SNEAP 79

PROCEEDINGS

of the

SYMPOSIUM OF NORTHEASTERN ACCELERATOR PERSONNEL 1979

held at the
University of Pennsylvania
Philadelphia

Editor
H.R.McK. Hyder

October 8 - 10 1979
FOREWORD

The Thirteenth Symposium of North Eastern Accelerator Personnel was held at the University of Pennsylvania in Philadelphia from October 8th to October 10th, 1979. Representatives of more than twenty-five laboratories attended and the ten sessions were made up of the usual mixture of laboratory reports, formal papers and informal discussions. A visit to the Tandem laboratory of the University of Philadelphia took place on the evening of October 9th.

The sessions of the Symposium were recorded on tape and Charles Adams, who organized the meeting, was heard on several occasions to request contributors to hand their manuscripts to him for incorporation in the published proceedings. No proceedings were ever published by the University of Pennsylvania and any manuscripts which were handed over must now be assumed lost. However, the eleven tapes have survived in good condition and these, supplemented by notes taken by the present editor at the time, have made possible a summary of the proceedings. This summary has been compiled not only in order to complete the historical record of SNEAP meetings from the first up to the twenty sixth, but also to preserve some important ideas on ion sources, charging systems and strippers which are not easy to find elsewhere.

The limitations of a record made twenty years after the event without the benefit of slides, viewgraphs, blackboard notes and written contributions are obvious. In a sense, the editor’s task was made easier by the fact that comments not audible on the tape are omitted. To paraphrase Henry Ford, >What is absent from the record can’t be wrong.= Speakers who failed to give their names or who were distant from a microphone remain anonymous, indicated by >?=. More seriously, speakers who relied heavily on slides or viewgraphs are under-reported. No attempt has been made to achieve a literal transcription of papers and discussions, which varied widely from the formal articulation of a written text to the informative but unstructured mode of communication adopted by many SNEAP members. The editor’s aim has been to record the essence briefly and accurately, preserving the spirit if not the detail of the original. To all those whose words he has altered, he asks indulgence. He apologises to those he has misreported, curtailed or ignored.

The proceedings of some more recent SNEAP meetings are still outstanding. In the course of transcribing this record, the editor became aware of the lessons to be learnt from contemporary reports of difficulties and achievements in developing technologies now taken for granted. Completing the SNEAP record is surely better done late than never.

The editor is grateful to John McKay for making the Pennsylvania tapes available.

Long Hanborough, April 2000

Richard Hyder
CONTENTS

SESSION I  LABORATORY REPORTS
Chairman: Charles Adams

Los Alamos Scientific Laboratory
  R. Woods .............................................................................................................. 1

Oak Ridge National Laboratory
  C.M. Jones ........................................................................................................... 1

University of Pennsylvania
  C.T. Adams ........................................................................................................... 2

University of Lowell
  Charles Connolly ................................................................................................. 2

Argonne National Laboratory
  Pat Den Hartog ..................................................................................................... 2

McMaster University
  John McKay ......................................................................................................... 3

Chalk River Nuclear Laboratory (part 1)
  Peter Hurley ........................................................................................................ 3

Queen=s University
  Henry Janzen ........................................................................................................ 3

Chalk River Nuclear Laboratory (part 2)
  Don Walker ......................................................................................................... 4

Yale University
  Kenzo Sato .......................................................................................................... 5

Oxford University
  Dick Hyder .......................................................................................................... 5

Centre de Recherches Nucleaires, Strasbourg
  Michel Letournel .................................................................................................. 6

University and Technical University, Munich
  Ludwig Rohrer ..................................................................................................... 6
SESSION II LABORATORY REPORTS (cont)
Chairman: Charles Adams

Stanford University
  Jack Harris

Notre Dame University
  Ed Berners

Université de Montréal
  Claude Brassard

Air Products
  Michael Pohl

Technical University, Bochum
  Klaus Brand

Centre de Recherches Nucleaires, Orsay
  Michelle Dumail

University of Rochester
  Tom Miller

Florida State University
  Ken Chapman

SUNY, Stonybrook
  John Noé

University of Pittsburgh
  Tillman Saylor

Australian National University
  David Weisser

University of Wisconsin
  James Billen

Triangle Universities Nuclear Laboratory
  Jim Willis

Brookhaven National Laboratory
  Hans Abendroth
SESSION III  DISCUSSION OF LABORATORY REPORTS
Chairman: Pat Den Hartog

Experiences with Improved Foils at Chalk River
Peter Hurley ..................................................................................................................14

Performance of Cracked Ethylene Foils at Pittsburgh
Tillman Saylor ..................................................................................................................15

SESSION IV  DISCUSSION ON SINGLE-ENDED MACHINES
Chairman: Henry Janzen

NEC 2UH Pelletron at Chalk River
Don Walker ......................................................................................................................17

Pumping Speed Measurements on a Varian Cryopump
Terry Lund .......................................................................................................................17

Upgrade of the Los Alamos P-9 Vertical Machine
Joe Tesmer ......................................................................................................................18

SESSION V  DISCUSSION ON GAS HANDLING AND $^{14}$C SOURCES
Chairman: Ken Chapman

Discussion on Gas Handling and Other Topics ..................................................................19

Generation of $^{14}$C beams at Los Alamos
Joe Tesmer ......................................................................................................................22

Production of Tantalum Carbide at Orsay
Michelle Dumail ..............................................................................................................23

SESSION VI  ION SOURCES
Chairman: Ed Berners

A Story of Two Ion Sources
Roy Middleton ..................................................................................................................24

Development of a Dedicated Sputter Ion Source for Carbon Dating
Dick Hyder ......................................................................................................................25
SESSION VII                     CHARGING SYSTEMS AND SF₆
Chairman: David Weisser

Laddertron Installation at Orsay
Michelle Dumail.................................................................27

The Separation of Air from SF₆
Charles Jones, Claude Brassard..............................................28

Thoughts on the Properties of Gas Mixtures
Kenzo Sato..............................................................................29

New Belt Structure in the Strasbourg MP Tandem
Michel Letournel...................................................................30

SESSION VIII                     UPGRADES AND NEW ACCELERATORS
Chairman: John McKay

The 25URC Machine at ORNL
Charles Jones, Norval Ziegler................................................31

The JAERI Tandem
Greg Norton...........................................................................32

The Oxford Folded Tandem
Dick Hyder............................................................................32

Upgrading the Strasbourg MP
Michel Letournel...................................................................35

SESSION IX                       POST ACCELERATORS
Chairman: Dick Hyder

Progress on the Legnaro XTU Tandem
Cosimo Signorini..................................................................36

The Superconducting LINAC Booster at ANL
Lowell Bollinger...................................................................36

The Stonybrook Superconducting LINAC Booster
John Noé................................................................................37

SESSION X                       BUSINESS MEETING
Chairman: John McKay.........................................................38
Dr Walter Wales, Department of Physics, University of Pennsylvania, welcomed the delegates to the Symposium and invited them to visit the campus. He reflected that the five high energy accelerators which he had worked on as a graduate student had now all been shut down. Low energy accelerators, such as the tandem at Penn, continued to operate because of their use in a variety of applications as addition to nuclear physics. He noted that the Penn tandem had started life as a military facility but had now assumed civilian garb. He remarked on the close links between operators and users of small accelerators and on the benefits this brings in terms of exploiting the machines.

LOS ALAMOS SCIENTIFIC LABORATORY       R. Woods

A $^{14}$C beam of several microamps has been accelerated in the FN tandem. This is produced in the sputter source from a cathode made of 95% enriched carbon. One cone has run for 700-800 hours and four or five more cones are available. After inflection, however, the beam is only 60% $^{14}$C. It is planned to put the $^{14}$C source into the terminal of P-9 in the next six months.

The vertical P-9 Van de Graaff at LASL is undergoing an upgrade. A new pulsed terminal, made by GIC, has been installed in P-9 and has worked well with both positive and negative light ions, producing 1 ns pulses. Control is by a home-made 60 channel digital telemetry system. The machine was tested without tubes and went to 13.5 MV positive and negative. When the new magnetically suppressed accelerator tubes from Dowlish Development were installed the voltage was limited to 6.8 MV, so the machine is tube limited.

OAK RIDGE NATIONAL LABORATORY       C.M. Jones and P.D. Miller (?)

[Glow discharge stripper foils have been tested in the EN tandem. A new technique has been developed for slackening foils. The MIT group at ORNL are continuing to work on air/SF$_6$ separation. A CAMAC controller for the new buncher has been built using only commercial modules.

There have been belt problems in a 2000 kV Van de Graaff used by the Solid State Division. This machine had been upgraded to 2500 kV. In December 1978 it was conditioned to 3.35 MV and ran for 30 hours at 3.1 MV with a N$^{2+}$ beam for H profiling with good stability. It then ran for two months of normal operation at voltages up to 2.5 MV. However, after some unusual sparks and poor stability it was opened to reveal dust and belt fibres in the column. Sparking down the core of the belt had caused it to delaminate after a life of 4033 hours. The replacement lasted 1229 hours and the next belt failed after 313 hours with long strips missing from the inner and outer surfaces, although both had been operated within their ratings. Finally a belt was installed which has so far lasted 1000 hours. HVEC say that these belts have come from different core and different rubber suppliers at different times.

A Scanditronix NMR digital field controller, modified to work at low frequency, has been operated down to 480 gauss where the signal to noise ratio is 1:1. The special low
frequency probe cost only $600 and has excellent signal-to-noise at all field levels. At 1000 gauss the S/N ratio is 3.8.

UNIVERSITY OF PENNSYLVANIA  C.T. Adams

Three ion sources are now installed on the FN. A UNIS source on the -40 line is used for 90% of experiments. A home made duoplasmatron with lithium charge exchange is used for \(^{3}\)He and \(^{4}\)He on the +40 line. This is pumped by a 1200 l/s turbo pump. The third source is that from the ion source test bench; it has a 90 inflector magnet which feeds into the 0 line of the main inflector. It has been used for a quark search and for the development of \(^{14}\)C dating with a sensitivity of 1 in \(10^{16}\). This source has produced 40 \(\mu\)A of \(^{58}\)Ni\(^{+}\), 0.05 \(\mu\)A of Be\(^{-}\) and 0.4 \(\mu\)A of BeH\(^{-}\). Beam identification is helped by a mass meter which computes the ion mass from the settings of the extraction voltage power supply and the field of the inflector magnet.

The diffusion pumps on the FN have been replaced by cryopumps and ion pumps at both ends. A turbo pump is fitted on the LE extension. The vacuum is now good.

Belt charging was a problem. The belt, which was worn out, was replaced by a new belt which tracked badly and was dusty. This was replaced by a satisfactory belt. Above 8 MV, column sparks have destroyed a pentode in the charge controller. It was suggested to fit improved filtering in the output line.

A Wien filter has been added to the HE extension after the quadrupole lens, for use in the carbon dating program, and a straight-through beam line for a medical program has been installed on the 0 port of the analyser.

UNIVERSITY OF LOWELL  Charles E. Connolly

The 5.5 MV positive CN accelerator has been used for irradiation studies on bubble memories for space. Doses of \(10^{15}\) fast neutrons have been provided. The Moberly magnet on the CN has produced pulses of 0.2 ns for high resolution time of flight studies of low energy neutron cross sections.

A 2 MV short column negative Van de Graaff from MIT (serial #2) has been rebuilt to run positive. It has a regular HVEC tube and terminal and home-made controls.

ARGONNE NATIONAL LABORATORY  Pat Den Hartog

There have been no major modifications to the tandem in the past year. Terminal valves like those at ANU have worked well; therefore the tubes have not been baked for one year. The tandem operates between 2.75 and 8.9 MV. No attempt has been made to run higher. It was used as injector to LINAC for a total of three months.

The energy straggling of heavy ions in terminal carbon foils has been measured. The lifetime of wrinkled (slackened) 3 \(\mu\)g/cm\(^2\) foils bombarded by a \(^{58}\)Ni beam is four times that of an unwrinkled 5 \(\mu\)g/cm\(^2\) foil. A terminal ion pump will become operational later this year. Fibre optic links to the terminal have worked well for several months.

An ion source test bench is being set up to help develop beams such as \(^{34}\)S. The half-life of \(^{32}\)Si has been measured as well as the cross-section of the \(^{26}\)Mg(p,n)\(^{26}\)Al reaction. An inverted Chapman sputter ion source has been used for beam production from very small samples (a few mg). Pellets of pure aluminum or zinc powder are compressed with isotopically enriched material such as \(^{34}\)S.
SUNY, ALBANY
A. Haberl
No formal report. Much down time during the year.

McMASTER UNIVERSITY
J. McKay
Tritium beams have been run from the sputter source for over 800 hours. One run lasted for six weeks. The current on target averaged 50-100 nA with a peak value of 400-500 nA. After one run the source was rebuilt without serious contamination problems. HVEC will not rebuild tubes which have been run with tritium. Most of the contamination ends up in the forepump oil.

The belt was replaced after 5000 hours. The aluminum tubes have operated for 65000 hours at voltages up to 10 MV. (However section #1 has been replaced.) Every plane has track marks. The voltage is now limited to 8.5 MV.

A home made buncher has been installed giving pulses of 1.5-2 ns. There is a pulser at the HE end. The carbon dating equipment is installed immediately after the analyser. The three carbon isotopes are injected simultaneously. Runs have also been carried out with two Be isotopes.

Two PDP-15 computers are used online for data handling.

The 24 year old column of the KN 2000 broke. HVEC supplied a new column which differed in some details. The KN ran up to 3.6 MV without tube and at 2.4 MV with tube. Beam intensities of 750 µA have required the use of water cooled slits and targets.

CHALK RIVER NUCLEAR LABORATORIES
Peter Hurley
The MP tandem ran for 5764.9 hours, mostly between 11.5 & 12.5 MV. Very little running above 12.5 MV. Total number of sparks was 284. The Pelletron has run for 3469.8 hours. All the old small HE idlers have been replaced with pulleys having improved bearings. In nine months (4000 hours) there have been no failures of the new type. A SF₆ purification system, able to deliver 98% SF₆ at room temperature, is being built with low priority, but tests at different pressures have shown that the voltage is not limited by gas contamination. The UNIS source was used for 75% of the runs, the duoplasmatron (for He and Li beams) for most of the remainder. The Penning source was used occasionally.

A new controller for the inflector magnet will preset values so that rapid changes between ion species are possible. The new analyser magnet controller enables NMR frequencies to be dialled up. It is stable to 1 part in 10⁶ at high current and 1 part in 10⁷ at low current (beam energies of 4-5 MeV).

Tests have been made using an I beam on standard, JAERI type and slackened foils. The slackened foils have 5 times to 25 times the life of standard foils. There is an initial increase in beam intensity with these foils. The slackened, cracked ethylene foils are at least x10 better than standard foils.

QUEENS UNIVERSITY, KINGSTON, ONTARIO
H. Janzen
The KN3000 single-ended, horizontal Van de Graaff has been upgraded to 4 MV with a stainless steel tube, new resistors and shields in the column. The HVEC standard RF source produces p, d, ³He and ⁴He. The beam is not pulsed. Attempts to accelerate heavier ions have had only limited success. Reed switches have replaced the unreliable mechanical switches inside the tank. The old switches had been affected by metallic dust and gas breakdown products. The gas mixture is 15% SF₆, 20% CO₂, 65% N₂ at 250 psig.

The original water-cooled slits, rated at 150 watts, have been replaced by air-cooled slits.
in order to overcome stability problems due to the conductivity of the cooling water. The air-cooled slits use a heat pipe and an aluminum radiator to reject a maximum of 400 watts with a temperature rise of 250°C at the slit. At 20 μA beam current, the temperature rise is less than 100°C. An anomaly was observed with the air-cooled slits. With a balanced slit currents, the HE slit was very hot, the LE slit rather cool. Apparently, unequal secondary emission was causing most of the beam to strike the HE slit, even though the net slit currents were equal. The solution was to stagger the analysing slits and fit dummy slits opposite them and a bias ring between them. The dummy slits and the ring were biased to -250 V. In addition, tungsten tips were fitted to the analysing slits so that the beam intercepts a sharp edge rather than a flat plate. This has cured the problem.

A terminal lens, as described by Vermeer NIM 163 (1979) 309, has been fitted. There was evidence of a gas discharge near the focus electrode; this has been cured by installing a new lens of Vermeer’s design. This has improved focus in the machine. The other changes described by Vermeer were not implemented. The first six pitches of the accelerator tube had already been fitted with low value (240 MΩ) resistors, so none were shorted. The new lens seems to produce a better focus.

The original rectifier and oscillator tubes in the RF supply were of US origin and worked well. Replacement tubes of Japanese manufacture have suffered repeated heater/cathode shorts. The rectifier tubes have been replaced by silicon rectifiers, rated at 7000 PIV, 5.5 A and protected by thyristors. No failures reported in 500 hours. Close examination of terminal strips in the HV terminal revealed that there were traces of arcing from every screw to ground and to the base over a distance of several mm. Additional back-up insulation has been added between the strips and their mounts.

A max/min thermometer has recorded a maximum temperature in the terminal of 106°F and a minimum, during rapid gas transfer, of 45°F which is only 5°F above the permitted minimum.

A 1μF paper capacitor used as a phase shifter in the RF power supply, which had been pressurized during operation as a result of leak, exploded violently 1 hour after opening. The ion source failed after 1 hour on trying to run on a cocktail of He, Ne and diborane due to a black deposit on the quartz and the bottle.

CHALK RIVER NUCLEAR LABORATORY

Don Walker

The 2 MV NEC 2UH Pelletron has been used since 1974 to produce mass separated beams of a few microamperes up to M=240, that is up to 2 MeV per charge. A Danfysik model 910 source is used in the terminal. A high temperature version will be used for gold beams. With slit stabilization the ripple is < 50 V. A focus electrode in the terminal has been removed and the source aperture reduced from 0.050" to 0.025". The terminal steerers have been replaced.

The Pelletron chain broke after 2500 hours, without secondary damage. Flared inductors have been fitted. Charge is removed from the sheaves by springs, although these break easily. Metal bands were added to the sides of the sheaves but they reduced the charging capability by 40% and were removed. An occasional loss of upcharge was cured by circulating the SF6 through the dryer. The equivalent resistance of the Pelletron has been measured by observing the terminal decay constant. It is between 1 - 5 x 10¹³ at 90 psig. Below 3 x 10¹³ upcharge loss is noticeable. The terminal stabiliser has been replaced by a simpler unit of CRNL design in NIM modular format. Beam time amounts to about 100 h/month, 70% heavy ions over the energy range 200 - 2000 keV.
One problem is the need to find radiation resistant tubes for the Freon cooling lines in the tank.

YALE UNIVERSITY

Kenzo Sato

1. A fast vacuum pump station has been installed between the LE base of the MP and the ion source in order to keep helium out of the MP. The station includes a Torr7 cryopump, an Alcatel air-bearing turbo molecular pump and a sorption trap. An RGA is fitted to aid diagnostics. The base vacuum is \( 2 \times 10^{-9} \) Torr, rising to \( 1 \times 10^{-8} \) Torr when running the Middleton source and to \( 5 \times 10^{-8} \) Torr when running the helium source.

2. As reported in 1977, the best gas mixture is 38% SF\(_6\), 12% CO\(_2\) and 50% N\(_2\). The Ingersoll-Rand compressor developed leaks from the water cooling jacket. After these were repaired the dewpoint improved. The 3-stage gas purification system includes alumina, a soda-lime bed and a 10 µ filter. The moisture content is kept intentionally at a dew point of -40 °F. Circulation is continuous at a flow rate of 100 cfm. The original circulator has been replaced with a Spencer turbine.

3. A RGA was used to detect a tank gas leak. After 30,000 hours of operation a leak developed where the inclined field in the accelerator tube deflects the beam onto the insulator. Also some outgassing from an epoxy joint was observed even after 2 years of operation.

OXFORD UNIVERSITY

Dick Hyder

There was little to report on the EN tandem since 95% of the available effort was devoted to the Folded Tandem conversion. The EN ran for 6000 hours during the year at voltages up to 6.7 MV. The insulating gas is 80% N\(_2\), 20% CO\(_2\). The aluminium spiral inclined field tubes have now operated for over 30,000 hours, except for tube #1, 11,000 hours. This tube has an obsolete insulator profile. It has many internal track marks and will be replaced with a titanium tube, as will the #2 tube. There have been a number of resistor failures in the LE column, correlated with the acceleration of heavy ion beams and associated with tube problems and loading. Over the past 18 months the corona needles have had a reduced life of 500-1000 hours before they become so blunt as to attract sparks to the mushroom and cause the corona circuit to run in an ineffective mode. A storage scope has been used to record effects before and after breakdowns.

The Middleton sputter source has been converted to reflected mode. This has eased sample preparation and improved the intensity and quality of the output. Ions accelerated included: p, \(^3\)He, \(^4\)He, \(^6\)Li, \(^{11}\)B, \(^{13}\)C, \(^{14}\)N, \(^{16}\)O, \(^{18}\)O, \(^{19}\)F, Mg, Al, S, Si, Cl.

The Model 9298 CERN NMR systems designed by Borer and Fremont have been in use for 6 months and are highly satisfactory. They are compact, each unit occupying one double width NIM module.

In preparation for the installation of a large magnetic spectrograph, the multigap has been removed and several beam lines have been rebuilt, including one for beam foil spectroscopy with a 400 watt CO\(_2\) laser.

The Research Laboratory for Archaeology and the History of Art are acquiring a 2.5 MV Tandetron for carbon dating. In conjunction with this joint project an ion source test bench, consisting of a Middleton source with a 90° inflector magnet and an automatic emittance measuring kit, has been set up. Samples of pyrolytic carbon from acetylene have been tested for yield, stability and freedom from contamination. Emittance measurements will be made to ensure the proposed samples are consistent with Tandetron acceptance. The relation between sample temperature and source output will also be measured.
The MP tandem has been in active use for research until the end of August at voltages up to 13 MV. The upgrade will re-use the existing tube sections, so the machine has not been pushed. Since April 1978, the belt has run in the ‘half-open’ configuration described at the European Tandem Conference at Ebeltoft in 1978. There are no grading rods in between the two runs of the belt and six rollers prevent the belt touching anything but the screens. The HVEC grading rods outside the belt have been replaced by round rods. Belt life problems have been overcome. The present belt has run for 9000 hours. The free-running belt ripple is 5-7 kV. In GVM mode the ripple is ±2 kV and with slit stabilisation the ripple is below 1 kV.

The standard #7 tube section was replaced last April by a lengthened section 88” long. This single tube was tested up to 4.6 MV. The four new LE tubes have been received from HVEC after lengthening. They will be installed in February. It is proposed to test the complete installation in next December. Stripper isolation valves have been fitted in the terminal.

A foil stripper has been installed in the CN at 0.4V between the two tube sections for high energy Ne beams.

MUNICH

L. Rohrer

The NEC tubes were expected to run at 13.3 MV, but attempts to reach 12-13 MV have been unsuccessful. The first set of NEC tubes went to 10-11 MV and then deteriorated. Contamination from the packing material was blamed. The second set was installed in early 1978 and carefully baked. They ran at 10 MV. Sections were then conditioned individually with shorting rods and the voltage increased to 11.7 MV at the end of 1978. After repairing a leak in the feedthrough to an electrostatic lens it was not possible to get back to the previous voltage and many column resistors and corona needles were destroyed. Early in 1979 the LE column resistors were replaced by open corona needles. Also new 2.1 mm column spark gaps were fitted to try and draw energy away from the tube and reduce deconditioning. (The standard spark gaps were 2.9 and 3.9 mm.) Needle plates and damaged resistors in the HE column have also been replaced. Gate valves were installed at the ends of the terminal stripper and the second stripper, thus avoiding the need to vent the tubes when replacing foils.

The MP was then conditioned to 12.6 MV and is now running between 11 and 12 MV. Tests under different conditions did not explain the deconditioning. It is necessary to reduce the energy dumped into the tubes during a spark. The MP is harder on tubes than an NEC machine. A long operating period, from January to October, without venting the tubes has resulted in excellent vacuum. This has had a positive influence on performance.

The GVM has been modified so that two signal plates are operated in differential mode. The output from a controlled rectifier and differential amplifier is proportional to $V_t$ and common mode interference (from ionization currents) is eliminated. Provided that the plates are cleaned every three months to remove the film of grey dust, the accuracy and linearity is good to 1 in $10^4$. The system is fast.

Control and metering in the terminal has been improved with the installation of microprocessors to handle the signal data. Microprocessors are not more sensitive to sparks than other devices and they can be protected by standard filtering and screening. The column currents are measured by voltage to frequency converters and are transmitted by fibre-optic links to ground potential. The digital signals and their complements are both transmitted. Only if the signal and its complement agree is the signal accepted.
SESSION II  LABORATORY REPORTS (continued)
Chairman: Charles Adams

STANFORD UNIVERSITY  Jack Harris
1. Fomblin Y18/8 oil is used in the vacuum pumps for the atomic beam polarized ion source, since atomic H or D causes severe polymerization of DC704. However, after 1400 hours at full gas load the vacuum failed. The symptom was that the forepump pressure rose to 2000 microns and the boiler temperature of the first diffusion pump increased from 150°C to 180°C. The first of the three of the pumps had lost 400 out of 500 cm$^3$ of its oil, the second half its charge and the third none. The loss of most of the charge from the first pump allowed the boiler temperature to rise, which resulted in rapid oil decomposition. The forepump was heavily contaminated with HF. Regular inspection and oil changes are needed to stop a recurrence.
2. The mechanical chopper at the LE end used a rocking motion drive, through a bellows, using a SLOSYN. It was unreliable and was limited to pulses longer than 30 ms. It has been replaced with a rotary motion chopper, which goes down to 1 ms. A laser beam through the chopper aperture provides the synchronization signal.
3. GVM stabilization of the terminal voltage using the Seattle system has been installed and works well.
4. A 240 foil wheel of ANU design will be installed.

NOTRE DAME UNIVERSITY  Ed Berners
A 25 year old 4 MV Van de Graaff, built at Notre Dame, has been installed as an injector for the FN. The beam is transported into the FN mostly by electrostatic elements. In addition there is a polarized ion source and a charge exchange ion source. There is an electron gun in the terminal in a separate accelerator tube for bremsstrahlung experiments.

The FN has run for 5000 hours, of which 1400 hours were 3-stage. The insulation gas is N$_2$/CO$_2$ at 180 psig, very dry. The aluminum tubes have now run for 56000 hours at voltages up to 9.655 MV. Some glass damage is visible on pitches 19 and 20 in tube #1. The last 6 magnets in the magnetic section have been reversed and no further damage has been seen during eighteen months. Charlie Goldie suggested that the dished electrodes should be reversed if the tube is rebuilt so as to shield the glass from electrons.

Three stage beams have included $^{11}$B and $^{12}$C. A 650 nA beam of C$^{6+}$ was accelerated to 68 MeV. The highest energy beam was $^{35}$Cl$^{11+}$, 0.1 eµA at 106 MeV. The best performance is obtained with three stage operation, since the good quality of the injected beam eliminates interaction with the tube electrodes.

Nitrogen costs have been reduced by recovering the boil-off from the storage tank, using a back pressure regulator. The gas goes to an accumulator tank, is compressed, mixed with CO$_2$ and sent to the accelerator.

The production of negative polarity beams revealed a serious problem with slit stabilization. The solution was to fit additional of slits. The defining slits clip the edges of the beam. Opposite each staggered defining slit is a polarizing slit connected to a 1 kV power supply. The defining slits are held at 300 V by a battery. The enhanced signal is large, positive and stable.

A crack has been discovered in a column glass insulator. What will happen?
The laboratory has two accelerators, a 4 MV single-ended Dynamitron and an EN tandem. The last three years have been devoted to achieving reliable Dynamitron operation. Purification of SF₆ is an old problem. Helium had been added to the gas by mistake and found its way into the glass rectifier tubes. A preliminary account of the purification system was reported at SNEAP 77 and a more detailed account was given in Strasbourg. The apparatus is made from simple equipment such as may be found around any laboratory. Details are available of the system which can handle one 115 lb cylinder per day. Starting with 30% air, the output gas contains 1 part in 1000.

Commercial quotations for a fast gas transfer system to improve on the present rate of 6 hours in either direction were prohibitive, about $100K. A new system has been made from standard commercial components, available off the shelf, which transfers in either direction in less than 1 hour. It has operated successfully for two years. There have been no major problems using oil-lubricated compressors and no problems with excessive cooling during transfer.

A sputter ion source is being developed from the Aarhus source. Per Tykesson was designing it, but after his death the project was abandoned at Aarhus and has now been completed at Montréal. A carbon beam of 2.5 µA has been delivered on target.

The use of tritium, as a target not a beam, has now ceased and decontamination of the target area is complete. Over the past year work has proceeded on the design of a 1 GeV continuous beam electron accelerator. If this project goes ahead, the tandem will be removed and the Dynamitron used as an injector.

COMMUNICATION FROM THE AIR PRODUCTS REPRESENTATIVE

Michael Pohl

Air Products make fluorine compound gases such as IF₅, SF₄, SF₆ and BrF₃. They have devised methods for measuring impurity concentrations in these gases to comply with or exceed the standards specified in ANSI/ASTM D2472/71. There are no standards for ‘arced’ SF₆. The Electric Power Research Institute will produce a report, RP1204, for measuring and specifying impurity levels in these gases. Using gas chromatography, Air Products have made progress in detecting impurities like HF, SO, SO₂F₂, SOF₄ etc. Their object is to establish preventive maintenance schedules for equipment operating with ‘arced’ SF₆.

TECHNICAL UNIVERSITY, BOCHUM

Klaus Brand

The Bochum laboratory contains a small single-ended accelerator and a RDI Dynamitron tandem, serial number 2. Serial 1, which is 15 cm shorter, is at ANL. The Bochum tandem is based on a standard RDI 4MV single-ended machine. The injector layout, originally designed by ORTEC and incorporating pulsing for H and D, comprises three sources feeding through a ±30 magnet. The left leg is for a direct extraction duoplasmatron or a charge exchange source for helium. The right leg contains a GIC Hiconex 834 sputter source, used solely in the reflected mode.

Eighteen months ago the thermionic diodes in the charging supply were replaced by solid state rectifiers, saving 40 KW or 250 MWH/year. Since then there have been no failures over 11,500 hours of operation, except for one anode resistor in the HE column. The lowest operating voltage is 200 kV, at which energy the transmission is 50%. The lucite column structure was replaced 2½ years ago and the LE column structure again in the summer of 1979. The design has now been changed to reduce the effect of radiation damage which is worse in the LE column.
In future, the radiation will be reduced by a terminal cryopump, better beam optics and maybe magnetically suppressed tubes. The unusual beam transport system has three identical switcher magnets, the first having lines at $\pm 52.5^\circ$, and the others serving ten further beam lines. The layout allows a 400 kV air-insulated accelerator to supply beam to two lines for crossed beam experiments.

The Dynamitron beam was used with nuclear techniques to analyse the distribution of ions implanted by the 400 kV machine, an experiment that requires fast switching from one beam to the other. The experiments were plagued by instability in the small accelerator due to surface charge buildup on the epoxy insulators of the accelerating tube, which was of the design described by Herb in the 1954 *Physics Handbook* as an “early tube”. This tube has been replaced by a section of 8” Dynamitron tube enclosed in a larger glass-fibre epoxy tube containing SF$_6$ at 0.7 bar (10 psig). The machine was then very stable with a 500$\mu$A mixed ion beam and the beam switching time reduced from half an hour to two minutes. The same technique will be used for the new Dynamitron heavy ion injector.

CENTRE DE RECHERCHES NUCLEAIRES, ORSAY
Pierre Bretonneau
This paper was presented by Michelle Dumail.

There has been little experimental operation of the MP since October 1978. In November 1978 the machine was shut down to install the Laddertron (this is described later). The MP has operated with the Laddertron from April to July 1979. In 1978 30% of the operating time was with light ions, 70% with heavy ions. Beams of $^{14}$C were produced in a home-made ion source, using TaC cathodes. The GIC UNIS source has also produced beams of MgH and CaH.

Transmission from the LE cup to the analyser object, with the Laddertron installed and 5 $\mu$g/cm$^2$ foils, is as follows:

- He from the Li charge exchange duoplasmatron at 12 MV >50%
- Si$^{8+}$ from the GIC 834 source with quenching gas at 11 MV 20%
- Si$^{8+}$ from the GIC 834 source w/o quenching gas at 11 MV 30%
- O$^{6+}$ from the GIC 834 source w/o quenching gas at 10 MV 40%.

The emittance of the proton beam was measured to be 0.22 mm.mrad at 25 MeV.
The emittance of the oxygen beam was measured to be 1.5 mm.mrad at 15 MeV.

Two Tiball pumps have been installed in the terminal, like Chalk River. A home-made stripper assembly with 80 18 mm diameter foils has been installed in the high energy dead section.

UNIVERSITY OF ROCHESTER
Tom Miller
The Rochester MP has continued to operate over 12 MV. A 2.5$\mu$A beam of $^{16}$O was accelerated at 12.73 MV. Without beam, the MP was conditioned to over 13 MV. The insulating gas is 25% SF$_6$, 75% N$_2$ at 140 psig. Cryopumps will be installed at the LE and He ends. Gove and Elmore have continued to develop $^{14}$C dating techniques.

FLORIDA STATE UNIVERSITY
Ken Chapman
The Super FN has continued to run well. For the past two years corrosion of the magnet coils by cooling water has been controlled by the injection of WC105 inhibitor, but a defective coil had to be replaced. New coils are made of copper nickel alloy.

A voltage modulated stripper, supplied by NEC, has been installed to improve stability for coupled operation with the superconducting LINAC. It is controlled by an infra-red light link.
The stripper capacity has been increased from 115 to 155 foils.

In preparation for the installation of a booster, a completely new LE beam line is being installed. The first phase of the upgrade will include a pre-accel buncher/pulser and a post-accel cryobuncher. This is funded. The LE pumping station has been replaced by a cryopump. The LE vacuum is $3.5 \times 10^{-7}$ Torr and the terminal vacuum $3 \times 10^{-6}$ Torr. The terminal gauge is very useful. It gives good indication of tube conditioning long before any other symptoms are present.

On 31/12/78 the belt broke after 31 months and 16216 hours. The new belt had a serial number between two bad belts. The practice now is to run a new belt for 12 hours with the terminal shorted and no upcharge and then for 24 hours, still shorted, with gradually increasing upcharge in order to avoid damage due to excessive self charging during initial operation. This procedure is then followed by slow conditioning.

The principal ions used were: Be, B$^{10}$, B$^{11}$, C, O, S.

SUNY, STONYBROOK

John Noé

The FN voltage has been limited to 8.5 MV in order to stretch the life of the old components prior to the upgrade. The original aluminum IF HE accelerator tubes have now done 65,000 hours. The LE tubes were replaced in 1972. There is no visible damage to the tubes, but they are very brown. They run easily up to 8 MV and can be conditioned up to 8.5 MV. Tube springs have given problems due to the use of pure SF$_6$, and will be replaced at the next maintenance.

On one occasion, with the machine at 8 MV and no one at the console, the machine sparked repeatedly with the result that there were many small holes in the belt due to the successive sparks. These were repaired with epoxy resin, by sealing the edges of the holes, and the belt has run for a further 1500 hours. During the previous two or three years, belts have had very short life (2000 hours) due to a faulty load cell which caused the belt tension to be set too low (total tension only 1000 lbs) so that the belt flapped badly and slipped.

Cryopumps at the LE and HE ends and a sublimation pump in the terminal have worked quite well; LE and HE pressure is about $3 \times 10^{-7}$ torr. However several hours are needed to recover cryopumps after a power outage. 30% of beam time has been devoted to H and He, 60% to light heavy ions such as $^{16}$O and $^{18}$O. There are three ion sources; a Li charge exchange source, a direct extraction source and a sputter source. An unreliable Spellman extract power supply has been replaced by a GIC unit.

One third of the beam time has been with a pulsed beam. The pulse length is 1 ns for protons and 1.5 ns for oxygen. A superconducting buncher (LINAC prototype) has been installed which compresses the pulse to 100 ps. A post-acceleration sweeper reduces the integrated dark current to 1 part in $10^6$ for 24 MeV alphas. A fast time pickoff, using a chevron channel-plate electron multiplier is used to control the tandem phase to 150 ps or better. The beam is allowed to hit a 1 mm wire biassed to 4 kV. By locating the detector at a backward angle, the energy spread of the electrons is kept small.

The HVEC Laddertron (having a guaranteed current of 250 $\mu$A), the Dowlish titanium spiral IF tubes and new computers will be delivered in 1980. The new GIC 400 kV injector platform will be installed mid-1980. This is specified to have a very high voltage stability so as to satisfy the superconducting LINAC requirements. Two PDP11/60 computers will replace the existing machines.
Two EN tandems (EN20 and EN22) can be used for coupled operation. There is an EXTRION UNIS source and a Wien filter in-line in the terminal of EN20 controlled by a radial infra-red link. This link has given problems. Improving the surge protection of components which have been damaged by sparks has cured the specific problems but has not solved the general problem. Terminating the columns in 50 resistors may have helped. Shields have been added to the terminal to prevent transient fields extending inside. It may be possible to build a duplicate control system using TV cameras, rods etc. A system for bleeding gas into the terminal source in order to improve the cesium beam focus is nearly ready for test.

For two-stage operation there is a Mark 7 EXTRION UNIS on a 80 kV platform for heavy ions and a HVEC duoplasmatron with lithium charge exchange for helium.

Over the past two years EN22 has been upgraded. The two LE tubes, which were in bad shape, were replaced early in 1978 and the two HE tubes late in 1978 with Dowlish titanium spiral IF tubes. A sublimation pump with remote control and metering was installed in the terminal, but has not yet been used. This pump and the foil stripper are controlled by strings and rods. The vacuum in the terminal, without the sublimation pump, is $2 \times 10^{-6}$ torr. A new NEC foil stripper, capacity 230 foils, has also been fitted and works well. Cracked ethylene foils, to be described later, are used.

Strict rules have been followed for conditioning the tubes:
1. Do not raise the voltage above the point at which the pressure in the terminal increases, as indicated by the terminal meter
2. Do not exceed external X-ray levels of 15-20 mr/h. Ensure the X-ray level is watched continuously.

After a trap warmup the tubes showed activity after a delay of 24 hours and then needed to be conditioned for a full week. With a gas mixture containing 1% SF$_6$, the voltage has been taken to 7.2 MV with beam on target.

A modified #4 accelerator tube has been installed in EN22 for the accel-decel scheme required by Jim Bayfield, studying the properties of fully stripped, low velocity heavy ions. In this scheme both machines are negative polarity; the heavy ions from EN 20 are charge exchanged from negative to positive in a helium gas stripper between the two tandems and then stripped in the (negative) terminal of EN22 and retarded to emerge with a final energy, for $^{16}$O$^{8+}$, of 300 keV.

This report covers the two and a half years since the Strasbourg conference in 1977.

Improvement to the voltage followed the discovery that the column castings contain major quantities of sand (from the sand casting operation). Cleaning the castings and removing the sand have resulted in a voltage increase. Early in 1978 a second stripper was installed in the He column, involving the removal of one third of a tube module. By March 1978, voltage had been conditioned to 14.85 MV and experiments ran at 14.3 MV. The machine now runs as well at 14 MV as it did at 12 MV in 1977.

Breakdown products in the SF$_6$ are a major concern. When operating at 12 MV it was sufficient to regenerate the dryer every six weeks, at 13 MV every 4 weeks and at 14 MV every week. Breakdown products are produced at a more rapid rate when the machine is conditioned hard. They have a number of impacts:
1. lost charge - unbalance up to 150µA
2. they attack the nylon chain links, but only in the presence of water
3. rusting and corrosion of compressor, valves and tanks - 2 kg of rust was removed from the storage tank before repainting
4. their presence on high field surfaces can promote instability - wiping restores “eerie” stability
5. good evidence that they can promote bearing failures on the shafts
6. effect on the stickiness of charging pulleys. If the breakdown products and the oil are removed so that the pulleys are clean and dry, there is significant negative self-charging. This itself is not a problem, but the chains then ride up the side of the pulley, touch the inductor and break.

Bair has speculated that lost charge may be due to stable positive ions associated with spark breakdown, as suggested by the brown deposits along field lines near the corona mushroom.

Lost charge can be avoided by the ‘proper’ reactivation of alumina. This involves heating to 300°F, blowing nitrogen through, evacuating to 50 torr, cooling and then refilling with SF₆. At ANL, where the spark gaps are sealed, it is not necessary to reactivate. Other gases may affect breakdown. One theory is that oxygen in a gas mixture may deactivate the reaction products.

The conditioning strategy at ANU is based on the observation that tubes contain dust, although no dust is visible on the electrodes. The object of conditioning is to move dust to low field regions. However, dust is redistributed if turbulence occurs during evacuation or when backfilling with air (?nitrogen). When the second stripper was installed, leaks necessitated evacuating and backfilling the tube 8 times. The threshold afterwards was 8 MV instead of 10 MV. The procedure now is to take 45 minutes to evacuate and backfill, with the result that the threshold rose to 13.67 MV without conditioning. If the conditioning procedure is linear there is no reason not to reach 1.15 x 13.67 = 15.2 MV, since individual tube modules can be conditioned to 1.15 MV.

Modifications: the covers to the castings were cylindrical. They are now convex. New terminal spinnings will also be installed. This will reduce the peak field by 15%. During tests the machine operated without tubes at 16-18 MV. With the lower peak field it should go to 18.5-21.5 MV.

Developments:
1. The leads to the heater plates were multiple copper strands with rubber insulation. These deteriorated, depositing rubber particles inside the machine.
2. Electron suppression (-5 kV) plates have been fitted either side of the HE stripper.
3. The nickel straps which connected the tubes inside the castings have been replaced by aluminum rods.
4. The shorting rod contacts continue to be a serious problem. There is an improved design.
5. By filling the tank from the gas phase, oil is separated from the SF₆.
6. A variable iris has been fitted at the LE end, for low current users.
7. A new design of idler pulley bearings should prevent the pulleys sliding off their bearings.

UNIVERSITY OF WISCONSIN

Jim Billen

The SNICS source is now in routine use with beams of ¹²C and ¹³C for nuclear physics and Al, Cu and Ni for damage studies. With outputs of 5-6 A the cathode life is several days.
Beams of $^{13}\text{C}$ have been produced using enriched powdered graphite and 25% lead by weight as a binder. The SNICS source and the duoplasmatron had to be moved to make room for the crossed beam polarized ion source which is nearly complete. These sources now use an electrostatic mirror, which can be rotated about 90°. The crossed beam polarized source uses a 50 keV beam of Cs$^+$, neutralized in Cs vapour, to intersect with the atomic beam from the ANAC source. 2-3 A of polarized H$^+$ or D$^+$ is obtained using a spherical deflector. With 1 A injected 0.5 A is measured on target. With weak field the polarization achieved is 0.19, 82% of the expected maximum. With strong field the factor is 0.16, 86% of maximum. The emittance of the tensor polarized deuteron beam is 6.5 mm.mrad.MeV. A new electrostatic scanning device, as used on the emittance test bench, will be installed on the tandem.

The EN tandem has now operated for 115,000 hours. There were no major problems last year. The tubes are IF stainless steel. When high radiation levels from these tubes have been observed the bad section can be diagnosed by running a steel ball on a string along the column, shorting out successive sections. When the bad section is shorted, the radiation level changes. Very high radiation, more than 1 r/h at the terminal, was observed when a single pitch near the end of the magnet section was shorted. This is not understood.

TRIANGLE UNIVERSITIES NUCLEAR LABORATORY  
Jim Willis

A microprocessor based control system is under test on the polarized source. This uses multiplexed optical links between source and ground. 150 nA of polarized pulsed deuterons have been delivered to target. The bunching system for the polarized beam consists of three stages. The first is a 100 V ramp applied to the duoplasmatron which bunches the 1 keV deuteron beam from the Lamb shift source over a 1.5 m drift space. This is followed by a double drift buncher as described by Miller and Ziegler at SNEAP 1977. This system delivers 80% of the DC on target, of which 90% is within 2 ns.

As well as the polarized source there are now two direction extraction sources, a helium source and the heavy ion sputter source all inflecting into the LE end. The beams included H, D, Be, B, C, O, Al, Ti, V, Cu. A mass identifier has been built which uses two ADCs to input the magnet field and the Faraday cup current and display the mass spectrum. At the HE end a post-stripper has been installed after the analyser to produce high charge states which are then selected by a 70 switcher magnet.

BROOKHAVEN NATIONAL LABORATORY  
Hans Abendroth

Brookhaven have experimented with 10µg/cm² cracked ethylene foils but found no improvement over conventional foils. Transmission is reported to be 80%. A new NEC 230-foil stripper assembly has been installed and works well. HVEC blue resistors have been failing at the rate of several per month. They are being replaced in tube #5 with Caddock resistors fitted with the Rochester design of shield plate. The shield plates provide capacitive coupling between resistors. The resistors are attached to the tube via inductors. In five months there has been very little change in R (< 5%).

A 10 nA beam of OCN⁻ has been accelerated and passed through the stripper without dissociating. This is being used for experiments with “super-collimated beams”.

Operating 2-stage, MP7 completed 39 runs above 12.5 MV, 22 runs above 13 MV and 3 runs above 13.5 MV. 50% of running time was above 12.5 MV.

Out of a total of 72 3-stage runs 39 were above 12.5 MV, 28 above 13 MV, 9 above 13.5 MV and 2 above 14 MV.
After 10,000 hours of operation the Pelletron broke. 20 pellets were replaced. The suppression inductor has been moved to avoid it rubbing on the sheave. The oiling system tubes had become hard and had broken. The oilers have been removed and the pads are saturated on maintenance. Because the little wires on the pick-off pulley break off, the pulley has been replaced by one made of carbon loaded polyurethane. This has worked well for 2000 hours.

A cryopump with a 500 l/s ion pump in parallel has been fitted at the HE end. The base pressure is $1.5 \times 10^{-8}$.

An attempt was made to run with pure SF$_6$ at 90 psig. It was impossible to get above 11 MV and the recovery time from sparks was very long. Performance with a mixture of 43% SF$_6$, 2% CO$_2$ and 55% N$_2$ at 150 psig was much better. An area SF$_6$ monitor has been installed.

SESSION III GENERAL DISCUSSION

Chairman: Pat Den Hartog

EXPERIENCES WITH IMPROVED FOILS AT CHALK RIVER

Peter Hurley

Work performed by Gallant, Burn, Mraskovic and Andrews.

Under ion bombardment stresses develop in carbon stripper foils, due to radiation damage. The heavier the ions, the faster the damage. Foils of 2 or 5 µg/cm$^2$ produced by electron gun sublimation of carbon may last over 1 hour with light ion beams but less than 1 minute with iodine.

Three improved methods of foil production have been tested at Chalk River.

1. JAERI Carbon evaporated by arc discharge is deposited on a glass slide, coated with a thin film of NiCl and heated to 300°C. The crucial feature of this method is the heating of the substrate. Tests with different surface coatings did not increase life.

2. Harwell/Daresbury. Using a hydraulic press the foils, mounted on machined aluminum rings, were forced through a tapered collet to reduce the diameter of the ring by 10%. The foils then adopt a dome shape, allowing more shrinkage and deferring the development of stress cracking.

3. Harwell/Daresbury. The foils are formed by cracking ethylene gas in a high voltage discharge. The carbon is collected on the cathode. The foils are then mounted and slackened.

Foils with an initial thickness of 2 and 5 µg/cm$^2$ were tested at ORNL and Chalk River. Tests with a 10 MeV beam of Cl at ORNL gave a factor of 10 improvement in life for unslackened ethylene foils and for JAERI type foils made at Chalk River and a factor of 40 for slackened foils made by either technique.

Three trials were carried out at Chalk River, the first using a 1µA beam of I$^-$ at 4.9 MV. In each case there was a short lived increase in transmission, followed by a decrease due to increased multiple scattering. The life, defined as the time for the transmission to fall to $\frac{1}{2}$ or $\frac{1}{10}$ of the initial value, was recorded. A second series of tests measured the effect of projectile mass and intensity. The third series increased the number of tests to improve statistics. The terminal pressure was about $1 \times 10^{-6}$ torr. The terminal pump was off. Elemental analysis of the foils by Cl scattering showed that the foils contained 3% H, the remainder being C. Under bombardment all foils become mirror-like in appearance and then develop wrinkles around the periphery. Breakage follows. The different lifetimes are believed to be due to differences in the atomic structure, resulting from the changes in the temperature of the deposition process.

In contrast to the sublimated foils, where a very small and very brief increase in transmission is followed by a gradual reduction, the cracked ethylene foils showed a slow
increase in transmission by a factor of as much as two, lasting for most of the life of the foil and followed by a rapid decrease from the maximum.

Accurate thickness measurements of used foils will be made to see if there is a correlation between initial thickness and the increase in thickness.

Summary: in comparison with standard (evaporated, unslackened) foils, slackened standard foils have 5x the life, slackened JAERI foils have 15x the life and slackened ethylene foils have 25x the life.

DISCUSSION
Q: What is the voltage of the glow discharge?
Hurley: Optimum voltage is 2.5 kV. No advantage is seen unless the voltage is at least 1.5 kV.
Jones: What is the effect of terminal pumping?
Hurley: No advantage, so not used.
Jones: What is the pressure in the terminal?
Hurley: About 1 x 10^{-6} torr.
Den Hartog: If foils were made of $^{13}$C, it would be possible by measuring the isotope ratio after use to determine if cracked carbon had accreted on the foil.
Hurley: At Chalk River there is no evidence of carbon accretion but Chalk River use ion pumps, so that there is little or no hydrocarbon in the system.
Woods: How does the increased transmission through slackened foils square with the increase in thickness due to slackening?
Hurley: Diameter only shrinks by 10%.
Billen: Perhaps the beam moves to a different part of the foil.
Hurley: No, the beam is seen not to move about on the foil.
Den Hartog: Foil thickening was discussed at the target makers’ meeting last week. There was no agreement. Some people think that thickening depends on the rate at which material is sputtered from the foil relative to the rate of deposition.
Hyder: The effect of pressure may be the cause of the different behaviour of foils in the EN tandem and the folded tandem at Oxford. In the EN there is no terminal pumping and the pressure is between 2 x 10^{-6} and 10^{-5} torr. In the FOLTAN terminal there are two sputter ion pumps and the pressure is a few times 10^{-7}. In the EN, foils are rejected because of loss of transmission due to thickening. In the FOLTAN, rupture is the usual cause of demise.
Berners: How can one get a detailed recipe for making cracked ethylene foils?
Hurley: Contact Joe Gallant at Chalk River.

EXPERIENCES WITH CRACKED ETHYLENE FOILS AT PITTSBURGH     Tillman Saylor

Westinghouse are carrying out a programme simulating neutron damage by bombarding materials with intense beams of silicon ions. Currents of 3μA are injected with the terminal at 4 MV and a beam of Si^{6+} is extracted. Previously 5 μg/cm² carbon-arc evaporated foils from the Arizona Foil Company were used, floated onto the foil holders with the aid of formvar. The life was short. Westinghouse had been using a commercial RF diode sputter-etch technique to clean substrates with argon ions. The same equipment has now been used to deposit carbon from ethylene gas. Five standard 1" x 3" slides, salt coated, are mounted at the centre of the pallet, surrounded by plane glass slides to make the field uniform. The carbon film is then uniform enough to make foils from all five slides. The sputter-etch device contains 6 pallets, so a single evacuation yields 30 slides or 150 foils. Ethylene at 15 μ pressure is deposited by an RF system
operating at 13 MHz, 1.6 kV and a power density of 1 w/cm². The measured foil thickness of 280 (5.3 µg/cm², assuming Δ = 1.9 g/cm³) is obtained after a 39 s. bombardment. The foils are deposited on a 2000 NaCl layer of NaCl formed by vacuum evaporation on a glass slide. The thickness of the salt film is critical. If too thin, the foils are difficult to float off. If too thick the foils are grainy and irregular.

The frames have a 3/8" diameter hole. They are first coated with a single layer of formvar. A drop of formvar solution (5-10% polyvinyl formvar dissolved in 1-2-dichlorethane) is allowed to spread over a bath of room temperature deionized water, drying in a few seconds. Frames are pulled vertically through the formvar film and allowed to dry thoroughly. The carbon foils on the slides are cut into five sections and floated off by being lowered at 45° into a bath of deionized water at 65°C using a worm drive. The success rate is 80%.

The foils are stored in a dry atmosphere. They are more transparent and more brittle than, but just as strong as, commercial foils of the same thickness. On first irradiating the foils, the formvar is evaporated and the terminal pressure rises by 1-2 x 10⁻⁶ torr for 15-30 s.

In comparison with standard foils, the ethylene foils transmit two or three times as much current, either because they are thinner or because they are more uniform. The transmission decreases gradually and foil life is terminated by rupture. After irradiation, foils that have ruptured are found to have fragments of foil still present on the holder. A few foils rupture as soon as the beam hits them. This may be due to defects in the foil causing failure as soon as the formvar is evaporated. When the formvar is burnt off it is possible that some of the carbon may add to the thickness of the foil. At least 50% of Westinghouse foils last longer than 2 hours. Standard foils have a much shorter life. Very few last 2 hours. The improvement due to the new foils is at least a factor of 10. We are grateful to Daresbury for pioneering this improvement.

DISCUSSION
Anon: What is the beam current?
Saylor: 5 µA is measured at the LE cup. Assuming the mean charge state is 6+, the stripper current is 3 µA
Jones: Are the foils slackened?
Saylor: No.
Sturbois: Why use foils as thick as 5µg/cm²?
Saylor: Not sure. It used to be thought that thinner foils would rupture more easily.
Sturbois: LeHigh use evaporated C foils deposited on slides covered with Teepol. The foils are immersed in a 7% solution of collodion in iso-amyl acetate and pulled out. The collodion layer (10µg/cm²) disappears with the beam.
Carlson: BNL can use 1-2µg/cm² foils occasionally but require thicker foils for the higher charge states. They use 5µg/cm² in the terminal and 10-20µg/cm² in the second stripper.
Weisser: Cracked ethylene foils have been tested on an external beam line of the Oak Ridge EN and compared with “standard” foils which are either arc discharge (ANU) or electron bombardment (ORNL). The glow discharge foils have been made with thicknesses ranging from 2 to 10 µg/cm². The beam was Cl, 10 MeV, 0.3 µA, 2 mm diameter. The line was cryopumped to a pressure of 3 x 10⁻⁸ torr.

The tests showed that foils get thinner under bombardment, down to 75% of the original thickness at the centre. Glow discharge foils have a lifetime which is linear with thickness, suggesting that sputtering limits life. Foils that fail prematurely show stress marks outside the beam spot. Foils which do not fail prematurely show cracks or ruptures within the beam spot.
Slackened foils, produced by shrinking the ring, last longer than unslackened foils. There is
evidence for initial foil thickening up to twice the original thickness, followed by thinning, where
the beam hits the foil. Scanning the beam across the foil reveals inhomogeneity, possible caused
by wrinkles. The ANU ethylene cracked foils were produced with a voltage of 2-2.5 kV in a
pressure of 100 µ. ANU have made slackened foils by picking up on foil holders which have
been deformed by pressing onto a hemisphere. These foils have not yet been evaluated.

**Chapman:** What is the lifetime of the slackened foils?

**Weisser:** Not yet measured.

**Jones:** Measurements suggest that the thickening effect due to beam bombardment is worse in
slackened foils than in unslackened ones, yet the lifetime is better. Why should this be?

**Den Hartog:** Three laboratories report improved results from glow discharge foils: ORNL,
CRNL, Pittsburgh. Three laboratories report no improvement: ANL, BNL, Munich.

**SESSION IV  SINGLE-ENDED MACHINES**

Chairman: Henry Janzen

**NEC 2UH PELLETRON AT CHALK RIVER**

Don Walker

This accelerator is used as a mass analyzer for beams of mass up to 240, including
radioactive species. It was installed in 1973. It will produce µA beams of singly charged heavy
ions at energies up to 2 MeV for damage studies and implantation. The tank is 11' long and 5' in
diameter. There is a quick opening flange at the tank base. The spinning has a 1 ft diameter
removable section for maintenance access to the ion source. Column grading is by point-to-plane
corona gaps so the tank pressure is varied from 40 to 90 psig in order to run at different energies.
The source, which is 45 kV above terminal voltage, is controlled by rods and metered through
mirrors by TV. The single chain is driven by a 2 HP motor. New NEC flared inductors have
increased the maximum upcharge to 120 µA. A 5 HP motor drives the two terminal alternators
via a 3" diameter lucite rod. Five NEC beam position monitors work very well down to currents
of 1 nA. Voltage stabilization is accomplished using a pair of slits which can be off-set from the
axis by up to 16 cms enabling them to lock onto an intense beam near in rigidity to the wanted
beam.

**PUMPING SPEED MEASUREMENTS ON A VARIAN CRYOPUMP**

Terry Lund

Two Varian VK-12A cryopumps with integral 8" valves. will shortly be installed on the LE and
HE ends of the MP. They have been purchased to save power and LN₂ costs. They use closed
circuit helium compressors and heads made by Air Products. Their pumping speed has been
measured in the laboratory using calibrated apertures. The speeds are slightly higher than the
manufacturer’s specification.

**DISCUSSION**

**Rowton:** Did you use AVS standard geometry for the speed measurements?

**Lund:** No.

**?:** Thermal radiation from an ion gauge can affect the temperature of the 77K stage if not
optically baffled.

**Adams:** In 1975 Penn installed a central compressor feeding three heads. It is essential to purge
and evacuate the compressor several times, using 99.999% helium, when servicing the
refrigerator unit in order to avoid problems with ice. The mechanical pump should have an effective vapour trap.

**Lund:** The CTI cryopumps in the terminal at Rochester have run for 20,000 hours. For these pumps the practice is not to carry out preventive maintenance but run them until they fail.

**Den Hartog:** Two CTI pumps have been in operation for 1 year. What maintenance is needed?

**McKay:** When CTI repaired heads from McMaster they replaced the displacers with a revised model.

**Saylor:** Oil pumps were used at Pittsburgh with cold (-150 to -200°F) refrigerated traps. These were unreliable. When they warmed up tube performance was affected. They have been replaced with LN\(_2\) traps.

**Sturbois:** Use oil pumps and a refrigerated baffle at -40°F. Although the total voltage is low, the gradient on the tube is high.

**Jones:** Use DC704 and water cooled baffles with no apparent trouble for more than 10 years.

**McKay:** KSU reported a serious failure with an oil pump system 4/5 years ago.

**Hurley:** Chalk River have replaced GE ion pumps with Varian. The pressure is now < 1 x 10\(^{-7}\) torr.

**Harris:** The main advantage of cryopumps and ion pumps may be in avoiding the consequences of an accident with an oil diffusion pump system.

---

**UPGRADE OF THE LOS ALAMOS P-9 ACCELERATOR**

Joe Tesmer

The P-9 accelerator is now 30 years old. It is currently being upgraded with a new terminal, new accelerator tubes and new telemetry. The new GIC terminal contains a floating deck at 40 kV for the duoplasmatron source, the inflector magnet and a 7.5 MHz buncher for p, d and t ions. This produces 1 ns proton pulses. A 2.5 MHz synchronizing signal is transmitted to ground. The telemetry system contains 60 analogue channels which can be sampled at 100 Hz. Data transfer inside the terminal is by fibre optic links, between terminal and ground via infrared. All electronics within the terminal is double screened. The heavy ion terminal has not yet been built. Power consumption in the terminal is close to the 4 KW limit of the alternator. The top of the magnetically suppressed accelerator tube is pumped by a triode ion pump. An Al-Zr sorption pump is used to pump hydrogen, for which its speed is 1400 l/s. These pumps need periodical regeneration. They absorb N\(_2\), O\(_2\) and CO\(_2\) but do not release these gases on regeneration at 700°C. Hence if allowed to pump large quantities of these gases, they die. The terminal is cooled by circulation of the column gas. The source is cooled by freon carried up the column in a teflon tube. The freon pressure is 80 psig. The pressure in the separation column is 100 psig.

---

**DISCUSSION**

**Walker:** If double shielding is needed, how are the barrier strips protected?

**Tesmer:** Protection is inside the screened box. The protection of the GIC power supplies works well.

**Walker:** At CRNL wires are protected by two layers of braid.

**Harris:** Are the freon lines coiled?

**Tesmer:** They are straight, tied to the column every 2'.

**Saylor:** How many tank sparks?

**Tesmer:** P-9 never tank sparks, most sparks are in the tube, some in the column.

**Noé:** Why not use a sublimation pump in the terminal?
Tesmer: Might not be able to handle the gas load, which can be 100 cm$^3$/h (?). The sorption allows for recycling of the tritium.

Weisser: The edges of the holes in the section plates have been rounded where the eighteen 1/4" nylon tubes for the high pressure SF$_6$ gas-operated controls pass through them.

Tesmer: Signal leads are protected with back-to-back avalanche diodes which break down in picoseconds (Semtech L10A). The wires pass through copper tubes which are soldered into the connectors. Most of the surge damage is confined to the telemetry system. Op-amps are especially vulnerable. Equipment at the base of the column is well screened by the column base plate, which is 1/4" thick. LASL are developing a single strand plastic fibre for telemetry links to the terminal.

SESSION V GAS HANDLING AND OTHER TOPICS
Chairman: Ken Chapman

DISCUSSION
Brassard (Montreal): The new gas handling system for the Dynamitron and the tandem uses standard, oil-lubricated refrigeration compressors. Why use Teflon sealed compressors when the mechanical vacuum pump is oil-lubricated? Two Tecumseh units with a combined speed of 100 cfm were chosen because they were rugged, cheap and off the shelf. They have external motors so as to avoid the problem of motor cooling during the low pressure part of the cycle. The system includes a Roots blower which is started at the same time as the vacuum pump. Roots blowers are not normally run at atmospheric pressure, but by driving at reduced speed with a DC motor the compression ratio is reduced at high pressure so that the rotors do not overheat. Although this is outside the manufacturer’s limits, the duration of this phase is so short that the rotors do not reach excessive temperature. A second Roots blower, used only with the Dynamitron, does run at constant speed and is only turned on at the end of the cycle. The whole system is under automatic control, with interlocks and hydraulically operated Jamesbury valves. The large Roots blower has a speed of 800 cfm, the small one 400 cfm and the mechanical pump 130 cfm. Oil removal is by an activated charcoal filter after the compressor and a commercial oil separator. Transfer either way takes one hour with SF$_6$ at 65 psig. The cost was $20K, compared with a quotation of $100K for a purchased system with the same performance.

On transferring gas into the accelerator, heat exchangers ensure that the gas enters near ambient temperature. On removing gas, there is some cooling but the effect is small. Because there is near thermal equilibrium between the gas and the tank, the effect is small. The thermal effects in the gas phase are small compared with liquefaction.

McKay: The thermal effects may be larger than has been suggested.

Rowton: What changes are needed to make refrigeration compressors suitable for this duty?

Brassard: The changes are minimal. Select a refrigeration compressor with a reputation for being indestructible. Replace refrigeration oil with vacuum pump oil.

McKay: What went wrong with the oil-free compressor at Stonybrook?

Noé: A seal ruptured causing some damage. New parts were needed.

Weisser: Apparently a shaft came unscrewed from a piston.

Adams: Penn had a problem with corona point life when running 30-40µA of current, using a 12 point corona probe on the EN. The problem went away when a similar system was used on the FN.

Hyder: Oxford attempted to save money by using stainless steel needles. This did not work.
Berners: HVEC said that the needles were originally wool carding needles.
Ashbaugh: Corona points at McMaster are changed every six months. The corona current is 100 µA. The HVEC needles are tungsten.
Saylor: Pittsburgh run the same gas and the same corona system in the same machine as Oxford. The needles are changed 3-4 times in a year, but not from necessity.
McNaught: What are the details of the fast pick-up at Stonybrook? 
Noé: A 1 mil platinum wire is mounted in a modified HVEC Tee with a bias voltage of -4 kV. The secondary electrons are detected in the backward direction by a chevron channel plate multiplier with a gain of 10^6. The pulse rise time is 1 ns, the timing reproducible to < 200 ps. The wire is movable. The backward angle minimizes the energy spread of the electrons. The timing pulse length is short and the pulse rate is up to 1 MHz.
Adams: What type of epoxy for used for repairing holes in belts? 
Noé: A commercial 12-hour curing epoxy resin, but it was only used to seal the edges of the tears. 
?: The edges of tears in the belts can also be sealed using an air-curing neoprene rubber cement (as used for wet-suits).
Saylor: Pittsburgh use Be-Cu tube springs in a N_2/CO_2 mixture. We have had no failures.
Noé: There are problems with Be-Cu in SF_6.
Carlson: Erosion of both the tube and column spring connections has been a very serious problem, both in N_2/CO_2 and SF_6. There has also been sparking on the shorting rod connections in the upper and lower columns. Rivetting some connections has cured part of the problem.
Hurley: Similar problems with tube springs. One set of tube springs has been removed and the two sides of the column connected by solid rods.
Richardson: Similar problems with tube springs on the EN in 10% SF_6 were cured by twisting the springs to increase the tension.
Ashbaugh: Many problems with resistors when running in pure SF_6, especially near section 20 in tube #1. Resistors are now bolted in. Connections are made with 18 swg tinned copper wire, fastened to the tube electrode with a nut and bolt. Since this change there have been only one or two failures - in areas where there is a lot of tube activity.
McKay: It is not necessary to drill and tap the column to make these changes. Just unscrew the pins used to attach the springs.
Letournel: Many problems during HV tests. Springs are not mounted only on one side. The connection between the grading rods is made with two large springs.
Hyder: Ten years ago there were problems with springs sparking through. These have been replaced with much heavier springs which are crimped to a tag and attached to a spark gap clip at the tube end. The material is spring steel.

The CERN NMR was designed by Borer and Fremont and is described in a report, CERN 77/19. The precision is 0.01 gauss. Four probes are needed to cover the range 1 - 20 kG. Using a deuterium probe the range can be extended to 60 kG. The sample is water + nickel sulphate in a probe which is ½" thick in the field direction and 1" wide. The oscillator circuit must be within 17 cms of the probe. The system can be used as a controller, either indirect by sending the measured frequency to a digital comparator, or directly with circuit modifications to the main board.
Weisser: ANAC may manufacture these devices for sale.
Abendroth: BNL were unable to go above 11 MV using pure SF_6. After a spark the machine would not return to the previous voltage. The performance was inferior to that of the mixture.
(43% SF₆, 2% CO₂, 55% N₂). The gas is continuously recirculated; the dryers are regenerated twice a year. They had been reactivated two months before SF₆ was introduced. They do not seem to need more frequent activation with SF₆, but perhaps the absence of CO₂ allows breakdown products to build up.

**Carlson:** Propose to use a 2 MV JN machine to carry out tests on insulating gases to see if there is a deconditioning process with SF₆ and if drying or reactivating affects it.

**Hyder:** Were sources used during the tests at BNL?

**Carlson:** Tests were made with the sources in, half in and out. They made no difference. All these results were obtained from one test run. The machine was not allowed to spark more than three times per hour.

**Chapman:** What is the importance of CO₂?

?: Sato says it is needed to quench excited nitrogen.

**Janzen:** Adding SF₆ to a N₂/CO₂ mixture caused the voltage holding to deteriorate. After trying various expedients, added more CO₂ and the voltage improved.

**Hurley:** Have never added CO₂. The water content is kept below 5 ppm. To date there have been 300 sparks this year, mainly due to defects, e.g. objects on the floor of the tank. Most are tube or column sparks. The gas could contain as much as 5-10% air. The proportion of O/N seems higher than in air, for reasons unknown.

**Sturbois:** How can one remove SF₆ from a mixture? We store the SF₆ as gas.

**Brassard:** We were able to separate gas containing 30% air without major consumption of liquid argon or LN₂. A preliminary report has been published.

**Ashbaugh:** Is there a good area monitor for SF₆?

**Jones:** ORNL use portable units for leak detection and a multiple head unit for fixed installations.

**Carlson:** BNL have a continuously operating area monitor with 13 heads, cycling at 1 minute per channel, which produces a written record. It is sensitive and accurate, even for heads as distant as 450 ft. It is an infra-red absorption device costing $20K.

**Signorini:** Use a cheap ($150) portable monitor for leak checking.

**Walker:** Silicon rectifiers in the terminal are protected from surges by GE MOVISTORS (?). No losses since replacing previous suppressors.

**Haberl:** No failures of silicon rectifiers in Dynamitron. Select devices with a high current rating and protect with avalanche diodes. Rectifier strings operate up to 40 kV.

**Carlson:** The SF₆ is analysed every 6 months. Does anyone analyse the gas online during transfer?

**Jones:** Teledyne oxygen monitor can be used at high pressure.

**Weisser:** Use an RGA to check if oil from the pumps is getting into the gas.

?: Where does the oil go?

**Weisser:** It plates out on the tank walls and can be wiped off.

Sato: Found pressure sensitive leaks during evacuation. From 150 to 100 psig, no change. From 100 to 0 psig, decrease in pressure. At 100 microns, the pressure reached a minimum. On pressurizing with nitrogen to 20 psig saw a nitrogen peak in the RGA. Found small leaks on the tube joints which were sealed with an epoxy resin.

**Saylor:** Found a pressure sensitive leak by fitting a tank flange with 4 plastic tubes leading to tube sections which were bagged. Helium was bled in through the tubes sequentially.
Sturbois: A pressure sensitive leak occurred in the (external) LE beam line, which opened up only when the tank was pressurized to 60 psig.

Janzen: External pressure may seal a cracked insulator.

Hyder: A circumferential crack (270°) in an insulator below an ORTEC RF source was undetectable using a helium leak detector, but showed up on overpressurising with air and freon to 2 psig.

Tesmer: Gassing up procedure on P-9 is to evacuate, pressurize with nitrogen, dry, evacuate and repressurize. An increase from ~10^-7 to ~10^-6 is seen during evacuation. The leak recovers on pressurizing. The same effect is seen during the drying cycle, but smaller.

Weisser: These pressure fluctuations are seen at ANU but are ignored unless the RGA shows a rise in the SF6 peak. It is an advantage to have a leak detector in the terminal because of the rapid response. One can get an indication of the position of the leak from the energy of the secondary particles.

Noé: Have seen a pressure rise of 10^-6 torr during filling.

Sato: Varian needle valves may be affected by external pressure.

Rowton: “O” rings shift during pressurizing. Over-greasing traps gas bubbles which pop, so giving periodic bursts of pressure. How many tandem users have high transmission gridded lenses?

Various: The CRNL MP uses one, as well as an ESQ. McMaster still use one. Stonybrook have removed theirs; with an injection energy of 50-70 kV and an einzel lens, matching is good and transmission for oxygen is 80%.

ORNL: Veeco recommend leak testing with neon and looking for M=10 (Ne^2+) when ion pumps with helium loads cause a large M=4 background.

Letournel: The new accelerator tubes will have double seals. The inner gasket is metal with an internal spring, the outer Viton for leak checking.

GENERATION OF 14C CARBON BEAMS Joe Tesmer

Users required larger beams of 14C than could be produced from FeC (several µA). Contamination was not a problem as the machine had already accelerated tritium. Administrative restrictions on purchasing and using 14C made it necessary to examine safety procedures for making cones. Installation of the polarized source between the heavy ion source and the tandem had resulted in large transmission losses in this region, up to 75-80% loss. A high output was needed in order to inject 2 µA into the tandem, so as to compensate for losses in the HE beam line.

The biological hazards of 14C are uncertain. Measurements of biological half life are based on the exhalation of 14CO2. The behaviour of solid carbon particles is not well understood.

Experiments have been carried out in the 834 source using 14C as a powder, like lamp black. The powder was made from barium carbonate by American Radiochemical. 0.9 Ci (200 mg) was purchased. A commercial binder (BARCOM 8251) was used to help partially polymerise the powder. 100 mg of carbon and a catalyst (malleic anhydride) were added to the binder and dissolved in alcohol. The product was like wet sand. Eight mg of this was loaded into the cone, hand pressed and heated to 200°C for 1 hour. The result is not real graphite, which would require vacuum baking at 800°C; the density is much lower than real graphite. A current of 8 µA was obtained from the 834 source, thanks to Bill Weitkamp’s suggestion, at SNEAP78, of drilling peripheral holes around the target. Using a Cs current of 1 mA, the first sample lasted 300 hours. After 100 hours a very small pit appeared in the sample. At the end, there was a 3/32"
hole through the sample. The second sample has now run for 200 hours producing 8-10 μA of beam out of the source.

The source output is 60% $^{14}$C, 40% $^{12}$C. Since the mixture comprised 100 mg of $^{14}$C and 25 mg of binder, which is 50% carbon, the amount of $^{12}$C in the beam is twice what was expected.

There was a vacuum accident on the source after 500 hours. The source and the LE beam line were not badly contaminated. Some $^{14}$C was detected around the sample, but none on the ionizer and none on the stripper foils. No personal exposures were detected.

Three-stage operation is planned with a $^{14}$C Model 834 source in the terminal of P-9.

DISCUSSION

Chapman: The density of the sample is very important. Pressing a boron sample gave a big increase in output.

Tesmer: Carbon black is made up of small hard spheres which are difficult to compress.

Adams: Carbon black can not be evaporated with an electron gun.

Tesmer: Graphite manufacture requires the right fraction of binder. The mixture must be baked at low temperature until fully outgassed, then vacuum baked in an induction furnace at 800°C. The graphite shrinks on baking.

Middleton: With a 1 mA beam of Cs a bright spot can be seen at the centre of the carbon. This is thought to be caused by the low density and poor thermal conductivity of the sample. The high ratio of $^{12}$C to $^{14}$C is not surprising. One always gets at least 1 μA of C− from everything.

? How do you insulate the extractor to measure the Cs beam?

Tesmer: Move the extraction electrode away and add an insulated section at the top, using boron nitride or machinable glass.

Weisser: What is the secondary electron current associated with the cesium beam?

Tesmer: It is not easy to measure the cesium current alone.

?: High radiation levels have been measured from the gridded lens of the 834 source.

Carlson: We measured the cesium current and the electron current separately by isolating the cesium boiler. In the EXTRION source 0.5 mA of Cs is accompanied by 1-2 mA of electrons.

Brand: Under good conditions, need 500 μA of Cs to produce 100 μA of C−. Any current in excess should be electrons. Running with an ionizer temperature of 1120°C, observed that after 2000 hours the cesium current was still 500 μA but the output was down by a factor of three. Noted that the reservoir temperature was lower and the suppressor current higher. Observed that new ionizers are up in price but down in quality.

PRODUCTION OF TANTALUM CARBIDE AT ORSAY

Michelle Dumail

This method for producing tantalum carbide has been published in French in NIM. The first idea was to use iron carbide. Then changed to TaC or Ta$_2$C. A test bench similar to the MP LE beam line up to the pre-accel tube was used for these experiments. The output of the first pressed TaC sample was 1 μA.

Carbide is made by decomposing hydrocarbon vapour at low pressure on to a metal surface heated to 2/3 melting temperature. The temperature is a compromise between the conditions for pure metal, semi-carbide and carbide phase. The reaction speed can have either a linear or a parabolic variation with temperature. It is important to control the temperature and pressure of the carburizing process.

Two samples, prepared from labelled propane, have been made and tested. A beam of
150 nA at the LE cup was accelerated and had an emittance of 1.5 B.mm.mrad at 75 MeV. Surface activity in the source was 1 nCi/cm². After 65 hours the output had declined by < 10%.

DISCUSSION
Signorini: What are the advantages of this method?
Dumail: Safety, avoiding handling $^{14}$C powder, and yield.
Brassard: How do you compare the two methods?
Dumail: The output of the TaC is less, but it is important to avoid the use of powder.

SESSION VI ION SOURCES
Chairman: Ed Berners

THE STORY OF TWO ION SOURCES Roy Middleton

This report discusses the behaviour of two similar sputter sources and presents an explanation for the very different behaviours that were observed.

One year ago a new design of sputter source was tested at Penn. With the cathode set at -3 kV with respect to the ionizer, large outputs with good emittance were obtained from this prototype, 3 µA of $^{56}$Fe from an iron cathode. Because this prototype was not well engineered, a second unit was made and put on test. However the new source did not behave as well. The output was much lower, e.g. 5 µA of Ni compared with 50 µA from the prototype. Furthermore we experienced trouble, in the shape of uncontrolled increases in the cathode current from 1-3 mA to 20 mA (the limit of the power supply). Actually this problem had been seen occasionally on the old source. A series of systematic changes were introduced to make the new source more like the old, but nothing helped. After two months, the old source was reinstalled and worked like a charm. The new source was then replaced and continued to misbehave. The old source was mounted for a third time and on this occasion it gave low output and the cathode current ran away. After deep thought we concluded that there are two modes of operation; one stable, the other unstable.

When a porous tungsten frit is heated and fed from behind with cesium vapour, surface ionization takes place and cesium diffusing through the frit emerges as positive cesium ions. As the reservoir temperature or the vapour pressure of the cesium increases, the positive ion current increases until a peak value is reached, typically at 2-3 mA for a 2 mm diameter ionizer. At this point cesium coverage is thought to be about 1%. If the cesium flow is increased further, the coverage increases above 1% and the work function of the surface falls below the ionization potential of cesium. At this point the ionization efficiency falls and neutral cesium leaves the surface. Cesium pours out and arcing starts, loading the power supply. Furthermore, the increased current results in an increase in secondary electrons which strike the ionizer and increase its temperature. The process is inherently unstable. A family of curves can be drawn for varying ionizer temperatures showing the cesium current increasing with vapour pressure, reaching a peak and then falling.

The new ionizer has ten times the area of the old one. For an ionizer temperature of 1100°C one would expect not less than 40-50 mA current, beyond the capability of the power supply. Any tendency of the cesium current to increase will increase the vapour pressure of the cesium and also increase the electron current bombarding the ionizer. Even if one can operate in this condition, the output will be low due to inadequate neutral cesium coverage of the cathode. However, by operating at low ionizer temperature and high vapour pressure one can operate in a
stable mode with negative feedback on the ionizer current and a high neutral flow to the cathode. One can achieve this stable condition by turning on all the power supplies simultaneously and, when the cesium current rises to 2-3 mA, back off the ionizer temperature, keeping the current below 5 mA. After 2-3 hours, there will be adequate neutral cesium in the source to coat the cathode and the ionizer temperature may then be increased to the normal operating value. Once the source has been conditioned in this way, it is not necessary to repeat the procedure.

DISCUSSION
Den Hartog: How do you account for the long time constant?
Middleton: This is not understood at present, but cesium from the reservoir accumulates somewhere in the system and is sensitive to the ionizer current. Once this cesium has accumulated, one can valve off the reservoir and run for 12 hours.
Ashbaugh: Are there problems raising the ionizer temperature?
Middleton: No.
?: Does the curvature of the sputter target matter?
Middleton: It is not curved, it’s flat.
Weisser: What is the effect of changing the position of the cesium input tube?
Middleton: Did not seem to make any difference. The geometry is very uncritical.
Berners: Could you build a source to run in a terminal?
Middleton: No comment.
Billen: The SNICS source behaved in a similar way, running away at high ionizer temperature.
Middleton: Once after cleaning the source it started up in condition B, but ran away within 30 minutes. The conclusion is that one needs ample cesium in the source for stability. Originally we used a rhenium ionizer because it is ductile at high temperature, but we now use tantalum which is cheaper and just as good. Air cooling on the cathode has been replaced with freon and a heat shield has been fitted to keep everything else hot.
Weisser: Claimed that increasing the ionizer heater current caused the ionizer to cool because of the heat removed by increased cesium evaporation.
Middleton: I find that hard to believe! The effect may be there, but at the microwatt level.

DEVELOPMENT OF A DEDICATED SPUTTER SOURCE FOR CARBON DATING
Dick Hyder
Work carried out by R. Hedges, J. Wand, N. White, G. Doucas & T. Philpott.

The source for the Oxford radiocarbon accelerator must have high efficiency and low emittance. A home-made reflected sputter source, like the 834 source but with the cesium reservoir outside the vacuum, has been set up on a test bench with a vertical 90° magnet and emittance measuring equipment beyond the magnet. The cesium beam from the ionizer is focussed by a retarding einzol lens, brought through a small hole and then reflected by the field between the target wheel and the extract electrode. The efficiency and the emittance have been measured. Reflection occurs in the bending plane of the magnet so the horizontal emittance looks good but the vertical emittance includes the energy spread of the beam and the aberrations of the reflection optics, which are not yet understood.

Efficiency of production has been studied for charcoal, amorphous carbon, graphite, cracked methane which has been pyrolised and pressed into a recessed aluminium holder at a pressure of 1000 bar and pyrolised acetylene, which was deposited directly onto a tantalum wire
at 2000°C, the wire then being used directly as a sputter target. The cesium currents were quite small, never exceeding 400 µA. However the carbon currents were large; in one test 80 µA of C⁻ was produced by only 200 µA of Cs⁺. The efficiency, C⁻/Cs⁺, was up to 0.4.

The yield from different materials varied widely. Output from the charcoal was always low and decreased with increasing cesium current. The amorphous carbon was somewhat better, but a maximum current was seen above which output dropped as the cesium current increased. The thermal conductivity was poor but better than charcoal. The graphite was greatly superior, regularly producing 20 µA of C⁻ for 150 µA of Cs⁺. The cracked methane was a lot better than the graphite at low cesium currents but not much better at higher currents, suggesting that the surface was better but the conductivity worse. The pyrolysed acetylene on the wire was better still, giving 80-90 µA from a 1.5 mm diameter tantalum wire coated with 0.1-0.2 mm of carbon over a length of 2mm. The overall efficiency was measured by operating a wire at 10-20 µA for 200 hours, at the end of which time the output rapidly dropped to zero within 2-3 hours and the centre of the wire was completely cleared of carbon. Typically, 30 mg of CO₂ was converted to 12 mg of C₂H₂ and then reduced to 7 mg of carbon on the wire. This particular sample had 4 mg of carbon on the wire, yielding an average of 15 µA of C⁻ for 200 hours, i.e. 10% of the carbon atoms in the sample emerged as negative ions with an emittance less than the acceptance of the accelerator. Overall, in addition to the 10% ¹²C⁻ ions, 10% emerged as C₂⁻ and a few percent as other negative ions. Almost 30% of the material emerged as negative ions, the remainder as neutral atoms. The carbon on the wire glows under bombardment, sometimes as hot as 1500°C. The power on the wire must be limited to 1 Watt. The thermal conductivity of pressed samples may be as much as a factor of 1000 less than that of the cracked ethylene on the wire. The yield is consistent with the idea that cesium is lost from the wire by simple thermal diffusion. Fractionation was less than 1% and differential fractionation about 0.05%.

Calculations of the trajectories of the cesium beam in the reflected source show that, in comparison with a beam of 1 µA for which there is no space charge, a beam of 200 µA is severely blown up by space charge so that it cannot be focussed through the aperture by the einzel lens. The calculations show that, as the reflected bias voltage changes, the focus of the beam moves sideways as well as along the beam axis. This source was modified from a straight through source and has no provision for steering. Alternative future systems are an off-axis source with provision for steering or an axial source with an annular beam which passes round the sample and is then reflected. The area of the 95% emittance contour is 11B.mm.mrad./MeV in the x (bending) plane and 2.5 B.mm.mrad./MeV in the y plane.

One measurement of a brighter beam of 8 µA gave an emittance of 16B.mm.mrad./MeV, with little difference between x and y planes. A measurement on a coated wire, with a current of 49µA, gave an emittance of 36B.mm.mrad./MeV and 9B.mm.mrad./MeV (at right angles to the wire) in the two planes. The brightness was twenty times higher than in the first case.

**DISCUSSION**

**Ashbaugh:** What was the size of the aperture for the cesium beam?

**Hyder:** It varied between 1 and 3 mm.

**Middleton:** How is the wire mounted?

**Hyder:** A slot 3-4 mm wide is milled in a standard cone and the wire is clamped in the slot.

**Weisser:** Could the cesium beam be taken around both sides of the wire as at LASL
Hyder: No advantage, already bombarding with as high a power density as can be tolerated.

Middleton: Why is the cesium beam not badly aberrated? At Penn the cesium beam is cusp-shaped. Brand may get away with it at Bochum because the cesium axis is not parallel to the carbon axis.

Hyder: We have calculated the field and trajectories for several different geometries, e.g. cylinder and plane, tapered snout, etc. The geometry has a profound effect on the cesium focus. Oxford may have found a fortunate geometry, but the displacement (3 mm) is not arbitrary.

SESSION VII CHARGING SYSTEMS AND SF₆
Chairman: David Weisser

THE LADDERTRON INSTALLATION AT ORSAY Pierre Bretonneau
[presented by Michelle Dumail]

MP9 has been equipped with stainless steel tubes since 1974. In 1978 there were a series of problems with the conventional belt charging system. Initially, when operating up to 10 MV, the belt was satisfactory. But on increasing the voltage to 13 MV many problems arose and in some cases the belt life was as short as 1000 hours. Many changes - to tension, to screens etc. - were tried but without success. Between October 1977 and October 1978 scheduled maintenance occupied 6% of available time, unscheduled maintenance, including three belt changes, 44% and experiments the remaining 50%. Other faults included a problem with the analyser magnet power supply and water leaks in the ion source. As the charging system became less and less reliable, the decision was taken to replace it with a Pelletron or a Laddertron. Although several MP tandems have used Pelletrons for several years, much time has been needed to install them and bring them up to specification. Also speed was important and the quoted delivery for a Pelletron system was 1 year, compared with 5-6 months for a Laddertron. The costs were similar. A single Laddertron chain can carry 400 μA. The components are simple and robust and the total number of parts is small. For instance a Pelletron system would require 120 idler pulleys, compared with 20 for a Laddertron. The Laddertron is supported by large (250 mm) diameter idlers in the dead sections. A new set of gradient rods prevent tube damage if the Laddertron breaks.

Tests at Daresbury have shown that a Laddertron can operate in a gradient of 3 MV/m. The Laddertron is well isolated from other components in the column. The chain links are stainless steel thus eliminating the production of metal dust; the HVEC ladder rungs are polished light alloy and are assembled with screws not welds. The insulating links are monocab nylon, the pulleys carbon-loaded polyurethane. Test results at Burlington have been good. The chain weighs 8 kg/m and operates with a mechanical tension of 450 kg. Lateral oscillation is not more than 1.5 to 1.8 mm and vertical oscillation about 10 mm. Using an 18 kVA drive motor, the Laddertron runs at a speed of 12.5 m/s and drives a 3.5 kW, 400 Hz terminal alternator.

Installation was completed in six weeks and the first tests took place in March 1979. The maximum charging current was 420 μA and 60 μA required an inductor voltage of 10 kV. The charge transfer efficiency was 98%. A terminal voltage of 13 MV was reached without difficulty after brief conditioning. The unstabilized ripple was 3.5 kV peak to peak and with GVM stabilization this reduced to 1 kV at 13 MV. With slit stabilization $V/V = 5 \times 10^{-5}$. MP-9 delivered beam for experiments from April to mid July. After 400 hours of operation the lateral oscillation increased and HVEC took the chain to Burlington in July and reassembled it. On two occasions a short-circuited protective device on a badly screened wire overloaded the Geator
drive belt, causing lots of dust and sparks. There were also problems when the Laddertron was started with the downcharge supply not set to zero. This resulted in failure of an undersized transformer, which has been replaced.

The tubes have now done 13000 hours, 30% at $12 < V_t < 13$ MV. Typical injected currents, both light and heavy ions, are 2-3 $\mu$A. Four tube sections have been shorted, some cracks have been seen in the glasses and tube connectors have been replaced with metal pieces like those at Legnaro. Permanent magnets on tubes #4 and #5, on the BNL pattern, have improved conditioning and made it quicker to get to high voltage. However, we still add quenching gas above 11 MV.

Yesterday, however, the chain broke. There was no damage to the tubes, hoops or gradient rods.

DISCUSSION

?, HVEC: The original chain had run for 3500-4000 hours in the plant. It was decided to replace the bushes before installing it in MP9. The original monolithic bushes were replaced with split bushings which wore rapidly. When the chain was returned to Burlington in July the split bushes were replaced with new bushes similar to the originals. This chain ran well until the break. Possible one link may have come loose.

Hyder: Why was it necessary to realign the pulleys after the initial tests?
HVEC: The main pulleys had to be removed in order to replace the alternator belt.
Hurley: What happened to the drive belt between the motor and the Laddertron pulley?
HVEC: Misalignment caused rapid wear to the side of this belt. HVEC were concerned about the possible mechanical oscillations of a horizontal chain, so we ran tests at a range of speeds from 2 to 17 m/s. However there were no oscillations anywhere within that range, just lateral run-out.

Noé: What was the problem with the idlers?
HVEC: The split bushings resulted in rapid wear which allowed lateral movement to develop. This damaged the idler wheels.

SEPARATION OF AIR FROM SF$_6$  Charles Jones

[This a report on the progress made by members of the MIT School of Chemical Engineering working at Oak Ridge.]

If the calculated solubilities of air in liquid and gaseous SF$_6$ are correct, then liquefaction will do most of the job. Starting at 85 psig, if the mixture is to -50°F, 90% of the SF6 liquefies and the mole fraction of air in the liquid is only 1%. The mixture would be cooled in a counter-flow heat exchanger. The vapour phase would contain 60% and must then be passed through a secondary separator. The MIT students are working on this process. The sorption coefficient of SF$_6$ in activated charcoal must be measured at pressures below the vapour pressure, which is 1500 torr at -45°F. At -83°C the vapour pressure is 170 torr and the isotherm indicates that 0.8g of SF$_6$ can be absorbed per gram of charcoal. The isotherm and the lack of hysteresis indicate that the sorption is physical not chemical and that capillary action is unimportant, i.e. the sorption depends on the surface area. The sorption of air, O and N has been measured at -45°C. The heat of sorption approaches the latent heat of vaporization and the amount of O and N sorbed are 0.035 and 0.05g respectively at -45°F. The implication is that activated charcoal could separate SF$_6$ from air. Little SF$_6$ would pass through the column until it was loaded. The ideal pressure, temperature and heat transfer conditions are required in order to design a suitable column.
Adsorption would probably take place at -100°C and desorption at -45°C.

DISCUSSION
Brassard: We built a similar device three years ago which works well. We solved the problem of heat removal by building a column with a large internal thermal inertia, rather than using external heat exchange. A large part of the internal volume of the column is taken up with aluminum plates drilled with holes. The hole spacing is fine, about 5 mm, because of the poor thermal conductivity of the charcoal. The temperature should not be cycled. Cycling the temperature makes process control ten times more difficult.

THOUGHTS ON THE PROPERTIES OF GAS MIXTURES  

Kenzo Sato

The composition of the gas mixture and the reactivation procedures must be controlled in order to exploit SF₆ to the full. SF₆ has a large thermal electron capture cross-section which helps to prevent avalanches. Two other processes can be exploited. At 0.5-0.6 eV the cross section for SF₆ | SF₅ + F⁻ is large and at ≥35 eV the reaction SF₆ | SF₄ + F₂⁻ can take place. It has been observed that when operating with pure SF₆ or mixtures an unstable condition can persist for a long time after a spark, preventing a return to the original voltage. This may be due to F⁻. In the non-uniform field of a tandem, light negative ions near the terminal may give rise to enhanced space charge which can increase the local field to the point where a spark may occur at an unusually low voltage. One therefore wants to prevent the formation of F⁻ or O⁻ and control the energy of electrons in the gas. The atomic data show that the best gases for slowing down electrons are CO₂, H₂O and NO. The electron scattering cross section for CO₂ is large up to a peak at 1.5 eV, above which it drops rapidly. Something else is needed to slow down electrons of higher energies. N₂ has a sharp peak in the inelastic cross section at 20 eV. At higher energies the nitrogen cross section is larger than the CO₂ cross section. Water has an even better inelastic cross section, but the amount that can be tolerated is small. Water has the added advantage that its presence reduces the self-charge of the Pelletron chains and also reduces the need for chain lubrication. This leads to stable Pelletron charging current. In addition water improves the efficiency with which the alumina dryers remove decomposition products.

The ideal gas mixture contains 50% N₂, 38% SF₆ and 12% CO₂ with a dew point of -40°F at a pressure of 185 psig. This has enabled the MP tandem to run at 13 MV without sparking for days on end, in spite of an erratic mains supply.

The transfer system uses an oil-lubricated compressor, a Kinney pump and a Roots blower. The Roots blower will be replaced by a Spencer turbine (oil free, 100 cfm). Operate so as to minimise metal chips, microparticles, oil contamination and fluorides. The corona current is kept down to 3 µA even though this makes stabilization more difficult. We try to schedule experiments so as to avoid rapid changes in voltage and frequent changes in ion beam.

Dryer reactivation has been carried out at different intervals (8 hours, 1 day, 1 week, 1 month) to see if this affects performance. Reactivation is now carried out every three weeks and the amount of water released is measured. Water is added at the rate of 200-500 cm³/month in order to keep the dew point at -40°F. Soda-lime is now used to remove breakdown products. This is replaced once or twice a year.

After 12 months of satisfactory operation, performance deteriorated and the spark rate increased. This was blamed on deterioration of the SF₆. “New” SF₆ is now added at the rate of 1 cylinder/week. This has improved the voltage by 1-2 MV.
DISCUSSION
Carlson: How does the amount of added water compare with that removed?
Sato: The amount removed was not weighed.
?: What is the operating temperature?
Sato: 65-70°F.
Ashbaugh: Have you looked at the alumina?
Sato: Oil is observed on the alumina. It is discoloured.
Hurley: How do you use dry ice to measure dew points below -40°F?
Sato: Comparisons were made with electrolytic cell measurements.

NEW BELT STRUCTURE IN THE STRASBOURG MP TANDEM  
Michel Letournel
1. Charge is deposited on the outer surface of the belt. This charge creates a field between the belt and the gradient rods which depends on the distance between the belt and the rods. This distance is 5 cms. If the spacing is less the belt may be damaged by the excessive field. At 13 MV the belt charge is 2 x 400 µA. The behaviour of the system depends on where on the Paschen curve it is operating. The total field due to the column gradient and the belt charge must be kept below a critical value.
2. The belt is an insulator. Both surfaces must be considered. If the belt is not properly discharged, negative charge may build up on the inner surface. The belt than acts like a capacitor. Poor charge control may result in large charges accumulating, causing discharge through the carcass. This the most common cause of belt deterioration.
3. Static charges produced by contact with metal surfaces, mainly negative, are deposited on the inner surface of the belt, especially by the drive motor where the mechanical forces cause slipping. There is therefore a layer of irregularly distributed static charge, renewed by contact with the drive motor and alternator, which determines the belt ripple as it enters or leaves the terminal Faraday cage. These charges should be minimized with a system of charge control which removes or reduces them as soon as they are created. Reducing the speed of the belt is helpful since the amount of charge is proportional to the square of belt speed.

By applying these principles the belt at Strasbourg has now operated for 9000 hours, 110 days above 12 MV. In the close HVEC structure, the belt will always rub on the belt guides on one side or the other, resulting in frictional charging of whichever side is in contact. So all components have been removed from between the two runs of the belt and small rollers have been added to control parasitic charge.

DISCUSSION
Jones: How much time has been spent above 12 or 13 MV?
Letournel: 25% of 2500 hours above 12 MV.
?: The FN belt runs vertically and failures occur at the bottom where the tension is higher. What should be done?
Letournel: In the FN both sides of the belt are in contact with insulators and acquire parasitic charges, which can be enhanced ten times by moisture. If the screens are not properly adjusted the belt can be damaged by these charges. We found, five or seven years ago, that it is necessary to have a double screen to discharge the belt properly. If the belt is charged positively, negative charge must be deposited by the pick-up screen in order to neutralise the charge. The field at this point is determined by the voltage between the belt, the radii of the tips of the screen, the charge on the belt and the proximity of other metal parts. The field can be too high, thus adding
excessive charge, or not high enough, leaving charge on the belt. A second screen helps to neutralise the excess. The chance of removing excessive charge can be reduced by putting a resistor in series with the discharge screen.

SESSION VIII UPGRADES AND NEW ACCELERATORS
Chairman: John McKay

PROGRESS ON THE OAK RIDGE 25URC TANDEM - PART 1 Charles Jones
Work carried out by Alton, Bair, Benjamin, Biggerstaff, Juras, Mann, Richardson and Ziegler with help from Fazzini and Weisser.

Column installation started in December 1978, complete April 1979. SF₆ transfer system commissioned in April. Voltage tests on the column without tubes in May 1979. October 1979: all components received, accelerator tubes installed, aligned and now being leak tested, injector partly tested, control system installed and tested. NEC plan a test with beam and voltage in late 1979, depending on success in curing leaks.

The recirculator was not ready for use during the voltage tests because of leaks. The water content was 20-30 ppm. The voltage calibration was obtained from corona data on other NEC machines and was uncertain to ±5%. This data was used to calibrate the GVM. A graph of voltage v. pressure showed a non-linear curve. At 90 psig the lowest voltage at which breakdown occurred was 26.4 MV, the highest 32 MV and the average 28.8 MV. After these tests, gas was circulated overnight and the performance was much worse. The machine was covered with a fine metallic grit, ferrous oxide, and with paper from a temporary filter. The column has therefore never been tested with dry gas. Sparks from the tandem did not trip fire alarms or gas sensors or CAMAC or the computers in the building, but there was no electronic equipment in the column.

The injector platform operates at 500 kV and contains a single ion source. There is a quick disconnect system for changing sources.

The complete tandem control system is contained in one panel. There are three assignable knobs and three assignable meters.

DISCUSSION

?: How long did the voltage tests take?
Jones: They started on May 1 and ended on May 12.

?: Where did the rust come from?
The recirculator pipework. The pipes between the filters and the machine were rusty.

PROGRESS ON THE OAK RIDGE 25URC TANDEM - PART 2 Norval Ziegler
Diagnostic devices used during the voltage tests included several cameras sited on side ports, and a CRT recording fast transients in terminal voltage taking a signal from a fast CPU. The cameras are a BNL design. Photographs were obtained at various voltages, e.g. 9 MV at 5 psig, 16 MV at 20 psig, 28 MV at 90 psig etc, of sparks observed at the top of the terminal. The terminal voltage oscillates with a frequency of about 2 MHz. After the initial collapse the voltage reverses, sometimes almost to -V. The amplitude of the oscillation decreases as the pressure increases. Sparks cause some local melting of the high voltage electrode over an area of 1 or 2 cm² to a depth of 0.5 mm.

?: What determines the time scale of the oscillations?
Ziegler: There are two types of ringing oscillations. One type is due to the inductance and resistance of the arc and the capacity of the terminal. The second type occurs if there is a short
along the column or the tube. If the column is shorted it looks like a quarter wave line, capacitively loaded. The capacity of the terminal is about 300 pF. Recovery time after a spark is measured in minutes.

DISCUSSION
Brassard: People building streamer chambers would be able to advise on ways to measure the duration of the arc discharge.

JAERI 20URC TANDEM Yamanuchi, presented by Greg Norton
The site is in an earthquake zone. Tremors of varying intensity can occur daily, weekly or monthly. Some are very severe. The building foundations are 10 m deep, consisting of 3-4 m of concrete, a layer of sand then a further layer of concrete. The 35-40 m high building is very solid.

The gas transfer system is similar to Oak Ridge, but smaller. One way transfer takes 12 hours.

The injector is similar to Oak Ridge but at 300 kV. There are four ion sources on the platform feeding into an inflector magnet. A heavy ion buncher is installed just in front of the tank and a light ion buncher nearer the injector. The injection system is designed to operate down to a terminal voltage of 2.5 MV. The column layout is similar to Oak Ridge with two dead sections, but no minor dead section. The column diameter is 9' compared with ORNL which is 11'. There are three pairs of chains in the column, two drive shafts and light links to each dead section and to the terminal. The tube is graded by an enclosed corona tube system. A second system runs the full length of each module.

The terminal controls are in double screened boxes with honeycomb ventilation. The terminal contains a quadrupole lens, the 180° magnet, the gas and foil strippers, another quadrupole lens and a titanium sublimation pump. The stripper can be swung off the beam axis. There is differential pumping of the stripper which is 4 ft long and is insulated for stripper modulation. The control system contains many dedicated controls and meters, three NMRs and CRTs for readout of voltages. Under test a 1 µA beam of O⁺ has been injected and measured at the terminal with no lost charge at an energy of 10-12 MV. No beam has yet been transmitted through the machine.

A voltage test without tubes late in 1978 reached 24 MV, limited by charging capacity because one set of chains were not running.

There are five target rooms with 12 beam lines, The rooms are entered via underground passages.
The smaller NEC machine at Tsukuba withstood a severe earthquake without damage, although the injection magnet was found to have moved 2 mm. A vertical CN accelerator has also survived over many years.

DISCUSSION
Noé: How is alignment done?
Norton: By laser.

OXFORD FOLDED TANDEM Dick Hyder
The arrangement of the Oxford coupled electrostatic generators shows a vertical Van de Graaff (designed to operate at 10 MV positive or negative), designed by W.D. Allen’s group at
the Rutherford Laboratory and built by a joint Rutherford/Oxford team, which can be coupled to a HVEC EN tandem. During the design of the vertical injector in the early 1960s, a 4 MV single ended machine was built at Harwell, mainly out of spare parts from the Harwell tandem. This was used to test many features of the injector design and was subsequently shipped to New Zealand where Harry Naylor converted it into the world’s first folded tandem. It took several years for us to realise that we should convert the injector to a folded tandem. Fortunately Doug Allen had designed the injector with provision for a differential pumping tube. So space was available to fit in a pair of tubes, separated by 965 mm, which is enough for a 180° magnet capable of bending most ions except for the highest energy deuterons and tritons.

The injector is sited in a tower, with a 21' deep basement below it in which is a 6' radius magnet with a bending capability of 320 amu.MeV (10 MeV S'). Inside the tank, there is limited space at the base below the 20' column, which has an intershield mounted 12' above the base. The accelerator tubes are located on either side of the belt. The column is surmounted by a large terminal. Space below the tank for the ion source, inflector magnet and vacuum pumps is very limited. Few changes have been needed to convert this machine to a folded tandem and none to the liner or tank. The accelerator tubes have a pitch of 3/4 inch, the column a pitch of 1½ inch. Alternate electrodes on the tubes are connected to the mid-points of strings of Welwyn resistors which are attached to the column planes. These resistors are protected against transverse surges by metal plates and so far none have been damaged by surges, although some have broken as a result of faulty mechanical assembly. The resistors are positively connected at both ends. There is no reliance on springs.

The beam entering the terminal encounters a beam sensor, followed by a Faraday cup. It then passes through a differential pumping tube, an NEC foil stripper, the gas stripper which is 8 mm in diameter and 1.07 m long, a second differential pumping tube and the 180° magnet whose inclined poles produce a focus just beyond the mid-point. Although this magnet is not strictly isochronous, the resulting time dispersion is acceptably small. After leaving the normal exit poles of the magnet, the beam crosses a second beam sensor and Faraday cup, a drift space and a quadrupole doublet (which focusses the beam at the second stripper) before entering the positive accelerator tube. A positive RF source has been retained in the terminal for beams of helium and neon; a 15° inflector magnet transports the beam from this source into the drift space above the quadrupole.

The space above the 180° magnet is occupied by singly and doubly screened boxes containing the high voltage power supplies; these are protected with 60 kV filters of Daresbury design. So far there has been no damage to any HT supply. Below the magnet there are gas cylinders for the stripper and the RF source as well as the cooling systems for the magnet and the electronics.

The 180° magnet box is integral with the poles. The stainless steel side pieces are welded directly to the poles; a pocket is provided for a Hall probe and a large port provides a connection with good conductance to a 500 l/s ion pump. The power is provided by a 6-phase rectified supply from the 400 Hz alternator fed directly to the magnet without further smoothing. The output of the Hall probe, which is temperature stabilized at 80 ± 0.05°C, is fed to an ADC and compared with demand signal. The error is amplified and used to control the field excitation of the alternator. The resulting magnet field is stable and constant 1 in 10⁴. The Hall probe is sensitive to neutron damage and if it were subjected to the radiation from intense deuteron beams its life would be reduced to a few hundred hours. The magnet current is also fed to the quadrupole doublet, whose field can be trimmed by adjusting shunt resistors. A variation of
±10% is possible.

After a few months of operation, vacuum leaks developed in the magnet. The critical
welds between stainless steel and magnet iron were intact, but the reversing pressure stresses had
caused cracks to develop in the thin stainless steel walls of the box at places where pockets or
stiffeners had reduced the flexibility. A temporary repair has been made by welding the cracks,
covering with solder and then applying a layer of plasticized epoxy resin. The permanent cure
involves replacing the existing stainless steel walls with thicker material of circular cross section.

The gas stripper passes through the middle of one of the two 500 l/s ion pumps. This
pump handles the gas leaving the stripper. The stripper is relatively thick walled mild steel tube,
ensuring that the magnetic field from the pump does not perturb the beam.

A permanent magnet Georator alternator provides power for all the components in the
terminal apart from the magnets and quadrupoles. A series of belts connect this device to the
main pulley and to pumps and fans which power the liquid cooling circuit for the magnet and the
gas circulators which control other components.

The high current bellows-actuated Faraday cups are rated at 100 W. They are cooled by
flexible copper strips attached to benzene heat pipes which reject heat to a liquid circuit. They
are entirely metal and ceramic in construction.

The two static beam sensors consist of four-sector anodes centred round an aperture just
larger than the focussed beam facing a cathode polarized at 1 kV. The secondary electron current
to each anode is detected with a logarithmic amplifier covering the range 1 nA to 10 µA.

Two negative ion sources have been installed at the base of the machine; a GIC
duoplasmatron with lithium or sodium charge exchange for helium beams and a reflected sputter
source for other ions. The helium source can produce 15 µA of He⁺ with lithium exchange or 19
µA of He⁺ with sodium exchange. The charge exchange canal has a gauze liner which acts as a
wick to recirculate lithium by capillary action. The temperatures at the ends of the canal are
controlled by separate heaters. A 2g charge of lithium will last 1000 hours. The only
maintenance needed in 500 hours of operation has been to remove a sputtered deposit from the
zwischen electrode of the duoplasmatron.

Serial data links connect the negative ion sources and the terminal equipment to local
control panels. They use a combination of Daresbury, Oxford and Triskelion AG technology.
The infra-red link to the terminal operates at 1 Mbit/s and transmit 64 words, each made up of 6
address bits and 10 data bits, in each direction. Software control enables one address to be
interleaved to give a signal rate of 16 kHz. The other channels operate at 1 kHz. Similar links,
using fibre-optics, link the ion sources to local control panels and these to the main console. The
control system is a hybrid. There are many dedicated knobs and meters. The serial data links use
an Oxford designed microprocessor similar in power to an LST1103, but with a faster response
to interrupts, 2 µs versus 150 µs. The message protocol is stored in a 4k memory together with
safety and operational interlocks.

The accelerator tubes have titanium electrodes on a 3/4" pitch. The negative tubes have
two magnetic spiral suppression sections at the entrance, followed by spiral inclined-field
electrostatic suppression. There is a magnetically suppressed section at the top of the positive
tube to accept low energy ions from the terminal RF source, followed by electrostatic sections.
The optical system is designed to produce a rather broad crossover at the second stripper, 8'
below the terminal. The beam radius at the exit of the quadrupole below the positive tube is 15
mm.

Funds for the conversion were requested in 1974. An initial grant of £70K was received
In 1975 with supplements of £20K at the end of 1975 and £10K in early 1978. The injector was shut down in mid 1977. A delay with the infra-red links delayed completion but tests started in mid 1978. Beam was injected in September 1978 and beam was received on target in January 1979. Since then the machine has run for 3000 hours, 2000 hours for experiments and 1000 hours for machine development. There have been 9 scheduled and 7 unscheduled shutdowns. The scheduled shutdowns were required to load foils in the second stripper, which has limited capacity. Foil life under neon bombardment is short. A terminal voltage of 8 MV was reached in March. The maximum voltage reached was 9.8 MV. Some instability and random sparking in the column at 9 MV was cured by fitting a take-off screen to the inner run of the belt at the suggestion of Michel Letournel. After fitting this screen the stability improved, the belt ripple was reduced and we were able to condition from 9 to 9.5 MV in six hours. The transmission efficiency for light ions is 70%. Heavy ion transmission is unknown because of uncertainty in the relevant charge state fractions.

There is no evidence of tube activity or tube damage. The gas is N$_2$/CO$_2$. We believe that adding 10% SF$_6$ would give a voltage increase of 1 MV.

The following ions have been accelerated: He, Li, Be, B, $^{12}$C, $^{13}$C, O, Ne, Si, S.

**DISCUSSION**

**Dumail:** Who made the tubes and what did they cost?

**Hyder:** Dowlish Developments; £20K. But the design was changed when they were half constructed.

**UPGRADING THE STRASBOURG MP TANDEM**

Michel Letournel.

The voltage of the MP is to be increased by installing longer accelerator tubes, 88" in place of 72". We aim for the same gradient on the longer tubes as was achieved at 13 MV on the shorter ones. Making use of the existing protrusion of field lines into the LE and HE tube extensions, the dead sections and the terminal, the tubes will extend 8" into these regions. The dead section bellows will be shortened. It was intended to reduce the dead section length in the tubes from 610 to 130 mm but HVEC advised against reducing the end flange thickness below 36 mm. The vertical gradient rods near the end of the column sections will be curved to extend into the dead sections so as to control the curvature of the equipotential lines in these regions. In order to accommodate a second stripper, the #5 tube section will be displaced 2" from a symmetrical position towards the terminal. Double gaskets are used on all the tube seals. The inner gasket is a Metallastic gasket with an internal metal spring. The outer gasket is a Viton “O” ring. The resistor assemblies will be located below the tube. The LE and HE tube extensions and the terminal assembly will all be shortened. All tubes have now been returned to HVEC for lengthening.

The MP has run at 16-17 MV without tubes. Lengthening the tubes is expected to lead to a substantial increase in voltage.

**DISCUSSION**

**Signorini:** What size are the apertures inside the tube?

**Letournel:** We followed BNL experience. Adding magnets did not help, but putting apertures in the dead sections improved the performance. However, the SF$_6$ was purified and more was added at the same time and this may have caused the improvement. Orsay run at 13 MV without apertures.
SESSION IX  BOOSTERS
Chairman: Dick Hyder

PROGRESS ON THE LEGNARO XITU TANDEM    Cosimo Signorini
This project started in 1976 with initial funding of $1M. Installation of the tandem started
in February 1979. The tank is the same length as an MP but 1 m greater in radius. The
Laddertron was installed in August. Gas was transferred to the tank two weeks ago and the
Laddertron has run in 2 bar of gas carrying 160 µA on the up and down runs. The immediate
problem is to make the circulation system work fast enough.

THE SUPERCONDUCTING LINAC BOOSTER AT ANL     Lowell Bollinger
This project started four years ago with the main motivation being to develop a new
technology but also to make something useful and cost effective for the users. The initial funding
was $2M. The decision was made to extend the energy of the system so as to make it comparable
with a much larger tandem for precision nuclear physics. The design assumes conventional
operation of the tandem with a second stripper after the tandem followed by an array of
independently phased resonators with focussing by superconducting solenoids. This requires a
very refined bunching system; most of the beam must be compressed into bunches 100 ps wide
with high efficiency, so as not to degrade beam quality. This is accomplished in two stages: a
pre-tandem buncher produces 1 ns pulses and these are further compressed in the post-tandem
buncher. It is essential to have a phase detector which can correct the phase of the first buncher
to compensate for variations in the transit time through the tandem, which can amount to
nanoseconds.

The linac consists of a series of modular tanks; all except the first are interchangeable.
There are two types of resonators, low $\mathcal{F} = 0.06c$ and high $\mathcal{F} = 0.10c$. Each resonator contains
two drift tubes within a cylindrical can. The resonators are contained within a liquid nitrogen
heat shield. Power is fed to the resonators through a superconducting probe. Although the tanks
contain many different materials including plastics, the actual resonators are cryopumped by the
liquid helium and the local vacuum in the high field region is very good.

A total of 150 watts of RF power at 97 MHz is fed to the resonators, the frequency being
controlled by a vacuum capacitor partly shunted by diodes. The effective operating acceleration
is 1.5 MV per resonator corresponding to an average field of 4 MV/m across the 14" length of
the resonator. The actual peak voltage between the two drift tubes is then 800 kV. The resonators
are effective over a wide range of velocities, almost a factor of four. The inner drift tubes of the
resonators are made of pure niobium; liquid helium flows in and out of these drift tubes to cool
them. The outer housing consists of niobium sheet explosively bonded to copper, cooled by
liquid helium at the base. The heat dissipation is 4 watts per resonator. The Q of the resonators is
a function of field; by helium conditioning the field can be raised from 2 to 4 MV/m. Fast control
of frequency fluctuations caused by mechanical vibrations is by a hard-wired feedback circuit.
Slower variations are controlled by software.

Beam was first transmitted through the linac in June 1978. Since then there has been
1800 hours of beam time. In June 1979, using a small tank (A) contained 2 high-$\mathcal{F}$ resonators
and a standard tank (B) with 6 high-$\mathcal{F}$ resonators, beams of O, Si and S from the tandem,
operating at 8.7 MV with double stripping, were nearly doubled in energy by the booster. The
average field was 3.3 MV/m and the effective total voltage gain corresponded to 9.3 MV or 1.16
MV per resonator. This is equivalent to a 15 MV tandem. However, the resonator performance
is not as good on-line as on the bench, where better diagnostics and probe position control help
the operation.

The turnaround time for a linac tank is 7-10 days. Most of the problems have been with
minor plumbing components and service failures. Fast recovery is possible from power failure.
For instance, after a power outage which occurred at 7 a.m., staff were called in, the refrigerator
restarted and the beam restored within two hours. Operation is reliable enough to permit
overnight running without operators.

The next stage is to install 12 more high-3 resonators in two tanks. This will increase the
effective voltage boost to 12-14 MV. In 1980 low-3 resonators will be added. The ATLAS
programme will add a new target area and double the power of the booster.

DISCUSSION
Brassard: What effect does the beam have on the system?
Bollinger: Beam intensity from the tandem is low. The beam has no observable effect on the
system.
Signorini: Is the analysing magnet isochronous?
Bollinger: No. It is not necessary for masses up to nickel. We are developing a pair of
isochronous superconducting magnets for higher mass beams.
Chapman: How rapidly does the phase vary?
Bollinger: The phase signal is averaged over a few milliseconds. For the first 12-24 hours of
tandem operation there is jitter on a time scale of 0.1 seconds. After long periods of stability
there are slow drifts, but also occasionally rapid shifts. Papers on the bunching system have been
published by Lewis and Lynch.

THE SUPERCONDUCTING LINAC BOOSTER AT STONYBROOK John Noé

The FN tandem upgrade will start in January 1980. A Laddertron will be installed and the
accelerator tubes will be replaced with Dowlish titanium spiral-inclined field tubes. Higher value
resistors will be fitted and a new 300 kV high stability ion source platform installed.

Since the early 1970s a small group at CalTech, funded by the NSF, have worked on the
development of new accelerating structures. The first linac structure for heavy ions was the spiral
room-temperature resonator installed at Heidelberg. The second design is the double split loop
developed at CalTech and ANL. SUNY collaboration with CalTech started in 1975. Those
involved included Paul, Sprouse, Noé and Ben-Zvi. In July 1978 construction of a prototype
low-3 module began, with an initial budget of $100K. In February 1979 an energy gain of 1 MV
per charge was demonstrated with a module containing four low-3 resonators. The control
system is being constructed by the CalTech collaborators (Dick, Delayen and Mercereau). The
first phase, funded at $500K, includes the new beam line and the buncher. The first modules will
be in place in June 1980. A high-3 module is under development, for which production starts in
mid-1980. The overall budget, including NSF salaries, is $3M. In addition the State of New York
are contributing $1M for the tandem upgrade and the helium refrigerator. The linac will be
accommodated within the existing building.

The chosen frequency for Stonybrook is 150 MHz, rather than 100 MHz as at Argonne,
because the smaller resonators are easier to transport. The superconducting material is lead-
plated copper. The copper components of the resonators are electron beam welded together. The
plating procedure is relatively easy. The spiral arms are cooled by pool boiling liquid helium in
contrast to the forced flow needed in the inverted ANL resonators.
The low- resonateors in the initial phase should run at 2.5 MV/m, corresponding to an
energy gain of 400 kV per charge. An operating field of 3 MV/m is anticipated and the
refrigerator has the capacity to handle that energy loss. A high level of RF power is used
reactively but that power is rejected at room temperature.

The bunching system is designed to produce a 100 ps time focus at the stripper in order
to minimise the growth in longitudinal emittance. There is provision for two rebunchers.
Transverse focussing is accomplished with room temperature quadrupoles between the modules.
The high- modules are mounted in pairs with no lens between the two elements of the pair. The
complete system will comprise twelve modules. An isochronous 180° turn will be made with a
pair of magnets and a quadrupole triplet between them.

DISCUSSION
Brassard: What is the line power into the refrigerator?
Noé: 300 kW.
Brassard: What happens in a power failure?
Noé: A lengthy power outage might result in the loss of some helium because the
compressors would not return the helium boil-off to the storage tank.
?: How is the coupling link cooled?
Noé: The coupling link is at liquid nitrogen temperature, but most of the RF power is
reactive and is reflected back to the room temperature termination.
Hyder: What is the beam intensity and what are the transmission losses through the linac?
Bollinger: Typical beams are 20 pnA. Losses in the first buncher are 20-30%. Transmission
through the second buncher and the linac is 100%.

SESSION X  BUSINESS MEETING
Chairman: John McKay

The Chairman advised members of a potential safety hazard with the use of liquid air or liquid
oxygen in Ge-Li detector cryostats because of the presence of organic materials in these vessels.
The Chairman reported that SNEAP now has a balance of $883.04 (Canadian) at the bank
compared with $400.85 a year ago. Fees have covered expenses at national labs at recent
meetings. The balance is a reserve intended to help impecunious institutions take on hosting a
meeting.
The mailing list now includes 46 institutions and 225 individuals.
The proceedings would be sent to every attendee with a separate copy for each laboratory.
There was a discussion on the form of the next meeting and on advance submission of lab reports
and data.
The offer of the University of Wisconsin to host the 1980 meeting was accepted.
Thanks were expressed to Charlie Adams for running the meeting and to the sponsors, GIC,
HVEC, NEC and the University of Pennsylvania, for their support.

The Symposium adjourned.

\SNEAP\SNEAP79  April 11, 2000