THE ATLAS UPGRADE PROJECT

Lowell M. Bollinger

Argonne National Laboratory, Argonne, IL 60439

ABSTRACT

ATLAS is a heavy-ion accelerator system consisting of a 9-MV tandem electrostatic injector coupled to a superconducting linac. A project now well advanced will upgrade the capabilities of ATLAS immensely by replacing the tandem and its negative-ion source with a positive-ion injector that consists of an electron-cyclotron resonance (ECR) ion source and a 12-MV superconducting injector linac of novel design. This project will increase the beam intensity 100 fold and will extend the projectile-mass range up to uranium. Phase I of the work, which is nearing completion in late 1988, will provide an injector comprising the ECR source and its 350-kV voltage platform, beam analysis and bunching systems, beam lines, and a prototype 3-MV linac. The ECR source and its voltage platform are operational, development of the new class of low-frequency interdigital superconducting resonators required for the injector linac has been completed, and assembly of the whole system is in progress. Test runs and then routine use of the Phase I injector system are planned for early 1989, and the final 12-MV injector linac will be commissioned in 1990.

I. INTRODUCTION

In its present form, ATLAS is a heavy-ion accelerator[1] consisting of a small (9-MV) tandem electrostatic accelerator and a 40-MV superconducting linac with 42 independently phased split-ring accelerating structures. The layout of this system is shown in Fig. 1. The linac, during its gradual evolution, has been used as a research tool for more than ten years and has by now provided about 35,000 hours of beam time to users, substantially more beam time than any other superconducting accelerator of ions.

ATLAS is an excellent machine for many areas of nuclear-physics research, but it has two important drawbacks: (1) its beam current is less than some users want and (2) it can only accelerate projectiles in the lower half of the periodic table. Both of these limitations result from the characteristics of the tandem and especially from the difficulty of stripping heavy-ion beams in the tandem terminal. Consequently, when in 1984 we examined the question of how the performance of ATLAS could be upgraded, we concluded that the present tandem and its negative-ion source should be

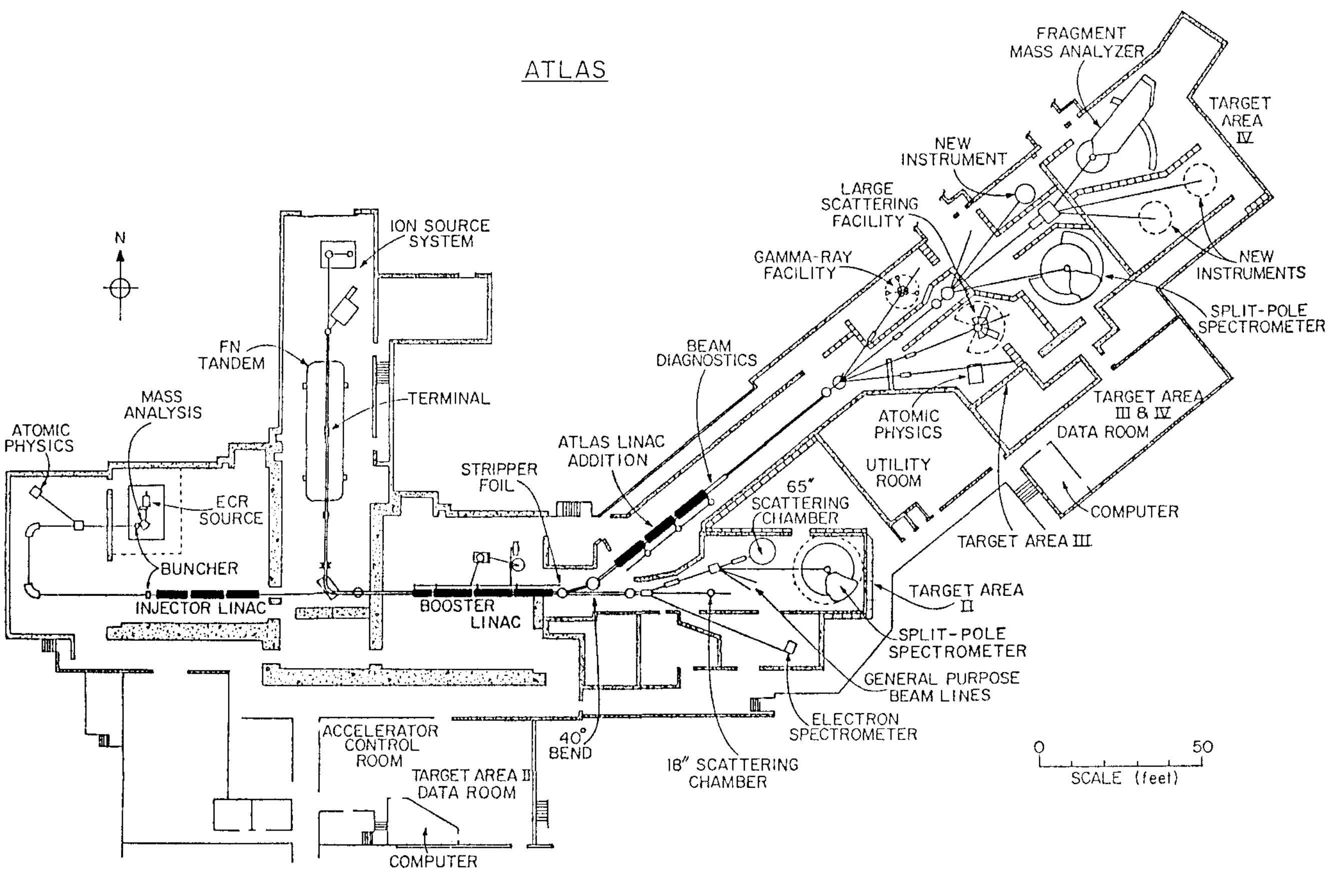

Fig. 1 Layout of ATLAS. The new positive-ion injector is on the extreme left and new experimental area (upper right) is labelled Area IV.

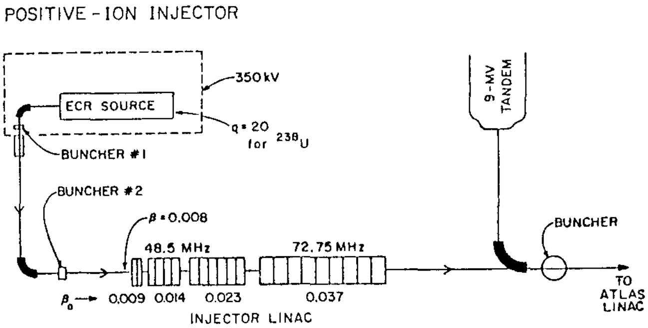

Fig. 2 Schematic of the positive-ion injector for ATLAS.

replaced with a positive-ion injector. The objective of this upgrade was: (1) to extend the mass range of projectiles up to uranium ions, (2) to increase beam intensity by a factor of 100 for all ions, and (3) at the same time, to preserve the good qualities of the tandem. That is, we still need to have CW operation, easy energy variability, and good beam quality. A small longitudinal beam emittance $\Delta E \Delta t$ is particularly important because our users need very short beam pulses delivered to their targets.

After considering several possibilities, we concluded that the optimum positive-ion injector for us is the concept[2] outlined by Fig. 2. The ion source is an electron cyclotron resonance (ECR) source on a 350-kV platform. The slow-moving ions from this dc system are bunched and injected into a superconducting injector linac. Since the linac must be capable of accepting ions with β as low as 0.008 and must increase their velocity to $\beta \approx 0.045$, the linac is formed from an array of four kinds of short, independently-phased accelerating structures. Also, in order to optimize longitudinal beam quality and to maximize the accelerating potential per structure, we wanted the rf frequency

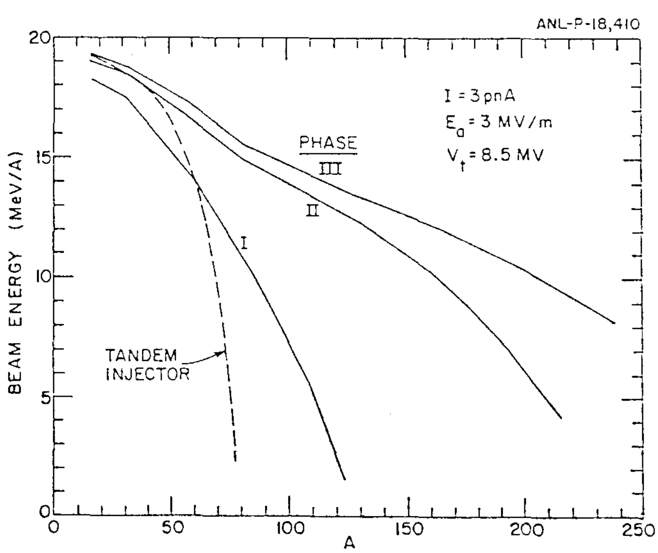

Fig. 3 Comparison of performance of ATLAS for the several phases of PII.

to be as low as possible and still have a structure that is rigid enough to permit rf-phase control. We chose the value f=48.5 MHz, which is half the base frequency of the present ATLAS resonators. The defocussing action of the accelerating structures is counterbalances by means of superconducting solenoids at appropriate intervals.

We are often asked why we chose to build a superconducting drift-tube linac rather than an RFQ. At the time (1984), there were various practical reasons (such as the need for CW operation) for the choice. However, the fundamental reason was and is that the beam out of an RFQ does not have a small enough longitudinal emittance for our needs because of the non-linear character of its acceleration process. In contrast, realistic calculations[4] show that our linac can provide the required acceleration without a serious degradation of the high-quality beam from the ion source, if the incident beam is well bunched.

The positive-ion injector (PII) system[2,3] outlined above was approved in 1986 and is being constructed in three distinct steps. Phase I, to be completed in late 1988 or early 1989, provides the ECR source, voltage platform, beam transport, bunching system, and a 3-MV injector linac, the smallest system that we consider useful as an injector for ATLAS. Then, in Phases II and III, the linac is enlarged step-wise to 12-MV, which can bring U-238 ions up to the velocity required for acceleration by the ATLAS linac.

Some performance objectives of the planned PII are given by Fig. 3 and 4. Even the tiny Phase I injector will be superior to the tandem for ions with A > 50, and the Phase III system will provide beam energies that are well above the Coulomb barrier (~5 MeV/u) for all ions.

The layout of PII relative to the present accelerator is shown by Fig. 1. Also, at the other end of the facility, the target area is being enlarged in order to have space in which to locate the experimental apparatus that is needed to exploit the new research capabilities that will be provided by the upgraded accelerator.

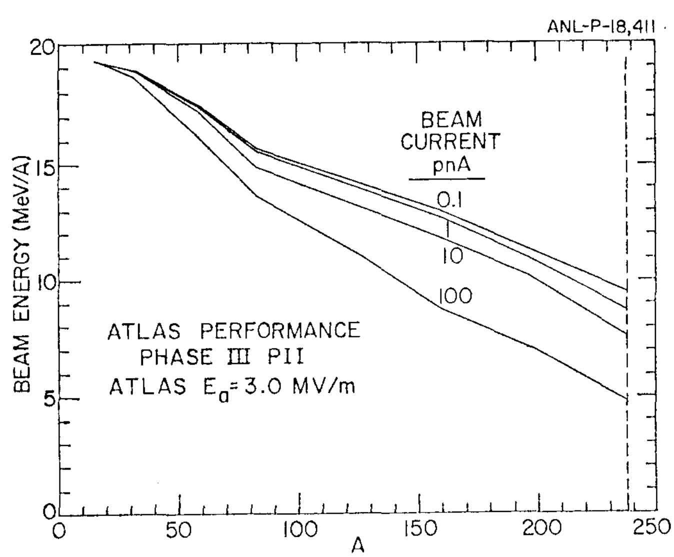

Fig. 4 Performance of ATLAS for the final 12-MV positive-ion injector.

ATLAS is continuing to be operated steadily as a research tool while PII is being built.

II. STATUS OF THE POSITIVE-ION INJECTOR

In general terms, all developmental work for PII has been completed and the Phase I system is in the final stages of assembly. The various subsystems are being tested as they are completed, in preparation for beam tests in late 1988 or early 1989.

The ECR Ion Source

The ECR ion source[5] was completed in 1987 and has been in operation since then to provide ion beams for research in atomic physics. The main attraction of the source for this research is that the 350-kV platform of the system allows the energies of highly-stripped ions to be varied over a range of considerable interest. This combination of an ECR source on a high-voltage platform is not available elsewhere at this time.

The ECR source itself is a conventional source in the sense that it incorporates many features that had proven successful in other sources designed for highly-stripped ions. The operating frequency of the plasma is 10 GHz. A main requirement of the system is that it must provide ions over the full range of the periodic table for a variety of feed materials, especially metals. Efforts to develop this capability are now in progress.

In order to design PII and project its performance capabilities, it was necessary to know the performance of the planned ion source with respect to charge state and beam intensity. For this purpose, we collected[5] the best data in the literature in 1985 and plotted the results in the form shown in Fig. 5. The performance of the new source is turning out to be consistent with the curves in the figure except that, for some heavier materials, the performance is substantially better than implied by the curve for an ion current of 0.1 μA. Similar results are now being reported for other ECR sources.

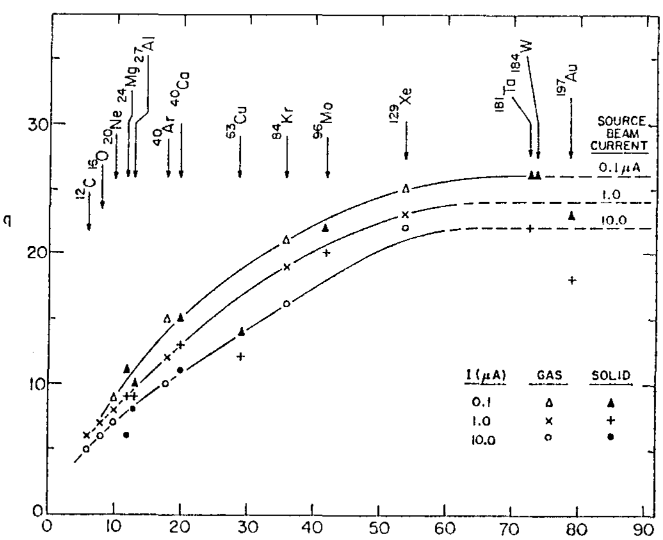

Fig. 5 Summary of ion beams available from ECR sources in 1985.

The main requirements of the voltage platform[5] of the ECR source are that it should be able to operate at 350 kV with a stability of $\Delta V/V < 10^{-4}$ and should be able to support a power load of 140 kW. The present source is not expected to require more than 65 kW, but it seemed wise to provide additional power capability for possible future developments.

The main difficulty with the source system has been voltage breakdown in the isolation transformers used to provide power to the platform. These units have been rebuilt twice and at this writing are performing well at 250 kV. For the time being, we are limiting the voltage to this value even though the manufacturer has tested the rebuilt transformers at 375 kV.

Mass Analysis and Beam Bunching

The charge-to-mass ratio of the beam from the source is analyzed[6] in two steps. First, a 90° magnet on the voltage platform analyzes the beam with a resolution of about 100, thus limiting the beam current accelerated to ground potential. Then, after acceleration, the beam is analyzed by a magnet with a nominal resolving power of 400.

The beam is also bunched[6] in two stages. On the voltage platform, the beam extracted from the source is bunched by a gridded 1.5-mm accelerating gap that is driven by a saw-tooth-like voltage wave form generated by 4 harmonics. Initially, this structure will bunch at 12.125 MHz and, if the experimenters want it, a 24.25-MHz capability will be added later.

After acceleration to ground potential, the beam is bunched again by a room-temperature spiral-loaded resonator operating at 24.25 MHz. This 2-gap accelerating structure, which is located about 1.5 m upstream from the injector linac, provides ~50 kV of acceleration for a power dissipation of 400 watts.

The two-stage bunching system outlined above is similar in most respects to the one[7] now used to bunch the beam from the tandem injector of ATLAS. The primary difference is that in PII there is no stripper between the two bunchers. Consequently, the first buncher does not need to form a time waist at any fixed location. It only needs to form a pulse that is narrow enough to fit within the linear region of the 24.25-MHz second-stage buncher, say, < 4 ns (FWHM). Thus, by adjusting the relative amplitudes of the two bunchers, one can vary the ratio $\Delta E/\Delta t$ of the phase ellipse transmitted to the injector linac and in this way achieve optimum longitudinal matching.

The Superconducting Injector Linac

The SC injector linac[8,9] is formed of the four kinds of independently-phased interdigital accelerating structures shown in Fig. 6. In each of these 4-gap structures, the two outer drift tubes are driven by a quarter-wave line, and the inner drift tube is grounded to the outer housing. Prototypes of all four types of interdigital structures have been built and successfully tested,[9] and all operate stably at accelerating fields that are twice as great as the design value of 3 MV/m. Also, the $\beta = 0.025$ unit has been tested with all of its auxiliary equipment (tuners, etc.) attached. It ran stably for several hours with complete phase control at a field of 4.2 MV/m and a power dissipation of only 4.5 W. Thus, the interdigital resonators are now ready for use.

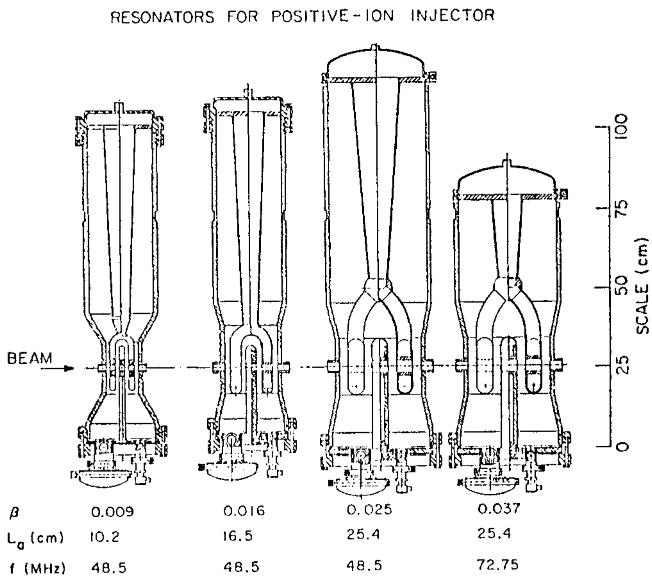

Fig. 6 The four types of interdigital superconducting accelerating structures used in PII.

The full injector linac will have 18 of the interdigital accelerating structures: 1 with β = 0.009, 2 with β = 0.016, 5 with β = 0.025, and 10 with β = 0.037. Strong radial focussing is provided by superconducting solenoids similar to those[10] now used in ATLAS. In most of the linac, a solenoid lens is located after each pair of accelerating structures, but near the front end of the machine,[2,4] where the resonators cause strong defocussing, a solenoid follows each resonator. This array of accelerating structures and solenoids will be mounted in three cryostats, each having a vacuum box 124 in. long, 32. in. wide, and 72 in. high.

The Phase I linac consists of the four prototype resonators and one additional unit with β = 0.025. These 5 resonators provide at least 3 MV of accelerating potential and, for ions with $Q/A \gtrsim 0.20$, span the full velocity range from β = 0.008 at the input up to β = 0.05 for injection into the ATLAS linac. All components of the Phase I linac (resonators and their associated auxiliary components, focussing solenoids, and cryogenic features) are now being installed in their cryostat in preparation for cold tests.

The interdigital accelerating structures in PII are cooled by gravity flow of liquid helium into the hollow quarter-wave line and by thermal conduction of heat in the resonator housing made from explosively-bonded niobium and copper.[11] Installation of the 100-W helium refrigeration and distribution system required to cool the Phase I linac has been completed.

The rf controls for operation of the PII resonators are similar to those used for the ATLAS linac. However, all aspects of this system have been improved. In particular, the resonator fast tuner, which is a voltage-control reactance operating at liquid-nitrogen temperature, has been completely redesigned[12] and now has a tuning capacity equivalent to a 20-kW rf amplifier even though the rf power dissipation is only 50 W. All of the rf equipment for Phase I is on hand and is being installed.

III. NEAR-TERM PLANS

Work on all parts of PII is proceeding with the aim of accelerating a beam through the injector and on through ATLAS in February 1989. At the ECR source, the emphasis now is on the development of beams that are suitable for the Phase I injector, namely those with A < 100. The beam line from source to linac and the bunching system will be completed and tested in early December, 1988.

The linac will undergo its first cool down in November 1988, with liquid helium provided by the completed helium-distribution system. Then, after the installation and testing of the rf-control equipment, beam tests with the whole injector will start in late December or early January. Perhaps the main challenge in these tests will be to achieve the good beam quality that we expect. These tests will not interfer with the operation of ATLAS in its present form.

When the operation of PII is judged to be satisfactory, its beam will be injected into the ATLAS linac and accelerated through the whole system. Thereafter, until the Phase II injector linac is installed in late 1989, the positive-ion injector and the tandem injector will be used alternately, depending on the quality of operation of PII and on user needs.

ACKNOWLEDGEMENT

This paper is based on the accomplishments of many persons, including R. Benaroya, P. J. Billquist, J. M. Bogaty, B. E. Clifft, P. K. DenHartog, P. Markovich, F. H. Munson Jr., J. M. Nixon, R. C. Pardo, K. W. Shepard and G. P. Zinkann.

This work was supported by the U.S. Department of Energy, Nuclear Physics Division, under Contract No. W-31-109-ENG-38.

REFERENCES

1. L. M. Bollinger, Ann. Rev. Nucl. Part. Sci. 36, 475-503 (1986).
2. L. M. Bollinger and K. W. Shepard, in Proc. 1984 Linear Accel. Conf., Seeheim, Fed. Rep. Germany, May 7-11, 1984, 24-30 (1984).
3. R. C. Pardo, L. M. Bollinger, and K. W. Shepard, Nucl. Instrum. Methods in Phys. Res. B24/25, 746-751 (1987).
4. R. C. Pardo, K. W. Shepard, and M. Karls, Proc. 1987 IEEE Particle Accel. Conf., Washington, D. C. 16-19 March 1981, IEEE Cat. No. 87CH 2387-9, p. 1228 (1987).
5. R. C. Pardo and P. J. Billquist, in Proc. International Conf. on ECR Sources and Their Applications, East Lansing, Michigan, 1978, National Superconducting Cyclotron Laboratory Report MSUCP-47, p. 279 (1988).
6. P. K. DenHartog, et al, to be published in Proc. 1989 Particle Accel. Conf., Chicago, March 1989.
7. F. J. Lynch et al, Nucl. Instrum. Methods 159, 245-63 (1979).
8. K. W. Shepard, in Proc. 1986 Linear Accel. Conf., Stanford, California, 2-6 June 1986, SLAC Report 303 (June 1986).
9. K. W. Shepard, Proc. 1987 IEEE Particle Accel. Conf., Washington, D. C., 16-19 March 1987, IEEE Cat. No. 87CH 2387-9, pp 1812-13 (1987).

10. A. H. Jaffey, R. Benaroya, and T. K. Khoe, in Proc. 1976 Proton Linear Accel. Conf., Sept. 14-17, 1976, Chalk River, Atomic Energy Canada Ltd. Report AECL-5677, pp. 102-5 (1976).
11. K. W. Shepard, C. H. Scheibelhut, et al, IEEE Trans. Nucl. Sci. NS-24(3), 1147-49 (1977).
12. J. M. Bogaty, B. E. Clifft, K. W. Shepard and G. P. Zinkann, to be published in Proc. 1989 Particle Accel. Conf., Chicago, March 1989.