two months. The radiation field provided by this pion beam will give a real challenge to the medical physicist, in that the dosimetry required to understand the predict the effect of this beam on living systems is formidable indeed. We feel that we have a good start toward a program which will provide guidance in the early stages of therapy for the physician, and will lead to basic understanding of this complex radiation field as well as the effects of radiation in general.



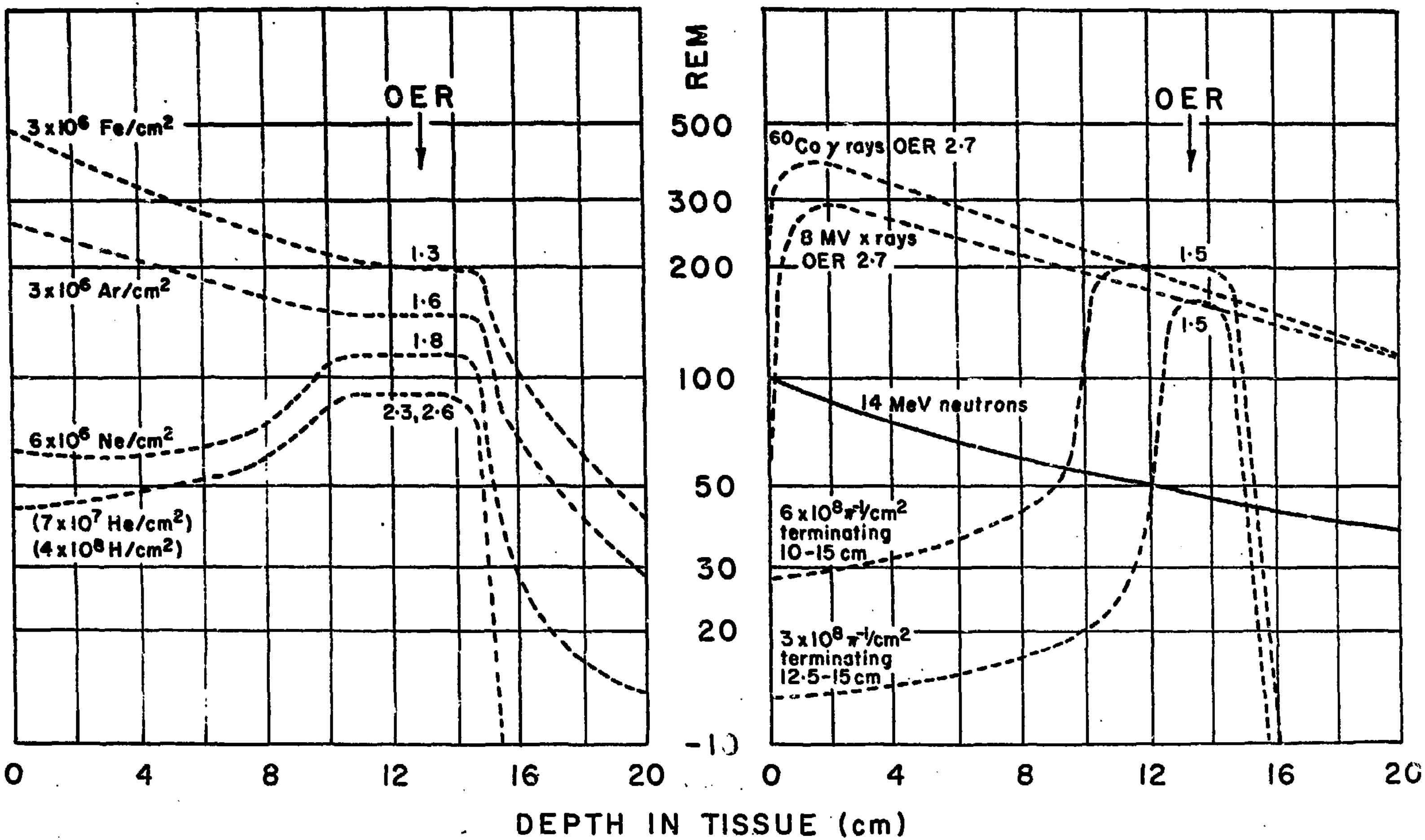
THE LOS ALAMOS MESON PHYSICS FACILITY
BIOMEDICAL PION CHANNEL

STUBOUT FLOOR



Treatment volume shaping with fan beam-a rapid vertical scan of stopping region is accompanied by a slow translation of the patient perpendicular to the plane of the fan.

DEPTH DOSE DISTRIBUTIONS



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——— (Horst and Conrad, Fortschritte auf dem Gebiete der Röntgenstrahlen u. der Nuklearmedizin, Diagnostik, Physik, Biologie, Therapie 105, 299 (1966))