

RELOCATION OF THE HELIUM ION RADIOTHERAPY PROGRAM FROM THE 184" SYNCHROCYCLOTRON TO THE BEVALAC*

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Abstract

The closure and dismantling of the 184" Synchrocyclotron has required that the helium ion radiotherapy program be transferred to the Bevalac. To this end, the extremely precise and sophisticated patient positioner named ISAH has been relocated to a new radiation enclosure at the Bevalac. This has formed the basis for a new fully-equipped patient treatment area which is now totally integrated into the existing Biomedical facility at the Bevalac. Now fully commissioned, this new area has seen the resumption of the very promising ocular melanoma, AVM and precision dose-localization treatment programs after only a six month interruption. Details of the move of ISAH and its modifications to fit into its new environment will be presented, along with the instrumentation and changes that were needed to the VAX-based control system to integrate the new treatment room into the existing Biomed facility. Operation of the full facility will be discussed, with emphasis on the substantial increase in complexity of scheduling and resource allocation.

Introduction

The medical program at the 184" Synchrocyclotron has enjoyed a record of great accomplishments and longevity. Since its inception over thirty five years ago¹, close to 2000 patients have received treatments, primarily with helium ions at 225 MeV/amu, for pituitary disorders, malignant tumors of various kinds, and arterio-venous malformations in the brain.

In its latter years the accelerator has been devoted exclusively to the medical program, and as such compiled a truly spectacular performance record, with reliability figures generally greater than 99%. In its last five years, not more than a handful of treatments were delayed or postponed due to machine failures. With a total staff of 3 FTE's, and with its excellent performance record, this accelerator has provided solid evidence to reinforce the case that particle-beam technology is sufficiently well-developed to be transferred to a hospital environment for routine therapy treatments.

In its long history of pioneering achievements, much has been learned about techniques needed to most effectively use the highly meritorious characteristics of charged particle beams for radiation treatments. Utilizing the superb dose-localization possibilities, by means of which one can place a very high dose into a desired treatment volume while sparing to a high degree the normal tissues surrounding this volume, has not been straightforward. Methods for generating and shaping the radiation fields with the right degree of uniformity and precision had to be developed, dosimetry techniques and instrumentation had to be designed and characterized, treatment planning techniques had to be substantially refined, and diagnostic imaging tools (CT and MRI) integrated into the treatment planning process. Perhaps most importantly, methods of supporting the patient, accurately placing the treatment volume at the right spatial coordinates in the beam reference frame, and preserving this alignment throughout the treatment have presented a particular challenge. For the pituitary treatments, a positioning accuracy of 0.1 mm was deemed necessary to place the treatment field without damaging adjacent tissue.

Through the years these problems have been attacked and elegantly solved, to the point that the hardware, software, and operating procedures have evolved into a finely-tuned, highly efficient treatment facility. A beam-delivery system based on scattering foils and blocking rings was developed²; ionization chambers, ridge-filters and range-modulating devices for dosimetry and beam shaping were designed and implemented³. After an extensive evolutionary period, an extremely sophisticated patient positioner, named ISAH (Irradiation Stereotactic Apparatus for Humans)⁴ was built, providing accuracies

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of the required 0.1 mm for positioning, and in addition capable of holding this tolerance while translating or rotating the patient.

ISAH

This patient positioner consists of two systems set on a common base. This base is a large (3 meter square, ten ton) granite slab polished to a surface finish of about 1 micron. The slab is held in position by four precision jacks around its sides, but the weight of the slab is supported by a large rubber wine-skin bladder, holding the slab a few inches off of the concrete floor. To this granite slab are attached the patient positioner and the "optical rails" which hold the dosimetry and beam-definition apparatus.

The positioner rides on air bearings, floating 3.3 microns above the surface of the slab. This positioner provides three translational and two rotational degrees of freedom (one about a vertical axis defined by a precision-ground hole in the center of the slab, the other about a horizontal axis). Precision of the positioner motions allows definition of the central-axis point, labelled the "isocenter" to 0.1 mm. That is, a pointer placed at this point will not deviate by more than 0.1 mm as the positioner is rotated through its full 370° arc range. The head of the positioner can be fitted with a bed, a chair or a platform to accommodate a patient in supine, seated or standing positions.

The optical rails are attached to a superstructure, also mounted on the granite base. These rails are actively load-compensated through the use of hydraulic cylinders and position sensors. This compensation system allowed variable loads to be added to the rails, such as heavy collimators and range modulators, without loss of accuracy due to deflection of the support structure. Again, a positioning accuracy of 0.1 mm is maintained.

Contemplation of the Move

It became clear about three years ago that the Light Source being sought by LBL management would best be situated on the site of the 184". Thus, plans had to be made to relocate the radiotherapy program. To successfully move and integrate this program into the Bevalac environment would require several major undertakings. First, a new radiation enclosure was needed, adjacent to the existing Biomedical irradiation facilities. Support buildings would be needed for the medical and physics staff as well as for staging of the patients. To provide the proper intensity of helium ions a new ion source (a duoplasmatron) would be required for the Bevalac Local Injector. The conduct of therapy in two treatment rooms on a concurrent basis would require the ability to rapidly switch between neon and helium beams in the Local Injector. Then, when the actual shutdown of the 184" took place, the therapy facility there would have to be dismantled and moved to the Bevalac. Key elements to be moved would include ISAH, as well as the x-ray and laser alignment systems, closed-circuit TV monitoring, and communication systems. Following mechanical installation of these components, the beam-delivery system would have to be developed, and fully characterized to provide the radiation fields required for the treatments. Dosimetry systems would have to be provided, which were integrated into the Biomedical VAX-based control system. This control system would also have to be made fully aware of all the hardware under its control in the new Treatment area; not only the dosimetry devices, but also the positioner data, interlock chains, environmental radiation monitoring, and communications. All told, not a trivial task.

Preparations for the Move

In 1986 the new radiation enclosure was built. This room, designed to conform to current-day seismic and radiation safety standards is much more massive than the other Biomedical caves. As seen in Figure 1, this new room, designated "Treatment Room 2" adjoins the end of the Biology room, and forms a common radiation enclosure with this room.

At the same time work was started on installing the duoplasmatron source and beamline on the Local Injector. The need for this source had been foreseen at the time of the addition of the RFQ to this Injector giving it heavy ion capability⁵, so space was available for a new injection port, as well as for the high voltage power systems for the ion source. Proceeding at a relatively low priority rate, this project was completed in April of 1988. After its successful commissioning, this source has proven reliable and effective, delivering beams of completely adequate intensity. Details of the source performance are reported elsewhere in this conference⁶.

The Move

In early 1987 it was learned that the ALS would definitely be built, so serious planning for relocating the therapy program began. The timetable for this move was established: the 184" would run until the end of December, 1987, the dismantling of this machine would begin immediately thereafter. The Bevalac would be shut down for the months of March and April 1988 to allow for mechanical installations and for integration of the new therapy facility into the Biomedical and Bevalac control systems. All systems were to be ready for commissioning studies by May, with beam characterization to take place in May and June. First patient was scheduled for July 1988.

A first decision point was whether it would be more cost-effective to move existing equipment or to build a totally new facility. There was no question about the mechanical components of ISAH: duplication costs would be very significantly higher than moving the existing device. Although some major overhauling was indicated for ISAH (after 15 years of uninterrupted service!), ample opportunities for this maintenance would be available after it had been dismantled for moving. Furthermore, it was very clear that there was not another device in existence in the world which could come close to the positioning accuracy and flexibility of this device. It is irreplaceable.

For the other components of the 184" Therapy Facility, the decisions were not so straightforward. Integration of the new Treatment Facility into the existing Bevalac Biomedical complex would be extremely difficult with the obsolete electronics used at the 184". Consequently, it was decided to build a new electronic interface and control system for ISAH, and to replicate dosimetry electronics currently used in the first Bevalac Treatment Room for use in the new area. Some of the dosimetry and beam-modulating devices were used, while others, such as the ionization chambers for which considerable design evolution had occurred⁷, were replaced.

The plan as formulated was adhered to very well, both in scope and schedule. Software work and hardware designs were started immediately, while the tasks and fixtures necessary for dismantling and transporting ISAH were studied and assembled. The Synchrocyclotron shutoff occurred at the end of December, and decommissioning was started immediately thereafter. An account of the dismantling process is given elsewhere in this conference⁸. With tireless efforts from the Bevalac rigging crew and mechanical supervision team, the positioner was dismantled, major mechanical components moved to a shop area adjoining the Bevalac for overhaul and maintenance. A thin epoxy-concrete grout base was prepared for the slab in the new treatment room, and in mid March the granite block was moved from its old site to its new bed. When it was properly

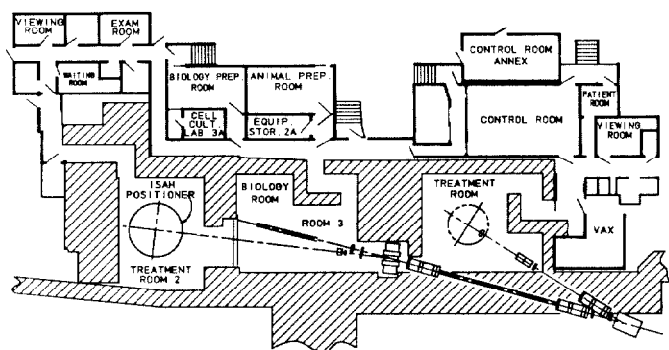


Figure 1. Bevalac Biomedical facilities, showing new ISAH therapy room and support facilities on the left.

supported with its leveling jacks, the surface of the granite was finished by a professional grinding firm to remove dings and irregularities. The optical rail assembly, slightly modified to accommodate the lower beam-height (10") and lower ceiling (12"), was then installed on the granite base, while the Treatment Room floor was built up around the slab. The positioner, also slightly modified for the new beam height, was reinstalled in early April, and a first (of many!) alignment of the entire device was performed shortly thereafter.

Concurrently with the mechanical work, the new control electronics for ISAH were being completed. Installation of this hardware and software meshed almost exactly with the mechanical readiness of ISAH to accept its new controls.

New Electronics for Control of ISAH

When ISAH was located at the 184" it was a standalone, dedicated and totally self-contained system. It had few controls and lacked self-testing capabilities. The transition to the Bevalac caused it to become a part of a much larger system, with multiple facilities operating at the same time all controlled from one central area. This new philosophy required the designing of a totally new control system for the positioner. The new drive electronics were designed to make ISAH compatible with the existing Biomedical control system, and also to improve safety and reliability.

New power-drive modules to drive the 5 large stepping motors were built, improving performance by applying a 3-step function to each phase: a high voltage "kick" to get the motor going, followed by a standard-specification "step" voltage to move to the next position and finally a low-voltage "hold" to maintain this position without consuming excessive power. The drivers were designed and severely tested to insure reliability and were assembled in Euro-chassis modules for quick replacement. To date no driver module has failed since ISAH's commissioning.

The old optical position encoders were replaced by resolvers which are much more reliable and include large LED read-outs mounted in the control rack. Along with a new hand-held manual control unit, the continuous read-out of all 5 axes has allowed for easier patient setup. Motion limits are interlocked to the drive system using redundant and fail-safe systems, thus preventing over-driving. The fact that ISAH's optical rails are supported by an active suspension system allows easy detection of collisions between the couch and rails, and so is thoroughly interlocked.

Computer control of ISAH is done with dedicated Camac modules. The controller for each axis maintains both the absolute position as well as the relative position, deriving its data from both its internal calculations and directly from the resolvers. This redundancy provides another layer of safety in the system. Motion to a new set of coordinates is accomplished by one of three techniques: by manual control through the hand-held pendant or switches on the control panel in the system racks; by typing in coordinates at a system terminal, these are located in the Treatment Room, or the various tech and control stations around the Facility. A third technique is directly from the main control computer, where the coordinates are drawn from the patient treatment record file, and the positioner is set so as to accept the patient when he enters the Treatment Room.

Beam and Dose-Control Systems

Integration of the new Treatment Facility into the existing Biomedical control system was a relatively straightforward, but tedious process. The control philosophy had all been thoroughly worked out, and thoroughly tested in the existing radiotherapy area⁹, so all that was needed was to replicate this system for the new room. With significant foresight, too, a VAX-780 system had recently been installed, supplanting the PDP-11/44 used previously, and the control system codes had all been ported to this new hardware. This move ensured adequate capacity to accept the task of controlling the new therapy area on a concurrent basis with other ongoing activities, whether biology, therapy, or both. The software effort consisted primarily of resurrecting and updating the codes used for the original (scattering-foil) beam delivery system (since supplanted by the Wobbler¹⁰ system), and entering a new set of channel-tables for all

the control and monitoring points in the new area. This was accomplished in an eight month time frame, and was ready by the time the mechanical component installation had been completed.

The hardware segment of the project required duplication of several chassis required to serve as an interface between the Biomedical control system, the devices in the treatment area, and the Bevalac control system. These include functions of beam-plug pulling, fast cutoffs, interlock chain monitoring, global timing coordination, and beam simulation. Again, these units were completed in time for overall system integration.

Beam Delivery System

A decision was made that the initial beam preparation and delivery system would be a passive one, based on beam scattering, and not an active Wobbler or Scanning system. This would only be an interim solution, as development of the Raster Scanning system¹¹ was proceeding at a rapid enough pace to expect its readiness for patient treatments within a year. Thus, the startup of the new Treatment Facility would be limited to helium beams and relatively small field sizes. Although somewhat restrictive, it affords treatment capabilities for all the AVM and ocular melanoma patients, and some of the dose-localization patients.

Commissioning

All the pieces of the project came together by late April, 1988, and commissioning and characterization work was begun. During this process, which lasted through May and June, no unexpected developments were encountered. System performance, after initial debugging, was excellent, both in reliability and efficiency of the subsystems, and in the available dose rate from the Bevalac.

The new Treatment Room is shown in Fig. 2. One can see the positioner with its chair attachment (holding a patient's head-mask). The granite slab is about two feet below the floor level. The optical rail systems support the collimators and dosimetry devices.

Resumption of Operations

The first patient treatment took place at the start of July, almost exactly six months following the last treatment at the 184". The facility is now in routine operation, with typically 5 to 6 patients per day (somewhat less than half of our total load) receiving irradiations. The facility continues to function according to design, with good reliability and dose rates.

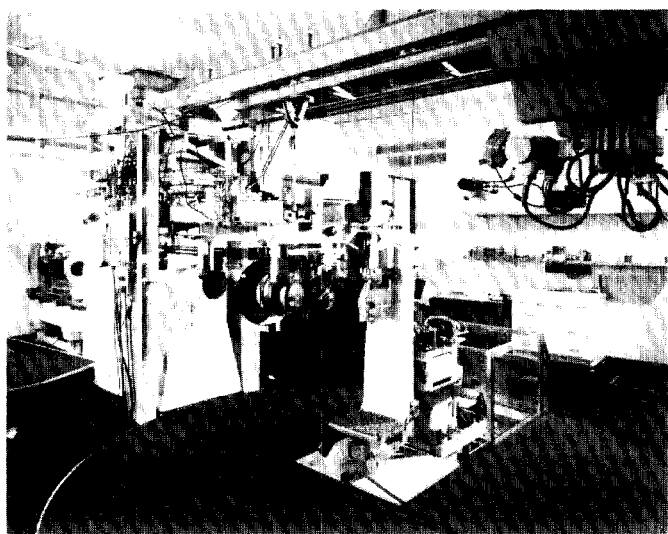


Figure 2. ISAH fully installed in the new Treatment Room.

Integration of the second radiotherapy facility into the daily Bevalac program has necessitated some changes in our scheduling philosophy¹². The previously-developed fast-switching mode of operation¹³ is utilized to switch beams between the two therapy rooms, however there is not much time left over for nuclear science running during the therapy hours. This has required some careful compromises in the allocation of beam time to ensure maximum productivity of the overall Bevalac facility. Our operations to date in this mode indicate that we have achieved a good level of success in tackling this most difficult problem.

Development of the Raster Scanner has proceeded at the expected pace, and we anticipate moving this system into the ISAH beamline this summer. This will provide ISAH with a large-field capability, as well as all the other advantages accruing from this advanced beam delivery system.

With the wedding of ISAH and the Raster Scanner we will have what is perhaps the world's most sophisticated patient therapy facility, one which will go a long way towards achieving the greatest possible benefits of charged particle radiotherapy.

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