

STATUS OF THE POSITIVE-ION INJECTOR FOR ATLAS

L. M. Bollinger, R. C. Pardo, and K. W. Shepard

Argonne National Laboratory, Argonne, IL 60439 USA

Abstract

Introduction

The planned positive-ion injector for ATLAS consists of an ECR ion source on a 350-kV platform and a superconducting injector linac of a new kind. The objective is to replace the present tandem injector with a system that can increase beam intensities by two orders of magnitude and extend the mass range up to uranium. In the first, developmental stage of the work, now in progress, the ECR source will be built, the technology of superconducting accelerating structures for low-velocity ions will be developed, and these structures will be used to form a 3-MV prototype injector linac. Even this small system, designed for ions with $A < 130$, will be superior to the present FN tandem as a heavy-ion injector. In later phases of the work, the injector linac will be enlarged enough to allow ATLAS to effectively accelerate uranium ions. The injector system is expected to provide exceptional beam quality. The status of the work, expected performance of the accelerator system, and the technical issues involved are summarized.

The Argonne Tandem-Linac Accelerator System¹ (ATLAS) is a heavy-ion accelerator consisting of a superconducting linear accelerator that is injected by a 9-MV tandem electrostatic accelerator. As is seen in Fig. 1, the linac has two major parts: the original prototype booster linac completed in 1982, and the ATLAS-project addition completed in 1985. Each of these sections provides about 20 MV of acceleration. Various parts of the linac have been used for research since 1978, and beams from the full ATLAS system have been used steadily since October 1985.

ATLAS was designed for the needs of high-resolution nuclear physics. Thus, the primary objectives of the system were to achieve beam energies that are much greater than are available from the 9-MV tandem alone but at the same time to preserve the excellent beam quality and easy energy variability of the tandem. These objectives have been achieved.

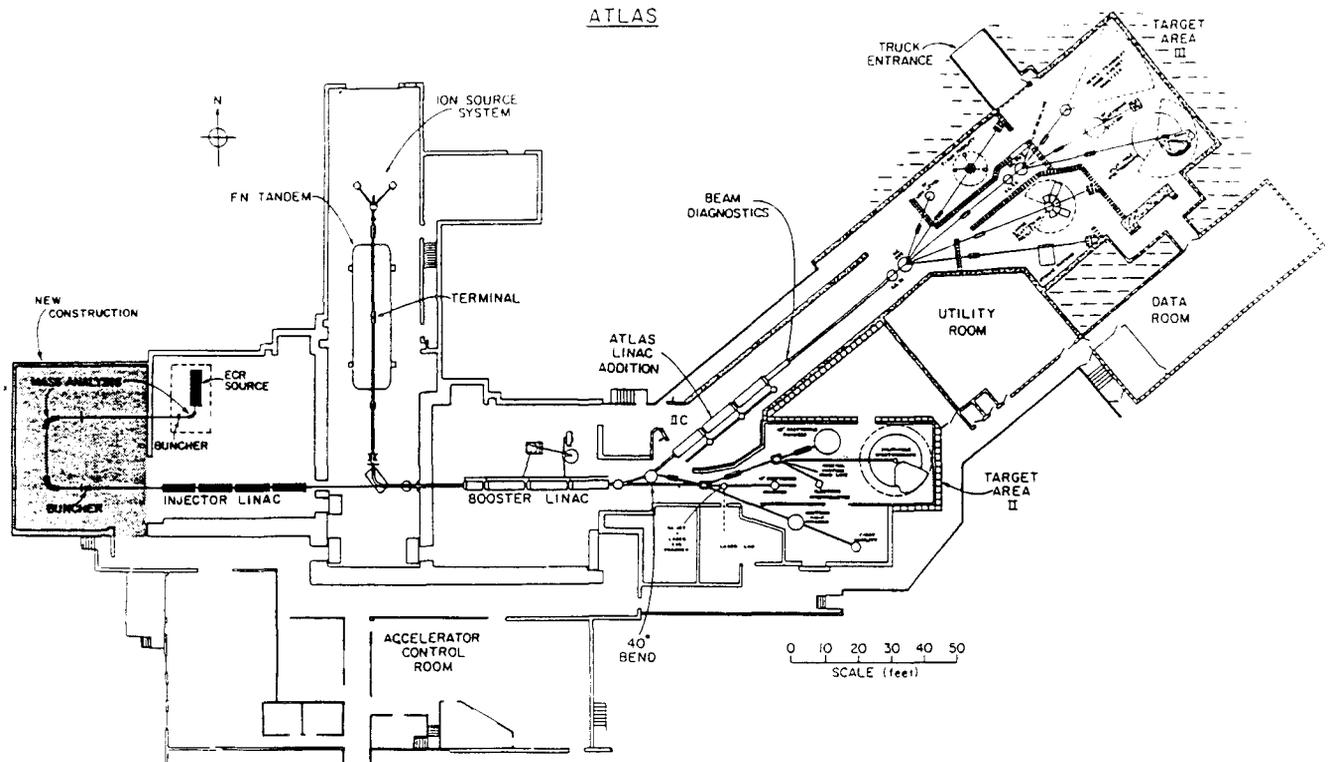


Fig. 1 Layout of ATLAS and (on the left) the planned layout of the positive-ion injector.

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POSITIVE-ION INJECTOR

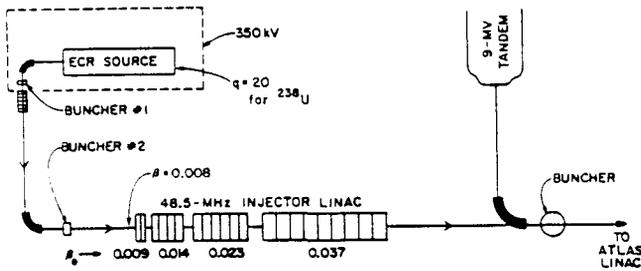


Fig. 2 Schematic representation of the positive-ion injector.

Looking toward the future, however, we recognize that ATLAS has two important limitations: (1) the beam intensity is less than is needed by some users and (2) ions in the upper part of the periodic table cannot be accelerated. Since both of these limitations are caused by the tandem and especially by the short lifetime of the stripping foil in the tandem terminal, we have undertaken to replace the tandem and its negative-ion source with a superconducting-linac injector and a positive-ion source². The ultimate objective is to develop a positive-ion injector system that will allow ATLAS to accelerate uranium ions effectively. To be fully successful, this positive-ion injector system must have a beam quality that is competitive with the tandem.

Description of Positive-Ion Injector System

The main components of the planned positive-ion injector are shown in Fig. 2, and the relationship to ATLAS is shown in Fig. 1. The source is an electron cyclotron resonance (ECR) ion source on a 350-kV voltage platform. Ions from this source are mass analyzed, bunched, and feed into the injector linac, which consists of an array of short independently-phased superconducting accelerating structures. The ECR source provides ions with very high charge states, and thus the injector linac can be rather small.

The technology of the ECR source is well developed and our design³ is being strongly influenced by the work of others. Major design features are that both the first-stage and second-stage plasma are driven by a single 10 GHz transmitter, and the second-stage chamber is relatively small (~ 10 cm diameter). Since the source must be mounted on a high-voltage platform, effort is being devoted to the reduction of power requirements. Also, since our unit must be able to produce ions from all kinds of solid materials, convenient access to the interior of the plasma chamber is being emphasized.

As is discussed in detail in a companion paper⁴, the planned superconducting injector linac consists of four kinds of 48.5-MHz independently-phased resonators that are sized to form an appropriate velocity profile between the lowest incident velocity ($\beta \approx 0.008$) and the velocity required for injections into ATLAS ($\beta \geq 0.04$). The very low incident velocity $\beta = 0.008$ amplifies all design problems.² The strong radial defocusing generated by the acceleration process is controlled by using very short accelerating structures^{2,4,5}

followed by strongly focusing superconducting-solenoid lenses. For this, the good emittance of the ECR source is important.

Perhaps the main challenge is to obtain the excellent longitudinal beam quality that is required. Three design features help to satisfy this need:

- (1) The gaps between accelerating structures are minimized by using superconducting solenoids for transverse focusing.
- (2) The RF frequency of the accelerating structures is 48.5 MHz, a much lower value than has been used in other superconducting linacs. The large resonator size required to obtain this low frequency raises questions about mechanical stability and the feasibility of phase control, but this potential problem has been solved^{4,5}.
- (3) The incident beam is bunched into very narrow pulses (~ 0.3 ns FWHM) by means of a two-stage system consisting of a room-temperature gridded buncher on the voltage platform followed by a 48.5 MHz accelerating structure at ground potential. This concept is similar to that now used with our tandem injector⁶ except that the sawtooth wave form on the grids of the first-stage buncher will be driven by a broad-band linear amplifier rather than by harmonic oscillators. This more refined approach is feasible because of the small energy spread of ions from the ECR source. Also, the absence of a stripping foil between the two bunchers implies that it is not necessary for the first buncher to form a narrow beam pulse; the only requirements are that this buncher operate in a highly linear mode and that it form pulses that fit within the linear part of the wave form of the second buncher.

Construction Plan

The construction of the positive-ion injector system will be carried out in several phases, depending on the availability of funding. In Phase I, now under way, the goal is to develop the technology, build the ECR source, and build a linac that is just large enough to compete favorably with

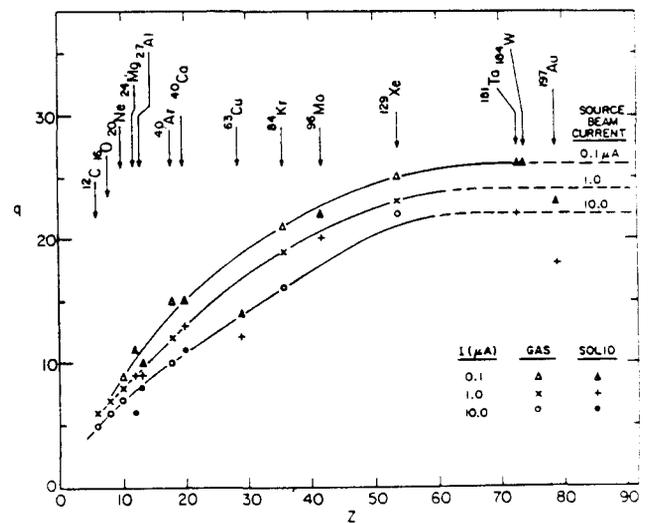


Fig. 3 Performance of ECR sources. The plotted points were obtained by interpolation from the best results reported before Oct. 1985.

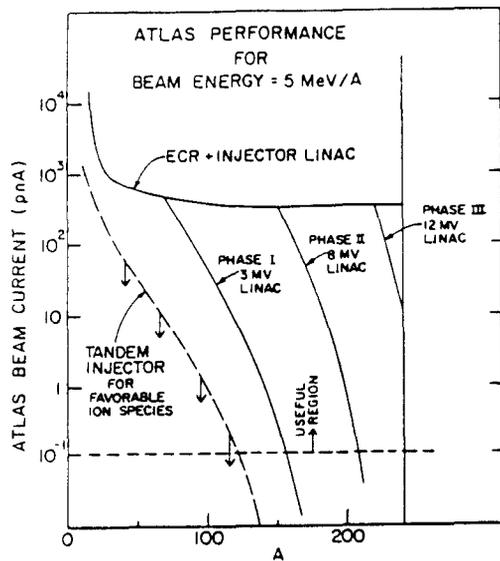


Fig. 4 Performance of ATLAS for several injectors.

the tandem as an injector. A 3-MV linac (which will allow ATLAS to accelerate all ions in the lower half of the periodic table) is adequate for this purpose. The planned Phase II will enlarge the injector linac to 8 MV, which will allow ATLAS to accelerate ions up to about $A = 200$. And finally, in Phase III the injector linac will be further enlarged to 12 MV, enough to allow ATLAS to accelerate uranium ions well above the Coulomb barrier.

Performance

The performance of the injector linac depends sensitively, of course, on the performance of the ECR source. In order to estimate beam intensities and charge states for the many source materials that have not been studied yet, we make use of Fig. 3, which summarizes most of the data available in 1985. These data are consistent with the hypothesis that the behavior of all isotopes available in pure form fall on curves such as are drawn through the data. The few cases (such as gold) that fall well below the curve can be explained by the fact that the technique used to vaporize these substances was inadequate. This is thought to be a practical problem that can be solved.

The energy-mass-beam intensity performance of ATLAS was calculated for several injector linacs under the assumption that the source intensities are given by the curves of Fig. 3. The main features of the results obtained are summarized by Fig. 4, which gives the beam current out of ATLAS as a function of projectile mass for a representative output energy. The general behavior of such plots are similar for a wide range of energies. Our conclusion is that even the 3-MV linac outclasses the tandem injector for ions with $A \geq 30$, whereas for $A < 30$ the greater maximum energy available from the tandem may be marginally advantageous. This advantage of the tandem disappears rapidly as the linac voltage increases. More important, the greater output energy provided by a larger injector linac allows ATLAS to accept a wider range of ions for effective acceleration, as shown in Fig. 4.

The relationship between injector size and

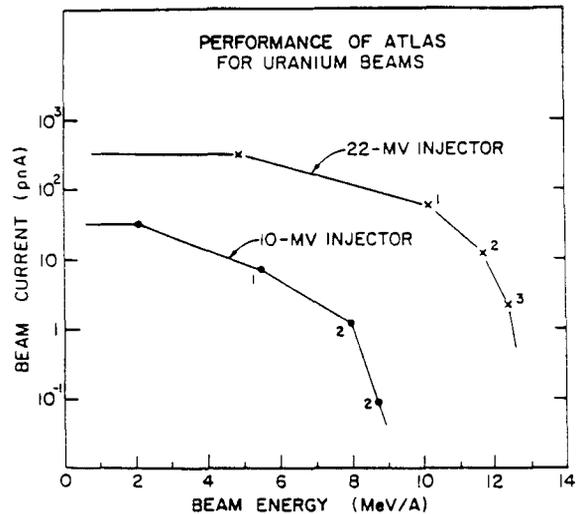


Fig. 5 Performance of ATLAS for uranium beams provided by an ECR source and two different injector linacs.

ATLAS performance is illustrated in Fig. 5 for the special case of a uranium beam. For the 10-MV injector, the velocity of the beam entering ATLAS is too low to match properly the design velocity profile. A better match can be achieved by multiple stripping, but this results in a large loss of beam current. In contrast, for the larger injector the ATLAS accelerating structures can work efficiently for output energies up to at least 10 MeV/A. The planned 12-MV Phase III injector will give perform somewhat above the lower curve.

The most interesting question about the performance of our positive-ion injector is whether its beam quality can really be competitive with that from a tandem. The answer is yes, as may be judged from calculations outlined in Ref. 4 and 5. The main reason for this perhaps surprising conclusion is that the beam quality of the tandem is dominated by angular and energy straggling caused by the foil stripper in the tandem terminal, a problem that is avoided entirely with the positive-ion injector. Whatever stripping may be carried out after the injector need not cause much deterioration in beam quality because the stripper can be located at a waist in both transverse and longitudinal phase space. In short, we expect our positive-ion injector to set a new standard of beam quality for heavy ions.

This work was supported by the U.S. Department of Energy under contract W-31-109-Eng-38.

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