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TITLE LABORATORY PERFORMANCE OF THE BEAR RFQ

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LABORATORY PERFORMANCE OF THE BEAR RFQ*

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The BEAR (Beam Experiment Aboard Rocket) accelerator will be part of an experiment to demonstrate the operation of an ion accelerator in space and to characterize the exoatmospheric propagation of a neutral particle beam. The RFQ (radio-frequency quadrupole) has been designed to produce a 25-mA H^- beam with an emittance of 0.01 π cm-mrad (rms normalized) at an energy of 1 MeV. Because of the rigors of spaceflight, the accelerator design has been constrained by factors not normally applicable to conventional terrestrial accelerators. These factors and the mechanical features are described in a companion paper in these proceedings. The design techniques developed for BEAR would be applicable whenever rugged, lightweight, or power-efficient systems are required. The BEAR RFQ has been operated under power with beam in the laboratory. This paper presents details of measured beam transport, emittance, and energy spectra.

1. Introduction

The BEAR accelerator will be the first complete rf particle accelerator to be tested in space [1]. The exigencies of launch and space flight require that many novel techniques be developed to fabricate a lightweight, reliable, and rugged system. Details of the design considerations, fabrication, mechanical testing, and

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tuning are reported elsewhere in these proceedings [2]. This paper will report the results of laboratory beam transport studies on the BEAR Test Stand.

The main components of the BEAR accelerator are as follows: an H^- ion source [3], with 30-keV extraction, a low-energy beam transport (LEBT) quadrupole system, radio-frequency quadrupole (RFQ) accelerator that takes the beam to 1 MeV, a high-energy beam transport (HEBT) quadrupole system, and a gas neutralizer. Design parameters of the BEAR RFQ are given in table 1.

The RFQ body is an electroformed aluminum/copper structure, with no rf or mechanical joints. The cavity walls are copper plated on aluminum, with the vane tips being bare aluminum.

The RFQ was designed to have a copper power requirement of 70 kW and 1 kW/mA of accelerated beam. The low duty factor of 0.025%, along with the frequency control of the rf amplifier, precluded the need for cooling.

The rf power for the RFQ [4] is provided by two solid-state amplifiers, capable of producing 60-kW pulses, 60 μs long, at 5 Hz with a frequency of 425 ± 0.5 MHz. The amplifiers are capable of tracking the RFQ resonant frequency to within 0.02 MHz, which eliminates the need for temperature stabilization of the RFQ. The amplifiers have a specific power output of 0.9 W/g

The LEBT, which focuses the H^- beam from the source to the RFQ, consists of a quadrupole triplet made of NdFe permanent-magnet blocks. This was designed to be a fixed focus system with no on-line adjustment of quadrupole strength or position. The match into the RFQ is adjusted by varying the extraction voltage from the ion source and by controlling the plasma neutralization in the LEBT region through the addition of Xenon gas [3]. This has resulted in a less than ideal, but stable and reliable, match in to the RFQ.

The vacuum system for the LEBT region consists of two specially modified Sorbac™ getter pumps, which have a pumping speed of 600 ℓ/s for hydrogen and zero for xenon. The only xenon pumping from the LEBT is 0.6 ℓ/s through the RFQ orifice to a cryo trap in the HEBT region. This provides a means of allowing a high partial pressure of xenon and a low partial pressure of hydrogen, which is desirable for optimum operation.

The HEBT, which collimates the output beam from the RFQ, is similar in design to the LEBT. The HEBT was not installed while the measurements reported here were being made. An overview of the test-stand configuration is shown in fig. 1.

The RFQ has produced currents up to 27 mA at the design energy of 1 MeV. Details of the RFQ performance are given below.

2. LEBT output and match into the RFQ

The typical current output from the LEBT was 60 mA at a source extraction voltage of 34 kV. Extraction from the source was through a 4- by 1-mm slit. This extraction voltage was found to be the one that produced the best transverse match into the RFQ and, therefore, the highest current out of the RFQ. The match was found to be strongly dependent on the degree of space-charge neutralization. This neutralization was controlled by adding xenon to the LEBT vacuum chamber through a piezoelectric bleed valve.

The emittance of the beam near the RFQ entrance was measured using 30-keV electric sweep scanners [5]. Because of the tight spacing between the LEBT and the RFQ, emittances could only be measured with the RFQ removed. The scanners were configured to measure in two perpendicular planes, and the entrance slits were positioned 1 cm downstream of the RFQ entrance plane. Fig. 2 shows the transverse phase space (emittance) of the beam in the direction parallel to the short axis of the source slit. Without the addition of Xe, the base pressure in the LEBT was 3×10^{-5} torr or lower, and the match to the RFQ was extremely poor. In this situation, the current exiting the RFQ (I_{rfq}) was typically no more than 5-10 mA. The addition of Xe had a dramatic effect on the match into the RFQ, resulting in an increase in I_{rfq} to 24-27 mA. The optimum partial pressure of Xe was found to be approximately 4×10^{-5} torr. The emittance (rms normalized) of the beam (50 mA) at the RFQ entrance in directions parallel to the short and long axes of the source slit are 0.008 and 0.015 π cm·mrad, respectively. Without xenon, the emittances are typically twice these values. The mismatch factor of the beam into the RFQ is 1.6 at best, which would be expected to result in approximately 50% of the beam in the LEBT being accelerated through the RFQ.

3. RFQ output

The I_{rfq} was measured at the design intervane voltage as the injection energy was varied. The peak I_{rfq} was found to be at 34 keV, which was in agreement with estimates of the optimum match based on LEBT phase-space measurements.

The RFQ output emittance was measured using newly designed compact 1-MeV electric sweep scanners. The angular resolution of the scanners is approximately 2 mrad. An RFQ output emittance plot is shown in fig. 3, the measured emittance being 0.014 π cm·mrad normalized rms at a current of 24 mA. The measurements were made at a distance of 134 mm from the end of the RFQ vanes.

The energy spectrum of the beam was measured using a magnetic spectrometer. The bending magnet was a 45°, stigmatic, homogeneous-field electromagnet with rotated poles. The resolution of the spectrometer was 5 keV at 1 MeV. Apart from resolution-related broadening, the measured spectrum is ~20 keV broader than that at the exit of the RFQ because of space-charge effects. A spectrum measured with $I_{rfq} = 26$ mA, and an intervane voltage close to 100% of the design value is shown in fig. 4. A single peak was found at 1 Mev and no other peaks were detected. At lower current levels (20 mA), the 1-MeV peak was split in two with peaks at 0.96 and 1.02 MeV with a shallow valley in between. This splitting of the peak has been observed previously for RFQ output [6].

Spectra were also taken at lower intervane voltages. At voltages above 75% of design, the peak energy remains close to 1 MeV. At lower field levels, the accelerating buckets collapse and so does the energy spectrum, resulting in a broad low level spectrum at 70%. Between 60 and 70%, a spectrum with a single peak at 0.25 MeV was found. This corresponds to particles being accelerated to half the design velocity in the RFQ.

4. Conclusion

The BEAR RFQ has met or exceeded all of its design requirements. It is the lightest operational RFQ in the world. Over 600 hrs of operation with beam have been logged, and there has been no discernable damage to the aluminum vane tips, nor has there been any degradation in performance. Many of the techniques developed for the BEAR project will have applications in ground-based accelerators where weight, size, and reliability are important. These will be described in future publications.

The definitive test will be during the spaceflight, which is planned for spring of 1989.

Acknowledgment

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Table 1

BEAR RFQ Design Paramaters

Particle	H^-
Resonant frequency	425 MHz
Injection energy	0.03 MeV
Final energy	1 MeV
Output current	25 mA
Output emittance (rms norm.)	0.01 π cm·mrad
Pulse width	50 μs
Rep. rate	5 Hz
Copper power	71 kW
Beam power	26 kW
Intervane voltage	0.044 MV

Figures

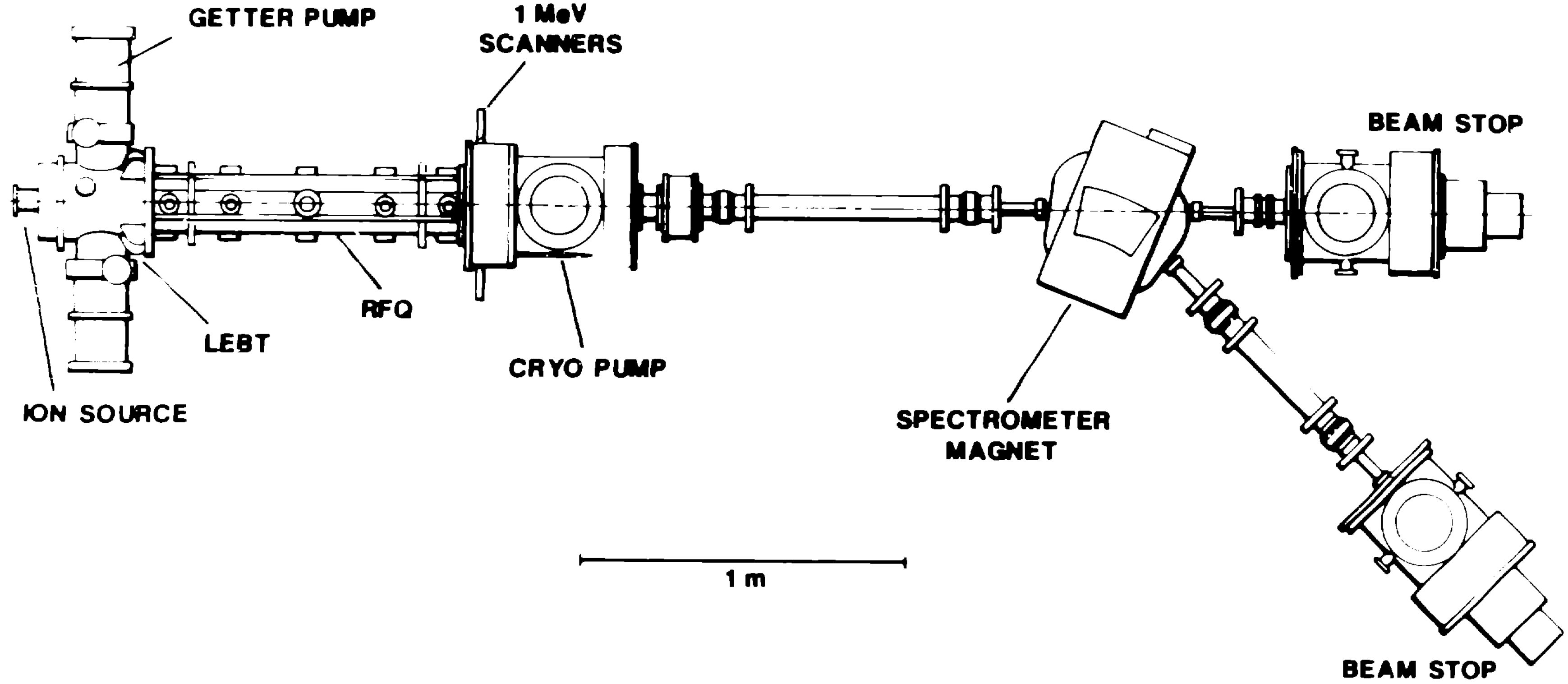
Fig. 1. BEAR test stand viewed from above.

Fig. 2. LEBT output emittance diagrams, (a) without xenon and (b) with a partial pressure of xenon of 3×10^{-5} torr. Contour levels are 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 of peak signal, measured parallel to the short axis of the source slit (x axis).

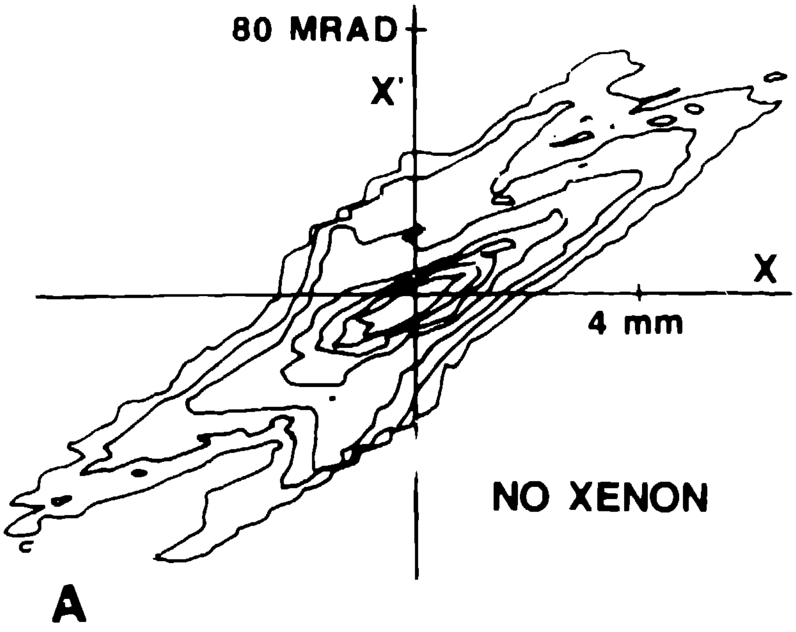
Fig. 3. RFQ output emittance diagram, measured parallel to the vertical vane at 134 mm from the RFQ at a current of 24 mA.

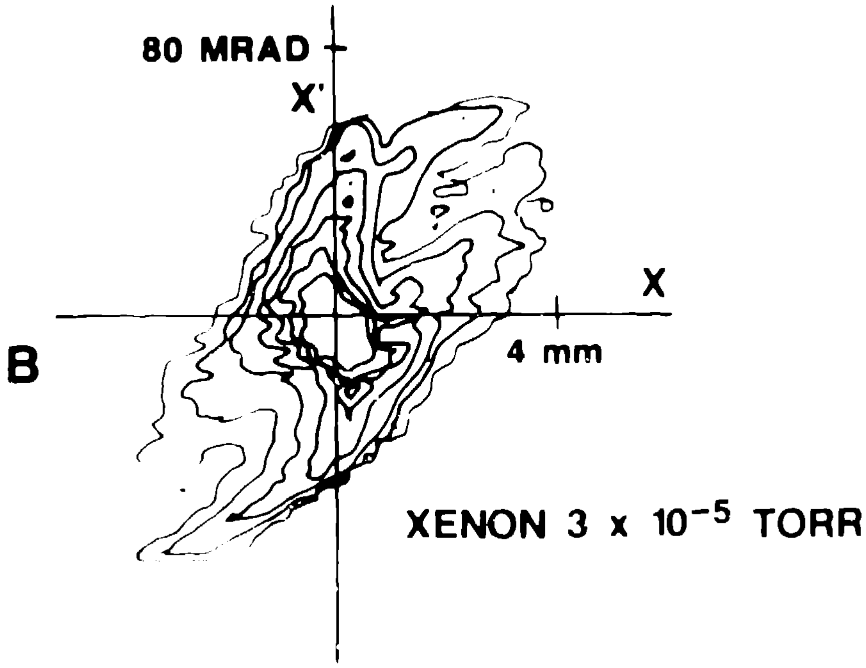
Fig. 4. RFQ output energy spectrum, measured at a current of 26 mA.

BEAR TEST STAND

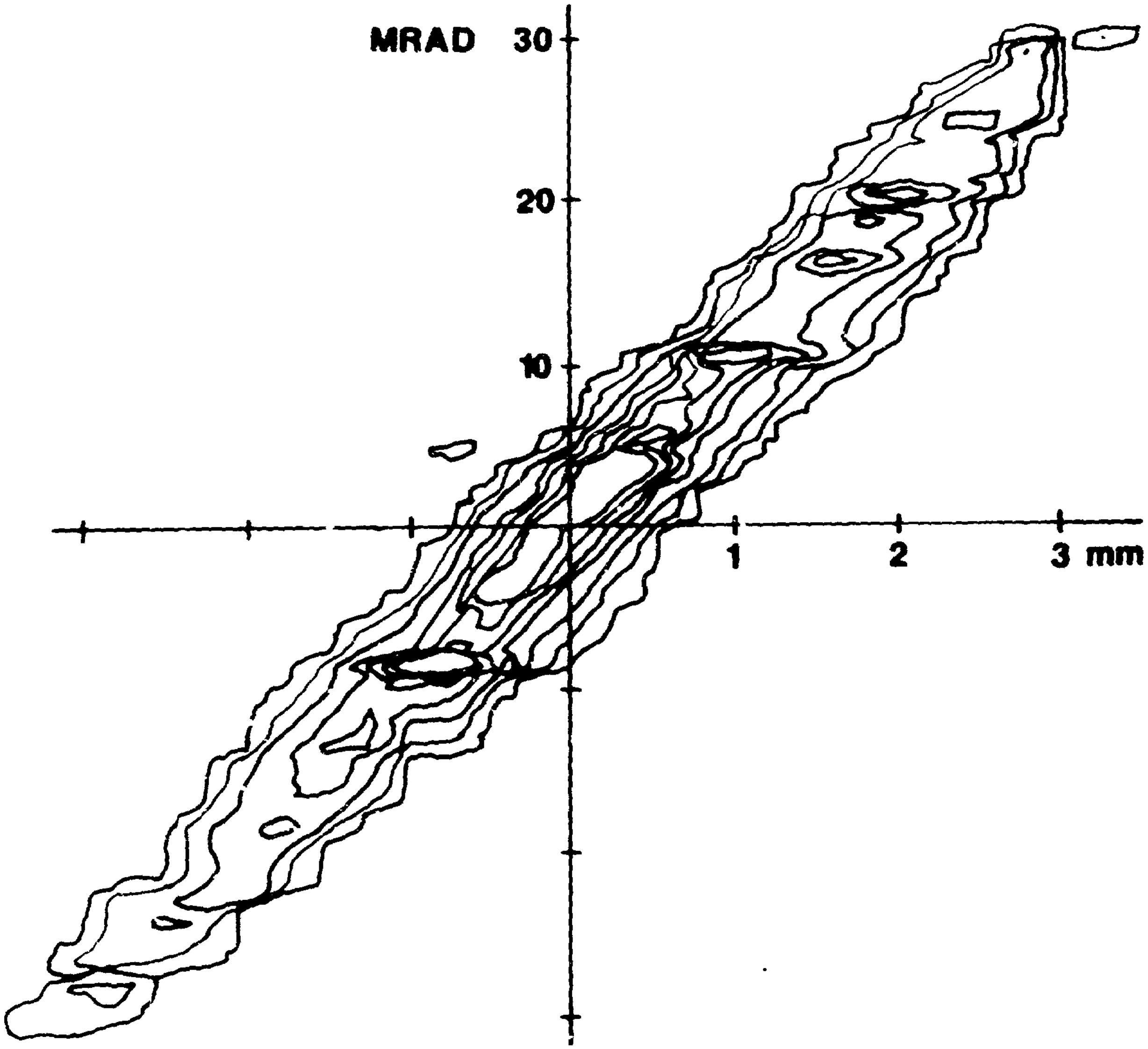


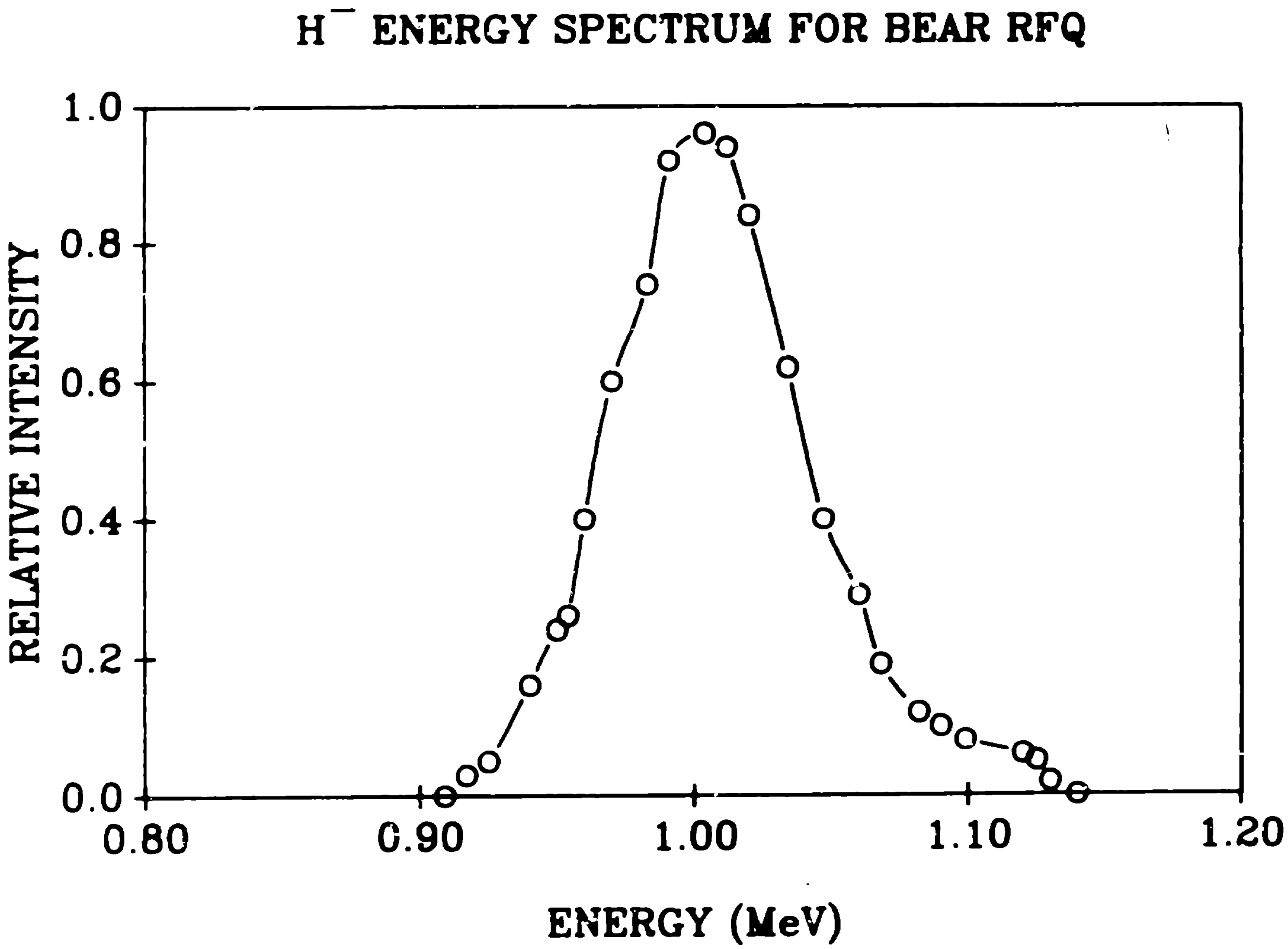
LEBT OUTPUT EMITTANCE DIAGRAMS
X PLANE





RFQ OUTPUT EMITTANCE
VERTICAL





H$^-$ ENERGY SPECTRUM FOR BEAR RFQ