**Title**
WOBBLER FACILITY FOR BIQMEDICAL EXPERIMENTS AT THE BEVALAC

**Permalink**
https://escholarship.org/uc/item/6b72h705

**Author**
Chu, W.T.

**Publication Date**
1985-05-01

LBL-18953 c.2

**Lawrence Berkeley Laboratory**
UNIVERSITY OF CALIFORNIA

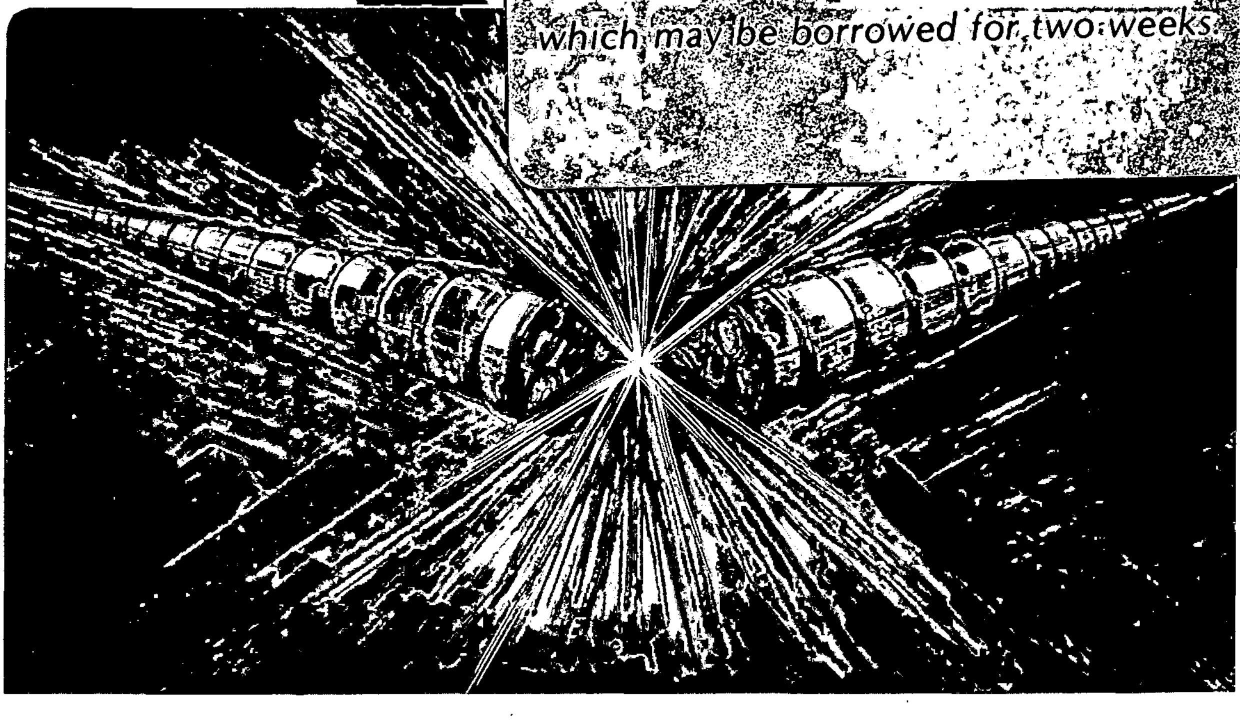
## Accelerator & Fusion Research Division

Presented at the 1985 Particle Accelerator
Conference, TRIUMF, Vancouver, B.C., Canada,
May 13-16, 1985

# WOBBLER FACILITY FOR BIOMEDICAL EXPERIMENTS AT THE BEVALAC

W.T. Chu, S.B. Curtis, J. Llacer, T.R. Renner,
and R.W. Sorensen

May 1985



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

# WOBBLER FACILITY FOR BIOMEDICAL EXPERIMENTS AT THE BEVALAC*

LBL-18953

W. T. Chu, S. B. Curtis, J. Llacer, T. R. Renner, and R. W. Sorensen
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

## Abstract

A new wobbler facility has been developed to deliver large uniform fields of relativistic heavy ions at the Bevalac without resorting to the use of scattering material in the beam. The charged particle beams are made to wobble and 'paint' a ring at the target by a pair of dipole magnets, which are placed tandem with their fields orthogonal to each other. The magnets are powered sinusoidally 90 degrees out of phase with each other. By superimposing several rings of appropriate sizes and intensities, large uniform fields are produced. Up to 30 cm diameter fields with less than 5% variation in uniformity have been achieved. Physics and biology measurements have been made to characterize the radiation field.

## Introduction

Many biomedical applications of accelerated heavy ions require uniform irradiation of large volumes. For example, radiation treatments of human cancer patients require uniform biological doses to be delivered in volumes with cross-sectional areas of up to 30 cm diameter and up to 14 cm of thickness to cover the extended target. This implies that the heavy ions beams from the Bevalac transported into the experimental areas must be broadened laterally and stopping ranges must be modulated to cover the target thickness.

## Double-scattering system

Currently the beam shaping is accomplished using two scattering foils and an occluding ring assembly as shown in Fig. 1 [1,2]. Tightly focused beams are made to go through the first scatterer located approximately 11 meters upstream of the isocenter and shaped into a broad Gaussian-like distribution with the flux peaked around the central ray of the beam. An occluding ring and a central post, both thick enough to stop the primary beam particles and placed in a concentric geometry centered on the beam, block out portions of particles near the central axis of the scattered beam. Multiple scattering by the second scatterer diffuses the beam into a wide field with a flat dose distribution at the isocenter. The second scatterer and the occluding ring assembly are positioned about 5.5 meters upstream of the isocenter. A spiral ridge filter is placed immediately upstream of the second scatterer. The spiral ridge filter is a brass absorber with specially shaped ridges, which when rotated introduces continuously varying thickness of metal degrader into the beam to modulate the stopping range of the heavy ions. The overall residual range of the beam is adjusted using a variable thickness water column positioned approximately 3 meters upstream of the isocenter.

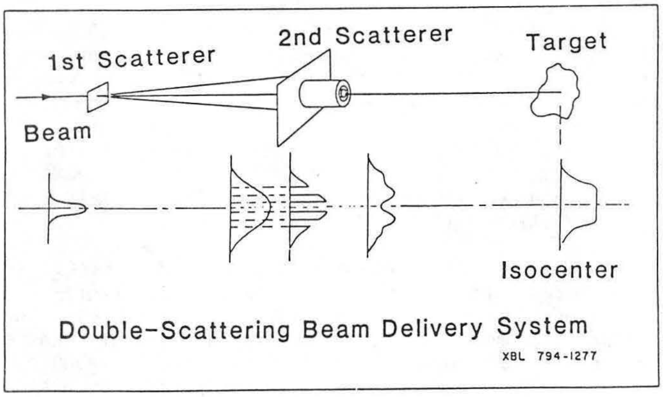


Fig. 1 Schematic illustration of the double-scattering system used at the Bevalac.

The above method requires a considerable amount of material in the beam. For example, to produce a uniform field of 20 cm diameter of the neon ion beam with an energy per nucleon of 670 MeV, the beam shaping devices used are 0.95 cm of lead as the first scatterer, 0.32 cm of brass as the second scatterer, the spiral ridge filter of an appropriate thickness of brass, and the water column. The disadvantages of this double-scattering system are: 1) the absorbing material in the beam shortens the available range of the beam particles, 2) the absorbing material, especially the low-Z material in the water column, introduces undue amount of nuclear fragments, and 3) the occluding ring assembly and the scatterers reduce the fraction of the beam delivered to the irradiation volume.

The double-scattering method cannot be easily extended to heavier ions, which scatter less and fragment more in a given scatterer thickness. For example, for silicon ions with an energy per nucleon of 670 MeV, using a 0.56-cm thick lead, this method can produce uniform doses in a cross-sectional area not larger than 14 cm diameter. At the distal edge of such beams, the doses due to the fragments are almost one half of the delivered doses.

## Wobbler

The newly developed wobbler facility overcomes many of the disadvantages encountered in the double-scattering system. The lateral broadening of the beam completely relies on the magnetic deflection, and eliminates the need for the scattering material

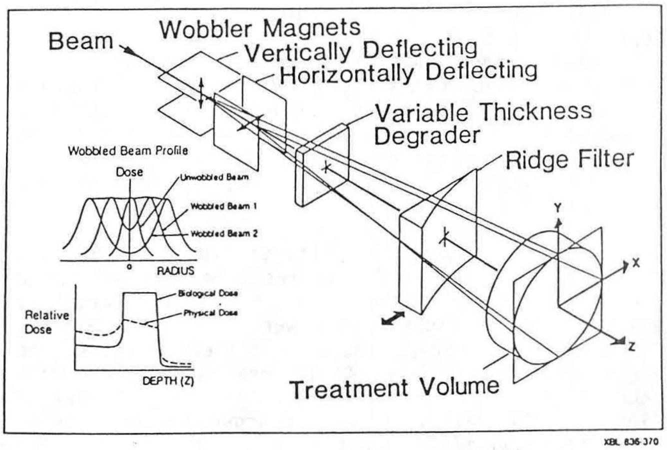
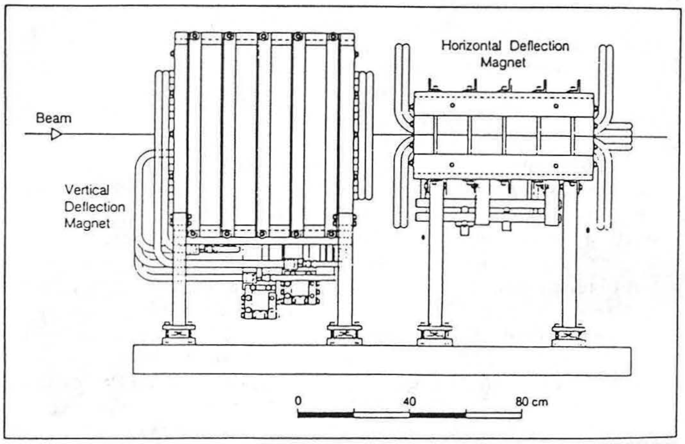


Fig. 2 Principles of the wobbler system.

---

*This work was supported by the U.S. Department of Energy Contract No. DE-AC03-76SF00098 and in part by the National Institute of Health under Grant Ca15184.



XBL 846-8804

Fig. 3 Illustration of a pair of wobbler magnets.

in the beam. The wobbler system lowers the contaminations by radiobiologically inferior fragments in the beam and increases efficiency of the beam utilization. The removal of the scattering material from the beam path also reduces the divergence of the beam and consequently improves the sharpness of the penumbra of the collimated beams.

The clinically acceptable dose delivery system is specified to deliver a biologically uniform dose of heavy ions with the range of 28 cm inside a tissue volume (of water density) of 30 cm diameter and 14 cm width, with dose variation not exceeding 5%. It is also desired that the entire irradiation time be limited to under few minutes, which translates to 30 to 45 accelerator pulses per treatment. (The Bevalac pulses every 4 seconds, or 15 times per minute.) Since the wobbler system will produce a uniform field by superimposing several rings of different wobble radii, say four different radii, only an average of approximately ten pulses can be spent at each wobble radius.

Early on in designing the wobbler power supplies, it was decided that the phase of wobbling would run independent of the start and stop of the extracted beams. This implies that if the system wobbles n turns during one pulse to 'paint' the target n times, there will always be a part of the circle that is 'painted' only n-1 times. The fractional difference in doses due to this effect is 1/n. Since these 'underpaintings' will happen in completely random phase, the intensity variation after wobbling N accelerator pulses is $1/\sqrt{N}n$. If one assumes values of N=10 and n=60, the intensity variation is approximately 0.5%. The spill length of the Bevalac beam pulse, approximately 1 second, and the wobble frequency of approximately 60 Hz (n=60) is regarded as adequate. The actual wobble frequencies vary between 57 and 59 Hz depending on the wobbler magnet currents. This range of frequencies was intentionally chosen so that the Bevalac pulsing and the wobbler are operated out of phase.

The wobbler system consists of two dipole magnets in series, one that deflects the beam vertically and the other horizontally (see Fig. 3). Specially designed power supplies power the two magnets sinusoidally, thus changing their deflection amplitudes sinusoidally, 90 degrees out of phase with each other. It produces effectively a rotating dipole field, which wobbles charged particle beams injected along the central axis of the system. The principle of the technique is schematically illustrated in Fig. 2.

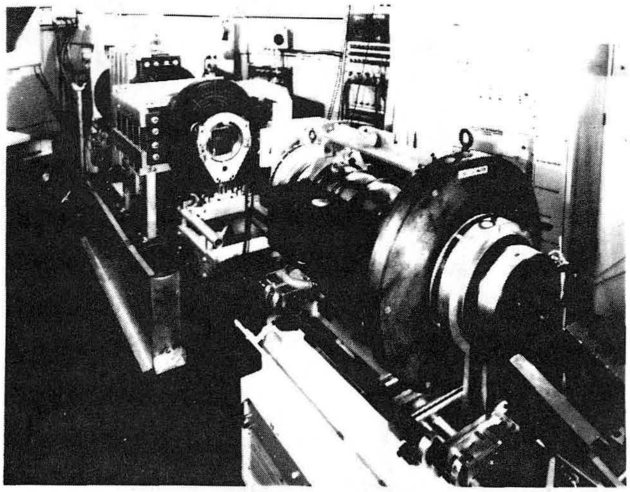


Fig. 4 Photograph of the wobbler system looking into the beam. The ridge filter is at the downstream of the wobbler magnets. The water column and dosimetric equipment are seen in the foreground.

A large uniform field is obtained by delivering doses distributed in wobbled beams of several different radii. It has been shown that a superposition of wobbled beams of approximately Gaussian-shaped beam spots at the target position can produce a flat field of 30 cm diameter with less than 5% variation in dose uniformity. This uniformity is achieved by carefully selecting the size of the swept beam spot, wobble radii, and the ratio of delivered fluxes at various radii.[3]

Table 1. Wobbler Magnets

| | |
|---|---|
| Magnetic field | 0.4 T |
| Effective length | 0.7 m |
| Gap size | 10.2 cm |
| Conductor diameter | 2.29 cm |
| Turns per magnet | 28 |
| Frequency | 57 - 59 Hz |
| Current (d.c.)+ | 1155 Amps |
| Voltage (d.c.)+ | 9.23 Volts |
| Power (average) | 5.33 kW rms |
| Stored energy | 1056 Joules |

+if operated in d.c.

The dipole magnets, each of which can be driven to 0.4 Tesla maximum field in either polarity, use specially designed power supplies. A three-phase, 60 Hz alternator is electrically wired to a special transformer, which is located near the magnets, to provide a two-phase, 4 wire system. The power supply delivers two sinusoidal currents, 90 degrees out of phase, each supplying one of the two dipoles. The alternator is driven by an electric motor. Fig. 4 shows a photograph of the wobbler magnets. The parameters of the magnets are listed in Table 1.

The system uses commercially available parts, is economical, and as tests have shown, meets the requirements for beam uniformity and reliability. The principal components, the motor and alternator, can be rated for more severe service than actually required, thus enhancing reliability. Spare parts can easily be kept on hand to be used in case of failure.

## Ridge Filters

As shown in the photograph in Fig. 4, specially shaped metal ridge filters are placed immediately downstream of the wobbler system to spread out the Bragg peak. The range of the monoenergetic beam particles are shifted according to the thickness of the ridge they happen to pass through; and the multiple scattering in the filters as well as other material in the beam path produces the desired dose distribution in the spread Bragg peak within the entire radiation field at the target.

## Requirements on Beam Extraction

Three requirements must be met to achieve the clinical acceptable radiation field. First, the beam intensity during the spill must remain constant and must be free of excessive low frequency microstructure. Intensity variation in the spill will lead to field inhomogeneities because the nature of the wobbling system is to convert the time structure of the particle spill into spatial variations in the treatment field. Very high frequency beam structure may not affect the field flatness, provided that this frequency is sufficiently above the inverse of the time required to traverse a diameter of the beam spot for the wobbled beam. When these conditions are met, and the time average flux rate remains constant, adequate overlap of beam spots is achieved, and any intensity fluctuations in the treatment volume due to the time structure is washed out.

To 'paint' a uniform dose distribution using several wobble radii, larger fluxes are required in outer wobbles than those required for the smaller inner wobbles. If extracted intensity levels remain the same for all wobble radii, larger numbers of accelerator beam pulses are needed in outer wobbles. In other words, smaller inner wobbles may use a few spills or even a fraction of one spill. As mentioned above, to statistically dilute the effects of 'underpainting,' it is desirable to employ a comparable number of accelerator pulses per wobble radii. Therefore the second requirement is that one must be able to control the amount of beam being delivered in each spill. Another reason to adjust the spill level is to be able to lower the last few spills in a given wobble radius so that the last spill is long enough to cover multiple wobbling sweeps.

The third requirement is that the beam extraction characteristics, such as spiller magnet ramping rate, must remain constant regardless of the extraction intensities. This ensure that the extracted beams transported to the wobbler system do not wander away from the central axis of the wobbler. This last requirement is satisfied by adjusting the injected particle flux that are accelerated in the Bevatron and keeping the extraction efficiency constant.

The development efforts to meet these requirements on the beam extraction from the Bevalac are described elsewhere.[4]

## Physical and Biological Characterization of the Wobbled Beam

Within the entire target volume, the flatness of the wobbled beam, the proper spreading of the Bragg peak, the distribution of fragments, distribution of RBE (relative biological effectiveness) are measured for the wobbled beams. These results have been reported elsewhere.[5]

## Conclusions

Large fields of uniform doses of clinically useful heavy ion beams are produced with the wobbler facility. The dosimetry and monitoring system developed for the wobbler [3] ensure reliable beam delivery for patient treatments. The facility is now available for routine radiotherapy and biology experiments.

## Acknowledgements

We would like to extend our thanks to Jose Alonso and Tom Criswell for the contributions in the early phase of the wobbler development, Ron Yourd, Henry Lancaster, and Bob Yamamoto for the fabrication of the wobbler magnets, R. P. Singh, Maury McEvoy, Mark Nyman, and Ron Stradtner for maintaining the Biomed Facility at the Bevalac, and the entire Bevalac operating personnel for providing technical assistance in the wobbler implementation.

## References

[1] K. Crowe, L. Kanstein, J. Lyman, and F. Yeater, A large field medical beam at the 184-Inch synchrocyclotron. LBL Report No. 4235 (1975).

[2] A. M. Koehler, R. J. Schneider, and J. M. Sisterson. Flattening of proton dose distributions for large-field radiotherapy, Med. Phys., 4, 297 (1977).

[3] T. Renner, W. Chu, M. McEvoy, M. Nyman, B. Gonzales, R. Singh, and R. Stradtner. Wobbler dosimetry for biomedical experiments at the Bevalac, elsewhere in this Proceeding.

[4] M. Nyman, W. Chu, B. Mehlman, W. Mirer, H. Oakley, T. Renner, G. Stover, and M. Tekawa. New techniques for extraction of Bevalac beams, elsewhere in this Proceeding.

[5] W. T. Chu, S. B. Curtis, J. Llacer, M. B. McEvoy, M. A. Nyman, T. R. Renner, R. P. Singh, and R. Stradtner. Wobbler facility for biomedical experiments at Bevalac, presented at the 33rd Annual Scientific Meeting of Radiation Research Society, Los Angeles, May 5-9, 1985.

*LAWRENCE BERKELEY LABORATORY*
*TECHNICAL INFORMATION DEPARTMENT*
*UNIVERSITY OF CALIFORNIA*
*BERKELEY, CALIFORNIA 94720*