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MASTER

Operation of the ORNL ECR Source*

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During the past year, the ORNL ECR source has fully demonstrated its capability for providing the high charge state, high current beams required for our group's atomic physics research program. The ECR source, which is dedicated completely for use in our investigations of the collisional properties of multicharged ions, has permitted considerable expansion of research in some areas, and has opened other areas that were experimentally unaccessible to us previously. A partial list of publications resulting from implementation of the ECR source is provided in the appendix.

In addition to pursuing a very active atomic physics research program, we have also further optimized the performance of the ECR source. The first stage of the ion source was redesigned to operate at 10.6 GHz in the electron cyclotron resonance mode. Microwave power to the first stage is obtained from the main 10.6 GHz supply providing power to the second stage by means of a low reflectivity variable power divider. Addition of this improved first stage has been found to significantly enhance stability of very-high-charge-state beams, and of ion beams of the lighter elements. In order to compensate for the lower magnetic field in the first stage relative to earlier over-dense operation, an auxiliary coil was added to the middle second-stage coil. Figures 1-3 show various aspects of the present configuration of the ORNL ECR source, and Table I summarizes the source parameters.

In order to maximize axial field tuning capability, a third axial field coil supply was installed. The currents in all three axial field coils can now be independently varied over a sufficiently wide range to find the optimum axial magnetic field profile. In the event of a coil power supply failure, the third supply will also act as a back-up, since the two second stage coils can also be energized in series by one of the main supplies plus a much smaller trim supply, as was done in the original configuration.

The capabilities of the ECR source were extended to metallic ion production by use of a solid sample feed technique similar to that described by Delaunay et al.[1] Using this technique, a metallic vapor is created from a thin foil sample heated by insertion into the second stage plasma. The foil is clamped to the end of a lever arm that can be rotated about a pivot. Rotation of the sample into the plasma edge is achieved via a mechanical linkage to a linear motion feedthrough located on the microwave feedthrough flange. A 0.2 mm thick sample of type 302 stainless steel was used in this manner to obtain beams of Fe, Cr, and Ni ions. Beams stable over a period of hours were obtained with one foil position. Typical foil consumption rates were measured to be about 7 mg/hr. Charge states of iron up to +15 were produced with sufficient beam intensity for use in crossed beams experiments.

Table 2 lists ion currents presently attainable with the ECR source for beams produced from four representative permanent gases, and one volatile liquid (CH_3I), as well as for iron beams produced by the solid feed technique described above. The intensities of the particular elemental isotope quoted reflect natural, i.e., non-enriched, abundances. All beams were obtained for source voltages in the range 10-12 kV, and using maximum slit apertures consistent with the resolution required for unambiguous identification of the mass to charge ratio of the beam in question; typical entrance and exit slit widths used were 10 to 15 mm. In the case of Xe ions, slit widths were reduced to about 5 mm in order to sufficiently resolve the mass 129 isotope. The iodine beams were obtained during a short test run using methyl iodide vapor. For still poorly understood reasons, consumption of the liquid was extremely high, so that in a matter of a few days the roughly 50 ml of liquid contained in our glass reservoir was used up! The main suspect at the present time is a leak in the gas feed line between reservoir and leak valve. Source memory of the methyl iodide was short: while copious I beams could be extracted initially after switching to Ar source gas, after two hours the I beams no longer could be found, and the Ar beam charge state distribution, which initially was quite poor, returned to its previously measured state.

At the previous ECR workshop,[2] some suggestion was made that the energy spread of ions extracted from an ECR source could be in part due to voltage fluctuations in the source HV power supply due to imperfect load regulation in the presence of current drain fluctuations. Using our 90° charge analyzer in high resolution mode (i.e., narrow slits), and going to low source voltages, we have investigated this possibility by comparing beam profile widths obtained using different source HV supplies. The results, shown in Fig. 4, indicate that RF regulated supplies, when used at a small fraction of their rated voltage and/or close to their rated current limit may introduce spurious energy widths in extracted ion beams. Using the width obtained using the series-pass-element regulated HV supply, we obtain about 5 eV × q as an estimate of the maximum energy spread of extracted 8 keV Ar^{8+} ions. Analogous measurements on Ar^{1+} and Ar^{2+} gave results within a few eV × q of the above value.

All major components of the ECR source have functioned without breakdown since the source became operational a little over two years ago, with two exceptions. The first refers to a Klystron tube failure in April 1985 after only 1300 tube HV hours, 300 hours outside the VARIAN warranty period. Cause of the failure was a vacuum leak due to a crack in the ceramic insulator between filament and tube body, a very rare failure mode according to VARIAN. Thanks to a backup tube purchased together with the original Klystron, and stored at VARIAN under their "bonded storage" program, we were back on the air in a little over a week. Without the spare tube, we would have incurred a down time of over 12 months, due to the long lead times inherent in the fabrication of the VKX 7809 tube we are using! The other exception refers to development of a water leak in the extraction end axial field coil December 1985. The leak occurred in the interior of one of the double pancakes comprising the coil, probably at the cross-over point where excessive pounding may have weakened the conductor. The leaky pancake, while physically still being a part of the coil, was taken out of the electrical and cooling circuits by suitable bypasses (see gap in axial field coil in Fig. 2). The resulting decrease in the the number of turns of the coils was compensated by an increase in coil current, with no noticable loss of source performance. Total down time due to that failure was a couple of days.

As regards future plans for ECR source utilization at ORNL, a source very similar to the present one may be used in conjunction with an RFQ accelerator as an alternate ion injector for the proposed 2 T.m HISTRAP (Heavy Ion Storage Ring for Atomic Physics) project. The Holifield 25 MV folded tandem accelerator will be the main injector, while the ECR/RFQ will permit independent operation of the ring when the tandem is in use for nuclear physics experiments. Figure 5 shows the proposed layout of the ring, including the ECR/RFQ beamline, while Fig. 6 shows the ECR/RFQ beamline in greater detail. Tables 3 and 4 summarize the proposed RFQ linac parameters and simulation results, arrived at in collaboration with J. Staples of the Acclerator and Fusion Research Division at LBL. Figure 7 displays calculated beam profiles in the ECR/RFQ beamline, and illustrates the strongly converging beam required at the entrance of the RFQ linac. A decision on the funding status of the HISTRAP project is expected to be made by the Department of Energy sometime in FY '87.

References

[*] Research supported by the Office of Fusion Energy, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

1. M. Delaunay, S. Dousson, R. Geller, and B. Jacquot, Nucl. Instrum. Methods 213, 165 (1983).

2. Workshop on the Sixth International Ion Source, C. Lyneis editor, Jan. 17-18, 1985, Berkeley, California.

Table 1. ORNL ECR source parameters

Microwaves	
First stage 10.6 GHz	5 - 100 W
Second stage 10.6 GHz (2.2 kW max)	20 - 1000 W
Magnetic Fields	
Mirror ratio	1.6
Hexapole field at vacuum wall	4.0 kG
Field in extraction plane	5.0 kG
Field in first stage	around B_{res} for 10.6 GHz (3.4 - 7 kG)
Total solenoid power	60 kW
Vacuum (operating condition)	
First stage	10^{-3} - 10^{-4} T
Second stage (1 × 10^{-7} torr base)	1 - 3 × 10^{-6} T
Extraction	1 × 10^{-7} T
Dimensions	
Solenoids ID	18 cm
Solenoids OD	40 cm
Hexapole ID	9.5 cm
Hexapole length	33 cm
Vacuum wall ID second stage	8.6 cm
Anode aperture	0.8 cm
Extraction aperture	1.0 cm
Extraction gap	2.6 cm

Table 2. Representative ORNL ECR source beam currents (electrical μA); 10-12 kV source voltage (see text for slit widths)

	^{16}O	^{40}Ar	^{56}Fe	^{84}Kr	^{127}I	^{129}Xe
+1	400	110	10			
+2	300	120	*			
+3	170	90	20			
+4	100	75	*			
+5	83	*	23	20		
+6	50	65	25	25		
+7	2.5	73	*	26		
+8	0.1	105	*	27		
+9		45	20	33		5.0
+10		*	10	31	8	4.5
+11		3.0	5	33	10	3.5
+12		0.7	*	40	14	3.5
+13			2	23	18	3.2
+14			*	21	20	2.5
+15			1.5	15	18	1.5
+16				5	*	1.2
+17				1	10	1.0
+18				*	*	0.6
+19				0.25	3	0.6
+20					2	0.5
+21					*	0.25
+22					0.5	0.12
+25						0.08
+26						0.05
+29						0.01

*Indicates m/q degeneracy with contaminant beam.

Table 3. Summary of RFQ Linac parameters

Design ion	$^{197}Au^{+33}$
Frequency	228 MHz
Input energy	5 keV/nucleon
Output energy	251 keV/nucleon
Vane length	236.6 cm
Average bore radius (r_0)	1.42 mm
Maximum surface field	28 MV/m
Vane-vane voltage	29 kV
Peak rf power	30 kW
Cavity radius	13.7 cm

Table 4. Summary of RFQ simulation results
(5-keV/nucleon RFQ input energy)

Unnormalized acceptance	79π mm·mrad
Input phase space ellipse parameters:	$\beta_x = 0.025$ m $\alpha_x = 0.95$ $\beta_y = 0.025$ m $\alpha_y = 0.95$
Output phase space ellipse parameters:	$\beta_x = 0.055$ m $\alpha_x = 1.1$ $\beta_y = 0.055$ m $\alpha_y = -1.2$
Output energy:	251 keV/nucleon
Output energy spread (90%):	±5 keV/nucleon (±2%)
Output phase spread (90%):	±22°
Emittance growth:	0%
Theoretical transmission:	98%

Appendix

F. W. Meyer, A. M. Howald, C. C. Havener, and R. A. Phaneuf, "Observation of Low-Energy Z Oscillations in Total Electron-Capture Cross Sections for Bare Projectiles Colliding with H and H_2," Phys. Rev. Lett. 54, 2663 (1985).

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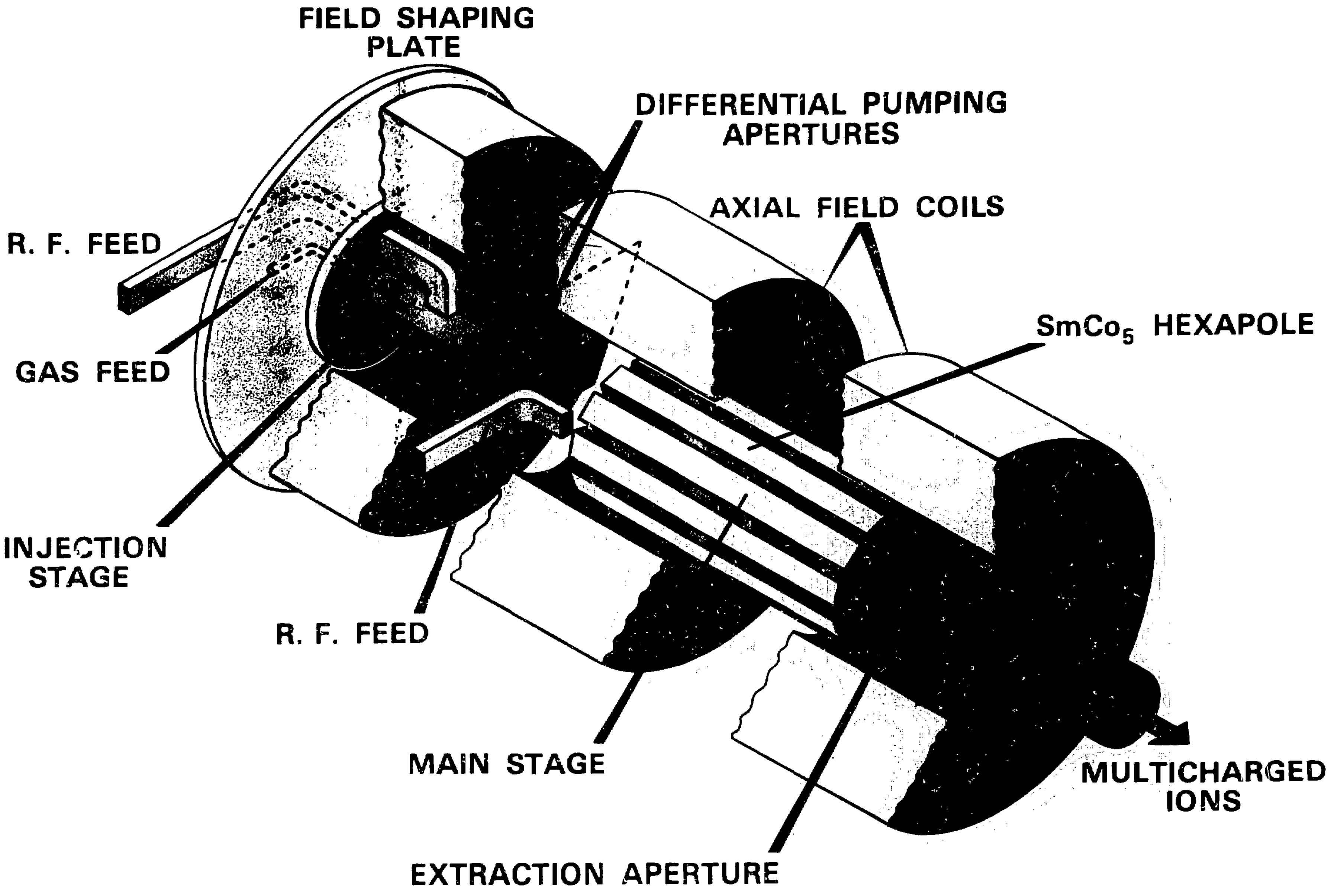
ORNL-DWG 85-13312B



ORNL ECR Multicharged Ion Source

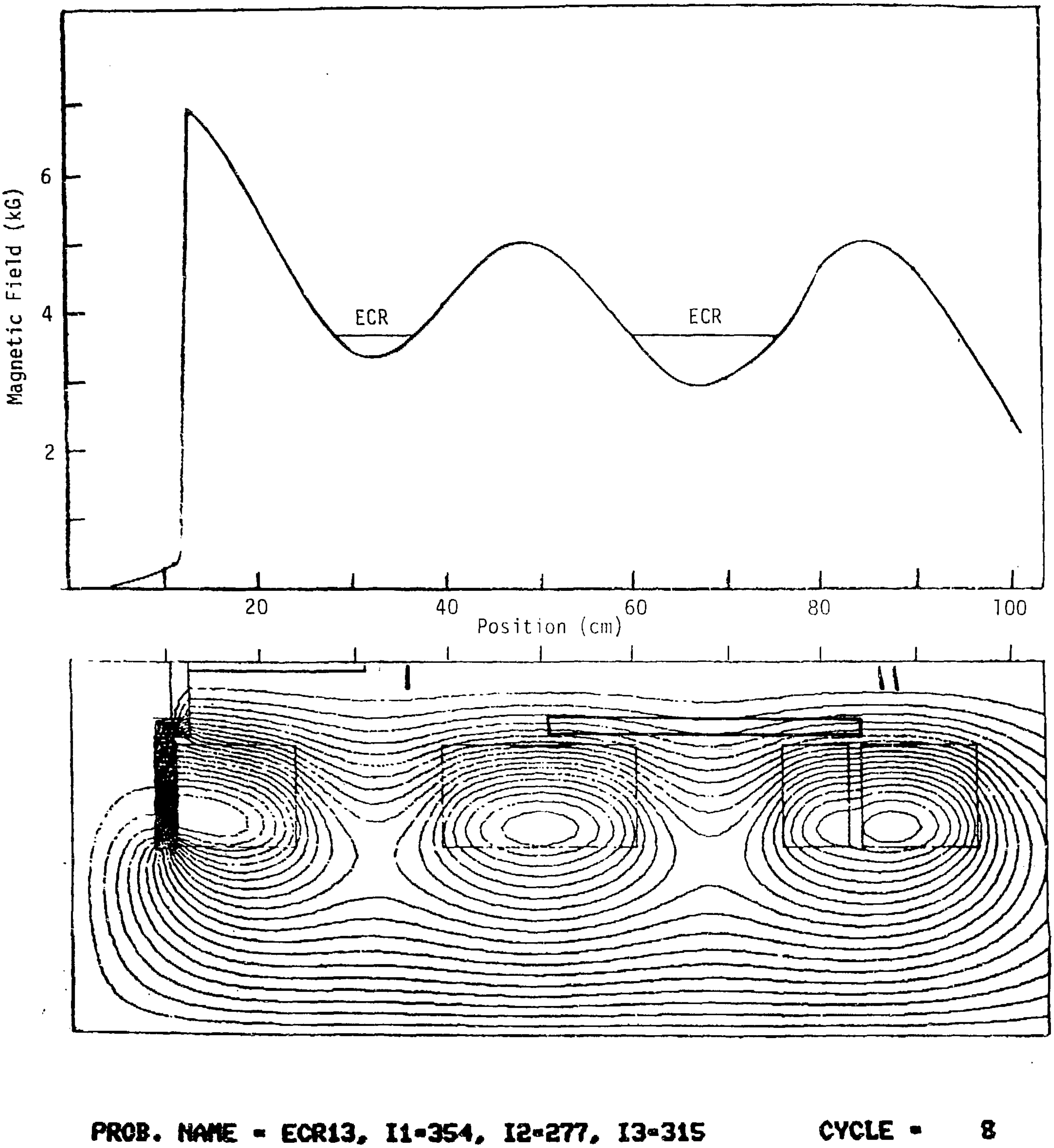


Fig. 2. ORNL ECR source solenoidal magnetic field

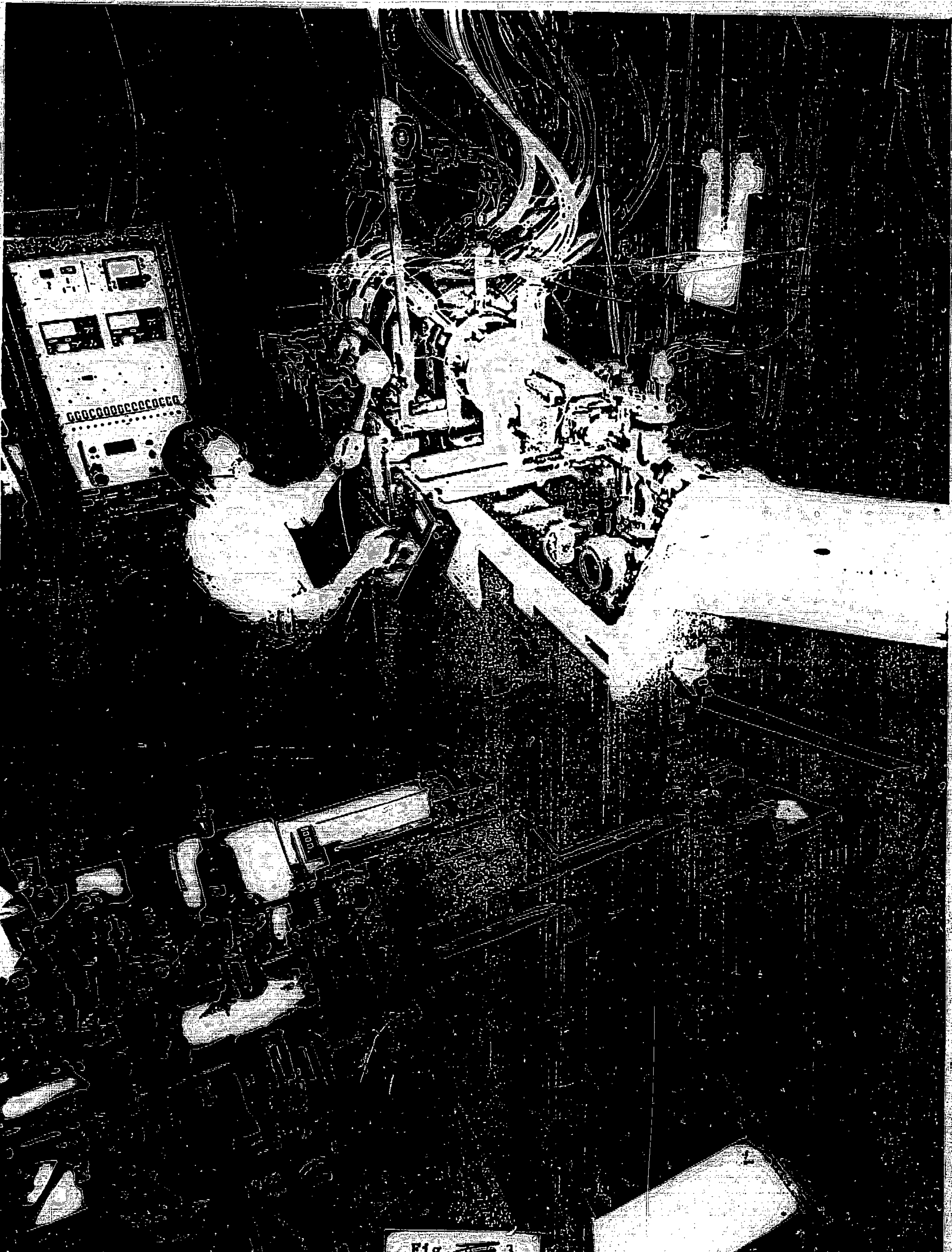


Fig 3

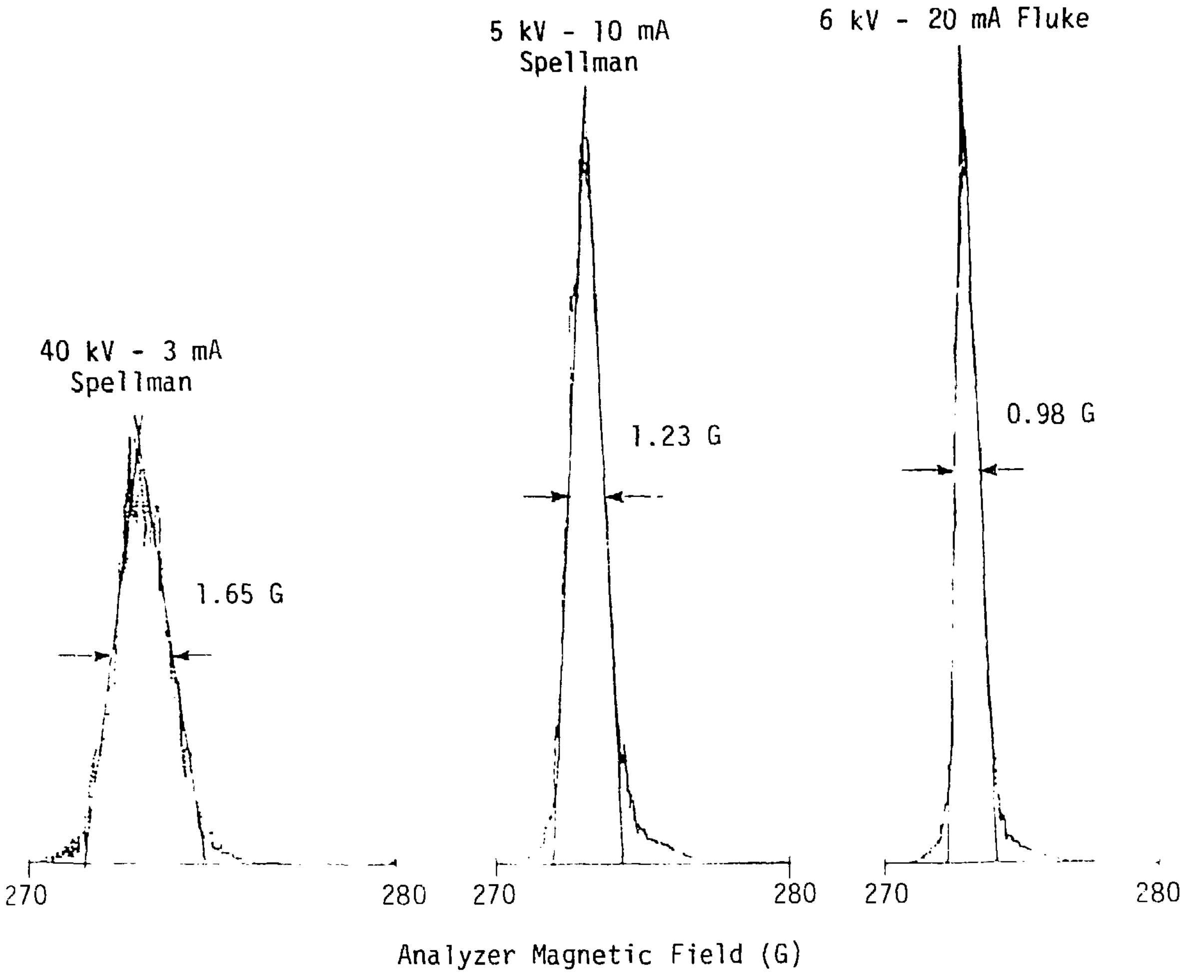


Fig. 4. Analyzed beam profiles for Ar^{8+}*, 2 × 2 mm analyzer slits,*
1 kV source HV, using different HV power supplies
(~2 mA current drain)

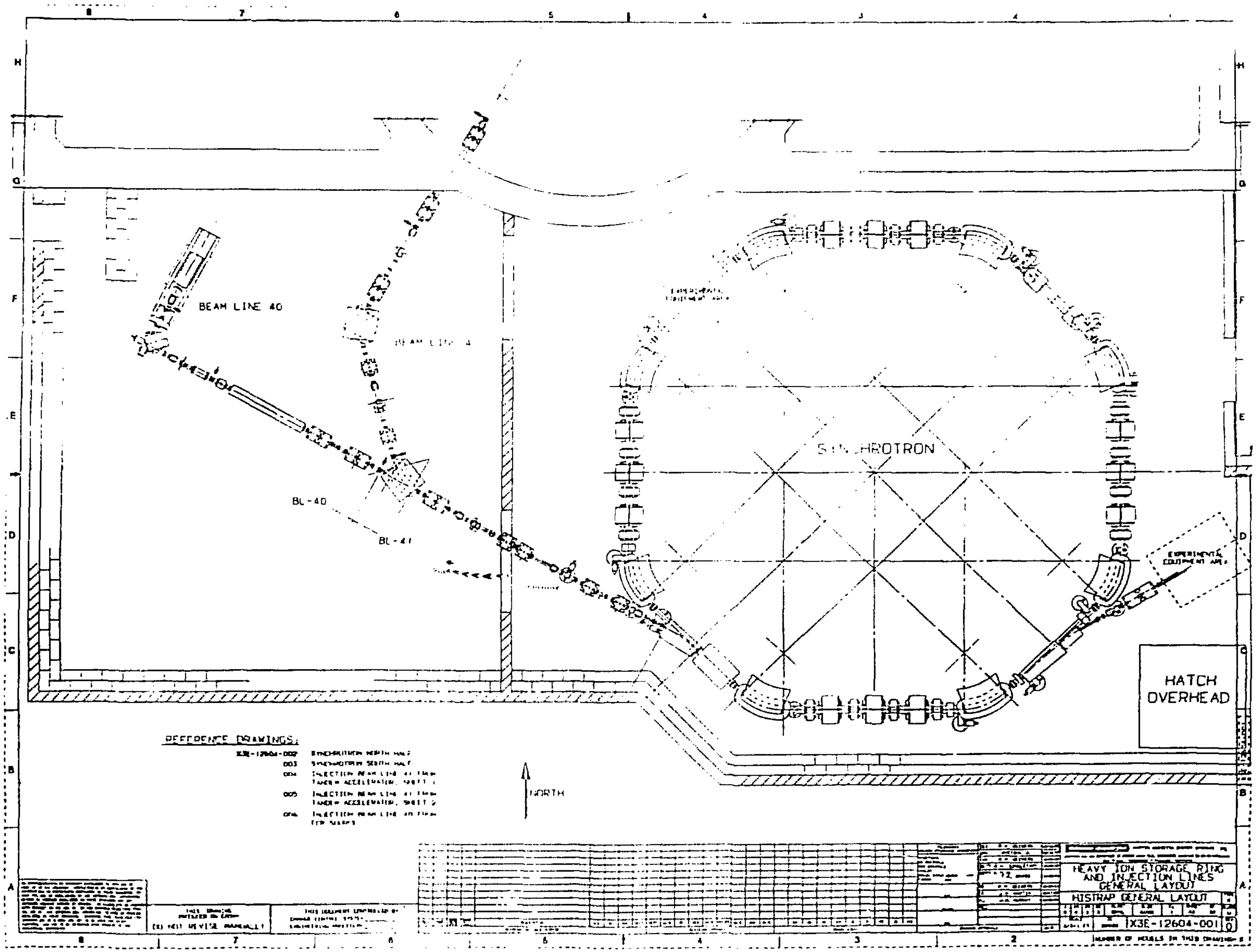
FWHM instrumental width $\Delta B_{inst} = \frac{aB}{\ell}$, where a is the slit width (2 mm)
ℓ is the object dist. (800 mm)
B is the magnetic field (273 G)

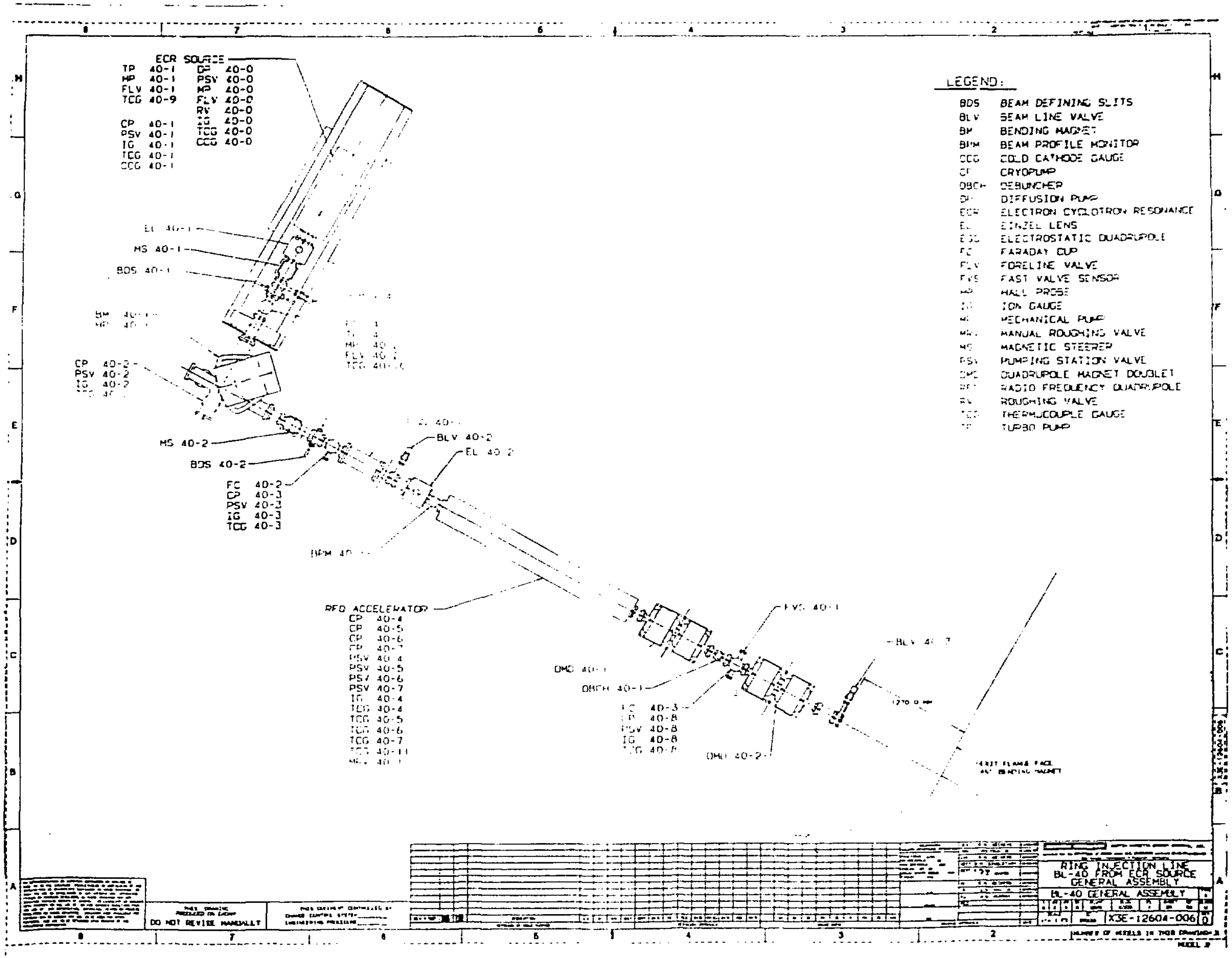
$$= 0.683 \text{ G}$$

FWHM due to source $\Delta B_S = \sqrt{(\Delta B_{meas})^2 - (\Delta B_{inst})^2}$ assuming Gaussian profiles.

Source energy spread/charge $\Delta E/q = 2 \times eV \times \Delta B_{S/B} \cong 5$ eV using Fluke supply.

Note: This value represents upper limit on energy spread of extracted ions.


BEAM LINE 40
BEAM LINE 4
BL-40
BL-41
SYNCHROTRON
EXPERIMENTAL EQUIPMENT AREA
EXPERIMENTAL EQUIPMENT AREA
HATCH OVERHEAD
NORTH
REFERENCE DRAWINGS:
X3E-12604-002 SYNCHROTRON NORTH HALF
003 SYNCHROTRON SOUTH HALF
004 INJECTION BEAM LINE 41 FROM TANDEM ACCELERATOR, SHEET 1
005 INJECTION BEAM LINE 41 FROM TANDEM ACCELERATOR, SHEET 2
006 INJECTION BEAM LINE 40 FROM ECR SOURCE
HEAVY ION STORAGE RING AND INJECTION LINES GENERAL LAYOUT
HISTRAP GENERAL LAYOUT
X3E-12604-001
0
(E) 1 REVISE MANUALLY
8
7
6
5
4
3
2
1
H
G
F
E
D
C
B
A


ECR SOURCE
TP 40-1
MP 40-1
FLV 40-1
TCG 40-9
CP 40-0
PSV 40-0
MP 40-0
FLV 40-0
RV 40-0
IG 40-0
TCG 40-0
CCG 40-0
CP 40-1
PSV 40-1
IG 40-1
TCG 40-1
CCG 40-1
EL 40-1
MS 40-1
BDS 40-1
BM 40-1
HP 40-1
CP 40-2
PSV 40-2
IG 40-2
MP 40-1
FLV 40-1
MS 40-2
BDS 40-2
BLV 40-2
EL 40-2
FC 40-2
CP 40-3
PSV 40-3
IG 40-3
TCG 40-3
BPM 40
RFQ ACCELERATOR
CP 40-4
CP 40-5
CP 40-6
CP 40-7
PSV 40-4
PSV 40-5
PSV 40-6
PSV 40-7
IG 40-4
TCG 40-4
TCG 40-5
TCG 40-6
TCG 40-7
TCG 40-11
MRV 40-1
QMD 40-1
DBCH 40-1
FC 40-3
CP 40-8
PSV 40-8
IG 40-8
TCG 40-8
FVS 40-1
QMD 40-2
BLV 40-3
1270.0 mm
EXIT FLANGE FACE AT BENDING MAGNET
LEGEND:
BDS BEAM DEFINING SLITS
BLV BEAM LINE VALVE
BM BENDING MAGNET
BPM BEAM PROFILE MONITOR
CCG COLD CATHODE GAUGE
CP CRYOPUMP
DBCH DEBUNCHER
DP DIFFUSION PUMP
ECR ELECTRON CYCLOTRON RESONANCE
EL EINZEL LENS
ESQ ELECTROSTATIC QUADRUPOLE
FC FARADAY CUP
FLV FORELINE VALVE
FVS FAST VALVE SENSOR
HP HALL PROBE
IG ION GAUGE
MP MECHANICAL PUMP
MRV MANUAL ROUGHING VALVE
MS MAGNETIC STEERER
PSV PUMPING STATION VALVE
QMD QUADRUPOLE MAGNET DOUBLET
RFQ RADIO FREQUENCY QUADRUPOLE
RV ROUGHING VALVE
TCG THERMOCOUPLE GAUGE
TP TURBO PUMP
RING INJECTION LINE
BL-40 FROM ECR SOURCE
GENERAL ASSEMBLY
BL-40 GENERAL ASSEMBLY
X3E-12604-006
DO NOT REVISE MANUALLY
A
B
C
D
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H
1
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3
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Fig. 6

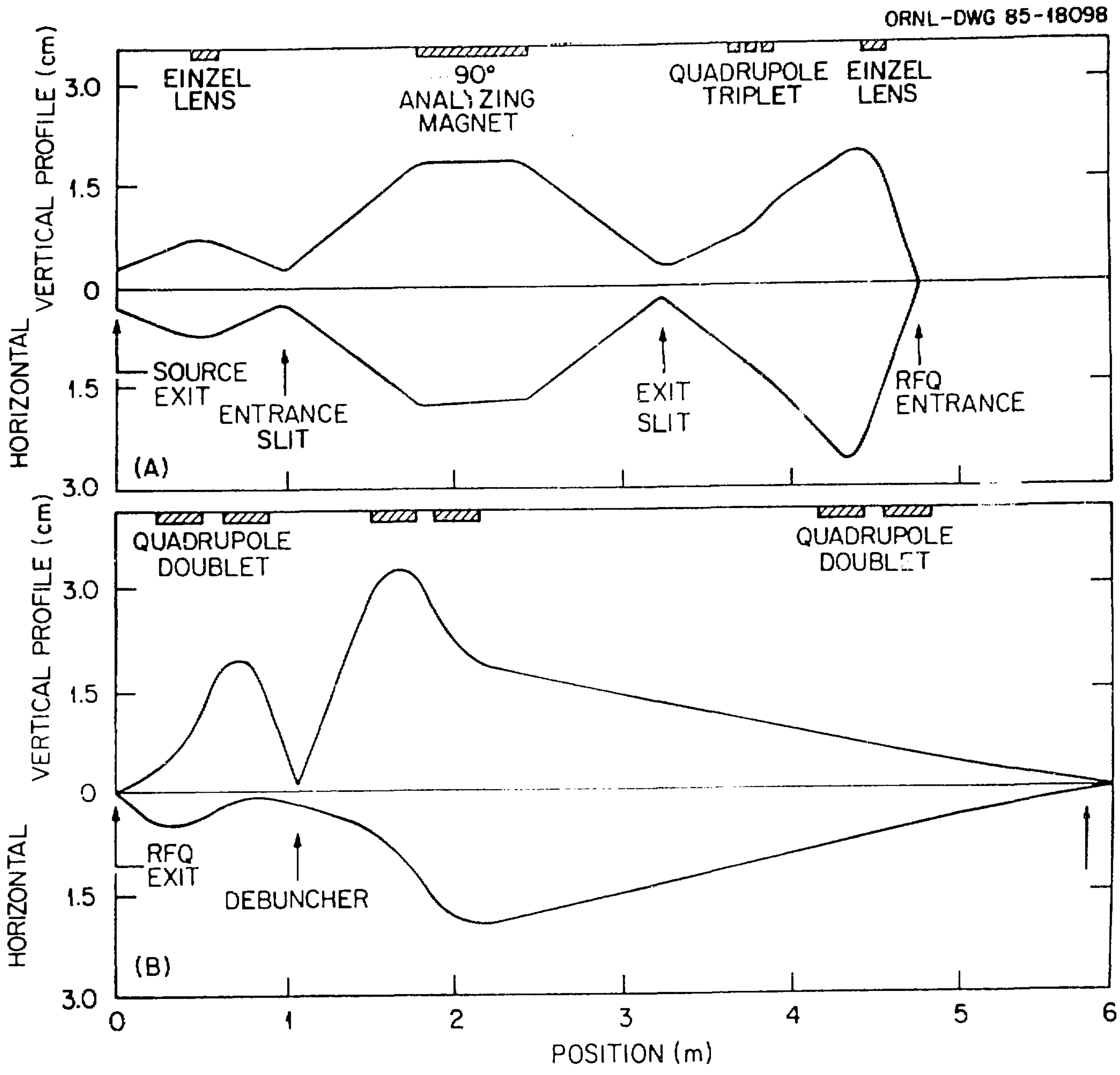
ORNL-DWG 85-18098
VERTICAL PROFILE (cm)
HORIZONTAL
3.0
1.5
0
1.5
3.0
EINZEL LENS
90° ANALYZING MAGNET
QUADRUPOLE TRIPLET
EINZEL LENS
SOURCE EXIT
ENTRANCE SLIT
EXIT SLIT
RFQ ENTRANCE
(A)
VERTICAL PROFILE (cm)
HORIZONTAL
3.0
1.5
0
1.5
3.0
QUADRUPOLE DOUBLET
QUADRUPOLE DOUBLET
RFQ EXIT
DEBUNCHER
(B)
0
1
2
3
4
5
6
POSITION (m)

Fig. 7