

# Lawrence Berkeley National Laboratory

## Recent Work

**Title**

ACCELERATION OF URANIUM AT THE BEVALAC

**Permalink**

<https://escholarship.org/uc/item/6g31m16f>

**Author**

Alonso, J.R.

**Publication Date**

1982-07-01



# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## Accelerator & Fusion Research Division

RECEIVED  
LAWRENCE  
BERKELEY LABORATORY  
AUG 18 1982  
LIBRARY AND  
DOCUMENTS SECTION

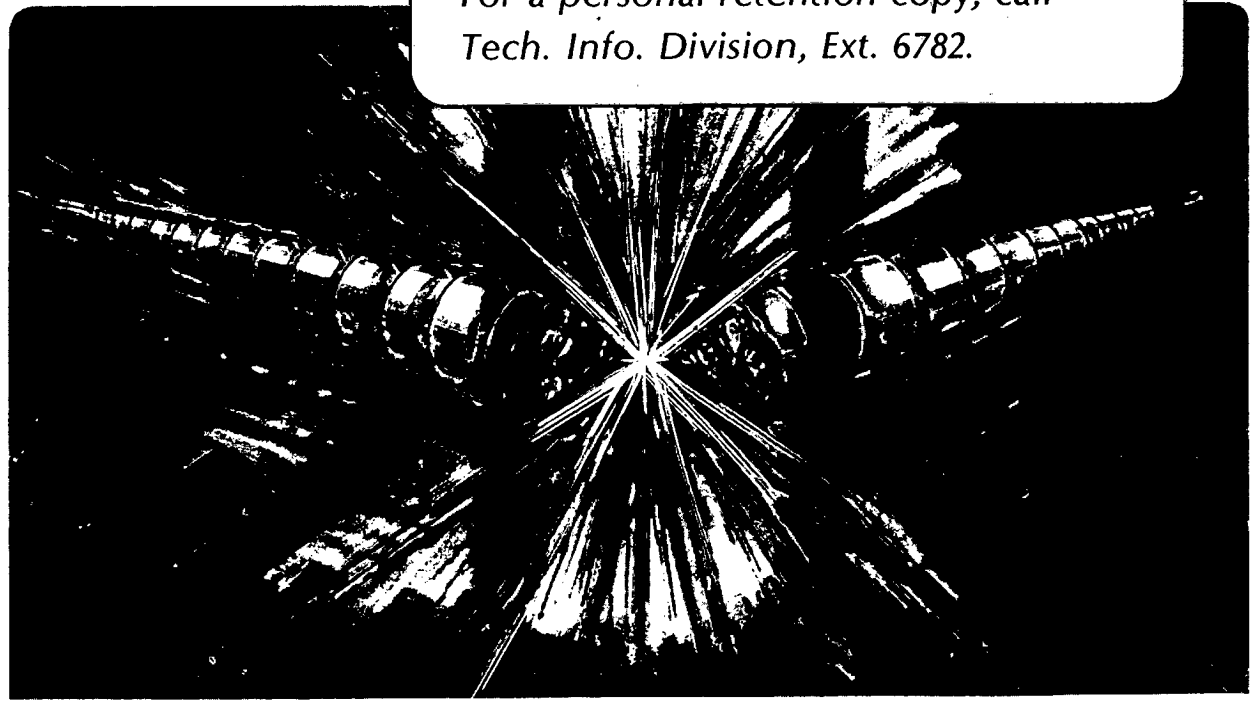
Submitted to Science

ACCELERATION OF URANIUM AT THE BEVALAC

J.R. Alonso, R.T. Avery, T. Elioff, R.J. Force,  
H.A. Grunder, H.D. Lancaster, J.R. Meneghetti,  
F.B. Selph, R. R. Stevenson, R.B. Yourd

July 1982

**TWO-WEEK LOAN COPY**  
*This is a Library Circulating Copy  
which may be borrowed for two weeks.  
For a personal retention copy, call  
Tech. Info. Division, Ext. 6782.*



LBL-14737  
c.2

## 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.

Acceleration of Uranium at the Bevalac

J. R. Alonso, R. T. Avery, T. Elioff, R. J. Force, H. A. Grunder, H. D. Lancaster, J. R. Meneghetti, F. B. Selph, R. R. Stevenson, R. B. Yourd

Accelerator & Fusion Research Division  
Lawrence Berkeley Laboratory  
University of California  
Berkeley, CA 94720

Abstract

Recent upgrade projects have extended the mass range of particles which can be accelerated at the Bevalac to include any element of the periodic table to energies above 1 GeV/amu. Verification of this capability was achieved on May 11, 1982 with the production of a uranium beam at 147.7 MeV/amu.

Introduction

It was first demonstrated in 1971<sup>1</sup> that the Bevatron at the Lawrence Berkeley Laboratory was capable of accelerating heavy ions when nitrogen ions produced by the local Alvarez linac injector were successfully accelerated, extracted and identified. The original beam intensities were very low, of the order of  $10^6$  ions per Bevatron pulse, limited by the use of the proton injector for producing heavy ion beams. The Bevalac came into being in 1973<sup>2</sup> (see Figure 1) when a transfer line was built connecting the Bevatron and the SuperHILAC a linear heavy ion accelerator that could produce beams of ions up to mass 200 at energies to a maximum of 8.5 MeV/amu. In this configuration heavy ions from the SuperHILAC could be transported and injected into the Bevatron, and subsequently accelerated to relativistic energies (up to 2.1 GeV/per atomic mass unit).

With the new injection capability a national relativistic heavy ion program was launched. Nuclear Science, astrophysics, biomedical and even atomic physics experiments have been conducted with beams ranging from protons to iron. The biomedical program<sup>3</sup>, to single out one, has proceeded from early radiobiology with cells and animals, to a presently-on-going clinical large-field radiotherapy program with treatments delivered to up to twenty cancer patients per day.

As progress was made in heavy ion physics, it became apparent that acceleration of the heaviest mass ions would be highly desirable, possibly opening up new fields hinted at by the lighter ion results. As a result, a proposal to upgrade the Bevalac for uranium beam capability was submitted, and it received funding in 1980.

#### The Bevalac U-Beams Project

The extension of the ion mass to beams heavier than iron was limited by two factors, the availability of adequate intensities of the heavier beams, and the vacuum in the Bevatron accelerating ring.

Although SuperHILAC beams of ions up to xenon (maximum mass 136) were of adequate intensity for Bevalac use, heavier mass beams were much weaker and suffered from short ion-source lifetimes and poor reliability. The construction of a new pre-accelerator system specifically tailored to the heaviest ions was required.

The new injector system (named Abel, to go along with Adam and Eve, the two existing injectors) incorporates innovations in many areas of accelerator technology. The high intensity PIG ion source (Penning Ion Gauge) produces ions of all elements, a sputter electrode being employed for non gaseous

materials. Beam intensities as high as several particle-milliamperes of ions with charge-to-mass ratios ( $Q/A$ ) greater than 0.021 ( $U^{5+}$ ) are produced, and the ions are accelerated from the high voltage terminal of a 750-kV Cockroft-Walton power supply, to an energy of 15 keV/amu, the velocity required for injection into a new Wideroe pre-injector linac. A 90 degree bend following the high voltage terminal provides adequate resolving power to isolate any isotopic species, eliminating the need for separated isotope material in the ion source.

The Wideroe linac, modeled after a similar structure at GSI in Darmstadt<sup>4</sup> accelerates the beam to an energy of 112 keV/amu, the injection energy required for the first tank at the SuperHILAC. After the Wideroe, the beam passes through a fluorocarbon vapor stripper<sup>5</sup> which raises its charge state to meet the minimum requirements for the SuperHILAC ( $Q/A$  greater than 0.046,  $U^{11+}$ ).

The need for an improved vacuum in the Bevatron can be understood from atomic collision arguments. The capture and acceleration time of the beam in the Bevatron is of the order of one second, the total flight path thus approaches  $10^8$  meters. In this distance the probability of an interaction with a gas atom is very high--more than 1,000 interactions were occurring for each ion in the Bevatron's  $10^{-7}$  Torr vacuum.

The most damaging interactions involve the change of the charge state of an ion, i.e., the ion either picks up or loses an electron, its charge-to-mass ratio changes, and it rapidly falls out of synchronization with the accelerating fields and is lost. Note that the normal focusing forces in the accelerator are more than adequate to compensate for the small-angle scattering from other (non charge-changing) collisions with residual gas atoms.

Although quite complex in nature, the basic characteristics of electron pickup and loss interactions are fairly well understood<sup>6</sup>. Of greatest importance for our considerations is the velocity dependence of these processes. Electron loss collisions are generally explainable by Born approximation arguments and follow a  $\beta^{-2}$  dependence, while electron capture processes are much more dependent on ion-orbital velocity matching, and fall off very rapidly at high energies ( $\beta^{-6}$  or greater).

In actual Bevalac experience with fully stripped ions, substantial beam losses were observed in the first few milliseconds of acceleration, but thereafter no losses were apparent. Early attempts at accelerating partially stripped ( $\text{Ar}^{17+}$ ) ions<sup>7</sup> indicated less than 1% survival of the beam after 250 milliseconds, with an internal pressure of  $1 \times 10^{-7}$  Torr.

The inability to fully strip ions heavier than iron at the SuperHILAC energy meant that the pressure in the Bevatron would have to be reduced to the  $10^{-10}$  Torr range. To achieve this goal, a cryogenically pumped liner has been installed inside the quadrants of the original vacuum tank. The novel design of this liner, shown in Figure 2, is due to J. Meneghetti of our mechanical staff, and consists of nested boxes of printed-circuit boards. The innermost box of copper-clad Nema-G 10 is cooled by 12°K helium gas flowing through stainless tubes attached at the corners. The copper is etched with a striped pattern, the fingers pointing towards the center of the Bevatron, providing good heat conduction throughout the entire bore and eliminating the eddy-current problem one would have with a continuous metallic sheet. Many layers of super insulation (striped aluminized mylar blankets) separate the inner box from a second, similarly-patterned box cooled by liquid nitrogen.

More superinsulation isolates this box from a fiberglass case which provides support and protection for the liner. The original chamber is maintained under vacuum, thus eliminating atmospheric stresses on the new liner. The extensive use of organic materials appears quite surprising, however at 12°K the outgasing rate of these materials is not measureable. On the contrary, the total air pumping speed of the helium-cooled surfaces is many millions of liters per second. Pumping for hydrogen and helium is provided by activated charcoal panels on the vertical edges of the helium box, and by small auxiliary diffusion pumps in the straight sections of the Bevatron.

The four straight sections were handled differently, since injection, extraction, beam diagnostic and acceleration hardware are located in these areas. Only LN cooling is provided in these areas, but careful insulation and encapsulation of room-temperature components (water-cooled magnets) has kept heat loads within reason. The high-quality vacuum is ensured by preventing any room-temperature surface from having line-of-sight access to the inner Bevatron bore.

The installation and cool-down of the vacuum liner was completed on schedule in December 1981. The system has been under vacuum now for six months, and has performed flawlessly. The average pressure in the machine is about  $1 \times 10^{-10}$  Torr, and the total 12° K heat load is of the order of 150 watts, well within the limits of the installed refrigeration capacity.

The average pressure was determined by means of a beam-survival experiment. As part of an extensive program of charge pickup and loss cross-section measurements at the SuperHILAC<sup>8</sup> accurate values for these



cross sections were determined for carbon 4+ ions at 7.2 MeV/amu. To measure the vacuum, C<sup>4+</sup> ions were injected into the Bevatron and coasted at this energy for extended periods, while beam loss was being measured. From the previously measured cross sections, the average gas density seen by the ions was deduced.

### Commissioning Studies

During the first months of 1982 the renovated Bevalac has been brought back into full service. In this time new heavier beams have been accelerated at ever increasing intensities, while continuing nuclear science and radiotherapy programs have picked up where they left off after the July 1981 shutdown to install the liner. Table I summarizes the present experience with heavy beams at the Bevalac, and gives in addition the highest energy achievable for these beams in this accelerator. Intensities for all but the heaviest ions are within a factor of ten of the design goals, and have been quite adequate for the experiments which have been run to date.

During the program of developing heavier beams, new tuning procedures have had to be worked out. The use of stripping foils at various stages of acceleration has created a difficult tuning environment for the heaviest beams, because of the broad, essentially Gaussian distribution of charge states emerging from each foil. For example, uranium stripped at 8.5 MeV/amu will have a charge-state distribution with a FWHM of around 10 charge states, no one charge state having more than 12% of the total beam. Since each stage of acceleration is best matched by a single charge state (a well-defined charge-to-mass ratio), the presence of many charge states, often times not separable by our beam diagnostic instrumentation, leads to great difficulty in

achieving optimum tunes. The problem is greatest at the highest masses since more charge states are present, and they are more closely spaced in Q/A. To alleviate the problem a tracer tuning technique was developed.

A light, partially stripped ion is chosen which is very closely matched in Q/A to the heavy ion desired (generally to better than 0.2%). Since charge states for lighter ions are so widely separated in Q/A, it is straightforward to isolate the desired charge state, and tune it through the Transfer Line and Bevatron acceleration process. Because of Q/A matching, this tune will also serve for the heavier ion; all that is required is that the heavy ion beam position and velocity at the top of the Transfer Line be matched to those of the tracer.

In actual operation the technique has worked exceptionally well. For xenon beams ( $\text{Xe}^{7+}$  tracer), close to theoretical transmission through to the experimenter target is achieved with no adjustments of any Transfer Line or Bevatron parameters, and the final success with uranium was achieved by means of a tracer tune, after two unsuccessful attempts without it.

On the May 11 trial at accelerating uranium, a tracer of iron  $16+$  was selected for the  $\text{U}^{68+}$  ions expected from the stripper. Nitrogen  $4+$  ions could as well have been used, but an iron source was operating at the time, so was most convenient to use. While the Bevatron operators were tuning the  $\text{Fe}^{16+}$  ions from one injector down the Transfer Line and through the Bevatron, the SuperHILAC operators worked at peaking the Abel uranium beam. Upon completion of the tracer tune, the beam was switched from iron to uranium, while a crowded control room expectantly watched a scintillator signal from the external beam line at the Bevatron. As the energy matching

was done, by slowly varying the last SuperHILAC tank parameters, the scaler counts slowly grew from 10 per spill, on up through 100 to finally over 1000.

At this point beam characterization studies were performed, with the emulsion and CR39 exposures reported in the following papers<sup>9,10</sup> forming the final verification of the ionic species as uranium.

We are presently embarked on a program of improving intensities and reducing the tuning difficulty with the aim of routinely producing these heaviest beams. One further uranium experimental run is scheduled this summer, and it is anticipated that this fall will see extensive operation with lead, gold and uranium beams.

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

## References

1. H. A. Grunder, W. D. Hartsough, E. J. Lofgren, Science 174, 1128 (1971)
2. A. Ghiorso, H. Grunder, W. Hartsough, G. Lambertson, E. Lofgren, K. Lou, R. Main, R. Mobley, R. Morgado, W. Salsig, F. Selph, IEEE Trans. Nucl. Sci. NS-20, 155 (1973)
3. Biological and Medical Research with Accelerated Heavy Ions at the Bevalac, 1977-1980, M. C. Pirruccello and C. A. Tobias, Ed'S. LBL-11220, (1980).
4. K. Kaspar, 1976 Proton Linear Accel. Conf., Chalk River.
5. J. R. Alonso, B. T. Leemann, IEEE Trans. Nucl. Sci. NS-26, 3718 (1979)
6. H. D. Betz Rev. Mod. Phys. 44, 524 (1972)
7. J. Alonso, R. Force, M. Tekawa, H. Grunder, IEEE Trans. Nucl. Sci. NS-24, 1015 (1977)
8. J. Alonso, H. Gould, Phys. Rev. A 26 (Aug. 82)
9. H. H. Heckman, Y. J. Karant, E. M. Friedlander, Science, This Issue
10. S. P. Ahlen, G. Tarle, P. B. Price, Science, This Issue.

Table I: Intensities and Maximum Energies of High-mass Beams Accelerated to Date in the Upgrade Bevalac

| <u>Ion</u>               | <u>Observed Intensity</u><br>(Particles per pulse) | <u>Maximum Energy</u><br>(MeV/amu) |
|--------------------------|--|------------------------------------|
| $^{56}_{\text{Fe}} 24+$  | $1 \times 10^8$                                    | 1700                               |
| $^{93}_{\text{Nb}} 37+$  | $1 \times 10^7$                                    | 1550                               |
| $^{129}_{\text{Xe}} 45+$ | $2 \times 10^6$                                    | 1300                               |
| $^{238}_{\text{U}} 68+$  | $1 \times 10^3$                                    | 1000                               |

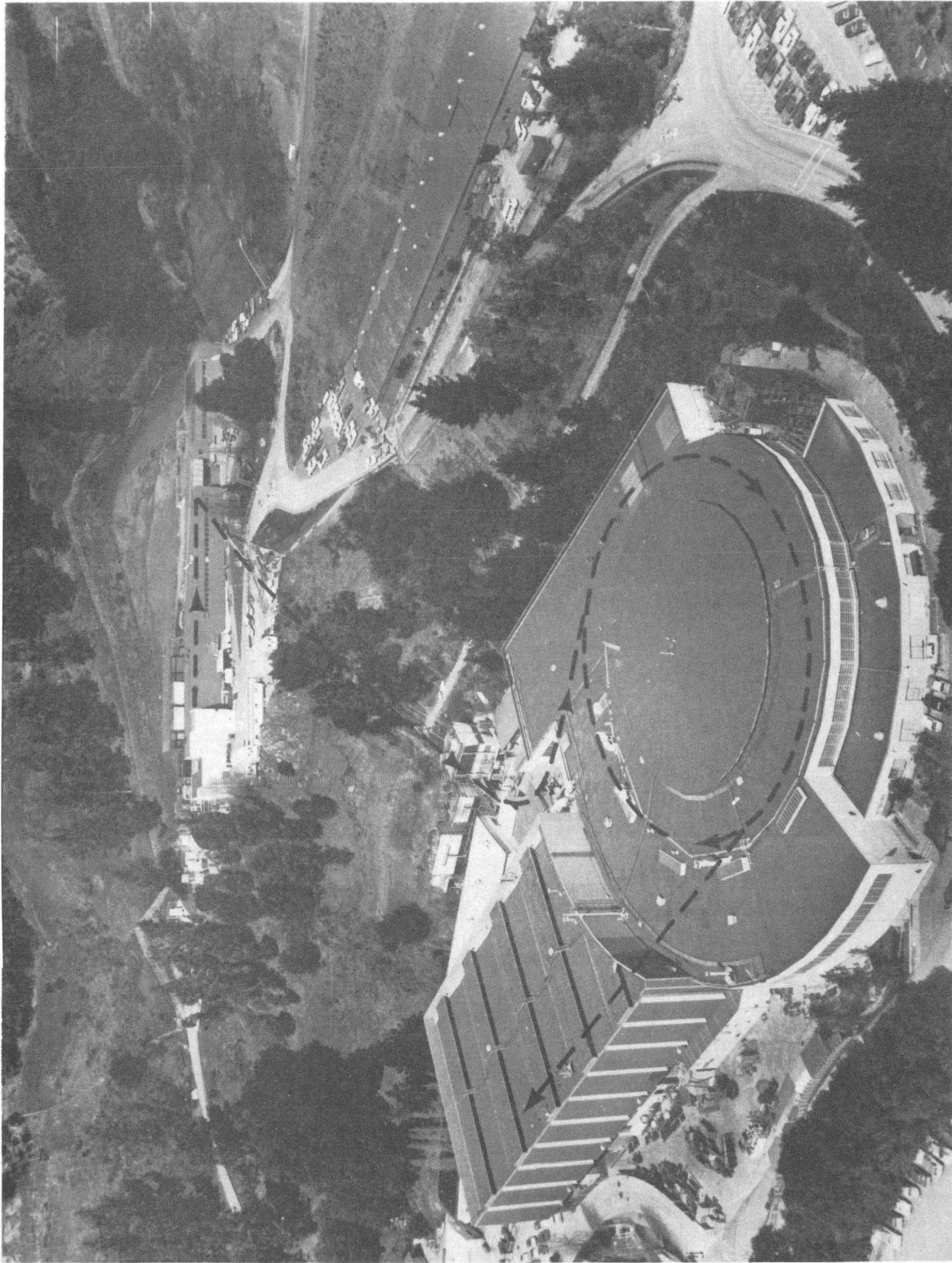


Figure 1. LBL's Bevalac--a combination of the SuperHILAC, an Alvarez-type linac, and the Bevatron (foreground), a synchrotron--was recently upgraded to accelerate ions as heavy as uranium to energies of 1,000 MeV/nucleon.

CBB 766-4673



CBB 817-6460

Figure 2. A model of the triple-walled vacuum liner (31 ft. x 4 ft.) that provides an ultrahigh vacuum in the curved portions of the Bevatron magnet pole gap.

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.



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