EARLY OPERATIONAL EXPERIENCE WITH URANIUM BEAMS AT ATLAS*

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Abstract

The first acceleration of a uranium beam using the new ATLAS Positive Ion Injector(PII) took place on July 27, 1992. Since that first run, ATLAS and PII have completely achieved the design goals of the project and now provide high-current heavy-ion beams with energies beyond the Coulomb barrier for the research program. ATLAS routinely and reliably provides low-emittance beams of uranium and other very high-mass ions at energies in excess of 6 MeV/n with available on-target beam intensities exceeding 5 particle nA. The expectation that the beam quality for heavy beams would be significantly better than that of the tandem injector has been fully realized. The longitudinal emittance of beams from the PII is typically one-third that of similar beams from the tandem injector. In the past year ATLAS provided uranium beams for approximately 19% of the total research beam time, while beams with A≥100 were used 33% of the time. The system performance and techniques developed which made for this successful result will be discussed. Improvement projects underway will be presented and future goals described.

Introduction

The ATLAS facility was developed initially to provide beams of heavy ions with A<100 at energies in the vicinity of the Coulomb barrier. For this purpose an independently-phased, superconducting resonator linear accelerator was developed to accelerate beams provided by an electrostatic tandem injector. The first beams from this version of ATLAS were delivered in 1985.

The most recent improvement to the ATLAS facility has been the design and construction of a new injector for the main linac. The goal of this new Positive Ion Injector (PII) injector was to remove the limitation on ion mass for beams from ATLAS and allow the ATLAS facility to provide ion beams of any species, including uranium at energies in excess of the Coulomb barrier. The PII consists of a new 12-MV low-velocity superconducting linear accelerator[1,2,3] which is injected by an electron cyclotron resonance (ECR) ion source[4,5] mounted on a high voltage (300 kV) platform.

The new PII injector has now been operational since April, 1992 and has provided beams to the heavy-ion research program ranging from the molecule HeH^+ to ^{238}U. In the 1993 fiscal year uranium operation constituted 18% of the beam time provided to the experimental program. This paper describes the performance of the PII and ATLAS facility for uranium acceleration and how that performance was achieved. Future improvements to the facility, either in progress or planned, are also discussed.

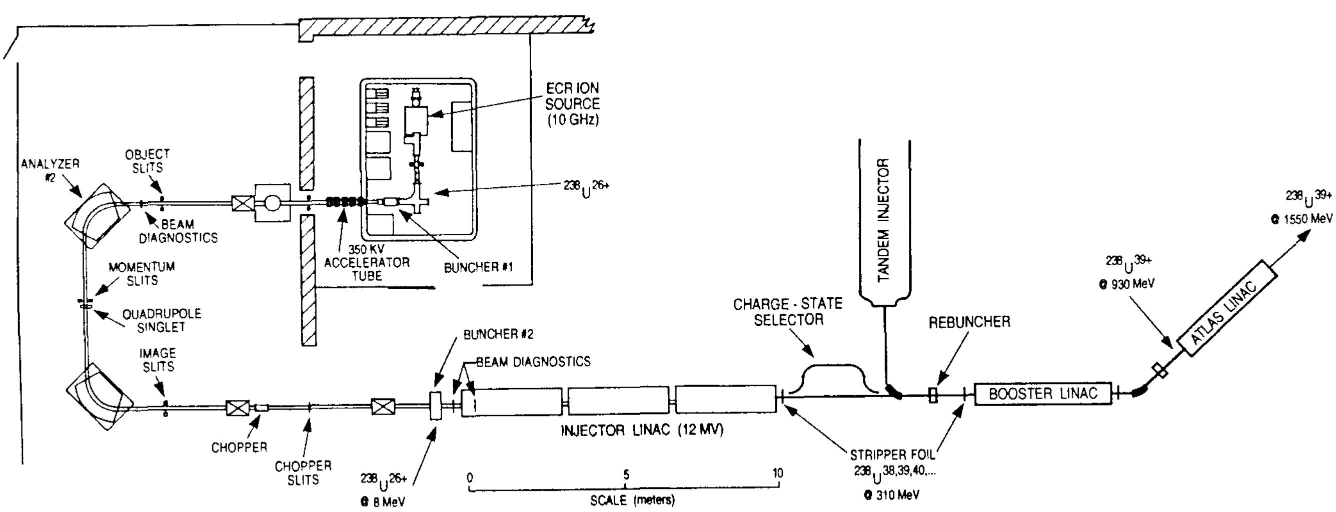

Figure 1. The ATLAS facility floor plan. The stages of acceleration for uranium are indicated on the plan.

ATLAS Operation for Uranium Acceleration

The ATLAS facility, including the new Positive Ion Injector, is shown in Figure 1. In order for the ATLAS linac to provide Coulomb-energy beams for A>150, the beams from the present ECR ion source must be stripped at least once. A typical acceleration process for these beams is indicated in Figure 1 and the location of the beam stripping point is indicated. Only one stripping, at the end of the PII injector, is necessary in order to achieve uranium beam energies up to 6.6 MeV/A.

Up to now the capability to provide a single charge-state beam into the next section of the linac after this stripping was not available. In order to tune this section of the linac, it has been necessary to use an analog beam from the tandem injector. The analog beam is chosen to approximately match the uranium beam in charge-to-mass ratio (Q/A) and velocity at the entrance to the 'booster' linac. The beam-RF phase must also be matched at this point for the two beams. With these requirements met, the analog beam may be used to set up the 'booster' linac section.

Once the 'booster' linac section is tuned with the guide beam, corrections to that tune must be applied to the amplitude and phase of the resonators to correct for the slight (Q/A) difference between the analog beam and the desired uranium beam, the energy loss from the stripper foil, and the relative phases of the two beams. This procedure has worked well and the beam quality and transmission for heavy beam acceleration has been good. The last linac section can be tuned with a single charge-state uranium beam since the beam transport to the last section of the linac cleanly selects a unique charge state.

The development of a uranium beam at ATLAS proceeded over a period of nine months. During that time improvements were realized in the operation of many accelerator systems. Significant improvements were realized in the ECR ion source operation, resonator field levels, and cryogenic capacity. The first acceleration of uranium occurred during the week of July 27, 1992. Since then seven additional runs using ^{238}U or ^{208}Pb have occurred.

Table I list parameters relevant to each of those runs and shows the improvement in performance which was realized as various changes have been made. The quoted longitudinal emittance, ε_l, is in units of πkeV•ns, and T/M is the maximum energy delivered in MeV/A. The longitudinal emittance quoted is measured after acceleration through the PII injector. At the maximum beam energy, the longitudinal emittance has worsened typically by a factor of four partially due to emittance growth in the stripping process and to imperfections in the analog beam setup procedures.

Table I

Important Parameters for Uranium and Lead Acceleration at ATLAS

Beam	Date	Q_1	Q_2	Analog	ε_l	I_{pna}	T/M
Pb	5/92	24	39	$^{16}O^{3+}$	30	0.2	4.9
U	7/92	28	42	$^{36}S^{6+}$		0.1	5.7
U	9/92	28	42	$^{36}S^{6+}$			5.6
U	2/93	27	40	$^{60}Ni^{10+}$	60	1.0	6.5
U	3/93	25	40	$^{60}Ni^{10+}$		4.6	6.1
U	5/93	24	39	$^{60}Ni^{10+}$	38	4.5	6.5
U	8/93	25	40	$^{60}Ni^{10+}$		4.4	6.1
U	11/93	26	40	$^{60}Ni^{10+}$		4.6	6.5
Pb	1/94	27	37	$^{34}S^{6+}$		6.3	6.3

Performance of Major Devices in ATLAS

The first uranium beams from the ECR ion source were generated using UF_6 as the source material. The maximum beam current with this material was approximately 3 eμA and the peak in the charge state distribution occurred at 22+. The performance of the source improved significantly with the use of a small ceramic rod of UO_2 directly inserted into the plasma. The maximum beam current increased to approximately 5 eμA and the peak in the charge state distribution increased to 24+. Additional improvements in the source have improved the charge state distribution so that it now peaks at 25+ or above.

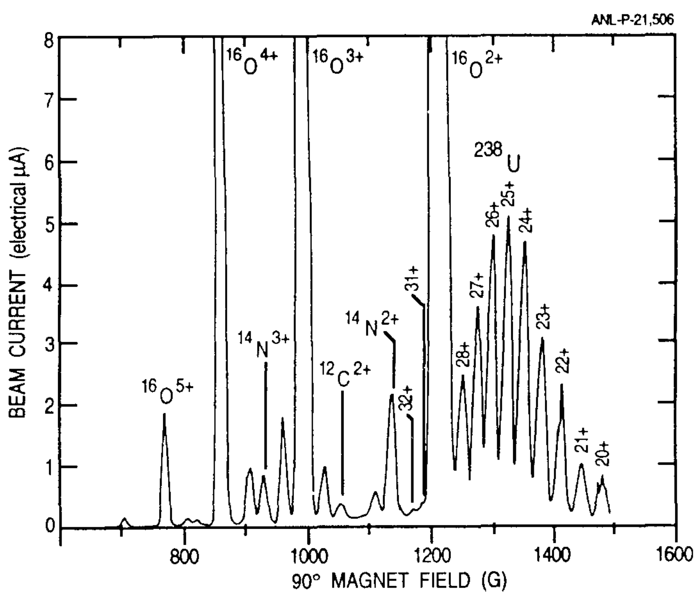

Figure 2. Charge state distribution for uranium from the PII ECR ion source using UO_2 feed material and an aluminum extractor electrode.

The consumption rate of material has been excellent. During the last run for uranium, the consumption rate was 0.11 mg/hr. For 3 eμA in the 26+ charge state, a total efficiency of .243% into the 26+ charge state was realized.

The performance and reliability of the PII resonators has been excellent. The average accelerating field for the PII quarter-wave resonators is 3.6 MV/m. Beam transmission through the PII linac has also been very good. Beam transmission, after correcting for the unbunched component, is 85-100%. The injector bunching system has performed well. Measured bunch widths from the harmonic buncher are typically 2 ns FWHM and the second stage bunching system produces beam pulses of approximately 300-350 ps FWHM for linac acceleration.

The beam stripping is accomplished using 50 $\mu gm/cm^2$ thickness carbon self-supporting foils. The average foil lifetime for beam currents of 56 pnA was 2.2 hours or 122 pnA-hours. At beam intensities of approximately 23 pnA the foil lifetime doubles. Beryllium foils show an increase in the average stripped charge-state of 2 charge units[6] but their lifetime is only 50% the lifetime of carbon foils. Therefore carbon foils have been used for most of ATLAS operation with uranium and lead beams.

Improvements

The most significant performance limitation for the operation with stripped heavy beams has been the quenching of solenoids in the accelerator due to beam loss from stray beam. During these runs, the section of the linac following the stripping was operated without any charge-state selection. Therefore all charge states are delivered into that section of the linac. Charge states more than one unit lower than the tuned charge state are not captured by the linac and are lost in the accelerator. The power from these lost charge states is sufficient to cause solenoid heating and quenching at beam currents into the stripper in excess of 1.5-2.0 eμA. This problem is being solved with the installation of a new charge-state selector. This device is being installed at the time of this conference and will be available for runs beginning in the Fall, 1994. Available uranium and lead beam currents on target are expected to increase to approximately 10 pnA at that time.

Stripping these heavy beams after the PII injector in order to achieve Coulomb barrier energies poses a number of limitations to the performance of the ATLAS facility even with the addition of the new charge-state selector. Available beam current is reduced by a factor of five, beam quality is worsened in the stripping process, and the complexity of operation is increased. A new ECR ion source, based on the LBL 'Advanced ECR' ion source[7], and high voltage platform is now in the design and early procurement stage which is expected to provide uranium beams with useful charge states in the 30's. Such ECR source performance would allow ATLAS to provide uranium beams at 6 MeV/A or greater without stripping, thereby greatly improving beam current efficiency and beam quality. Operation of this source system with ATLAS is expected in late 1996.

The capacity of the ATLAS cryogenic system is severely taxed during acceleration of these heavy beams and is a significant limitation to certain aspects of ATLAS performance. Last year a new wet engine expander was installed to replace the Joule-Thompson expansion valve in one refrigerator and improved the system capacity by approximately 50 watts. In the next year, two additional wet engines will be added to the other two facility refrigerators. The total system capacity is expected to increase by 25-30% or 175 watts which should allow greatly improved cryogenic reliability and efficiency as well as accelerator performance.

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