II. OPERATION AND DEVELOPMENT OF ATLAS

OVERVIEW

This section reports on the operation of the Argonne Tandem Linear Accelerator System (ATLAS) as a national user facility and related accelerator physics R&D projects. ATLAS is used for basic research in nuclear and atomic physics, and occasionally for other areas of research and development, such as material science. Over half of the beam time is allocated to experiments for which the spokesperson is an outside user. Recent ATLAS operating performance and related development projects are described in the next section. ATLAS personnel are also involved in developing technology in support of a future advanced facility for beams of short-lived nuclei based on ATLAS. Projects related to the exotic beam facility are described in Section III.

ATLAS operates on a seven-day-per-week schedule but may change to 5-day operation in 2001 due to funding limitations. The research program at ATLAS with Gammasphere ended on March 14, 2000 after 26 months of operation. During that time ATLAS provided over 6000 hours per year of available beam time, 69% for Gammasphere. For FY2000, ATLAS provided beams from twenty-seven different isotopes. Statistics about beam hours and users are given in Table II-1. At the end of the Gammasphere research program, ATLAS entered a six-week maintenance period .

ATLAS continued to provide a range of radioactive species with intensities generally in the range of 10^5 to 10^6 particles per second. This year 7% of all beam-time went to radioactive beams. Beams of long-lived ($T_{1/2} > 2$ hours) species produced at other facilities and placed in the ATLAS tandem ion source and beams of short-lived species produced in-flight by inverse-kinematics reactions have been developed at ATLAS. See the Heavy-Ion Research section for a summary of recent physics results from experiments using radioactive beams.

Table II-1. SUMMARY of ATLAS EXPERIMENTS and USER STATISTICS

	FY 2000 (actual)	FY 2001* (extrap.)	FY 2002* (pred.)
Beam Use for Research (hr)			
Nuclear Physics	4832	4495	3450
Atomic Physics	82	70	50
Accelerator R & D	109	70	100
Other	437	565	300
Total	5460	5200	3900
Number of Experiments Receiving Beam	51	45	40
Number of Scientists Participating in Research	236	190	150
Institutions Represented			
Universities (U.S.A.)	25	18	12
DOE National Laboratories	5	4	5
Other	35	19	15
Usage of Beam Time (%)			
In-House Staff	45	47	35
Universities (U.S.A.)	23	40	40
Other DOE National Laboratories	14	0	10
Other Institutions	18	13	15
Total	100%	100%	100%

*Assumes cutting back to 5-days/week operations on June 1, 2001 and continuing through FY2002.

A. OPERATION OF THE ACCELERATOR

(R.C. Pardo, D. Barnett, J. Bogaty, B. E. Clifft, S. Daley, A. Deriy, G. Gribbon, R. Jenkins, A. Krupa, E. Lindert, S. McDonald, F. H. Munson, Jr., D. R. Phillips, D. Quock, A. Ruthenberg, R.H. Scott, J. R. Specht, P. Strickhorn, R. C. Vondrasek, G. P. Zinkann)

a.1. Operations Summary

During the first half of FY2000, physics with Gammasphere continued to play a dominant role in the research program at ATLAS. The last scheduled Gammasphere experiment at ATLAS stopped at 08:00 March 13, 2000 ending a 26 month running period with Gammasphere. During the first half of FY2000, a total of 2134 beam hours were provided to Gammasphere corresponding to 69% of the available time during that period. Operational reliability for all of FY2000 was 94.7%, the best ever achieved at ATLAS although some creative rescheduling figured prominently in that performance when a tandem accelerator charging-chain broke. The total facility performance for FY2000, in which ATLAS provided a total of 5460 hours of beam available for research, is tabulated in Table II-1.

The facility performance for FY2000, measured by total available research hours, was somewhat less than achieved during the past two fiscal years due to an extended six-week maintenance period in April and May. Major repairs to the cryogenic system and significant resonator maintenance were undertaken during that period along with a wide variety of preventive maintenance tasks and other facility improvements. Many of these improvements and modifications are discussed in separate sections below.

ATLAS provided a total of 27 different isotopes for research in FY2000 covering the mass range from protons to uranium. The distribution of species is shown in Figure II-1. The demand for these isotopes continued to be quite uniform over the entire mass range with no single species accounting for more than 10.7% of all beam time during the year. Only 32% of all beam time was for isotopes heavier than ^{58}Ni, similar to our experience in FY1999.

The tandem injector was used for beam delivery 24% of the scheduled time. The tandem plays an important role in the ongoing radioactive beam program at ATLAS today. It is used for the acceleration of long-lived isotopes made at other facilities such as ^{18}F, ^{56}Ni, and ^{44}Ti. The development of these beams has been described in past annual reports. Very little maintenance effort has been expended on the tandem in recent years. Over the past two years three different incidents occurred in which a portion of one of the charging chains broke. These chains have long exceeded their expected lifetime and were finally replaced this year. Not only has that solved the chain reliability problem, but the voltage holding capability and voltage stability has markedly improved for the tandem.

The in-flight radioactive beam program received a setback this year with the coil failure of the 2.5 Tesla solenoid used immediately after the production target to maximize the capture of the produced radioactive beams and refocus those ions for final transport to the spectrograph target station. A new 6 -Tesla solenoid has been ordered and delivery is anticipated in early 2001. The in-flight radioactive beam program will begin again with the installation of the new solenoid.

To support the program in long-lived radioactive beams, a new hot laboratory was created using a room previously used for off-line developments of negative-ion sputter sources. The new laboratory contains two HEPA vented hoods and a glove box for rebuilding the SNICS ion sources which have become activated from acceleration of beams of long-lived radioactive species. The facility will also be available for other activity involved in the Division’s research program involving radioactive sources.

The ECR-I ion source was decommissioned to begin an upgrade in April 2000. Reassembly of a new and improved ECR-I source was completed in September 2000. First beam was achieved in October and the source is expected to be quickly returned to normal operation. Early performance looks excellent.

The upgrade of ATLAS experimental area II was completed this year. A full implementation of the radiation interlock system (ARIS) is now in place for that area containing both the CPT/Spectrograph target station and a 65”-diameter scattering chamber, the only other station remaining in Area II. The controls for all the beamline elements to the CPT/Spectrograph have also now been incorporated into the ATLAS control system.

A significant new research initiative to search for super-heavy elements has been initiated at ATLAS. To be successful, this program will need to have available extremely high currents of heavy-ion beams such as ^{86}Kr and ^{56}Fe. Initial efforts to develop and demonstrate the necessary capabilities were started this year. In test runs, beam currents of 1330 pnA ^{86}Kr^{15+} were accelerated through the PII linac and studies of the linac performance and stability were made. Currents of up to 330 pnA at 450 MeV were also provided to the FMA target station for studies related to target reliability, beam background and detector performance. These efforts are discussed elsewhere in this annual report. Based on the observed performance of the accelerator system in these tests, the ATLAS facility appears immediately capable of providing ^{86}Kr beam currents in excess of 650 pnA on target. In order to accomplish this, some changes will be required in the ATLAS radiation safety rules and hardware. Efforts toward providing these high-intensity beams for super-heavy element searches will continue in the coming year.

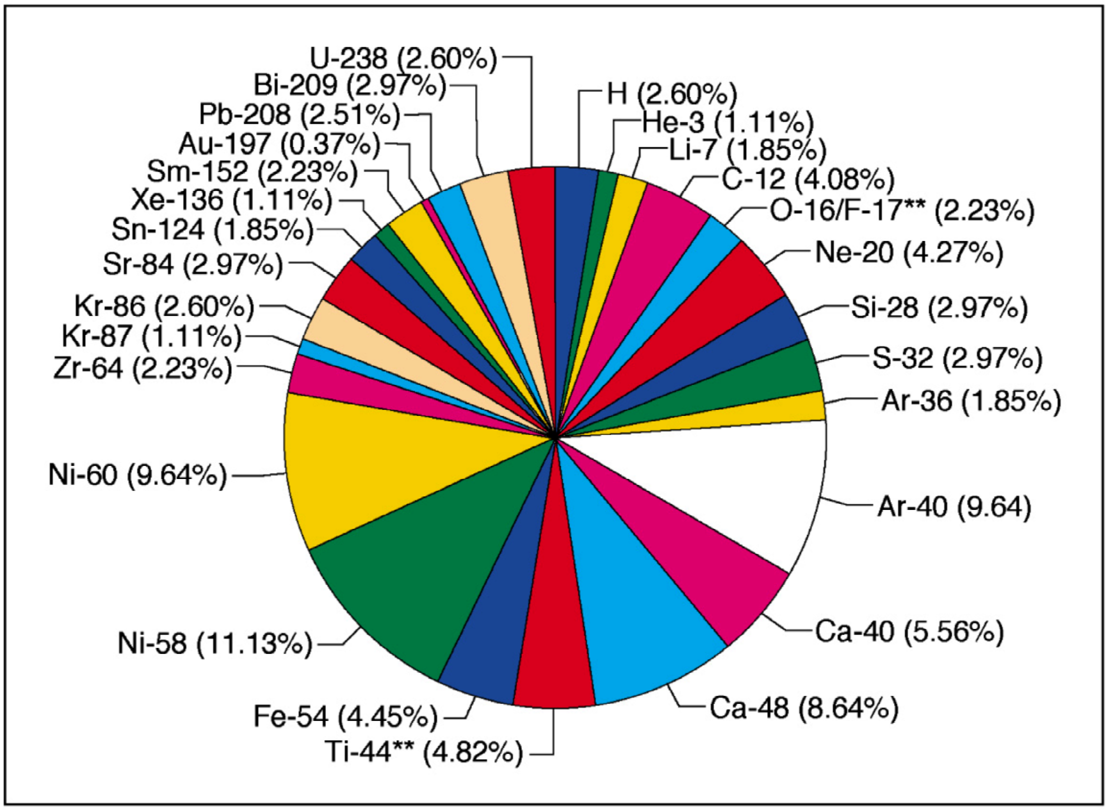


Figure II-1. Distribution of beam time by isotope provided by ATLAS in FY2000. A total of 27 different isotopes were provided to the research program. Radioactive beams of ^{17}F and ^{44}Ti comprised 7% of all beam time in FY2000.

B. DEVELOPMENTS RELATED TO ATLAS

b.1. Status of the 14-GHz ECR Ion Source (ECR-II) (R. Vondrasek and R. H. Scott)

During the ECR-I upgrade, ECR-II was responsible for the production of all beams accelerated with the PII injector. The main production technique continued to be a gas feed followed by the high-temperature oven and then the sputter technique. This year the oven was used to produce beams of ^{48}Ca, ^{60}Ni, ^{88}Sr, ^{124}Sn, ^{197}Au, and ^{209}Bi. The sputter technique was used for beams of ^{28}Si, ^{90}Zr, and ^{238}U.

As was described in the previous status report, difficulties were encountered when using the sputter technique with magnetic materials. Due to the smaller port sizes of ECR-II some of the sputtered material would bridge the gap between the sample and the plasma chamber wall and cause a short. Several attempts were made to eliminate this problem but the geometry of the source does not allow sufficient clearance for reliable, long-term operation. The three materials in question (Fe, Ni, Co) can all be produced from the high-temperature oven without performance being affected and the development of the sputter technique for these elements is no longer a priority.

Source performance was enhanced with the addition of high power waveguides for the 14-GHz transmitter. Previous to this change, at an RF power of 1.0 kW, the reflected RF power would be approximately 10% of the forward power. With the new waveguides in place, this reflected power has been reduced to 4% under the same operating conditions. The lower reflected power means that more power is reaching the plasma hence allowing higher beam currents at the same forward power. It has also reduced the thermal load on the waveguides which results in better long-term stability of the RF power and hence the beam current.

Development work took place in preparation for a ^{3}He AMS experiment. The normal extraction aperture, which is 8.0 mm in diameter, was replaced with a 1.0-mm aperture. The source was then run in a high-pressure mode in order to maximize the throughput of the sample gas. The normal operating pressure of the source is in the 10^{-7} Torr range. In this configuration stable operation was achieved with a pressure of 10^{-2} Torr using helium as the source gas. Due to the high beam output and the high flow rate of the sample gas, this high-pressure mode of operation allows very low sample concentrations to be measured in a timely fashion.

As part of the solid materials development program, an off-line chamber was established using parts recovered from the ECR-I upgrade. This chamber will be utilized to test new ovens and characterize material behavior before introduction in the ion source. It consists of a 20” diameter chamber pumped with a 760 l/s turbo pump. There are feed-throughs for thermocouples, cooling water, power, and vacuum gauging. This chamber will be first utilized to test a new high-temperature oven which is designed to achieve 2000 °C. If the off-line tests are successful, the oven will be tested on-line in ECR-II with an appropriate material (i.e. – UO_2, Pt, CaO, Mo, Ru)

b.2. **Upgrade of the ATLAS ECR-I Ion Source** (D. P. Moehs, R. H. Scott, R. Vondrasek, R. C. Pardo)

Renovation of the original two-stage 10-GHz ECRIS at ATLAS, is now complete following six months of construction. Disassembly of the original source, which began operations in 1987, started in April 2000 and its conversion into a new single-stage source started. The new source design includes a large magnetic-field gradient, aluminum plasma chamber and biased disk following modern ECRIS design concepts. The solenoid coils from the original source were reused to form the new magnetic mirror. Iron yokes were manufactured to encase these coils and great care was taken in assembling the new coils to insure that they were coaxial and properly aligned with the extraction beam line. At a current of 400 A, models predicted a minimum axial B-field of 3 kG with injection and extraction mirror ratios of 4.4 and 2.9 respectively. Hall probe measurements of the axial B-field, shown in Figure II-2, proved to be in good agreement with the predicted values.

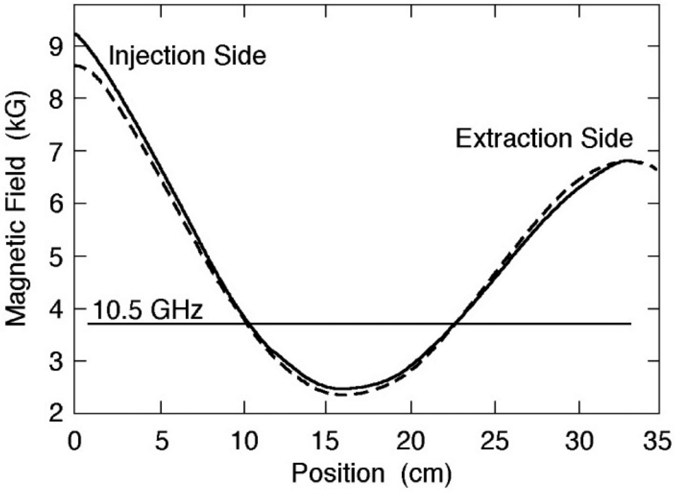


Fig II-2. The axial magnetic mirror measured at 400 amps (solid line) together with the POSSION prediction (dashed line).

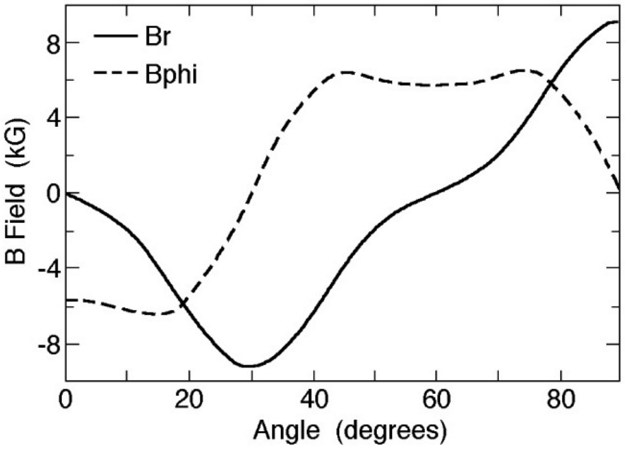


Fig. II-3. The hexapole field profile modeled near the surface of the plasma chamber. One quarter of the magnet configuration is shown with pole tips at 30 and 90 degrees and gaps between the magnet bars at 0 and 60 degrees.

A new aluminum plasma chamber was also manufactured to house the hexapole magnets and provides additional secondary electrons to the plasma. The NdFeB hexapole magnets producing the high radial-gradient magnetic field were initially loaded into the plasma chamber in May. Measurements of the hexapole field were within 13% of the designed B-fields of 9.3 kG along the poles and 5.7 kG along at the plasma chamber wall 4 cm in radius. Figure II-3 shows the predicted B-field as function of angle at the plasma chamber wall. During operation, cooling of the magnets is provided by flowing water through the walls of the plasma chamber directly around the magnet bars, which are encased in austenitic stainless steel. Water leaks in an aluminum weld slowed down progress and eventually a second chamber had to be built. Mounting of the plasma chamber and surrounding vacuum tank took place in late August following vacuum testing of the O-rings seals between the two components. Testing of the surrounding personnel and equipment interlock systems, including water flow, high voltage isolation, lead wall position and X-ray detection were completed and approved by the safety committee late in September. The first plasma in the new source was obtained on October 10. The source is operating well and its performance continues to improve as it outgases and cleans itself. It has already exceeded the best $^{16}O^{6+}$ beam current obtained from the original ECR-I by a factor of roughly 2.5, achieving 140 euA using the biased disk. A typical oxygen charge state spectrum is shown in Figure II-4.

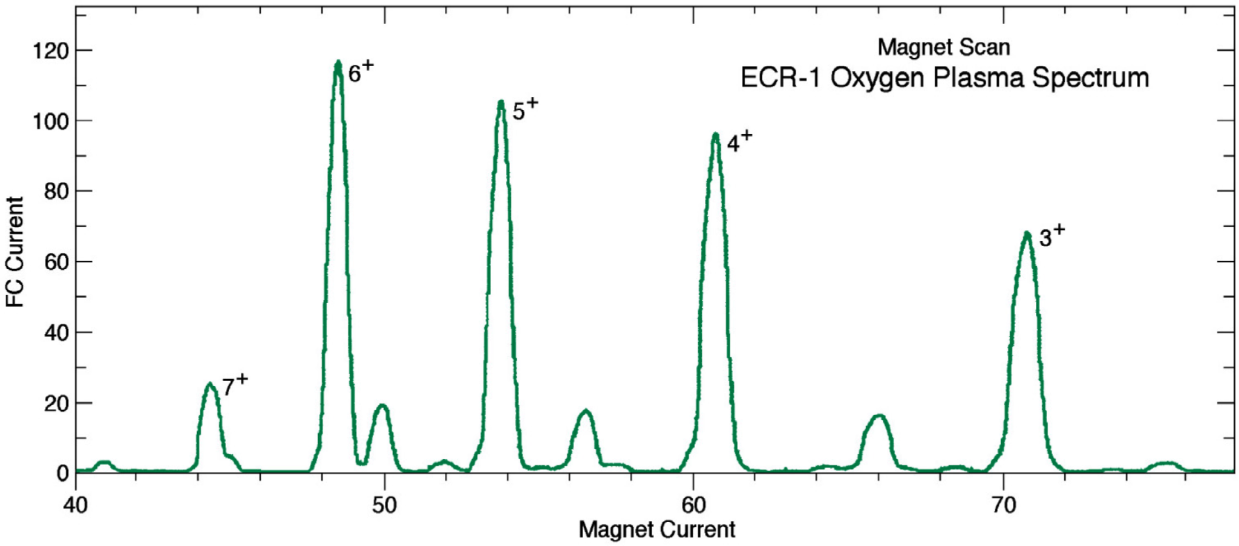
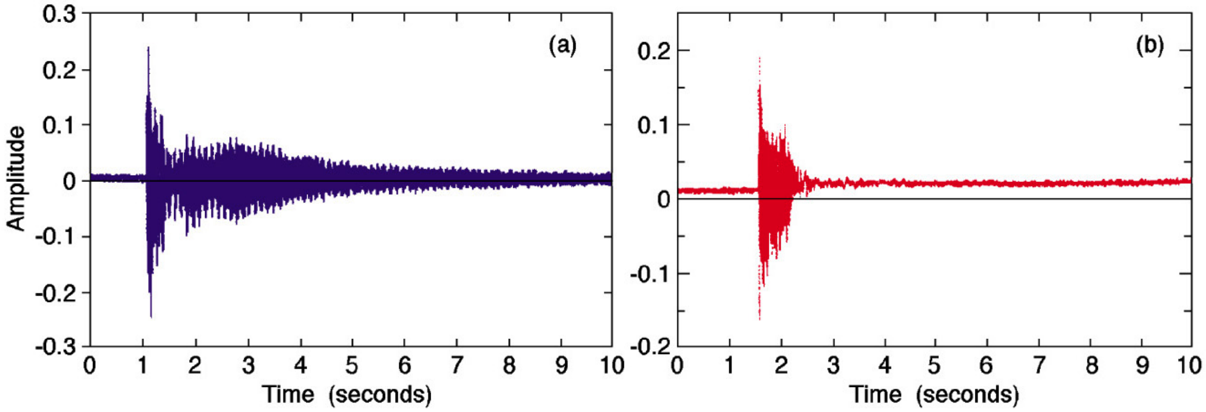


Figure II-4. Typical oxygen plasma charge-state spectrum for ECR-I using the biased disk.

b.3. Vibration Damper (A. Facco*, G. P. Zinkann, and K. W. Shepard)

The results of the first vibration damper installation were reported in the FY 1999 Annual Report. At that time we stated plans for the installation of a second vibration damper in an I1 class interdigital resonator. In April 2000 we had a maintenance period where, among other tasks, we installed the second vibration damper in the I1 (β= 0.008) resonator, the first resonator in the PII linac. During this scheduled maintenance time we had sufficient time to measure the characteristics of the mechanical vibration modes. Figures II-5 and II-6 show the decay times of the mechanical oscillations and the frequency spectrum with and without the damper.



(a) (b)

Figure II-5. Mechanical vibration decay time for the I1 resonator without the vibration damper installed (a) and with the vibration damper installed (b).

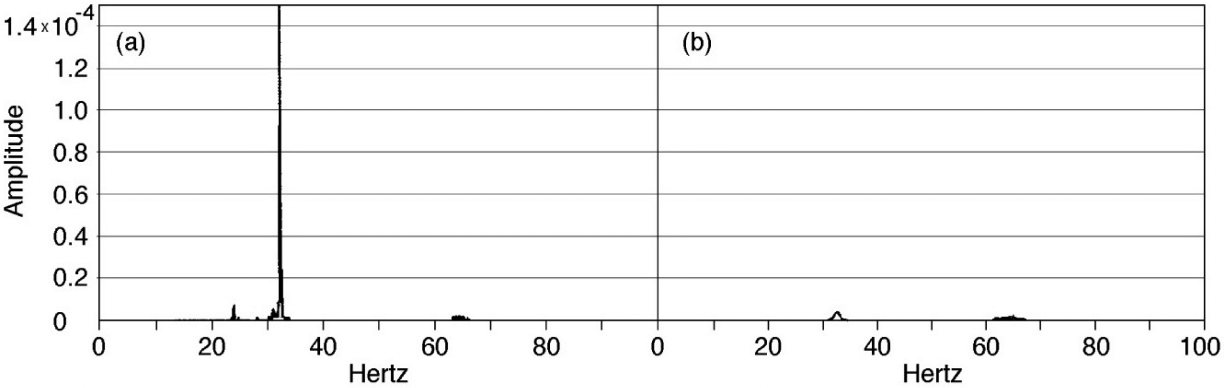


Fig. II-6. Mechanical oscillation frequency spectrum for the I1 resonator comparing before (a) and after (b) the installation of the vibration damper

The final result for the I1 damper was a reduction in the vibration level of 32.5%. This reduction relates proportionally to an equivalent reduction of the power dissipated by the fast tuner device. It also means that the tuning window can be reduced by the same factor. This will result in a reduction of the phase wobble and the related energy spread induced in the beam.

During this maintenance period, we also reduced the tuning window of the I2 resonator that received the original vibration damper installed in FY1999. Prior to the tuning window reduction measurements of the energy spread of the beam were made. Now that the tuning window has been reduced we will repeat this measurement and compare the results.

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* INFN- Laboratori Nazionali di Legnaro,via Romea 4, I-35020 Legnaro (Padova) Italy

b.4. PII Injection Bunching System (R.C. Pardo, J.M. Bogaty, B.E. Clifft)

A new bunching system for injecting into the PII-Linac system has been under development and is nearing final operational status. The new system consists of a new, four-harmonic 12.125 MHz buncher system located in much closer proximity to the PII linac than the original buncher design, a new traveling-wave chopper, and an existing 24.25 MHz spiral buncher located near the entrance to the PII-Linac. The new configuration uses the harmonic buncher to create a virtual time-waist downstream of the spiral buncher. The spiral buncher then creates a real time waist near the first PII-Linac resonator. Because this bunching scenario produces a poorly bunched beam at the chopper location, a new traveling-wave chopper is necessary to remove the unbunched beam components before acceleration in PII. The previously used sine-wave buncher produces significant emittance growth in the beam under these conditions.

Benefits of the new system include better bunching for high current beams and better matching into the PII-Linac than for the previous system. A second benefit is that only one harmonic buncher is needed for PII rather than separate bunchers for each source as required for the original geometry.

A benefit of this new geometry, not appreciated prior to testing, is the much improved capture efficiency into the main bunch bucket. As high as 75% transmission through PII has been achieved with the new bunching system. The virtual waste optics also results in less than 5% of the unbunched beam being captured into the satellite bucket of the 24 MHz spiral buncher.

The traveling-wave chopper has been demonstrated at both 6 and 12 MHz operation, but full operation at 12 MHz continues to be only a goal. Good progress has been made and we are hopeful this last component of the system will be operational in the next few months.

b.5. ATLAS Control System (F. H. Munson, D. Quock, K. Eder)

At the core of the ATLAS control system's real time activities is Vsystem, which is a networked process control software and real time database offered by Vista Control Systems Inc. It is estimated that Vsystem comprises 25 percent of all software written for the ATLAS control system. Previous versions of Vsystem were based solely on the VMS operating system running on the VAX/Alpha platforms utilizing the DECnet protocol for networking.

The most recent version of Vsystem has been ported to operating systems such as Windows NT/2000, Linux, Unix, and others, allowing for the use of additional platforms including Intel based machines. The network protocol used by the new Vsystem version is the more popular TCP/IP. An upgrade to this most recent version of Vsystem was accomplished during this reporting period. The upgrade provides the first step to providing distributed I/O processing, which will bring the ATLAS control system more in line with present day control system designs.

PCs that provide accelerator control and monitoring in locations other than the main control room have been using a 1980's PC flavor of the DOS operating system, the DECnet network protocol, and outdated X-windows server software. These systems were upgraded to the current Windows NT version operating system, the TCP/IP network protocol, and the latest X-windows server software. To enhance this upgrade, Windows NT primary and backup domain controllers have been installed, which also function as the control system's domain name servers.

A control system intranet and home page have been established. Using a standard WEB browser, the home page can be activated providing the user with easy access to data stored in the control system's Oracle Rdb relational database.

b.6. ATLAS Cryogenic System (J. R. Specht, S. W. MacDonald, and R. C. Jenkins)

The major cryogenic maintenance activity this year was the replacement of the 80K absorbers in the 2800E liquid helium refrigerator. Near continuous operation for about eighteen years caused the absorbers to become plugged with fine charcoal dust. This condition severely limited normal operation of the refrigerator. ATLAS was shut down for a six week planned maintenance period during which time the refrigerator was cut apart and the absorbers replaced. During this shutdown period, many other maintenance activities were performed.

The replacement of one of the three screw compressors for the 2800W liquid helium refrigerator by a spare was completed in less than one week. The original compressor failed after 62,000 hours of operation. ATLAS operation was not affected because several smaller stand-by compressors could be operated as needed.

Vacuum insulated hoses were installed on LN_2 lines from the ATLAS and some of the booster cryostats. These new lines replaced foam insulated lines that would freeze, become stiff and brittle, and their insulation would break if moved while cold. This has vastly reduced condensation and ice problems.

b.7. New Solenoid for the In-Flight Production of Radioactive Beams at ATLAS (R.C. Pardo, C.L. Jiang, K.E. Rehm, J. Specht, B. Zabransky, P. Collon, J. Cagiano, A. Heinz)

The superconducting solenoid located immediately downstream of the production gas cell for in-flight produced radioactive beams such as ^{17}F, ^{21}Na, and ^{8}B failed last year after a quench during a ^{17}F experiment. The purpose of this solenoid is to refocus the rapidly diverging secondary beams and maximize their transmission through the rest of the beam transport system to the spectrograph target station. Without this focusing element the available beam is reduced by over a factor of 1000 effectively ending the in-flight program at ATLAS. This failed solenoid had been adapted to our use from another discontinued program and was only marginally adequate for this application since its maximum field was less than 3 Tesla.

A new solenoid with a maximum field of 6 Tesla and effective length of 0.65m was ordered to replace the failed unit. Delivery is anticipated in early 2001 at which time our in-flight program will restart. The improved field of the new solenoid will improve transmission of the more rigid beams of interest in our program and will be operated in a more reliable range for the new solenoid.

b.8. Multiple Charge-State Acceleration of Uranium in ATLAS. (P. Ostromouv, R. C. Pardo, K. W. Shepard, and G. Zinkann)

Simultaneous acceleration of multiple charge-state uranium beams is planned for RIA to maximize the accelerator efficiency and achieve the highest possible beam current on the production target. Although there have been a few experiments demonstrating the feasibility of such a concept, there is presently no facility where multiple charge-state beam acceleration is used to increase the beam current. Therefore in order to demonstrate the concept, we have accelerated a multiple charge-state uranium beam in the existing ATLAS heavy-ion linac, and carefully measured the accelerated beam parameters for comparison with the results of numerical simulations.

The acceleration of multiple charge-state uranium beams has been observed at the ATLAS 'booster' as part of the 'normal' uranium beam configuration. However, the multiple charge states have been considered parasitic. Therefore systematic studies of all the accelerated charge states were not performed and accelerator parameters were not chosen to optimize the acceleration of the other charge states.

The $^{238}U^{+26}$ beam from the ATLAS ECR-II ion source was accelerated to 286 MeV (~1.2 MeV/u) in the Injector Linac, and stripped in a 75 $\mu g/cm^2$ carbon foil 0.5 m before the 'Booster' linac as shown in Fig. II-7. The beam energy was carefully measured by a resonant time-of-flight (TOF) system. The ATLAS Booster was tuned using a $^{58}Ni^{+9}$ 'guide' beam from the ATLAS tandem injector whose velocity was matched to that of the stripped $^{238}U^{+38}$ and which has a similar charge-to-mass ratio. The synchronous phase for $^{238}U^{+38}$ was chosen to be –30°. Therefore the synchronous phase, φ_G, required for the guide beam is given by

$$\varphi_G = -\arccos\left[\frac{58\cdot 38}{9\cdot 238}\cos(-30°)\right] = -27°$$

The synchronous phase in all 24 cavities of the booster is set by an auto-scan procedure using a silicon detector for beam energy measurements. Tuning of the focusing fields to get 100% transmission was accomplished with the guide beam prior to switching to the uranium mixed beam.

After optimizing the Booster linac and 40°-bend tune with the $^{58}Ni^{+9}$ guide beam, the stripped uranium beam was injected into the Booster. Magnet slits were used to cleanly select only the 38+ beam after the bending magnets and the uranium injection phase was matched to the guide beam's phase empirically based on maximum transmission through the system. Further tuning of the bunching system and last PII resonator made small adjustments to the uranium beam energy to better match the guide beam's velocity. After this tuning process, a 91% transmission of the multiple charge-state uranium beam was achieved. The transmission improved to 94% when a 10 mm aperture was inserted upstream of the stripping target. Figure II-8 compares the intensity distribution of the mixture of multiple charge-state uranium beams accelerated in the the booster to the measured stripping distribution for the unaccelerated uranium. The difference in the distributions is caused mainly by poorer transmission of lower charge states through the booster. Also, some discrepancy can be expected due to slightly different tuning of unaccelerated and accelerated beams and collimator slits in the 40° bend region.

The individual charge states then were analyzed in the 40° bend region and sent to the ATLAS beam diagnostics area. The parameters of each selected charge state that were measured included: transverse emittance, beam average energy, and beam energy spread.

Finally, the multi-charged uranium beam was stripped for the second time at the exit of the Booster and $^{238}U^{+51}$ was selected. The same beam parameter measurements were performed and the beam was further accelerated in the last section of ATLAS. Certainly, the use of multi-charged uranium beam on the second stripper increased the intensity of double-stripped $^{238}U^{+51}$ beam. The double-stripped $^{238}U^{+51}$ was accelerated up to 1400 MeV and used for a scheduled experiment at ATLAS.

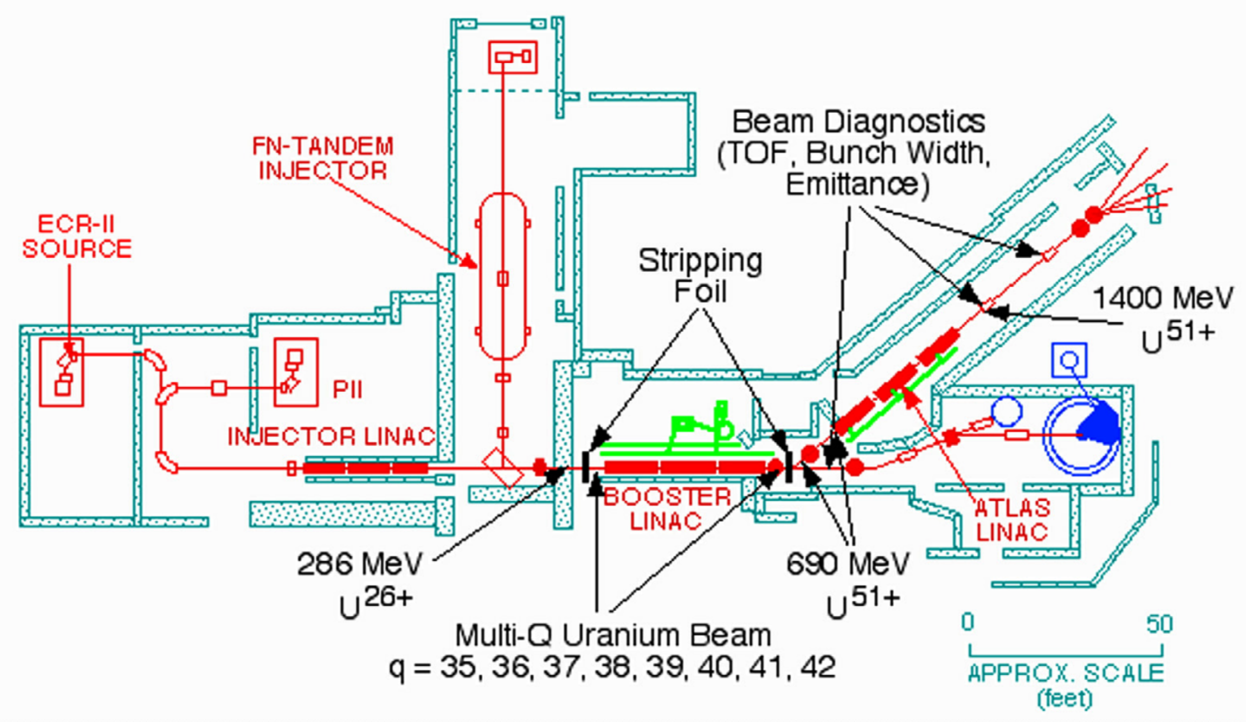

Figure II-7. Layout of ATLAS linac showing the positions for stripping the uranium beam during the multi-charge state acceleration test.

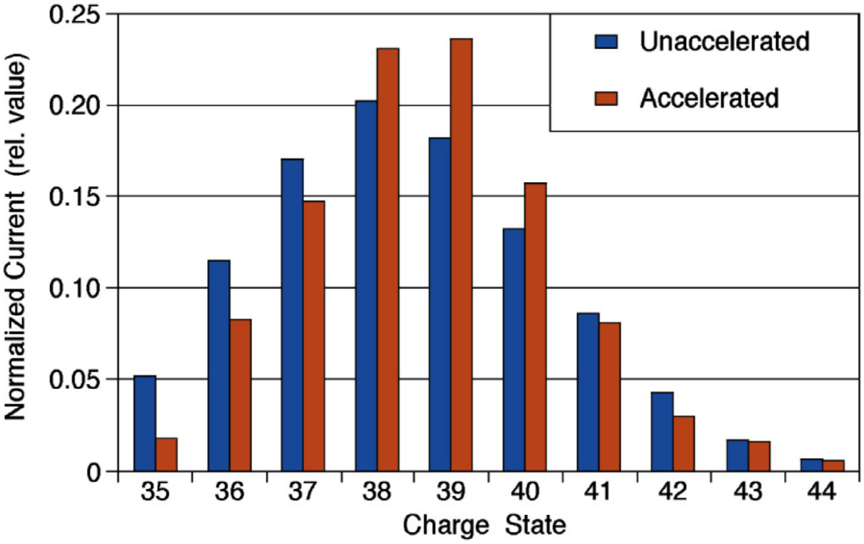

Figure II-8. Comparison of intensity distribution of accelerated and unaccelerated multiple charge uranium beams.

b.9. Superconducting Cavity Development for ATLAS

We completed construction of two 97-MHz niobium split-ring assemblies, which were successfully tested and are currently operating in ATLAS. Construction was carried out entirely through commercial vendors, rather than the Argonne shops. The successful completion of these split-rings helps to establish a cost-effective commercial means of producing niobium drift-tube cavities.

We are in the process of designing and constructing three different niobium quarter-wave cavities to serve as (a) spare parts for the critical front-end of the ATLAS PII, (b) a replacement for the existing beta 0.06 rebuncher cavity for ATLAS, and (c) a replacement for the beta 0.1 re-buncher for ATLAS. The cavities that will be replaced can be used in the existing ATLAS linac, while the new cavities provide an opportunity to update and improve the design of cavities for this valocity range. Tooling, dies, and niobium are currently being procurred for these cavities.

The superconducting RF surface preparation room was also upgraded this year. An automated buffered-chemical-polish setup has been installed, as well as a high-ressure water-rinse system. These are described in more detail in Section III of this report.