OPERATIONS EXPERIENCE AT THE BEVALAC RADIOTHERAPY FACILITY*

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Introduction

The use of the Bragg peak of charged particles for medical treatments was first proposed in 1946 by Wilson[1]. The greatly enhanced dose deposited at the end of the beam range compared to the entrance dose, and the sharp falloff of dose beyond the beam range and at the edge of the collimated field due to small heavy-ion straggling and multiple scattering lead to very precise localization of the dose delivered to the treatent volume, thus maximizing the sparing of normal tissue. In addition, the enhanced biological effectiveness due to the high LET (dE/dx) of heavy ions has also pointed to these beams as potentially being a very superior modality for the treatment of cancer. Testing of these ideas became possible when heavy ion beams of adequate energy and intensity became available with the creation of the Bevalac in 1974.[2]

During the first years of Bevalac operation the biomedical effort concentrated on radiobiology work, laying the foundation for patient radiotherapy.[3,4] A dedicated radiotherapy area was created in 1978,[5] and in 1979 full-scale patient treatment was begun. As of now over 500 treatments with carbon, neon and argon beams have been delivered to about 50 patients, some as boosts from other modalities and some as complete heavy ion treatments. Up to 12 patients per day have been treated in this facility. Continuing efforts in refining techniques and operating procedures are increasing efficiency and accuracy of treatments, and are contributing to the alleviation of scheduling difficulties caused by the unique requirements of radiotherapy with human patients.

Facilities

The treatment area, beam delivery and dosimetry instruments were reported in an earlier paper[5] so will only be briefly described. Figure 1 shows the treatment room with support areas for therapists, physicists, operators and technicians. Beam enters the treatment room from the lower right corner, passes along optical rails containing beam shaping, range modulation and dosimetry apparatus and finally into the patient. The patient is supported on a Philips Mark I ram-style couch[6] with attachments to hold the patient in a wide variety of positions to best utilize our static horizontal beam. Alignment of the patient is performed with x-ray and laser systems carefully positioned in relation to the beam axis.

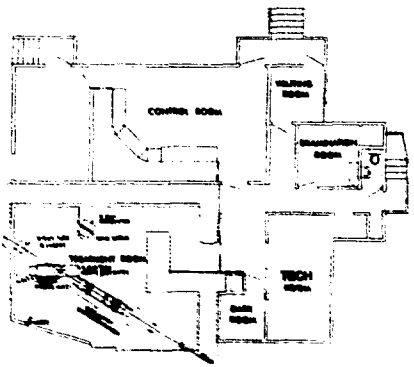

Figure 1. The Bevalac Radiotherapy Facility.

Beam preparation utilizes the scattering foil-occluding ring system[7,8] shown in Figure 2. The tightly focused accelerator beam is passed through the first scattering foil, 9 mm of lead placed 10 meters upstream of the patient. At a point 6 meters from the patient occluding rings block out portions of the Gaussian beam, and a second scatterer diffuses the beam passing through open spaces in the ring system. As the beam moves towards the patient the holes are filled in by scattered beam, and if everything is done correctly, right beam width, ring diameters and drift distances, the beam intensity distribution will be flat to within ± 2% over the desired 20 to 25 cm diameter field used for treatment.

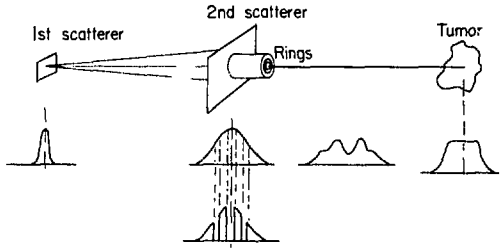

Figure 2. Occluding Ring beam delivery system.

The selection of parameters is entirely empirical, so that a substantial amount of beam-development is necessary to obtain the desired field size and uniformity. To aid in this development and in fine-tuning parameters for different ions and energies heavy use has been made of MEDUSA, a multi-plane multi-wire proportional chamber capable of reconstruction in a few seconds beam intensity profiles over a full 25 cm diameter circle[9,10]. This chamber, with a spatial resolution of a few mm is capable of detecting intensity variations as small as 1 or 2%. Because of its rapid turn-around, one can perform a substantial amount of beam-development in a short period of time.

Beam range modulation, to place the Bragg peak at the treatment depth and to distribute the stopping particles over the full thickness of the tumor is performed with brass spiral ridge filters and an adjustable water column[11].

Dose monitoring is done with three multi-segmented ionization chambers[11] and a secondary electron monitor (SEM) located along the beam path. Each ion chamber has two collecting foils, the first is divided into quadrants providing east/west and top/bottom balance information, the second is divided into concentric rings giving data on the radial distribution of the beam intensity. A total of eleven independent signals are generated by each ion chamber. The ion chambers are located as follows; one just upstream of the second scatterer (at the beam entrance to the treatment room), the second half-way to the patient, and the third just upstream of the

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patient collimator.

This collimator, poured from cerrobend to the contours specified by the therapist is located as close to the patient as possible and defines the field shape delivered to the patient.

Control System

Key to smooth operation of the facility is the computer control system. A PDP 11/45 with three 80 Mbyte discs and numerous other peripherals provides the computational power. Dosimetry and other data flow to the computer through a CAMAC system. The control software, designed by S. Shlaer at LBL is a channel-table driven system capable of monitoring and controlling the 4000 odd data entries associated with the therapy room and the two additional beam lines dedicated to radiobiology and biophysics. It is a highly diversified multi-tasking system, keyed from critical timing points associated with the Bevatron spill cycle. During an irradiation data are read, stored and checked for consistency in each of the two time zones, corresponding to beam on and background. Beam size, alignment, steadiness and dose-rate are all monitored and presented to the operator. Irradiations can be terminated quickly by the operator or the control system in the event of any detected irregularity. Normal termination of an irradiation takes place either by the computer detecting after a pulse that the dose on the selected monitor has achieved the desired value, or for more precise control preset cutoff scalers are loaded by the control system with the desired dose. These scalers, five are assigned to each beam line, are connected directly to independent dose-monitoring elements, and also to a fast-cutoff unassis. When a scaler reaches its preset value a clamping signal is sent directly (not routed through the computer) to the Bevatron extraction system providing a beam cutoff in about one millisecond.

A great deal of attention has been paid to safety considerations to prevent exposure errors in the event of equipment malfunctions. Redundancy in dose monitoring (five units working in parallel) prevent against ion chamber or recycling integrator unit failures. A watchdog-timer system which must be reset by the computer every 100 milliseconds to keep the beam plug from dropping in guarantees against an undetected computer crash. As a final guarantee, two Ortec thumb-wheel preset scalers at the operator's console are connected to two different dose-monitoring elements and are completely independent of the computer system.

The operator's console area is separated into three logical areas, therapy, biology and central, each with a separate control terminal and a dedicated display screen. Thus two operators can work independently as the beam is switched between biology and therapy during the normal day's operation. The central display screen is a dedicated error flagging station, logging unusual situations detected by the system which may require operator attention.

A great deal of effort has gone into the operator interface software to enable smooth control performance and to minimize lost time and frustration.

Date logging, printouts and archiving is performed automatically, providing the experimenter or the therapist with a detailed summary of the irradiation just completed.

Dosimetry

Measuring the dose delivered to the treatment volume inside a patient is not a straightforward matter. The dose, which depends on beam ion density as well as the dE/dx distribution within the beam, is different at all points along the beam path by virtue of our range modulation and beam preparation systems. Measuring the dose inside the patient, where the dose distribution is uniform, is difficult since patients don't normally swallow ion chambers. So, indirect measurements are made, the dose delivered being determined by a calibration procedure for each patient's unique geometry.

A small (1 cc) industrially-calibrated EG&G ion chamber is placed at the treatment isocenter (where the treatment volume is normally located) behind a thickness of tissue-equivalent material equal to the depth of the tumor in the patient. The rest of the treatment parameters are set up exactly as if a treatment were taking place; the proper collimator, water column setting, and spiral ridge filter thickness are used. Then the response of each element in the beam line is calibrated in relation to the dose detected on the EG&G chamber. Delivering the prescribed dose is then simply a matter of applying these measured ratios to the beam monitoring elements used in the fast cutoff channels. Our experience has been that these ratios are very stable, even for elements located in areas where small variations in beam position produce large intensity fluctuations (such as the intermediate ion chamber). The spread in the determination of the dose delivered between the different elements is typically less than 1% of the total dose.

Beam Verification

The versatility of a heavy-ion accelerator in being able to accelerate many ion species is also a potential curse in that one may have a hard time determining what ion is being accelerated. Numerous examples have been recorded where ions of similar charge-to-mass ratios have been accelerated erroneously or simultaneously; deuterons and alphas, lithium 6 and carbon; nitrogen 15 is routinely used to tune up the Bevatron for iron 56 runs since iron beams are too low in intensity to be recorded on internal instrumentation. Thus beam verification is an important aspect of daily calibrations.

a. Range determination. This is the most sensitive and also most important measurement since differences in range will affect the area of the patient treated. Range is measured each day by taking a full Bragg curve using the water column and the downstream ion chamber. In addition the Beam Energy-Measuring Wedge[12] is used, providing a photographic record of the beam-range in copper to an accuracy of 0.2 mm.

b. Beam intensity distributions. The beam preparation system with its scattering foils and blocking rings provides us with a secondary beam verification technique. Different ions losing energy at different rates will go through the preparation system in slightly different ways, so that beam intensity distributions will be slightly but significantly different on the various ion chamber elements. During patient treatments, when the range cannot be monitored directly, the proper intensity ratios are checked for and flagged for immediate operator attention if they are out of range.

Patient Treatment

As one can see from the above, considerable effort is devoted to accuracy in treatment delivery and in patient safeguarding. We shall now follow a patient through a daily treatment sequence, illustrated in Figure 3. First the radiotherapy group enters a prescription file into the control system, establishing parameters for the treatment based on clinical experience and treatment planning data. When the patient is set up and aligned properly in the treatment room, a procedure usually taking 15 to 20 minutes, the console operator initiates the treatment

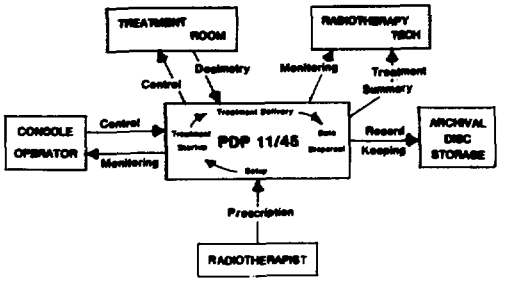

Figure 3. Control sequence for patient treatment.

sequence. This involves flashing the prescription file to be invoked to the therapy technician for verification, monitoring that the physical hardware called for in the prescription is actually in place, establishing the proper settings for the dose monitor preset scalers based on previous calibrations and instructing the operator of the values to put into the Ortec backup thumb-wheel preset scalers. When all the preliminaries are performed the control system initiates the treatment. The progress of the treatment, usually lasting about 2 minutes, is monitored by the console operator and the therapy tech, both having the ability to abort treatment should any irregularity appear. Following the successful completion of the treatment hard copy of the monitored parameters is produced for the patient's records, and all data are also archived on disc for future reference and analysis should this prove necessary.

Bevalac Scheduling

The institution of the radiotherapy program at the Bevalac has caused a major readjustment in the philosophy of scheduling experimental time[13]. The requirement of using day shifts four times a week for therapy with off-shifts and weekends available for nuclear science goes counter to the established tradition of scheduling large continuous blocks of time for each experiment. To maintain a viable program in the new operating mode it has been necessary to perfect rapid beam switching techniques to perform the greater number of additional tunes without undue loss of time. New hardware and software in the Bevatron control system has made this capability a reality, it is generally possible to change between experimeters requiring different particles and energies in a half-hour or less. For experiments using the same particle and energy switching is accomplished in less than one minute. This in fact has allowed us in this past year to utilize the time between patient treatments for radiobiology work in a second irradiation area. The Bevatron staff is working on decreasing the switching time for different ions and energies with the eventual aim of being able to return to the scheduling philosophy of long blocks of dedicated time for nuclear science experiments. These experimenters would only see a two to four minute interruption every half hour while a patient was receiving his treatment. We anticipate reaching this goal by early 1983.

Future Plans

Major developments anticipated in coming years are in two fronts, improving beam delivery systems and building of dedicated hospital-based accelerator facilities. We will shortly be installing a two-dimensional beam-scanning system in one of the radiobiology lines, to gain experience in control, required instrumentation and biological effects associated with this mode of treatment delivery. It is generally conceded that such scanning systems offer great advantages over other beam delivery systems for charged particles[14,15], but there are numerous questions, both technical and biological which must carefully be addressed before using such a system for patient treatments.

Interest in dedicated medical heavy ion accelerators is very high in the US as well as in Canada[16] and Japan[17]. A design study jointly undertaken by LBL and the University of Arizona[18] in 1977 established the feasibility and cost-effectiveness of siting such a facility in a hospital, and more recently a grant proposal has been submitted by LBL to the National Cancer Institute for funds to carry out a conceptual design study for a medical accelerator[19]. Should this project proceed on the anticipated schedule, it would be operational by 1988.

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