LBL-22168

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

MAY 12 1987

Presented at the 1987 Particle Accelerator Conference, Washington, DC, March 16–19, 1987

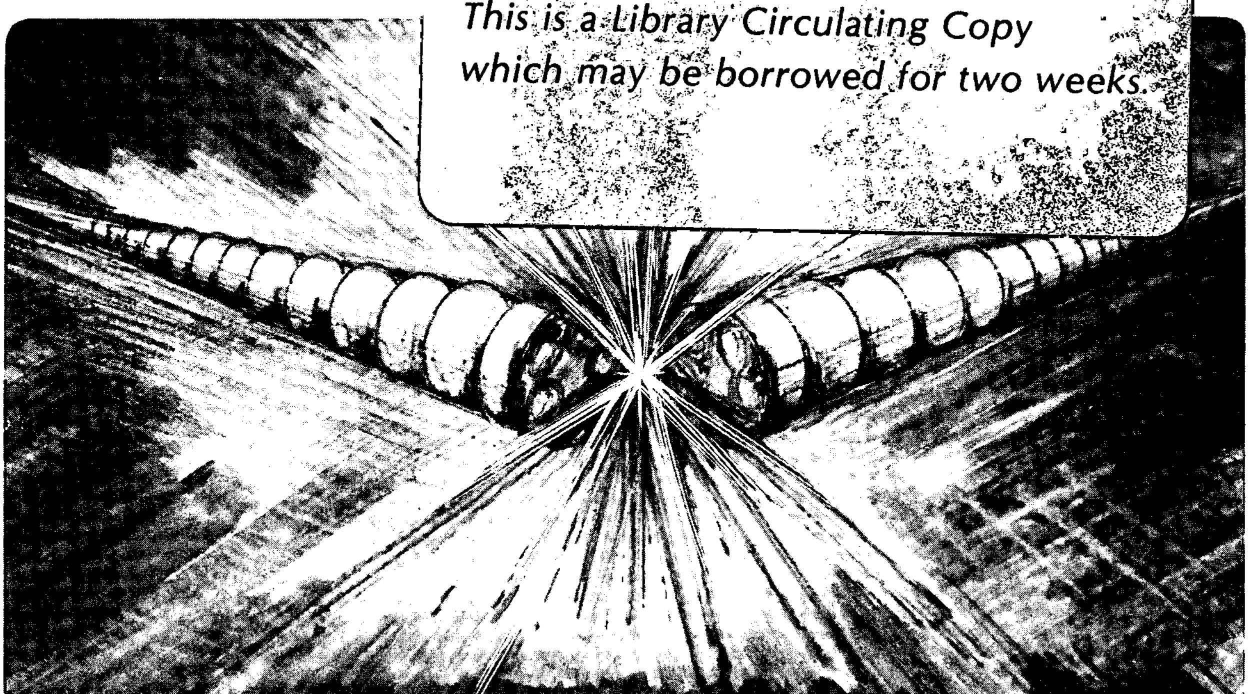
THE BEVALAC UPGRADE PROJECT

J.R. Alonso, R.D. Dwinell, B. Feinberg, R. Frias, R.A. Gough, D.R. Howard, D.B. Hunt, G.F. Krebs, J.T. Krupnick, S.A. Lewis, J.N. Marx, R.M. Reimers, J.W. Staples, G.D. Stover, and J.T. Tanabe

March 1987

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks.



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

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

The Bevalac Upgrade Project†

J. R. Alonso, R. D. Dwinell, B. Feinberg, R. Frias, R. A. Gough, D. R. Howard, D. B. Hunt, G. F. Krebs, J. T. Krupnick, S. A. Lewis, J. N. Marx, R. M. Reimers, J. W. Staples, G. D. Stover, J. T. Tanabe

Lawrence Berkeley Laboratory, University of California, Berkeley, Calif 94720

Abstract

This paper describes a proposed upgrade of the Bevalac accelerator complex in which the present Bevatron is replaced with a modern, strong-focusing 17 T-m synchrotron. This new ring is designed to accelerate all ions throughout the periodic table with intensities 100 to 1000 times higher than the present Bevatron. It will also provide a substantially improved beam spill structure and will reduce operating costs. A fast extraction capability can be used to inject a future heavy ion storage ring. Pulse-to-pulse switching of energy and ion species is an important goal. The existing injectors, shielding, experimental facilities and utilities of the present Bevalac will remain substantially intact.

Introduction

The Bevalac has been for many years the pioneering accelerator for heavy ion physics in the 1 to 2 GeV/n energy range. Even with the currently-planned construction efforts around the world covering this energy and ion range, the applications for these heavy ion beams have grown fast enough to justify upgrading the Bevalac into a modernized facility with state-of-the-art capabilities. The goals of the Upgrade Project are clearly stated: to provide significant increases in beam intensity, improve beam quality and control, and to provide more operational flexibility and efficiency, all for minimum construction costs.

Building on an extensive base of existing facilities which are compatible with the Upgrade goals, namely the SuperHILAC and Local Injector linacs, transport lines, shielding, installed physical plant and experimental areas, the Upgrade Project will consist of removing the Bevatron and replacing it with a strong-focusing synchrotron[1,2]. The Project will require three years to complete. It is anticipated that the Bevalac will remain in operation during most of the first two years of the Project as components are fabricated and assembled. In the last 15 months the Bevatron will be dismantled and the new accelerator installed. This schedule minimizes the disruption of the ongoing experimental programs.

Accelerator Performance Goals

The new synchrotron will offer great improvements in performance in many areas. Specific details of new machine performance are given below.

Intensity. The intensity of the Upgraded Bevalac will be improved by factors between 100 and 1000 over performance of the present Bevalac. In the highest mass region a factor of ten in this improvement arises from upgrade programs presently underway at the SuperHILAC[3,4]. At the conclusion of these programs peak uranium intensities of over 1 pμA will be available for Bevalac injection. The remaining factor of 100 intensity gain is uniform across the whole mass range, and results from hardware and operational changes in the Bevalac. Several factors contribute to this overall gain: improved inflection and stacking ($\times$3), r.f. capture ($\times$2.3), extraction ($\times$3), and more rapid cycle rate ($\times$5). At the low mass end, up to A $\sim$ 20 the expected beam currents of 1-2$\times 10^{11}$ ions/second will be limited by Laslett tune shifts, while the maximum uranium currents of 3×10^9 ions/second will be comfortably below space charge limits as shown in Figure 1.

Energy. The design maximum rigidity of the new synchrotron of 17 Tesla-meters, along with the charge-to-mass ratio of the ion being accelerated, specifies the maximum energy of the beam. Table 1 gives maximum intensities and energies for representative ions accelerated in the upgraded Bevalac. The highest energies are slightly lower (~15%) than present Bevalac energies, but this drop in top energy will have minimal effect on the scientific program planned for the upgraded Bevalac. The top energy of accelerated beams will be sufficient to produce fully stripped uranium ions, and also comfortably spans the range of requested energies for the majority of present Bevalac programs.

Ne^{+10}	1×10^{11}/pulse	1782	MeV/n
La^{+31}	2×10^{10}	538	
U^{+40}	3×10^{9}	334	
U^{+68}	4×10^{8}	797	

Table 1. Representative Ion Intensities and Energies

Duty Factor. Flattop length for the new synchrotron can be of arbitrary length, from as short as 100 msec for fast spills, to tens of seconds. With a ramp time of 0.5 seconds to maximum field, duty factors of 90% or higher are possible.

Beam Quality. Emittance and intensity control of the extracted beam will be significantly improved over what is available from the Bevatron today. Presently, structure on the extracted beam is a serious problem, arising in large measure from ripple on the main magnet supply, and difficulty in controlling the spill. These problems generally find satisfactory solutions with modern power supplies and well-understood extraction systems. The emittance of the extracted beam will be several times better than the present Bevatron extracted beam. This results from better control of coupling between horizontal and vertical planes, and better control of the beam growth during the extraction process.

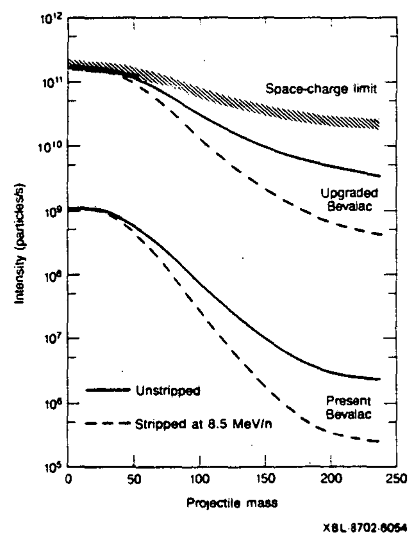


Figure 1. Intensity per Pulse vs Projectile Mass

Versatility of Operating Modes. The operational philosophy at the Bevalac today is very different than in the era of proton operations. Instead of splitting the beam and simultaneously sending portions of the beam down several beam lines, the accelerator is now dedicated to a single user at a time but has the capability to alter configurations in about one minute to deliver a different ion and energy to a different experimenter. This "Fast Switching" mode allows different programs to run concurrently without restrictions on the ion species and energy delivered to each, and serves to inter-

† This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Division, U.S.Department of Energy under contract number DE-AC03-76SF00098.

leave the nuclear science program with the radiotherapy program[5]. The new synchrotron will expand on this capability, providing independent selection of ions, energies and beam lines on a pulse to pulse basis. Much experience with this type of operation exists now, with the highly successful "Time-sharing" operating mode at the SuperHILAC,[6] where each of the 36 pulses per second can be independently dedicated to one of three different ions and energies. Such flexible operation for the new synchrotron, with the ability to select for each pulse ions from either the SuperHILAC or the Local Injector and to deliver them independently to different areas, will provide a great improvement in the versatility and efficiency of the new Bevalac experimental program.

Compatibility with Future Upgrades. Finally, the introduction of a modern strong-focusing synchrotron into the Bevalac complex will provide a firm basis for further enhancements in heavy-ion capabilities. The improved beam quality and ability to extract beam in a single turn are vital to matching beams from the synchrotron into another ring. Although the present project will not contain the hardware for single turn extraction, space in the ring is being reserved for this capability, as well as for a reinjection channel to accept beam back into the ring from a storage ring.

Machine Overview and Highlights

Lattice Design. The synchrotron must fit within an existing shield wall, have less than a 1.8 T dipole field and accelerate ions to a maximum rigidity of at least 17 T-m. The 12 period lattice is of compact design with a circumference of 136 meters and a dipole field of 1.72 T as shown in Figure 2. The lattice is a FODO missing magnet design with phase advances per cell of 111° and 81° in the horizontal and vertical planes respectively. The SIS-18 ring, the most similar accelerator to this one, has a circumference of 210 meters[7]. The small Upgrade circumference is made possible by short quadrupole length of 0.6 and 0.8 meters operating at pole tip fields of 1.0 T, two 1.72 T dipole lengths of 1.43 and 3.73 meters, and relatively short (3.38 m) straight sections.

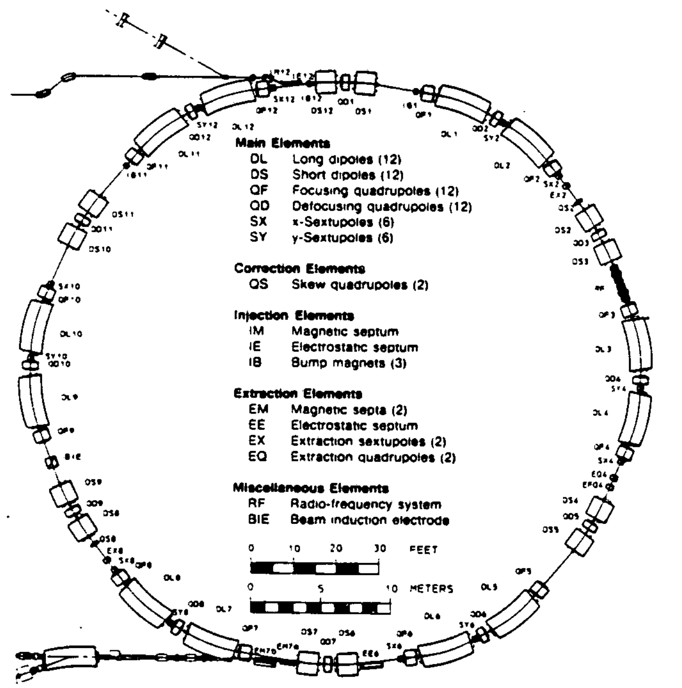


Figure 2. Accelerator Lattice

The FODO approach requires the lowest quadrupole excitation, reducing the quadrupole filling factor in the ring to 12.4% and the high phase advance in the horizontal plane limits the peak dispersion to 2.69 meters. The peak dipole field of 1.72 T results in a dipole filling factor of 45.5%.

The periodicity of 12 reduces the number of structure resonances in the vicinity of the working point of ν_x=3.7, ν_y=2.7, and raises γ_T to 3.62, above the peak gamma of any heavy ion to be accelerated (protons will go through transition if accelerated to more than 2.5 GeV). A period consists of two cells, mirror-images of each other. This places two long 3.38 meter long straight sections within about a 60° phase advance of each other, facilitating the design of the extraction system. Table 2 lists some important accelerator parameters.

Maximum Rigidity	17	T-m
Circumference	136	meters
Number of Periods	6	
Lattice Type	FODO	
Peak Dipole Field	1.72	T
Maximum Cycle Rate	0.87	Hz
Vacuum	10^{-10}	Torr

Table 2. Accelerator Parameters

Ring Magnets. The ring contains 12 each of long and short dipoles, and long and short quadrupoles, along with two families of 6 chromaticity correction sextupoles. The twelve 3.38 meter long straight sections include the injection and extraction systems, the r.f., skew quad correctors, and auxiliary injection and extraction elements. Two additional straight sections are included for future single turn extraction and reinjection from a storage ring, and one more reserved for future application.

The momentum spread is ±0.9% after r.f. turn-on. The maximum betatron amplitude is about 20 meters in each plane. With a peak dispersion of 2.69 meters the maximum horizontal beam semi-axis of 10 cm is contained within the ±11 cm aperture with a 1 cm combined stay-clear and corrected closed orbit allowance on all four sides. The full magnet gap is 27 cm by 9.4 cm.

The dipole magnets are designed to match the present motor-generator based power supply system, have good field quality and rise to full field in 0.5 second. The low current density of 350 A/cm^2 in a combination H-gap and window frame design satisfies these requirements. The low current density allows long flattop operation with a steady-state power demand of 2.5 MW, the limit of the motor-generator set.

The 1.5 mm laminations will be stacked on an arc to allow for a 17.6 cm sagitta in the 3.73 meter long dipole, and will be stacked straight in the 1.43 meter dipole. The dipole lamination stacking efficiency is estimated to be at least 95%, so the peak field in the iron will be less than 1.82 T, and the hysteresis losses in all dipoles will be less than 310 kW for a maximum cycle rate of 0.87 Hz (no flat-top). Each long dipole weighs 44.8 tons, bends 21.7° and is excited to 1.72 T by a 1080 ampere current. The maximum field error, principally sextupole, is 0.02% at maximum aperture at 1.72 T, decreasing to less than 0.005% at fields less than 1.64 T.

Extraction. Third-integer resonant extraction begins in one long straight with a 0.5 mm electrostatic septum, followed in the next straight with two magnetic septa in tandem. The 60° phase advance from the first to the second long straight provides a 1.5 cm beam separation with the electrostatic septum for the coil of the first magnetic septum. Extraction efficiency is over 90% down to near injection energy.

Injection. Two existing injector linacs are available for the synchrotron: the SuperHILAC for the entire mass range, and an RFQ-DTL injector, the Local Injector, for ions up to mass 40. The SuperHILAC has three preinjectors: a 750 kV Cockcroft-Walton for ions up to mass 40, a 2.5 MV dynamatron for heavier ions at low intensity, and a 750 kV C-W and Wideröe combination for high intensity ions through uranium. This injector is capable of multiplexing beam species and energy at a 36 pps rate, of which 2 pulses per second are transported along the 350 meter long transfer line to the synchrotron. The Local Injector provides high intensity light ions.

The beams from the two injectors are multiplexed together near the synchrotron in an achromatic injection line. The dispersion at the 0.25 mm thick electrostatic septum is kept at much less than 1 meter for good injection efficiency. The achromaticity is independent of the tune of the matching quadrupoles. Systems of dipoles form achromatic translations and bends, and the quadrupoles are at locations of zero dispersion.

Multiturn injection uses a 0.25 mm electrostatic septum with a beam whose emittance in the horizontal plane has been reduced by a factor of 3 with an *emittance exchanger* which concurrently increases the vertical emittance by a factor of 3, preserving transverse brightness[8]. With a linac momentum spread of $\pm 0.5\%$, 69 effective turns are injected out of 150 actual turns with an injected beam emittance of 0.4π cm-mrad.

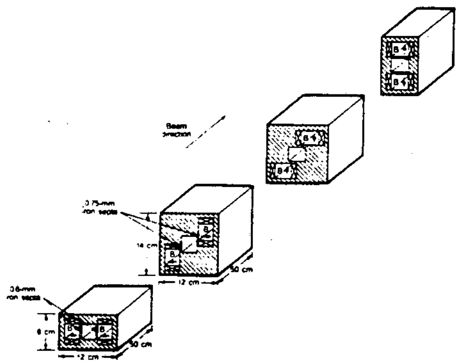


Figure 3. Emittance Exchanger

The emittance exchanger, shown in Figure 3, reduces the horizontal emittance at the expense of vertical emittance by splitting the SuperHILAC beam apart with a magnet consisting of two iron septa, a zero field in the central third, and oppositely directed 450 Gauss fields in the other two apertures. The three beamlets are then recombined with three following double iron septa of similar design, the last two rotated around the beam axis by 90°, which reassemble the beam with one-third the width but three times the height without affecting the divergence. The thin septa intercept less than 10% of the beam. The lowered horizontal emittance increases the injection efficiency and the increased vertical emittance is a better match to the vertical aperture in the synchrotron. The larger vertical emittance decreases the vertical Laslett tune shift and reduces the disparity between the circulating horizontal emittance of 40π cm-mrad and the vertical of 4π.

Vacuum. The vacuum required is at least 10^{-10} Torr to accelerate partially stripped ions to full energy with no more than 20% losses due to recombination. The vacuum system uses a 12 K gaseous helium cooled cryoliner, similar in concept to the one used in the present Bevatron[9], surrounded by superinsulation and a liquid nitrogen cooled heat shield as shown in Figure 4. The vacuum chamber is conformal to the beam envelope in the long dipoles to maximize the aperture utilization. This system has the benefits of relative immunity from contamination due to vacuum accidents: it does not need exotic materials, baking or ultraclean assembly. The system consists of a 10^{-5} Torr guard vacuum outside of the 10^{-10} Torr 12 K helium-cooled bore. The materials are non-metallic where eddy currents would be a problem, and the cryogen supply lines are decoupled to prevent circulating currents.

The guard vacuum tank uses the magnet pole faces themselves for the top and bottom walls, sealed and bonded to a thin kapton skin, with an o-ring against fiberglass sides. In the other synchrotron elements, the guard vacuum tank will be decoupled from the magnets. The 12 K surface is a fiberglass tube of rectangular cross section with a copper stripe pattern etched on the surface similar to a printed circuit board. The narrow copper stripes provide a thermal path to the helium lines at the sides of the chamber while preventing eddy currents. The beam pipe impedance is kept low by a continuous longitudinal stripe, interrupted at the ends to prevent eddy currents.

R.F. System. The r.f. system accelerates the beam on the first harmonic providing a 14 kV peak accelerating voltage over the frequency range of 0.18 to 2.17 MHz. Two independent half-wave cavities are used in tandem with two gaps, with the ferrite bias systems in series and the two gaps in parallel across a single push-pull r.f. amplifier. The wide frequency swing requires the use of a high-μ ferrite and minimizing the non-ferrite volume in the cavity. The cryopump is continued through the reentrant cones up to the accelerating gap from each side and in the space between the two gaps.

Control. To provide different ion species to various experiments on a time multiplexed basis, the synchrotron, injectors, and external beam lines will operate on an independently cycling basis which is an extension of the present 36 pps multiplexing of the SuperHILAC (itself one of the injectors).

The computer control system extends concepts in use at the SuperHILAC and Bevatron. It is based on graphical workstations as universal control consoles at any control room site, communicating over a high-speed local area network with highly distributed front-end processors collected into 32-bit backplanes. A major goal of the control system design will be a reduction in the number of operating personnel.

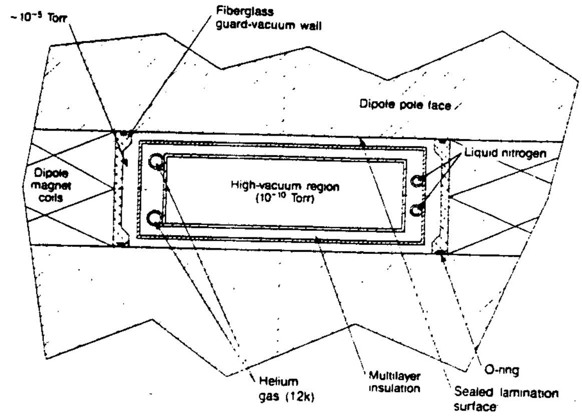


Figure 4. Vacuum Chamber Cross Section

Conclusions.

The accelerator presented here satisfies the requirements set forth in the first sections. A construction plan has been prepared to complete the construction and installation of all components within a three-year period. This plan requires a 15-month user downtime during which the existing Bevatron would be dismantled and removed, and the new synchrotron would be installed. Operation would resume, following a short commissioning period at the beginning of year four.

References

1. The Bevalac Upgrade, LBL PUB-5166 (1986)
2. The Bevalac Upgrade CDR, LBL PUB-5183 (1987)
3. B. Feinberg et al, IEEE NS-32, No. 5, p. 3202 (1985)
4. K. Halbach et al, IEEE NS-32, No. 5, p. 3643 (1985)
5. F. Lothrop et al, IEEE NS-32, No. 5, p. 3119 (1985)
6. H. Lancaster et al, 1979 LAC, BNL, p. 269 (1979)
7. K. Blasche et al, IEEE NS-32, No. 5, p. 2657 (1985)
8. G. Lambertson, private communication.
9. R. Avery et al, IEEE NS-28, No. 3, p. 3260 (1981)

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

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