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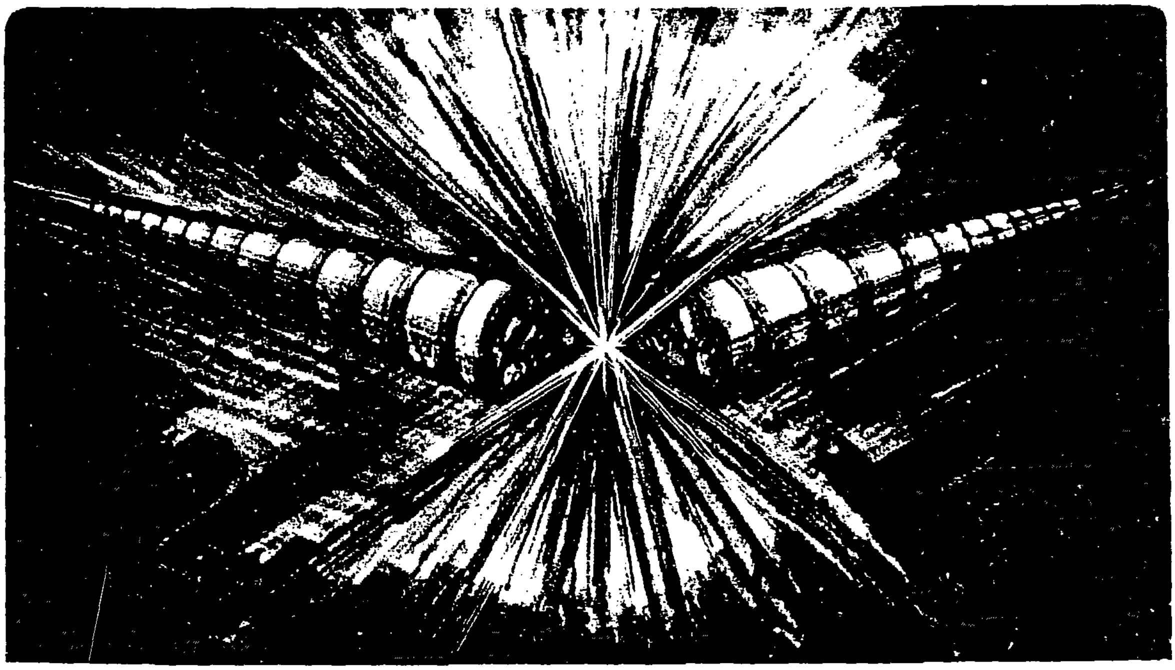

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THE SUPERHILAC UPGRADE PROJECT*

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THE SUPERHILAC UPGRADE PROJECT

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Summary

A high current MEtal Vapor Vacuum Arc (MEVVA) ion source[1] is to be installed in the third injector (Abel) at the SuperHILAC, representing the first accelerator use of this novel ion source. The MEVVA source has produced over 1 A of uranium in all charge states, with typically more than 100 electrical mA (emA) of U^{5+}. A substantial fraction of this high current, heavy ion beam must be successfully transported to the entrance of the Wideroe linac to approach the 10 emA space-charge output limit of the Wideroe. Calculations show that up to 50 emA of U^{5+} can be transported through the present high voltage column. A bouncer will be added to the Cockcroft-Walton supply to handle the increased beam current. The Low Energy Beam Transport line vacuum will be improved to reduce charge exchange, and the phase matching between the 23 MHz Wideroe and the 70 MHz Alvarez linacs will be improved by the addition of two 70 MHz bunchers. The installation of the MEVVA source along with the modifications described above are expected to result in a five-fold increase in beam delivered to Bevatron experiments, increasing the extracted uranium beam to 5×10^7 ions/pulse.

Introduction

The SuperHILAC serves as an injector for the Bevatron, injecting ions as heavy as uranium at energies up to 8.5 MeV/nucleon. The Bevatron then further accelerates the ions to 2.1 GeV/nucleon for the lighter ions or 1 GeV/nucleon for uranium. This combination of accelerators, called the BEVALAC, is the only facility in the world capable of accelerating the heaviest nuclei to relativistic energies.

The BEVALAC now produces beams of low-Z ions such as neon at intensities up to 1×10^{10} ions/pulse, and 960 MeV/nucleon uranium beams have been delivered to experimenters at up to 1×10^6 ions/pulse. In addition a new operational mode has been demonstrated in which uranium of somewhat lower energy can be produced at intensities of 1×10^7 ions/pulse. Results show that different conditions can be selected by passing uranium beams through thin targets to produce high yields of either fully stripped uranium (85%), U^{91+}(50%), or U^{90+}(40%).[2]

Increasing the beam intensity by a factor of 5 will open to exploration wide fields of atomic physics research. One notable example would be the measurement of the Lamb shift in H-like and He-like uranium. Such measurements would be of considerable interest to quantum field theorists because one cannot use perturbation theory to accurately calculate the Lamb shift of such high-Z ions. Thus, measuring the Lamb shift of He-like uranium would almost certainly stimulate theoretical activity in nonperturbative quantum field theory. The present intensity permits measurements of the Lamb shift to an accuracy of 10%, while the upgrade will allow the accuracy to be increased to about 0.5%.[3]

The recent development of the MEVVA ion source provides the basis for the SuperHILAC upgrade[1]. Figure 1 shows the SuperHILAC accelerator. Since the object of the upgrade is to increase the beam intensity, the chief concerns of the project are the production and transport of low energy, high current, heavy ion beams. Transporting this increased beam intensity to the Wideroe linac of the Abel injector will enable better use of the 10 emA output capacity of the Wideroe. In addition, improving the longitudinal phase matching between the Wideroe and the Alvarez linacs will further increase the beam intensity.

MEVVA Ion Source

The source uses a metal vapor vacuum arc discharge as the plasma medium from which the ions are extracted. The metal plasma is created simply and efficiently and no carrier gas is required. Beams have been produced from metallic elements spanning the periodic table from lithium through uranium, at extraction voltages from 10 to 60 kV and with beam currents as high as 1.1 Amperes (electrical current in all charge states).

The plasma is created directly from the solid by means of an arc discharge between two metallic electrodes in vacuum. A characteristic of the metal vapor vacuum arc is the formation of 'cathode spots' on the surface of the cathode. These are minute regions of intense current concentration (many megamps/cm^2 at a micron-size spot) where the metal plasma is generated from the solid surface. In general many cathode spots will participate in the arc, and the assemblage of spots constitutes a prolific source of metal plasma produced from the cathode material. This quasi-neutral plasma plumes away from the cathode toward the anode and persists for the duration of the arc current drive. The anode of the discharge is located on axis with respect to the cylindrical cathode and has a central hole in it through which a part of the plasma plume streams; it is this component of the plasma that forms the medium from which the ions are extracted. The plasma plume drifts through the post-anode region to the set of grids that comprise the extractor - a three-grid, accel-decel, multi-aperture design. A small magnetic field, produced by a simple coil surrounding the arc region and of magnitude up to about 100 gauss, serves to help duct the plasma plume in the forward direction but is not essential. A schematic of the source is shown in Figure 2. The extractor diameter is 2 cm as is the initial beam diameter.

High current beams of Li, C, Mg, Al, Si, Ti, Cr, Fe, Co, Ni, Cu, Nb, Mo, Sn, La, Gd, Ho, Ta, W, Au, Pb, and U have been produced by the MEVVA source. The cathode may also be made from a conducting compound, which produces a beam containing a mixture of the component species; beams from FeS, PbS, LaB6, CdSe, SmCo, SiC, and WC have been produced. It is noteworthy that in this way beams can be made which contain non-metallic species, such as B from LaB6 and S from FeS and PbS.

The emittance has been measured with a pepper pot diagnostic. Typically half the beam current resides within a normalized emittance of from 0.2 to 0.5π mm mrad. The charge state spectrum of uranium is shown in Figure 3. The distribution is peaked at U^{5+} and extends from U^{2+} to U^{7+}. The charge state distribution can be varied to a small extent via the arc current, but this effect is small. (As the arc current is increased more cathode spots form to participate in the arc, but the physics of each spot is not greatly changed.) The spectrum is clean, showing no contamination from the stainless steel trigger, the alumina trigger/cathode insulator, or other components of the source, presumably reflecting the fact that the origin of the plasma is indeed the cathode spots, which form only on the cathode.

Terminal Modifications

Figure 4 shows the Abel terminal and the beginning of the LEBT line. At present the ions are produced in the source magnet using a PIG source. This source is capable of producing about 5 emA of U^{6+} at the entrance of the accelerating column. The MEVVA source will be mounted outside of the source magnet as indicated in the figure, since it cannot operate within the strong magnetic field of the source magnet.[1] Note that the installation of the MEVVA source in no way interferes with the operation of the PIG source, so that either source can be used as required. In between the ion source and the source magnet a quadrupole triplet and a pair of steering magnets will provide the necessary optical elements to transport the beam into the magnet. The source magnet will then be used to separate the charge states produced by the MEVVA source, making use of 69° of analysis. An existing quadrupole triplet will transport the analyzed beam to the entrance of the present medium gradient column.

Computer calculations using a beam envelope code show that up to 50 emA of U^{5+} can be transported through the present column. Modifications are needed to the Cockcroft-Walton power supply to handle the increased current of the MEVVA beam. A small bouncer will be installed to maintain the voltage regulation of the terminal at ±0.1% under the increased loading of the high current beam.

Low Energy Beam Transport Modifications

Vacuum improvements will be made to decrease the residual gas pressure from the present average pressure of 8×10^{-7} Torr to 1×10^{-7} Torr. This decrease in pressure combined with the switch from U^{6+} to U^{5+} should increase the transmission from less than 60% to greater than 98% by decreasing the charge exchange losses. The vacuum in the LEBT line will be improved by modifying the line to allow low-temperature baking and replacing diffusion pumps with cryopumps. Since an average pressure of 10^{-7} Torr is sufficient, it is not necessary to rebuild the line with ultrahigh vacuum components.

The vacuum will be improved by providing and maintaining a clean system to reduce the outgassing. Several improvements are needed to achieve this. The Wilson seals will be replaced with bellows seals, which should eliminate the slight air leaks when the seals are activated. All neoprene "o-rings" will be replaced with Viton, and all epoxy and lucite will be removed from the system to allow low-temperature (100° C) baking.

While it is difficult to quantify the expected improvement in pressure, these changes should result in a great reduction of outgassing. Eliminating the leaks and providing for low-temperature baking should result in the major contaminant being hydrogen instead of water vapor. Since hydrogen is of the order of 10% of the background pressure at present, the required reduction should be attainable.

Medium Energy Beam Transport Modifications

The longitudinal bunch structure in the Medium Energy Beam Transport (MEBT) line has been measured to determine the best way to improve the matching of the 23 MHz beam bunches produced by the Wideroe into the 70 MHz buckets of the prestripper. Measurements of the bunch width were made at three positions along the MEBT line using crystal detectors in a fast timing mode.

The measurements in the MEBT line show that the amount of beam captured in the prestripper can be increased by bunching the beam at 70 MHz with two bunchers upstream of the prestripper, filling one out of every three prestripper buckets. The quantity of beam accepted by the prestripper can be increased by more than a factor of three by this means. Since a recently installed single buncher has demonstrated a factor of two increase in intensity it is expected that the calculated improvement will be realized.

Conclusions

The SuperHILAC Upgrade Project will increase the uranium output of the BEVALAC heavy-ion facility from the currently available 10^7 to $5x10^7$ ions/pulse. This upgrade will open to exploration wide fields of atomic physics research, such as enabling detailed Lamb shift measurements to be made in H-like and He-like uranium with important applications to nonperturbative quantum electrodynamics field theory.

This increase in ion intensity will be accomplished by the addition of a MEVVA source to the Abel terminal along with the appropriate focusing elements and by increasing the current handling capability of the Cockcroft-Walton power supply to accelerate 50 emA of beam through the existing medium gradient column. The LEBT line will be modified to improve the vacuum, reducing charge exchange losses. Finally, the phase matching between the beam exiting the 23 MHz Wideroe and the acceptance of the 70 MHz prestripper will be improved by the addition of two 70 MHz bunchers upstream of the prestripper. These improvements should result in a factor of 5 improvement of beam intensity for the heaviest beams, such as uranium.

Acknowledgements

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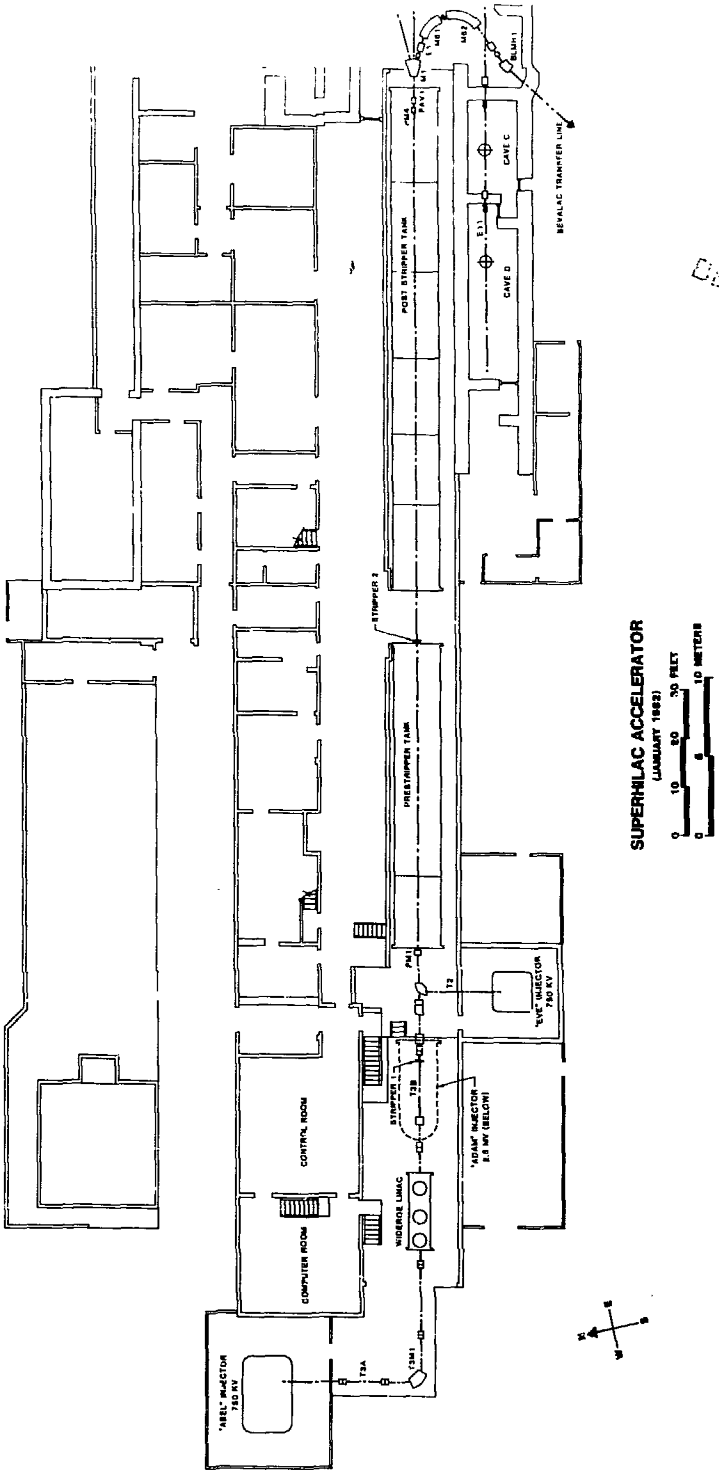

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Figure 1 - The SuperHILAC accelerator. The upgrade involves modifications to the Abel injector, both upstream and downstream of the Wideroe linac.

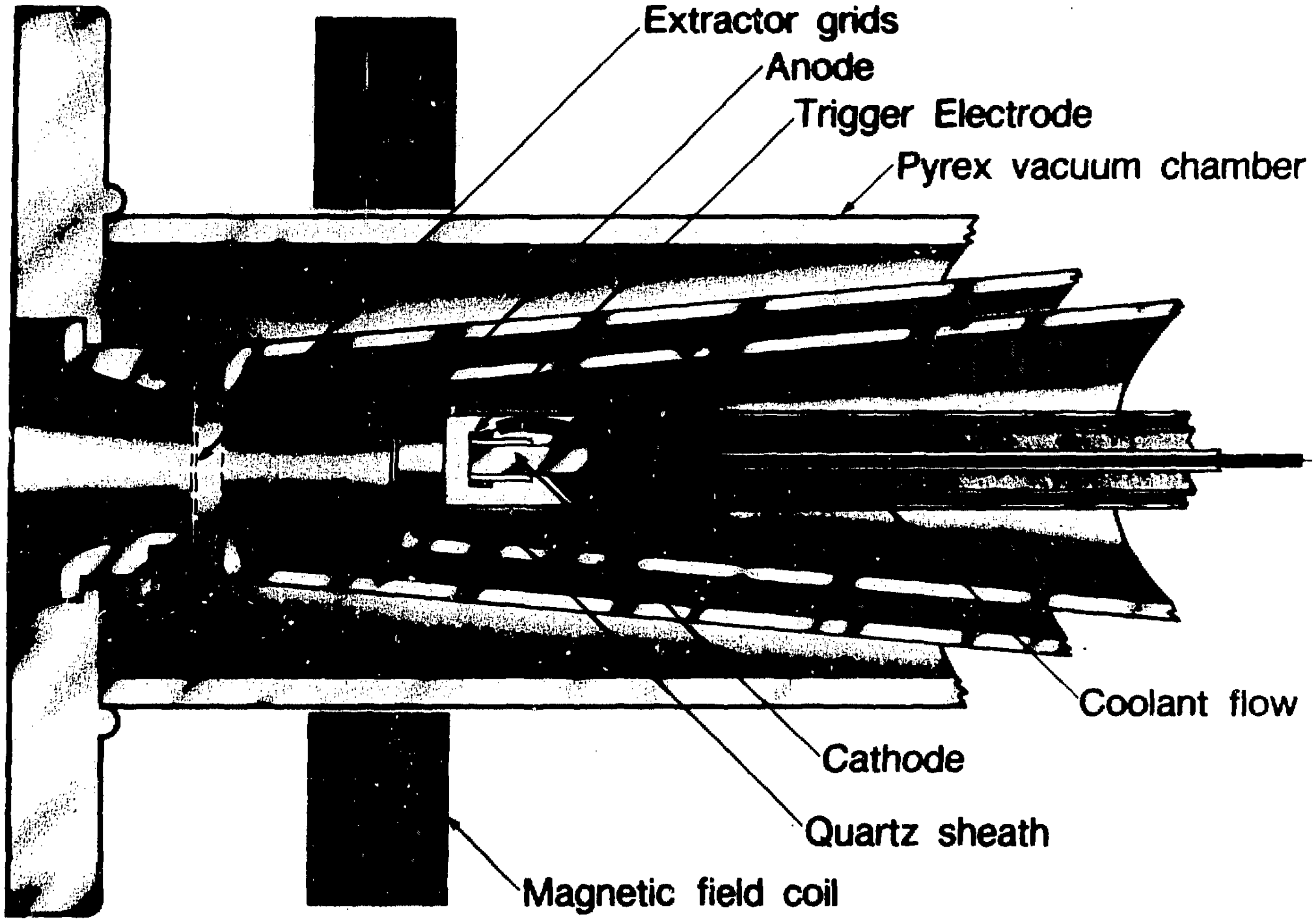

Figure 2 - Schematic of the MEVVA ion source.

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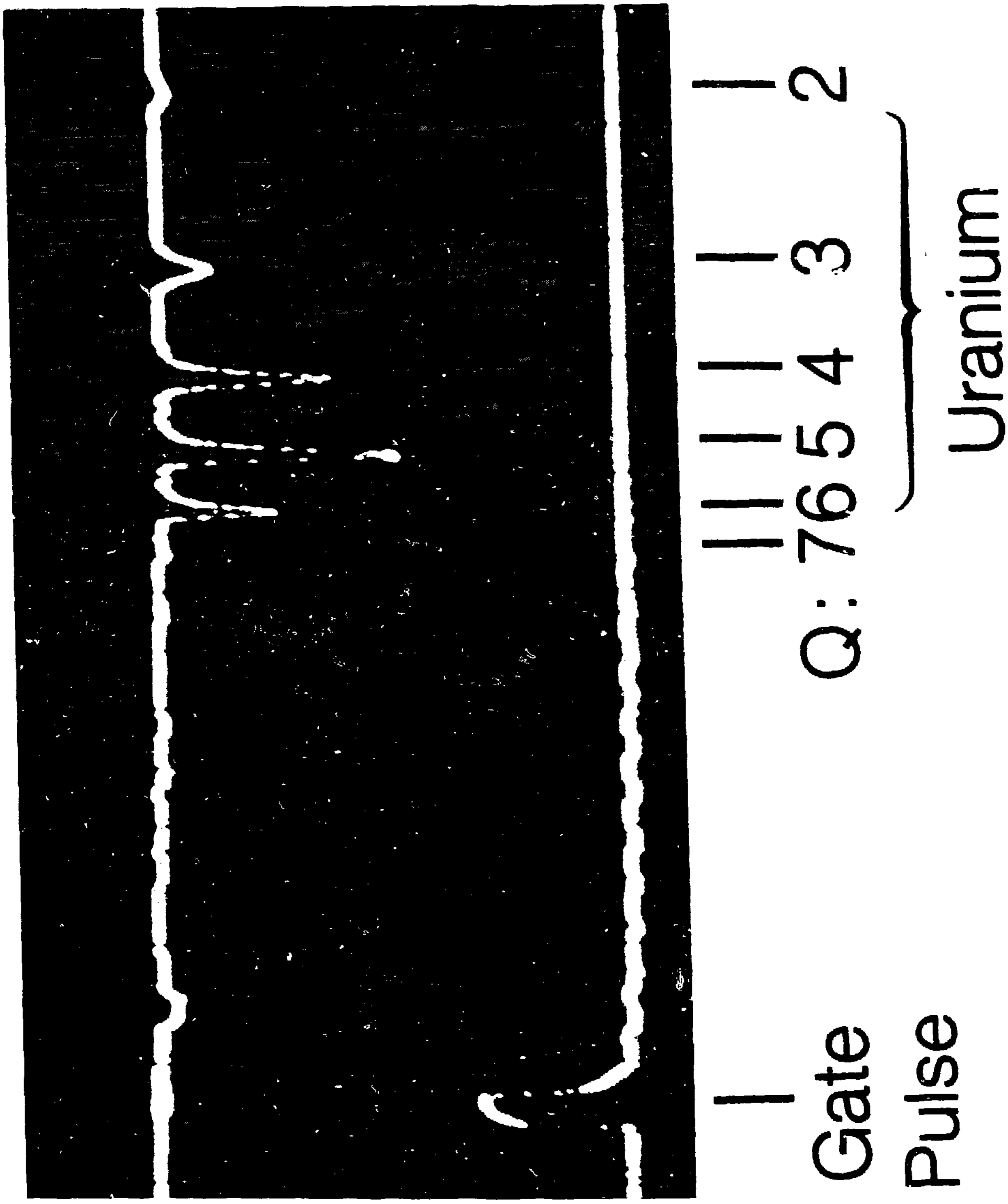

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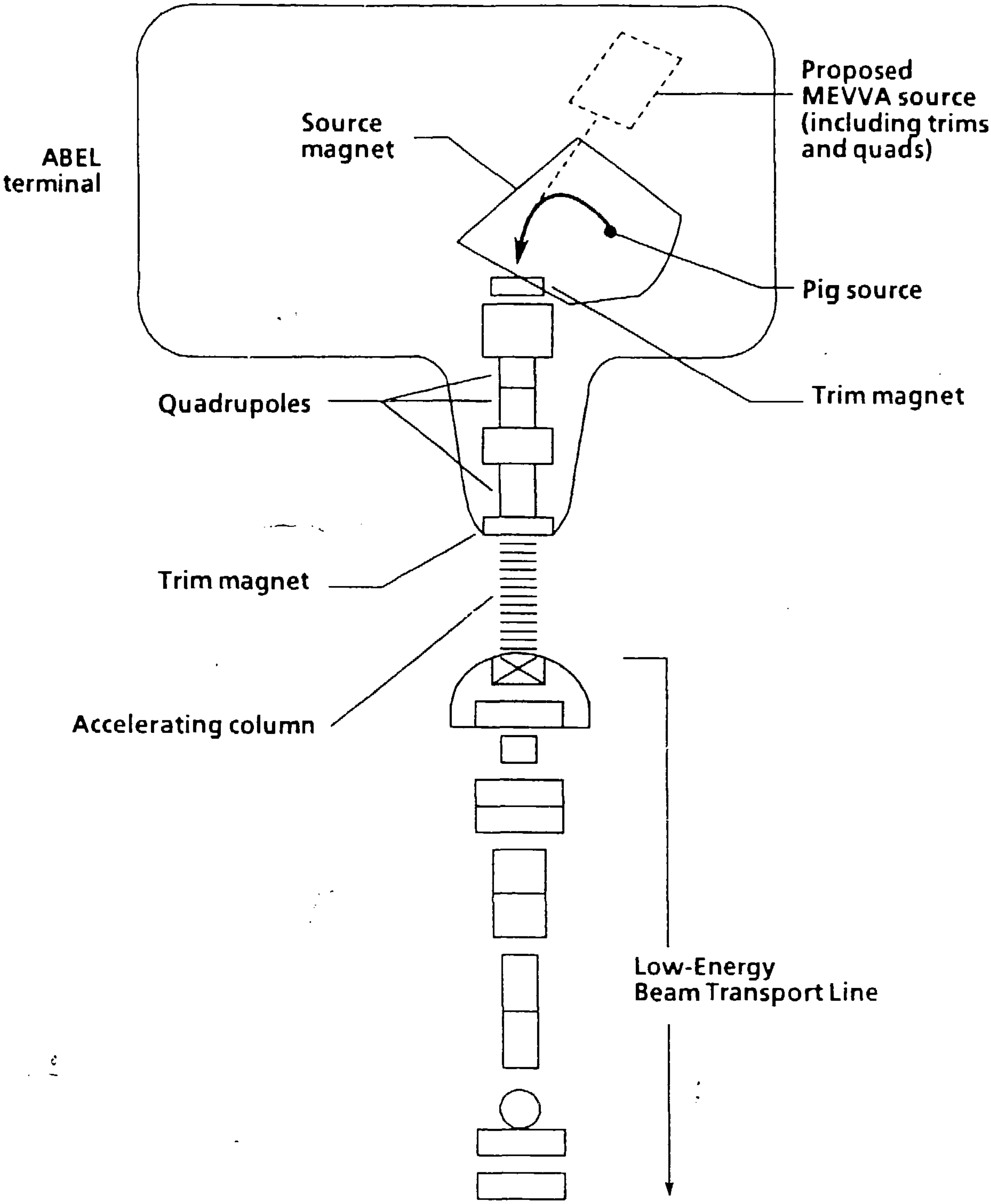
Figure 3 - Charge state distribution for uranium.



ABEL Injector, showing proposed MEVVA source

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Figure 4 - The Abel terminal and the beginning of the LEBT line. Note the MEVVA ion source placement upstream of the source magnet.