LBL-16125 c.2
UC-28

ANNUAL REPORT

RECEIVED
LAWRENCE
BERKELEY LABORATORY

OCT 19 1983

LIBRARY AND
DOCUMENTS SECTION

accelerator & fusion research division

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-16125 c.2

May 1983
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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.

ANNUAL REPORT

ACCELERATOR & FUSION RESEARCH DIVISION

Fiscal Year 1982

(October 1981 - September 1982)

Scientific Editor: R.K. Johnson
Production Editor: C. Bouret

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The support came from (1) the Director, Office of Energy Research, Office of High Energy and Nuclear Physics (Nuclear Physics Division and High Energy Physics Division), Office of Fusion Energy (Applied Plasma Physics Division, Development and Technology Division, and Planning and Projects Division), and Office of Health and Environmental Research (Nuclear Medicine Applications Division), (2) the Director, Office of Basic Energy Sciences (Advanced Energy Projects Division), and (3) the Assistant Secretary for Defense Programs, Office of Inertial Fusion (Laser Fusion Division).

FOREWORD

This report covers the activities of LBL's Accelerator and Fusion Research Division (AFRD) during 1982, a year that saw some major projects end successfully while others began with great promise.

In nuclear physics, the Uranium Beams Improvement Project was concluded early in the year, and experimentation to exploit the new capabilities began in earnest. Technical improvement of the Bevalac during the year centered on a heavy-ion radiofrequency quadrupole (RFQ) as part of the local injector upgrade. Looking toward the future of the field, we collaborated with the Nuclear Science Division in studies of high-energy heavy-ion collision facilities that may provide scientists with their first glimpse of a quark-gluon plasma. Theoretical work continues on defining the most productive energy range to explore and on developing an economical accelerator with the requisite performance.

In support of the nation's high-energy physics program, the Division continued its collaboration with Fermilab to design a beam-cooling system for the Tevatron I proton-antiprotron collider and to engineer the needed cooling components for the antiprotron source. On its way to developing a technology base and systems understanding for future ultrahigh-energy accelerators, the high-field magnet program set yet another record for field strength in an accelerator-type dipole magnet (9.2 T @ 1.8 K). Division scientists joined their colleagues at Snowmass (and later at Cornell) to discuss the long-range needs of the community.

The Division's experience in accelerator design and permanent-magnet wigglers and undulators was mobilized early in the year when a research team developed the design for the Advanced Light Source (ALS), a 1.3-GeV electron storage ring designed explicitly (with low beam emittance and 12 long straight sections) to generate high-brilliance synchrotron light from insertion devices. The ALS is part of the Laboratory's proposed National Center for Advanced Materials (NCAM).

The Division's Magnetic Fusion Energy group continued to support major experiments at the Princeton Plasma Physics Laboratory, the Lawrence Livermore National Laboratory (LLNL), and General Atomic Co. by developing positive-ion-based neutral-beam injectors. Progress was made toward converting our major source-test facility into a long-pulse national facility, the Neutral Beam Engineering Test Facility, which was completed on schedule and within budget in 1983. LBL is the leading laboratory for the development of negative-ion-based neutral-beam injection systems, which operate efficiently at the high energies proposed for future experiments. Also looking ahead, we collaborated with LLNL in developing a free-electron laser to be tested on the ETA. Such a laser could provide an alternative source of power for electron-cyclotron resonance heating.

Heavy Ion Fusion research focused on planning, theoretical studies, and beam-transport experiments leading toward a High Temperature Experiment—a major test of this promising backup approach to fusion energy.

Other research activities included the completion of a small project to investigate electron-beam ion sources, and the design, jointly with the Biology and Medicine Division, of a dedicated biomedical accelerator.

Both in improving existing accelerators for the benefit of research today and in laying the technological base that will make possible tomorrow's scientific breakthroughs, the Division strives for excellence. With the continued support of our user groups and the strong backing of the DOE, we are confident that this excellence can continue to benefit the nation's science effort.

Hermann Grunder

ACCELERATOR & FUSION RESEARCH DIVISION STAFF

Hermann A. Grunder, Division Head

Klaus H. Berkner, Deputy Division Head

Staff Senior Scientists
William S. Cooper, III
Warren W. Chupp
Bruce B. Cork
Kenneth W. Ehlers
Tom Elioff
Alper A. Garren
William S. Gilbert
*Allan N. Kaufman**
Denis Keefe
Hogil Kim
*Wulf B. Kunkel**
Glen R. Lambertson
Lawrence J. Laslett
Morton A. Levine
Edward J. Lofgren (emeritus)
Robert M. Main
*Edward Morse**
Jack M. Peterson
*Robert V. Pyle**
*Lawrence Ruby**
Frank B. Selph
Andrew M. Sessler
Lloyd Smith
Clyde E. Taylor

**UCB Faculty*

Staff Scientists
Jose R. Alonso
Oscar Anderson
Joseph J. Bisognano
Ian G. Brown
Charles R. Burrell
Chun-Fai Chan
William Chu
Kenneth C. Crebbin
Tommy L. Criswell
Benedict Feinberg
Robert J. Force
Basil F. Gavin
David Goldberg
Richard A. Gough
James R. Guggemos
William V. Hassenzahl
Kendrick J. Hebert
Robert K. Johnson
Juris G. Kalnins
Charles H. Kim
Kwang J. Kim
Edward Lee
Beat T. Leemann
Christoph W. Leemann
Ka-Ngo Leung
Alan F. Lietzke
Fred H. Lothrop
Darlene Markevich
Richard J. McDonald
Philip A. Pincosy
Joseph B. Rechen
Eliezer Rosengaus
Ronald Ruth
Richard C. Sah
Hans Sann
Alfred S. Schlachter
Joseph H. Shiloh
Richard Smith
John W. Staples
John W. Stearns
William F. Steele
Christoph A. Timossi
Michael C. Vella
Alexander Wekhof
Emery Zajec
Michael Zisman

Visiting Postdoctoral Research Assistants
Ryiochi Wada
Tai-Sen Wang

Graduate Student Research Assistants
Norman Abt
Young Bae
Swapan Chattopadhyay
Gary Guethlein
Kouichi Jimbo
Jin Soo Kim
Geoffrey Krafft
Michael Lampel
Steven McDonald
Stephen Omohandru
Richard Spencer
Kenneth Stalder
Michael Tiefenback
John Trow
Motori Wada
Jonathan Wurtele

Supervisors
Robert S. Everett
Leal L. Kanstein
Robert R. Stevenson

Operators
Richard L. Anderson
Douglas A. Bentsen
George S. Boyle
Robert W. Brokloff
Gary M. Byer
Warren Byrne
Norris D. Cash, Jr.
Robert C. Coates
Donald N. Cowles
Thomas Gimpel
Aran P. Guy
Chester W. Hatch, Jr.
Cheryl Hauck
Rudin M. Johnson
Orland J. Jones
James L. MacMullen
Dexter J. Massoletti
Robert M. Miller
William S. Mirer
Stewart W. Pugh
Catherine R. Siero
Joseph F. Smith
Harvey K. Syversrud
John E. Tommaney
Malcom Williams
Michael D. Wolfe
Billy O. Yant
Frederick W. Yeater

Technical Support
Robert V. Aita
Ronald Barr
James P. Brannigan
Royce Calloway

AFRD STAFF

Elmer F. DeMartile
Hugh M. Ellison
Charles Gibson
George R. Gray
Ross G. Nemetz
Jack M. Palmatier
Emery Parker
Darrell D. Pohl
Robert E. Purvis
Robert M. Richter
John W. Roberts
Donald W. Schmeyer
Leo J. Skvarla, Jr.
Edward W. Stuart
Marsh M. Tekawa
Raymond K. Thatcher
Glenn E. White
Oliver S. Wiggins, Jr.

Administrative Support
Augustine Aitkens
Kenneth E. Bregger
Martha H. Duenas
Gloria Dunn
Linda Egeberg
Ann G. Fitzgerald
Lillian B. Hill
Linda Hines
Joy N. Kono
Aletha Lundblad
Laurie Sampietro
Betty Strausbaugh
Heather A. Thomson
Alline Williams
Katherine E. Williams
Olivia S. Wong
Judy A. Zelver

CONTENTS

	Page
ACCELERATOR OPERATIONS	1
INTRODUCTION	3
OUTSIDE USER SUPPORT	4
1982 OPERATIONS	6
MACHINE RESEARCH AND DEVELOPMENT	10
ACCELERATOR IMPROVEMENTS	12
184-INCH SYNCHROCYCLOTRON	15
HIGH ENERGY PHYSICS	19
HIGH FIELD MAGNETS	21
STOCHASTIC BEAM COOLING	23
Cooling System Theory and Design	25
Development of Electrodes	25
Electronics Design	26
HIGH ENERGY HADRON COLLIDERS	26
MAGNETIC FUSION ENERGY	29
NEUTRAL BEAM DEVELOPMENT	32
Positive-Ion Beam Research and Development	32
Negative-Ion Beam Research and Development	34
Test Stand Fabrication/Operation	38
BASIC RESEARCH AND THEORY	39
Neutral Beam Plasma Research	39
Neutral Beam Atomic Physics Studies	41
Basic Plasma Theory	41
ELECTRON LASER FACILITY (ELF)	41

HEAVY ION FUSION 43
SINGLE BEAM TRANSPORT EXPERIMENT 46
DIAGNOSTICS 46
Electron Beam Probe 46
Scintillation Imaging 46
Long-Pulse Induction Accelerating Unit 48
THEORY 48
Longitudinal Stability 48
Transport and Focusing 50

NATIONAL CENTER FOR ADVANCED MATERIALS 51
INTRODUCTION 53
ADVANCED LIGHT SOURCE 54
ALS Lattice 58
Injection System 63
INSERTION DEVICES 63
PHOTON BEAM LINES 65

ADVANCED ACCELERATOR PROJECTS 69
MEDICAL ACCELERATOR 71
TEVALAC 74
ELECTRON BEAM ION SOURCE 75

PUBLICATIONS 79

ACCELERATOR OPERATIONS

BEVALAC COMPLEX OPERATIONS

J. Alonso (op. manager)
R. Stevenson (machine op. dep.)
M. Zisman (exp. prog. op. dep.)
F. Selph (accel. R&D leader)
R. Reimers (ME project engr.)
R.M. Miller (mech. tech. leader)
S. Abbott
R.V. Aita
D. Anderson
R.L. Anderson
J. Barale
J. Barley
R. Barr
P. Batson
G. Behrsing
R. Benjegerdes
D.A. Bentsen
F. Bieser
G.S. Boyle
J.P. Brannigan
D. Brodzik
R.W. Brokloff
G.M. Byer
T. Byrnes
G. Carmignani
N.D. Cash
H. Crawford
R. Caylor
R. Coates
D.N. Cowles
K.C. Crebbin
T.L. Criswell
A. Dancosse
E.F. DeMartile
R. Edwards
H.M. Ellison
D. Embree
R.S. Everett
M. Fahmie
W. Faust
V. Fletcher
R. Frias
J. Fugitt
B.F. Gavin
G.R. Gray
J.R. Guggemos
A.P. Guy
C.W. Hatch, Jr.
J. Henderson
T. Henderson
J. Hinkson
D. Howard
R. Jeffre
R.M. Johnson
J.B. Johnston
O.J. Jones
J.G. Kalnins
S. Knoll
J. Krupnick
J. Lax
B.T. Leemann
A. Loop
R. Lorber
F.H. Lothrop
R. MacGill
S. Magyary
W.S. Mirer
H. Oakley
J.M. Palamatier
E. Parker
E. Pauletich
H. Pines
D.D. Pohl
J. Porter
R.E. Purvis
K. Ransdell
J. Redding
R.M. Richter
A. Ritchie
D. Rothfuss
H. Sann
D.W. Schmeyer
L. Skvarla
J.F. Smith
J.W. Staples
G. Stover
E.W. Stuart
H.K. Syversrud
J. Tanabe
M.M. Tekawa
R.K. Thatcher
C.A. Timossi
R. Wada
J. Waddell
G.E. White
O. Wiggins
M.D. Wolfe
G. Yuen
E. Zajec

Administrative Support

G. Dunn
L. Hill
L. Hines
H. Thomson
K. Williams

184-INCH SYNCHROCYCLOTRON

L. Kanstein (in charge)
G. Hampton
J. MacMullen
F. Yeater

LOCAL INJECTOR UPGRADE

R. Gough (project leader)
S. Abbott
D. Bowman
D. Brodzik
R. Caylor
R. Demarco
R. Dwinell
J. Guggemos
J. Halliwell
D. Howard
M. Hui
N. Kellogg
J. Krupnick
J. Lax
R. MacGill
B. Mehlman
J. Mellbourne
M. Morrisson
R. Richter
S. Rovanpera
*H. Schneider**
D. Schumann
C. Sealy
J. Staples
G. Stover
J. Tanabe
G. Waddell
E. Zajec

**On sabbatical leave from Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada.*

ACCELERATOR OPERATIONS

INTRODUCTION

The Accelerator and Fusion Research Division operates the Bevalac Complex as a national research facility for studies in high-energy, heavy-ion physics, nuclear physics, nuclear chemistry, biomedicine, biophysics, and astrophysics. The Bevalac is unique in the opportunity it provides for the study of collisions between nuclei at energies high enough to convert nuclear matter into hadronic matter in which protons, neutrons, their excited states (e.g., delta resonances) and free pions all coexist. One third of its time is devoted to biomedical research, including a trial program of cancer therapy. At low energy, the SuperHILAC has been the U.S. vanguard of discovery of new heavy elements in strong competition with a Soviet effort at JINR, Dubna, and, more recently, a West German effort at GSI, Darmstadt. This portion of the Bevalac Complex is maintaining its primacy among U.S. installations for the delivery of ions with $A > 100$ to elucidate many of the global features of the fusion, deeply inelastic (damped), and fission reactions that typify nuclear phenomena in this energy range.

The SuperHILAC, an Alvarez-type linear accelerator, provides heavy-ion beams of lithium through uranium at energies from below 1 to 8.5 MeV per nucleon. Its three injectors can supply three different ion species to five different beam lines on a timesharing basis; that is, the beam is pulsed 36 times each second, and these pulses may be apportioned in any desired ratio between three different ion beams and any number of different energies. Normal operation involves the use of 32 pulses/second of a heavy-ion beam by the principal research group at the SuperHILAC, the sending of 2 pulses/second of a second ion beam to the Bevatron for further acceleration to relativistic velocities (this combined operation is called the Bevalac), and the use of 2 pulses/second of either beam—at a different energy if desired—for a parasitic experiment at the SuperHILAC. The SuperHILAC has 11 experimental areas.

The Bevatron is a weak-focusing positive-ion synchrotron that can accelerate heavy ions from either the SuperHILAC or a local injector to any energy between 40 MeV and 2 GeV per nucleon. The delivery rate is 10 to 15 pulses per minute, dependent on the operating mode. Beam sharing at the Bevatron is accomplished by dividing a specific ion beam at a given energy between two major branches of the beam delivery system on a particular Bevatron pulse, or by diverting the beam on a pulse-to-pulse basis from one target area to another.

Continual effort is given to improving the accelerator complex, both in machine operation and experimental facilities, so that it remains at the forefront of scientific investigation.

OUTSIDE USER SUPPORT

The focus of outside user support for the Bevalac Complex is the Accelerator Research Coordination (ARC) Office. Additional technical support is often required by outside experimenters to increase their research productivity. Ultimately, the entire Accelerator Operations Group is dedicated to serving the needs of Bevalac-Complex researchers, but a core of individual technicians, computer specialists, and scientists have the primary responsibility for such assistance. Duties of these support personnel include designing or modifying beam lines to achieve specific performance characteristics, designing and interfacing data acquisition systems, and installing and maintaining sophisticated research equipment.

For Bevalac users, the primary staff for nuclear physics research support consists of H. Crawford, F. Bieser, and R. Wada (scientific, beam lines), J. Porter (engineering, cryogenics), and H. Pugh (Scientific Director). The Bevalac biomedical community is assisted by W. Chu (physics, beam lines), T. Criswell (radiotherapy, computers, instrumentation), J. Howard (radiobiology), and E. J. Ainsworth (Scientific Director). At the SuperHILAC, principal staff contacts for user support are R. McDonald (physics, beam lines), C. Maples (data acquisition), E. Potter (supplies, coordination), W. Elwood (technician), and R. Diamond (Scientific Director).

During this period, two new facilities were created for guest experimenters. Badly needed staging areas were set up adjacent to the Bevalac to facilitate setup work by outside users. In addition, some effort has been made to address the problem of on-site user housing. Although space at LBL remains limited, we are just finishing the implementation of a 4-bed temporary user housing trailer near the experimental areas. In addition, support has been provided for the HISS facility in terms of engineering help for the cryogenic system associated with the superconducting dipole.

Long-range scheduling is performed by an ARC Office staff committee, which periodically sends notices to all users. The immediate operating program is arranged in weekly scheduling meetings; every effort is made to accommodate users' preferred running schedules.

The Bevatron/Bevalac and SuperHILAC Users Associations communicate user concerns to the accelerator operations staff. These groups also hold annual meetings to share research results and discuss future directions. The governing body (Executive Committee) of each group is given in Table 1.

Proposals for research time are reviewed twice a year by Program Advisory Committees (PAC's). Members are generally chosen from among experts in heavy-ion research who may be involved in LBL experiments but are not major facility users. There is one PAC for the SuperHILAC (Table 2) and one each for the nuclear science and the biology and medicine programs at the Bevatron/Bevalac (Table 3). These expert panels recommend the allocation of research hours to the LBL Director, and, as a rule, their recommendations are implemented.

LBL's Nuclear Science Division appoints a Scientific Director for each accelerator to provide leadership for the nuclear science research on the floor and to coordinate long-term improvements. Howel Pugh now holds this post at the Bevalac, as does Richard Diamond at the SuperHILAC. In addition, the Biology and Medicine Division appoints a Scientific Director (presently E. John Ainsworth) for its accelerator-based research. The Scientific Directors may allocate 10% of the research hours on a discretionary basis.

Table 1. Membership in the Users Association Executive Committees.

SuperHILAC	Bevatron/Bevalac
M. Blann, LLNL	S. Curtis, LBL, Chairman
D. Cline, U. of Rochester	R. Poe, U.C. Riverside
R. Diamond, LBL	J. Slater, Loma Linda U.
R. McDonald, LBL	K. Wolf, Argonne National Lab.
A. Mignerey, U. of Maryland	
	E. Ainsworth, LBL (ex officio)
J. Cerny, LBL (ex officio)	J. Cerny, LBL (ex officio)
H. Grunder, LBL (ex officio)	H. Grunder, LBL (ex officio)
	H. Pugh, LBL (ex officio)

Table 2. Program Advisory Committee for the SuperHILAC.

D. Fossan (Chairman) State U. of NY, Stony Brook	J. Randrup, LBL
S. Datz, Oak Ridge Nat'l Lab.	M. Zisman, LBL (exec. secretary)
C. Gelbke, Michigan State U.	J. Cerny, LBL (ex officio)
J. Hardy, Chalk River Nuclear Lab.	H. Grunder, LBL (ex officio)

Table 3. Program Advisory Committees for the Bevalac

Nuclear Science	Biomedical
H. Feshbach, M.I.T. (Chairman)	M. Bagshaw, Stanford Med. Ctr.
R. Klapisch, CERN	R. Durand, Johns Hopkins Oncology Center
D. Scott, Michigan State U.	R. Fry, ORNL
P. Siemens, Texas A&M U.	W. Schimmerling, LBL
E. Vogt, U. of British Columbia	P. Todd, Penn. State U.
W. Wenzel, LBL	E. Ainsworth, LBL (exec. secretary)
T. Yamazaki, U. of Tokyo	
H. Pugh, LBL (ex officio)	E. Alpen, LBL (ex officio)
	H. Grunder, LBL (ex officio)

1982 OPERATIONS

Final touches were made early in 1982 to the High Intensity Uranium Beams Project, an improvement program in which a low-temperature high-vacuum pumping shell was inserted into the Bevatron, and a high-intensity, low-charge-state injector (ABEL) was added to the SuperHILAC. (See the previous annual report, LBL-14230, for a description of these improvements.) These facilities were brought on line in March for the research program, and in September of 1982 a full-energy (960 MeV/N) uranium beam was delivered to an emulsion experiment at the exit of the Bevalac (Figure 1).

Operations for FY 1982 were limited to five and a half months, but during that time major tests of heavy-ion acceleration were done, and the repertoire of relativistic ions delivered was expanded to include ^{84}Kr, ^{93}Nb, ^{129}Xe, ^{139}La, ^{197}Au, and ^{238}U. Table 4 details all the delivered ions and their intensities. For the most part, experimenters made use of carbon and neon, with protons and silicon also getting a substantial percentage of attention. Iron is becoming a popular ion, especially for the cosmic ray physicists and NASA-associated experimenters.

Beam time at the Bevalac is still divided approximately two thirds for the nuclear science program and one third for the radiotherapy and biology program (Table 5). Radiotherapy trials continued during 1982 using neon as the primary ion of choice, with some initial exploration into silicon treatments. Biology efforts this year were directed toward investigations of the effects of several ions: neon, silicon, argon and iron.

At the Bevalac the rewards of the recent uranium upgrade were almost immediately evident. Some programs that have been waiting years for heavy ions, those above iron in atomic mass, could now be scheduled for operation on the improved Bevalac. Budgetary constraints limited Bevatron operation to half of the maximum guide field strength, or about half the maximum achievable energy of a heavy-ion beam. Even with this rather severe restriction, time was well subscribed, the Bevalac program was full, and interesting science was produced. Nuclear science operation in 1982 at the SuperHILAC also benefited from the fact that the third injector (ABEL) was in operation and provided higher intensity heavy-ion

Table 4. Ion species and intensities delivered to Bevalac experimenters during FY 1982.

Ion	Intensity[a]	Ion	Intensity[a]
Hydrogen-1	2×10^9	Calcium-40	4×10^7
Helium-4	5×10^8	Iron-56	3×10^7
Carbon-12	2×10^9	Krypton-84	1.5×10^6
Neon-20	5×10^9	Niobium-93	1.5×10^6
Silicon-28	1×10^9	Xenon-129	1.5×10^6
Argon-40	5×10^8	Uranium-238	2×10^4

[a]Particles per pulse in the external beam channel.

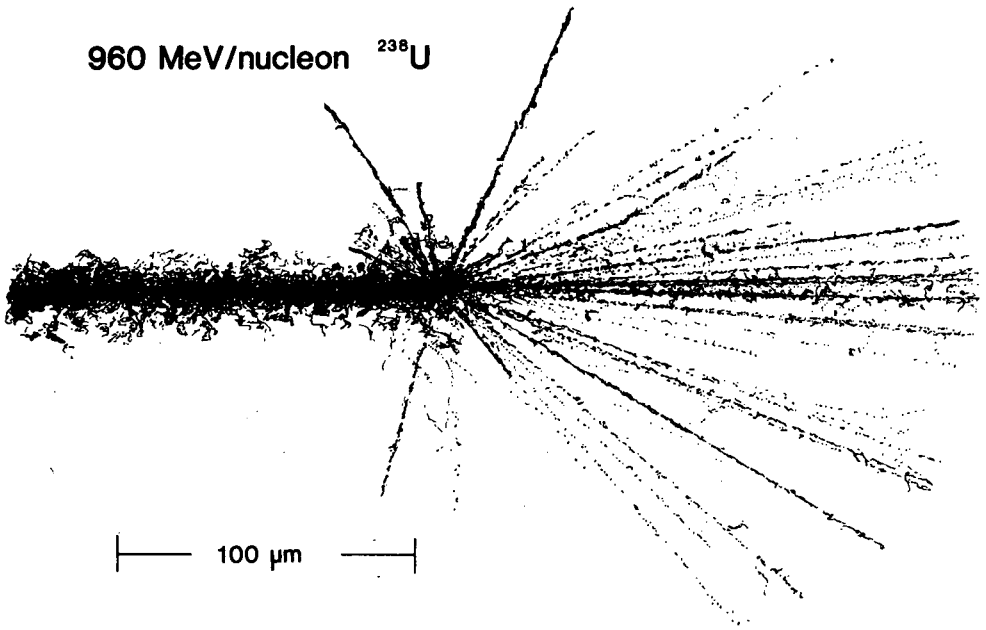


Figure 1. Microprojection drawing of 960 MeV/N ^{238}U in nuclear research emulsion. Seen entering from the left, the uranium beam nucleus interacts with a target nucleus, e.g., Ag or Br, of the emulsion. The nuclear collision results in virtually complete disintegration of the uranium nucleus, whose (light) fragments are emitted in the forward cone. The dark tracks at larger angles are remnants of the target nucleus. (XBL 829-11834)

beams than had been produced ever before for the low-energy heavy-ion program. Also in support of the low-energy experimental program, 2 grams of ^{48}Ca material have been loaned to GSI, Darmstadt as part of the joint LBL/GSI program to search for superheavy elements.

In the Bevalac experimental area, a long-term project, the Heavy Ion Spectrometer System (HISS), was brought into operation. This facility consists of a large dipole magnet having a cryogenically cooled set of superconducting coils and several sets of large-scale particle detectors (Figure 2). The active magnetic volume of the dipole, which is approximately 2 m in diameter by 1 m high, is designed for a field of about 3 T. Measured fields by the end of 1982 were about 2 T. Most of the magnetic volume is bounded by a vacuum chamber for which thin plastic windows were developed.

Experiments performed so far in the HISS spectrometer include carbon fragmentation by Greiner *et al.* of LBL, and correlation studies by Nagamiya *et al.* of INS, Japan. Elsewhere on the experimental floor, the LBL-GSI collaboration performed a Nb + Nb excitation function experiment using the Plastic Ball detector; it was the earliest of the new series of heavy-ion experiments made possible by the uranium improvement project.

Table 5. Summary of Bevalac Complex operations during FY 1982.

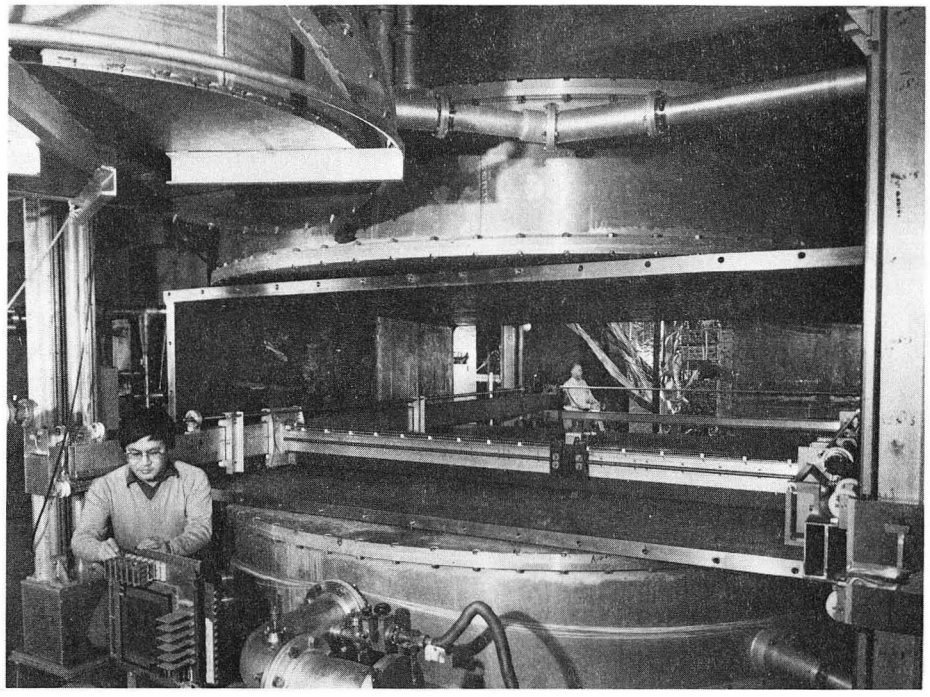
Machine Operation (hours)	
Research	1886
Tuning	930
Machine Studies	199
Unscheduled Maintenance	521
Scheduled Shutdowns	5224
Total	**8760**

Experiment Summary And Projections

	FY 1982	FY 1983	FY 1984	FY 1985
Beam Utilization for Research (hours)				
Nuclear Science	1220	1970	2880	3200
Biology and Medicine	666	980	1440	1600
Subtotal	1886	2950[a]	4320[b]	4800[b]
SuperHILAC	2151	2000	2000	2000
Total	**4037**	**4950**	**6320**	**6800**
Number of Bevalac nuclear science and SuperHILAC experiments receiving beam	**44**	**48**	**54**	**58**
Number of participating scientists	**156**	**175**	**185**	**195**
Institutions represented				
Universities	20	20	20	22
DOE National Laboratories	4	4	4	4
Other	9	10	11	12
Total	**33**	**34**	**35**	**38**
Percentage of Beam Time				
In-house staff	50.5	50	50	50
Universities	39.1	35	35	35
DOE National Laboratories	0.4	5	5	5
Other Institutions	10.0	10	10	10

[a]Multiplicity for FY 1983 estimated to be 1.13.

[b]Multiplicity for FY 1984 and FY 1985 estimated to be 1.2.



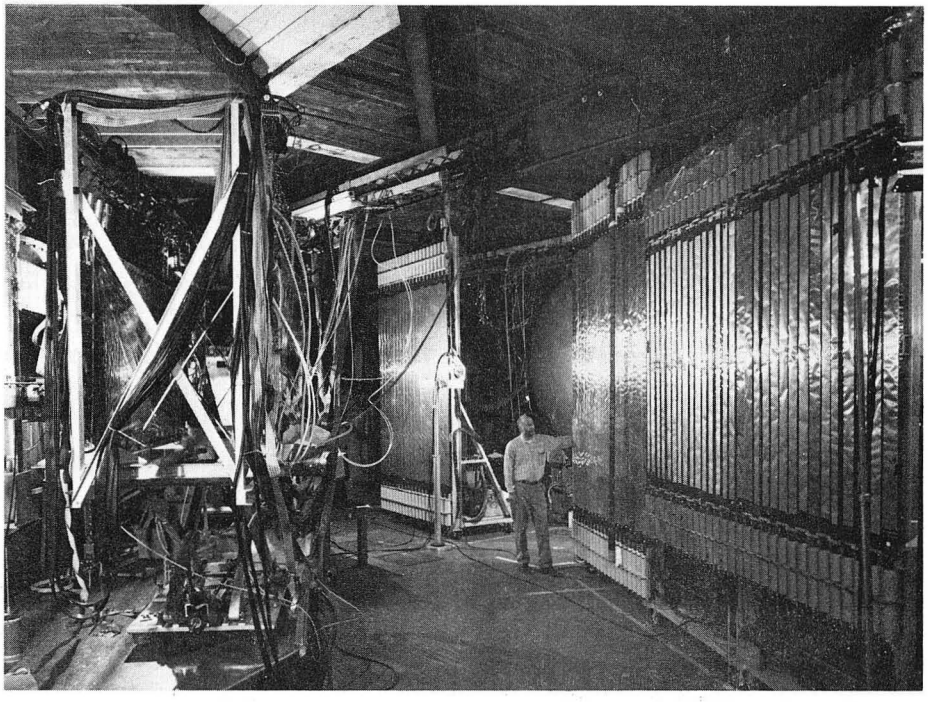


Figure 2. Two views of the Heavy Ion Spectrometer System (HISS) at the Bevalac. Top: A view looking downstream through the dipole magnet gap. Bottom: A view of the downstream detector area, showing the large-area scintillation hodoscopes. (Top: CBB 820-10981; Bottom: CBB 820-10979)

MACHINE RESEARCH AND DEVELOPMENT

With completion of the uranium beams project early in 1982, subsequent work has been aimed at performance improvements. Measurements were made of beam quality in the ABEL pre-injector system. Performance of the ion source for the heaviest ions was found to be satisfactory – typically an intensity greater than 1 pmA was obtained. Some transmission losses were found in the 750-keV column, resulting in intensities of 0.6 pmA of U in the transport line to the Wideröe. Beam emittance was found to be 0.5 π mm-mrad (normalized), which is within the acceptance of the transport line. Studies of beam transmission in the ABEL injector line pointed out problems with the beam optics. These have now been corrected (February, 1983) by relocating the Fomblin vapor stripper and providing additional quadrupole focusing between the Wideröe exit and the vapor stripper.

An increase in uranium beam delivered by the Bevalac from 2×10^4 to 1×10^6 ions per pulse resulted from these modifications. Moreover, the intensity increase in many cases should be sufficient to eliminate the need for a "tracer beam" tuning technique, which involves the use of a lighter ion beam (having higher intensity and fewer, well-separated charge states) whose charge state is chosen to give the same charge-to-mass ratio as the heavier beam. (An example is the use of $^{56}Fe^{16+}$ as a tracer for $^{238}U^{68+}$.) The disadvantages of the tracer technique are that it ties up two injectors at the SuperHILAC and that it is time-consuming to have to tune up the SuperHILAC to precisely match the velocities of the two beams. In the future, we anticipate more rapid and more reliable tuning of heavy beams to the Bevalac.

Work continued on development of a liquid-film stripper. The test box was modified for installation in a beam line where tests can be made using ion beams from the SuperHILAC.

To aid with tuning heavy Bevalac beams and provide data needed to optimally design future heavy-ion accelerators such as the Tevalac, we have measured the charge fractions of uranium ions at energies of 962 MeV/N and 430 MeV/N passing through various thickness targets of mylar ($Z \approx 6.6$), Cu ($Z=29$) and Ta ($Z=73$). From these we have determined the equilibrium charge-state distributions for uranium at these energies.

Uranium 68+ ions were transported in vacuum through a windowless beam line and passed through targets located upstream of the Zero Degree Spectrometer. Charge states produced by collisions in the target were spatially separated in the spectrometer and could therefore be detected by a position-sensitive ionization chamber located approximately 10 m downstream.

The observed equilibrium charge-state distributions are shown in Figure 3. Note that at 962 MeV/N the average charge state of the uranium ions increases monotonically with target Z. However, at 430 MeV/N the average charge state first rises and then falls with increasing target Z. The qualitative behavior of the charge-state distributions can be understood in terms of the different energy and target-Z dependence of the ionization cross section and the charge exchange, and radiative electron capture cross sections.

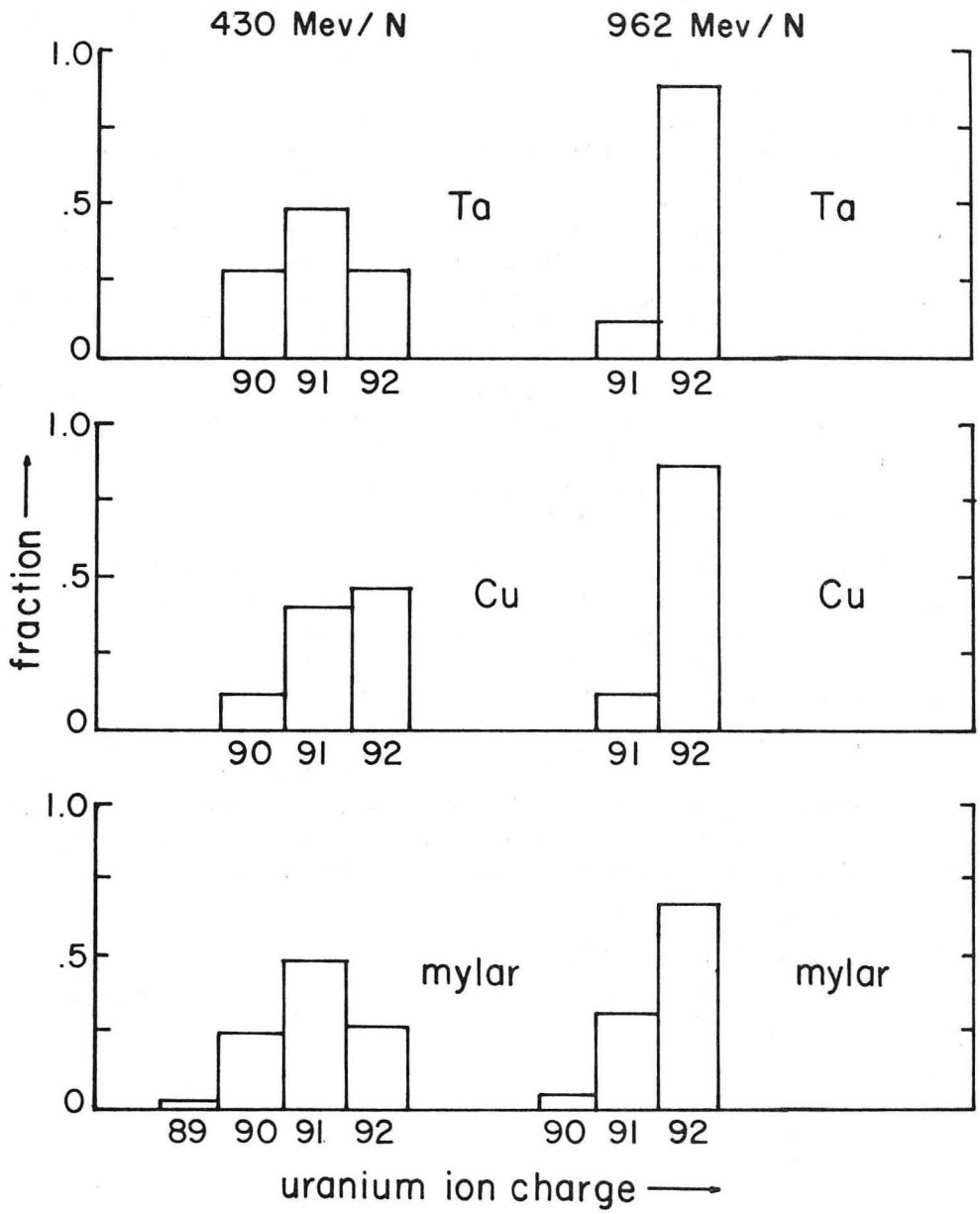


Figure 3. Equilibrium charge state distributions of 430 MeV/N and 962 MeV/N uranium from mylar ($Z \approx 6.6$), copper ($Z = 29$) and tantalum ($Z = 73$) targets.
(XBL 829-11834)

ACCELERATOR IMPROVEMENTS

Completion of the Bevatron local injector upgrade project, which progressed rapidly during the year, will make available a source of ions as heavy as silicon (or argon at reduced intensity) that is independent of the SuperHILAC. The programmatic goal of this effort is to enhance the efficiency of overall Bevalac operations by providing an independent injector for biomedical use. More efficient switching will then be possible between the lighter ions used for biomedical work and the heavier ions from the SuperHILAC needed for the nuclear science experimental program. This will translate directly into an increased number of beam-on-target hours for nuclear science.

The design of the upgraded injector is based on radiofrequency quadrupole (RFQ) linac technology, which has been adapted by LBL staff to the acceleration of heavy ions. In 1982 the engineering design of a working heavy-ion RFQ was completed, and a full-scale structure was built as described below. Several technical innovations (for which patents have been awarded) have been incorporated into the LBL RFQ design. Advanced mechanical design concepts were developed to permit the extremely precise alignment and verification of pole tip geometry required for optimized heavy-ion RFQ linacs. A field-stabilization technique, pioneered in a parallel R&D effort, has also been incorporated into the design. Finally, techniques for matching beam dynamics and RF parameters between the RFQ and the linac that it injects have been developed and implemented.

The configuration of the local injector before and after the upgrade is depicted schematically in Figure 4. The main elements of the project are a duoplasmatron and a PIG ion source, a two meter length of ion optics for mass analysis and matching, the heavy-ion RFQ, a new 2-$\beta\lambda$ Alvarez linac (Table 6), a new stripper assembly, and a control system to permit rapid switching of the injector between the two ion sources.

The heavy-ion RFQ linac is designed to accelerate ions with charge-to-mass ratios as low as 0.14 from an energy of 8.4 to 200 keV/N with high capture efficiency and high overall transmission. The design parameters of the RFQ are summarized in Table 7. Beam dynamics calculations, which provide the specifications for the complex pole tip geometry, and the numerically controlled machining of these pole tips were done at LBL.

Table 6. Parameters of the new Alvarez linac.

Design frequency, MHz	199.3
Injection energy, keV/N	200
Output energy, keV/N	817
q/A	0.143
Mode	2 $\beta\lambda$
Stable phase	-30 degrees
Focusing sequence	+ + − −
Average axial field, MV/m	2.25-2.63
Number of drift tubes	37 plus 2 half drift tubes
Overall length, m	3.54

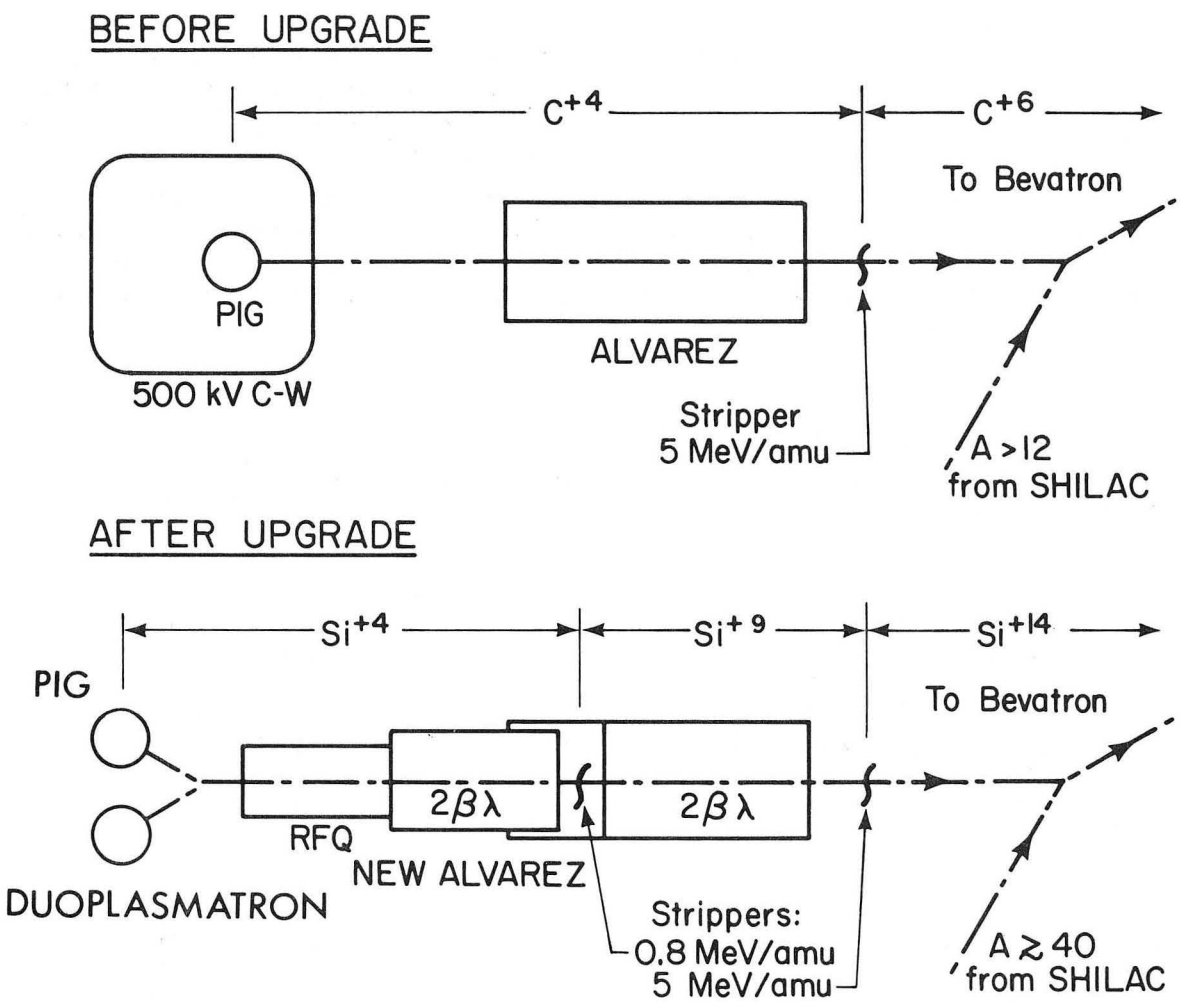


Figure 4. Configuration of the Bevatron local injector before and after upgrade.
(XBL 8211-1308)

Much of the year's activities centered on translating these specifications into a working device. The rough cut of the vane modulations removed nominally 0.7 mm from the vane blank at cuts spaced longitudinally by 1 mm. The final machining operation, removing an additional 0.25 mm every 0.5 mm longitudinally, was done by passing the tool over the work always in one direction to prevent machine hysteresis and to remove position error in the feedback system due to finite velocity of the machine bed. The finish cut on each 225-cm vane tip required a total of 30 hr of machining time, including initial setup and tool changes. Once started, the machining continued nonstop until the vane was completed. The data for each pair of vanes are contained on 25 500-ft reels of punched mylar tape, or about 1.5 million characters of information. There were no errors detected in the large amount of data transferred.

The vane tip machining was completed in October 1982, and a surface roughness of approximately 1.6 μm was achieved. The cavity and vanes were copper plated to a thickness of 50 μm using an acid process except in the area of the vane tips. There, the 5 μm cyanide copper strike, which underlies the 50-μm plate, was the only finish given to the surface.

Figure 5 shows a typical cross section of the RFQ. Each vane is mounted using six cylindrical plugs equally spaced along the length of the cavity. These plugs fit into bored holes in the base of the vanes and are aligned against precision ground flats on the outside of the cavity. This design provides for axial, radial and transverse degrees of freedom for precise

Table 7. RFQ design parameters.

Structure	4 vane loop driven
Design ion	$^{28}Si^{+4}$
Frequency, MHz	199.3
Vane length, cm	224.86
Average bore radius, cm	0.254
Cavity radius, cm	15.583
Input energy, keV/N	8.4
Output energy, keV/N	200
Total number of cells	346
Radial matcher	6.4 cm (20 cells)
Exit matcher	54 cm (45 cells)
Normalized acceptance, π cm-mrad	0.05
Transmission	90%
Rf power, kW peak	180
Stored energy, J	0.6
Duty factor	0.002
Vane-vane voltage, kV	51
Maximum surface field, MV/m	27

vane alignment. Fiducial notches are located on each side of the vanes to facilitate accurate positioning of the vane tips. A numerically controlled mill was used to machine these fiducials during the same setup used to produce the modulated surface on the vane tips. Bars are mounted at the base of each vane for coarse frequency tuning. Provision has been made to install as many as five sets of vane coupling rings along the length of the RFQ. These aid in field stabilization of the structure and in suppressing unwanted dipole modes. One rf drive loop and one frequency tuner loop are located in opposing quadrants at the longitudinal center of the cavity. The frequency tuner penetrates the vacuum through a ferrofluidic seal and is driven with a dc gear motor. Ports for rf monitoring loops are located at six places along each quadrant.

Each quadrant of the RFQ is pumped through a radial port using a 1,000 liter/s cryogenic pump. A base pressure below 4×10^{-7} Torr in the cavity has been achieved. Electrical properties of the cavity have been studied using both low and high levels of rf power. An azimuthal field distribution balance of $\pm 2\%$ was achieved using 3 pairs of vane coupling rings. Axial field distribution was controlled by various end-tuner adjustments. Voltage flatness along the vanes is approximately $\pm 5\%$. Figure 6 is a photograph of the assembled RFQ taken shortly before high-voltage testing began at the Bevatron.

As of this writing, the RFQ has now been assembled, tuned and recently operated at full rf power. Early tests indicate that the structure's stability, dimensional accuracy and adjustability meet the requirements that are critical for successful beam acceleration and transmission. On June 7, 1983, the first beam, N^{3+}, was accelerated in the RFQ.

Fabrication of components for the Alvarez linac is in progress, aimed toward final testing and commissioning of the upgraded local injector in early 1984. A prestripper tank approximately 3.5-m long and containing 37 drift tubes is used to accelerate the beam from 200 to 817 keV/N. Pulsed, wire-wound drift tube quadrupole magnets will provide the needed focusing gradients.

184-INCH SYNCHROCYCLOTRON

The 184-Inch Synchrocyclotron continued to operate this year as a dedicated medical accelerator, providing helium ions for radiotherapy and associated biological experiments. One hundred eight patients received 1409 treatments as part of the program to compare helium and heavier ions with the best conventional radiotherapy. Tumors treated were located in the eye, head and neck, and the torso, with emphasis on sites near sensitive structures such as the optic nerve or the spinal cord. Eleven patients having arterio-venous malformation in the central part of the brain were treated. The helium ions are stopped in a well-defined volume of a few cubic centimeters to minimize damage to nearby normal tissue.

The reliability of the cyclotron has continued to be exceptional. The time that the accelerator was unable to be used due to malfunction was less than 2% of the scheduled operating time.

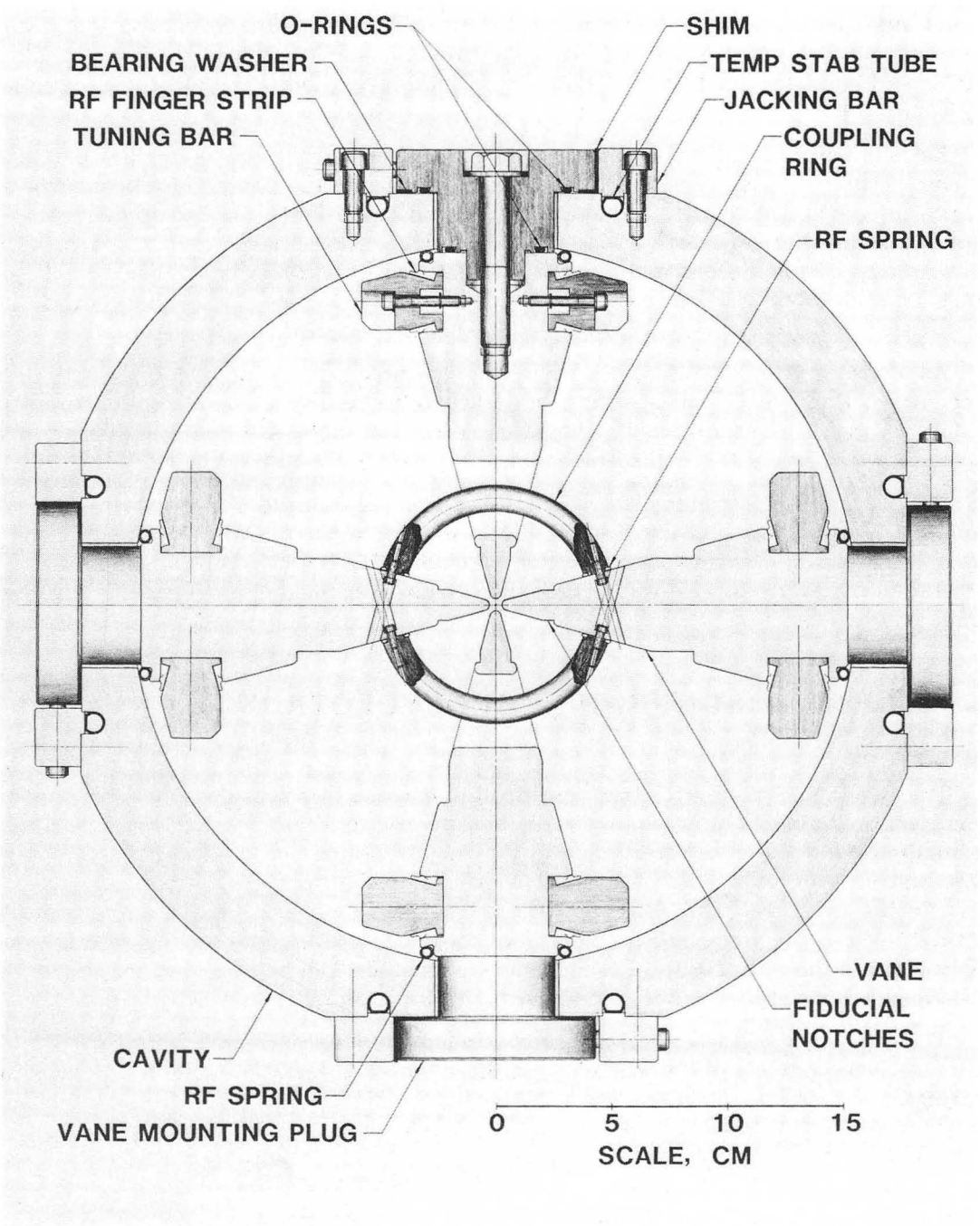


Figure 5. Typical RFQ cross section. **(XBB 833-2642)**

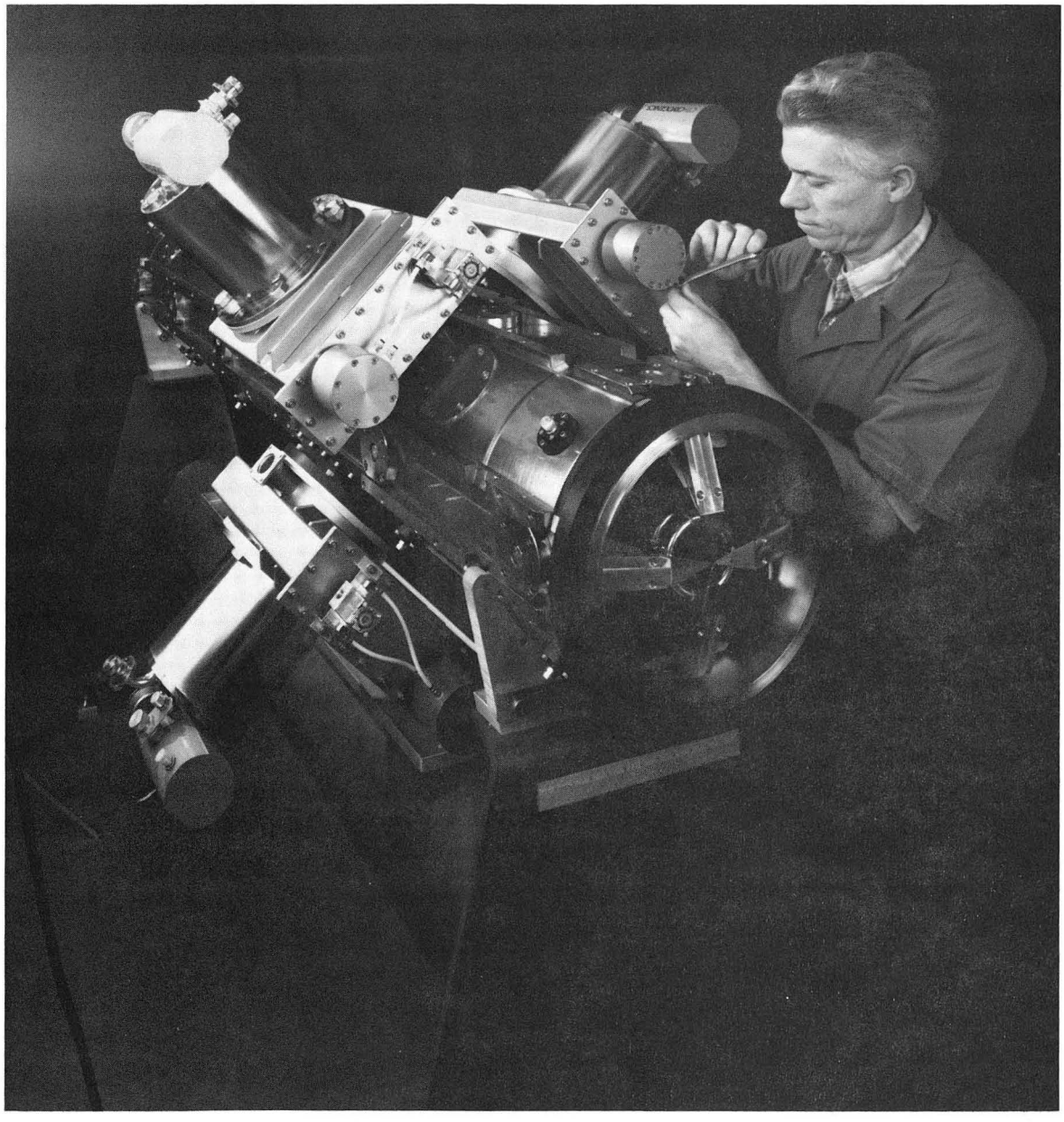


Figure 6. Photograph of the RFQ after assembly and alignment was completed at the Bevatron. (CBB 833-2193)

HIGH ENERGY PHYSICS

SUPERCONDUCTING MAGNETS

C. Taylor (group leader)
R. Althaus
S. Andreae
A. Borden
S. Caspi
C. Chavis
W. Gilbert
R.B. Grigsby
R. Hannaford
W. Hassenzahl
B. Heppler
J. Holthius
J. Jacobsen
R. Meuser
J. O'Neill
L. Parsons
F. Penny
C. Peters
J. Rechen
R. Scanlan
R. Schafer
R. Wolgast
T. Young

BEAM COOLING

G. Lambertson (group leader)
A. Arthur
J. Bisognano
V. Brady
V. Burns
C. Chavis
W. Flood
D. Goldberg
T. Henderson
D. Hopkins
J. Johnson
C. Kim
K. Kim
A. Kruser
C. Leemann
B. Leskovar
C. Lo
C. Pike
F. Voelker
A. Wekhov
E. Young

ACCELERATOR THEORY

L. Smith (group leader)
J. Bisognano
D. Douglas
A. Garren
G. Krafft
L.J. Laslett
E. Lee

ADMINISTRATIVE SUPPORT

J. Kono
A. Lundblad
A. Williams
O. Wong
J. Zelver

HIGH ENERGY PHYSICS

In support of the nation's high-energy physics program, we are playing key roles in the development of magnet technology for a future very large multi-TeV hadron collider and of stochastic beam-cooling systems and components for the Tevatron I proton-antiproton collider at Fermilab. The Division's accelerator physics staff members also participate in the national and international planning for future facilities.

HIGH FIELD MAGNETS

We are developing magnet technology for a very large, multi-TeV future accelerator. Emphasis is on designs that have promise of substantial cost reduction when compared to present superconducting accelerator magnets. The program includes design and analysis of complete magnet systems; design, fabrication, and testing of model magnets; development of magnet test facilities; and development and testing of advanced design methods, superconductors, and construction materials.

The beam in a multi-TeV accelerator has a very small cross section, which permits the magnet aperture to be very small; therefore, an important cost reduction can be gained by reducing magnet bore diameter, thus reducing the amount of superconductor, structural material, etc. To further reduce costs it is possible, in a colliding beam accelerator, to locate magnets of the two rings side by side in the same liquid helium enclosure, thus eliminating half the cryostats and their associated helium distribution system.

We have built and tested a series of model dipole magnets with ~50-mm-bore diameter to evaluate winding techniques, various cable designs, and low ratio of copper to superconductor. Table 1 lists parameters of the three most recent models; these models are 58-mm-bore diameter, l-m-long, single bore, and without magnetic iron. They all reached record magnetic fields for accelerator-type magnets at their respective short sample performance.

Figures 1 and 2 show cross sections of the 4-block design and the 4-layer designs, and Figure 3 shows the finished D9-A model.

D9-B is similar to D9-A except it is much more efficient in use of material, having a 21-strand cable with 0.030-in. strands, with copper-to-superconductor ratio of 1.0, used for the inner two layers. D9-A had very little training and used the same cable in all four layers. D10-B is the first dipole magnet built with the very low ratio of copper to superconductor of 0.86; it uses the first 27-strand cable made in the United States. The D10-B's four-block support structure was designed for subsequent use with a much heavier Nb_3Sn cable.

These models demonstrate that very high fields can be achieved with Nb-Ti at 1.8 K using a variety of cable types and structural supports, and that copper-to-superconductor ratios as low as 0.86:1 can be used.

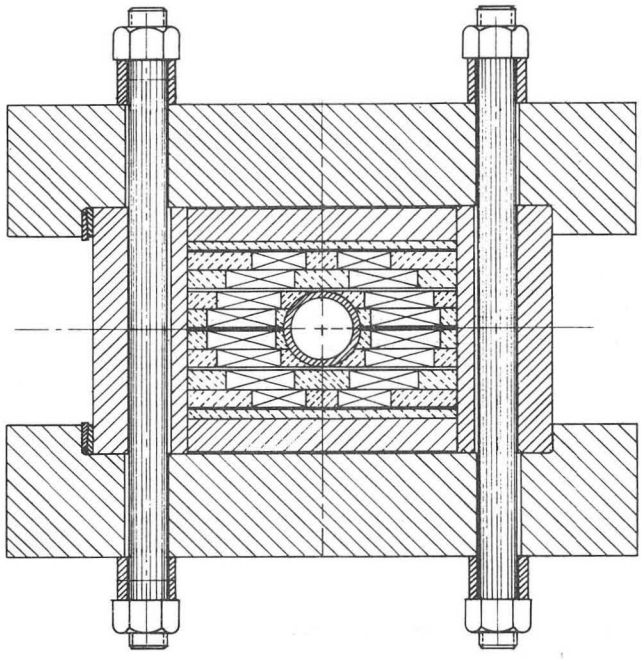


Figure 1. Four-block model with temporary demountable retaining structure. (XBL 836-10127)

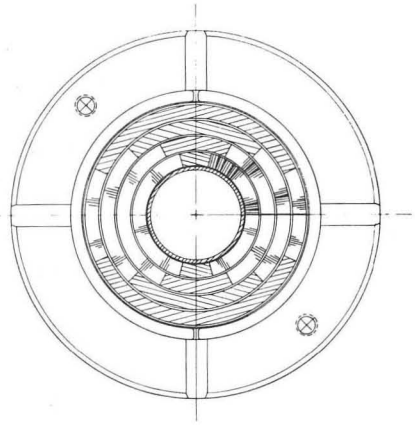


Figure 2. Four-layer model with retaining ring structure. (XBL 836-10128)

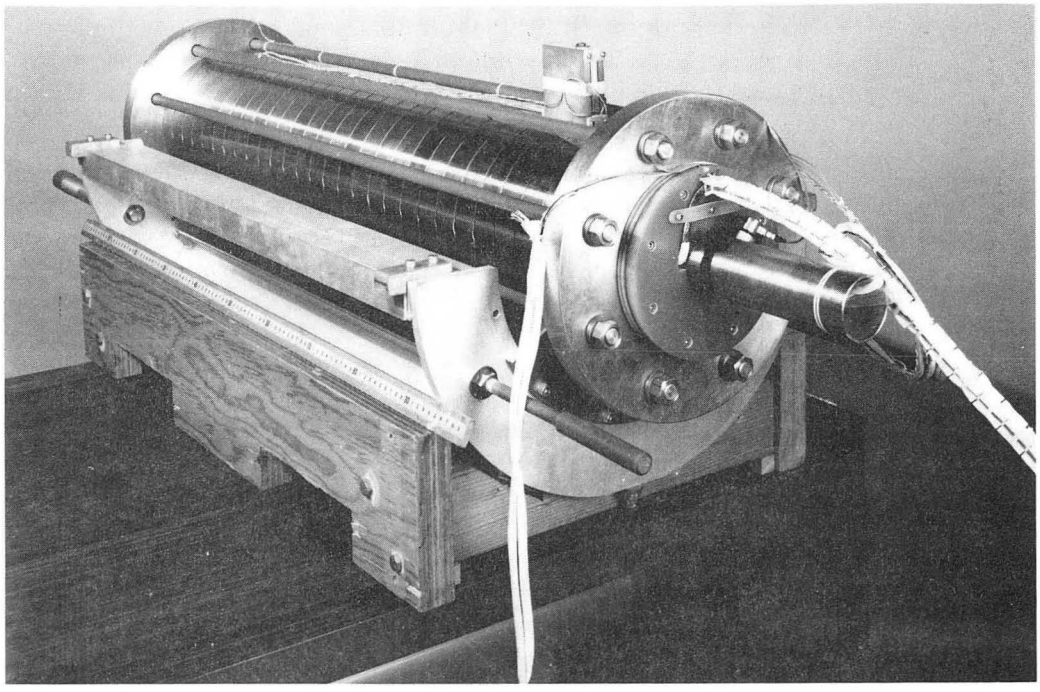


Figure 3. The D9-A dipole model, a 1-m-long, 5-cm-bore magnet that reached 5.8 T at 4.4 K at a ramp rate of 1 T/s after only two training quenches. Made of all-Stabrite cable with a copper-to-superconductor ratio of 1.5 and all-Kapton insulation, the magnet reached 8.0 T at 1.8 K. (CBB 820-10248)

Table 1. Small-bore LBL model magnets.

Magnet Number	B_0 (T) 4.5 K	1.8 K	Configuration	Cu/S.C.	Cable Details Strand Diameter (cm)	Number Strands
D9-A	5.9	8.0	4 Layer	1.5	0.0268	23
D9-B	6.9	8.6	4 Layer	1.0 1.3	0.030 0.0268	21 23
D10-B	7.0	9.1	4 Block	0.86	0.032	27

Model D10-A, the first Nb_3Sn model, is under construction. The unreacted 0.068-in.-diameter wire was delivered by Intermagnetics General Corp. in December 1982 and fabricated into an 11-strand cable in January 1983. This cable is the first internal-tin material that has ever been produced in practical quantities. Tests on the 0.068-in.-diam. strands confirm that j_c is about twice that of commercial "bronze process" Nb_3Sn material. Similar material, made by Teledyne Wah Chang via a different internal-tin process, has given similar j_c in small, experimental-size batches. Wire manufactured by this technique will be tested in model magnets.

New technology developments include: a mechanically improved cable design now being incorporated into an industrial process, an improved data recording system for detailed study of quench origin and propagation, and strain-gage techniques for measuring assembly pressures and operating stresses.

The fast energy extraction system and power supply have been upgraded to 15-20 kA to enable testing of new conductors now being developed.

Future models will include two-layer, 6-8 T designs and two-in-one models. Figure 4 shows an example of a schematic design for an 8-T two-in-one collider magnet that is iron free, has a 5-cm winding bore diameter, and has 16-cm separation between the two beams. We are exploring designs with a range of magnetic field (6-8 T), bore diameter (3-5 cm), both with and without magnetic iron.

STOCHASTIC BEAM COOLING

With the goal of producing in 1986 collisions between protons and antiprotons at 2 TeV center-of-mass energy in the Tevatron I at Fermilab, the LBL beam-cooling group is developing system designs and components for the necessary antiproton source. A system design was developed in collaboration with Fermilab researchers that will produce, concentrate, and accumulate batches of 1.8×10^{11} antiprotons for injection into the new Doubler accelerator ring. The scientific design and development work on this collider system at LBL are focused on the development of beam electrodes and low-noise electronics.

The technique of stochastic cooling is applicable to particles, such as antiprotons, circulating in a storage ring. Sensitive electrodes are needed to pick up from each passing

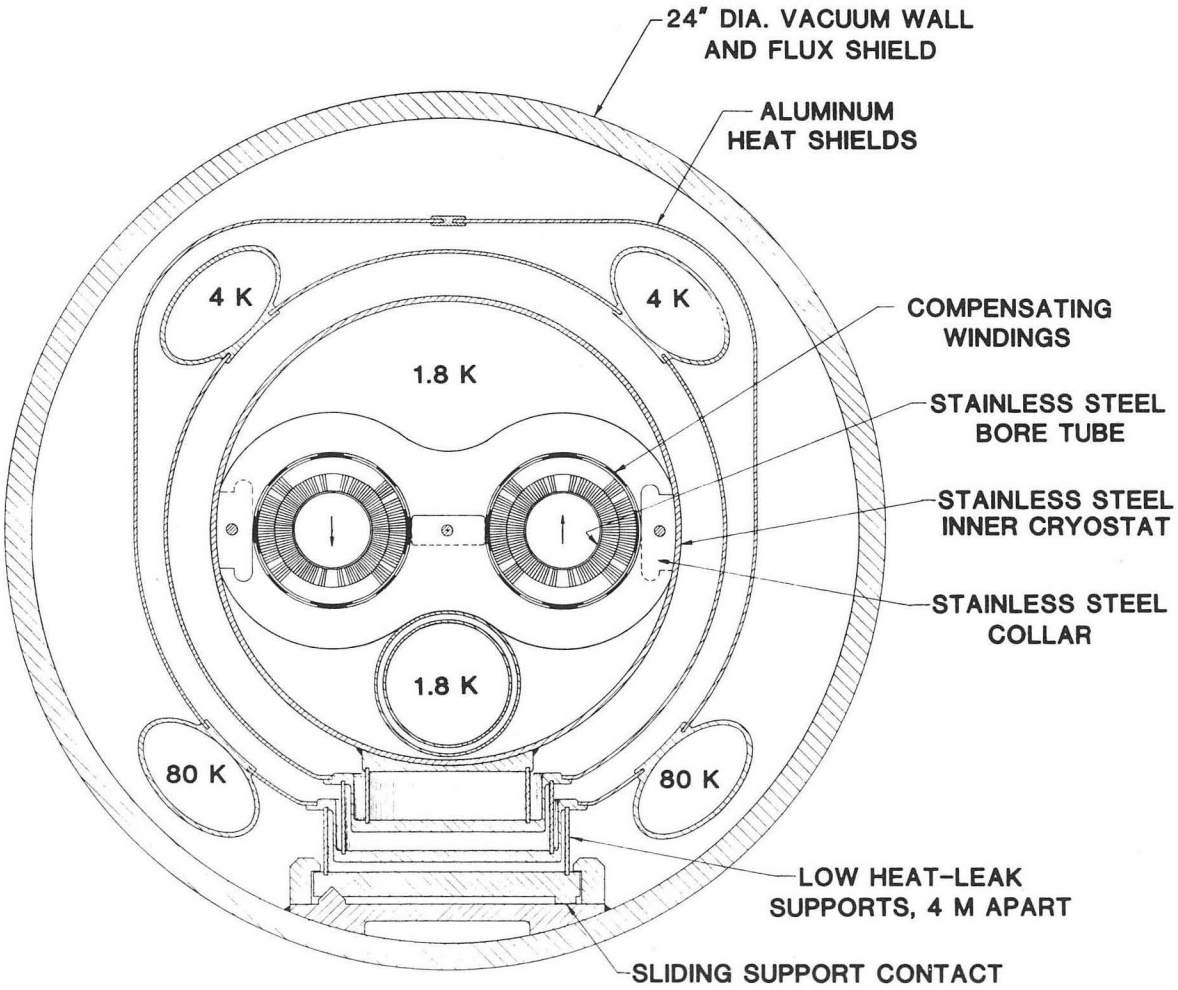


Figure 4. Example design of an iron-free two-in-one magnet for a very high-energy collider. The magnet has a 50-mm bore diameter and 160-mm ring-ring separation. Shown is a 2 K cryostat for Nb-Ti superconductor. (XBL 836-10255)

antiproton the tiny signal indicating its deviation in position or velocity. That signal is then amplified and transmitted downstream by fast electronics to a kicker electrode where it is applied as a corrective impulse to the same antiproton. This process, repeated each turn, steadily increases the density of the beam of particles in phase space. While conceptually simple for the single particle, the process is complicated and limited by the presence of thermal electronic noise in the circuits and by interactions with the other 10^7 to 10^{11} antiprotons in the circulating beam. These complications introduce the "stochastic" aspects.

Work under way at LBL this year includes the following activities:

- Beam-cooling systems designs for Tevatron I at Fermilab.
- Theory of signal suppression and application to accumulator design.
- Analysis of nonlinearities in pickup response.
- Analysis of cooling of bunched beams.
- Optimization of loop pickup geometry.
- Fabrication of 16-loop pair electrode array.
- Measurement of distortions in traveling-wave tubes.
- Development of low-noise preamplifiers.

Cooling System Theory and Design

Selection of the cooling-system parameters was influenced by analytical work and previous experience of LBL researchers. The virtues and practical possibilities of operating at high frequencies, compared to previous practice, were emphasized. Two operating bands were chosen: 1 to 2 GHz and 2 to 4 GHz. At higher frequencies, both electronics and beam electrodes can more readily provide a linear response over a wide frequency band, which is needed for a fast cooling rate. The option to go to the 4- to 8-GHz range remains as an improvement possibility.

The coherent (contrasted with the individual particle) response of the beam to cooling signals leads to an effect called signal suppression. Studies show how to predict the conditions that will arrest cooling and cause heating. As a result, limitations were prescribed on the use of electronic filters to shape gain versus frequency; instead, the spatial response characteristics of the beam electrodes must be used. Additional design criteria came from analysis of spurious signals arising from the spatial nonlinearities of the typical pickup response.

An analysis was completed of the cooling of bunched beams including coupling between three degrees of freedom, gain nonlinearity, and signal suppression. Results indicate that with sufficient synchrotron-frequency spread, cooling proceeds at a rate reduced to the extent that bunching has caused a higher local beam current.

Development of Electrodes

Critical in the cost and performance of the beam-cooling system are the pickups and kickers that couple beam to electronics. As a pickup, the electrode is asked to produce a good ratio of signal to noise; the analogous quality in a kicker is good power efficiency. This is required over the full high-frequency band. The basic structure used in the beam-cooling electrodes is the quarter-wave loop, which appears to be most economical of straight-section space in the cooling ring. Modeling of the loop geometry to maximize response and remove resonances has shown that a single pickup loop pair 7-cm long can produce a signal of 40 volts per ampere of beam modulation in an impedance of 50 ohms. In the rings of the Fermilab

antiprotron-source, a single circulating antiproton will produce in that loop pair a signal power of 10^{-21} W in the 1- to 2-GHz band. The 10^7 particles will then produce 10^{-14} W, which is still low compared to a typical thermal noise level of 10^{-12} W. Therefore, arrays of 128 pairs at 1 to 2 GHz and 198 pairs at 2 to 4 GHz will be used to increase the signal/noise ratio. Adding the signals from many loops has required the development of special low-loss combiners made on printed-circuit board that can be mounted inside the vacuum tank to reduce the otherwise large number of vacuum feedthroughs.

A prototype array of 16 loop pairs with combiners mounted on a beam aperture has been fabricated to evaluate actual performance and lead to production designs. This unit will be cooled to a temperature of 80 K to reduce vacuum outgassing from rf electronics materials and to provide a lower noise level. In combination with special low-noise preamplifiers under development, a factor of four noise reduction is expected, which is equivalent to having four times as many pickups. Measurement of the response of such a strong pickup array cannot be done using the usual pulsed current in a wire. A modulated particle beam for these measurements is under construction.

Electronics Design

The delicacy of the gain and phase specifications for beam-cooling places demands on the responses of amplifiers used. Commercial traveling-wave tubes (TWT's) were chosen for power amplifiers, but these have nonlinearities that can cause beam heating. To judge the seriousness of this problem, measurements were made of the intermodulation products from typical TWT's. A combination of reduced power level plus filtering will be necessary in the antiprotron source application.

Using selected GaAs transistors at the temperature of liquid nitrogen (80 K), a development program was started to produce low-noise, wide-band preamplifiers for the input circuits. The first developmental model operating in the range 1 to 2 GHz has an equivalent noise temperature of 36 K. It is expected that improvements can be made in a second model, but it is already a factor of four lower than commercial units.

HIGH ENERGY HADRON COLLIDERS

A three-week workshop, organized by the Division of Particles and Fields of the American Physical Society, took place at Snowmass, Colorado, during the summer of 1982 to explore the technical feasibility of a new national facility for high-energy physics in the 20-40 TeV range of center-of-mass energies. Several members of the Division participated in this study, which was notable for an unusually intense and productive interaction between accelerator physicists and high-energy experimental and theoretical physicists. The group reached the conclusion that such a facility is desirable and probably feasible in the sense of satisfying budgetary and other constraints. A further workshop was held at Cornell University, March 1983, with the goals of identifying machine-design features with significant cost impact and defining the most urgent R&D needs. Demonstrating their intent to play a major role in the design of a 20-TeV class collider, LBL participants contributed significantly to the workshop in the areas of accelerator physics, injector design, systems engineering, and magnet technology.

No radically new phenomena of beam behavior are expected to occur. For cost savings, however, the design must incorporate many novel features such as very small aperture, raising questions of field quality, dynamic aperture, closed-orbit error corrections, wall impedances and the handling of synchrotron radiation, or the clustering of all interaction regions, reducing machine symmetry and periodicity. The capability to follow vertical variations of the terrain may also be needed to minimize enclosure cost. Substantial cost

reductions are expected from engineering R&D in all areas, but most importantly those of magnet technology, cryosystem design, and civil construction.

Present activities focus on selected high-priority items with the ultimate goal of establishing a reference design. This is in line with the workshop recommendations which consider the time ripe for the development of integrated, sharply focused design efforts.

MAGNETIC FUSION ENERGY

W. Kunkel (group leader)
R. Pyle (deputy group leader)
N. Abt
G. Ackerman
O. Anderson
K. Berkner
I. Brown
F. Burrell
C. Chan
W. Cooper
J. Crawford
K. Ehlers
B. Feinberg
*J. Fink**
D. Goldberg
G. Guethlein
C. Hauck
K. Jimbo
A. Kaufman
J.-S. Kim
J. Kwan
K.N. Leung
M. Levine
A. Lietzke
D. Markevich
D. Massoletti
E. Morse
S. Omohundro
P. Pincosy
S. Pugh
J. Roberts
L. Ruby
A. Schlachter
A. Sessler
L. Soroka
W. Stearns
R. Steele
J. Trow
M. Vella
M. Williams
J. Wurtele
B. Yant

Administrative Support
A. Aitkens
K. Bregger
C. Cannon

Engineering and Technical Services Division Support
R. Anderson
R. Archer
C. Arthur
P. Barale†
P. Bean
L. Biagi
D. Bishop
T. Breckon†
G. Burritt
D. Calais
G. Cave
K. Chesley
*J. Colman**
M. Coleman
J. Cullen
C. Cummings
R. Curtis
J. DeVries
T. Downs
E. Doyle
R. Ellis
M. Fitzgerald
M. Fong
C. Garrett
G.R. Gray
A. Gould
E. Hazelton
R. Heep
M. Holeman
C. Hollister
V. Honey
D. Hopkins
H. Hughes
*V. Jacobson**
G. Jones
*R. Kilgore**
D. Kippenhan
G. Koehler
H. Krapf
R. Kuenning
G. Leonard
W. Low
I. Lutz
Y. Maruyama
C. Matuk
D. Morris
D. Moussa
T. Nakae
G. Newell
W. Ogelsby
H. Owren
J. Palmatier
J.A. Paterson
J. Perez
N. Peterson
P. Purgalis
*L. Shalz**
L. Skvarla
H. Smith
J. Tanabe
*E. Theil**
R. Wells
M. West
D. Williams
C. Wong
D. Yee
F. Zucca

ELECTRON LASER FACILITY (ELF)
A. Sessler (project leader)
D. Prosnitz (project leader)‡
C. Chavis
K. Halbach
D. Hopkins
R. Kuenning
M. Mobeus‡
T. Orzechowski‡
E. Panko‡
A. Paul
D. Rogers‡
G. Stover
J. Tanabe
J. Wurtele
T. Yakoda‡
R. Yamamoto

**RTSG*
†*Consultant*
‡*LLNL*

MAGNETIC FUSION ENERGY

The Magnetic Fusion Energy program at LBL is devoted primarily to the research and technological development of systems for heating and maintaining plasmas in mirror and tokamak experiments. Part of this work involves the development of neutral beam components and systems, including large test facilities. At the same time, basic studies are under way to improve our understanding of the atomic physics, plasma characteristics, and general theory of neutral beams. We also have an active research program in basic plasma theory, developing and applying modern mathematical techniques to plasma physics problems. In pursuit of these activities during 1982, we

- Demonstrated operation of a neutral beam module at 120 kV and 65 A on the Neutral Beam System Test Facility (NBSTF).
- Operated a fractional-area (7 cm x 10 cm) advanced positive-ion source with a plasma generated by 1-MHz rf power (with TRW).
- Completed the design and construction of a full-size (10 cm x 40 cm) 30-s pulse ion source for MFTF-B Tandem Mirror development.
- Demonstrated a "magnetic filter" concept for reducing the molecular-ion component in a neutral beam system, yielding 90% D^+.
- Designed a transverse field focusing (TFF) accelerator for a 1-A negative-ion beam line.
- Demonstrated long-pulse operation of a beam-stop panel in a neutral beam system at a power density of 2 kW/cm^2.
- Continued construction of our major new test facility, the Neutral Beam Engineering Test Facility (NBETF).
- Completed a computer-model analysis of the physics of our conventional ion sources.
- Demonstrated a technique for neutral beam diagnostics, using D-D reaction products.
- Measured H^- yields on a surface imbedded in a plasma, as a function of the surface work function.
- Made much progress in basic plasma theory, specifically regarding a self-consistent kinetic field theory and a Hamiltonian field theory for plasma fluid models. Other topics included (1) transition to incoherence for waves, (2) decay of correlations, (3) averaging methods, and (4) bifurcation analysis of the beam-plasma instability.

The official programmatic elements of our neutral beam research and development activities are Positive-Ion-Based R & D, Negative-Ion Based R & D, and Test Facilities, the latter including a Major Device Fabrication (NBETF). In this section, we report on the progress made during 1982 in each of these program elements, and we also report on our work in atomic physics, plasma theory, and microwave heating.

NEUTRAL BEAM DEVELOPMENT

Positive-Ion Beam Research and Development

Present neutral beam activities at LBL in support of magnetic fusion experiments at the Lawrence Livermore National Laboratory (LLNL), Princeton Plasma Physics Laboratory, and General Atomic Company involve the production, acceleration, and neutralization of 80- and 120-keV positive hydrogen and deuterium ions. During the past year we have devoted a substantial part of our research to long pulse lengths (from 30 s to dc), and we have emphasized the composition and purity of the beams. The results of this research will be applied to experimental devices built and operated between 1985 and 1995.

During the year we continued testing of neutral beam sources for the TFTR (120 kV, 65 A) and for the Doublet III (80 kV, 80 A), both designed for 0.5-s pulse lengths. In addition, we tested a large advanced positive-ion accelerator, a prototype for the MFTF-B mirror machine experiment at LLNL. This water-cooled assembly is capable of accelerating a 40-A deuterium beam to 80 keV, with a 30-s pulse length. So far, because of a lack of a suitable test facility, the pulse length has been limited to 2 s.

In developing large sources, we test the concepts first on fractional-area sources, which produce 10- to 15-A beams and duplicate the geometry of the large accelerating structures in all respects except total area. Consistent with this philosophy, we tested a fractional-area plasma source for a 7 cm x 10 cm (beam cross section) water-cooled accelerator, with plasma generated by 1-MHz radiofrequency.

The source was developed in collaboration with TRW. An insulated induction coil was fitted into a 10 x 10 cm LBL magnetic bucket and driven by a 1.6-MHz, 30-kW rf supply. At TRW, this was shown to have an acceptable plasma profile. The source was mated to the LBL 7 cm x 10 cm long-pulse accelerator in TS-IIIA for beam tests. Although rf oscillations were observed on the accelerator grids, the beam was shown to be unmodulated by observing a small floating plate behind the beam dump during accelerator pulses of 100 μs duration. The source was run from 35 to 85 keV, up to 1.5 s, at which point the glass cloth antenna insulator melted. The atomic fraction was slightly higher than for an arc source in the same bucket. A similar antenna (Figure 1) was also successfully run in the LBL 10 cm x 10 cm filter bucket, at similar beam voltages. Development of a 10 cm x 40 cm rf plasma source is now under way at TRW, and a 150-kW rf plasma source has been designed at LBL. The principal activity in both groups is finding a long-pulse antenna design.

For many fusion applications, an essentially monoenergetic beam of neutral atoms is desirable. Neutral atoms in the beam at less than full energy do not penetrate as far into the magnetically confined plasma as do full-energy atoms. Also, they adversely affect the electric potential distribution. Therefore, one of our highest priority goals is to develop ion sources that produce nearly pure D^+ beams, with only a small component of D_2^+ and D_3^+ molecular ions that break up in the neutralizer and produce neutral atoms with one-half and one-third of the full energy, respectively. Our model calculations predicted that the atomic fraction should increase with increasing volume-to-surface ratio. This has been borne out in practice. Operated with a modified TFTR accelerator structure, our large "magnetic bucket" plasma source – which has rows of permanent magnets on the walls to improve the electron and ion confinement – produced a 120-keV, 65-A beam of deuterium ions in which the D^+ fraction was 79%. This is substantially higher than the 65% D^+ obtained at the same current from smaller-volume "field free" sources.

The ion fractions (D^+, D_2^+, D_3^+) are determined, in part, by the electron energy distribution in various parts of the plasma. We have shown experimentally that it is possible to affect the ion composition in a dramatic way by changing the electron energy distribution.

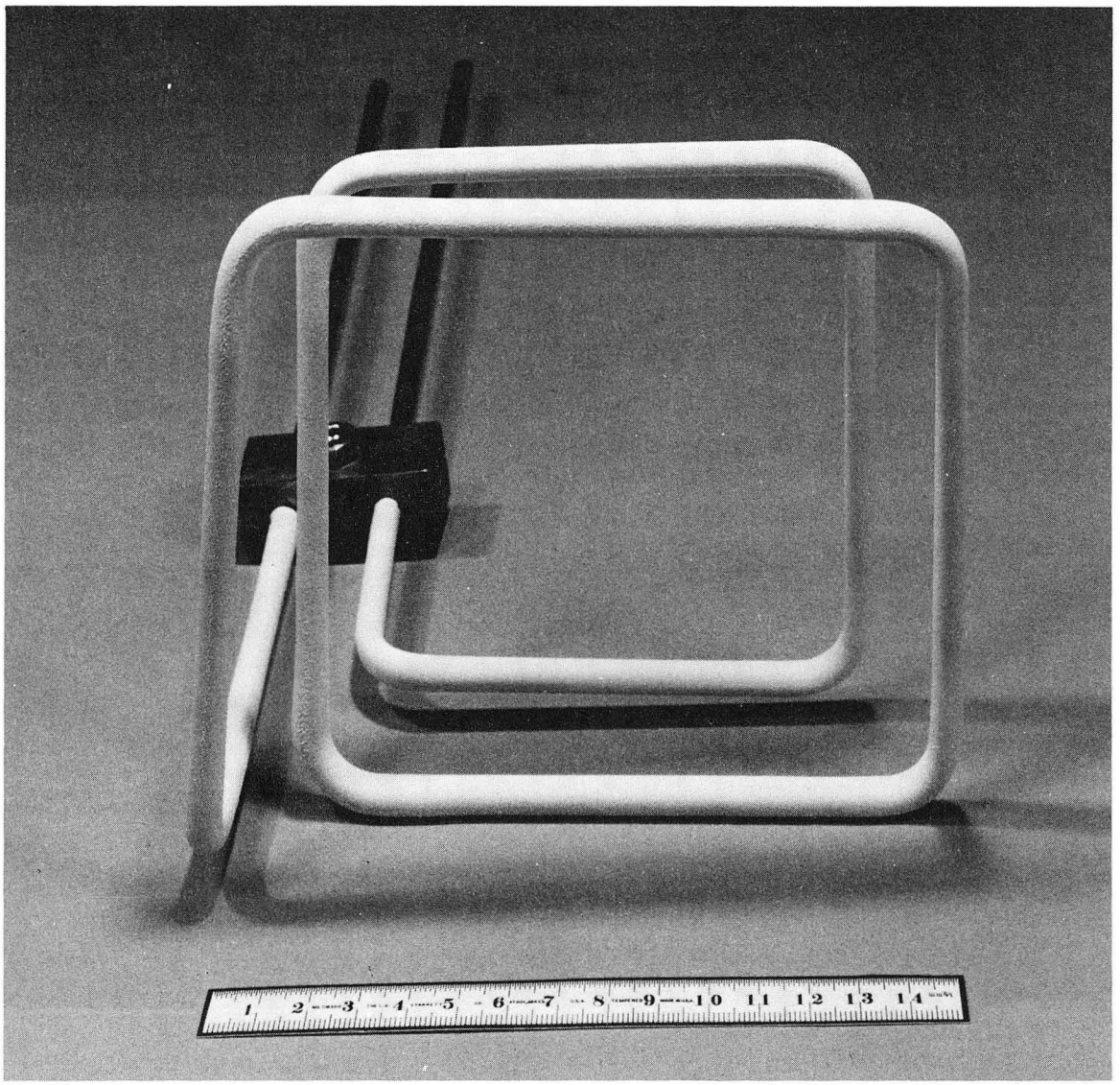


Figure 1. Antenna for 10 cm x 10 cm (beam) magnetic bucket. (CBB 820-10616)

The experiment is shown schematically in Figure 2. Energetic electrons from the cathodes (filaments) produce a dense plasma containing D^+, D_2^+ and D_3^+ ions. To minimize the accelerated D_2^+ and D_3^+ fractions that reach the accelerator, a transverse magnetic field ("magnetic filter") was applied which helped degrade the electron energies as the plasma diffused through the filter. When electron energies on the accelerator side of the magnetic filter are low enough that D_2^+ ions are not produced in this region, then both the D_2^+ and D_3^+ components are attenuated more than is the D^+ ion density. The result was that the atomic-ion fraction from such a source (photo shown in Figure 3) could be increased to as much as 90%.

Source-modeling studies incorporating the magnetic filter concept have been carried out by assuming that all primary (energetic) electrons have been removed. All other features of our "bucket" sources were retained, and a Maxwellian electron energy distribution was postulated with a temperature T_e as a variable parameter. Leakage of 30% to the side makes the computed results agree with the experimental observations. It is shown that more than 90% atomic species is difficult to reach. The optimum value for T_e appears to be 3 eV. Experimental results of species mix improvement by filter action are shown in Figure 4.

Negative-Ion Beam Research and Development

Future fusion experiments and reactors may require the injection of very energetic neutral beams to heat large-diameter, high-density plasmas. For example, the use of monoenergetic beams in the end plugs of tandem mirror machines can increase the Q-value significantly. Also, very high-energy neutral beams (0.5-1.0 MeV/N) may be used for driving current in tokamaks, thereby providing a mechanism for obtaining steady-state operation. At energies of about 200 keV the neutralization efficiency for positive ions decreases drastically, whereas the relatively easy stripping of the electron from a negative ion can result in higher efficiency. Therefore, the LBL neutral beam R & D program includes the development of efficient, long-pulse (dc) negative-ion-based neutral beam systems. Recently, we have been investigating the operation of an ion source to produce continuous, or long pulses, of self-extracted, surface-produced negative ion beams with large currents but at modest current densities.

The surface-produced negative ions have two disadvantages. They require the presence of a controlled amount of cesium on the converter surface and in the discharge. This is a complication and may lead to depletion problems during long-term operation. They also seem to be created with an irreducible initial transverse energy spread of about 5 eV. While the latter is low enough for the planned applications, a lower "temperature" would be preferable. Negative hydrogen ions produced in the volume via dissociative attachment to vibrationally excited molecules would avoid both of these disadvantages. Current experiments with filter buckets and controlled plasma potentials are beginning to give encouraging results for this production technique, but it is too early to predict whether the negative-ion current density can be raised to useful levels at sufficiently low gas pressures.

The most promising acceleration and transport system, developed here, is called the Transverse Field Focusing (TFF) accelerator. In a TFF accelerator, a transverse field is set up between pairs of curved deflecting plates. Charged particles passing between the plates are both deflected and strongly focused by the field. Average straight-line motion (if desired) is obtainable by having the successive pairs of plates curve in alternating directions (with corresponding reversal of the field). Acceleration is achieved by adjusting the mean voltage on each succeeding pair of plates. Computer simulations are in good agreement with the analytically calculated beam dynamics; they show no evidence of beam instabilities and almost no emittance growth. A design for a 400-keV, single-ribbon dc accelerator with neutron shield is shown in Figure 5. The strong-focusing transport system will allow the source and accelerator to be outside of the reactor's radiation vault.

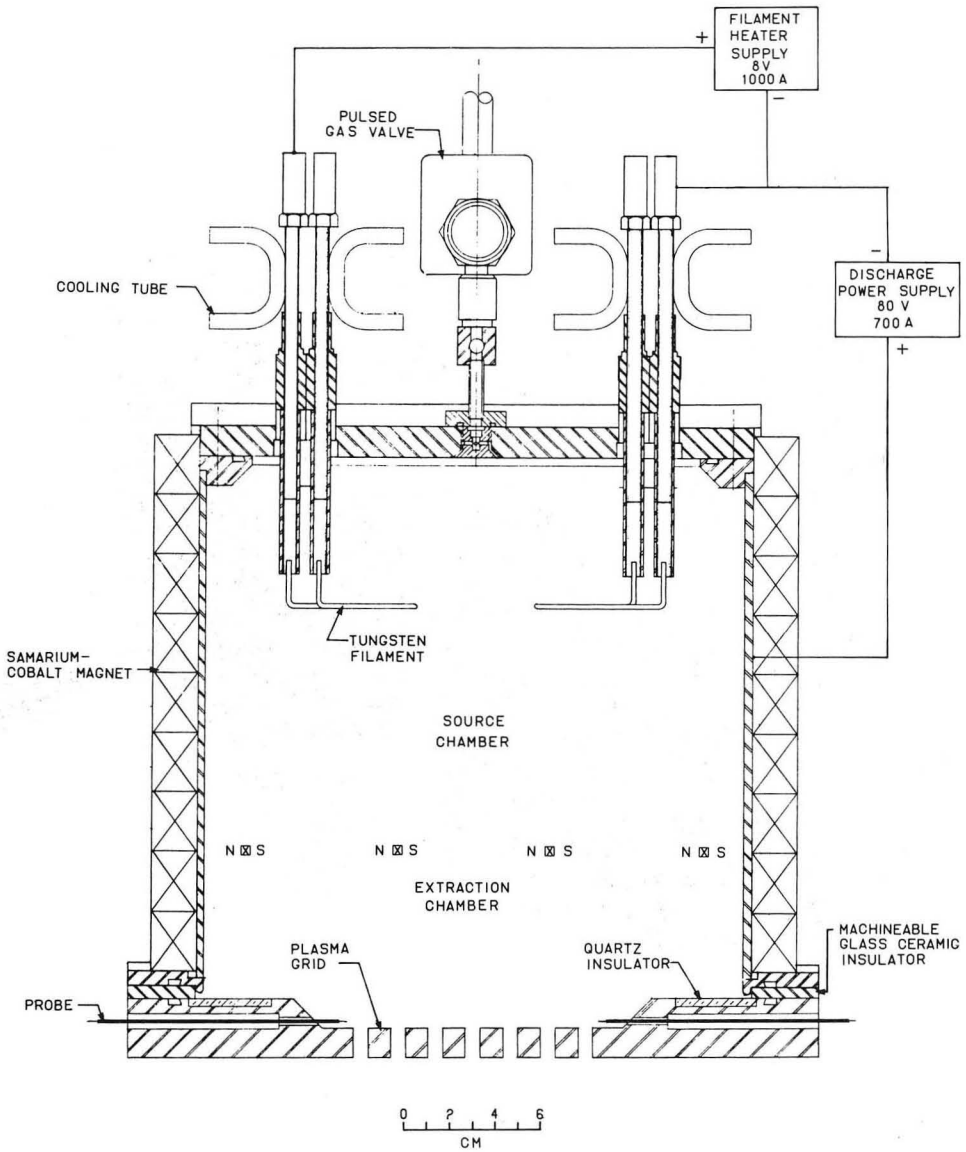


Figure 2. Schematic of a filter bucket source. **(XBL 7810-12004B)**

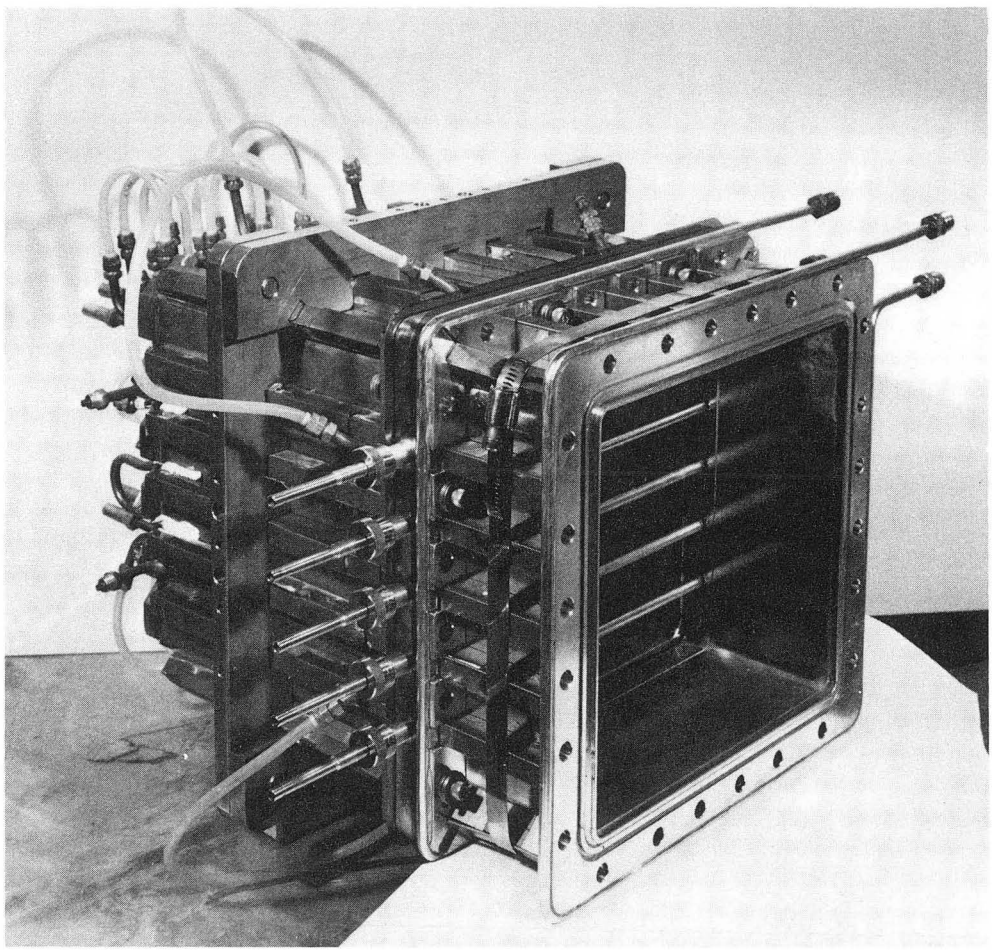


Figure 3. A photo of one of our 10 x 10 cm fractional area sources which was equipped with a magnetic filter consisting of tubes containing small permanent magnets. (CBB 813-2189)

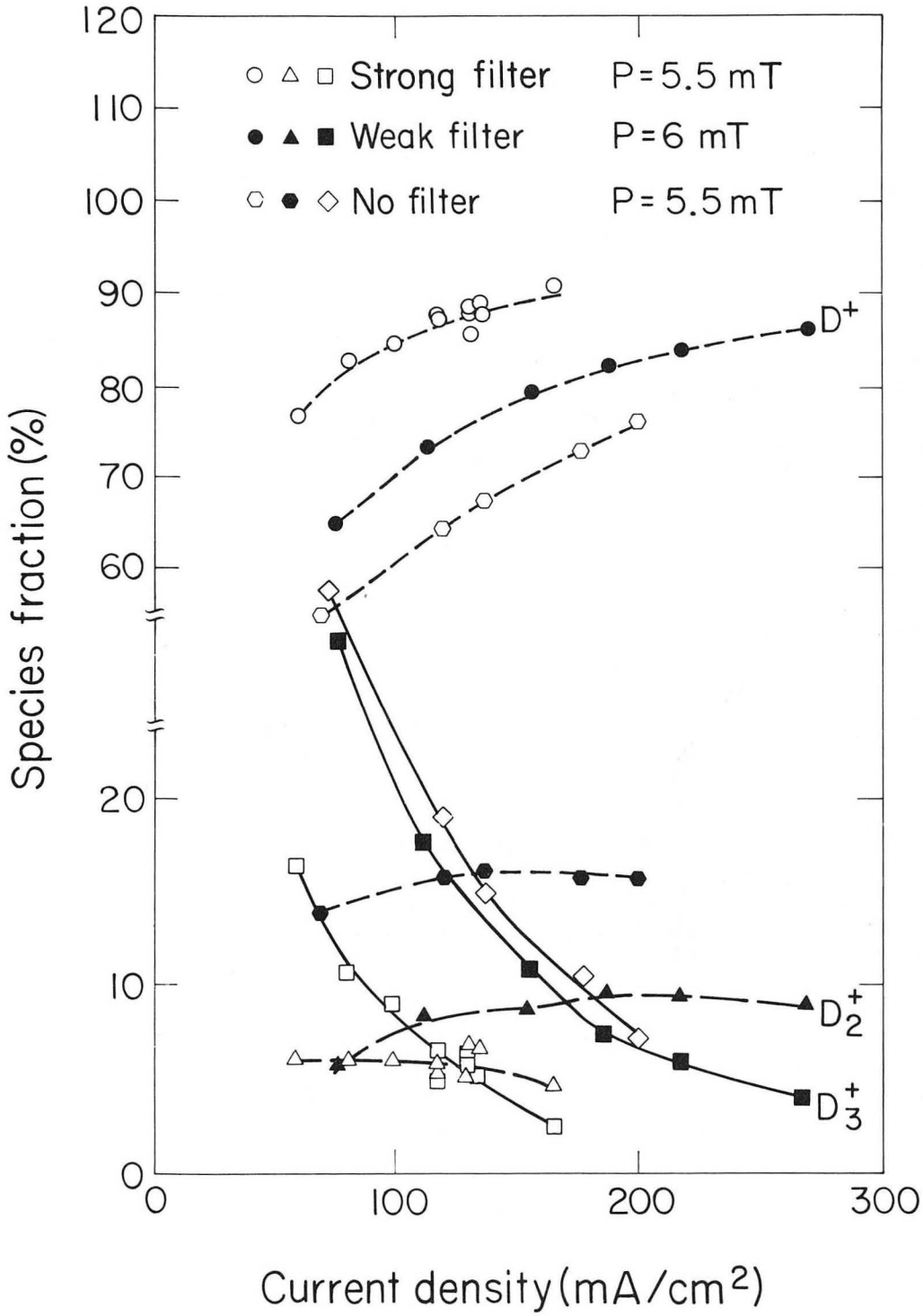


Figure 4. Effect of magnetic filter strength on beam composition.

(XBL 836-2640)

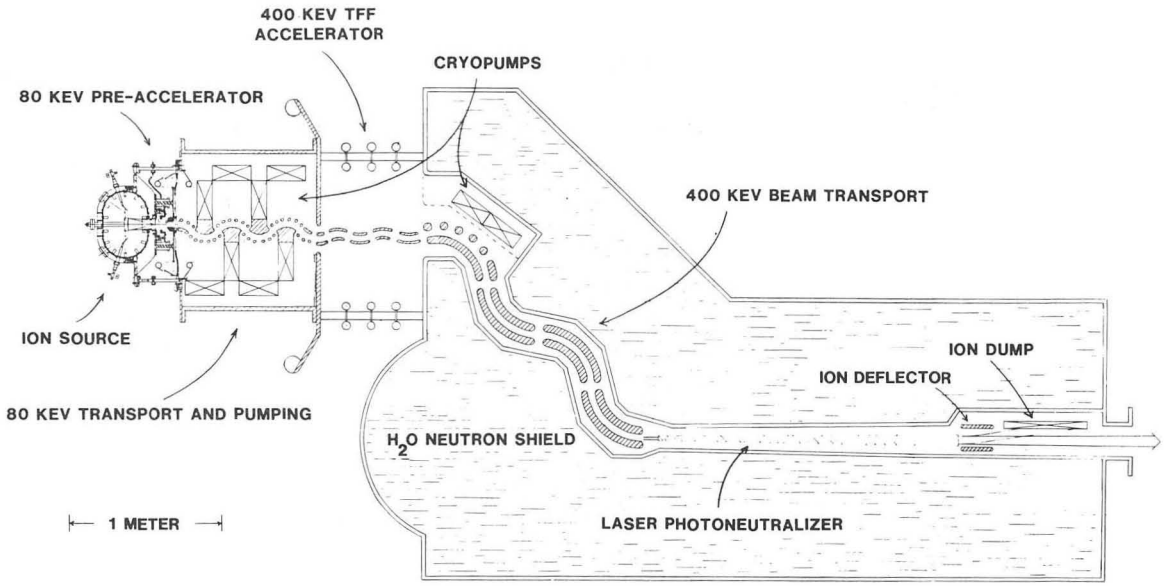


Figure 5. A 400-keV neutral beam system based on negative ions.
(XBL 8211-7449A)

Test Stand Fabrication/Operation

Large facilities are required to test the ion sources and accelerators developed for neutral beam injection. These facilities consist of multimegawatt power supplies capable of being switched off in a few microseconds, large vacuum systems to handle the gas load from the neutralizer, beam dumps that can handle power densities of several kilowatts per square centimeter, and the associated controls and beam diagnostics.

There are three major facilities for positive-ion injector testing at LBL. Test Stand IIIA is for beams up to 120 kV, 15A, and 30 s at 5% duty factor, and it is used for the development of fractional-area modules. Larger injector modules are tested for voltage-holding and beam optics on Test Stand IIIB (120 kV, 65 A, 30 ms, 1% duty factor). The pulse length is limited by the capacitor-bank power supply, so that we cannot investigate properties that may vary with time.

The largest neutral beam facility at LBL, and in the world, is the Neutral Beam Engineering Test Facility (120 kV, 50 A, 30 s, 10% duty factor), which started operating as a national test facility in May 1983. Its specifications are included in the previous Annual Report (LBL-14230).

BASIC RESEARCH AND THEORY

In addition to the progress in engineering of neutral beam components, systems and test facilities, described above, basic studies of atomic physics, plasma characteristics, and neutral beam and plasma theory progressed during the year.

Neutral Beam Plasma Research

We are conducting research to understand better the physics of neutral beam plasma sources and neutralizer plasmas. The results of this research may help to improve the efficiency of neutral beam systems and the reliability of long-pulse neutral beam systems, as well as to reduce beam divergence. Our approach is to

- Develop the measuring techniques required.
- Develop computer models of the plasmas.
- Use the validated models to recommend modifications for the neutral beam ion sources and neutralizers.

Two examples of the work carried out in this program are neutral beam positive-ion source modeling, which has recently been completed, and neutralizer plasma studies, which are discussed below.

We need to develop an understanding of the plasma processes occurring in the neutralizer section of a neutral beam line and determine any possible effects on beam operation. The plasma density and temperature have been measured by Langmuir probes, and plasma flows are measured using ion-acoustic waves. These numbers are compared to predictions of a computer model being developed. The density profiles agree reasonably well with the model predictions, as shown in Figure 6. The observed electron temperature T_e agreed with a simple model of collisional energy transfer processes only at low ion-current density. Anomalous electron heating at ion-current densities above 0.2 A/cm^2 is suspected, but has not yet been confirmed.

Neutral Beam Atomic Physics Studies

Diagnostic techniques for determining the properties of neutral beams are still inadequate to give precise on-line determinations of neutral hydrogen currents at full, one-half, and one-third energies, and of the impurity components. During 1982 we started development of on-line techniques using laser-induced fluorescence. The first application will be the measurement of low current densities of heavy neutral atoms in our multimegawatt beams.

A nuclear-collision, rather than atomic-collision, experiment shows real promise of providing on-line measurements of the fraction of the neutral beam that is at full energy (lower-energy components come from breakup and neutralization of molecular ions). Reaction products from fusion of deuterons in the high-energy beam with cold deuterons in the gas neutralizer are detected in the backward direction. Compound nuclei with the three different center-of-mass velocities produce reaction products with well defined energies. A triton spectrum is shown in Figure 7. Although insufficient beam time was available in FY 1982 to exploit the technique, it appears suitable for installation on TFTR.

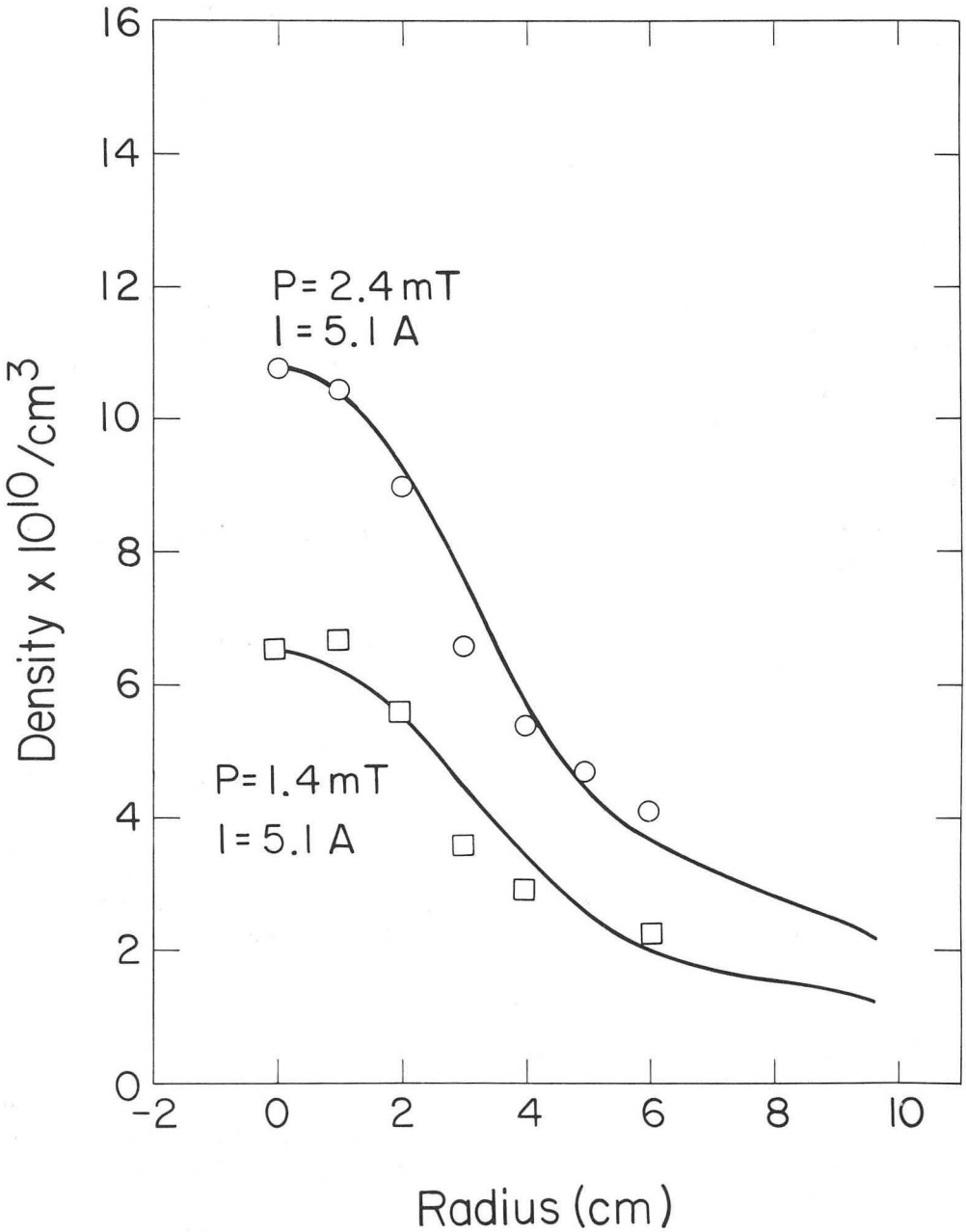


Figure 6. A comparison between measured and computer-generated plasma density in a neutralizer cell. The computer model required observed electron temperature as input to generate the curves. (XBL 825-10101A)

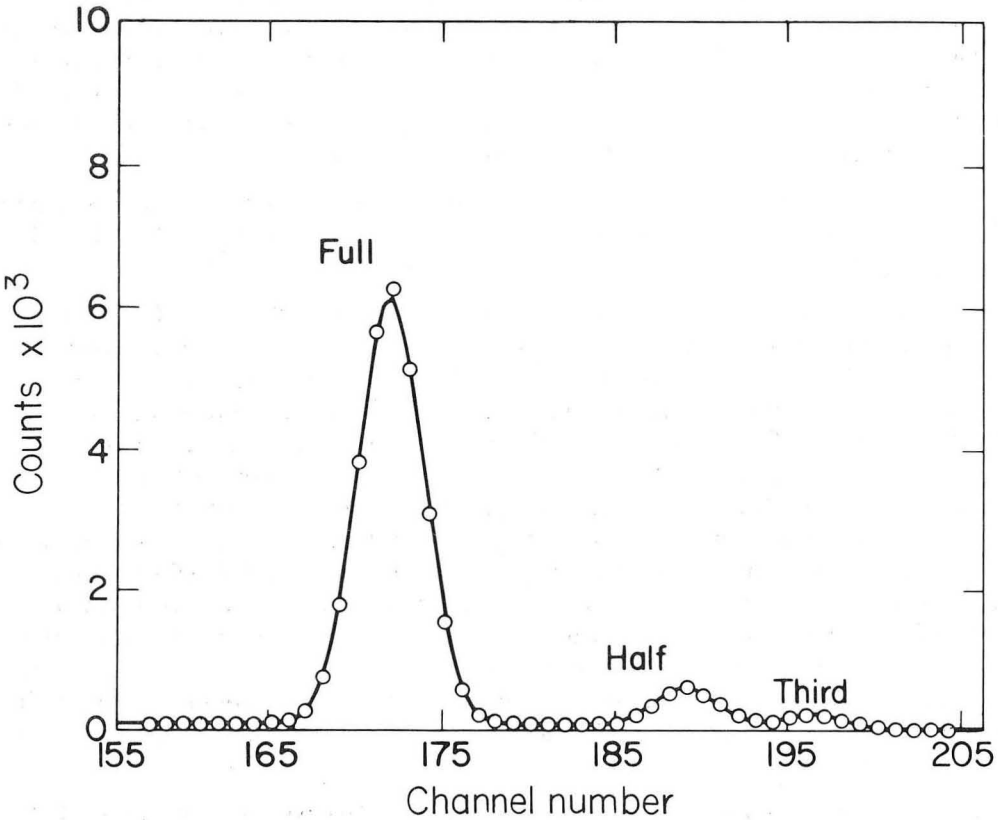


Figure 7. Gaussian-fitted spectrum of full-, half-, and third-energy fusion tritons from an 82-keV deuterium beam incident on a deuterium gas target for a total of 10 s of beam time. **(XBL 8210-3137A)**

Basic Plasma Theory

The dynamics of plasma waves in complex geometry has been formulated as a Hamiltonian system, in terms of Lagrangian manifolds embedded in ray phase-space. Both coherent and incoherent waves can be treated, as well as the transition to incoherence. The waves interact nonlinearly among themselves, and, in addition, interact with the plasma background. The latter interaction includes discrete and collective effects, linear and nonlinear effects, and resonant and nonresonant effects. Self-consistency is built into the formulation. Application can be made to plasma instability, to turbulence, and to wave-heating of plasmas.

ELECTRON LASER FACILITY (ELF)

The kinetic energy of a relativistic electron beam can be converted into coherent radiation. That such conversion is possible has long been known, but only in recent years, with experimental realization of this conversion by means of the free electron laser (FEL), has there been considerable attention – both theoretical and experimental – given to such devices. Thus, there is now a considerable body of information about FEL's.

At least two of the approaches to magnetically confined plasmas for fusion, namely the tandem mirror with thermal barriers and the Elmo Bumpy Torus, require for their successful operation "hot electrons." To heat the electrons, it is contemplated that one will use electron cyclotron resonance heating (ECRH), and some experience has been obtained with this approach using gyrotrons as a source of the rf power. Future devices will require several megawatts at higher frequencies (100 GHz and even 160 GHz).

The FEL appears to be competitive with gyrotrons as a source of microwave power for ECRH. ELF was constructed, starting in March 1982, to explore FEL physics in order to see if the tapered wiggler FEL can be an alternate source of power for ECRH.

The ELF experiment uses the beam generated by the ETA at LLNL and is attached to the end of the ETA beam propagation section. The ELF consists of three sections: a beam conditioning region, an interaction region, and a microwave diagnostics section. The first section reduces the current in the 4.5 MeV beam from 8 to 1 kA and reduces emittance from ~100 to 20 mrad-cm. The beam conditioning section also has an electron energy filter which allows an energy band (4.5 to 4.2 MeV) to pass into the wiggler section. The interaction region is the actual FEL region. In this section, the beam propagates through a rectangular wave guide. A periodic and tapered wiggler field transverse to the beam direction is established with electromagnets. This wiggler field has a period of 9.6 cm and provides the pump wave for the FEL. An input signal of the desired laser frequency is injected at the beam entrance to the interaction region. This signal is then amplified in the FEL wiggler. (The ELF experiment is run as a laser amplifier.) At the exit of the interaction region, the electron beam is swept out of the rectangular wave guide by a transverse magnetic field. The microwave radiation propagates down the wave guide where pulse shape, total energy, and frequency spectrum are measured.

Experiments with ELF are scheduled for the first two weeks in March 1983, four weeks in June 1983, and two weeks in September 1983. Measurements of total microwave energy at 8 and 4 mm, and of the microwave spectrum, are planned.

HEAVY ION FUSION

Experiment

D. Keefe (group leader)
C. Chavis
W. W. Chupp
E.R. Edwards
A. Faltens
M. Firth
W.B. Ghiorso
W. Greenway
E.C. Hartwig
R.R. Hipple
C. Houston
C.H. Kim
A. Kruser
M. Lampel
E.J. Lofgren
H.I. Meyer
R.G. Nemetz
C.D. Pike
T.J. Purtell
S.S. Rosenblum
G.L. Stoker
G.L. Tabler
M. Tiefenback
D. Vanecek

Theory

L. Smith (group leader)
J. Bisognano
V. Brady
E. Close
A.A. Garren
G. Krafft
L. J. Laslett
*W.B. Herrmannsfeldt**

Administrative Support

A. Lundblad
A. Williams
J. Kono
O. Wong
J. Zelver

**SLAC*

HEAVY ION FUSION

The AFRD Heavy Ion Fusion group continued its work toward a better understanding of high-current heavy-ion accelerators that eventually could be used to generate electrical power via inertial confinement fusion (ICF). LBL's program is focused on the induction linac as the basis for a conceptually simple single-pass ICF scheme in which heavy-ion beams are accelerated to high current and then focused onto a small pellet of deuterium and tritium fuel. The beams would heat the pellet surface, creating a rocket-like ejection of the surface material that compresses and heats the fuel to the point where a thermonuclear burn occurs.

Induction linac development currently involves the exploration of parameters for a High Temperature Experiment (HTE), in which an experimental accelerator facility would be built that can heat solid density material to a temperature of 50-100 eV. This is an ongoing study which will be continually updated to keep pace with the state of the art.

The physics issues relating to the generation and transport of high-current heavy-ion beams are being studied both theoretically and experimentally.

The major activities of the year are highlighted below.

- The 200-keV cesium ion injector for the Single Beam Transport Experiment was operated extensively for the development and measurement of the quadrupole matching system and beam emittance control device. Construction of the complete transport system is well advanced. The beam has been successfully transported through the first transport section. The beam-current density is found to be very close to the theoretical maximum.
- Beam diagnostic tools continue to be improved. The electron beam probe has been used extensively to study ion beams in varying stages of charge neutralization. Development of systems using scintillators and the EG&G Optical Multichannel Analyzer (OMA-2) continues.
- The Long Pulse Induction Accelerating Unit is in the final stages of construction. A two-core prototype test cell has been assembled and tested to nearly 10^6 pulses. Development of both the switch tube (ignitron) and pulse-forming network has proceeded rapidly and successfully. (The Accelerating Unit successfully accelerated cesium ions in March 1983.)
- Silica-loaded polymer insulator development is continuing at a low level.
- Theoretical studies of longitudinal beam bunch dynamics have been done using I. Haber's computer simulation code. Quadrupole and octupole transport channels and solenoid focusing channels using neutralized beams have received considerable emphasis.
- The exploration of possible induction linac parameters for the HTE is continuing.

SINGLE BEAM TRANSPORT EXPERIMENT

The Single Beam Transport Experiment was designed to test the theoretical predictions about the dynamics and stability of a space-charge-dominated heavy-ion beam. The 200-keV Cs^+ zeolite source and quadrupole matching section were constructed in FY 1981. This source was operated extensively in FY 1982 permitting the development of the emittance control grids and detailed studies of the quadrupole matching section (whose purpose is to match the round beam from the source into the alternating-gradient transport system).

Upon placing the five matching quadrupoles (MQ1-MQ5) into the system, we found that the beam envelope is approximated rather well by the KV-envelope equation. Deviations from calculated envelope parameters can be attributed to the very large tune depression caused by beam space charge, coupled with nonlinearities in beam and lens fields. These effects should be less pronounced at higher emittance or lower current for the beam.

Much of the hardware for the remainder of the transport line was completed in FY 1982, and beam diagnostic devices consisting of a small faraday cup and slit probes were constructed and utilized to characterize the beam.

The first quadrupole transport section, consisting of ten quadrupoles, was installed and operated early in 1983 (Figure 1). The remaining six transport sections are being assembled and will be installed as called for, with operation of the complete channel scheduled for the summer of 1983.

DIAGNOSTICS

Electron Beam Probe

Progress was made both in the experiment and data analysis. Experimentally greater flexibility in the diagnostic was achieved by adding an isolated cylinder at high voltage (-20 kV to +20 kV) through which the ion beam passes in entering the diagnostics tank. This allows control of the neutralization by regulating the electrons in the beam. Measurements of electron current, energy, and total charge can now be made.

Efforts in data analysis have yielded much better fits to the experimental data using the same five-parameter fits generated by the Pizza code. Work has also been done on a technique for obtaining both the radial and the longitudinal dependence of the space-charge distribution.

Scintillation Imaging

Since it is planned to use the EG&G Optical Multichannel Analyzer (OMA-2) to record a scintillator image of our heavy-ion beams, we have measured the linearity of the response of the OMA-2 system to a pulsed light source in its gated mode. In the gated mode the OMA-2 can capture events with a time resolution of 40 ns. This work is an extension of recent work reported by Liesegang and Smith [G.W. Liesegang and P.D. Smith, *Applied Optics, 21*, 1437 (1981)] in which they measured the linearity for a pulsed light source in the DC (ungated) mode of the OMA-2. The signal response is, indeed, found to be linear with the light produced, over a wide dynamic range.

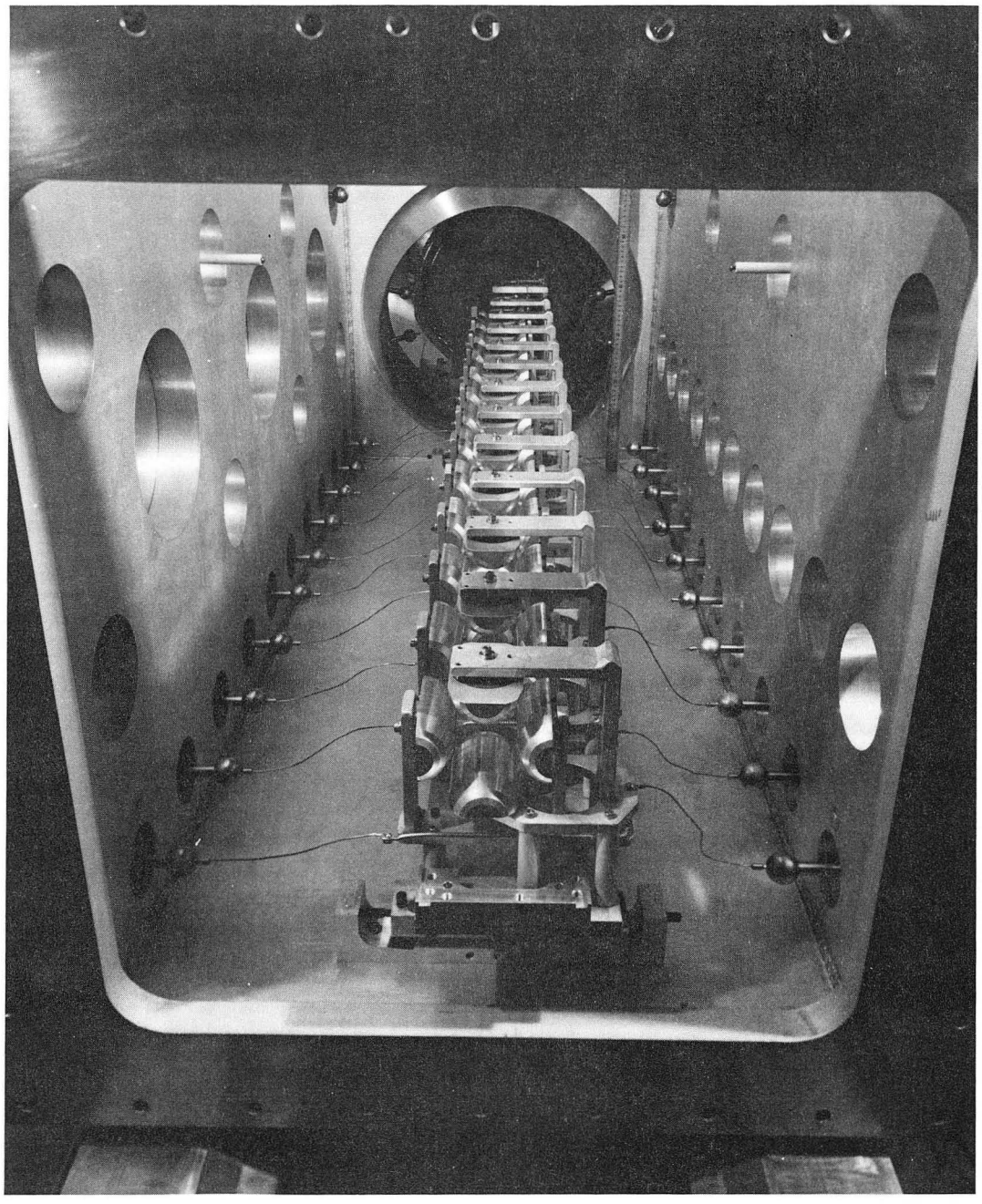


Figure 1. Installation of first section of electrostatic quadrupoles into the single beam transport line (view looking upstream into beam). (CBB 831-845)

Long Pulse Induction Accelerating Unit

During the past half year the design of the long-pulse induction unit was finalized, the various component parts were ordered, and life tests were performed on a prototype pulser and core-pair. At the end of the fiscal year all major components had been delivered and final assembly started (Figure 2). The unit successfully accelerated cesium ions in March 1983.

Throughout this reporting period a prototype developmental cell has been pulsing for most of the time, including several periods of around the clock operation for several days. The cell consists of two induction cores that are driven in parallel by a single pulser and reset by a separate circuit in such a manner that the core is pulsed at the peak of the reset current. The major fraction of the operation was at a 0.5 pps rate, which was initially determined by the power supply, but now has been designed into the triggering circuits as well. Maximum repetition rate was 1.5 pps for short periods. Typical tests lasted for 10^5 pulses, the longest was 5×10^5 pulses, and the total number of pulses is near 10^6 now. The cell and module were partly based on the requirements of the 1979 Ion Induction Linac 500 Joule Test Bed proposal, with nominal goals of a 25-kV ignitron-switched pulse forming network driving two cores to produce a 1.5-μs pulse length for a single cell. The module is simply a compact package of twelve independent cells as described, to give a total module voltage of 250 keV.

The three major activities related to the Accelerating Unit were the induction core selection and characterization, the switch tube development, and the pulse-forming network tuning.

A non-standard ignitron tube, the National Electronics T-2901A, was developed expressly for this program after several standard Size-A ignitrons failed after 10^5 pulses. Also, the standard tubes exhibited a jitter of ± 100 ns. An experimental glass tube with a control grid was quickly constructed by National, and almost immediately reduced the jitter to $\pm$ 10 ns. After a further modification, the first tube operated last year for 2×10^6 pulses into a resistive load at a current approximating the requirements of a single core. During this test the igniter voltage had to be increased several times, but otherwise the tube showed no deterioration.

THEORY

The AFRD theory group continued its work in support of the experimental program, and, in addition, devoted considerable effort to elucidating longitudinal instability, which is of considerable importance for the correct application of the induction linac approach to ICF. Several different beam transport schemes were also studied theoretically. Parameters for the HTE utilizing an linduction linac continue to be developed.

Longitudinal Stability

The induction linac bunches of heavy-ion fusion scenarios are strongly influenced by space-charge forces, and the resistive component of the machine impedance is narrowband. This situation is in distinct contrast to relativistic bunches in synchrotrons, where most of the data on bunched beam stability has been obtained. A particle simulation code to model induction linac bunches (developed by I. Haber of NRL) has been implemented at LBL. Induction linac impedances as well as flat resistances can be introduced through the fast Fourier transform. Finite pipe size effects, which cut off the high-frequency components of the space-charge force, may also be studied.

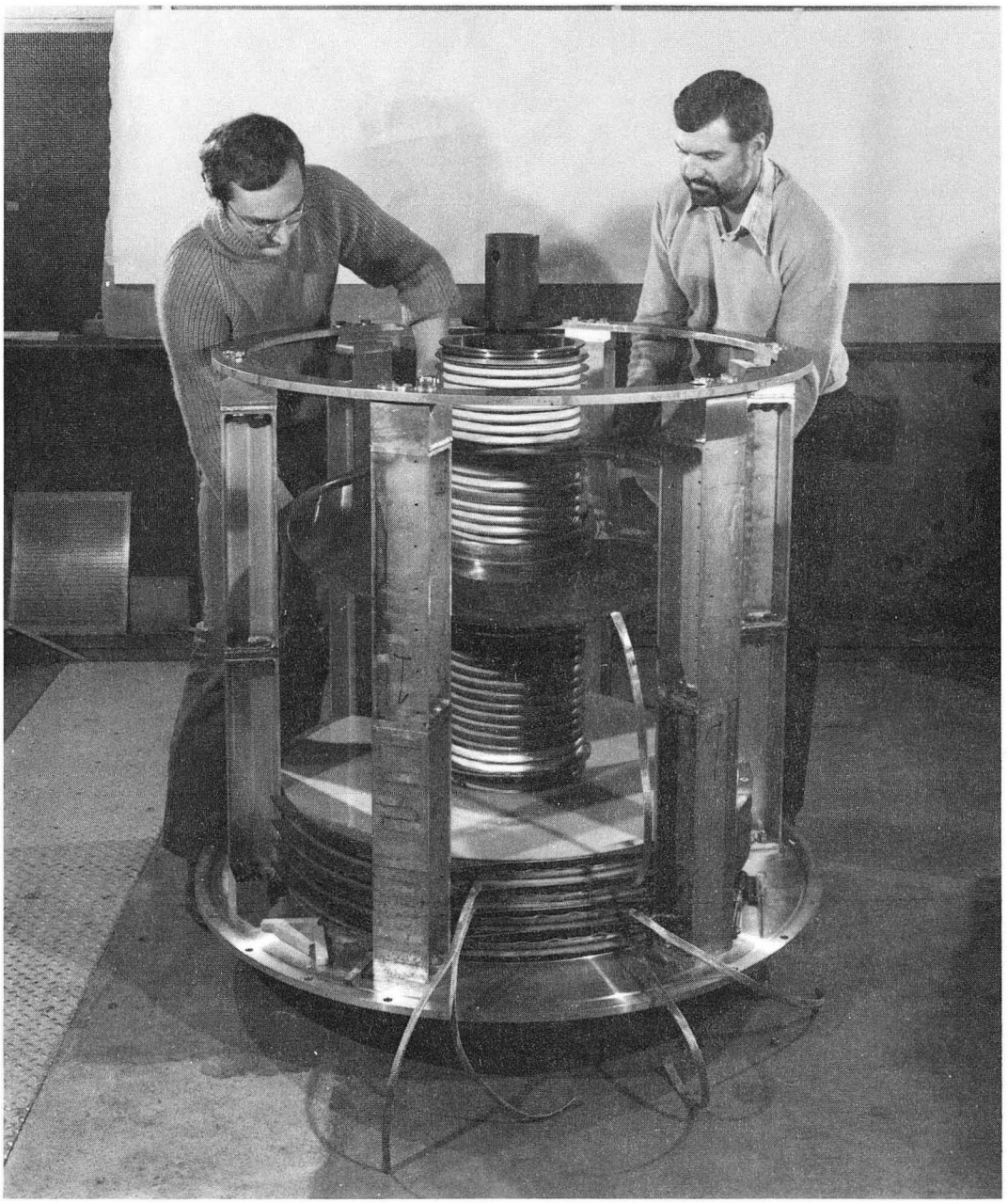


Figure 2. Long Pulse Induction Accelerating Unit during the core-stacking process. (CBB 831-582)

Results from this code indicate that the stability requirement of small growth rate relative to the synchrotron frequency characteristic of relativistic bunches can be relaxed significantly. Rather, the frequency spacing of the space charge modes of the bunch together with the growth rate determines thresholds. Runs were performed with local growth rates exceeding the synchrotron frequency by an order of magnitude with apparent long-term stability. Unstable behavior, however, was observed when that growth rate exceeded the mode-frequency spacing; other runs have indicated that dispersive effects introduced by the finite pipe size tend to make the higher frequency modes more susceptible to instability than the lower frequency modes. Since induction modules have a high resistive component only for the lowest bunch modes, stability is better than in the case of a broadband resistance.

Several cases which modeled possible induction module impedances for heavy-ion fusion drivers were run. These results indicate that long term longitudinal bunch stability is realizable for induction linac heavy-ion fusion. Short bunches together with narrow induction module impedances appear least susceptible to longitudinal instability.

Transport and Focusing

Studies relating to the maximum ion current transportable by a single-channel periodic electrostatic quadrupole or octupole transport channel have continued. The recent work has been devoted to computational investigation of the restrictions that nonlinearities necessarily present in periodic electrostatic quadrupole transport systems impose on usable aperture ratios for such systems, since this constraint substantially limits the system design and the magnitudes of transportable current.

It would be convenient in many ways to use solenoids to transport and focus heavy-ion beams, but the large magnetic rigidity of heavy ions combined with large defocusing space-charge forces makes their use impractical, if not impossible. We have become interested in a scheme [S. Robertson, *Phys. Rev. Lett.*, *48*, 149 (1982)], which, if feasible, would change the situation dramatically. He proposes to create a charge- and current-neutral stream of ions and electrons, moving together at the same velocity. When such a stream enters a relatively weak solenoid, the ions are not affected by the magnetic field, but the electrons begin to circle the axis, pulling in toward the axis to create a net negative charge density and proceed in a condition of Brillouin flow, with the inward magnetic force balancing the outward electric force and the centrifugal force. The ions are then subject to an inward electric force, which focuses them. The net result is a focusing strength for the ions greater than that for a weak beam of ions alone by the ratio of ion to electron mass, a factor of the order of 10^5 for heavy ions. We have extended Robertson's work to include non-zero emittance for both ions and electrons and have generated parameter lists for the HTE spot-heating experiment. Typically, a solenoid about a meter long with a field strength of a few hundred gauss would appear to do the job.

In order for the scheme to work, the potential at the edge of the beam must be positive, with zero potential on the axis. We believe that this can be achieved by biasing the vacuum pipe through the solenoid at a few hundred volts positive. However, it is not clear how the imposed electric and magnetic fields should be related in the fringing regions, or if the beam (or other) electrons will cluster either to permit or prevent penetration. Work continues on this problem and also on plans for a modest experimental test of the idea using the drift tube and diagnostic tank facility.

NATIONAL CENTER FOR ADVANCED MATERIALS

T. Elioff (NCAM Project Director)
R. Yourd (NCAM Manager)
B. Avery
R. Benjegerdes
J. Bisognano
D. Brodzik
T. Chan
C. Chavis
J. Chin
E. Close
D. Daymond
D. Douglas
D. Eagling
M. Fahmie
E. Fischer
J. Fugitt
A. Garren
K. Halbach
J. Hinkson
E. Hoedemaker
D. Hopkins
D. Howard
E. Hoyer
D. Humphries
D. Hunt
K. Kennedy
C. Kim
H. Lancaster
T. Lauritzen
S. Magyary
J. Meneghetti
V. More
J. Peterson
C. Pike
D. Plate
R. Sah
B. Tafelski
J. Tanabe
J. Thompson
C. Timossi
W. Wilson
R. Wolgast
B. Yamamoto

Administrative Support
E. Gailing

NATIONAL CENTER FOR ADVANCED MATERIALS

The National Center for Advanced Materials (NCAM) was proposed during the year to provide a national focus for basic research on the synthesis, characterization, and behavior of advanced and strategic materials. The Center will also serve to develop innovative concepts for high technology devices, thereby strengthening the nation's technology base. The Division worked closely with the Materials and Molecular Research Division and the Engineering and Technical Services Division in developing the NCAM proposal and assumed management responsibility of the project during its construction phase.

INTRODUCTION

NCAM will be composed of the Advanced Light Source (ALS) and three complementary laboratories--the Surface Science and Catalysis Laboratory (SSCL), the Advanced Materials Synthesis Laboratory (AMSL), and the Advanced Device Concepts Laboratory (ADCL).

The ALS is the first of a new generation of synchrotron radiation sources optimized to produce extremely high-brilliance photon beams by the use of special magnetic devices called "wigglers" and "undulators." The electron storage ring is designed to emphasize the capability of these devices. A combination of very low electron beam emittance in the storage ring together with adequate lattice provisions for undulator devices will provide a spectral brilliance that is nearly 10,000 times greater than that projected for existing light sources utilizing "bending magnet" sources. When these light sources are retrofitted with wigglers and undulators, the ALS will still retain a 100-fold edge in design spectral brilliance.

The nominal ALS electron energy (1.3 GeV) will provide photon beams in the energy range of 0.1 to ~5,000 eV. The maximum energy (1.9 GeV) extends the capability to 10 keV, while the use of a superconducting wiggler will extend the energy range to 40 keV. On the opposite end of the spectrum, the ALS also will provide relatively intense beams for experiments in the infrared region. The ALS is also designed to provide beam pulses of very short duration (tens of picoseconds), which will greatly expand the range of experimental capability.

The Surface Science and Catalysis Laboratory (SSCL) will provide facilities to further the fundamental understanding of the physics and chemistry of surfaces. Both basic and applied research projects will be emphasized. Research will focus on understanding catalysis on solid surfaces and on developing new catalysts in close collaboration with the Advanced Materials Synthesis Laboratory.

The Advanced Materials Synthesis Laboratory (AMSL) will be devoted to developing and understanding new kinds of polymers, metals, ceramics, and electronic materials. The AMSL will strengthen the United States' position in the synthesis and analysis of advanced

materials by pushing forward knowledge of the structure, composition, and formation of such materials, as well as by pioneering new techniques for synthesizing such materials, and by developing new materials to meet the specifications required for advanced devices or processes.

The Advanced Device Concepts Laboratory (ADCL) will be a major facility dedicated to fostering the development of novel concepts for devices. Pursuant to NCAM's emphasis on advanced materials, the ADCL will be devoted to research related to high-technology devices utilizing new materials and to innovative approaches to the study of materials. Thus, research at the laboratory will focus especially on developing concepts for devices made possible by new or better understood materials.

The NCAM project also provides for the upgrading of facilities at the Stanford Synchrotron Radiation Laboratory (SSRL). This includes experimental area improvements, emittance improvements to the SPEAR electron beam, new in-vacuum wigglers, and the development of an x-ray beam from the PEP storage ring (by moving the LBL permanent magnet undulator now at SPEAR to PEP). This upgrade will be extremely valuable to NCAM researchers during the ALS construction period, and the upgraded x-ray beam facilities will continue to serve as a valuable complement to the ALS facilities.

Considerable work was completed this year in preparation for this new project. Full specifications were developed for all areas of the project—the laboratory buildings, the accelerator systems, and the initial complement of candidate insertion devices and photon beam lines to be considered. (Note: these photon beam lines were the subject of extensive review by over 200 scientists from eight foreign countries, seventeen universities, four federal agencies, nineteen private companies, and seven national laboratories at a Workshop held May 9-11, 1983 at LBL. Recommendations for changes are being incorporated into the design as this report goes to press.) Thorough cost estimates for all components and an overall project schedule were developed. The complete conceptual design was presented in a five-volume *Conceptual Design Report* (Pub-5084). A summary description outlining the major elements of the Advanced Light Source is given below.

ADVANCED LIGHT SOURCE

The Advanced Light Source (ALS) is a synchrotron radiation source consisting of a 50-MeV linear accelerator, a 1.3-GeV "booster" synchrotron, a 1.3-GeV electron storage ring, and a number of photon beam lines, as shown in Figure 1.

The design of the Advanced Light Source has been optimized to achieve two major goals. This facility is designed to provide intense photon beams (especially in terms of spectral brilliance) in the nominal energy range 0.1 eV to 5000 eV, and the ALS is designed to provide very short pulses of synchrotron light (tens of picoseconds) for the many experiments with timing requirements in this range. In order to achieve these goals, the storage ring incorporates twelve long straight sections in which special magnetic devices, wigglers, and undulators will provide intense beams of synchrotron light.

Wiggler and undulator magnets have become increasingly important and successful as high-intensity synchrotron-radiation sources, and the capability to design and construct such devices has improved greatly. Therefore, the ALS will take advantage of the photon-beam intensity and the flexibility of such devices, and most or all of its photon beams will originate from wigglers and undulators rather than from bending magnets. Since wigglers can each service several photon beam lines, over 30 beam lines can eventually be constructed at the ALS from these sources as well as additional beam lines from bending magnets.

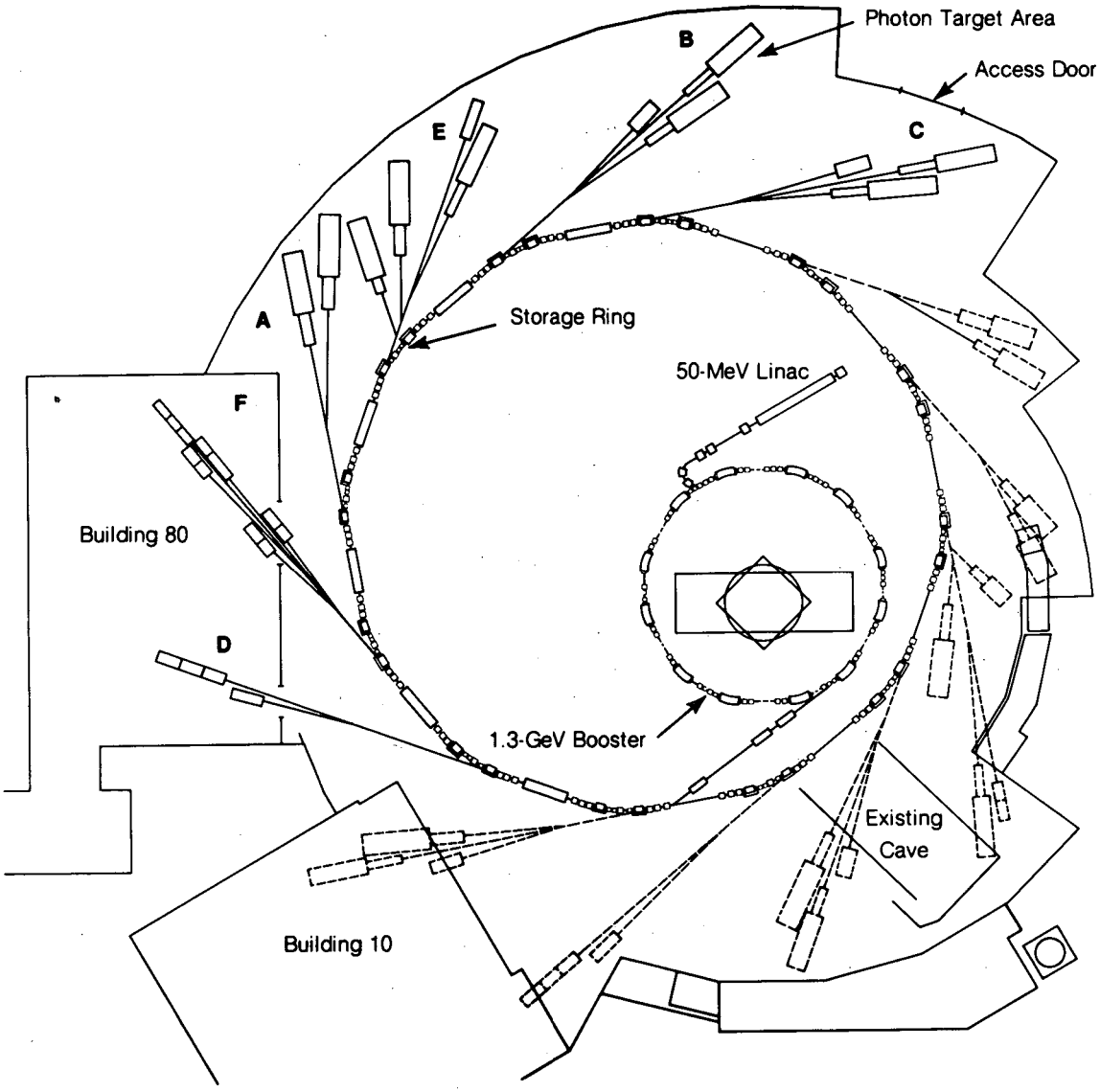


Figure 1. General plan for the Advanced Light Source. **(XBL 833-8926)**

Aside from providing high photon beam intensity, the use of wigglers and undulators has another important advantage. If the wiggler or undulator fields are higher than the bending magnet field, the photons emitted will have higher energies than those from bending magnets. That is, a relatively low-energy electron beam can provide high-energy photons from a high-field wiggler or undulator. An electron energy of 1.3 GeV is optimal for the ALS, since it will provide intense photon beams with energies from 0.1 to 5000 eV, the major region of interest. This electron energy is high enough for a long beam lifetime, yet low enough to permit a very low electron-beam emittance.

For the benefit of synchrotron-radiation experiments requiring high-energy photons, the ALS will be operated at electron energies up to 1.9 GeV. Photons with energies up to 10 keV will then be available from undulators, and photons with energies up to 40 keV will be available from a superconducting wiggler. However, at higher electron-beam energies the ALS will have an increased electron-beam emittance and, therefore, reduced spectral brilliance in some photon beams.

The low electron-beam horizontal emittance is very desirable for a synchrotron-radiation source, because a low emittance means a small cross-sectional area for the electron beam. In turn, a small cross-sectional area implies a high photon-beam spectral brilliance. Furthermore, a small emittance for the electron beam permits the construction of very high-performance undulators.

Several considerations are important in the choice of a frequency for the radiofrequency accelerating system. Foremost is the desire to provide a very short bunch length for the benefit of experiments with critical timing requirements. A fairly high frequency (around 500 MHz) has been selected to provide photon pulses as short as 23 picoseconds. For those experiments requiring long dead times between successive pulses, the storage ring will be operated with a few electron bunches, at lower average electron currents.

Table 1 presents a list of parameters for the ALS electron storage ring. Figure 2 shows the spectral brilliance of the ALS photon beam lines for an electron current of 400 mA. The spectral output of an undulator consists of a number of sharp peaks; the smooth curves shown in Figure 2 are drawn through the maxima of the spectral peaks for each undulator as it might be installed in the ALS. For all ALS and NSLS curves in Figure 2 the electron beam vertical emittance was assumed to be one-tenth the horizontal emittance. The label "average spectral brilliance" means that the spectral brilliance has been averaged over time, i.e., the small duty factor of the electron beam has been ignored. While an electron bunch traverses an undulator, for example, the instantaneous spectral brilliance is much higher than that shown in the figure.

The "initial performance goals" given in Table 2 represent the state-of-the-art performance as scaled from existing storage rings, and these figures may be used as a general guide by prospective users of the ALS. The peak currents in this table can be used to calculate instantaneous spectral brilliances and photon fluxes from Figure 2, which shows curves for 400-mA average current. The "ultimate performance goals" represent some extrapolation from current experience. However, these ultimate goals are consistent with presently understood limits on storage-ring performance.

In estimating the peak operating parameters presented in Table 2, a number of possible limitations to storage-ring performance have been considered. These include various high-current beam instabilities, gas scattering, ion trapping, etc., which have been the subject of detailed studies during the past year.

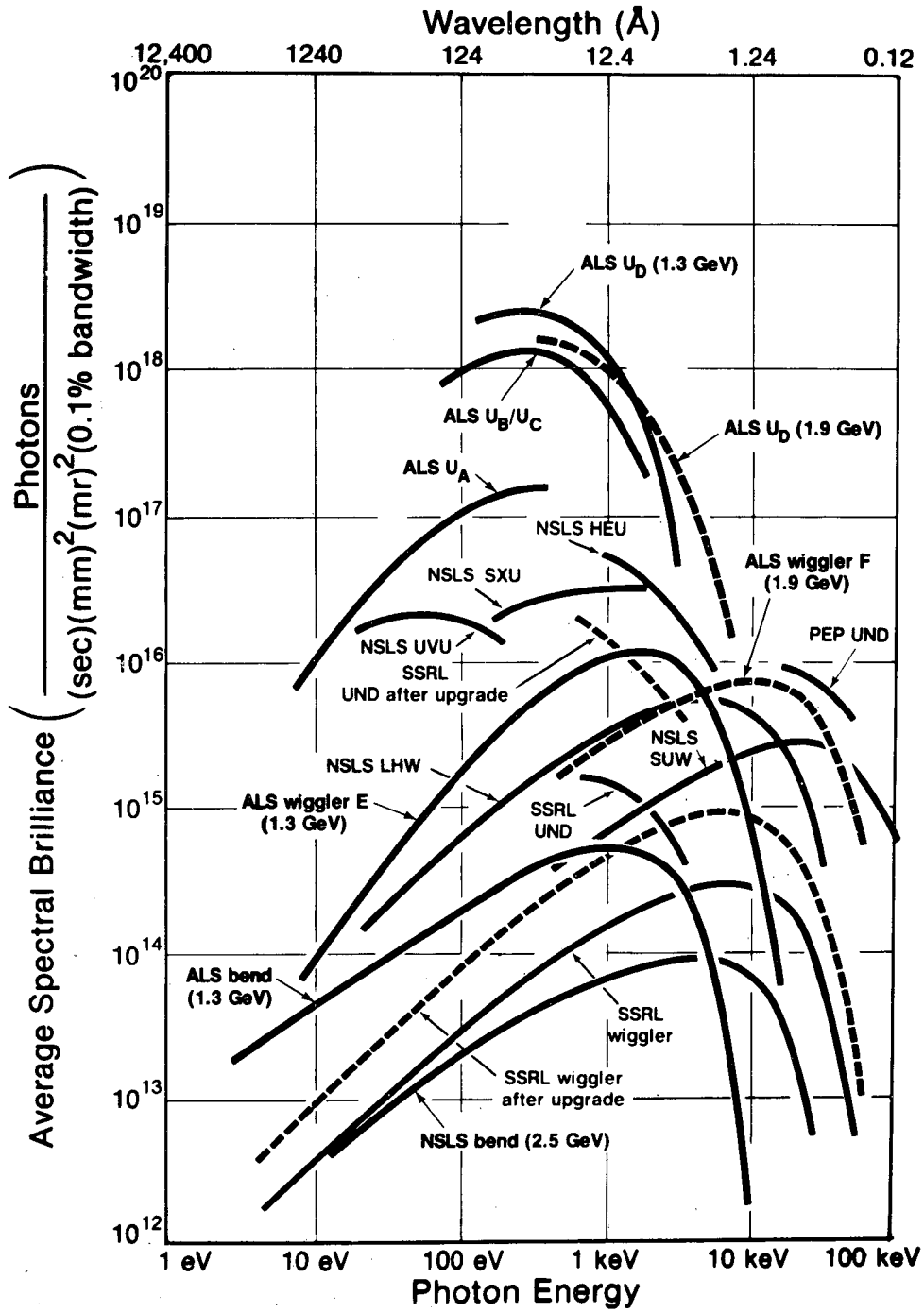


Figure 2. Spectral brilliance comparisons. (XBL 835-284)

Table 1. Advanced Light Source design parameters (electron storage ring).

Electron Energy, GeV	1.3
Electron Current, mA	400
Circumference, m	182.4
Horiz. Emittance, πm-rad	6.8×10^{-9}
No. of Superperiods	12
No. of Long Straight Sections	12
Length of Long Straight Sections, m	6
Maximum Horizontal Beta, m	13.3
Maximum Vertical Beta, m	13.3
Horizontal Tune	13.8
Vertical Tune	7.8
Horizontal Chromaticity	-32.0
Vertical Chromaticity	-17.5
Energy Loss per Turn – Dipoles Only, keV	64
Radiofrequency, MHz	499.65
Harmonic Number	304
1.9-GeV Operation	
Dipole Field, T	1.60
Max. Quad. Gradient, T/m	22.9
Energy Loss per Turn – Dipoles Only, keV	291

ALS Lattice

The lattice of the ALS electron storage ring is designed to accommodate a large number of radiation-source insertion devices, to produce a very low electron-beam emittance, to have favorable values of the various lattice functions at the long straight sections, to have an acceptable natural chromaticity, to have a high periodicity to reduce structure resonances, and to have low beta functions to minimize beam loss due to gas scattering.

The ring is divided into twelve superperiods, and it contains twelve 6-meter-long straight sections for undulators, for wigglers, and for injection. The dispersion is zero in the long straight sections to minimize source widths and angular divergences. Furthermore, because the wigglers and undulators are located where the dispersion is zero, they will actually tend to reduce the electron-beam emittance.

Table 2. Approximate parameters for ALS standard operating modes.

Energy, GeV	0.9	1.3	1.3	1.3	1.9
No. of Bunches	250	250	20	4	250
Initial Performance Goals					
Average Current, mA	400	400	200	30	400
Bunch Length, ps	23	23	38	35	27
Peak Current, A	34	34	128	104	29
Ultimate Performance Goals					
Average Current, mA	400	400	400	200	400
Bunch Length, ps	23	23	50	90	27
Peak Current, A	34	34	194	270	29

The unusually low emittance of the ALS storage ring is achieved by arranging to have low values of momentum dispersion and horizontal beta function in the bending magnets. Because the behavior of this dispersion is controlled solely by the single quadrupole, QF, located between each pair of dipoles, the tune and beta values may be controlled independently (within limits) by the quadrupole triplets located near the long straight sections. Studies have shown that this lattice can readily be retuned to compensate for the substantial vertical edge focusing of a superconducting wiggler.

The design of the ALS lattice leads to reasonable values of the natural chromaticity and also provides appropriate locations to place sextupole magnets for correcting this chromaticity.

The required vacuum-chamber aperture in the ALS, sometimes called the "beam stay clear," has been set at ± 32 mm horizontally and ± 24 mm vertically. These parameters were selected after considering the betatron oscillations of electrons, the momentum dispersion of the storage ring, the aperture requirements for injection, and an allowance for closed-orbit errors.

The ring magnets consist of four basic types: dipole magnets to bend the beam, quadrupole magnets to focus the beam, sextupole magnets for chromaticity corrections, and small dipole magnets for beam steering. The storage-ring bending magnets are "C" magnets (Figure 3) to permit the convenient extraction of the synchrotron radiation. Since the synchrotron-radiation beam and the electron beam leave a straight section along the same path, they separate only at the next bending magnet, where the beam ports for the photon beam lines are located. The magnets are straight, and the sagitta required for the curvature of the electron beam trajectory is accommodated by a large pole area. These bending magnets are laminated, and the entire "C" shape is punched in one piece to ensure structural rigidity

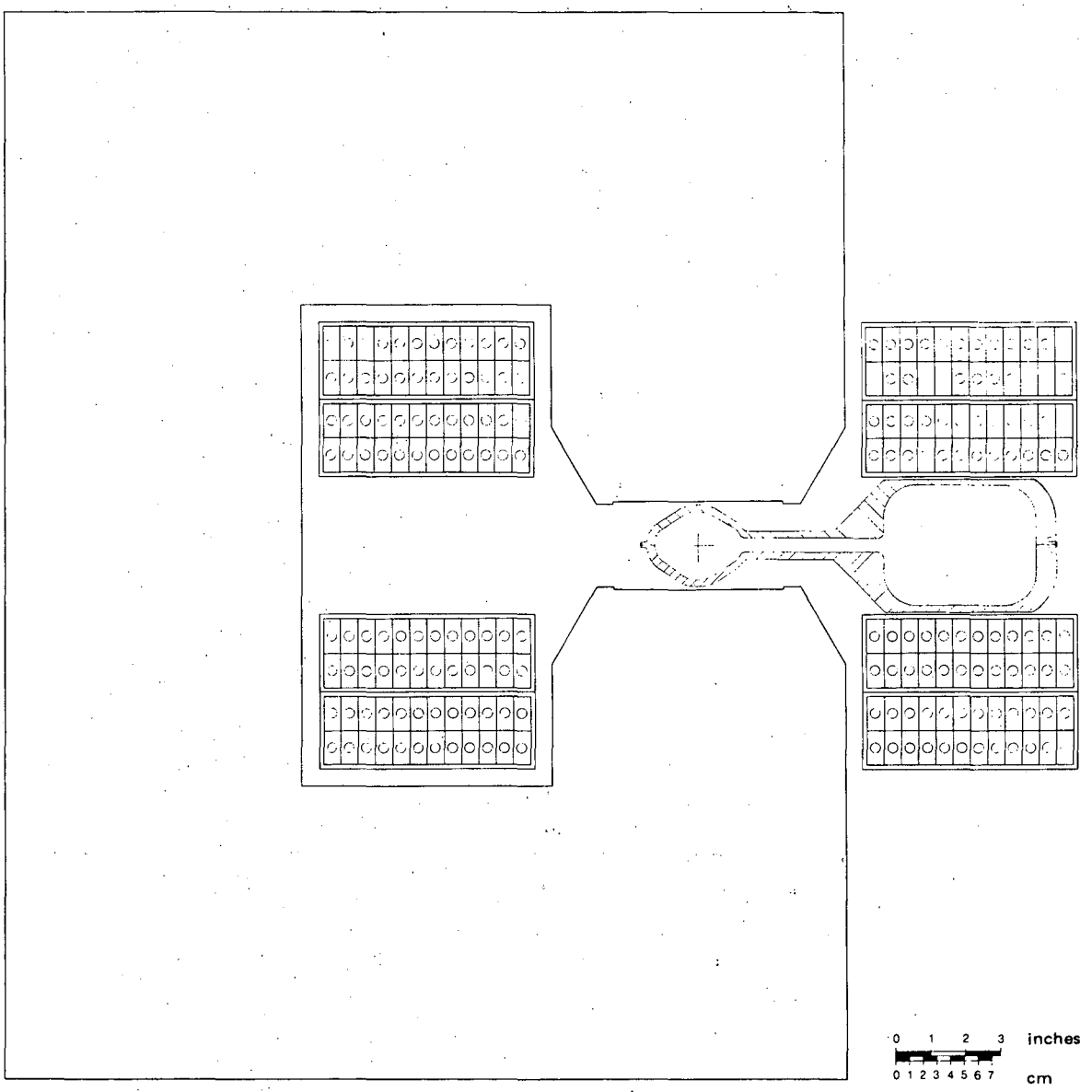


Figure 3. Storage ring bending magnet cross section. **(XBL 833-8932)**

Table 3. Storage ring dipole-magnet parameters.

Number required	24
Bending angle, degrees	15
Field, T @ 1.9 GeV	1.6
Gap, cm	6.5
Magnetic length, m	1.04
Current, A	958
Voltage, per magnet, V	22.1
Power, per magnet, kW @ 1.9 GeV	21.2

and to maintain the required high-precision poletip contour. Table 3 is a short list of storage-ring bending-magnet parameters for 1.9-GeV operation.

There are a large number of quadrupole magnets in the ALS electron storage ring because of the need to provide very strong focusing. These quadrupoles may be divided into four groups by magnet lengths: 20, 37, 29, and 30.5 cm. The aperture diameter is 6.5 cm for all magnets. In the ALS design, the synchrotron radiation from a wiggler or undulator passes through three quadrupole magnets before it leaves the ring at a bending magnet. Therefore, the quadrupole magnets must be designed to accept a vacuum chamber that is horizontally enlarged to transmit a wide, flat "fan" of synchrotron radiation. Some key parameters of the quadrupole magnets at 1.9 GeV are given in Table 4.

Thirty-six sextupole magnets are used to correct the natural chromaticity of the storage ring. These magnets also have a 6.5-cm-diameter aperture and are approximately 20-cm long. They are designed to accept a horizontally enlarged vacuum chamber, therefore they are constructed in three sectors and are supported in such a manner as to provide complete open access along the outer radius. The pole tip field is 0.44 T, and the power dissipation is less than 2.5 kW per magnet.

The functions of the radiofrequency accelerating system in the storage ring are to bunch the beam and to restore the beam energy lost through synchrotron radiation in the wigglers, undulators, and bending magnets. The rf system consists of four cavities driven by klystrons. The cavity gap voltage must be high enough to offset the beam energy loss and to produce very short electron bunches. Table 5 gives some parameters of the rf system for the storage ring.

The rf system is divided into two identical rf subsystems. The major components of an rf subsystem include two single-cell accelerating cavities, a 300-kW klystron amplifier, a high-voltage power supply and crowbar unit, regulation and control circuitry, and a phase-stable reference line.

The single-cell accelerating cavities have low-loss, semi-spherical designs, and they are very similar to those used at the KEK Photon Factory. The single-cell cavity design was selected because it has fewer potentially troublesome higher order modes, as compared with higher-impedance, multi-cell designs.

Table 4. Ring quadrupole-magnet parameters.

Quadrupole Type	Q1	Q2	Q3	QF
Number Required	24	24	24	12
Aperture Diameter, cm	6.5	6.5	6.5	6.5
Effective Length, cm	20.0	37.2	29.1	30.5
Maximum Gradient, T/m @1.9 GeV	10.7	22.8	22.8	22.8
Current, A	280	630	630	630
Voltage, per magnet, V	1.8	7.0	5.8	6.0
Power, per magnet, kW @ 1.9 GeV	0.5	4.4	3.7	3.8
Total Power for Circuit, kW	12	106	88	46

Table 5. RF-system parameters.

Frequency, MHz	499.65
Harmonic Number	304
Nominal Bunch Length, 2σ, ps	35
Peak Cavity Gap Voltage, MV	4.4
Transit Time Factor	683
Peak Electron Energy Gain per Turn, MeV	3
Beam Current, mA	400
Synchrotron Radiation Power, kW	200
Power Loss to Parasitic Modes, kW	25
Total Effective Shunt Impedance, MΩ	32
Fundamental-Mode Cavity Dissipation, kW	280
Total rf Power Installed, kW	600

Injection System

The injection system for the ALS consists of a 50-MeV electron linear accelerator and a 1.3-GeV booster synchrotron. High-energy injection into the electron storage ring was chosen to minimize for experimenters any possible interruptions caused by the filling process. Injection at the normal operating energy will help to avoid small, but disruptive, changes in the beam-spot positions that can be produced by energy ramping.

The electron linear accelerator is a 50-MeV S-band linac about 8-m long. The electron beam from the linac is modulated, or chopped, to provide the required time structure to fill the rf buckets in the booster synchrotron. The use of different operating modes permits varying the number of electron bunches in the booster and in the storage ring. All the rf buckets can be filled with electron bunches (aside from a gap in the train of bunches caused by the injection kicker magnet in the booster), some of the buckets can be filled, or even a single bucket can be filled in the booster and storage ring. To fill all the buckets, a 185-ns, 20-mA linac beam pulse fills 80% of the booster circumference, leaving a 40-ns gap for the rise time of the extraction kicker magnet. Fast, single-turn injection is used in this mode. An alternative mode of linac operation is required when the storage ring is to be filled with only a single bunch of electrons, to accommodate experiments that require a long "dead time" between photon pulses. For the single-bunch or few-bunch modes of operation, the linac beam is modulated so that each burst consists of a train of 2-ns pulses at intervals of 32 ns. Multi-turn injection into the booster puts all of these pulses into seven equally spaced rf buckets in the booster. Details of the booster operation can be found in the *Conceptual Design Report.*

The linac can deliver up to 50 mA, with a small duty factor. The traveling-wave linac consists of two sections of constant-gradient corrugated-wave-guide (CWG) accelerator. We estimate the linac emittance of about $6.4 \times 10^{-6}\ \pi$ m-rad in each transverse plane. The major beam components of the linac include a chopped electron gun, an S-band buncher phase-locked to the linac, and two sections of standard CWG accelerator. Other major linac components include a 30-MW klystron amplifier and power system, a signal source, and an rf control system.

The booster synchrotron accepts the the 50-MeV beam from the linac, accelerates it to 1.3 GeV, and transfers it to the storage ring. The booster cycles at 1 Hz, each cycle consisting of a 0.35-second accelerating ramp, a 0.2-second flat top for allowing the beam to damp completely, a 0.35-second descending ramp, and a 0.1-second quiescent period.

The lattice of the booster synchrotron is shown in Figure 4. It is similar to the lattice of the storage ring in that it is made up of a series of achromatic cells with intervening long straight sections. There are six such achromatic cells, and the six long straight sections are each 2.4-m long. The circumference is 67.2 m (7/19 of the storage-ring circumference). This lattice was chosen over several others that were studied because it has the following favorable properties: convenient injection and extraction; low emittance; low dispersion; high superperiodicity; adequate space for sextupoles, beam monitoring equipment, and correction magnets; and efficient use of space. These properties tend to minimize the injection- and extraction-magnet requirements, the required apertures, and the required rf voltage.

INSERTION DEVICES

The task of the accelerator design team is to provide an electron storage ring with characteristics such as low emittance, short bunches, and long straight sections that permit great flexibility in the selection of insertion devices. The ALS storage ring described above meets these criteria. Altogether, 12-long straight sections are available, and 12 insertion

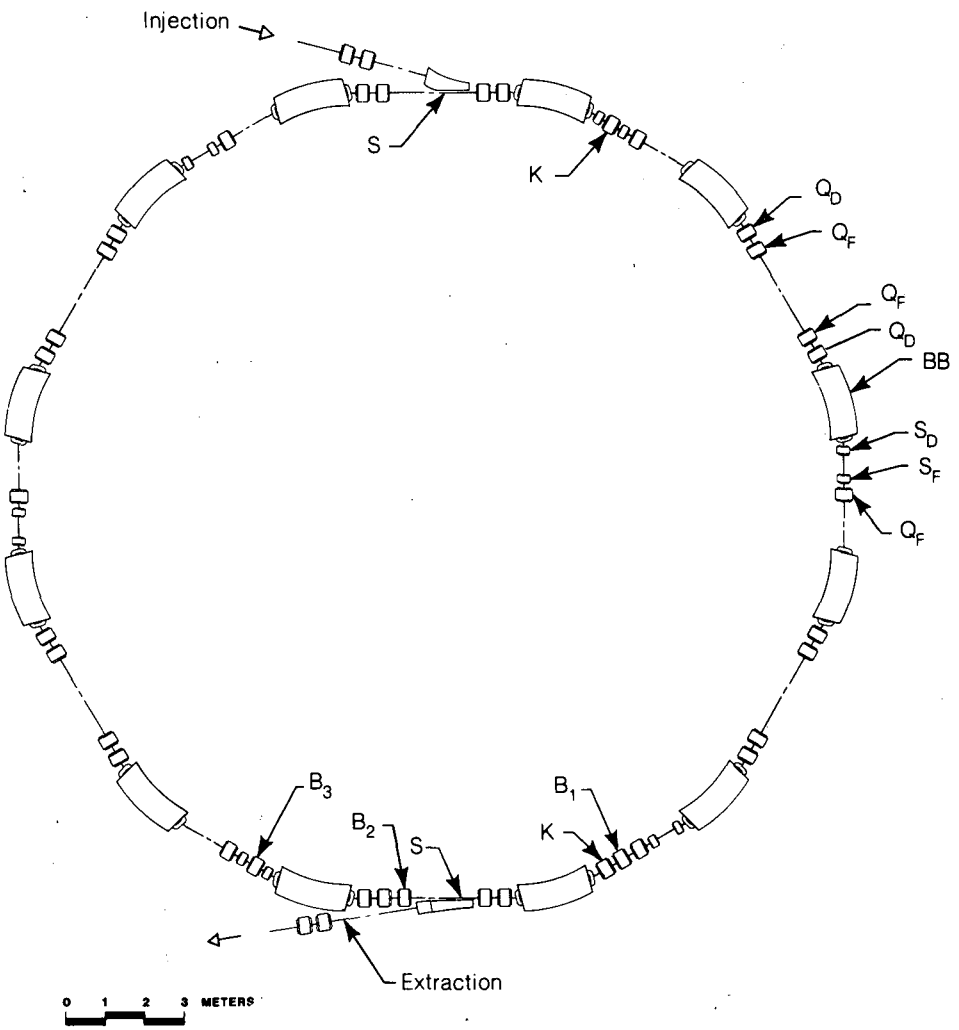


Figure 4. Booster synchrotron lattice. **(XBL 833-8940)**

Table 6. Tentative ALS insertion devices (1.3 GeV).

Name	Insertion Device Type	Peak Field (T)	Period (cm)	No. of Periods	Length (m)	E (eV)
U_A	Permanent Magnet Undulator	0.29	16.7	30	5	8-200
U_B/U_C	Hybrid Undulator	0.54	5.0	100	5	75-3000
U_D	Hybrid Undulator	0.57	3.5	142	5	200-5000 (up to 10000 at 1.9 GeV)
W_E	Hybrid Wiggler	1.60	10.0	25	2.5	0.1-10,000
W_F	Superconducting Wiggler	5.0	14.	14	2	1-20000 (up to 40000 at 1.9 GeV)

devices can ultimately be accommodated. Initially, however, a complement of only six devices (four undulators and two wigglers) is planned.

We have selected a set of possible insertion devices, whose properties are summarized below. We recognize, however, that the users of the facility must be involved in the final choice of insertion devices, and, as noted above, modifications to the present list are already underway in response to the May 9-11 user's workshop. Further modifications are also possible.

The parameters of the six planned insertion devices are listed in Table 6. (Note that the undulators U_B and U_C are identical devices.) These parameters are chosen to maximize the high spectral brilliance of the undulator radiation and also to cover the maximum range of photon energies.

The high-field wiggler W_F will use superconducting technology. The low-field undulator U_A has a field that is low enough to build it as a pure permanent magnet device. The other insertion devices (U_B, U_C, U_D, W_E) will be built as hybrid devices using both samarium-cobalt permanent magnets and vanadium permendur pole pieces. Undulator U_D and wiggler W_E have the smallest pole tip gaps, 1.2 cm, at the indicated fields, which will result in a 1.0-cm minimum beam aperture. These hybrid designs will be very similar to that of the wiggler for the LBL/Exxon beam line at SSRL, which is now close to completion (Figure 5). This hybrid wiggler is 2-m long, has 55 poles with a 7.0-cm period, and has a maximum field of 1.64 T at a 0.8-cm gap.

Photon Beam Lines

Multiple photon beam lines can be built to use the radiation from a single insertion device, and, in some cases, the simultaneous operation of multiple beam lines is possible. In other cases, however, a removable mirror is used to switch the radiation from one beam line to another. Present plans call for fourteen photon beam lines to be constructed during the startup phase of the ALS; these beam lines will make use of the radiation from the initial

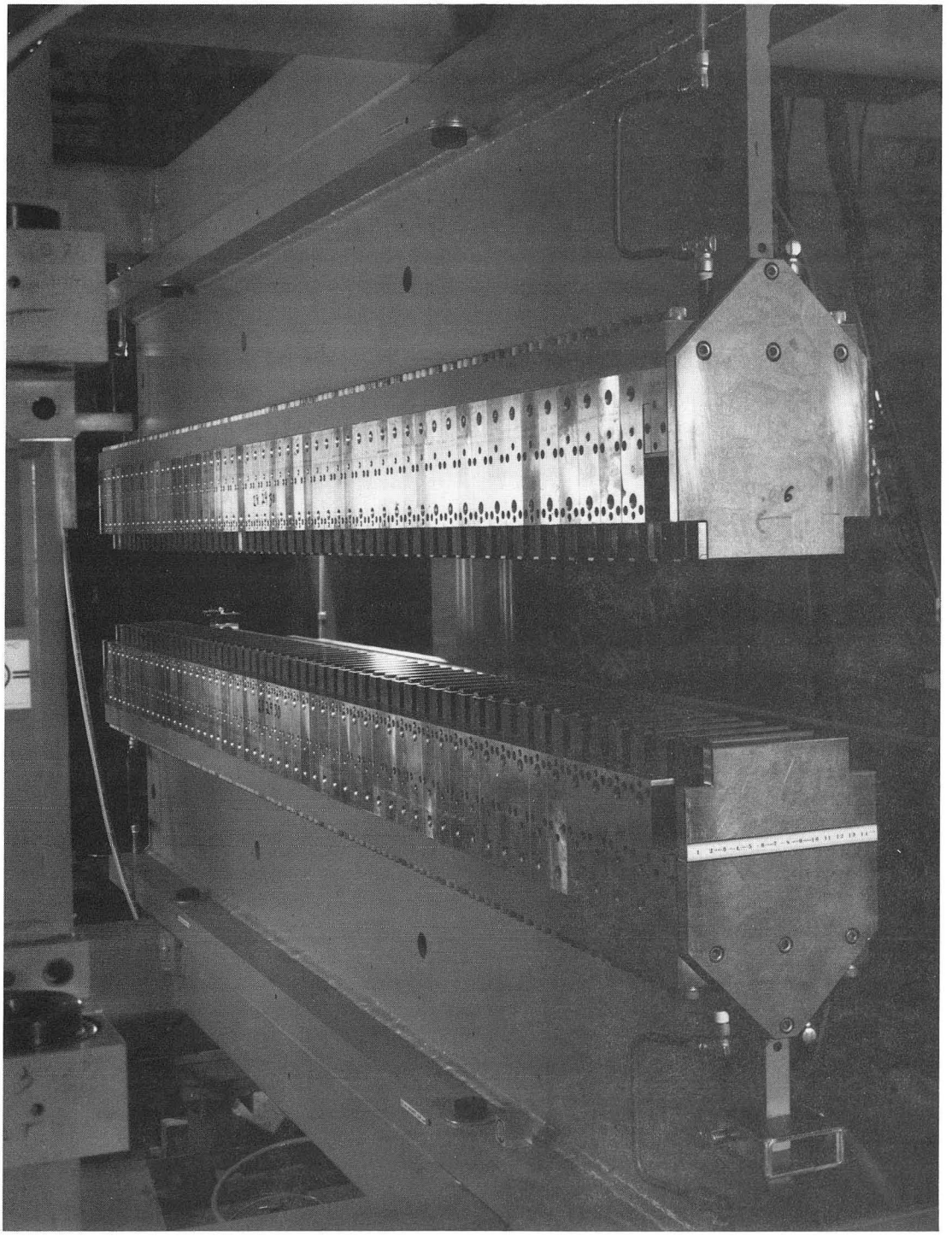


Figure 5: Hybrid wiggler for LBL/EXXON Beam Line VI at SSRL. (CBB 832-1798)

complement of six insertion devices. These 14 beam lines have been planned in such a way that an additional 5 photon beam lines can be built at these 6 straight sections. Of course, we recognize that final plans for these experimental areas must be made in consultation with the users of the facility; thus, modifications to the layouts described here will be accommodated as required.

The first optical element of a beam line is usually a mirror. The glancing angle of incidence on the mirror must meet three criteria. First, the cutoff energy must lie above the desired range of the deflected beam line. Second, the thermal loading on the mirror must be within tolerable limits, i.e., less than about 10 W/cm^2 with present technology. Third, enough working space must be provided between the beam lines. The first two requirements tend to make the glancing angle smaller, whereas the third makes it larger. Deflection angles of the ALS beam lines are obtained by balancing the above conflicting requirements.

Undulator radiation achieves its maximum spectral brilliance when observed through a small aperture, which for the ALS is a pinhole 6 mm in diameter at 20 m. Therefore, an undulator beam line is provided with a downstream slit assembly. If the main beam line has a secondary line, this means that the deflected and undeflected lines cannot be operated simultaneously. However, efficient use of the undulator line by several experimental groups can be achieved by producing separate monochromators for the main line and the secondary line. One team can then be performing an experiment in the main line while the other team is installing an experiment in the secondary line. Details of the proposed beam lines are provided in the *Conceptual Design Report.*

ADVANCED ACCELERATOR PROJECTS

ADVANCED ACCELERATOR PROJECTS

MEDICAL ACCELERATOR

AFRD, in collaboration with the Laboratory's Biology and Medicine Division, is developing a detailed design for an advanced medical accelerator facility dedicated to clinical uses of heavy ions. This engineering design will form the basis of a construction proposal which will include details of cost estimates, construction schedules, and operating costs.

During the year, optimized specifications for all major accelerator components were developed in considerable detail. This activity has proceeded in close interaction with BioMed personnel, and a careful integration with engineering and technical staff has been maintained to ensure that all requirements of potential users of the facility are met in the most cost-effective manner. Continuing evaluations of technical and scientific options have been made, conceptual engineering design work has been completed, and detailed engineering design is ready to proceed. Beam delivery schemes and layouts of the treatment facilities have been refined to provide the most compact arrangement for efficient use of the facility.

The accelerator is designed to provide flexibility in the choice of ion species and energies on a patient-to-patient basis, while at the same time providing the highest standards of reliability and operational simplicity that are required for a hospital-based operation. The injection system provides the synchrotron with 8 MeV/N ions up through argon at typical intensities of 4×10^8 particles/pulse for silicon and 1×10^8 particles/pulse for argon. The injector consists of multiple PIG ion sources injecting an RFQ linac at 8.4 keV/N with a low charge state ion, typically Si^{4+}, with $q/A > 0.14$. The RFQ accelerates the beam to 200 keV/N and injects an Alvarez linac, which continues the acceleration to 1750 keV/N. At this energy, a stripper raises the charge state to $q/A > 0.35$, and a second Alvarez linac accelerates the ion to 8 MeV/N. The ion is then fully stripped and injected into the synchrotron in a single turn. Technical parameters for the injector package are summarized in Tables 1 and 2.

The synchrotron has a circumference of 91.8 m and consists of 12 main dipole magnets and 18 quadrupole magnets. A resonant energy storage power supply is proposed for the dipole magnets. A resonant extraction system will spill the beam at a uniform rate from the synchrotron at energies which can be varied from 100 to 800 MeV/N. The maximum cycle rate is 4 Hz. Lattice parameters for the synchrotron are summarized in Table 3.

A key element in the design of this accelerator is a high-performance control system that provides: accelerator modeling, to facilitate changes in operating mode; automatic beam tuning, to simplify accelerator operations; and diagnostics, to enhance reliability. Our approach is to utilize many microcomputers operating in parallel to collect and transmit data; complex numerical computations are performed by a powerful minicomputer. In order to provide the maximum operational flexibility, the capability of dealing with pulse-to-pulse

Table 1. RFQ parameter summary.

Input energy, keV/N	8.4
Output energy, keV/N	200
Length, cm	225
Frequency, MHz	200
Normalized acceptance, π cm-mrad	0.05
q/A	0.143
Total number of cells	346
Rf power (peak), kW	180
Vane-vane voltage, kV	51

Table 2. Alvarez linacs parameter summary.

	Prestripper	Poststripper
Input energy, keV/N	200	1750
Output energy, keV/N	1750	8000
q/A	0.143	0.357
Frequency, MHz	200	200
Focusing sequence	FFDD	FFDD
B′, first cell, kG/cm	11.8	7.7
Quad strength B′L, kG	51	35
Aperture radius, cm	0.5, 0.8	1, 1.25
Axial field, MV/m	1.8-2.4	2.2
g/L	0.2-0.24	0.26
Length, m	10.74	11.27
Tank inside diameter, cm	95	95
No. of cells	90	79
Mode	$2\beta\lambda$	$\beta\lambda$
Normalized acceptance, π cm-mrad	0.1	0.5
Nominal rf power, MW	1.0	1.2
Stored Energy	45	53
Filling time, μs	46	44

Table 3. Medical accelerator lattice parameters.

Parameter	Expression	Design Value
Maximum kinetic energy, MeV/N	T	800
Injection energy, MeV/N	T_i	8
Charge/mass ratio	Q/A	$\frac{1}{2}$
Circumference, m	$2\pi R$	91.8
Superperiods	N_S	3
Number of cells	N_C	9
Dipoles	M_D	12
Quadrupoles	M_Q	18
Lengths, m		
– dipole/quadrupole	LD/LQ	3.2/0.4
– drift spaces	O/L	0.75/4.70
Magnetic field, T	B_o	1.593
Magnetic radius, m	ρ	6.1115
Rigidity, T-m	$B\rho$	9.7373
Gradients $K = B'/B\rho$, m^{-2}	KF/KD	0.7068/-0.5549
Maximum beam displacement, mm		
– quadrupoles	a_x/a_y	$\pm 42.3/\pm 19.6$
– dipoles		$\pm 37.0/\pm 17.8$
Vacuum chamber half apertures, mm		
– quadrupoles	A_x/A_y	50/50
– dipoles		45/19
Beta function, dispersion maxima, m	$\beta_x/\beta_y/\beta_\rho$	15.6/17.0/5.43
Tunes	ν_x/ν_y	2.312/2.285
Natural chromaticity	ξ_x/ξ_y	-1.70/-2.40
Transition gamma	γ_t	2.309
Injection gamma/beta	γ_i/β_i	1.0086/0.13134
Extraction gamma/beta	γ_f/β_f	1.859/0.8430
Normalized emittance ($\varepsilon\beta\gamma$), mm-mrad	ε_n	1.5π
Emittance at injection, mm-mrad	ε_i	12.5π
Momentum spread at injection, %	$(\Delta p/p)_i$	± 0.4

changes in beam energy and ion species is incorporated. Some control system elements have been tested in a working accelerator environment at LBL.

An RFQ linac has been built at LBL in order to enhance Bevalac operations (see *Bevatron Local Injector Upgrade*). The specifications of this device are identical to those for the medical accelerator. Early tests indicate that the design holds promise for reliability and simplicity of operation.

TEVALAC

Efforts to define the most desirable performance characteristics and the most efficient design for a next-generation high-energy heavy-ion accelerator continued through 1982, culminating in a document (Pub-5081) submitted to DOE/NSAC at year's end. The report presents the scientific potential of high-energy nucleus-nucleus collisions based on the work of numerous contributors, workshops abroad and in the U.S. (Bielefeld, MSU, LBL) and outlines the thrust of our long-range planning and R&D plans for the development of superconducting magnets and detectors.

Based on the then current understanding of the physics and an analysis of the diverse user needs, the following performance specifications were derived:

- Maximum kinetic energy: ~10 GeV/N for U ions.
- Large energy range: extracted beams down to < 20 MeV/N.
- High-intensity, high-quality beams of all ions with emphasis on performance for mass numbers A ~ 200.
- A high degree of experimental multiplicity and flexibility.

Such a facility will allow experimentation in a broad area of physics, from atomic physics and low-energy nuclear physics through Bevalac-type experiments and their extensions right to the pinnacle of heavy-ion physics, the predicted observation of quark deconfinement. Figure 1 shows how such a facility would both complement and transcend the capabilities of existing facilities in the U.S. and abroad.

The machine design developed aims at meeting these requirements while minimizing capital cost by maximum utilization of valuable existing facilities, and at keeping operating cost low through attention to power demand and operating and maintenance staff requirements. The design makes use of the SuperHILAC as a powerful heavy-ion injector and two superconducting magnet rings of identical focusing structures, one atop the other in the same enclosure. One ring is for accelerating the ions and a second for "holding" fully stripped ions, either for transfer back to the accelerating ring or for slow extraction at essentially 100% duty factor to experimenters. The two rings can deliver beams to experimenters simultaneously, thereby providing good user multiplicity and flexible operation. Basic ring parameters are summarized in Table 4.

The basic mode of operation proceeds as follows:

Ions are injected, without stripping at the linac exit, into R1 and accelerated to ~ 1 GeV/N. They are then ejected, passed through a stripper to produce bare nuclei, and injected into R2. There they circulate while the magnetic field in R1 is readjusted to match the lower rigidity of the fully stripped ions. Reinjection into R1, acceleration to final energy and extraction, completes the cycle.

This approach provides significant advantages. First, it provides a simultaneous intensity and energy optimization. Intensity is kept high by eliminating low-energy stripper

Table 4: Tevalac ring parameters (R1 = accelerator; R2 = stretcher/holder).

Parameter	Expression	Design Value R1	Design Value R2
Magnetic rigidity, T·m	$(B\rho)_{max}$	94	47
Kinetic energy (for U^{92+}), GeV/N	T_{max}	10	4.6
Peak field, T	B_{max}	6	6
Ramp rate, T/s	B	1	$\ll 1$
Machine circumference, m	C	460	460
Acceptance, vertical, mm·mrad	ε_v	60	60
Acceptance, horizontal, mm·mrad	ε_h	30	30

stages where losses are high compared to stripping at ~1 GeV/N, as recently verified at the Bevalac. Through the availability of fully stripped ions, then, optimum use is made of the magnetic guide field. Second, as outlined in Pub-5081, the availability of the second ring allows numerous variations of the basic cycle, resulting in the availability of at least two primary beams (different ions and/or energy) to the experimenters. The particle flux available on target, based on the space-charge limit of the machine which should be attained with future SuperHILAC improvements, is shown in Figure 2.

The rings were designed to be larger than the minimum size required for the specified energies. This lattice design is deliberately loosely filled with dipole magnets to allow either an upgrade to a fixed target accelerator of at least 20 GeV/N for uranium or a conversion to a colliding beam facility.

Although developed in considerable detail, the present Tevalac design is but one possible solution to producing, in a cost-effective way, high-energy, heavy nucleus-nucleus collisions. Alternatives continue to be pursued, as does theoretical work to clearly delineate the energy region of greatest experimental interest.

The technologically most important component in achieving these goals is the development of a suitable superconducting magnet. Envisaged is a medium high field (~6T) magnet, capable of being rapidly ramped with low heat loss (1 T/s, < 15 W/m) and with a large dynamic range (~50/1). An R&D program has been formulated that concentrates on coil design, conductor development, multipole correction coil design, and construction methods.

ELECTRON BEAM ION SOURCE (EBIS)

The EBIS program that has been carried out over the last three years has now been completed. The R&D effort was directed toward gaining an understanding of EBIS operation and engineering requirements so that a full-scale cryogenic device could be constructed if chosen. Although this option was not taken, the objectives of the R&D program were achieved – an EBIS "test stand" was constructed that demonstrated EBIS behavior and with

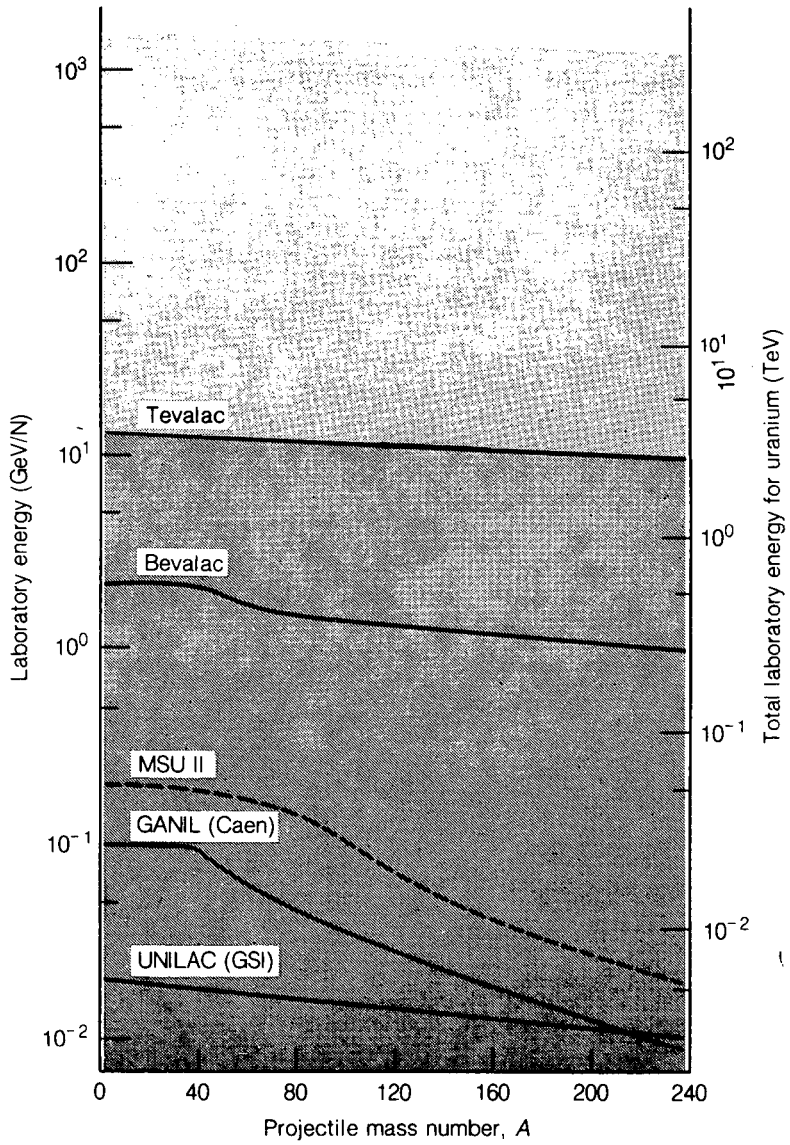


Figure 1. The range of laboratory kinetic energies (GeV/N) as a function of projectile mass (*A*) available with the Tevalac. For comparison, several other accelerators that either have or will have the capability of accelerating uranium for nuclear science research are also shown. The Tevalac would replace the Bevalac, increasing the projectile energy by a factor of ten. The total kinetic energy (in TeV) for a uranium ion is shown on the right-hand ordinate. The lightly shaded area at the top of the figure represents energies above the Tevalac that are presently obtainable only in cosmic-ray studies. (XBL 833-8637)

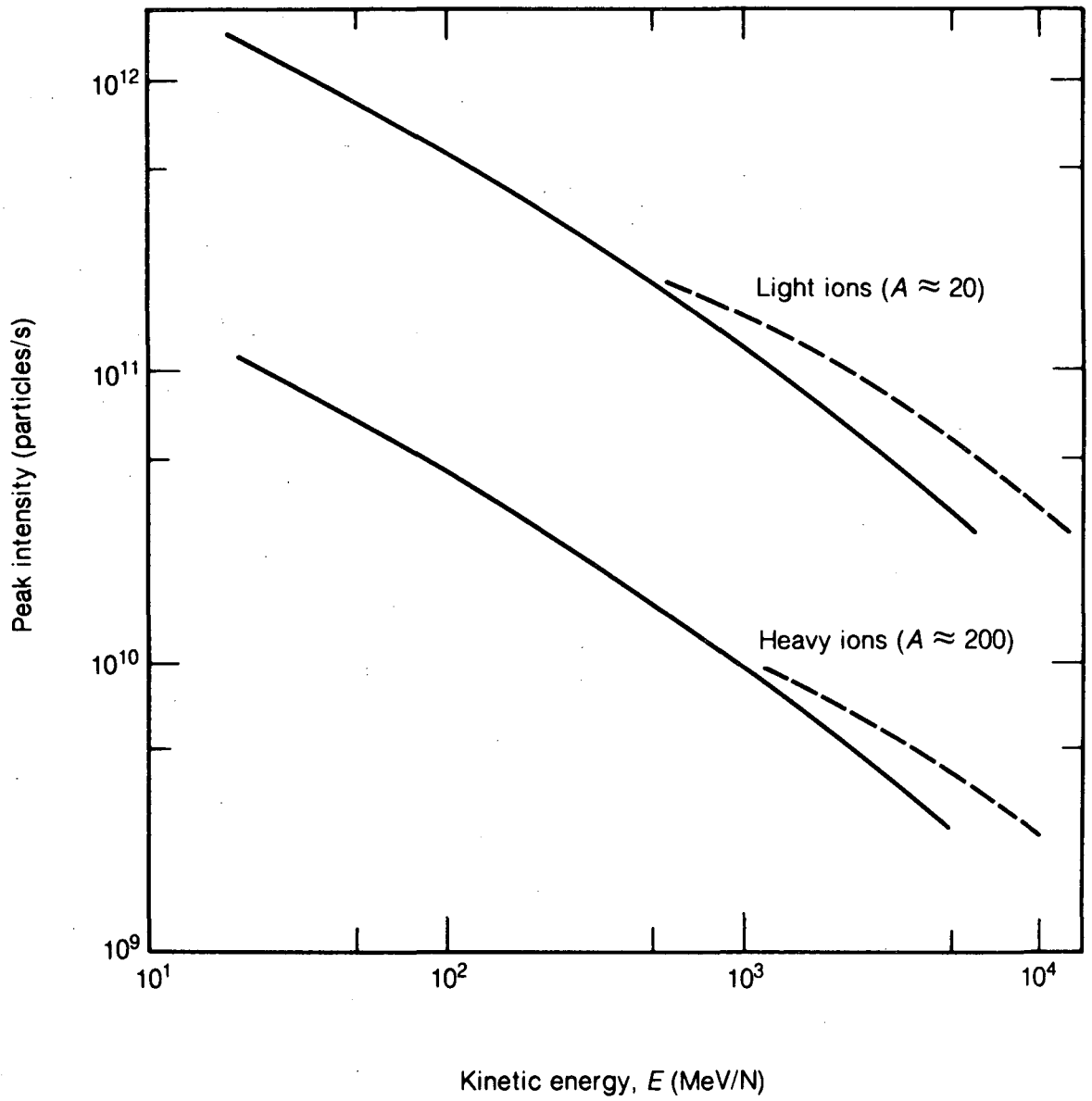


Figure 2. Peak intensity for partially stripped ions versus energy, for both light ions ($A \approx 20$) and heavy ions ($A \approx 200$). The dashed lines show the peak intensity increase and the doubling in maximum energy that result from complete stripping at an intermediate energy followed by further acceleration.

(XBL 836-329)

which meaningful research was carried out. The amount of positive ion charge extracted per pulse reached a maximum of 10^{10} (electron charge equivalent). In normal operation the extracted ion pulse was about 30 μs wide. However, for cyclotron applications, a much wider pulse is needed, together with a high repetition rate. By appropriately tailoring the drift tube potential distribution as a function of time, the pulse width has been stretched to 5 ms and the repetition frequency to 30 Hz.

Four different methods of injection of feed material were investigated: (i) simply bleeding into the vessel a fixed pressure of the running gas, e.g., 2×10^{-8} Torr argon; (ii) a calcium atomic oven was constructed and located so as to spray calcium vapor through the electron beam; (iii) a ruby laser (both Q-switched and normal mode) was used to evaporate material from a well-outgassed manganese target, located so as to plume across the electron beam; (iv) a piezoelectric gas puff valve was used to inject gas at low pressure into the drift tubes. In all cases, the ion mix was dominated by background gas, even at a base pressure in the 10^{-10} Torr range (in the vessel, if not inside the drift tubes), and we concluded that cryogenically cooled and pumped drift tubes are indeed essential for good EBIS operation.

The phenomenon of electron beam space-charge neutralization due to the positive ion component (and the consequent collapse of the electron beam due to high current density) is very important to EBIS design. By comparing the maximum charge state observed with that calculated on the basis of the measured electron beam density ("bare beam," with no ion loading), we can infer a beam collapse due to space-charge neutralization of a factor of up to one order of magnitude.

In summary, we achieved the following goals:

- Using a new technique, a magnetic field was established that is straight on axis to better than ±50 μm over a 55-cm axial distance. Similarly, the electron beam trajectory was straight to better than ±50 μm, and the beam profile was roughly Gaussian with a peak current density of around 200 A/cm^2.
- Systems allowing the micro-manipulation of the electron gun, the drift tube structure, and the magnetic axis were designed and installed. These systems were very satisfactory. This had not been achieved previously with other EBIS devices.
- A high-sensitivity charge-state-analysis system was developed and used.
- The output pulse was stretched to as long as 5 ms, and a repetition rate up to 30 Hz was used.
- Both the short-term (shot-to-shot) and long-term (weeks or more) reproducibility of the output ion charge-state spectrum were shown to be excellent.
- The expected EBIS scaling laws were verified. The output ion flux was measured as a function of magnetic field strength, electron gun voltage, and length of the confinement region. The scaling was as predicted theoretically: independent of magnetic field, approximately proportional to electron beam energy, and proportional to the length of the confinement region, i.e., varying as the amount of electron charge in the beam.
- The existence of beam compression was inferred.

A final report detailing the entire experiment is in preparation.

PUBLICATIONS

PUBLICATIONS

ACCELERATOR OPERATIONS

J.R. Alonso, R.T. Avery, T. Elioff, R.J. Force, H.A. Grunder, H.D. Lancaster, E.J. Lofgren, J.R. Meneghetti, F.B. Selph, R.R. Stevenson, and R.B. Yourd, "Acceleration of Uranium at the Bevalac," Science **217**, 1135 (1982).

J. Alonso, T. Elioff, R. Gough, H. Grunder, H. Lancaster, S. Magyary, R. Sah, J. Staples, and R. Yourd, "Advanced Medical Accelerator Design," presented at the Seventh Conference on the Application of Accelerators in Research and Industry, Denton, TX; LBL-14623 (1982).

W.T. Chu, J. Alonso, T. Criswell, and C. Tobias, "New Beam Shaping Devices for Accelerated Heavy Ions," presented at the Seventh International Congress of Radiation Research; LBL-15711 (1982).

R. McDonald, L. Sobotka, Z. Yao, G. Wozniak, and G. Guarino, "Conical Bragg-Curve Spectrometer (BCS)," to be presented at the American Physical Society Meeting, Baltimore, MD; LBL-15208 .

J. Porter, "Cryogenic System for a Superconducting Spectrometer (HISS)," to be presented at the Cryogenic Engineering Conference and the International Cryogenic Materials Conference, Pittsburg, PA; LBL-15771 .

J. Porter, "Cryogenic System for a Superconducting Spectrometer Magnet (HISS)," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15100.

J. Porter and F. Bieser, "The Automation of a Superconducting Spectrometer Facility (HISS)," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15099.

R. Reimers, R. Wolgast, and R. Yamamoto, "Magnet Coil System for a Superconducting Spectrometer (HISS), to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15108.

F. Selph, H. Grunder, and B. Leemann, "An Isochronous Stacking Ring Approach to the HTE," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15209.

Accelerator Improvements

S. Abbott, R. MacGill, and R. Yourd, "Mechanical Design of a Heavy-Ion RFQ," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15142.

S. Abbott, D. Brodzik, R.A. Gough, D. Howard, H. Lancaster, R. MacGill, S. Rovanpera, H. Schneider, J. Staples, and R. Yourd, "RFQ Development at LBL," presented at the Seventh Conference on the Application of Accelerators in Research and Industry, Denton, TX; LBL-14624 (1982).

R. Gough, S. Abbott, D. Brodzik, D. Howard, K. Kennedy, H. Lancaster, R. MacGill, S. Rovanpera, H. Schneider, J. Staples, and R. Yourd, "Construction and Testing of a Heavy Ion RFQ: A Progress Report," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15139.

D. Howard and H. Lancaster, "Vane Coupling Rings: A Simple Technique for Stabilizing a Four-Vane Radiofrequency Quadrupole Structure," presented at the Seventh Conference on the Application of Accelerators in Research and Industry, Denton, TX; LBL-14640 (1982).

H. Lancaster and H. Schneider, "Improved Field Stability in RFQ Structures With Vane Coupling Rings," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15140.

J.J. Staples, "Beam Dynamics and Vane Geometry in the LBL Heavy Ion RFQ," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15141).

Biomedical Research

E.J. Ainsworth, L.S. Kelly, L.J. Mahlman, J.C. Schooley, R.H. Thomas, J. Howard, E.L. Alpen, "Response of Colony Forming Units - Spleen - to Heavy Charged Particles," accepted for publication in Radiation Research.

A. Chatterjee, W. Saunders, E.L. Alpen, J. Alonso, and J. Scherer, "Physical Measurements with High-Energy Radioactive Beams," Rad. Res. **92**, 230-244 (1982).

W.T. Chu, J.R. Alonso, and C.A. Tobias, "Imaging with a Multiplane Multiwire Proportional Chamber Using Heavy Ion Beams," in *Proceedings of International Workshop on Physics and Engineering in Medical Imaging*, IEEE Computer Society Press, Los Angeles, CA, (1982), p. 221-224.

S.B. Curtis, W.A. Schilling, T.S. Tenforde, K.E. Crabtree, S. D. Tenforde, J. Howard, and J.T. Lyman, "Survival of Oxygenated and Hypoxic Tumor Cells in the Extended-Peak Regions of Heavy Charged-Particle Beams," Rad. Res. **90**, 292-309 (1982).

J.T. Leith, M. McDonald, P. Powers-Risius, S.F. Bliven, and J. Howard, "Response of Rat Spinal Cord to Single and Fractionated Doses of Accelerated Heavy Ions," Rad. Res. **89**, 176-193 (1982).

M.R. Raju, S.G. Carpenter, N. Tokita, J. Howard, and J.T. Lyman, "Biological Response Across a Ridge Filter Carbon Ion Bragg Peak," Int. J. Rad. Oncol. Biol. and Phys. **9**, 60-67 (1983).

T.S. Tenforde, S.M.J. Afzal, S.S. Parr, J. Howard, J.T. Lyman, and S.B. Curtis, "Cell Survival in Rat Rhabdomyosarcoma Tumors Irradiated *In Vivo* with Extended-Peak Silicon Ions," Rad. Res. **92**, 208-216 (1982).

T.S. Tenforde, S.B. Curtis, S.S. Parr, S.M.J. Afzal, J. Howard, and J.T. Lyman, "Increased Enhancement of Tumor Response to X-Rays and High-LET Neon Ions by Desmethylmisonidazole Relative to Misonidazole," Int. J. Radiat. Biol. **41**, 677-684 (1982).

C.A. Tobias, W. Chu, A. Chatterjee, E.V. Benton, J. Fabrikant, W. Holley, J. Schmidt, E. Blakely, and T.L. Hayes, "Special Topics in Heavy Ion Research," in *Pion and Heavy-Ion Radiotherapy: Preclinical and Clinical Studies*, L. Skarsgard, Ed., Elsevier Science Publishing Co., New York/Amsterdam (1983).

T.C. Yang, J. Howard, L. Craise, and C.A. Tobias, "Effects of Energetic Silicon Ions, U.V. Radiation, and X-Rays in Neoplastic Cell Transformation and Mutation," Rad. Res. **91**, 412 (1982).

HIGH ENERGY PHYSICS

H.A. Grunder and R.K. Johnson, "The Status of U.S. High Energy Accelerator Projects," presented at the VI$^{\underline{th}}$ European Symposium on $\overline{N}N$ and $\bar{q}q$ Interactions, Santiago de Compostela, Spain, August 30-September 3, 1982.

High Field Magnets

A.R. Borden and R.C. Wolgast, "Mechanically Improved Rectangular Cable," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM, SUMAG-89; LBL-15183.

S. Caspi, "The Use of Calorimetry in Superfluid He II to Measure Losses in Superconducting Magnets," presented at the Ninth International Cryogenic Materials Conference and Exhibition, Kobe, Japan, May 11-14, 1982, SUMAG-67; LBL-14105.

S. Caspi, W.S. Gilbert, and J.B. Rechen, "Ramp Rate Sensitivities of Several Superconducting Dipole Magnets Operated in He I and Superfluid He II," presented at the 1982 Applied Superconductivity Conference, Knoxville, TN, November 28-December 3, 1982, SUMAG-78; LBL-14445.

S. Caspi and W. Hassenzahl, "The Source, Origin and Propagation of Quenches Measured in Superconducting Pole Magnets," presented at the 1982 Applied Superconductivity Conference, Knoxville, TN, November 28 - December 3, 1982, SUMAG-77; LBL-14390.

S. Caspi, R.B. Meuser, and R.C. Wolgast, "Mechanical Properties of Stranded Superconducting Cable Windings, presented at the 1982 Applied Superconductivity Conference, Knoxville, TN, November 28 - December 3, 1982, SUMAG-80; LBL-14481.

S. Caspi, C. Taylor, B. Gilbert, B. Hassenzahl, J. Rechen, and R. Warren, "Large Scale Superfluid Practice," presented at the American Institute of Chemical Engineers CRYO-Symposia, Los Angeles, CA, November 11-14, 1982, SUMAG-69; LBL-14746.

W. Gilbert, S. Caspi, W. Hassenzahl, R. Meuser, C. Peters, J. Rechen, R. Schafer, C. Taylor, and R. Wolgast, "A 9.1 Tesla Iron-Free Nb-Ti Dipole Magnet with Pancake Windings," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM, SUMAG-87; LBL-15157.

W. Hassenzahl, S. Caspi, W. Gilbert, C. Peters, and C. Taylor, "Details of Design Construction and Performance of LBL High-Field Dipoles, to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM, SUMAG-90; LBL-15904.

W. Hassenzahl, S. Caspi, W. Gilbert, C. Peters, J. Rechen, and C. Taylor, "A Layer-Wound, 8.7 Tesla Superconducting Dipole Magnet," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM, SUMAG-91; LBL-15159.

W. Hassenzahl, C. Peters, W. Gilbert, C. Taylor, and R. Meuser, "A Four-Layer, Two-Inch Base, 8.5-Tesla Superconducting Dipole Magnet," presented at the 1982 Applied Superconductivity Conference, Knoxville, TN, November 28-December 3, 1982, SUMAG-79; LBL-15372.

W. Hassenzahl, C. Taylor, S. Caspi, J. Rechen, and D. Schafer, "Stability in Accelerator Dipoles in He I and He II," presented at the Second International Conference on Stability in Superconducting Magnets, Saclay, France, November 16-19, 1982, SUMAG-65; LBL-14253.

C. Taylor, R. Althaus, S. Caspi, W Hassenzahl, B. Meuser, J. Rechen, and R. Warren, "Alternative Dipole Magnets for ISABELLE," presented at the Ninth International Cyrogenic Materials Conference and Exhibition, Kobe, Japan, May 11-14, 1982, SUMAG-62; LBL-14215.

C. Taylor and R.B. Meuser, "Conceptual Magnet Design for an Iron-Free Colliding Beam Accelerator," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM, SUMAG-88; LBL-15158.

C. Taylor, R. Meuser, S. Caspi, W. Gilbert, W. Hassenzahl, C. Peters, and R. Wolgast, "High-Field Superconducting Accelerator Magnets," presented at the Ninth International Cyrogenic Materials Conference and Exhibition, Kobe, Japan, May 11-14, 1982, SUMAG-68; LBL-14400.

C. Taylor, R. Meuser, S. Caspi, W. Gilbert, W. Hassenzahl, C. Peters, R. Schafer, and R. Wolgast, "Design of a 10-T Superconducting Dipole Magnet Using Niobium-Tin Conductor," presented at the 1982 Applied Superconductivity Conference, Knoxville, TN, November 28 - December 3, 1982, SUMAG-81; LBL-14434.

Stochastic Beam Cooling

J. Bisognano, "Transverse Fokker-Planck Equation," BECON-24, December 1981.

J. Bisognano and S. Chattopadhyay, "Two-Dimensional Transverse Fokker-Planck Transport Equation for a Coasting Beam Undergoing Stochastic Cooling That Couples Both the Transverse Betatron Degrees of Freedom," BECON-30, April 1982.

J. Bisognano and Ch. Leemann, "Stochastic Cooling," in *Physics of High Energy Accelerators*, (Fermilab Summer School, 1981), American Institute of Physics, New York, 1982, p. 583-655; LBL-14106.

S. Chattopadhyay, "On Stochastic Cooling of Bunched Beams from Fluctuation and Kinetic Theory," Ph.D. thesis; LBL-14826 (1982).

C.H. Kim, "Design Options for the Fast Betatron Precooling Systems in the Injection Orbit," BECON-25, December 1981.

Ch. Leemann, "General PU-Response and Single Particle Schottky Spectrum," BECON-27, November 1981.

B. Leskovar, "Reliability Considerations of Traveling-Wave Tube and Power Gallium-Arsenide Field Effect Transistor Amplifiers," BECON-26, January 1982.

B. Leskovar and C.C. Lo, "Traveling-Wave Tube Amplifier Characteristics Study for Stochastic Beam Cooling Experiments," LBL-14142, March 1982.

C.C. Lo, "Low-Noise Gallium-Arsenide Field-Effect Transistor Preamplifier for Stochastic Beam Cooling Systems," BECON-32.

High Energy Hadron Colliders

G. Lambertson and Ch. Leemann, "Antiproton Production and Accumulation for a 20 TeV $\bar{p}p$ Collider," presented at the DPF Summer Study on Elementary Particle Physics and Future Facilities, Aspen, CO, June 28-July 16, 1982; LBL-15089.

L. Smith, "Luminosity of Continuous Beams with Crossing Angle." in *Proceedings of the DPF Summer Study on Elementary Particle Physics and Future Facilities, Snowmass, CO, June 28-July 16, 1982*, p. 351.

MAGNETIC FUSION ENERGY

Positive-Ion Beam Research and Development

Norman E. Abt, "Density and Potential Measurements on an Intense Ion Beam-Generated Plasma," Ph.D. thesis.

N. Abt, G. Guethlein, and W.B. Kunkel, "Continuing Neutralizer Plasma Studies," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

Norman E. Abt and J.W. Stearns, "Measurement of Ion-Acoustic Wave Velocity in a Pulsed Plasma," submitted to Physics of Fluids.

O.A. Anderson, W.S. Cooper, D.A. Goldberg, L. Ruby, and L. Soroka, "Negative-Ion-Based Neutral Beam System," in *Considerations of an Advanced Performance Fusion Engineering Device (FED-A)*, Oak Ridge National Laboratory report ORNL/TM8498, 1982.

K.H. Berkner, C.F. Burrell, V.L. Jacobson, A.F. Lietzke, and D.J. Markevich, "Initial Operation of the LBL 80-kV, 40-A (Deuterium) Long-Pulse Accelerator," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

K.H. Berkner, W.S. Cooper, K.W. Ehlers, V.L. Jacobson, H.M. Owren, J.A. Paterson, and R.P. Pyle, "Long-Pulse Neutral Injector Development at the Lawrence Berkeley Laboratory," presented at Third-Joint Varenna-Grenoble International Symposium on Heating in Toroidal Plasmas, March 22-27, 1982.

K.W. Ehlers and K.N. Leung, "A High Concentration H^{+2} or D^{+2} Ion Source," Submitted to Review of Scientific Instruments.

K.W. Ehlers, K.N. Leung, P.A. Pincosy, and M.C. Vella, "Effect of a Magnetic Filter on the Formation and Deposition of High-Z Impurities in a Multicusp Ion Source," submitted to Applied Physics Letters (May 1982).

K.W. Ehlers and K.N. Leung, "Increasing the Efficiency of a Multicusp Ion Source," submitted to Review of Scientific Instruments.

A.F. Lietzke, "Magnet Symmetry, Plasma Uniformity in Symmetric Rectangular Magnetic-Buckets," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

H.M. Owren, W.R. Baker, K.H. Berkner, D.B. Hopkins, and D.J. Massoletti, "The Effect of Capacitive Stored Energy on Neutral Beam Accelerator Performance," presented at the 12th Symposium on Fusion Technology, Julich, W. Germany, September 13-17, 1982.

P.A. Pincosy and K.W. Ehlers, "Ion Source Plasma Density Fluctuations," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

D. Post and R.V. Pyle, "Neutral Particle Beam Production and Injection," presented at the NATO Advanced Study Institute on Atomic and Molecular Processes in Controlled Thermonuclear Fusion, Palermo, Italy, July 19-30, 1982.

R.V. Pyle, O.A. Anderson, K.H. Berkner, C.F. Burrell, C.F. Chan, W.S. Cooper, J. DeVries, K.W. Ehlers, D.A. Goldberg, D.B. Hopkins, A.F. Lietzke, I. Lutz, H. Owren, J.A. Paterson, P.A. Pincosy, R. Smith, R. Steele, J. Tanabe, R. Wells, M.C. Vella, and ORNL staff, "The Development of Neutral Beam Injection Systems," presented at International Atomic Energy Agency 9th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Baltimore, MD, September 1-8, 1982.

A. Wekhof, R.R. Smith, and S.S. Medley, "Measurement of Deuterium Beam Energy Distribution and Species Using an Electrostatic Energy Analyzer," submitted to Nuclear Technology Fusion (May 1982).

Negative-Ion Beam Research and Development

O.A. Anderson, "The TFF Accelerator for Fusion Reactor Injection," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

O.A. Anderson, W.S. Cooper, D.A. Goldberg, L. Ruby, L. Soroka, and J.H. Fink, "An Efficient Radiation-Hardened 800-keV Neutral Beam Injection System," to be presented at the Fifth Topical Meeting on the Technology of Fusion Energy, Knoxville, TN, April 26-28, 1983.

O.A. Anderson, W.S. Cooper, D.A. Goldberg, L. Ruby, and L. Soroka, "Negative-Ion-Based Neutral Beam System," in *Considerations of an Advanced Performance Fusion Engineering Device (FED-A)*, Oak Ridge National Laboratory report ORNL/TM8498, 1982.

O.A. Anderson, D.A. Goldberg, W.S. Cooper, and L. Soroka, "A Transverse-Field-Focusing (TFF) Accelerator for Intense Ribbon Beams," abstract submitted to the 1983 Particle Accelerator Conference, Los Alamos, NM, March 21-23, 1983.

W.R. Baker, D.A. Goldberg, C.F. Burrell, D.B. Hopkins, Hogil Kim, and L.J. Laslett, "A Multi-Aperture Electrostatic Quadrupole (MESQ) Accelerator for Neutral Beam Injection," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

C.F. Burrell and D.A. Goldberg, "Calculations of Gas Density in a Closely Packed Multi-Channel Electrostatic Quadrupole (MESQ)," presented at the American Vacuum Society 29th National Symposium, Baltimore, MD, November 16-19, 1982.

C.F. Chan, C.F. Burrell, and W.S. Cooper, "Model of Positive Ion Sources for MFE Neutral Beam Injection," submitted to Journal of Applied Physics.

W.S. Cooper, "Summary of the Status of Negative-Ion Based Neutral Beams," to be presented at the Fifth Topical Meeting on the Technology of Fusion Energy, Knoxville, TN, April 26-28, 1983.

W.S. Cooper, O.A. Anderson, and D.A. Goldberg, "Improved Negative-Ion Based Neutral Injection System," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

K.W. Ehlers, "Negative Ion Sources for Neutral Beam Systems," abstract submitted to the American Vacuum Society-29th National Symposium, Baltimore, MD., November 16-19, 1982.

K.W. Ehlers and K.N. Leung, "Self Extraction H^- or D^- Source," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

D.A. Goldberg and O.A. Anderson, "Analytic Comparison of TFF and ESQ Systems," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

K. Jimbo, "Volume Production of Negative Ions in the Reflex Type Ion Source," Ph.D. thesis.

K.N. Leung and K.W. Ehlers, "Volume-Produced H^- Multicusp Source," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

K.N. Leung, K.W. Ehlers, and M. Bacal, "Extraction of Volume-Produced H^- Ions from a Multicusp Source," submitted to Review of Scientific Instruments (August 1982).

D. Post and R.V. Pyle, "Neutral Particle Beam Production and Injection," presented at the NATO Advanced Study Institute on Atomic and Molecular Processes in Controlled Thermonuclear Fusion, Palermo, Italy, July 19-30, 1982.

R.V. Pyle, O.A. Anderson, K.H. Berkner, C.F. Burrell, C.F. Chan, W.S. Cooper, J. DeVries, K.W. Ehlers, D.A. Goldberg, D.B. Hopkins, A.F. Lietzke, I. Lutz, H. Owren, J.A. Paterson, P.A. Pincosy, R. Smith, R. Steele, J. Tanabe, R. Wells, M.C. Vella, and ORNL staff, "The Development of Neutral Beam Injection Systems," presented at the International Atomic Energy Agency 9th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Baltimore, MD, September 1-8, 1982.

L. Soroka and O.A. Anderson, "Computational Phase Space Dynamics of the TFF Accelerator," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

M. Wada, K.H. Berkner, R.V. Pyle, and J.W. Stearns, "Photoelectric Work Function Measurement of a Cesiated Metal Surface and Its Correlation with the Surface-Produced H^- Ion Flux," presented at the American Vacuum Society 29th National Symposium, Baltimore, MD, November 16-19, 1982.

Test Stand Fabrication/Operation

D. Post and R.V. Pyle, "Neutral Particle Beam Production and Injection," presented at the NATO Advanced Study Institute on Atomic and Molecular Processes in Controlled Thermonuclear Fusion, Palermo, Italy, Palermo, Italy, July 19-30, 1982.

R.V. Pyle, O.A. Anderson K.H. Berkner, C.F. Burrell, C.F. Chan, W.S. Cooper, J. DeVries, K.W. Ehlers, D.A. Goldberg, D.B. Hopkins, A.F. Lietzke, I. Lutz, H. Owren, J.A. Paterson, P.A. Pincosy, R. Smith, R. Stelle, J. Tanabe, R. Wells, M.C. Vella, and ORNL staff, "The Development of Neutral Beam Injection Systems," presented at the International Atomic Energy Agency 9th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Baltimore, MD, September 1-8, 1982.

Neutral Beam Atomic Physics Studies

Y.K. Bae, C.F. Burrell, R.H. McFarland, R.V. Pyle and K.H. Berkner, "Balmer-Excitation Cross Sections Relevant to Neutral-Beam Diagnostics," Bull. Am. Phys. Soc. **27**, 1135 (1982).

Y.K. Bae, "Cross Sections for Balmer-Alpha Excitation in Heavy Particle Collisions," LBL-15013 (1982).

C.F. Chan, "Reaction Cross Sections and Rate Coefficients Related to the Production of Positive Hydrogen Ions," LBID-632.

C.F. Chan, C.F. Burrell, and W.S. Cooper, "Model of Positive Ion Sources for MFE Neutral Beam Injection," LBL-15097.

W. Groh, A. Muller, C. Achenbach, A.S. Schlachter, and E. Salzborn, "Correlated Capture Ionization in Slow Collisions of Multiply Charged Xe Ions with Xe Atoms," Phys. Lett. **85A**, 77 (1981).

W. Groh, A.S. Schlachter, A. Muller, and E. Salzborn, "Transfer Ionization in Slow Collisions of He^{2+} Ions in Rare Gases," J. Phys. **B 15**, L 207 (1982).

W. Groh, A. Muller, A.S. Schlachter, C. Achenbach, and E. Salzborn, "Transfer Ionization in Collisions Between Multiply Charged Ions and Atoms," presented at Arbeitstagung Schonau, Schwarzwald, Germany, 1982.

D. Markevich, R.R. Smith, and M.D. Strathman, "Deuterium Beam Species Measurements from Fusion Reactions in the Neutralizer," Bull. Am. Phys. Soc. **27**, 1136 (1982).

R.H. McFarland, A.S. Schlachter, J.W. Stearns, B. Liu, and R.E. Olson, "D^- Production by Charge Transfer of (0.3-3)-keV D^+ in Thick Alkaline-Earth Vapor Targets: Interaction Energies for CaH^+, CaH, and CaH^-," Phys. Rev. **A 26**, 775 (1982).

E. Salzborn, W. Groh, A. Muller, and A.S. Schlachter, "Transfer Ionization in Collisions Between Multiply Charged Ions and Atoms at keV Energies," presented at the Symposium on Production and Physics of Highly Charged Ions, Stockholm, 1982.

E. Salzborn, W. Groh, A. Muller, and A.S. Schlachter, "Electron Capture by Multiply Charged Ions with Simultaneous Ionization of the Target Atom," presented at International Workshop on ECR Ion Sources, Grenoble, France, 1982.

A.S. Schlachter, "Production and Destruction of D^- by Charge Transfer in Metal Vapors," presented at the U.S.-Mexico Joint Workshop on the Atomic Physics of Negative Ions, La Mansion-Galindo, Mexico, 1982; Notas de Fisica **5**, 481 (1982).

A.S. Schlachter, K.H. Berkner, H.F. Beyer, W.G. Graham, W. Groh, R. Mann, A. Muller, R.E. Olson, R.V. Pyle, J.W. Stearns, and J.A. Tanis, "Collisions of Fast Highly Charged Ions in Gas Targets: Ionization, Recoil-Ion Production, and Charge Transfer," invited paper presented at the Symposium on Production and Physics of Highly Charged Ions Stockholm, 1982.

A.S. Schlachter, W. Groh, A. Muller, H.F. Beyer, R. Mann, and R.E. Olson, "Production of Highly Charged Rare-Gas Recoil Ions by 1.4 MeV/amu U^{44+}," Phys. Rev. **A 26**, 1373 (1982).

A.S. Schlachter, W. Groh, A. Muller, and E. Salzborn, "Transfer Ionization in Slow Multiply Charged Ion-Atom Collisions," invited paper presented at the Conference on Application of Accelerators in Research and Industry, Denton, TX; 1982; Bull. Am. Phys. Soc. **27**, 760 (1982).

J.W. Stearns and D. Markevich, "Study of Cu L X Rays from Collisions of Slow Cu on Xe," to be presented at APS Division of Electron and Atomic Physics, May 1983.

M. Wada, K.H. Berkner, R.V. Pyle, and J.W. Stearns, "Photoelectric Work Function Measurement of a Cesiated Metal Surface and Its Correlation with the Surface Produced H^- Ion Flux," to be published in the Journal of Vacuum Science and Technology.

Basic Plasma Theory

J. Cary and R. Littlejohn, "Noncanonical Hamiltonian Mechanics and Its Application to Magnetic Field Line Flow," submitted to Annals of Physics.

J.D. Crawford and J.R. Cary, "Decay of Correlations in a Chaotic Measure Preserving Transformation," Physica D (in press, 1983).

J.D. Crawford and H.D.I. Abarbanel, "Applications of Bifurcation Theory to Plasma Instabilities," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

C. Grebogi and A.N. Kaufman, "Multidimensional Canonical/Symplectic Maps for Gyroresonance Crossings," in *Long-Time Predictions in Dynamics*, C.W. Horton et al., Eds., Wiley, New York (1982).

A. Kaufman, "Elementary Derivation of Poisson Structures for Fluid Dynamics and Electrodynamics," Phys. Fluids **25** 1993 (1982).

A. Kaufman, "Natural Poisson Structures of Nonlinear Plasma Dynamics," Physica Scripta **T2**, 517 (1982).

A. Kaufman, "Quasi-Hamiltonian Formulation of Nonlinear Dissipative Processes in General Geometry," presented at the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA, Paper No. 9P12.

A. Kaufman, "Unified Field Theory of Discrete and Collective Gyroresonant Wave-Particle Interaction in Complex Geometry," to be presented at the Sherwood Meeting, Arlington, VA, March 1983.

A. Kaufman, C. Grebogi, and S. McDonald, "Locally Coupled Evolution of Wave and Particle Distributions in General Magnetoplasma Geometry," presented at the Sherwood Meeting, Santa Fe, NM, April 1982.

A.N. Kaufman and P.J. Morrison, "Algebraic Structure of the Plasma Quasilinear Equations," Phys. Lett. **88A**, 405 (1982).

A. Kaufman and E. Rosengaus, "Eikonal Theory of the Transition to Phase Incoherence," in *Proceedings of the 5th Topical Conference on RF Plasma Heating*, February 1983.

J. Marsden, A. Weinstein, T. Ratiu, R. Schmid, and R. Spencer, "Hamiltonian Systems with Symmetry, Coadjoint Orbits and Plasma Physics," PAM-110, to be published.

S.W. McDonald and A.N. Kaufman, "Phase Space Representations of the Electric Field and the Wave Kinetic Equations," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

J.D. Meiss, J. Cary, C. Grebogi, J.D. Crawford, A. Kaufman, and H. Abarbanel, "Long Time Correlation of Periodic Area-Preserving Maps," Physica D, in press.

S. Omohundro, "Geometry of Lie Transforms and Applications to Plasma Physics," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 982, New Orleans, LA.

S. Omohundro and A. Kaufman, "Concepts in Waves," to be presented at the Sherwood Meeting, March 1983, Arlington, VA.

E. Rosengaus and A.N. Kaufman, "Transition to Incoherence of an Eikonal Wave in a Spatially Modulated Medium," abstract submitted to the 24th Annual Meeting, Division of Plasma Physics, November 1-5, 1982, New Orleans, LA.

R. Spencer and A. Kaufman, "Hamiltonian Structure of Two-Fluid Plasma Dynamics," Phys. Rev. **25A**, 2437 (1982).

R. Spencer, "Poisson Structure of the Equations of Ideal Multispecies Fluid Electrodynamics," submitted to Journal of Mathematical Physics.

Electron Laser Facility

D. Prosnitz, K. Neil, A. Sessler, K. Halbach, D. Hopkins, A. Paul, G. Stover, J. Tanabe, and J. Wurtele, "A High Gain Free Electron Laser Facility (ELF) at the ETA," International Conference on Lasers '82, December 13-17, 1982, Paper E-8.

D. Prosnitz, K. Neil, A. Sessler, K. Halbach, D. Hopkins, A. Paul, G. Stover, J. Tanabe, and J. Wurtele, "A High Gain Electron Laser Facility (ELF) at the ETA," Bull. Am. Phys. Soc. **47**, No. 8, Part II (October 1982), Paper 4W8.

D. Prosnitz, A. Sessler, K. Halbach, D. Hopkins, A. Paul, G. Stover, J. Tanabe, and J. Wurtele, "Electron Laser Facility at the LLNL ETA," presented at the International Free Electron Laser Conference, Bendor, France; UCRL-88067 (1982).

A. Sessler, "High Gain FEL Facility at the Experimental Test Accelerator," abstract submitted to the 13th Winter Colloquium on Quantum Electronics, January 12-14, 1983.

J.S. Wurtele and A.M. Sessler, "Particle Motion in the ELF Wiggler," presented at the International Conference on Lasers '82, December 13-17, 1982, Paper K-3,

J.S. Wurtele and A.M. Sessler, "Particle Motion in the ELF Wiggler," Bull. Am. Phys. Soc. **47**, No. 8 Part II (October 1982), Paper 4W9.

HEAVY ION FUSION

R.K. Cooper, P.L. Morton, P.B. Wilson, D. Keefe, and A. Faltens, "Linac Technology for Free Electron Lasers," in *Proceedings of the Free Electron Laser Conference, Bendor, France, September 27 - October 1, 1982*, LA-UR-82-3621.

A. Faltens, "Equilibrium Charge State for Ions Passing Through Cold Dense Matter," HI-FAN-194.

H.I.F. Staff, "Heavy Ion Fusion Half-Year Report: October 1, 1981 - March 31, 1982," HI-FAN-195; LBL-14374.

H.I.F. Staff, "Heavy Ion Fusion Year-End Report." HI-FAN-208; LBL-15123, October 1982.

I. Hofmann, L.J. Laslett, L. Smith, and I. Haber, "Stability of the Kapchinskij-Vladimirskij (K-V) Distribution in Long Periodic Transport Systems," HI-FAN-204; LBL-14922, October 1982.

E. Hoyer, "HIF-Accelerating System/Linear Induction Accelerator Cost Evaluating Program: Comparison of Cost Factors," HI-FAN-191; LBID-541.

D. Keefe, "Inertial Confinement Fusion," Ann. Rev. of Nucl. and Part. Sci. **32** 391-442, (1982), HI-FAN-183; LBL-14194.

D. Keefe, "Foreign Travel Report: September 26-October 2, 1982," HI-FAN-203.

D. Keefe, "The Challenge of Ultra-High Energies—Ultimate Limits, Possible Directions of Technology, An Approach to Collective Acceleration," presented during the Panel Discussion at the ECRA-RAL Meeting, September 27-30, 1982, in *The Challenge of Ultra-High Energies*, Oxford, England, HI-FAN-207; LBL-15233.

D. Keefe and S.S. Rosenblum, "Berkeley Research Program on Ion Induction Linacs for Inertial Fusion, in *Proceedings of the Symposium on Accelerator Aspects of Heavy Ion Fusion,* Darmstadt, Germany, April 1982, GSI Report-82-8; HI-FAN-196, LBL-14341.

G. Krafft, "Usefulness of Collective Focusing for Final Focusing," HI-FAN-200; LBL-14800.

L.J. Laslett, "Comments Concerning a 3rd Order Canonical Integration Algorithm Developed by R. Ruth," HI-FAN-210, January 1983.

L.J. Laslett, "Concerning Limits to the Acceptable Aperture Ratio in Periodic Electrostatic Quadrupole/Transport Channels—A Preliminary Account," HI-FAN-213, January 1983.

L.J. Laslett, "Introduction of Space Charge (or a K-V Distribution," HI-FAN-211; LBL-14487, January 1983.

L.J. Laslett, "Letter to Dr. I. Haber (NRL) with Data Concerning Hard-Edge Interrupted Solenoid Transport Systems with Small Occupancy Factor," HI-FAN-209, January 17, 1983.

L.J. Laslett, "Letter to Prof. M. Reiser Concerning Envelope Modes and 3rd-Order Modes in Periodic Transport Channels with $_0 > 90^0$," HI-FAN-205, November 10, 1982.

L.J. Laslett, "The Confluent 3rd-Order Mode," HI-FAN-201, August 1982.

E. Lee, "Plasma Phenomenon in AIF," HI-FAN-206; LBID-646, October 5, 1982.

E.J. Lofgren, "Accelerator, Particle," to be published as a chapter in *The Encyclopedia of Physics*, Robert Besancon, Ed., Van Nostrand Reinhold Co. New York, HI-FAN-192; LBL-14323, 1982.

R.D. Ruth and A.W. Chao, "Plasma Laser Acceleration: Longitudinal Dynamics, the Plasma/Laser Interaction, and a Qualitative Design" in *Proceedings of the Workshop on Laser Acceleration, Los Alamos National Laboratory, February 18-23, 1981,* AIP Conference Proceedings No. 91:94, HI-FAN-198; LBL-14332, 1982.

J. Shiloh, M. Lampel, and R. Sah, "Electron Beam Probe for Charge Neutralization Studies of Heavy Ion Beams," submitted to Review of Scientific Instruments, HI-FAN-197; LBL-14391, June 1982.

K. Reed Stalder, "Cs^+ + Cs^+ Charge Transfer and Ionization Cross Section Measurements by a Plasma Target Technique," Ph.D. thesis, HI-FAN-211; LBL-14487, January 1983.

T.F. Wang, "A Preliminary Study of Final Focusing for the Target Test Heating Facility," HI-FAN-199; LBID-594.

T.F. Wang, "Beam Matching for the First Injection Drift Tube," HI-FAN-190; LBID-593.

T.F. Wang and L. Smith, "Longitudinal and Transverse Coupling in a Heavy Ion Beam," HI-FAN-193.

NATIONAL CENTER FOR ADVANCED MATERIALS

The Advanced Light Source Preliminary Design Handbook, Pub-5082, November 1982.

Conceptual Design Report, Pub-5084, Vols. 1-5, March 1983.

K. Halbach, "REC-Steel Hybrid Wiggler Design," to be published *in* Nuclear Instruments and Methods for Physical Research.

K. Halbach, J. Chin, E. Hoyer, H. Winick, R. Cronin, J. Yang, and Y Zambre, "A Permanent Magnet Undulator for SPEAR," IEEE Trans. Nucl. Sci. **NS-28**, 3136 (1981).

E. Hoyer (representing the Beam Line VI design group), "A New Wiggler Beam Line for SSRL, "presented at the International Conference on X-Ray and VUV Synchrotron Radiation Instrumentation Conference at DESY, Hamburg, Germany, September 12-13, 1982; to be published in Nuclear Instruments and Methods for Physical Research.

E. Hoyer, T. Chan, J. Chin, K. Halbach, K-J. Kim, H. Winik, and J. Yang, "The Beam Line VI REC Steel Hybrid Wiggler for SSRL," to be presented at the IEEE 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15115.

K-J. Kim, "Emittance Effect on Undulator Radiation," to be published in Nuclear Instruments and Methods for Physical Research.

K-J. Kim, "Optics of Beam Line VI," LBL Internal Report, February 17, 1982.

R. Sah, "The Advanced Light Source," to be presented at the IEEE 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15160.

NCAM Notes

J. Bisognano, "Beam Current Limitations for the ALS," NCAM Note 7.

J. Bisognano, "Summary of Beam Limitations for the Advanced Light Source," NCAM Note 3; LBID-713.

D. Douglas, "Ion Trapping in Electron Storage Ring," NCAM Note 8.

A. Garren, "ALS Storage Ring Parameters," NCAM Note 6.

K. Halbach, "Anticipated Performance of a Pure REC Helical Undulator," NCAM Note 5.

K-J. Kim, "Calculations of Spectral Brilliance." NCAM Note 1; LBID-710.

J. Peterson and J. Staple, "Position Injection Option," NCAM Note 2; LBID-711.

ADVANCED ACCELERATOR PROJECTS

Medical Accelerator

J. Alonso, T. Elioff, R. Gough, H. Grunder, H. Lancaster, S. Magyary, R. Sah, J. Staples, and R. Yourd, "Design of a Dedicated Heavy Ion Accelerator for Radiotherapy," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15147.

H. Lancaster, S. Magyary, and R. Sah, "A High Performance Control System for a Heavy Ion Medical Accelerator," to be presented at the 1983 Particle Accelerator Conference, Santa Fe, NM; LBL-15148.

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