THE BEVALAC MINIBEAM FACILITY*

Walter Schimmerling, Jose Alonso, Richard Morgado, Cornelius A. Tobias,
Hermann Grunder, Frank T. Upham, Alfred Windsor, Rollin A. Armer,
Tracy C. H. Yang and Jack T. Gunn
Lawrence Berkeley Laboratory
Berkeley, California 94720

The Minibeam Facility is a biomedical heavy-ion beam area at the Bevalac designed to satisfy the following requirements:

1. Provide a beam incident in a vertical plane for experiments where a horizontal apparatus significantly increases the convenience of performing an experiment or even determines its feasibility. A typical experiment of this kind is the study of the electrical response of nerve cells in tissue culture. In this case, the use of electrodes and the need for a tissue culture medium require an open, horizontal liquid surface.

2. Provide an area that is well shielded with respect to electronic interference so that microvolt signals can be detected with acceptable signal-to-noise ratios. Experiments with such requirements are, for example, the above-mentioned neurophysiological work and studies of retinal preparations involving electroretinograms. High-impedance electrodes are used in both kinds of measurements.

3. Provide a beam of small diameter, typically a few millimeters or less, for various studies of cellular function. To make full use of the highly concentrated beams, a program is underway to develop particle detectors with high spatial resolution, of the order of 20 to 30 μm. This dimension corresponds to the diameter of some large cells currently projected for experimental studies. Detection of particles with this resolution will make it possible to observe single-cell biological effects with some degree of confidence. The small beam spot will also be required for possible treatment of eye tumors such as choroidal melanoma, currently being considered.

4. Provide a facility for experiments that require long setup and preparation times and apparatus that must be left relatively undisturbed between experiments and that need short periods of beam time.

This paper describes the design of such a facility and of its main components. In addition to the above criteria, the design was constrained by the desire to have inexpensive, simple devices that work reliably and can be easily upgraded for interfacing to the Biomedical PDP 11/45 computer.

Beam Transport Line

Figure 1 shows the beam transport system from the first external focus of the extracted Bevalac beam (F1) to the Minibeam house. The horizontal and vertical beam envelopes are shown over the beamline elements, demonstrating that the final focusing of the beam onto the target is performed by the quadrupole singlet B3Q1 in the vertical plane and by edge-angle focusing of the vertical bending magnet B3M1 in the horizontal plane. The magnification factors from F1 to the target are approximately 0.5 (horizontal) and 0.3 (vertical). Considerably smaller vertical magnification is possible but at the expense of beam loss due to beam pipe aperture restrictions. Preliminary tuning runs indicate that these magnification factors are achievable. Thus beam spot size on target can be selected by suitable collimation at F1.

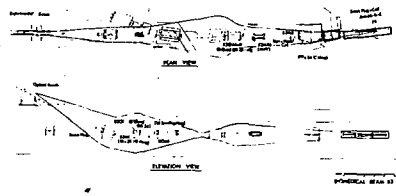

Figure 1

The maximum energy that can be transmitted to the experimental house is limited by the vertical bending magnet to a beam rigidity of 40 kG-m, which corresponds to about 200 MeV/amu for ions of e/A = 0.5. At these energies the natural size of the extracted beam at F1 is quite large, approximately 1 cm x 2 cm, so that collimation does involve some intensity loss. For a desired target spot of 3-mm diameter, approximately 10% of the beam at F1 can be transmitted, corresponding to about 1×10^8 ions per pulse on target for a typical run. For 200-MeV/amu neon ions this corresponds to a maximum plateau dose rate of about 150 kilorads per minute. Considerably lower intensities will be more than adequate for all experiments presently considered.

Preliminary runs have indicated that multiple scattering of the beam for the 3-meter air path from the beam pipe end to the target will increase the beam spot size by almost 10 mm. This will be reduced to about 1.5 mm by using helium-filled gas bags along the flight path. A second alternative is to extend the vacuum beam pipe from the Minibeam house entrance to a point much closer to the target.

Minibeam Experimental House

The Minibeam house is a 3.6-m by 7.3-m room situated on top of the Bevatron extracted-beam-line shielding blocks. The beam is brought into the room through a hole in the floor and traverses a roughly diagonal path from floor to roof and into a concrete beam stop located just outside the upper corner of the house. A set of optical rails runs parallel to the beam path and is used to support experimental equipment.

To ensure a low electrical noise background for high-impedance voltage measurements, the entire house is lined with 0.005-cm-thick copper sheeting, supported on the inside by plywood panels. Copper fingers are used to obtain electrical continuity at the doors in addition to suitably modified locks. Care has been taken to shield all openings such as air conditioning

*Work performed under the auspices of the U.S. Energy Research & Development Administration.

inlets, electrical feed-throughs and the beam entrance. All electrical connections and the house itself are grounded at an appropriate single location to avoid ground loops and the resulting signals induced by varying magnetic fields. Power is provided by an insulated and filtered transformer station. Measurements of spurious signals detected inside the house as a function of frequency indicate attenuations of 50 to 90 dB over a frequency range of 0.1 to 1,000 MHz. No signals over 10 μv/m were detected between 400 kHz and 45 MHz.

The optical bench that holds the experimental apparatus is made out of two 5-cm class-1 solid case hardened steel shafts, approximately 6 m long. The planned electrophysiological work requires extreme stability. To achieve this stability, the bench is supported on a single concrete block and weighted with 900 kg of lead. Measurements of vibration during Bevalac operation have shown that accelerations at the microscope stage are less than 1 milli-g except for a vertical component of 1 milli-g at 15 Hz and a horizontal component of 3 milli-g at 30 Hz. These vibration components will be damped locally. If a vibration isolation table should become necessary, it can be easily installed.

The house is constructed in two asymmetrical sections, which can be disassembled and removed by the existing crane if shielding modifications or access to the beam lines below the house are necessary. Removal and reassembly are estimated to require only one or two man-days. Seismic stability is ensured by tie-down brackets that affix the house to the concrete shielding blocks on which it rests.

Experimental Apparatus

Figure 2 is a photograph of the interior of the Minibeam house showing the various components assembled on the optical bench. The weighted support box can be seen in the bottom center of the picture. Not shown in the photograph are the wire chambers used for beam positioning and beam spot monitoring. These are standard chambers of the type developed at LBL[1] and display horizontal and vertical intergrated beam current profiles.

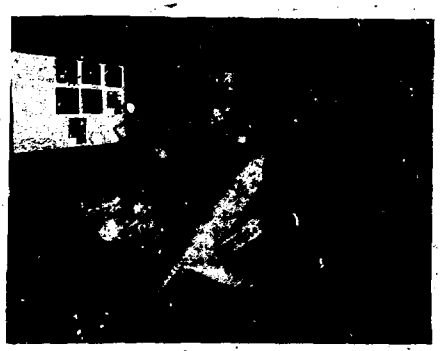

Figure 2

One of the most important components for use with on-line experiments involving living cells in culture is a high-quality microscope. We have installed a Zeiss-Wild optical system especially modified and adapted to our needs. A close-up view of the system is shown in Figure 3.

Figure 3

The microscope system is built around an Invertoscope D stand and has bright- and dark-field as well as phase-contrast optics. The inverted microscope allows relatively unrestricted access to the stage as can be seen in the photograph. One particular feature in this context is a special x16 phase-contrast objective with a 19-mm working distance adapted by the manufacturers for this application. The microscope illuminator, focusing and two-dimensional stage translation can be controlled remotely during an irradiation.

The optics have also been equalized to permit adjustment-free use of a movie camera (lower center in Figure 3), a still camera (seen end-on in the figure), and a TV camera (pointing away from the observer near the bottom of the figure). The TV camera and the movie camera are interfaced to time-lapse motion-picture equipment. The movie camera uses a Wild-Heerbrugg Variotimer, and the TV system uses an RCA model TC-3000 videotape recorder. The recorder and a still-frame display of a cell culture taped earlier are shown on the TV monitor in Figure 2.

A second platform has been built and will be installed. Eventually, two microscope stations will thus be available. The second station has a simpler platform but additional fixtures to support a laser. The laser will be focused through the microscope and can be used to stimulate neurons for electrophysiological studies as well as other applications. Micromanipulators for electrodes will be added at the time the experimental program begins.

The second most important component in a beam used for biological research is a variable absorber to vary the range of the beam below that determined by the extraction energy. This feature allows matching the variable thickness of biomedical targets without extensive retuning and makes it possible for the experimenter to determine the relative ionization density delivered by the beam to his system. We use the double wedge absorber shown in Figure 2 and in a closeup view in Figure 4. The advantages of such a device are its simplicity, reproducibility and inexpensive construction. Its main disadvantage is a limited dynamic range determined by the practical sizes of wedges that can be used and the existence of a minimum thickness determined by the fixed wedge.

Figure 4

In the present application these disadvantages are not limiting. The thickness range of the absorber has been extended by providing two 2.54-cm- and two 1.27-cm-thick fixed absorbers that can be inserted manually. The minimum thickness of the entire absorber is 1.27 cm, determined by the fixed smaller wedge. The larger wedge travels at an angle to the beam direction, yielding a maximum thickness of 5 cm for both wedges. The double wedge presents a 10- by 10-cm square cross section with both faces perpendicular to the incident beam direction. The fixed absorber and the wedges are presently made from polymethyl metbacrylate and are interchangeable with similar units of another material.

The wedge is driven by a stepping motor in either direction. An encoding disk is attached directly to the screw that drives the wedge. The unit is automatically initialized (driven to a fixed limit switch) when power is turned on and can be initialized subsequently by a pushbutton at the readout module. Two digital readout units are connected to the absorber simultaneously for local and remote operation. Pushbuttons at the readout and control module allow incremental or decremental motion by the amount specified on a presettable thumbwheel indicator. The total travel time of the wedge between limiting positions is approximately 32 sec. The position is reproducible to approximately 0.01 cm.

Beam monitoring and dosimetry are accomplished using two thin ionization chambers. Each ionization chamber consists of seven foils. The inner five foils are 0.008-mm-thick Kapton coated on both sides with 500 Å of gold. The central foil is used as a collector with a 10-cm-diameter active area. This area is continuous with a strip leading beyond the edge of the foil. The separation between the active area/connector strip and the guard-ring region on the foil was etched photochemically. The next two foils on either side of the collector are the high-voltage planes, and the final pair of Kapton foils are at ground potential, together with the iridited aluminum case. The external two remaining foils are nonmetalized Mylar, pierced with several holes to dampen microphonic noise. The spacing of the foils is 1 cm. When the ionization chambers are filled with propane (used because of its high electron mobility), the total area thickness of the ionization chamber is approximately 15 mg/cm^2. The small amount of material presented by the ionization chambers allows for a fine resolution of the sharp Bragg peak of heavy ions and for chamber calibration with an energetic alpha-particle source that can be removed during operation.

Contact between the foils and the external connectors is exclusively mechanical. Contamination from soldering materials and low-vapor pressure residuals from adhesives is thus avoided. Each ionization chamber has two metal covers that provide a vacuum-tight seal against an O-ring positioned in a groove machined on the outside surface of the aluminum case. The manifold shown on one of the ionization chambers in Figure 2 is used to evacuate the ionization chamber without introducing a pressure differential across the foils. After filling, the chamber is left at atmospheric pressure, and the metal covers are removed. An exit valve allows operation in a gas flow mode.

Readout for the chambers is presently under design. The high ionization produced by heay ions allows the use of the chambers in a pulse mode for single-particle detection at low beam intensities. At higher intensities, the integrated, digitized charge will be used for measurements of relative ionization (Bragg curves).

Conclusions

A relatively inexpensive facility has been designed specifically for biological experiments involving the on-line study of single cells.

A program of experiments by several groups at LBL is currently being assembled; these studies will probably begin this summer. It is anticipated that groups outside of LBL will also desire to use the Minibeam Facility for research projects that require the use of the finely tailored characteristics of this facility.

Acknowledgements

We would like to thank Marvin Hartley for help in measuring the RF interference and George Gabor for help in designing the ionization chambers.

Reference

1. J. Cuperus and R. Morgado. IEEE Trans. Nucl. Sci. NS-22, 1561 (1975).