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DATE: 20 February, 1973

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RE: Radiological Physics for Biomedical Facility
Report based on our visit 7-9 February

The enclosed report is based on the information we gathered when visiting Los Alamos 7-9 February. I have tried to represent the consensus of Bill's, Peter's and my own opinion. We did agree on all essential points. However, Peter and Bill might have somewhat different views on certain details. By means of copies of this memo and report, I ask them to let you know directly, if they want to add or modify.

We were instructed to consider primarily the "definition of physical dosimetry procedures for biomedical pion beams". In order to achieve a complete and balanced view, we found it necessary to study the status of the biomedical pion program in all its aspects of clinical radiological physics. I have broken down the report in the following sections:

1. Fundamental dosimetry.
2. Beam characteristics,
3. Treatment planning,
4. Beam shaping and treatment,
5. Equipment in the treatment room,
6. Simulation and patient measurements,
7. Casting and immobilization.

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I will work a time-schedule separately but I need an undisturbed half a day for that, so it will be sent to you later.

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RADIOLOGICAL PHYSICS FOR THE BIOMEDICAL FACILITY, LAMPF

REPORT ON VISIT 7-9 FEBRUARY, 1973 BY ALMOND, BJARNGARD AND HENDEE

REPORT PREPARED BY B. BJARNGARD

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1. Fundamental Dosimetry

One can define two separate objectives for the effort in fundamental dosimetry: 1) to develop methods with sufficient accuracy to start the biology and therapy programs as planned; 2) to develop methods for accurate characterization of the interaction of the pion beam with matter in order to allow an in-depth understanding of the biological action of the pion beam. The first objective is intimately connected with the target dates for the biological and therapeutical programs. The second objective can be reached only through an effort spanning over several years.

Ongoing work is directed towards the first of these objectives. Raju has approached it with a program with ionization chambers, based on his experiences at Berkeley. Meaningful experiments can start with 10 μA beam currents. Raju has planned to make such measurements. Additionally, particle fluxes will be determined as part of the beam diagnostics program.

In an unspecified manner, outside groups are expected to come in and perform calorimetry and microdosimetry.

Richman is pursuing a program with silicon detectors and pulse analysis. These measurements can provide information of the electron contamination. This will also be studied with Cerenkov detectors. The silicon detectors will provide data on the frequency distribution of the specific energy imparted in the silicon detector. These data will probably be useful for characterization of the beam in terms of LET distributions. However, it is not clear how this intrepretation will be made, but further theoretical and experimental studies are necessary. It should at least be possible (as pointed out by Richman) to separate the dose contributions from high LET and low LET radiation on the basis of the measurements with silicon detectors.

The problem of evaluating the exact status of the program in fundamental dosimetry is to find the proper balance between the two objectives mentioned in the introduction. The program can no doubt proceed at the present, rather leisurely pace for another couple of months without any threats that the deadlines for biology and therapy will be affected.

However, it must be recognized that the present program does not guarantee a reasonable depth of understanding of the effects of the pion beam in terms of physical dosimetry. The effort in fundamental dosimetry must be expanded and must be allowed to continue for several years, branching into calorimetry, microdosimetry, spectral analysis, and extensive theoretical studies. The goal of this part of the program should be accurate and sophisticated dosimetry. It is reasonable to expect that the most qualified experts on pion dosimetry should be members of the LAMPF team and not only available to the project on a consultant basis. We, therefore, recommend that the dosimetry effort is strengthened by adding a physicist to either the LAMPF group or the

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UNM group. The interest and assignment of this physicist should be fundamental dosimetry. By the way, neither Raju nor Richman are primarily oriented towards fundamental dosimetry. The new physicist could be at the level of a doctoral or postdoctoral physicist.

Since it will be difficult to find the person with the necessary qualifications, the search should start immediately.

2. Beam Characteristics

A large number of data have to be accumulated to describe the characteristics of the beam. Studies of the influence of inhomogeneities, the dose distribution at interfaces, depth dose data in water phantoms, confirmation of treatment plans, etc. are all parts of this project. A significant amount of theoretical work must be included to gain further understanding of the beam and allow the exact interpretation of measurements. This is especially important in view of the fact that treatment planning by necessity will be based on approximative mathematical techniques, and the validity and restrictions of these methods must be understood.

Our opinion is that while this part of the project suffers from shortage of personnel, it is not yet behind the general schedule. Richman, with the assistance of Barnes, is in the process of developing measuring techniques for this purpose. He has started the construction of a particular phantom for the study of the influence of inhomogenities on the dose distribution. The specifications for an automated isodose plotter, measuring in water, are being worked out.

In view of the limited manpower available, we strongly recommend that in-house construction and manufacture is considered only as a last resort and that more attention be paid to what can be bought commercially. Admittedly, the use of readily available equipment might impose some restrictions. However, in most cases this is a reasonable price to pay to free up available personnel to work on problems unique for the pion biomedical channel. Specifically, we propose that a computerized isodose plotter of proven construction be acquired, and the computer program be rewritten to suit the PDP 11/45.

3. Treatment Planning

It is intended that geometrical treatment planning be done on the PDP 11/45 computer. This decision is quite reasonable in view of the complexity of the beam and the beam shaping methods. We also agree that it is desirable to design the treatment planning program in such a manner that the therapist and his staff can calculate the dose distribution in the patient in a reliable, convenient and economical manner. To achieve such convenience, interactive computer operation, the use of approximating methods rather than complete and first-class physics programs will be necessary. This is acceptable since the spatial resolution and the accuracy have to satisfy the clinical needs which are much less demanding than those characteristic of a complete physical description.

We consider the treatment planning program under development (Shlaer) as an excellent first choice, to the extent we could evaluate it. Unfortunately, the further development of this program has been

interrupted. It is most essential that this program be restarted. We estimate that it will be necessary to assign one programmer to work full-time on this project, in close collaboration with a clinical physicist who will spend about 10% of his time on this assignment.

It is quite possible that at a later date, when accurate physical and biological data for the pion beam are known, the treatment planning program will be updated and modified to allow more accurate prediction of the treatment result. However, it is important to defer such a development and concentrate on the task to have available a treatment planning method of sufficient accuracy when the clinical trials should begin.

An interesting problem in pion radiation therapy is the need to include biological data in the treatment plan. Although radiotherapists are used to modifying dose distributions on the basis of radiobiological data and clinical experiences of fractionation schedules, the problem is compounded in the case of pions by the pronounced variation of RBE with depth. We propose* that the initial treatment plans be presented as threefold plans, specifying high LET dose, low LET dose, and total dose. This will allow the therapist to correlate dose with biological result in a reasonable manner, while the physical meaning of the treatment plans will remain clearly defined. However, it would be highly desirable to be able to calculate expected survival. Mathematical models are available for such calculations. They lend themselves to consideration of RBE as well as fractionation and can easily be computerized. We recommend that somebody in the radiobiological group look into this problem or the advice of a suitable expert (as Dr. L. Cohen) be sought.

4. Beam Shaping and Treatment

The dose distribution will be built up in the patient by the use of the beam through a stationary slit combined with range modulation and patient motion. This system will be operated by the PDP 11/45 computer in addition to the normal beam channel operation. The computer will derive the operational settings as part of the treatment planning program.

The treatment planning program in its turn receives its input data from tracings of the treatment volume and descriptions of the beams. All included, the system becomes quite complex, and it will be difficult for the radiotherapists and the physicists to get an overview in routine operation.

Although we have great confidence in the technical details of the system, it seemed to all of us important that an analysis of the overall system be made by a physicist with clinical experience. The purpose of this effort would be to evaluate the system as a whole, rather than the individual details. It is important that the interaction between simulators, treatment planning activities, patient positioning and holding devices, and the machine parameters be fully included in this "systems analysis".

In addition, responsibility for the overall performance and safety of this system should be assigned to somebody of the LA-UNM group to further eliminate possible oversight. We assume that this would be the duty of the deputy assistant director, when he joins the group.

*This was suggested to us by Richman, actually.

5. Equipment in the Treatment Room

The patient support assembly has been discussed by a subcommittee, which concluded that in the long run it would be desirable or necessary to design a special table, characterized by extreme versatility and precision in positioning. Furthermore, it was anticipated that the patients be set up outside the treatment room on a separate table top. On the other hand, the subcommittee felt that as a short-term solution a table with considerably more simplicity might be necessary. We strongly agree with the latter conclusion. The specifications on the ideal patient support assembly can only be evaluated in light of the experiences gathered from practical work.

Several structures have to fit in a box to be mounted on the last magnet. The most important of these are the range modulator, the collimators and the monitoring ionization chamber.

The clearance between this box and the patient was discussed at great length. Since extra distance means loss of pions, it should be kept as short as is possible. Yet, it cannot be allowed to interfere with accurate positioning of the patient. The box with the collimators, etc. must, therefore, be as short as is possible, and the end facing the patient must be as narrow as can be achieved. The present plans call for a box 40 cm long and 30 cm wide at the end. We feel that this will be acceptable.

However, the technique chosen for range modulation requires quite a lot of space. It uses a volume of water, the thickness of which is moderated by a piston. We are not convinced that the possibilities to use a rotating disk have been thoroughly investigated. This technique has been used for protons. It has the advantage that material with higher density than water can be used. It also seems simpler and safer in routine operation.

It is very desirable that one can verify that the patient setup is correct before treatment is initiated. In conventional radiotherapy, this is done with a port film. We propose that an x-ray tube is installed in a suitable manner so that a similar verification can be done. Admittedly, the convergence of the pion beam cannot be simulated with x-rays but this is a relatively minor limitation. Beam localization can be studied, however. It might even be possible to make a fast run with the moving collimators, moving patient and x-rays on, the motions controlled by the computer, to completely check positioning and collimation. We strongly recommend that these possibilities be further explored and an x-ray tube installed, even in the case that complete simulation cannot be achieved.

For patient setup and beam localization, it is also important that wall lasers be mounted to indicated the position of a reference point.

The fact that the beam is unusual and the beam shaping arrangements complicated have resulted in serious discussions of the possibility to localize the irradiated volume by detecting mesic x-rays and other photons with a gamma camera or a multiwire proportional counter. We feel that this demand for control is well founded. However, a gamma camera system is probably too complicated a technique to be considered

for the immediate future. Although it could be developed into a method for quantitative in vivo dosimetry, such a development would require at least a manyear of experiments and computations. To monitor the depth of the stopping region, we instead propose that a vertical array of detectors be used, looking at various depth of the center line.* See Figure 1. This arrangement will allow, with suitable computer interfacing, a record of the photon emission at various depths. Therefore, control of the range modulation device can be achieved at all times. The fact that the computer is available further enhances the possibilities that this simple control device be integrated with the operational system.

For control and documentation of the cross section of the beam, we recommend that a photographic film is mounted over the patient and rigidly attached to the table. The film will then indicate the shape of the irradiated area on the patient. With an x-ray tube being available, a film can be exposed in the same position for identification of anatomical structures within the irradiated volume. It is possible to replace the film with a multiwire proportional counter. This will require more development work and cannot give the same resolution. This problem is again a dilemma of long-term and short-term objectives. The immediate needs, which in this area seems to have taken a back seat, are extremely important. Various devices that can allow verification that the patient has been correctly irradiated are necessary for routine operation. They should be selected on the basis of simplicity, reliability and relevance. The development of certain other features, such as a gamma camera system or an ideal treatment couch, must be postponed if not absolutely essential for the clinical program.

6. Simulation and Patient Measurements

Because of the physical properties of the pion beam, it is very important that the inhomogeneities in the patient are accurately determined. Their influence on the dose distribution have to be taken into account. We did not find that anybody was actively working on this problem. An approximate measure would be to start with orthogonal films, accurate contouring, ultrasound and anatomical atlases. When density values are needed for structures such as bone and lung, it will be acceptable, in the beginning of the project, to use published average values. However, this will probably not suffice in the future. Further recommendations from the users group should be solicited. A search for an optimum method should be instigated.

A good contouring device, interfaced with the computer, will be needed. Development of such devices has been started by both industrial and academic institutions. These possibilities should be investigated. The use of this device will require assistance by a computer programmer under the direction of a clinical physicist.

A simulator installation is necessary. This will allow the therapist to make the decision of how the patient should be positioned for the treatment. Correctly designed, the simulator will also aid the therapist in defining and prescribing what volume should be treated and what volume should be spared. The ideal equipment for simulation would consist of one vertical and one horizontal x-ray beam. See Figure 2. These beams would be monitored by two stationary or one moving image

*This was the result of my later discussion with Ed Barnes.

intensifier. It must be possible to expose photographic film with either x-ray beam. Large distances between patient and focus should be used in order to simulate the convergence of the pion beam to the greatest possible estent. The x-ray beam arrangement should include collimators of the multiple leaf type, which can define and simulate the volume to be treated as well as areas to be spared. Surface contours can also be defined with these devices. This information should be fed directly into the computer for the treatment planning. This system might be more clear when studying Figure 2.

The general idea behind the suggestion of this rather complicated simulator arrangement is that due to the unusual and complex beam properties, every effort should be made to allow the therapist to interact directly with the technical system.

A simulator in conventional radiotherapy can sometimes be used to verify that everything is ready for treatment. We propose that this function be performed in the treatment room itself in order to eliminate the maximum number of possible errors.

We are concerned that the space allocated for simulation is too small, especially the control area. The therapist, aided by a technologist, will operate a fairly extensive system consisting of a control console with at least two, possibly three, TV monitors. It will be difficult to accommodate this equipment and this personnel in the present space. One possible solution is to move the dark room to the corner of the control room. Another possibility is to integrate simulation with treatment planning. This would further extend the interaction of the therapist with the system, in that simulation and treatment planning could be performed from the same position.

7. Casting and Immobilization

It is difficult to foresee the exact role of casting and immobilization at the present time. While the fact that the beam is fixed and vertical requires considerable versatility of the setup procedures, this demand will be somewhat compensated for by the fact that the beam shaping is extremely versatile. Also, the depth dose characteristics are such that the problem of protecting sensitive volumes in the patient's body are less serious than in conventional radiotherapy.

It is desirable that treatment plans are worked our for actual cases before final committments are made to acquire equipment for patient positioning and immobilization. This work should be done by the therapist and the clinical physicist. It can be started without the computer programmer.

We do not expect that a considerable amount of casting and custom-made immobilization devices will be necessary. The room set aside for casting is somewhat small. Also, it would have been more convenient to position the cast room between the simulator room and the mechanical shop. We understand that storage space is available on an upper level, where a supply of casts can be kept.

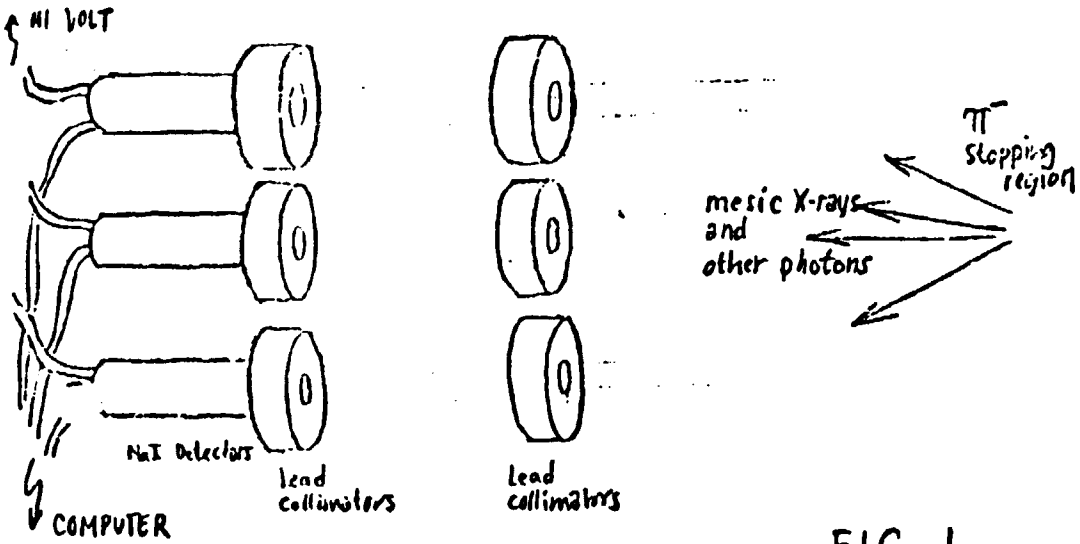

FIG. 1

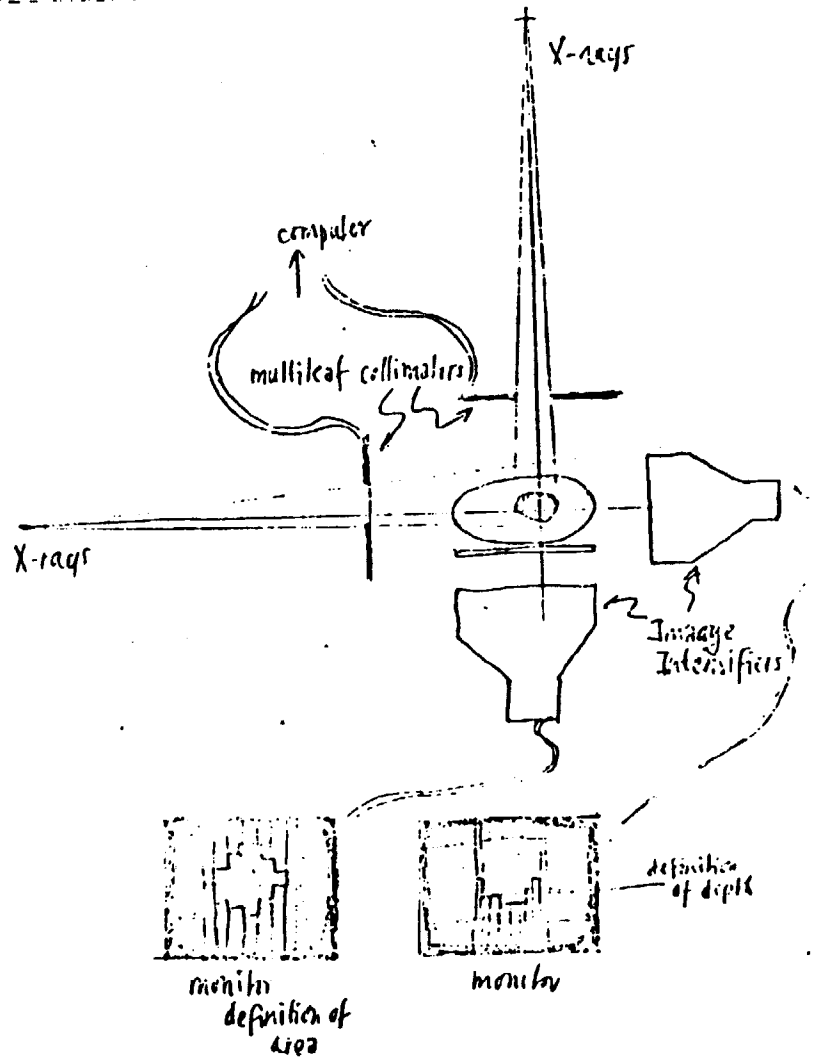

FIG. 2

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