Title

Proceedings of Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source Part II

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Proceedings of the Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source: Part 2 Workshop Presentations

October 24-26, 1994

Editors: Lee Schroeder, Ka-Ngo Leung and Jose Alonso

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

MASTER

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Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source

Lawrence Berkeley Laboratory
Berkeley, CA

October 24 - 26, 1994

As part of the LBL Pulsed Spallation Source (PSS) Study activity, this workshop was convened to address the present status of ion source technology with respect to the next generation PSS' in the 1-5 MW range for the neutron scattering community. As there is clearly an intimate coupling between the ion source and the LEBT (Low Energy Beam Transport system), throughout the Workshop considerations of LEBT parameters and designs were included in the discussions. We first addressed the ion source requirements for each of the accelerator-based spallation sources, then heard reports of actually-achieved performance for different ion sources. An assessment between requirements and performance was carried out, resulting in a determination of R&D activities that would be required to bridge this gap.

Proceedings from this Workshop are divided into two parts: Part I providing a summary of the Workshop, with assessments of technology, required R&D and recommendations for further activities. Part II, this volume, collects the presentations made by the participants of the Workshop.

This collection of "Vu-Graphs" is divided into five sections, corresponding to each of the sessions at which presentations were made.

In Session I we heard presentations about each of the currently proposed pulsed spallation sources, as well as data from ISIS, currently the world's highest power pulsed spallation source, and SINQ, the accelerator-based CW source soon to come on line in Switzerland. Included in this collection is a brief description of the AUSTRON project, contributed by M. Regler who could not attend the Workshop, but provided this input.

Session II includes presentations on Penning and magnetron sources for negative-ion production. Presentations in Session III dealt with H^- volume sources. Session IV collected reports on positive ion sources, both pulsed and CW. Session V was devoted to LEBT considerations, as well as to the problems of low-energy beam chopping to ensure minimum beam losses at high energies.

Three days of very fruitful and productive discussions have led to this collection of reports, and the summaries found in Part I of these Proceedings. The Organizers wish to express their gratitude to the participants of the Workshop for their excellent contributions.

Jose R. Alonso　　Ka-Ngo Leung　　Lee S. Schroeder

Berkeley, CA
November 8, 1994.

Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source

AGENDA

SITE: Bldg 4 Room 102

Monday, October 24, 1994

9:00	Welcomes, logistics	Schroeder, Alonso, Leung

Morning Session: (9:15 - 12:00, 15 min break at 10:30)
Chairman L. Schroeder

Requirements for Ion Source Performance (Descriptions of operating and planned facilities, tabulation of source-performance requirements)

Talks:	ISIS	C. Planner	Rutherford Appleton Lab
	SINQ	M. Olivo	Paul Scherer Institute
	ESS	H. Klein	Univ. Frankfurt
	BTA	H. Oguri	JAERI
	LANSCE II	A. Jason	LANL
	IPNS II	Y. Cho	Argonne
	Brookhaven proposal	J. Alessi	BNL

Lunch (12:00 - 1:00) LBL Cafeteria

Tour of ALS (1:00 - 2:00), Roderich Keller, guide

Afternoon Session: (2:00 - 5:00, 15 min break at 3:00)
Chairman A. Jason

Ion Source Technologies I: Negative Ions, Penning, Magnetron and Surface sources (Descriptions of technologies, tabulation of performance obtainable with current state of the art)

Talks:	Penning Sources for LANSCE II	V. Smith	LANL
	Penning sources for ISIS	R. Sidlow	RAL
	Penning Source Development for ESS	C. Planner	RAL
	BNL Magnetron sources	J. Alessi	BNL

Tuesday, October 25, 1994

8:30	Recapitulation of yesterday's material	J. Alonso

Morning Session: (8:45 - 12:00, 15 min break at 10:30)
Chairman H. Klein

Ion Source Technologies II: Volume sources, (mostly) negative ion, (Descriptions of technologies, tabulation of performance obtainable with current state of the art)

Talks:	Volume sources at TRIUMF	P. Schmor	TRIUMF
	Volume sources at BNL	J. Alessi	BNL
	Volume sources for LANSCE II	R. York	LANL
	Volume sources at LBL	K. Leung	LBL
	RF Volume source R&D at Grumman	S. Melnychuk	Grumman
	SSC volume source performance	K. Saadatmand	SSCL
	Volume H^- sources for ESS	K. Volk	U. Frankfurt

Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source

AGENDA

SITE: Bldg 4 Room 102

Afternoon Session I: (1:00 - 3:00) Positive Ion Sources
Chairman C. Planner

Talks:			
	A high brightness hydrogen ion source for the BTA	H. Oguri	JAERI
	Positive ion source work at LBL	L. Perkins	LBL
	Volume sources at PSI	M. Olivo	PSI
	Proton Ion Sources for LANSCE II	R. Stevens	LANL
	CRL Microwave Source	R. Stevens	LANL

Afternoon Session II: (3:15 - 5:00) LEBT / Chopping considerations
Chairman Y. Cho

Talks:			
	Experience with fast beam chopping at low energies	J. Alessi	BNL
	Travelling-wave choppers for LANSCE II	R. Stevens	LANL
	Beam chopping in the ion source - prelim. expts	V. Smith	LANL
	LEBT: advantages and problems of space charge compensation	J. Pozimski	U. Frankfurt
	Transport of high brightness beams	C. Chan	LBL
	A Frankfurt Electrostatic Injection system	M. Sarstedt	U. Frankfurt

Evening Session (7:00 - 10:00) Mandarin Garden Restaurant, Berkeley

Wednesday, October 26, 1994

9:00 Recapitulation of material covered — J. Alonso

Morning Session I (9:15 - 10:15) Comparison of "Requirements" and "Performance"
Discussion Leader K-N Leung

Discussions

Morning Session II (10:30 - 12:00) Generation of Recommendations
Discussion Leader J. Alonso

Discussions:
- Summary of technology evaluations and comparisons
- Proposed R&D programs

Afternoon Session (1:00 - 3:00) Preparation of Report
Discussion Leader L. Schroeder

- Preparation of report outline
- Incorporation of material generated during Workshop
- Agreement on summary conclusions and recommendations

Closing Remarks — **W. Barletta**

ADJOURN 3:00

Participants

Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source

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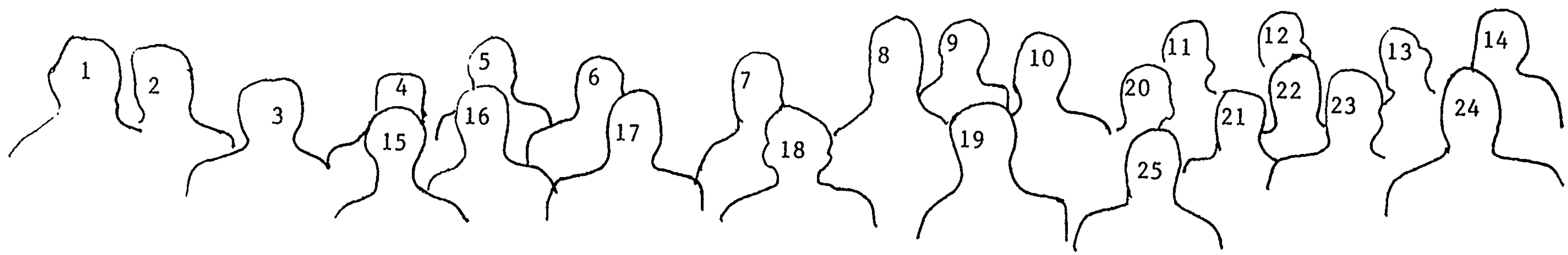
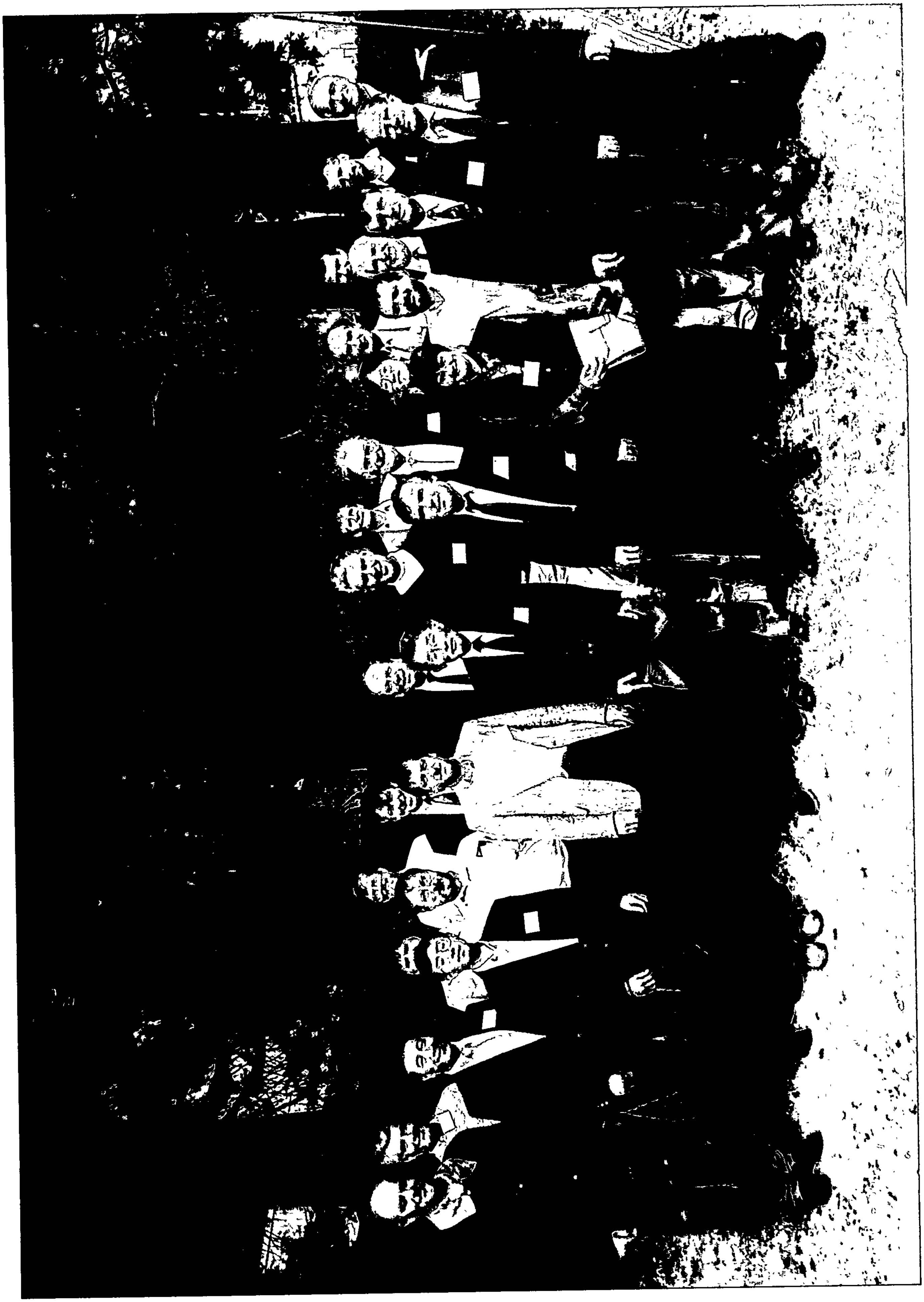


1. Klaus Volk
2. Roderich Keller
3. Ka-Ngo Leung
4. Rob York
5. Vernon Smith
6. Steve Melynchuck
7. Alan Todd
8. John Staples
9. Reginald Sidlow
10. Ralph Stevens, Jr.
11. Charles Planner
12. Luke Perkins
13. Juergen Pozimski
14. Jose Alonso
15. Yong-Chol Chae
16. Paul Schmor
17. James Alessi
18. Yanglai Cho
19. Andrew Jason
20. Hidetomo Oguri
21. Kourosh Saadatmand
22. Lee Schroeder
23. Miguel Olivo
24. Horst Klein
25. Margit Sarstedt



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Berkeley, CA

October 24-26, 1994

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Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source: Part 2 Workshop Presentations

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ISIS

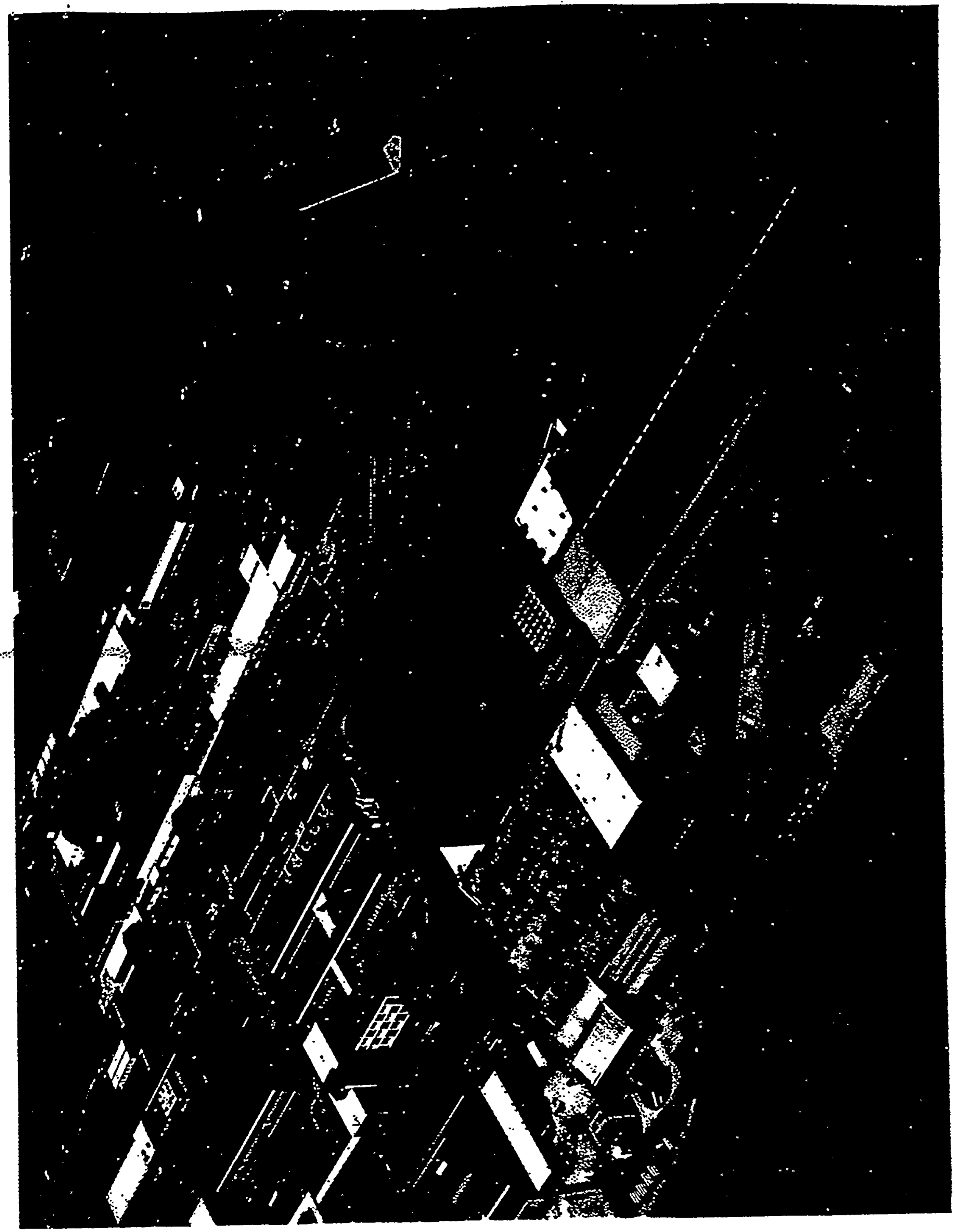
C. W. Planner

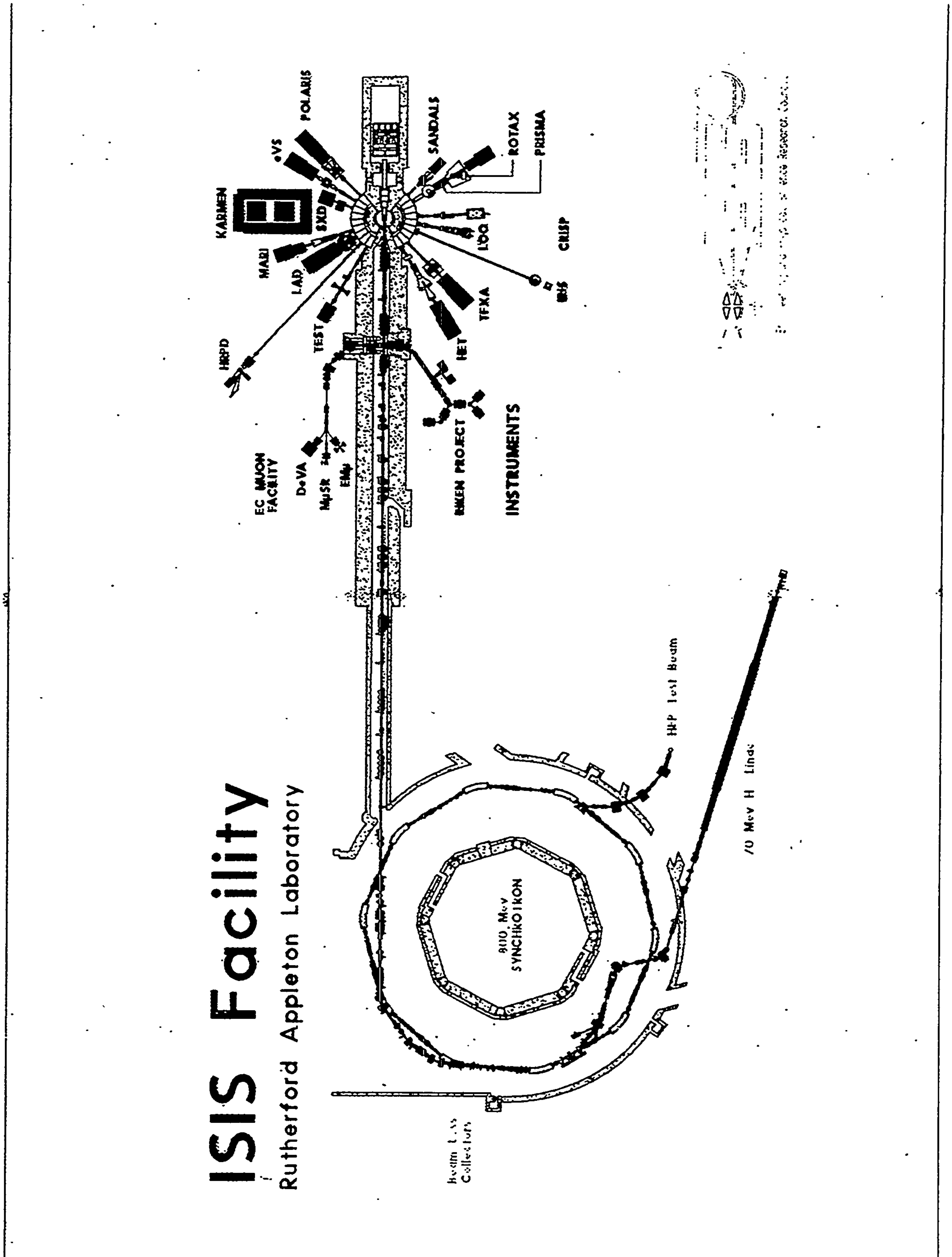
Rutherford Appleton Laboratory

ISIS

C. W. PLANNER.

RUTHERFORD APPLETON LABORATORY.

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Rutherford Appleton Laboratory
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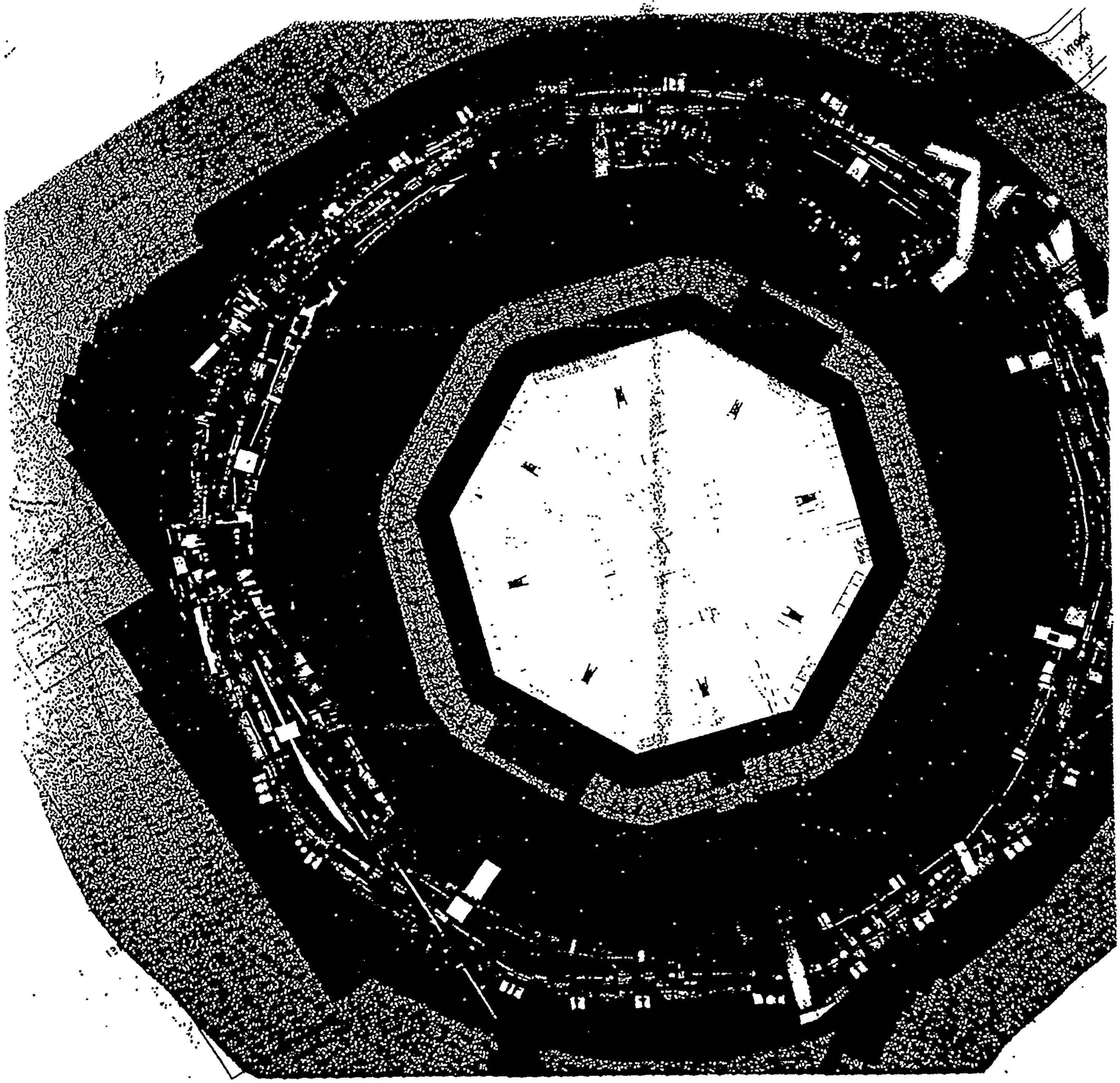
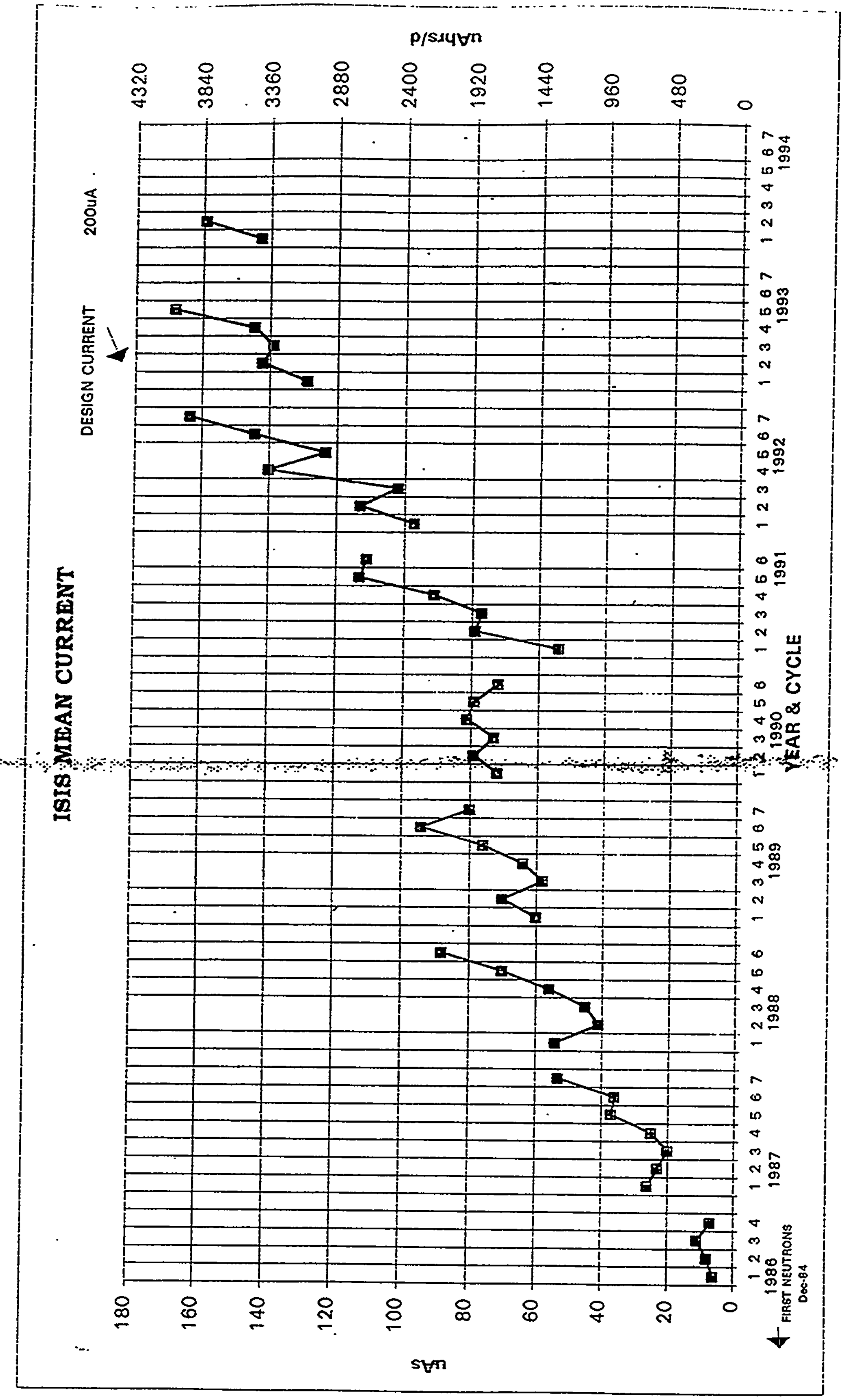
RIKEN PROJECT
INSTRUMENTS
800 MeV SYNCHROTRON
HEP Test Beam
70 MeV H Linac
Beam Loss Collectors

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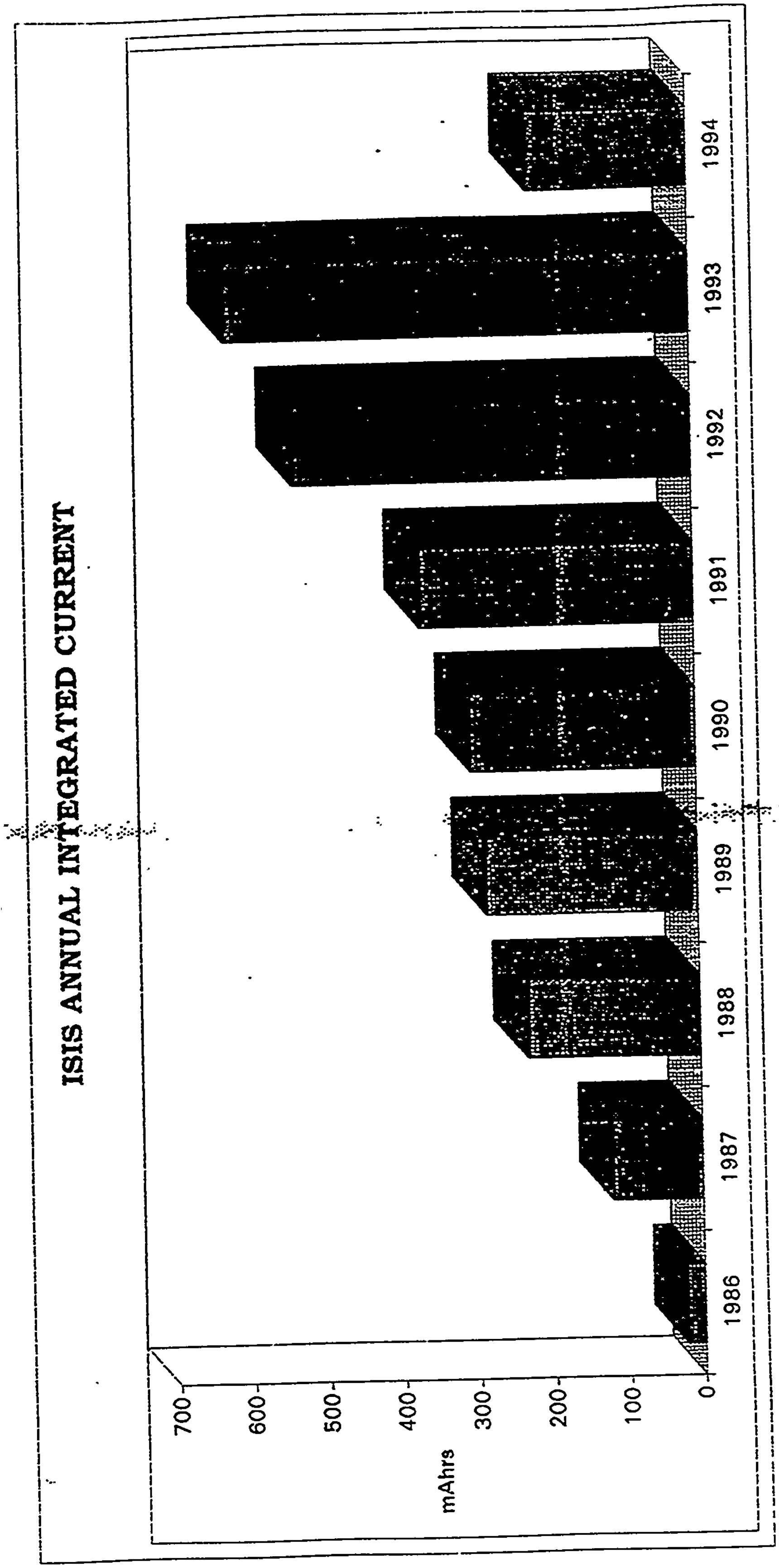
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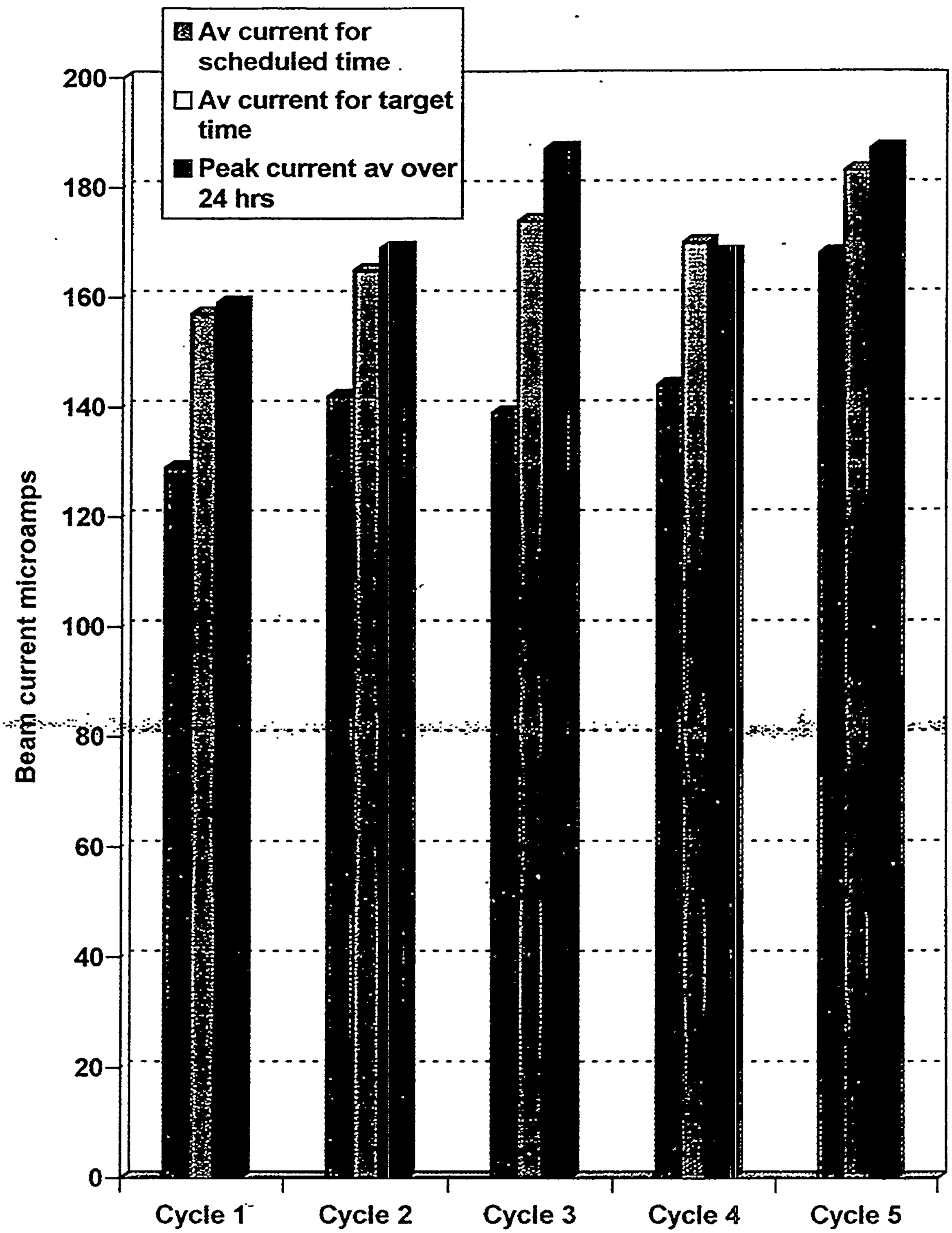
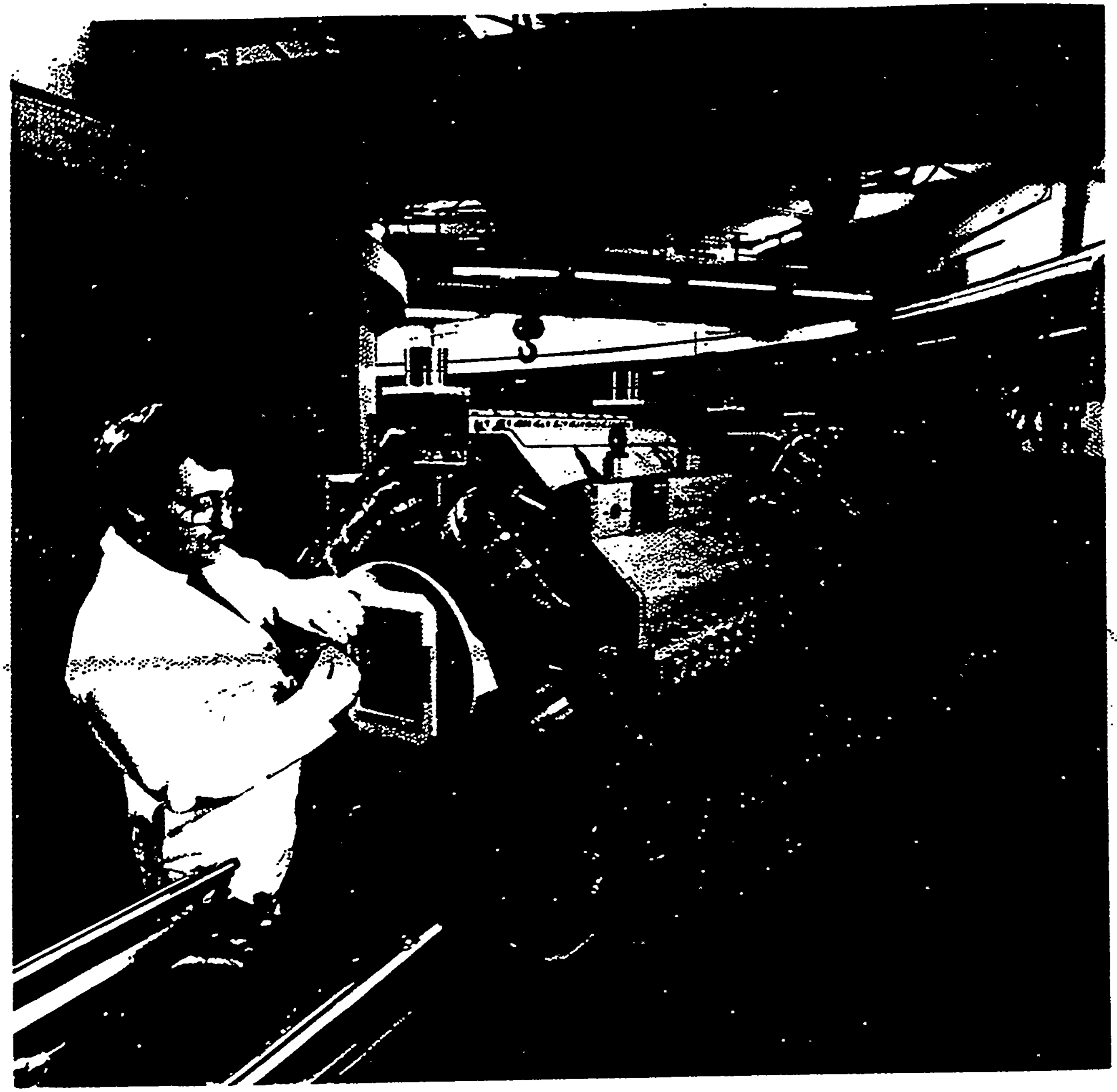
ISIS OPERATIONS 1993 Allocation Year





Features

- Injector

  - H^- Penning ion-source + 665 keV Preinjector + Bouncer
  - Single buncher and a Debuncher
  - 70 MeV Drift-tube Linac operating at 50 Hz - transmission 62%

- 50 Hz Proton Synchrotron.

- Design Intensity 200 μA - reached Feb. 1993.

- Hybrid lattice - Combined function + Separated function + Fast correction elements (dipoles, quadrupoles, sextupoles, octupoles).

- Multi-turn charge exchange injection.
  Up to 250 turns injected through an Aluminium Oxide stripping foil.
  Injection efficiency 97-98% at maximum intensity
  Painting large emittances in both transverse phase planes.
  Painting correlates large amplitude betatron oscillations in one plane with small amplitude in the other.

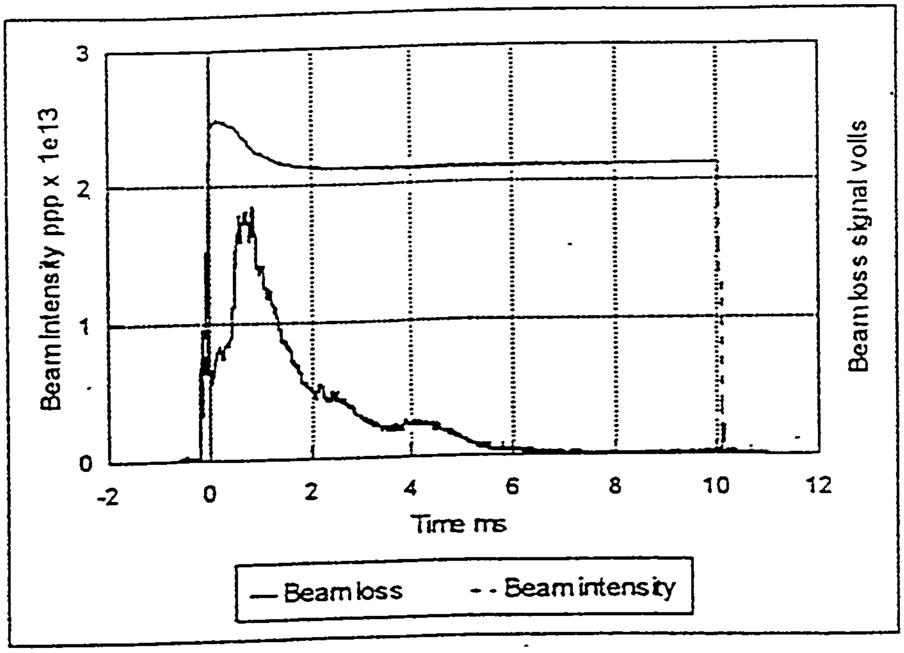
- RF System - operates at Harmonic number 2 - two bunches in ring.
  Coasting beam injected, but RF is on at low level during injection.
  'Adiabatic' trapping efficiency ~90%.
  Beam compensation - feed forward.

- All magnets have Ceramic vacuum chambers with RF inter shields.
  Allows fast correction of betatron tunes and closed orbits throughout injection, trapp and acceleration.
  Multipoles - sextupoles and octupoles - not effective in increasing intensity.

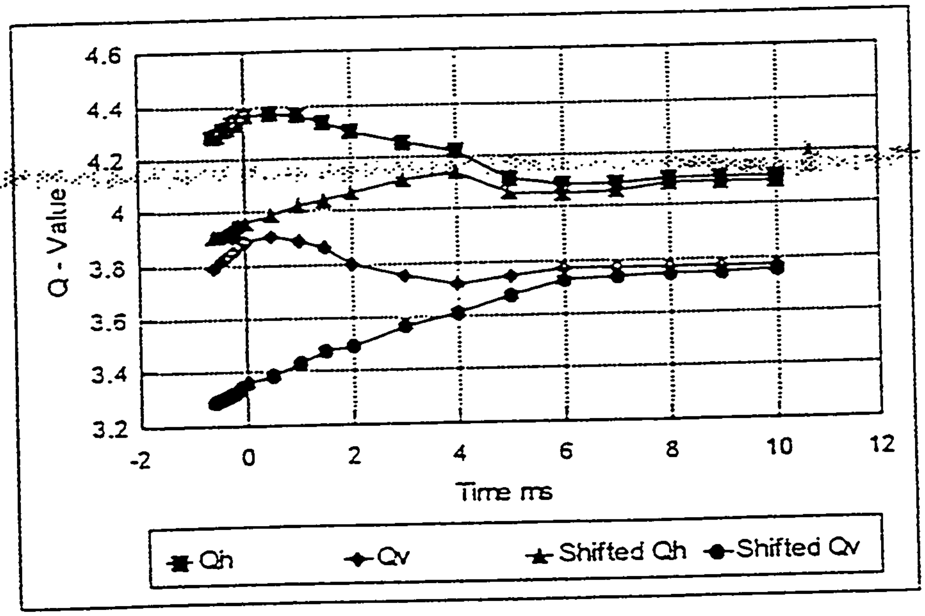
- Beam loss collection system fitted.
  Confines beam loss to special collectors in tenth of ring azimuth.
  Beam loss:

  unstripped H^0 at injection
  untrapped beam just after injection(low energy)

- Extraction.
  Fast extraction of both bunches in a single turn.
  Extraction Efficiency 100% -1 part in 10^4.



Beam Intensity and beam loss monitors sum signal during acceleration



Q-value variation with time for low intensity beam
and maximum incoherent tune shift due to space charge.

THU 04 FEB 1993 15:42:04 REP. RATE = 50 Hz

ISIS PROTON BEAM INTENSITY X 1E13

IHT5		2.59	
R5IM	0 mS	2.54	
R5IM	2.5 mS	2.28	
R5IM	9.5 mS	2.26	
EIM1		2.26	
EIM2		2.26	
EIM3		2.26	
EIM4		2.27	
EIM5		2.28	
EIM6		2.24	179.44 MICROAMPS

INJECTION EFFICIENCY %	97.97	
TRAPPING EFFICIENCY %	89.70	
ACCELERATION EFFICIENCY %	99.23	
EXTRACTION EFFICIENCY %	99.05	Includes 1% loss to muon target.

FRI 05 FEB 1993 21:40:57 REP. RATE = 50 Hz

ISIS PROTON BEAM INTENSITY X 1E13

IHT5		3.05	
R5IM	0 mS	2.94	
R5IM	2.5 mS	2.53	
R5IM	9.5 mS	2.52	
EIM1		2.51	
EIM2		2.51	
EIM3		2.50	
EIM4		2.52	
EIM5		2.54	
EIM6		2.52	201.66 MICROAMPS

INJECTION EFFICIENCY %	96.60
TRAPPING EFFICIENCY %	85.87
ACCELERATION EFFICIENCY %	99.54
EXTRACTION EFFICIENCY %	100.08

ISIS FUTURE DEVELOPMENT

- ADDITIONAL TARGET STATION
  OPTMISED FOR 10Hz OPERATION.

- TWO HARMONIC ACCELERATION
  INCREASE INTENSITY TO 300μA

- REPLACE PRE-INJECTOR WITH RFQ
  665KV PRE-INJECTOR OBSOLETE - SPARES
  DIFFICULT TO GET.

- IMPROVE ACCESS FOR CHANGING ION-SOURCE.
  REDUCE DEMAND ON ION SOURCE.

EXPERIMENTS ALSO TAKING PLACE FOR DEVELOPMENT OF RADIO ACTIVE ION BEAM TARGETS.

- ISIS - Penning source - slit aperture
  - unequal emittances in the transverse phase planes

POSSIBLE TO MATCH UNEQUAL TRANSVERSE EMITTANCES FROM AN H⁻ ION-SOURCE INTO A RFQ USING MORE THAN TWO SOLENOIDS

(to be published in Particle Accelerators)

- **SOLENOID TRANSFORMATION MATRIX**

$$[s] = \begin{bmatrix} C & 0 & S & 0 \\ 0 & C & 0 & S \\ -S & 0 & C & 0 \\ 0 & -S & 0 & C \end{bmatrix} \begin{bmatrix} C & S/K & 0 & 0 \\ -KS & C & 0 & 0 \\ 0 & 0 & C & S/K \\ 0 & 0 & -KS & C \end{bmatrix}$$

L = effective length of solenoid

$$K = \frac{B_0}{2B\rho} = \frac{\text{field inside solenoid}}{2 \times \text{momentum / electronic charge}}$$

$C = \cos(KL)$

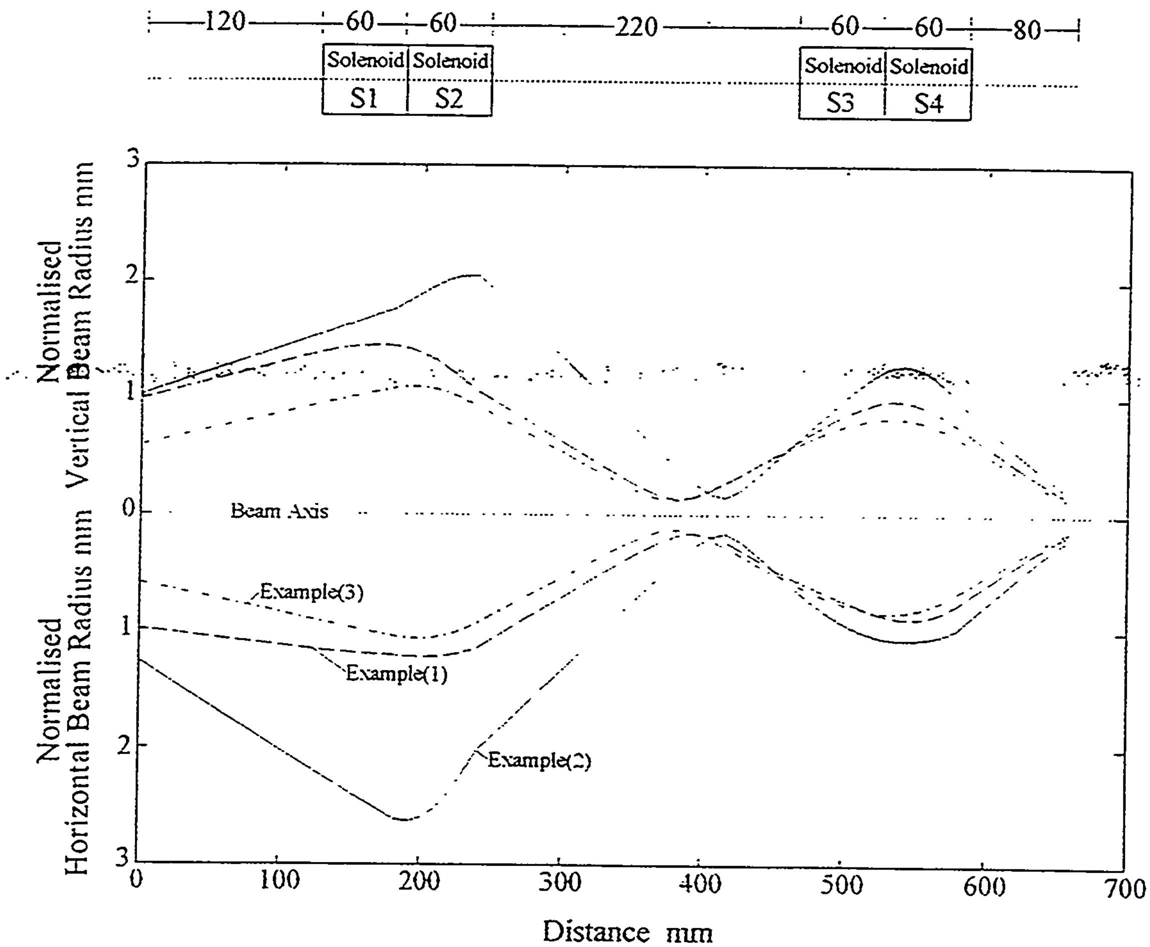
$S = \sin(KL)$

- **ROTATION PRODUCES EMITTANCE TRANSFORMATION**

$$\varepsilon_{x_1}{}^2 = \varepsilon_{x_0}{}^2 C^4 + \varepsilon_{y_0}{}^2 S^4 + \varepsilon_{x_0}\varepsilon_{y_0} C^2 S^2 \left(\gamma_{y_0}\beta_{x_0} + \gamma_{x_0}\beta_{y_0} - 2\alpha_{x_0}\alpha_{y_0}\right)$$

$$\varepsilon_{y_1}{}^2 = \varepsilon_{x_0}{}^2 S^4 + \varepsilon_{y_0}{}^2 C^4 + \varepsilon_{x_0}\varepsilon_{y_0} C^2 S^2 \left(\gamma_{y_0}\beta_{x_0} + \gamma_{x_0}\beta_{y_0} - 2\alpha_{x_0}\alpha_{y_0}\right)$$

Parameter	Example 1 ref. 18 Penning source		Example 2 ref. 14 Magnetron source		Example 3 ref. 15 Magnetron source	
	Initial	Final	Initial	Final	Initial	Final
α_x	-13.9212	**0.569**	-6.327	**0.569**	-1.4045	**0.569**
β_x m	9.6677	**0.0206**	1.057	**0.0206**	0.349	**0.0206**
$(\varepsilon_x)_n$ µm rad	0.1	**1.106**	1.5	**1.81**	1.0	**0.83**
$\hat{x}$ mm	12.5	1.92	16.0	2.45	7.5	1.67
$\hat{x}'$ mrad	18.0	107.03	97.0	137.03	37.0	93.13
α_y	-3.1136	**0.569**	-4.147	**0.569**	-2.589	**0.569**
β_y m	0.9733	**0.0206**	1.046	**0.0206**	0.562	**0.0206**
$(\varepsilon_y)_n$ µm rad	1.0	**1.106**	1.0	**1.81**	0.62	**0.83**
$\hat{y}$ mm	12.5	1.92	13.0	2.45	7.5	1.67
$\hat{y}'$ mrad	42.0	107.03	53.0	137.03	37.0	93.13



Beam profiles for three examples using four solenoids to match to a RFQ, starting with unequal initial emittances.

Targets

- Spallation Target

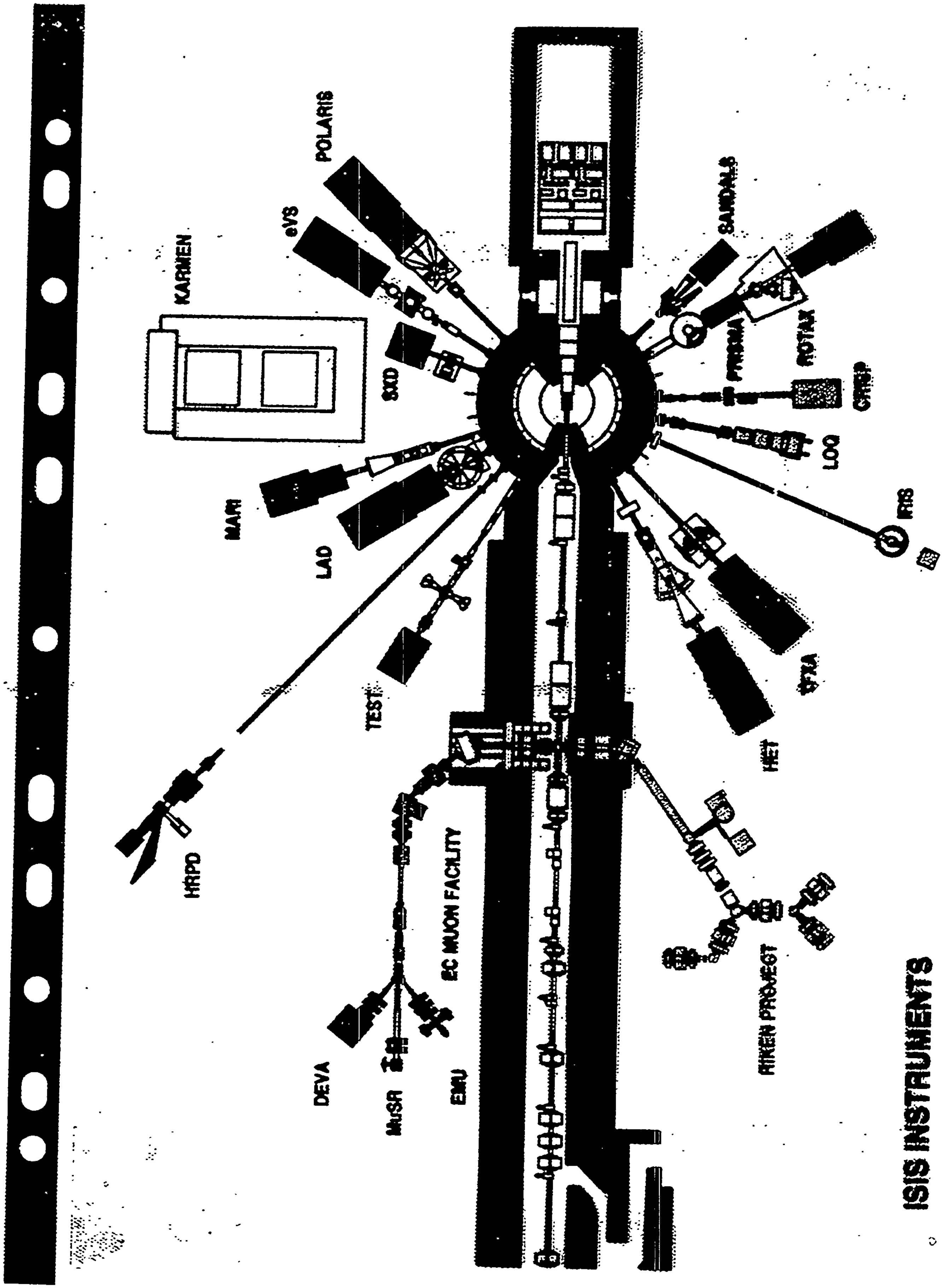
Beam Power 160 kW
Zircaloy-2 clad Uranium or Tantalum
4 'Wing' moderators with decouplers surrounded by a reflector.
(2 ambient and 2 cold(liquid methane and para hydrogen))
14 instruments installed + neutrino experiment

- Muon Target

Graphite transmission target - surface muon production μ^+ and μ^-
Also π production for a decay channel
Two experimental areas installed

- Internal Target in Synchrotron

Target 'dipped' into edge of beam to produce secondary particles for calibration of detectors developed at RAL for High Energy Physics experiments


POLARIS
eVS
KARMEN
SXD
MARI
LAD
TEST
HRPD
EC MUON FACILITY
DEVA
MuSR
EMU
SANDALS
PRISMA
ROTAX
CRISP
LOQ
IRIS
TFXA
HET
RIKEN PROJECT
ISIS INSTRUMENTS

ISIS TARGET PERFORMANCE SUMMARY TO 30/6/94

Target	Gross Thermal Cycles	Integrated Current mAh	Neutron Production mg
U#1	Not measured	92.4	75
U#2	40000	53.1	52
U#3	10389	174.9	163
U#4	4147	138.8	128
U#5	5074	295.6	273
U#6	2628	126.1	116
U#7	1805	107.2	99
Ta#1	73378	1751.6	1037
	Total	2740	1943

Requirements for Ion Source Performance for SINQ

M. Olivo

Paul Scherrer Institute

REQUIREMENTS FOR ION SOURCE PERFORMANCE FOR "SINQ"

MIGUEL OLIVO

PAUL SCHERRER INSTITUTE

PSI ION SOURCE

(OPERATIONAL VALUES FOR A 1.5 mA PROTON BEAM AT 72 MeV OR 1.0 mA AT 590 MeV)

MULTI-CUSP (CULHAM TYPE)

ARC CHAMBER: 10 cm × 10 cm × 10 cm Cu - H_2O COOLED

4 ROWS (PLUS BACK) OF 3.5 kG Sm-Co MAGNETS

4 (2×2) FILAMENTS W-1.5% ThO_2 ϕ1.5mm L=10cm (6V, 2×95

GAS FLOW: 3 sccm H_2 ; ARC CHAMBER PRESSURE: 4.7 mT

ARC DISCHARGE: 40 V, 24 A (TYPICALLY $1.5 \leq Z \leq 1.7\ \Omega$)

TETRODE EXTRACTION CONFIGURATION: 60 kV/52 kV/-2 kV

EXTRACTION APERTURE: ϕ 7mm ⇒ 0.38 cm²

TOTAL ION EXTRACTION CURRENT: 36 mA d.c. (95 mA/cm²,

H_1^+ = 12 mA (~33% PROTON EFFICIENCY)

~~H_1^+ = 8.6 mA THROUGH 810 kV ACC. TUBE~~

(3.4 mA LOST IN 60 keV B.T.S. COLLIMATORS)

NORMALIZED EMITTANCE [π mm mrad] [86%]

8.6 mA @ 60 keV (BEFORE TUBE) = 0.18
8.6 mA @ 870 keV (AFTER TUBE) = 0.30
8.1 mA @ 870 keV (AXIAL INJ. SYS TO INJ. II) = 0.50

(0.5 mA LOST ($H_2^+ + H_3^+$) IN 870 keV B.T.S.)

0.5 mA @ 72 MeV (B.T.S. TO RING) = 1.2
1.5 mA @ 72 MeV (B.T.S. TO 3mA, 72 MeV BEAM DUMP) = 5.0 (?)
1.0 mA @ 590 MeV (B.T.S. TO TARGETS) = 2.0

INJECTION INTO INJ. II:

$\Delta\phi \simeq 24°$ $B_f \simeq 3.7$ $\langle I \rangle = \frac{8.1 \times B_f \times \Delta\phi}{360} \simeq 2$ mA

$\langle I \rangle_{@72\,MeV}$ = 1.5 mA [0.5 mA LOST IN COLLIMATORS (v+h) IN FIRST 4 TURNS INJ. II]
($\Delta\phi \simeq 12° \equiv 0.7$ ns)

STATUS 1994

Inj.2: maximal beam current extracted 1.6mA

Ring: maximal beam current extracted 1.0mA

Note

- typical operation at 1mA
- beam loss detected by ionization chambers ca. 0.3μA (99.97 % TRANSMISS THROUGH THE RIN
- beam power 0.59MW
- RF data for the Ringcyclotron

	voltage	power wall	power beam	NEW R SYSTEM SINCE
cavity 1	730kV	300kW	150kW	1991
~~cavity 2~~	~~420kV~~*	~~100kW~~	~~80kW~~	
cavity 3	730kV	300kW	150kW	1993
cavity 4	730kV	300kW	150kW	1994
flattop	420kV	110kW	-60kW	1992

- energy gain is increased in order to reduce turn number and with this the effect of longitudinal space charge forces

1987/90 DEVELOPMENT OF A NEW 50 MHz R.F. AM (PSI DESIGN) 520 kW INTO CAVITY 800 kW INTO 50 Ω

* 1995 ⇒ 2.4 MeV/TURN (AVERAGE) ⇒ 214 TURNS

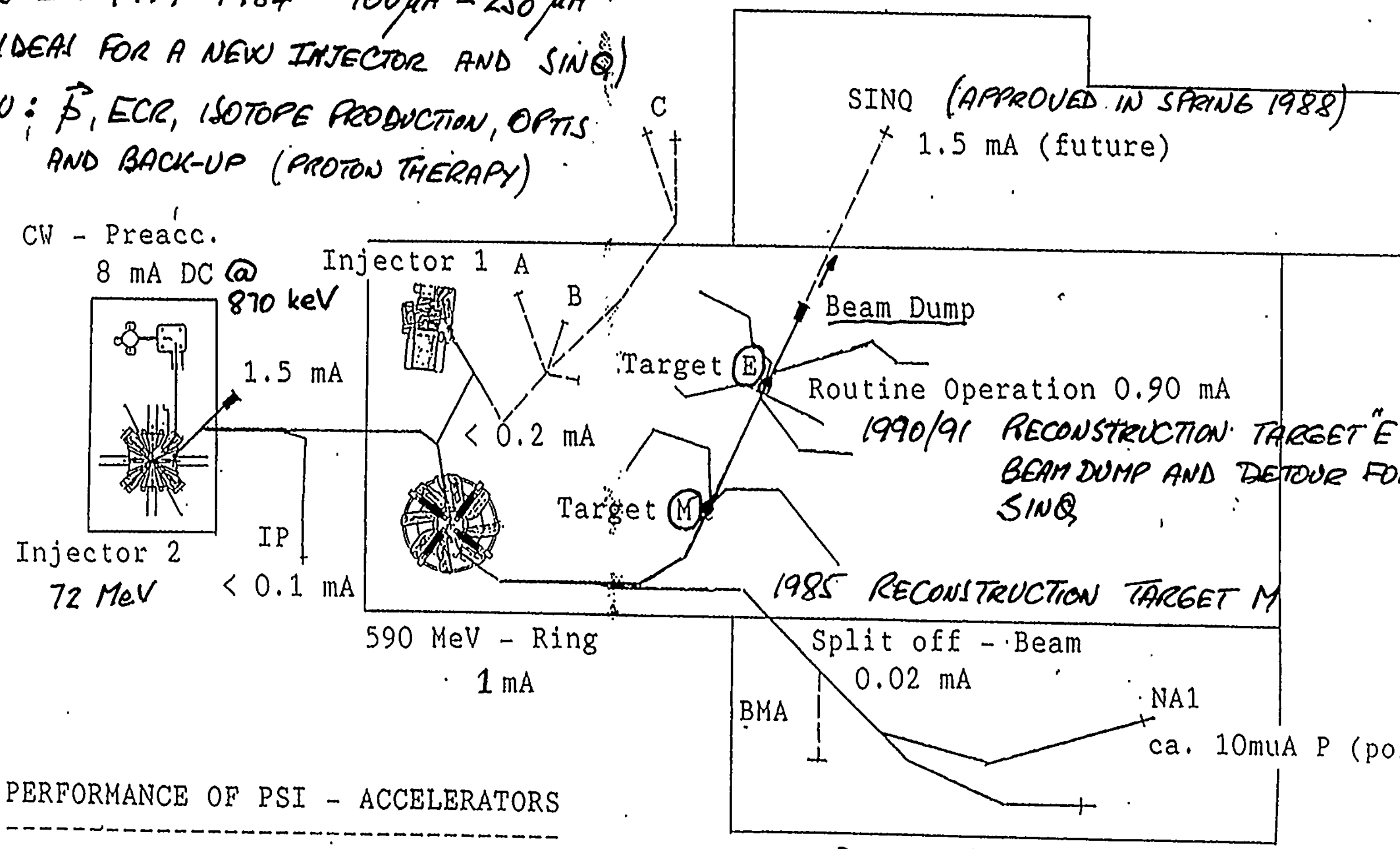
FUTURE: NEW Cu CAVITIES WITH PEAK VOLTAGE = 1 M
[Cu-SURFACE (INSTEAD OF Al) WILL INCREASE SHUNT IMPEDA FROM 850 kΩ TO > 1000 kΩ]

MESON FACILITY IN OPERATION SINCE 1974 (SIN)

INJ I : 1974-1984 100 μA - 250 μA

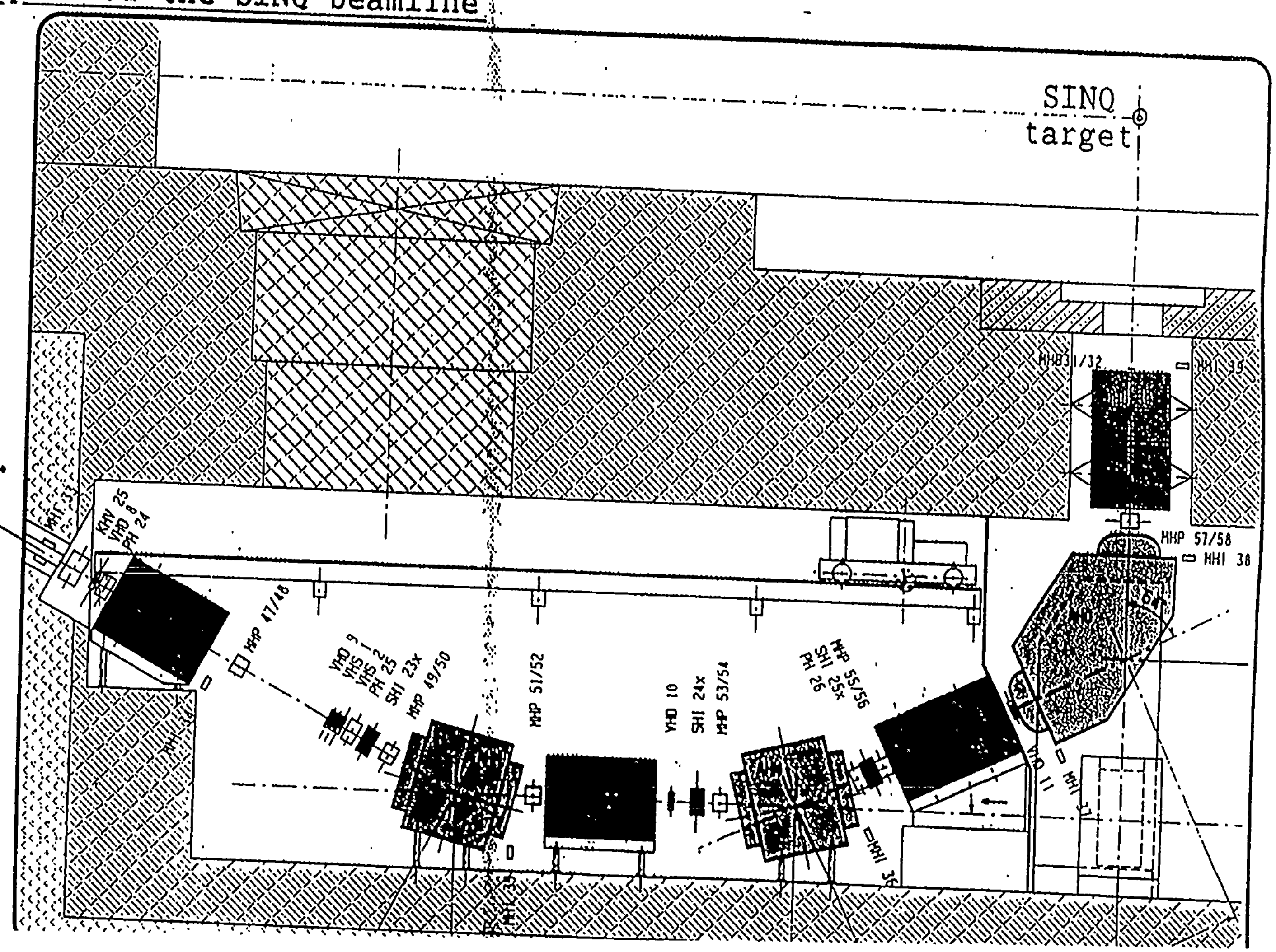
(IDEAL FOR A NEW INJECTOR AND SINQ)

NOW : $\vec{p}$, ECR, ISOTOPE PRODUCTION, OPTIS AND BACK-UP (PROTON THERAPY)



PERFORMANCE OF PSI - ACCELERATORS

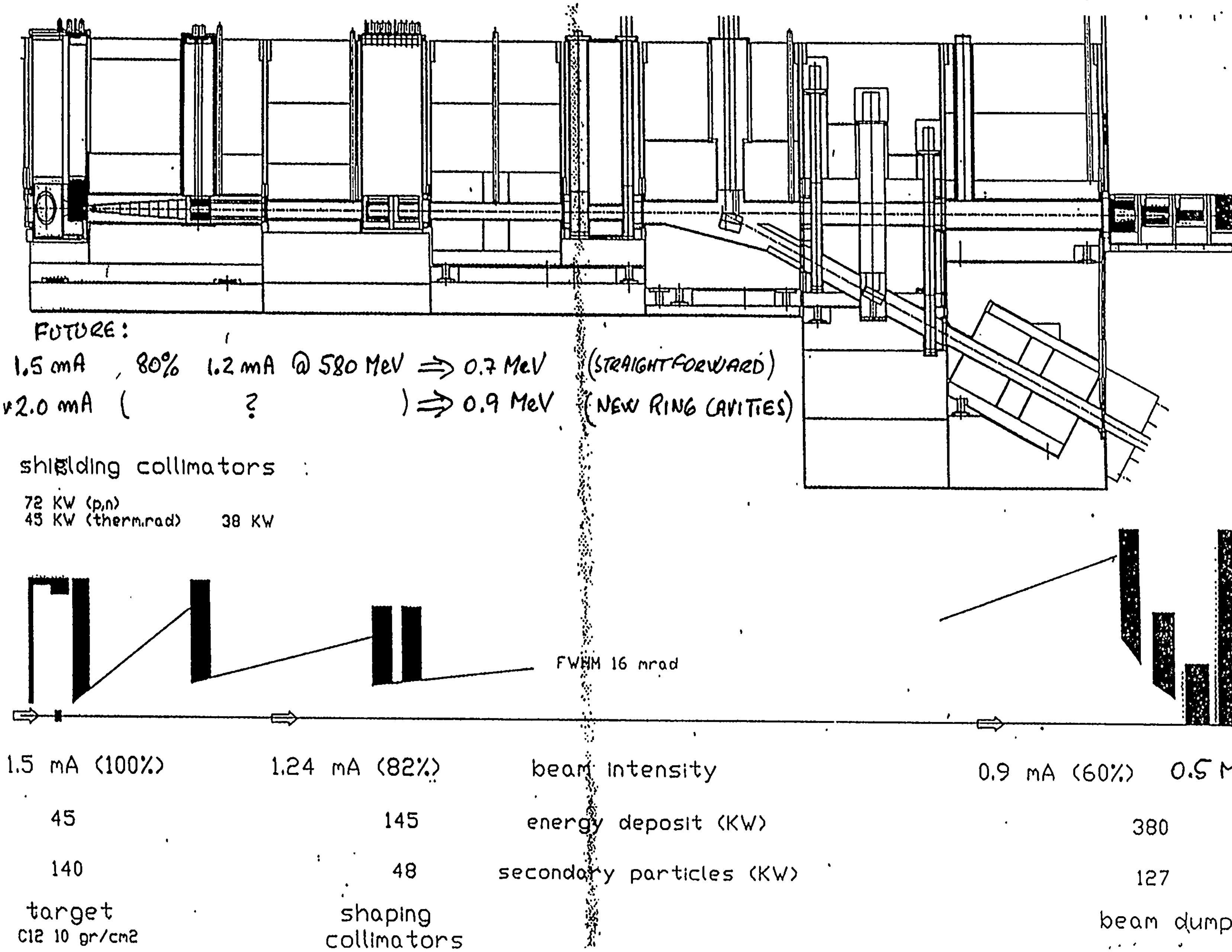
1992 NEW INJECTION AND EXTRACTION ELEMENTS FOR THE RING MACHINE vertical part of the SINQ beamline



beam from pion prod. traget

beamline aperture 200mm ø filled to 30%

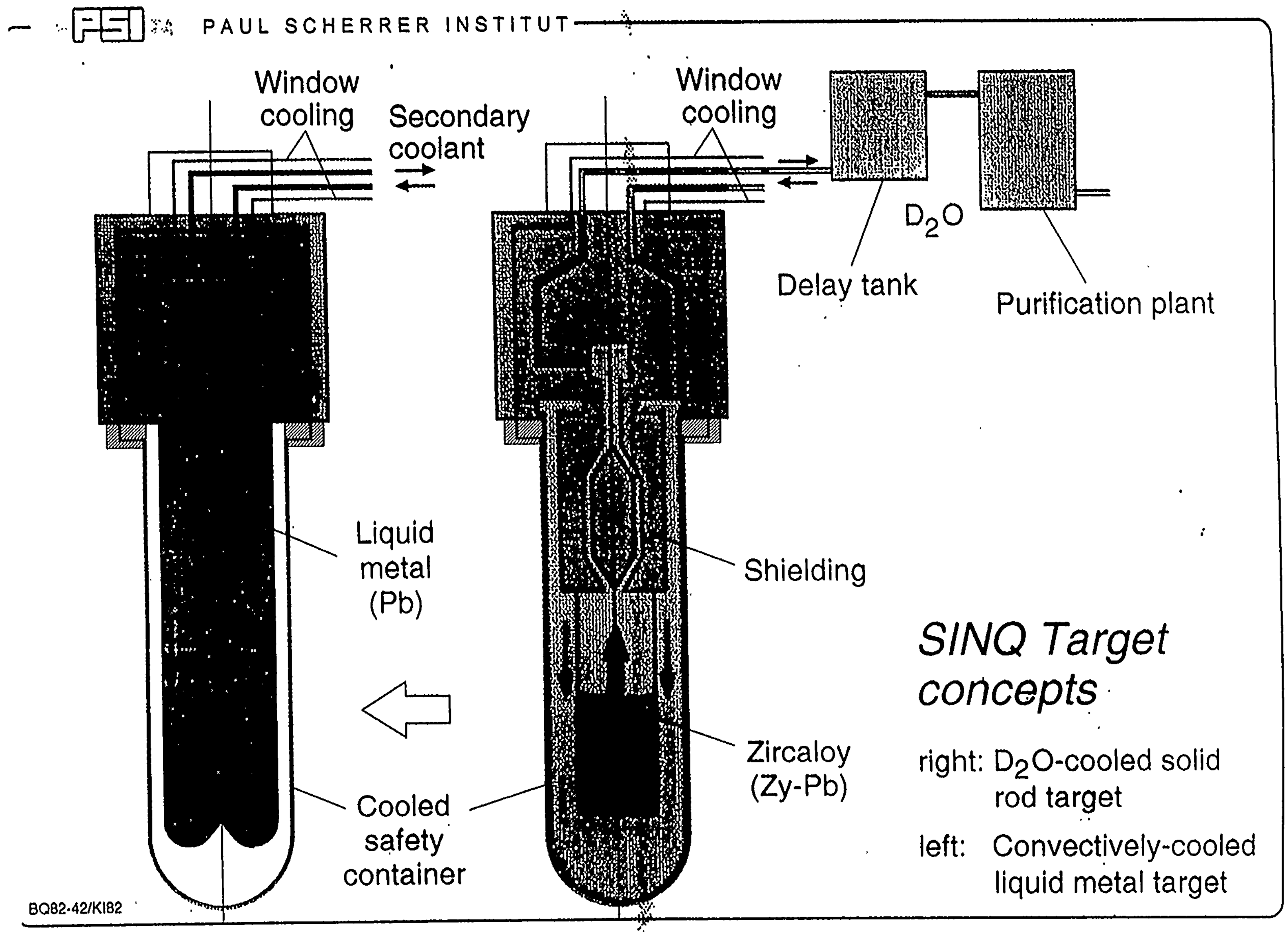
estimated loss 10nA

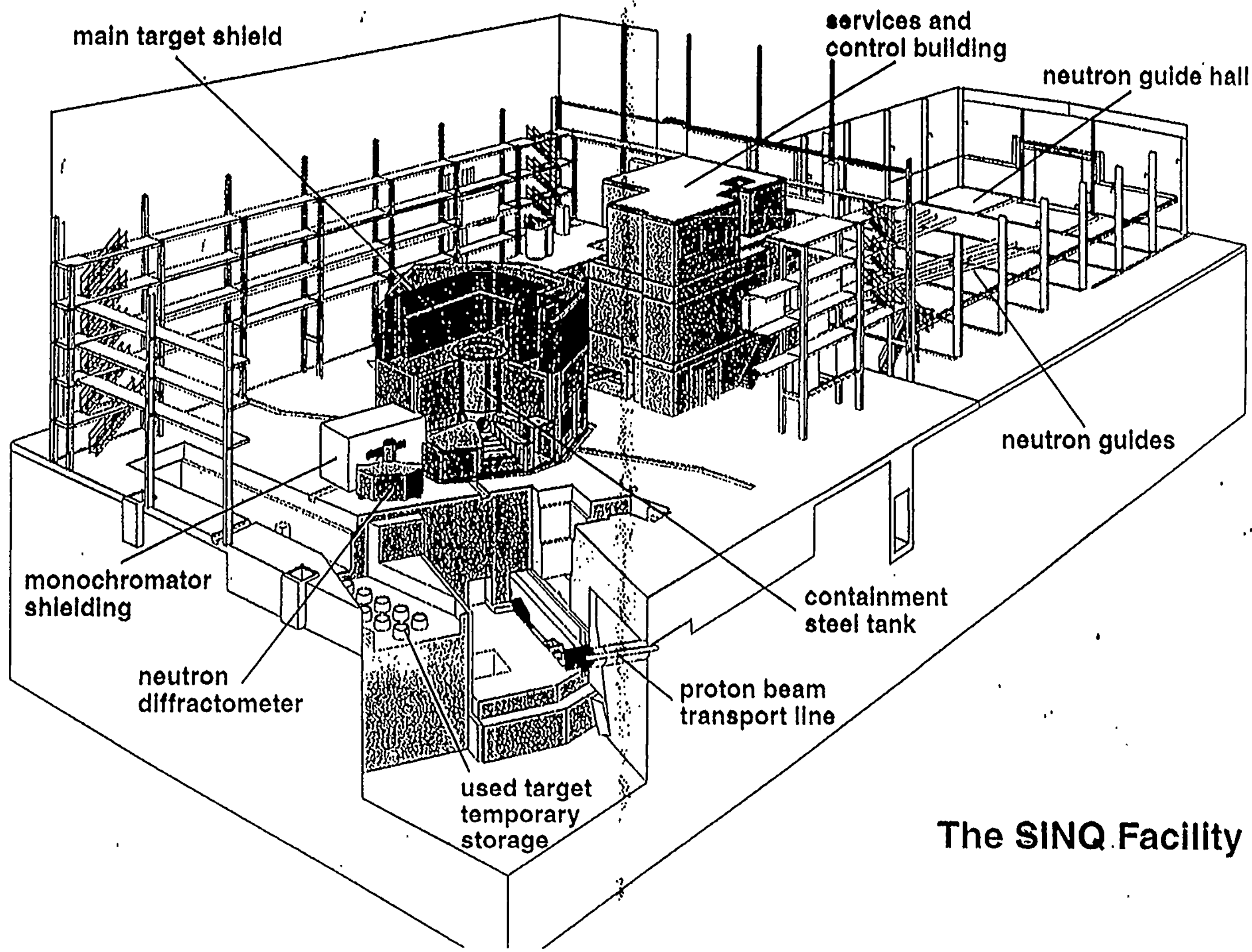

FUTURE:
1.5 mA , 80% 1.2 mA @ 580 MeV ⇒ 0.7 MeV (STRAIGHTFORWARD)
2.0 mA (?) ⇒ 0.9 MeV (NEW RING CAVITIES)
shielding collimators
72 KW (p,n)
45 KW (therm.rad)
38 KW
FWHM 16 mrad
1.5 mA (100%)
1.24 mA (82%)
beam intensity
0.9 mA (60%)
0.5 M
45
145
energy deposit (KW)
380
140
48
secondary particles (KW)
127
target
C12 10 gr/cm2
shaping
collimators
beam dump

Radioactivity data for SINQ cooling circuits

Quantity	Safety hull	Target
direct energy deposition (kW)	3.6	94
coolant mass flow rate (kg/sec)	2.2	9
pipe inner diameter (cm)	2.8	6.6
dose rate at target exit per m of pipe		
- from gamma rays (mS/h)	37	410
- from delayed neutrons (mS/h)	20	178
tritium production		
- after 1 year (10^{12} Bq	0.5	7.4
- equilibrium (10^{12} Bq)	14	180
7-Be production (equil., 10^{12} Bq)	0.3	5.2
10-Be production (per year, 10^{6} Bq)	0.2	3
14-C production (per year, 10^{9} Bq)	6	15

Data do not include the effects of corrosion, erosion and direct injection of spallation products into the coolant. These effects increase with surface area!


PAUL SCHERRER INSTITUT
Window cooling
Secondary coolant
Window cooling
D2O
Delay tank
Purification plant
Liquid metal (Pb)
Shielding
Zircaloy (Zy-Pb)
Cooled safety container
SINQ Target concepts
right: D2O-cooled solid rod target
left: Convectively-cooled liquid metal target
BQ82-42/KI82



The SINQ Facility

"SINQ" TARGET CONCEPT

a) THE PROTON BEAM HITS THE NEUTRON PROD. TARGET FROM <u>BELOW</u>

b) THE TARGET HANDLING SYSTEM AND PROTON BEAM SHIELDING ARE SITUATED ABOVE

THIS VERTICAL ARRANGEMENT LEADS TO:

a) AN ESSENTIALLY CYLINDRICAL SYMMETRY WITH ITS AXIS VERTICAL, FAVOURING THE ARRANGEMENT OF HORIZONTAL NEUTRON BEAM TUBE

b) THE POSSIBILITY OF PLACING A 2 m DIAMETER LOW ABSORPTION D_2O MODERATOR TANK <u>AROUND THE TARGET</u>: IT GUARANTEES A LONG THERMAL NEUTRON FLUX AND HENCE A HIGH THERMAL FLUX EQUIVALENT TO THAT OF A MEDIUM-FLUX REACTOR (ABOUT 10^{14} $cm^{-2}s^{-1}mA^{-1}$)

c) HAVE MORE SPACE AROUND THE TARGET FOR NEUTRON BEAM EXTRACTION.

d) MAKE IT SUITABLE FOR A LIQUID-METAL TARGET: COOLING BY NATURAL CONVECTION

"SINQ" CONCEPT

SINCE THE CYCLOTRON DELIVERS A C.W. BEAM WITH A 50.6 MHz STRUCTURE THE CONCEPT OF "SINQ" IS THAT OF A STEADY-STATE NEUTRON SOURCE.

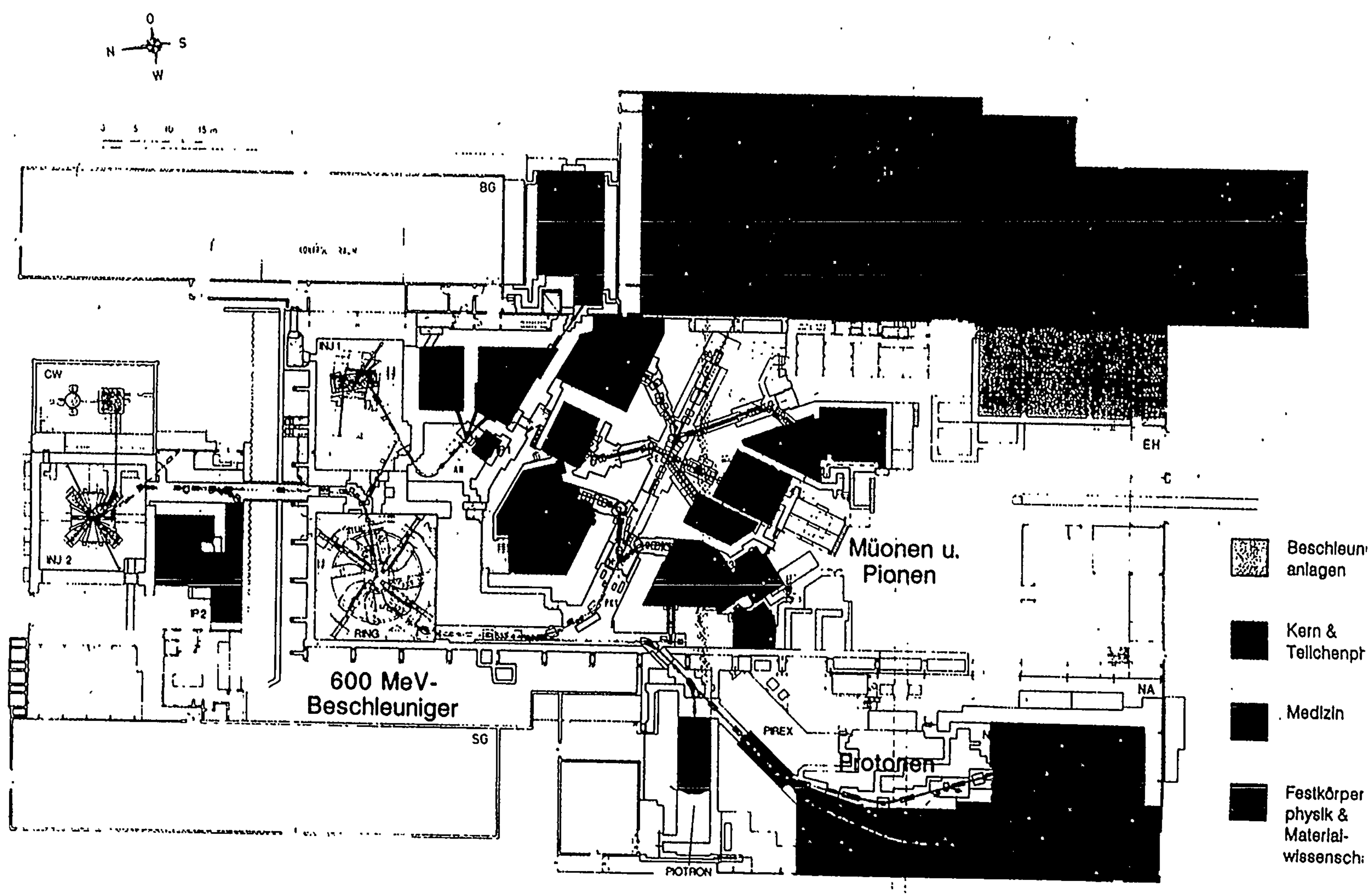
THEREFORE, THE AIM IN THIS CASE IS TO PROVIDE THE HIGHEST POSSIBLE NEUTRON FLUX FROM THE AVAILABLE BEAM POWER AND TO OFFER THE MAXIMUM POSSIBLE SPACE FOR INSTRUMENTATION.

PAUL SCHERRER INSTITUT

Existing experience with spallation neutron sources

Facility	Beam Power	Target	Operational since
KENS (Japan)	3 kW	238-U, Zy-clad	1980
IPNS (Argonne, US)	7 kW	238-U, Zy-clad	1981
		235-U, Zy-clad	1988
Lansce (Los Alamos, US)	60 kW	W, unclad	1977
TRIUMF (Canada)	50 kW	Pb in S. Steel	1978
ISIS (UK)	160 kW	Ta, unclad	1985
		238-U, Zy-clad	
			FROM
SINQ	0.5 MW →	ZIRCALOY (Zy-Pb)	1996
	0.9 MW →	LIQUID METAL (Pb)	FUTURE

BESCHLEUNIGER-ANLAGE UND EXPERIMENTIER-AREALE



— 1994 —

ANNUAL BUDGET : 160 MSFr ≃ 125 MUS$

1100 EMPLOYEES (INCL. 200 PAID BY NON-PSI FUNDS)

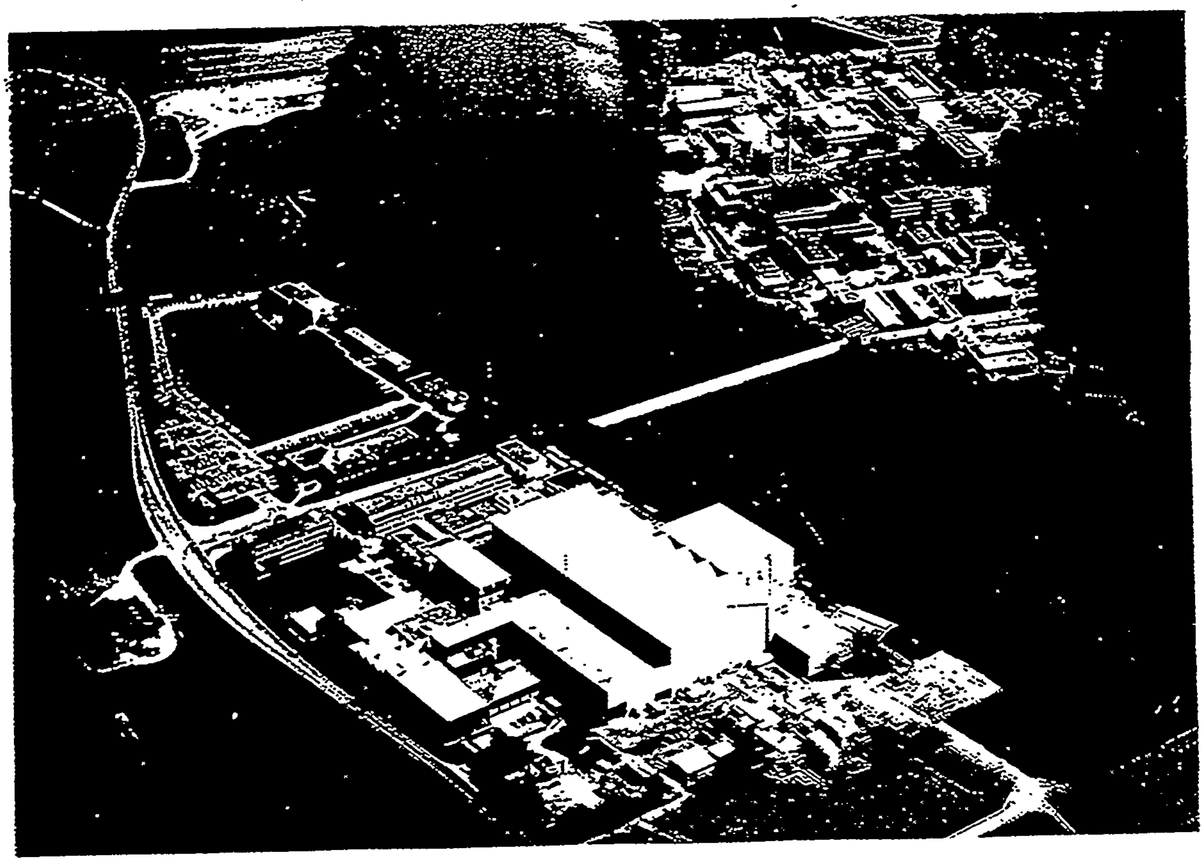
PSI PAUL SCHERRER INSTITU

FIELDS OF RESEARCH :

(%) PSI PERSONNEL INVOLVED

- Nuclear and Particle Physics (18%)
- Life Sciences (14%)
- Solid State Physics and Materials Science (35%)
- Nuclear Energy Technology (18%)
- General Energy Research (15%)

Aerial view of the P Scherrer Institut. The accelerator a experimental facilities are located the three halls at the centre of picture.



Requirements for Ion Source Performance for ESS

H. Klein

University of Frankfurt

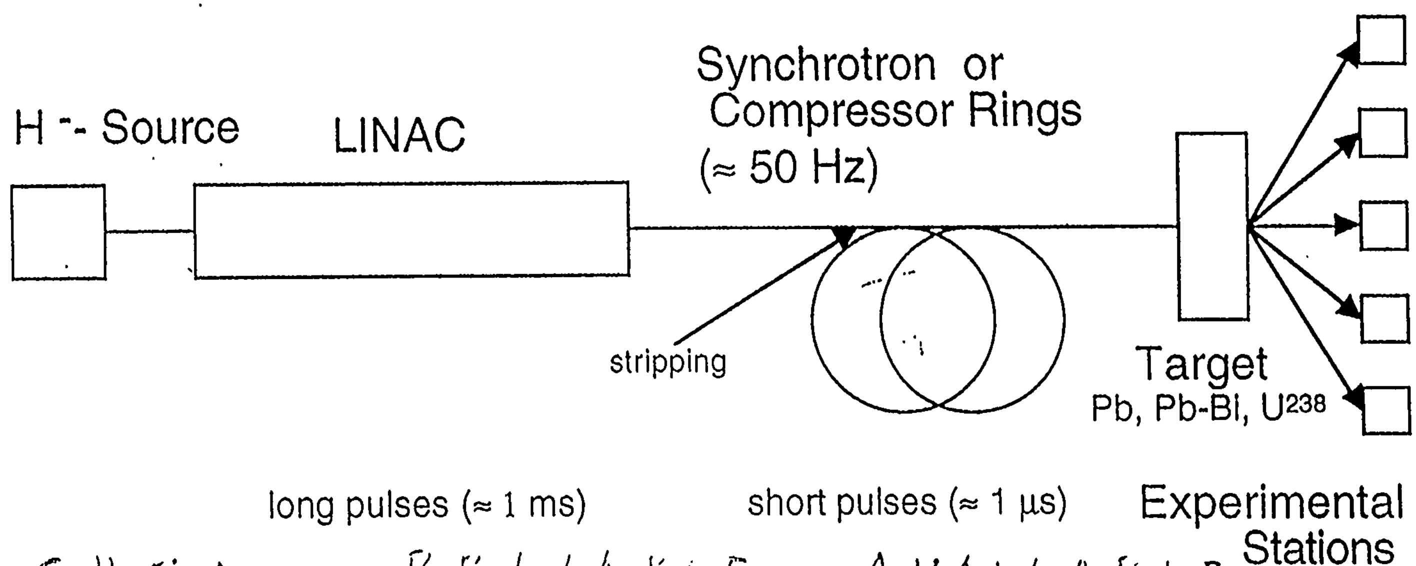
Requirements for Ion Source Performance for ESS

presented by:
H. Klein
Universität Frankfurt
Institut für Angewandte Physik

Berkeley / USA
October 1994

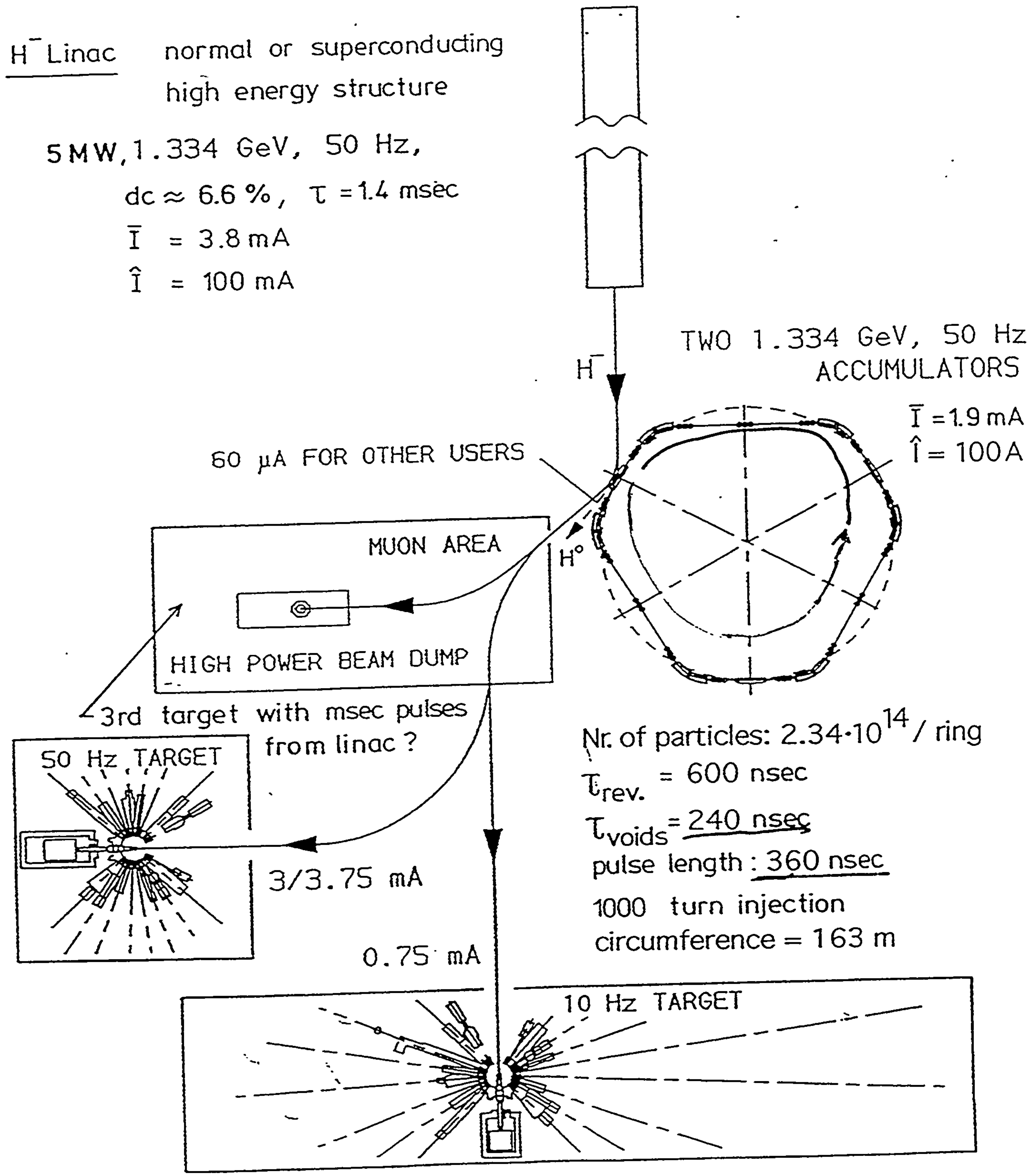
Pulsed Spallation Neutron Source

General Setup



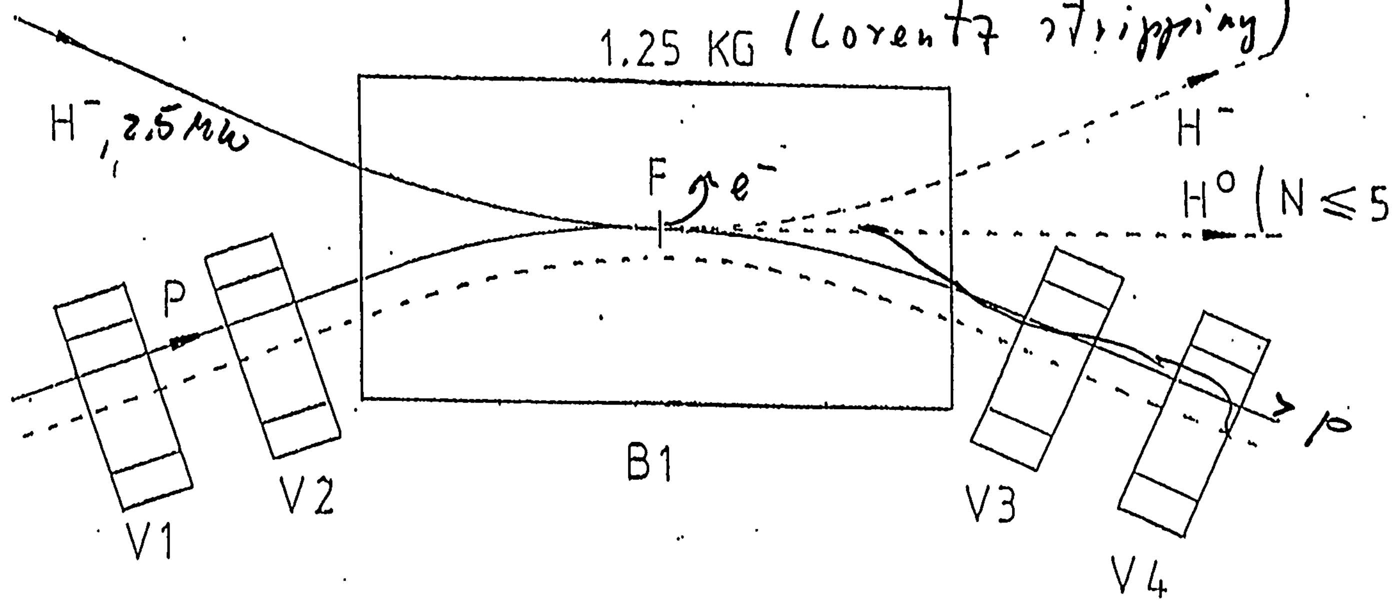
CHEAP, RELIABLE, AVAILABLE
HANDS ON MAINTENANCE + LOW BEAM LOSSES
MAXIMUM CURRENT, PULSED
MINIMUM ENERGY.

HALO!



EUROPEAN SPALLATION SOURCE

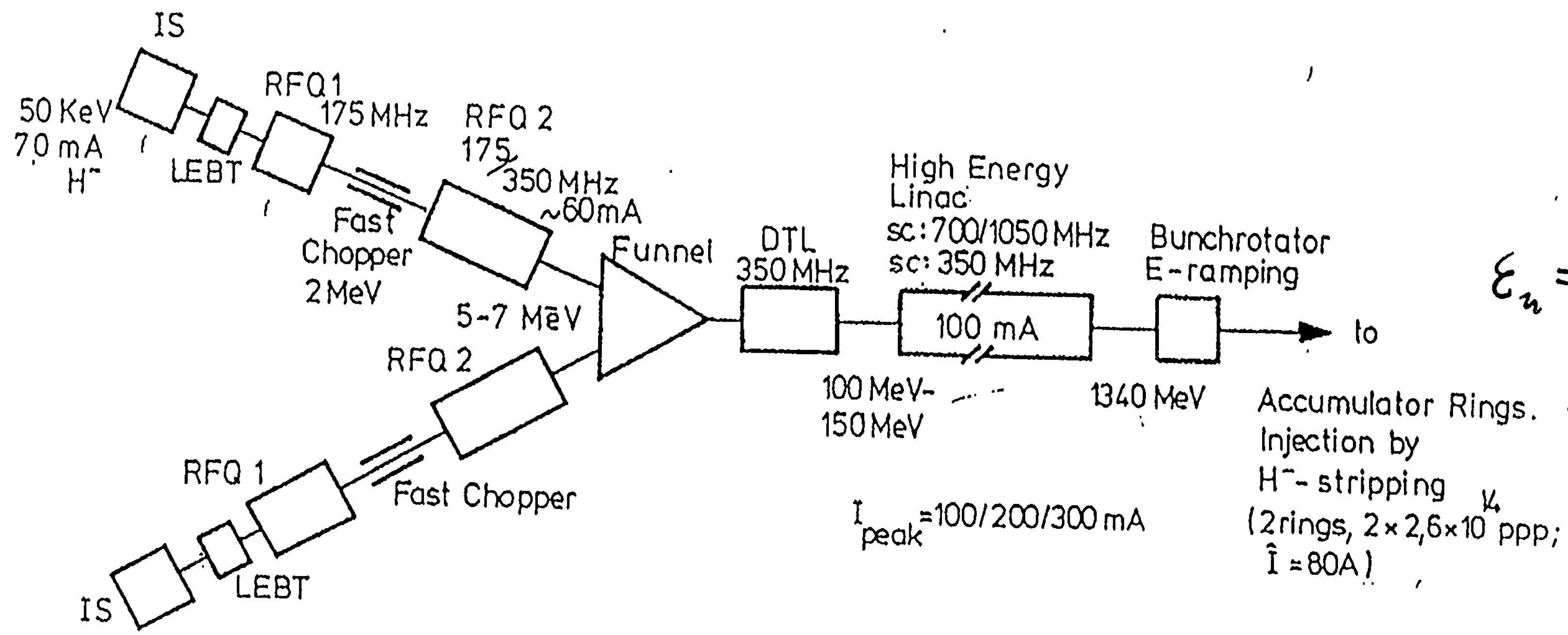
G. Rees (DRAL)



PREFERRED OPTIMISED H⁻ INJECTION SYSTEM

1000 turn injection

Foreseen Scheme for ESS Linac



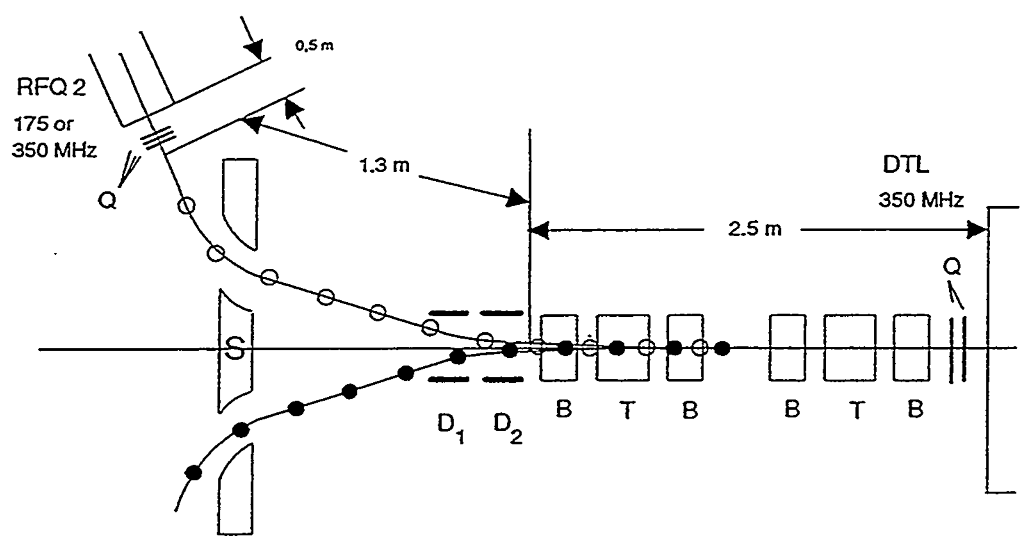
$\varepsilon_n = 5\pi$ mm mrad

$\frac{\Delta P}{P} = \pm 10^{-3}$

tails?

Beam losses $\leqq 0{,}4 \frac{nA}{m}$!

A. Bongardt
(KFA-Jülich)



ESS - Funneling line.
D_1, D_2 : rf-deflectors, 175 MHz,
S : septum magnet, Q: quadrupols
T: triplett, B : bunching cavity, 350 MHz.

Example of parameters of the ESS-injector-RFQs

		RFQ 1	RFQ 2	or RFQ 2
f	[MHz]	175	175	350
T_{in}	[MeV]	0.05	2.0	2.0
T_{out}	[MeV]	2.0	5.0 (7.0)	5.0 (7.0)
L	[m]	2.9	5.5	2.9
N_{rf}	[kW]	350	700	350
N_{beam}	[kW]	100	150	150
I_{lim}	[mA]	100	100	200

A. Schempp, H. Deitinghoff (IAP-FKA

Performance of existing H^- Ion Sources

Ion Source	Cesium	I [mA]	DC [%]	$\varepsilon_{norm,rms}$[πmm mrad]	T[ms]	I_e/I_H
BNL	yes	30	< 1	0.08	0.5	1
TRIUMF	no	9	100	0.07	DC	?
LBL	yes (no)	90 (35)	> 1 (1)	? (0.07)	? (1)	10(12)
LANL	yes	60	2	0.06	2	1.5
Culham (with cathode)	yes	86	100	0.13 (for 30mA)	DC	?
RAL	yes	30..50	2.5	0.05	0.5	1
KEK (with cathode)	yes	20	1	1 (for 12mA)		

Y. Mori Th2-3

Project Requirements

	Cesium	I [mA]	DC [%]	$\varepsilon_{norm,rms}$[πmm mrad]	T[ms]	I_e/I_H
ESS	?	70	10	< 0.1	1.45	?

... chopping!

Source requirements for ESS

1. **Current**

   $\geq$ 70mA $\tau \sim 2$ msec dc = 10%
   rep. rate 50 Hz

2. **Emittance** ~ 0.1 (norm., rms)

   a) after RFQ I:

   $\varepsilon_{(norm,\, rms)} < 0{,}3\pi$ mmmrad

   b) end of Linac (1,334 GeV, $\beta\gamma = 2.3$):

   $\varepsilon_{(norm,\, rms)} < 1{,}3\pi$ mmmrad

   $\Delta p/p = \pm\ 10^{-3}$

   in tails only $\pm 5\cdot 10^{-5}$ particles
   with energy deviation $\geq\ \pm 0{,}5$MeV

3. **Pulse shape**

   chopping: rise time: 10 - 20 nsec

   prechopping at ion source: ?

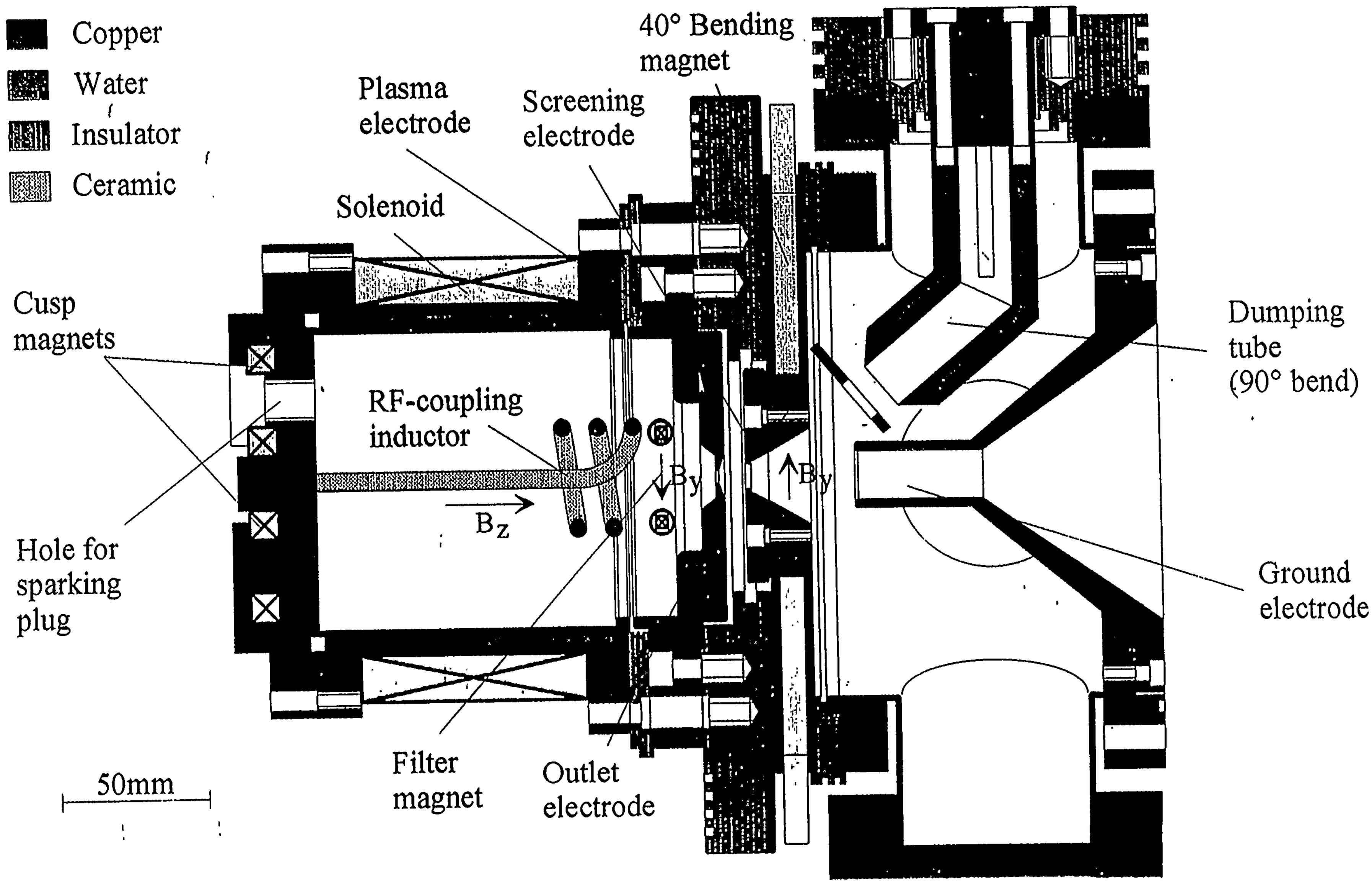
4. **Low noise**

   ripple < 1%

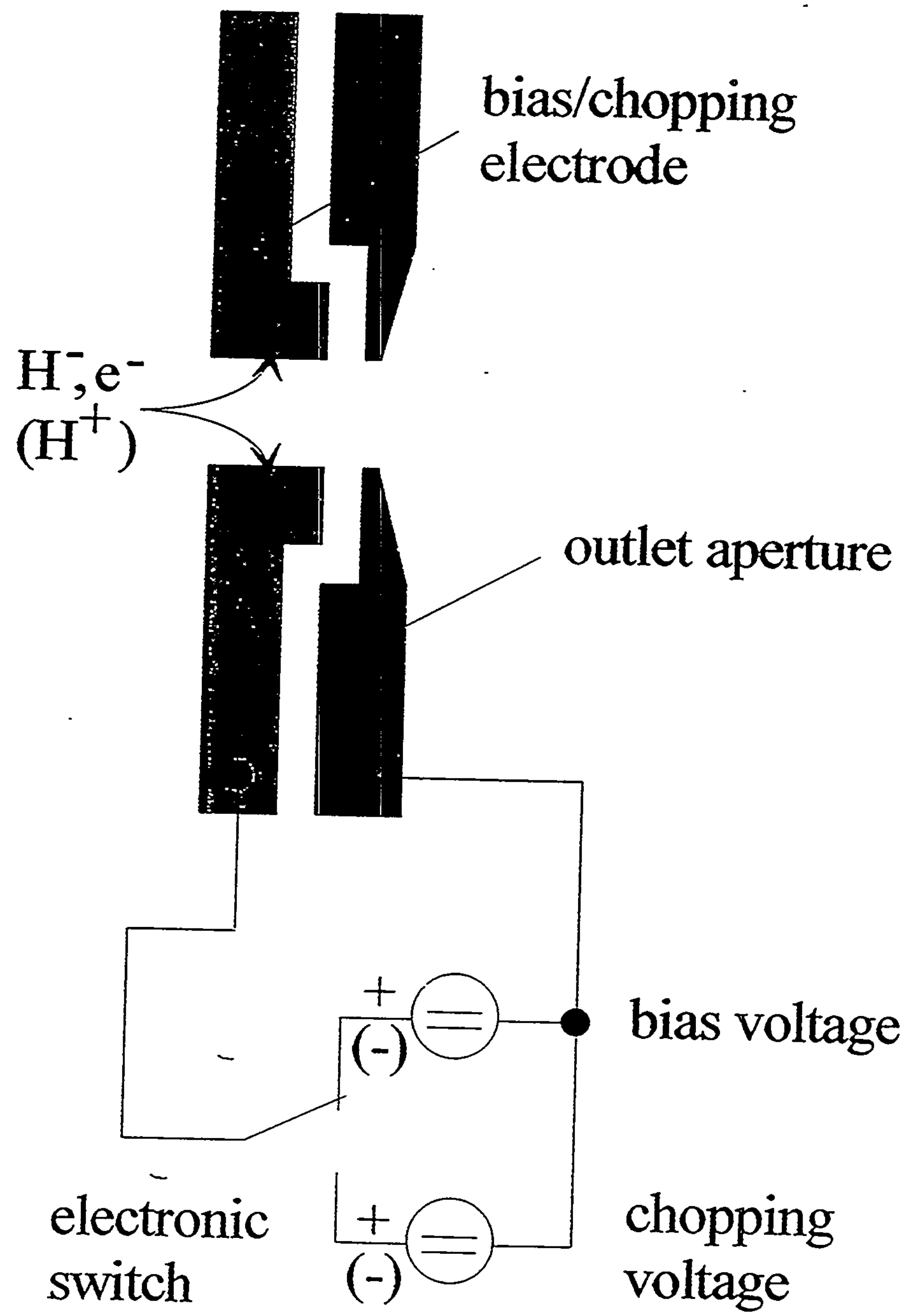
5. **High reliability and availability**

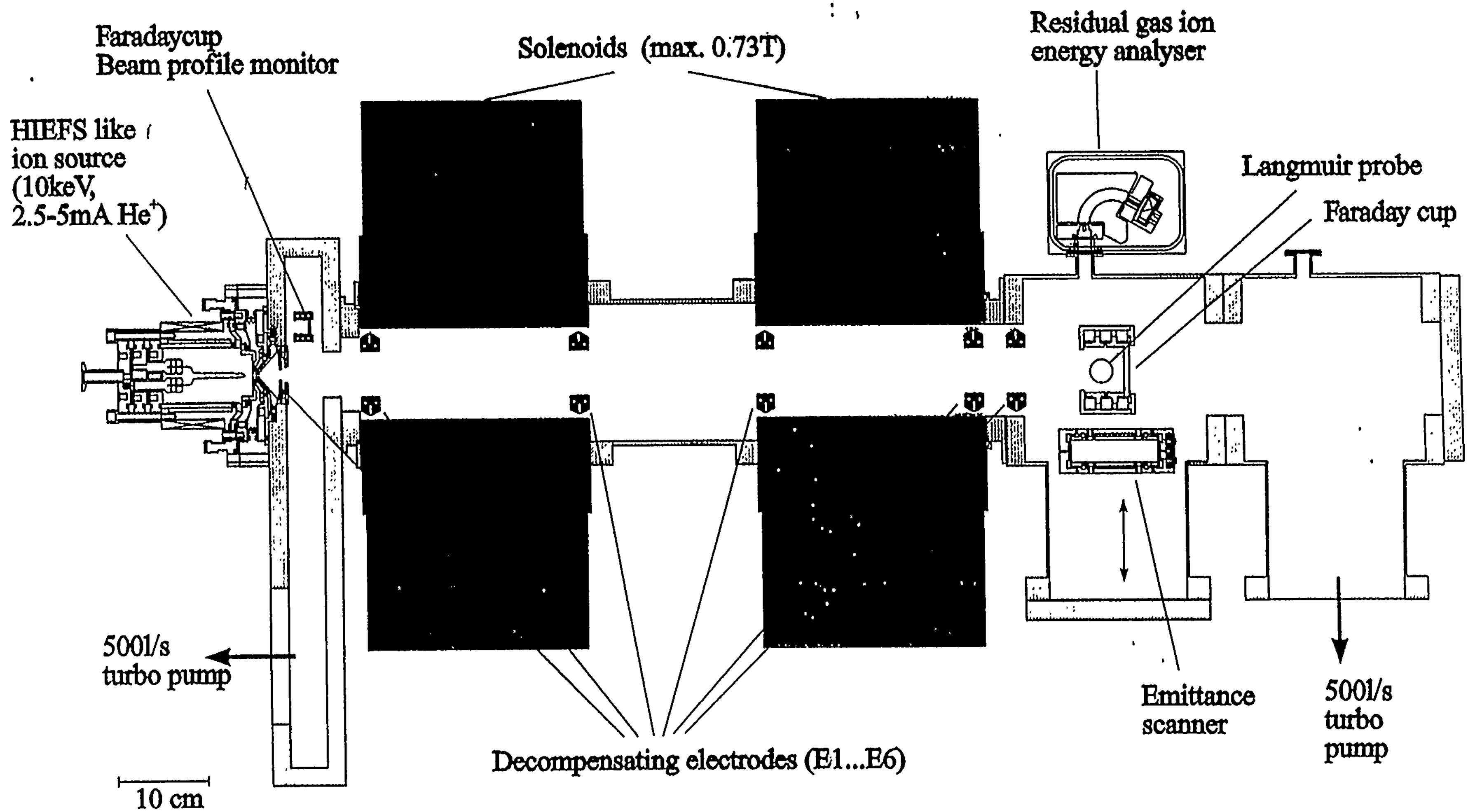
   rf - generating of plasma

Schematic drawing of the H^- source

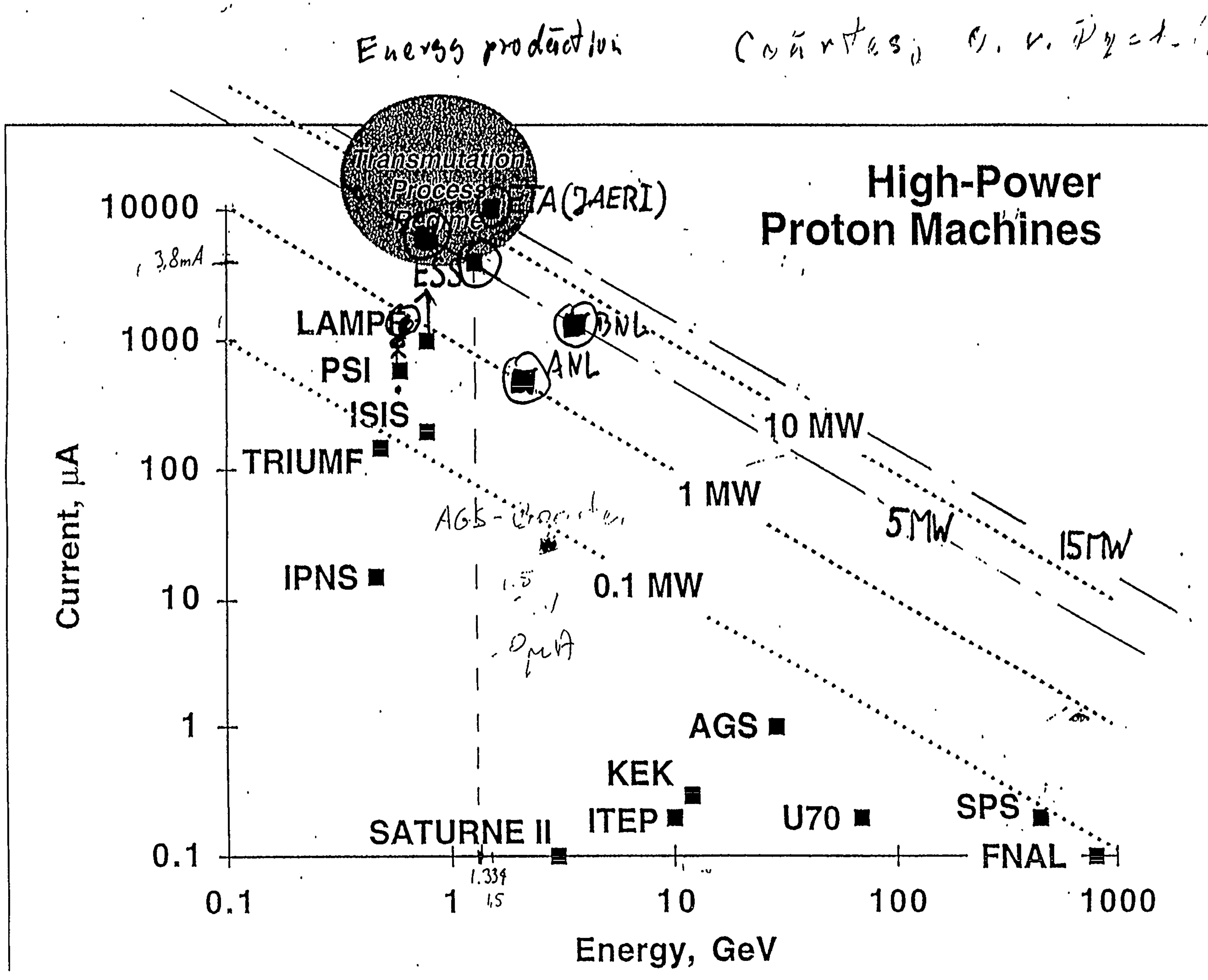


Principle of chopping





Schematic drawing of the Frankfurt LEBT


High-Power
Proton Machines
Current, μA
Energy, GeV
10000
1000
100
10
1
0.1
0.1
1
10
100
1000
Transmutation Process Regime
ETA (JAERI)
ESS
LAMPF
PSI
ISIS
TRIUMF
IPNS
BNL
ANL
10 MW
1 MW
0.1 MW
5MW
15MW
AGS
KEK
ITEP
U70
SPS
FNAL
SATURNE II
3.8mA
1.334
Energy production

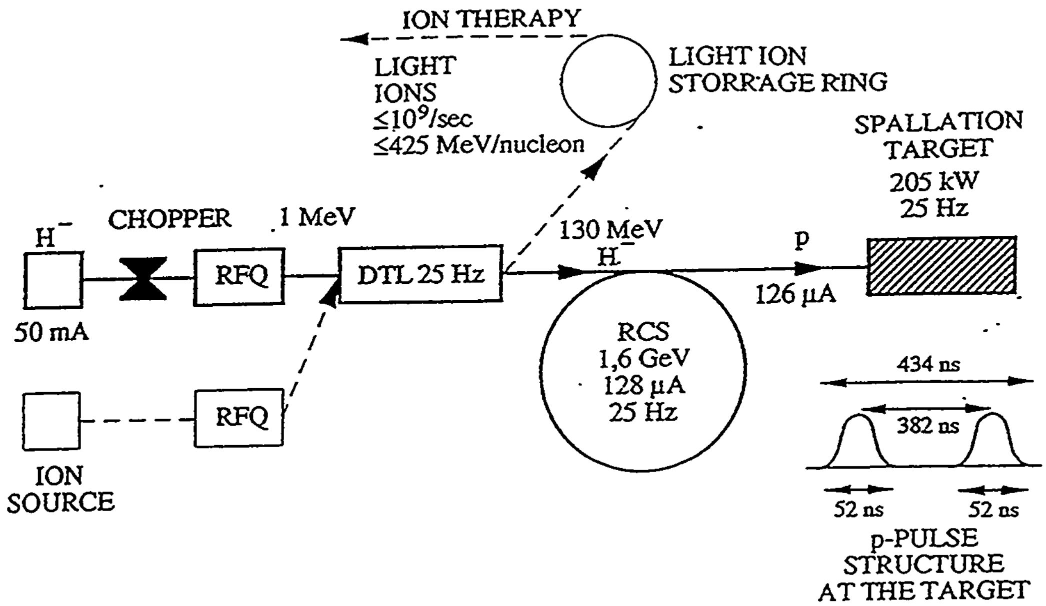
The AUSTRON Project

M. Regler

AUSTRON

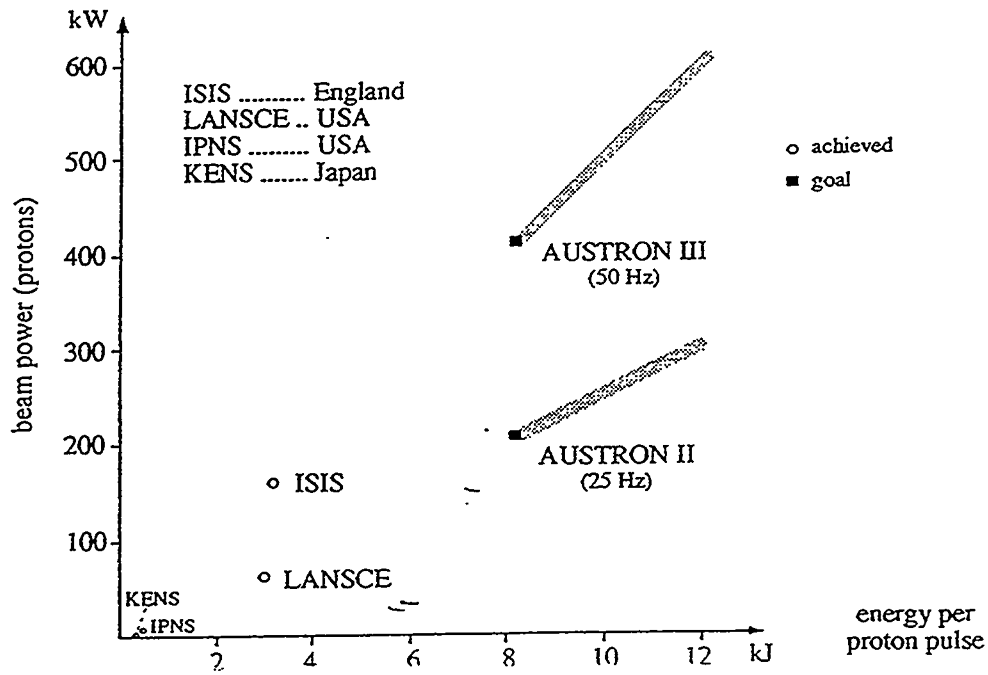
The AUSTRON Project presented by M. Regler (Project Leader)

The AUSTRON Accelerator Complex



Comparison of Neutron Spallation Sources

(beam power and energy per pulse on target)



The shaded areas of AUSTRON II and AUSTRON III indicate the estimated range of possible further increase in beam power due to future optimization.

The main parameters of the AUSTRON spallation source

Accelerator

	AUSTRON II	AUSTRON III
Proton Beam power	205 kW	410 kW
Proton energy	1.6 GeV	1.6 GeV
Proton current	128 μA	256 μA
Pulse repetition rate	25 Hz	50 Hz
Proton pulse length (double bunch)	434 ns	434 ns
Light ions	≤ 10^9/s	≤ 10^9/s
Kinetic energy per nucleon	≤ 425 MeV	≤ 425 MeV

Target (AUSTRON II)

Material	Tungsten rhenium alloy (W-5%Re)
Geometry	flat one piece target or cylindrical split target
Cooling	edge cooling only

Target station (AUSTRON II)

Proton beam	horizontal beam injection
Supply lines	horizontal - cooling plant is behind the target station
Target installation / maintenance	vertical - the maintenance area is above the target

Requirements for the Ion Source Performance of the ETA

H. Oguri

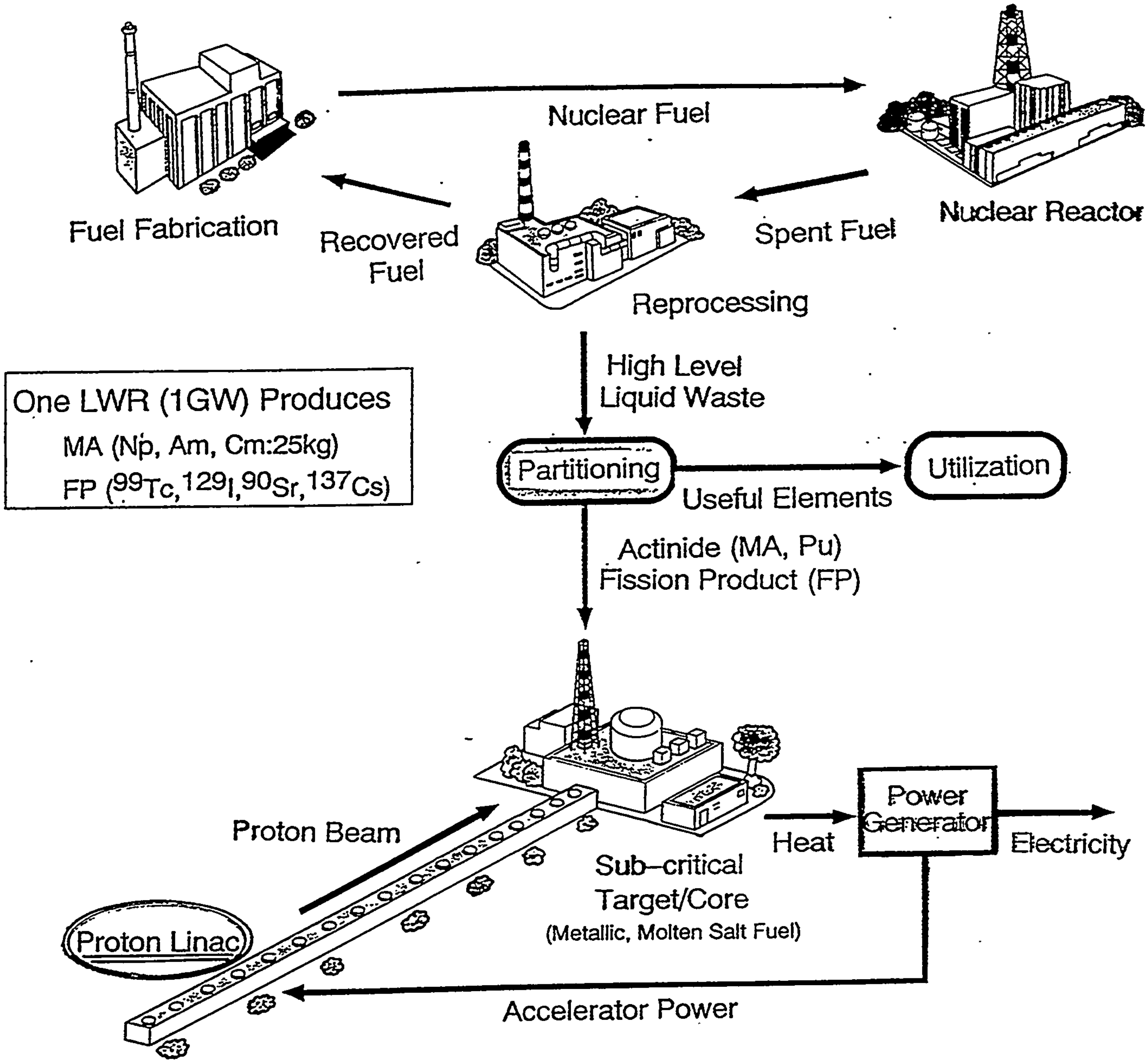
Japan Atomic Energy Research Institute

Requirements for the Ion Source Performance of the ETA

H. Oguri, Y. Okumura and M. Mizumoto

Japan Atomic Energy Research Institute

Workshop on Ion Source Issues Relevant to
a Pulsed Spallation Neutron Source
(at Berkeley)
October 24, 1994



Accelerator-based Transmutation System

Accelerator Development Plan at JAERI

1. R&D

2 MeV, 100 mA, Pulse (Duty Factor 10 %)
Beam Test of Ion Source and RFQ,
DTL High Power Test, RF Source Development

↓

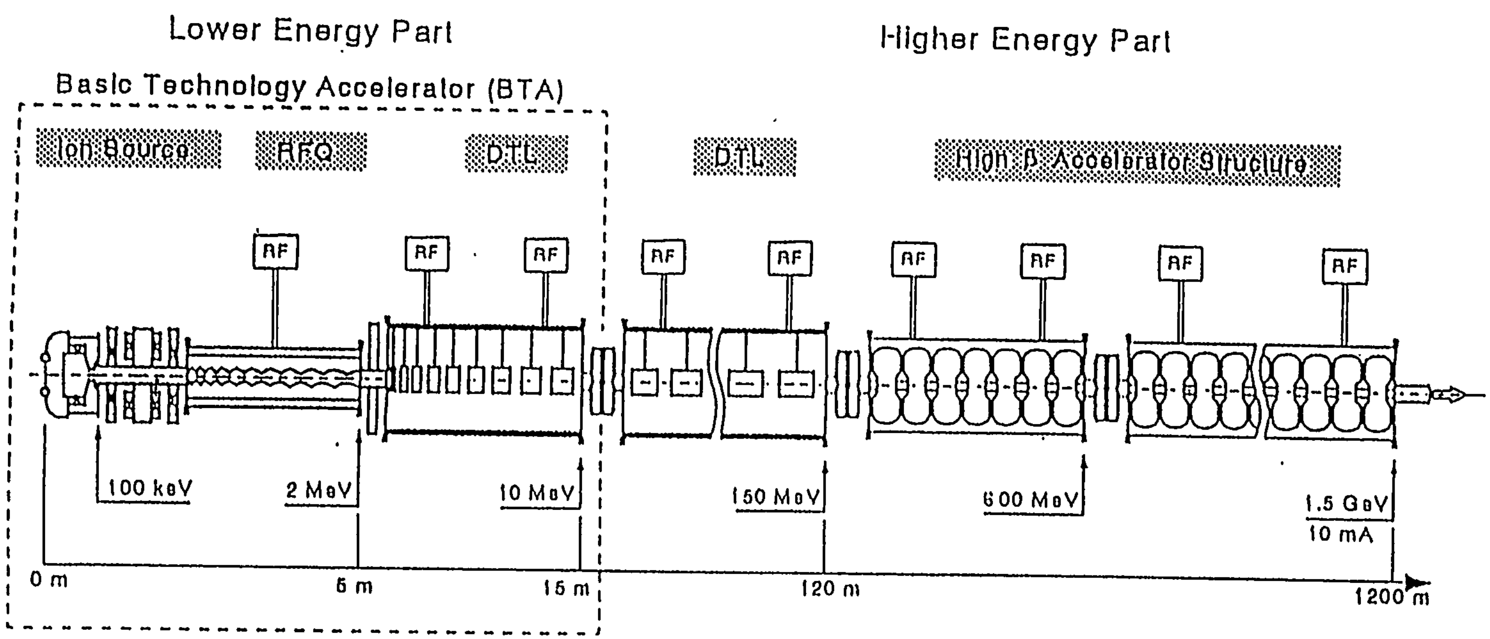
2. BTA (Basic Technology Accelerator)

10 MeV, 100 mA, Pulse (Duty Factor 10 %)
Mock-up Test of Low Energy Portion

↓

3. ETA (Engineering Test Accelerator)

1.5 GeV, 100 mA, Pulse (Duty Factor 10 %)
Plant Test, Basic Science Research



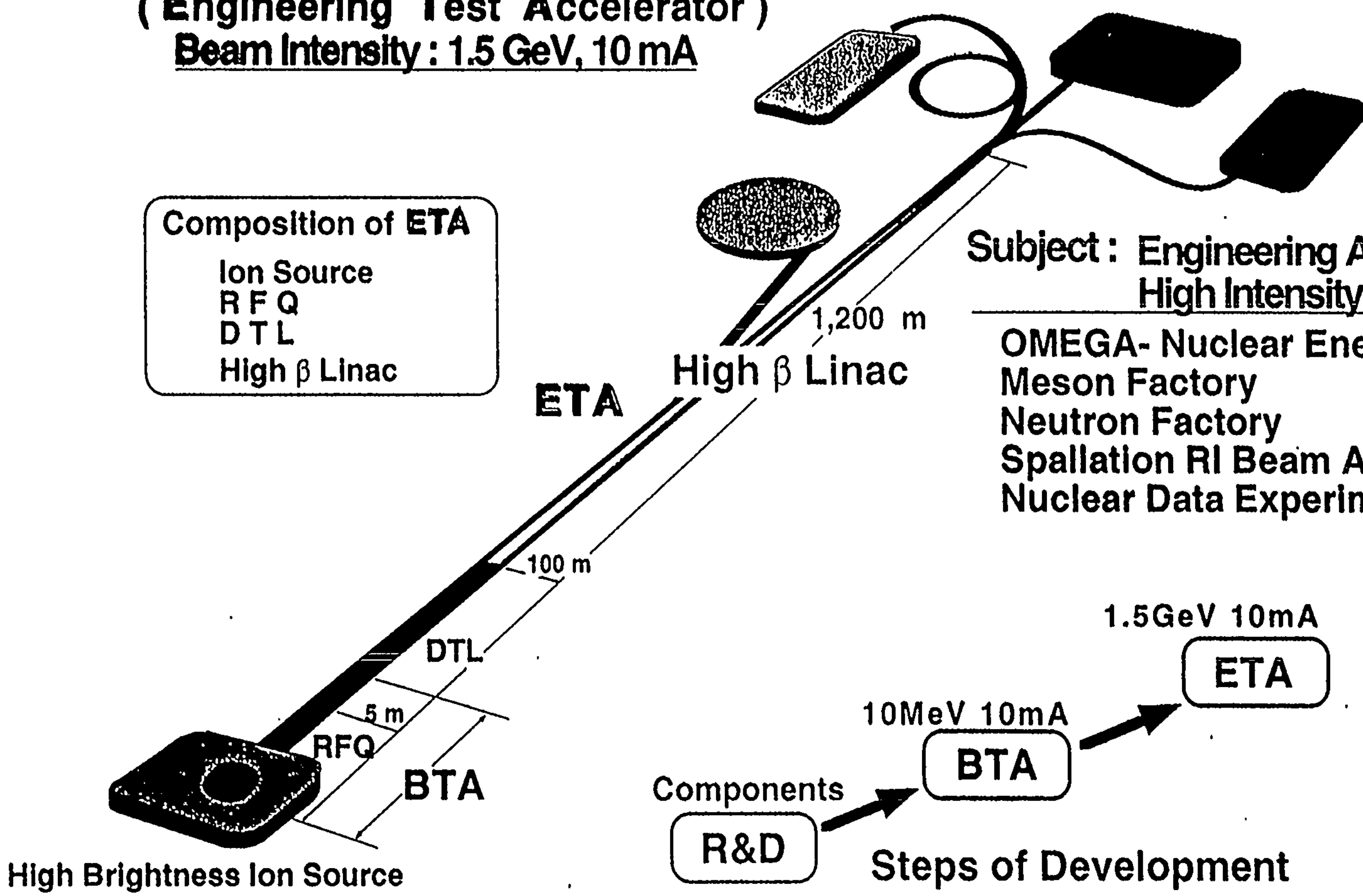
Accelerated Particle	H^+, H^-
Beam Energy	1. 5GeV
Beam Current	10mA(Average)
Beam Power	15MW
Operating Mode	Pulse,10%(1ms,100pps)
Total RF Power	13.5MW
Average Gradient	1.5MV/m

Engineering Test Accelerator (ETA)

Development of High Intensity Proton Accelerator

(Engineering Test Accelerator)
Beam Intensity : 1.5 GeV, 10 mA

Composition of ETA
- Ion Source
- R F Q
- D T L
- High β Linac



Subject : Engineering Application of High Intensity Proton Beam

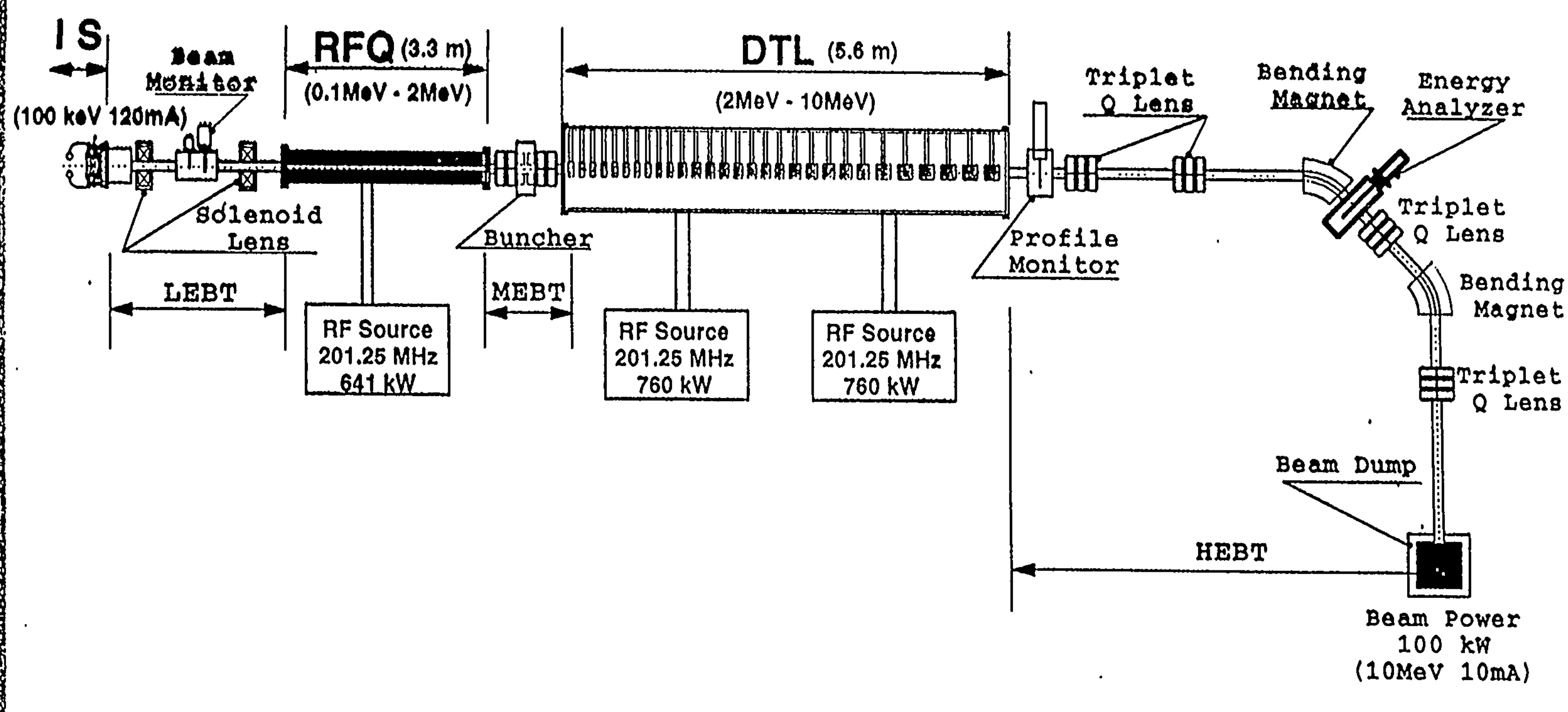
- OMEGA- Nuclear Energy Technology
- Meson Factory
- Neutron Factory
- Spallation RI Beam Application
- Nuclear Data Experiment

Components **R&D** → 10MeV 10mA **BTA** → 1.5GeV 10mA **ETA**

Steps of Development

DESIGN PARAMETERS OF BTA

Accelerated Particle	:	Proton
Beam Energy	:	10 MeV
Peak Beam Current	:	100 mA
Average Beam Current	:	10 mA
Operating Mode	:	Pulse, 10 %
		(1 ms, 100 pps)
Transverse Emittance	:	0.1 πcm.mrad
		(Norm. rms)
Energy Resolution	:	1 %



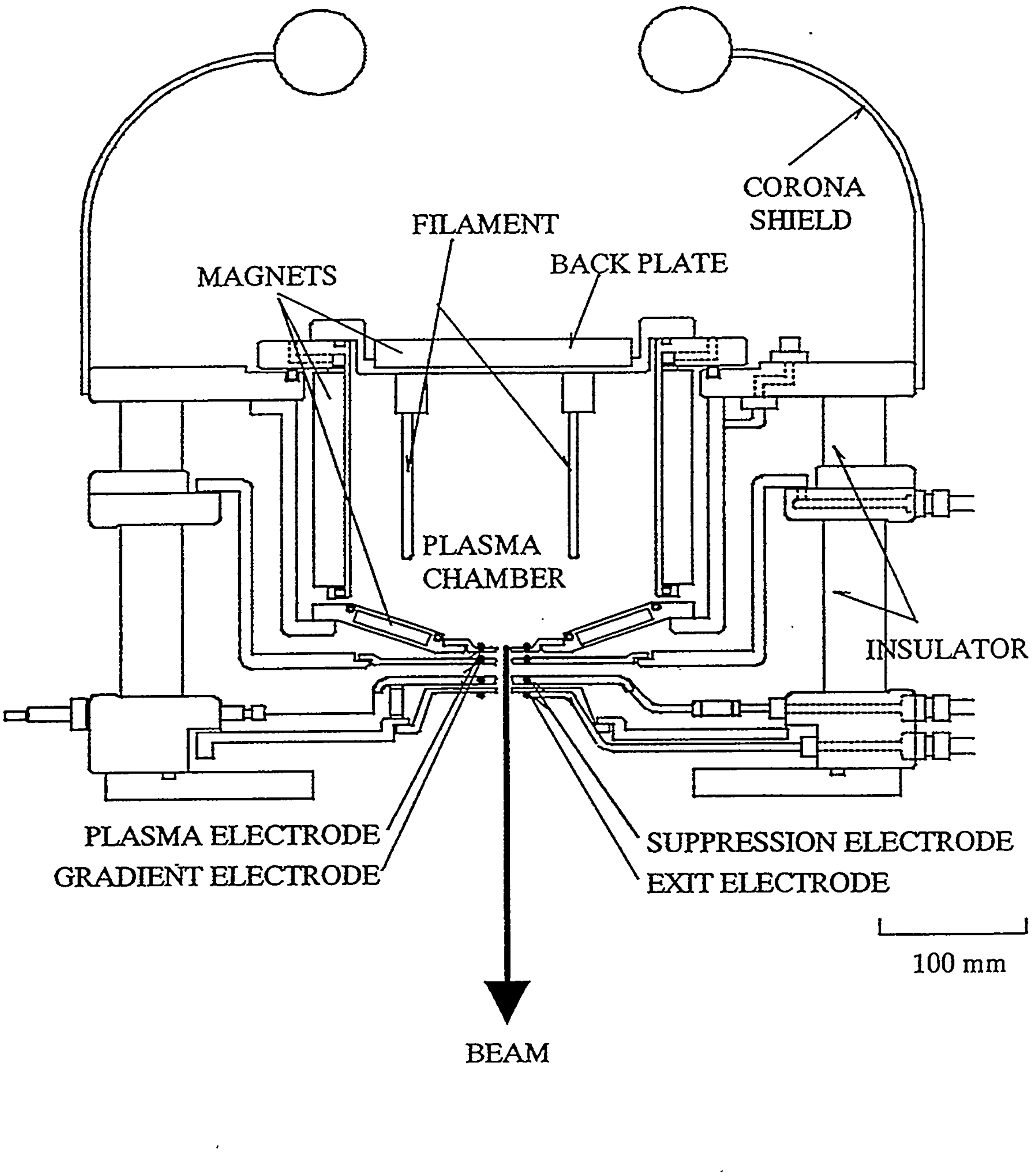
A Conceptual Layout of BTA (Basic Technology Accelerator)

Design Parameters of Proton Ion Source for the BTA / ETA

(Constructed)

Ion Source Type	:	Multi-cusp Type
Extraction Voltage	:	100 kV
Extraction Peak Current	:	120 mA
Normalized Emittance	:	0.5 π mm.mrad (100%)
Proton Yield	:	>90 %
Impurity	:	<1 %
Operating Mode	:	CW, Pulse
Plasma Chamber		
Size	:	20 cmϕ x 17 cm
Production	:	Arc discharge (W Filaments)
Arc Voltage	:	70 V
Arc Current	:	120 A
Confinement	:	Multi-cusp magnetic field
Field Intensity	:	> 2kG (inner surface) < 20G (central region)
H_2 gas flow rate	:	4 SCCM
Pressure	:	0.3 Pa
Beam Extractor	:	2 stage
Aperture	:	10 mmϕ (single)
Field Intensity Ratio	:	0.42
Electron Suppressor	:	-5.5 kV
Current Density	:	150 mA/cm^2

Cross Sectional View of the Proton Ion Source



Design Parameters of Negative Hydrogen Ion Source for the ETA

(Proposal)

Ion Species	:	H^-
Extraction Voltage	:	100 kV
Extraction Current	:	120 mA (peak)
Norm. Emittance	:	0.5 π mm.mrad (100%)
Operating Mode	:	CW, Pulse
Pressure	:	0.3 Pa
Source Type	:	Magnetically Filtered Multicusp Cesium-seeded Volume Production
Extractor	:	4 electrodes (Plasma, Extraction, Electron-suppression, Grounded Electrode)
Aperture	:	9 mm in diam. x 7 in the Plasma Electrode
Extraction Area	:	0.636 x 7 = 4.45 cm^2
Insulator	:	Alumina Ceramic

Present Status of the BTA R&D

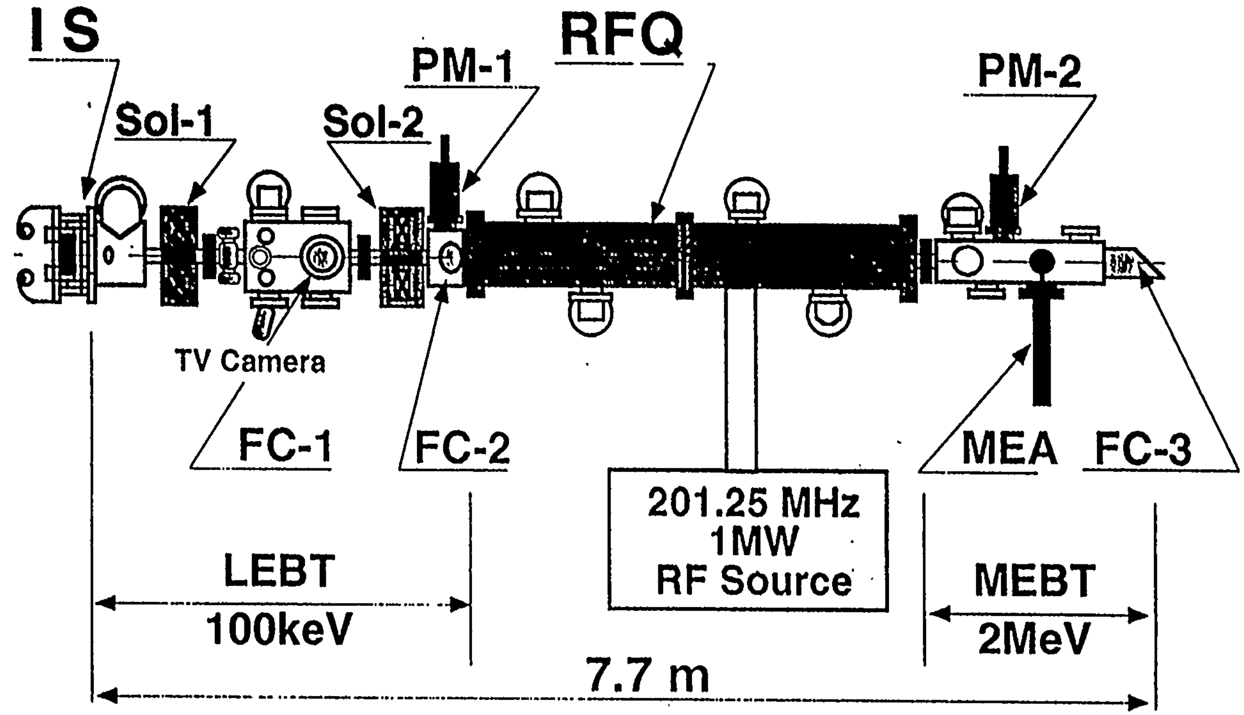
(1) High Brightness Ion Source
Beam of 140 mA at 100 kV has been extracted.

(2) RFQ
Structure has been constructed..
Electromagnetic field measurement has been completed.

(3) DTL
Hot test model (9 cells) has been fabricated.
High power test has been completed.

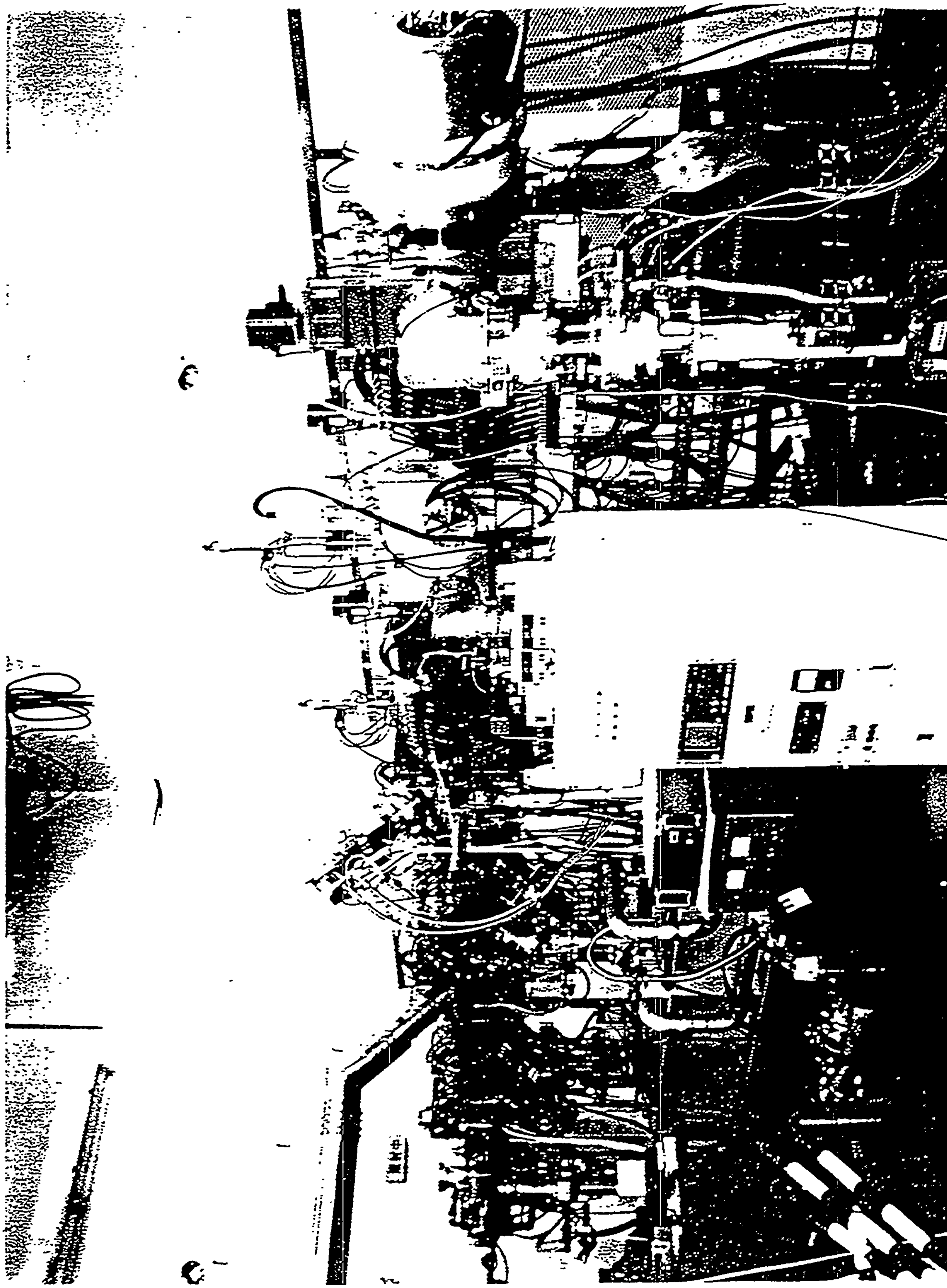
(4) RF Source
One unit of 1 MW amplifier has been constructed.
High power test has been completed.

(5) 2 MeV Beam Test through RFQ
The maximum peak current is 52 mA with a duty factor of 5.0 %.



FC: Faraday Cup
PM: Profile Monitor
MEA: Magnetic Energy Analyzer

Layout of R&D 2MeV Beam Test



Results of LANSCE II Study Ion-Source Specifications

A. Jason

Los Alamos National Laboratory

Results of LANSCE II Study

ION-SOURCE SPECIFICATIONS

Andrew Jason
Los Alamos
October 24, 1994

Workshop on ion sources relevant to a pulsed spallation neutron source
Berkeley, CA

LANSCE II Proposal

- 800 MeV Linac-accumulator ring approach, 1-MW beam power delivered to target

- Utilize existing side-coupled linac
  - already a 1-MW facility
  - constitutes 90% of linac

- Replace front end
  - RFQ-DTL (402.5 MHz) to 20 MeV, 805 MHz DTL to 100 MeV
  - higher current use and reliability
  - possible 5-MW upgrade by funneling

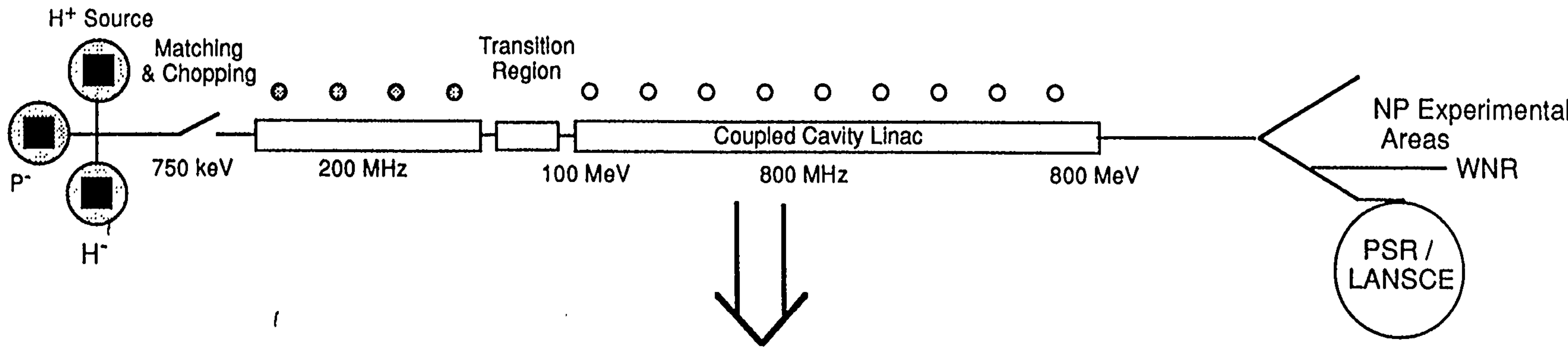
- Second-order achromat injection line with momentum scraping and momentum compaction

- Accumulator ring - 1.3×10^{14} particles in 1.2 ms at 60 Hz

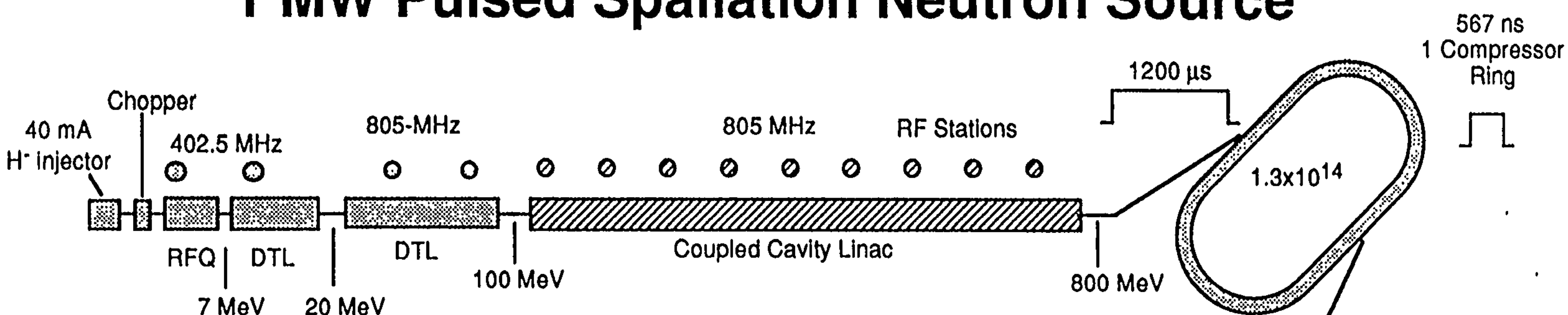
- Vertical insertion target

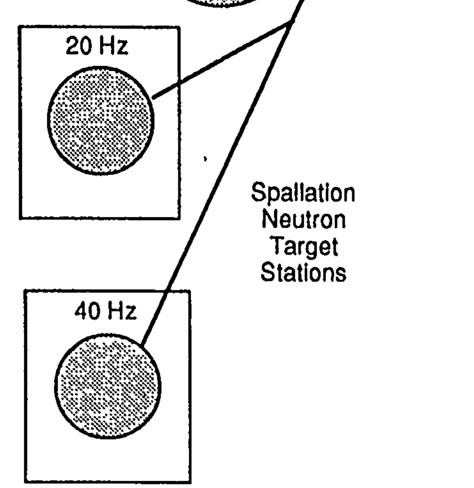
- Source, Chopping are issues

Existing Los Alamos Meson Physics Facility



1 MW Pulsed Spallation Neutron Source

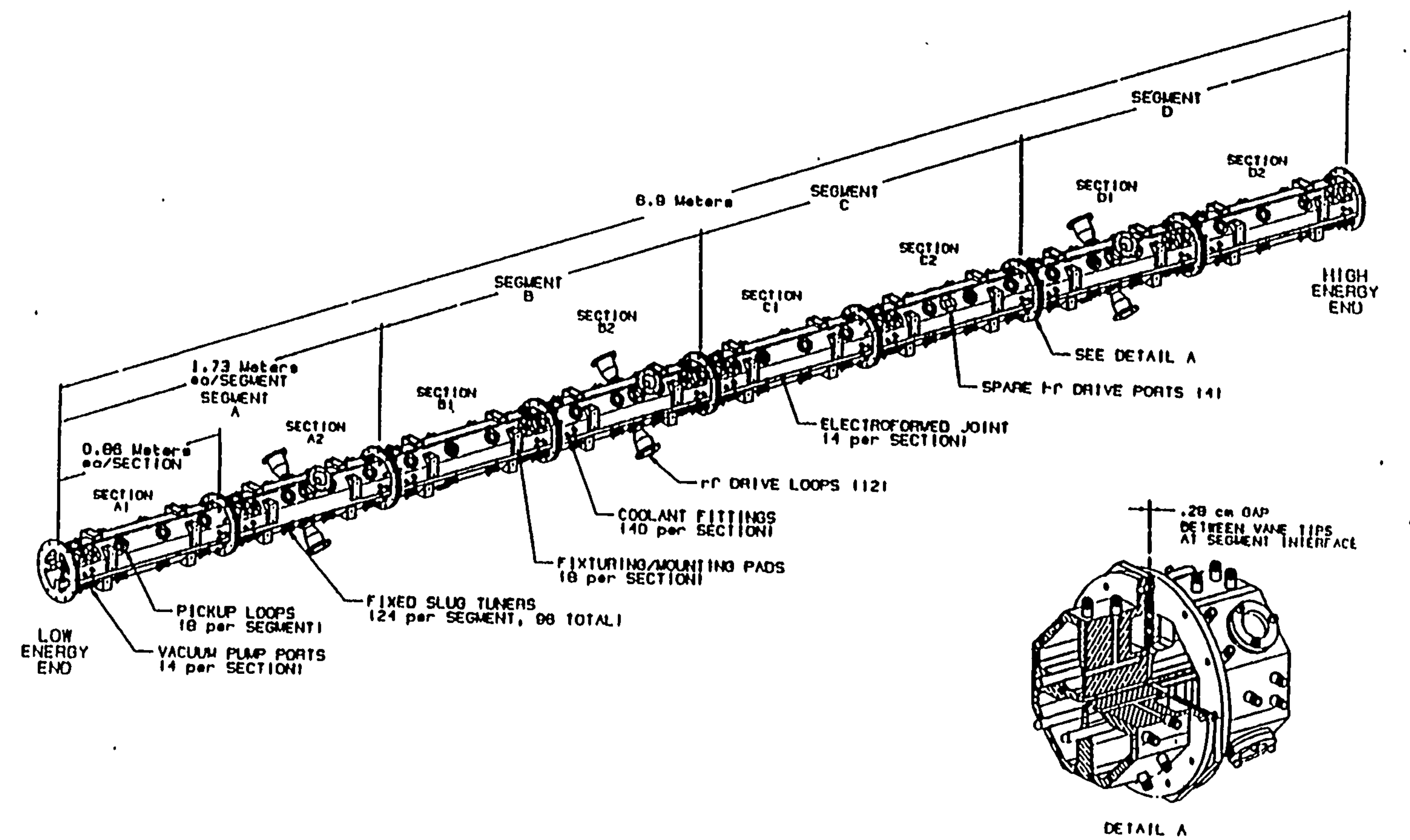




Pulse Rate	Pulse Length	Linac Peak Current	Average Current	Total Energy	Total Power
60 pps	1.2 millisec	30 mA	1.25 mA	800 MeV	1 MW

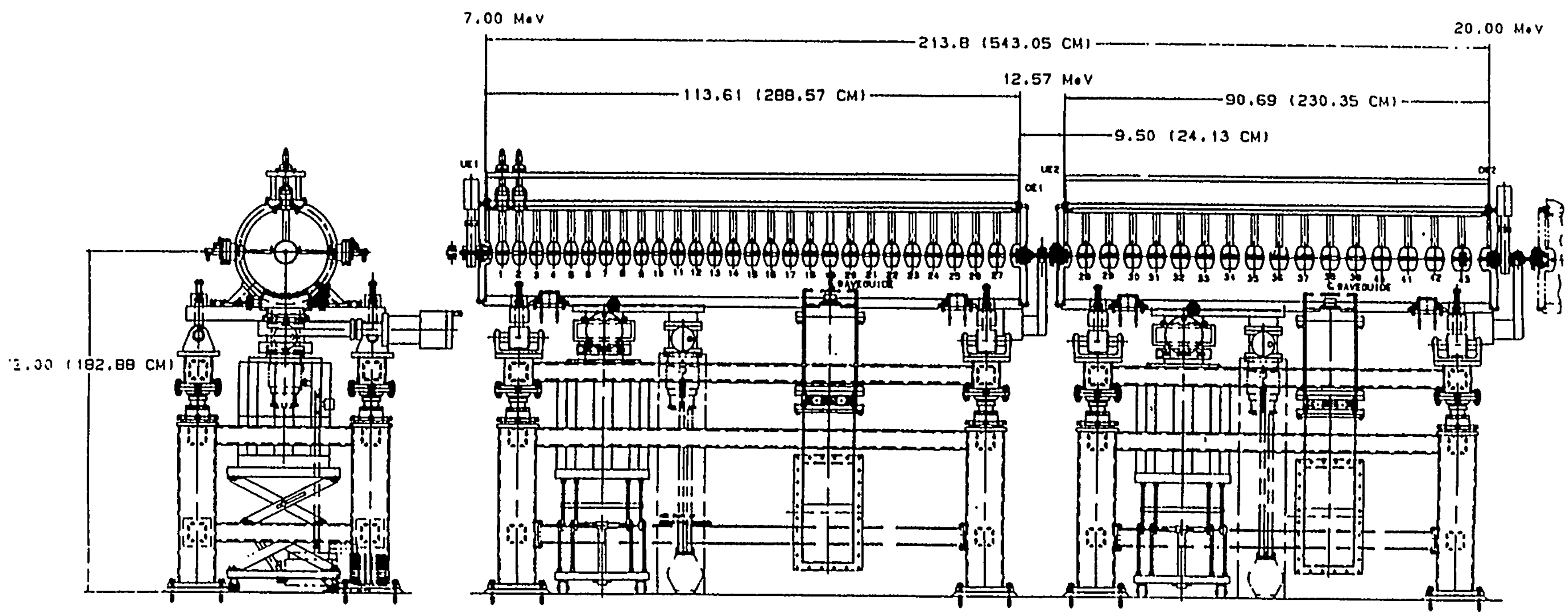
Added/ replaced equipment   Existing Equipment

Long 7-MeV RFQ



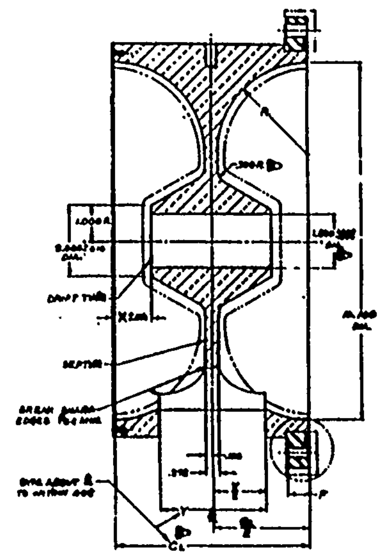
402.5 MHz DTL Accelerates to 20 MeV

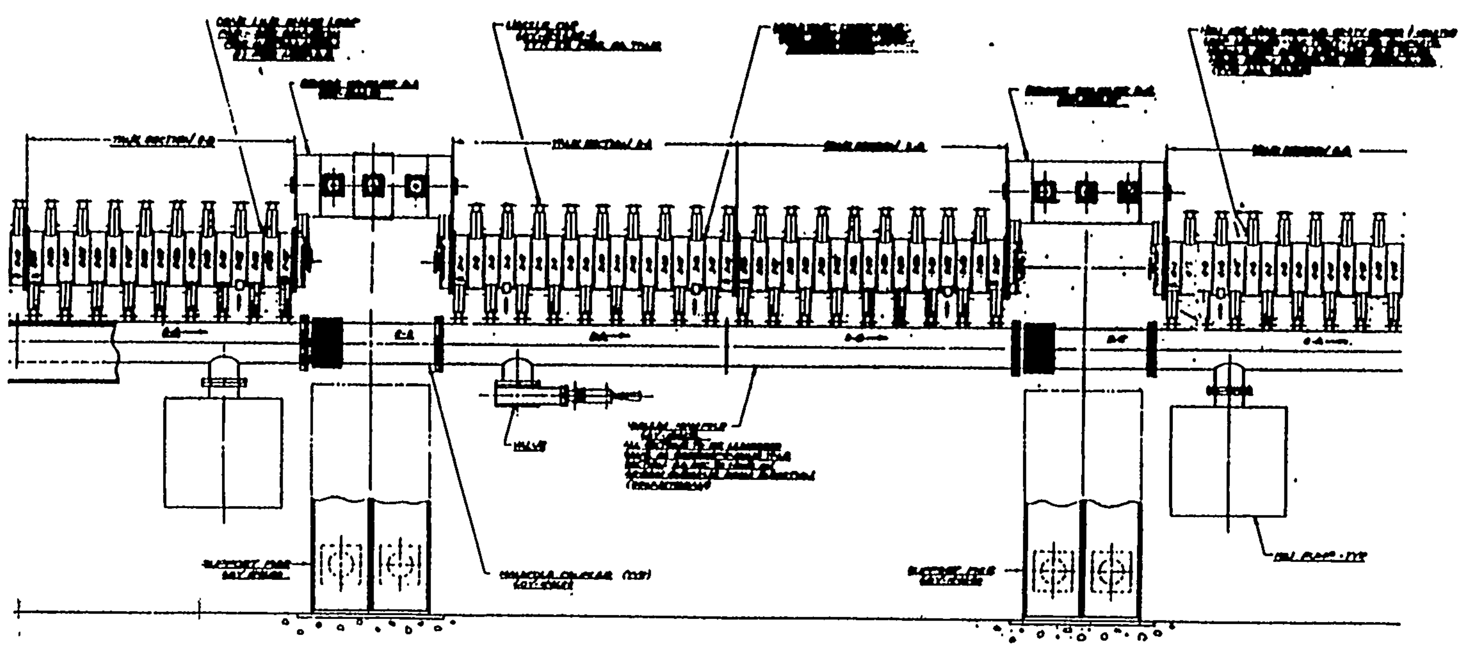
- Permanent-Magnet Quadrupole focusing, FFDD lattice, 5.43 m long
- 1.8 cm bore, 5σ aperture
- 1.5 MW peak power



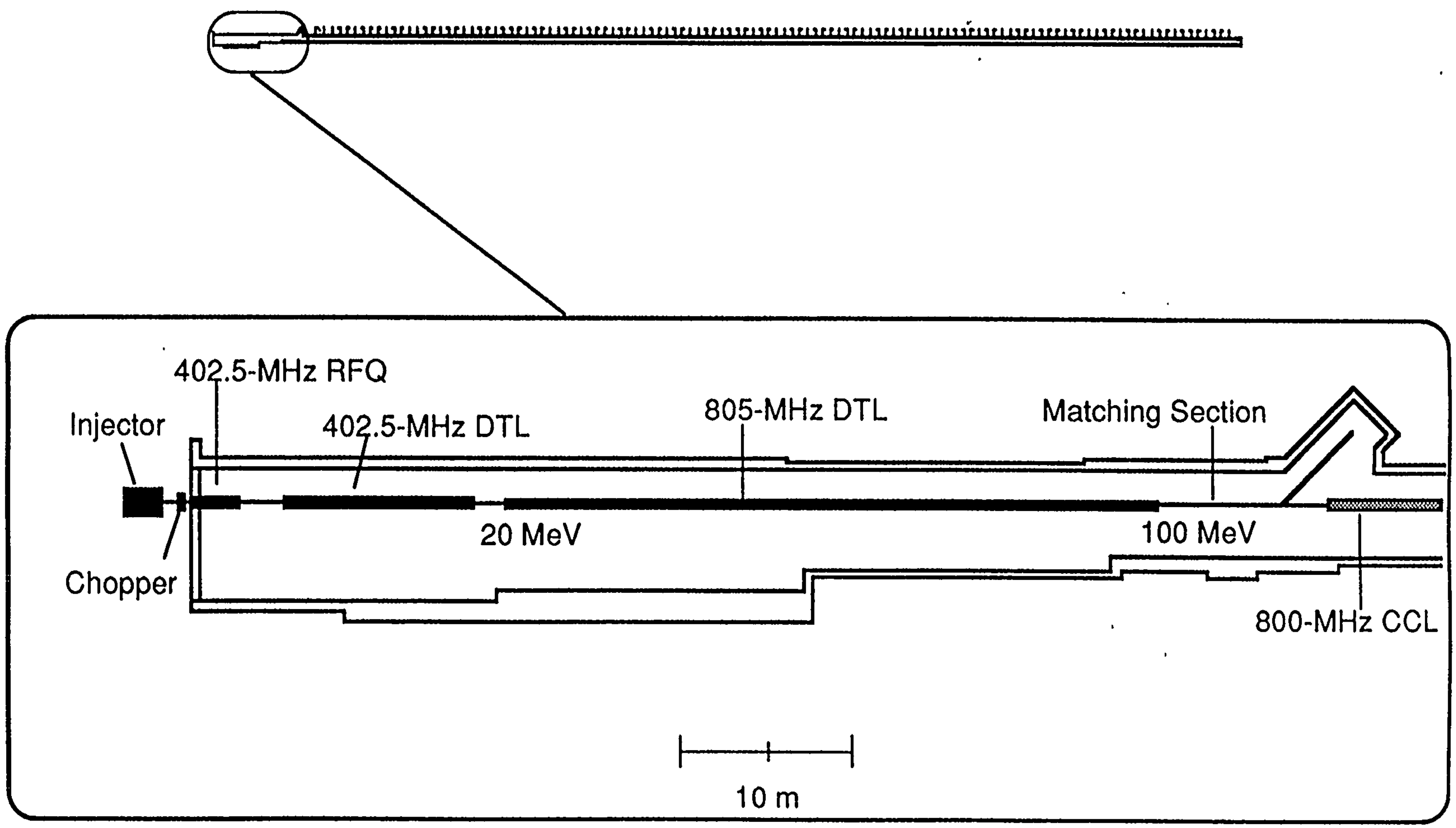
Coupled-Cavity Linac

- 800 MHz bridge-coupled structure
- Accelerates from 100 to 800 MeV
- High reliability

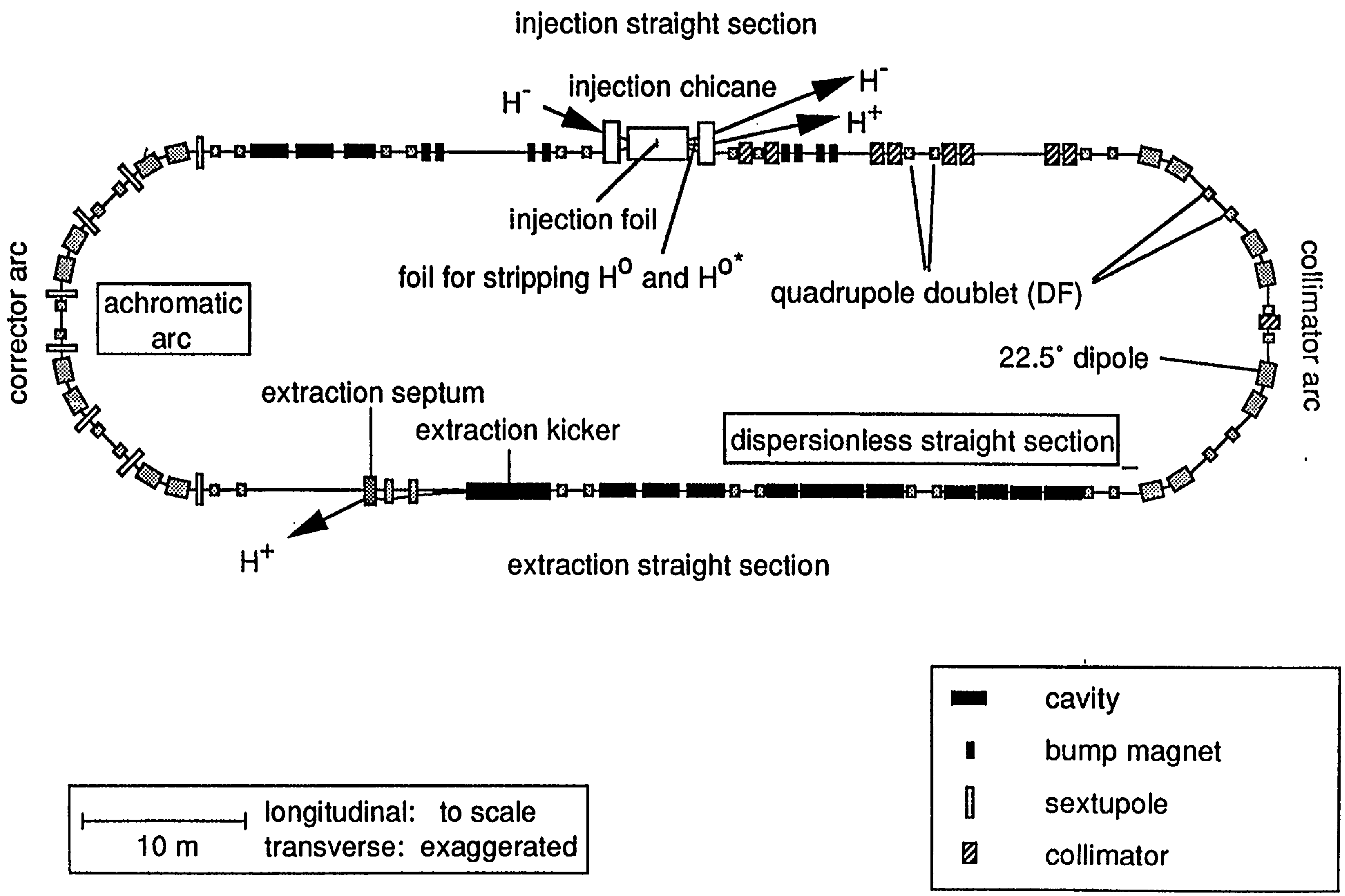




Small Fraction of Existing Linac Replaced

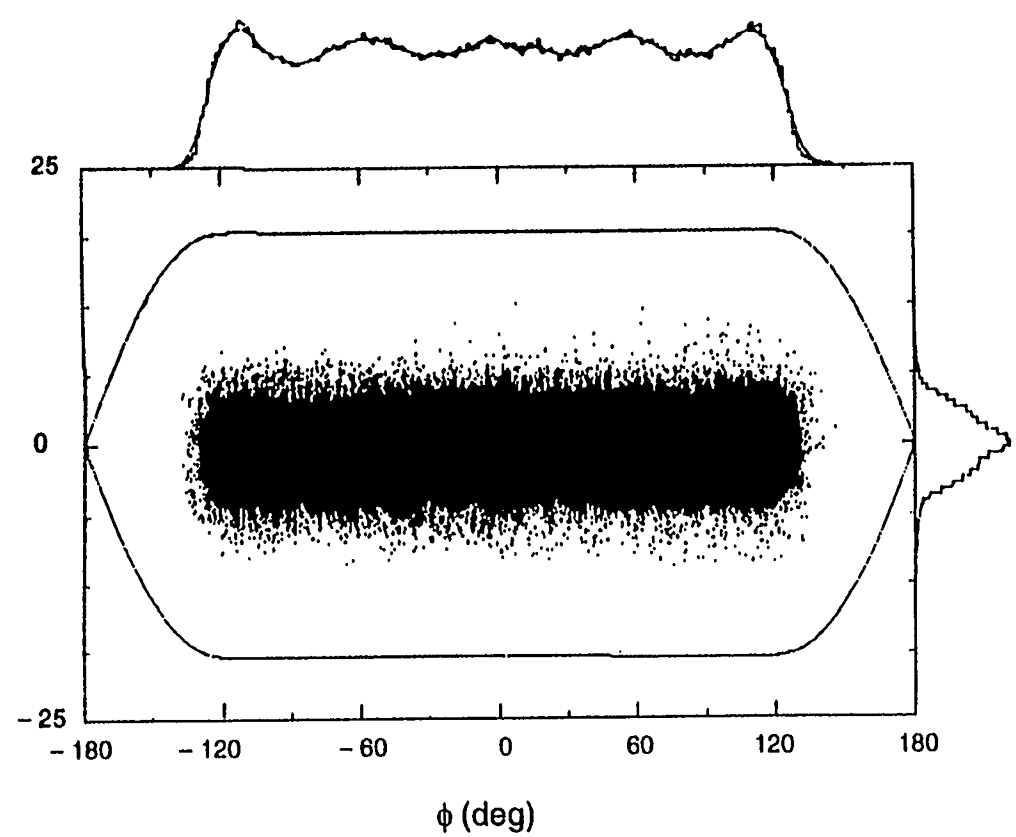


1-MW Accumulator Ring



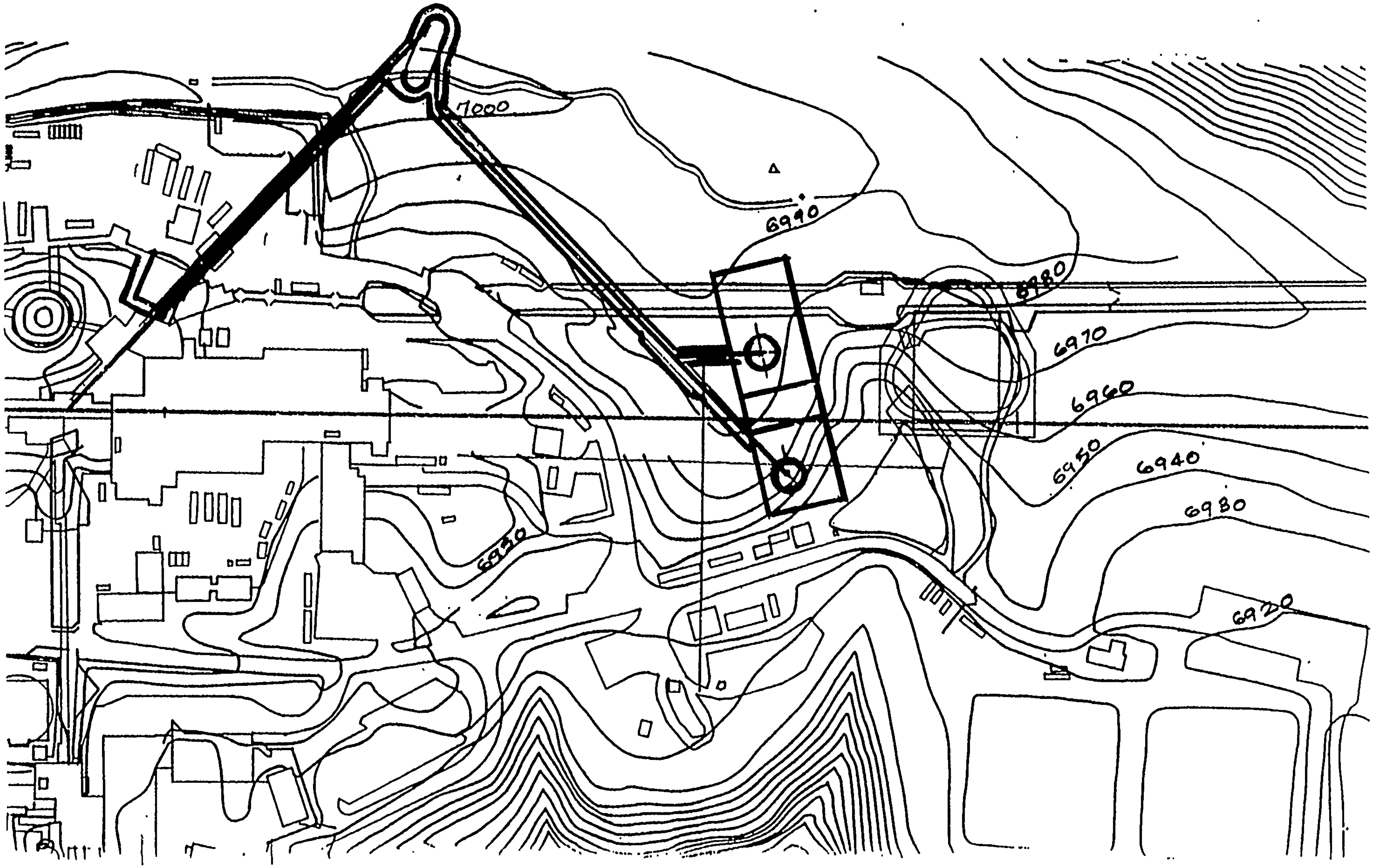
Longitudinal Dynamics

- injected-beam energy is swept by ±4MeV (±0.33%δp/p)
- a five-harmonic barrier bucket keeps gap beam free
- beam-free gap at extraction is 0.25 x ring circumference (~~168~~ 110 ns)
- beam-bunch length at extraction is 0.75 x ring circumference (~~503~~ 560 ns)
- bunching factor (average current/peak current) is 0.55



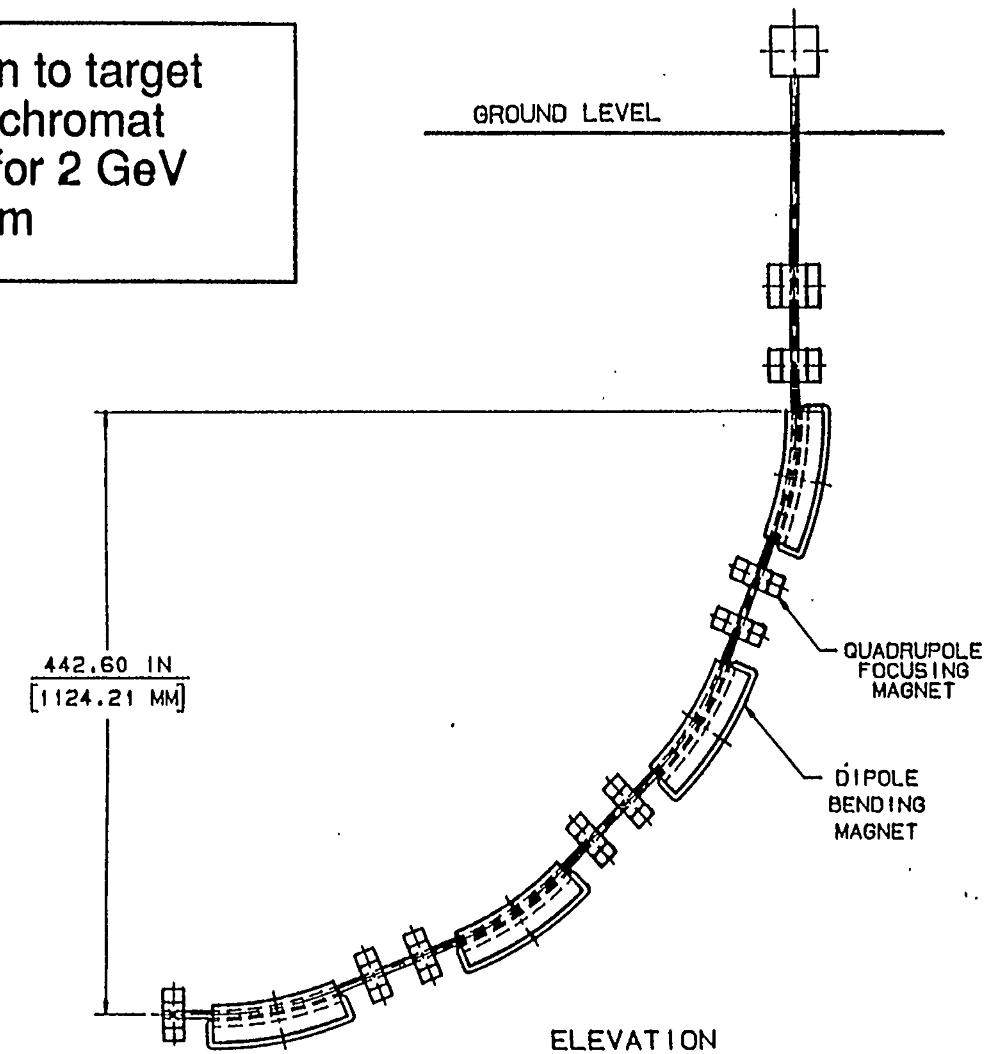
longitudinal beam distribution at extraction

LANSCE II
800 MEV SITE LAYOUT



Transport to Target

- Vertical insertion to target
- Second-order achromat
- Magnets sized for 2 GeV
- Aperture < 13 cm



Current in linac

rep rate		macropulse length		ring fill factor		injection efficiency		peak current		average current
60 Hz	x	1.2 ms	x	0.65	x	0.9	x	i_{peak}	=	1.25 mA

$\Rightarrow$ i_{peak} = **29.7 mA**

with an average peak of 19 mA

Include LEBT efficiency and 10% loss in RFQ

i_{source} = **40** mA

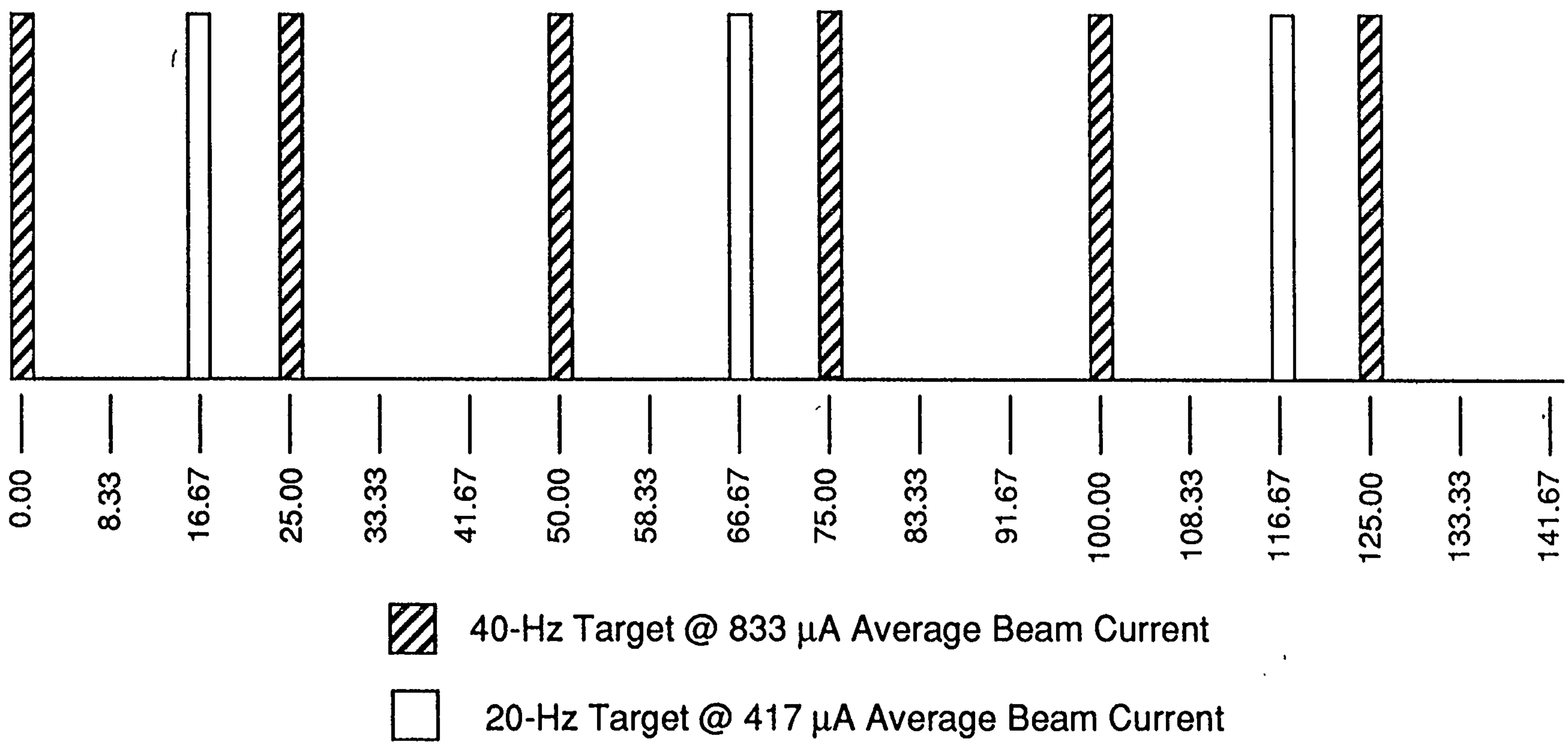
Relationship to LAMPF

- Same power, 1 MW
- Similar peak-average current - is 17 mA, will be 19 mA
- 65% of beam in bucket because of change from 201.25 to 402.5 MHz
- Low duty factor tests show that 26 mA peak at 201.25 MHz is easily controlled
- Negligible effect from droop (tank tilt from beam loading) and drop (response to chopping)

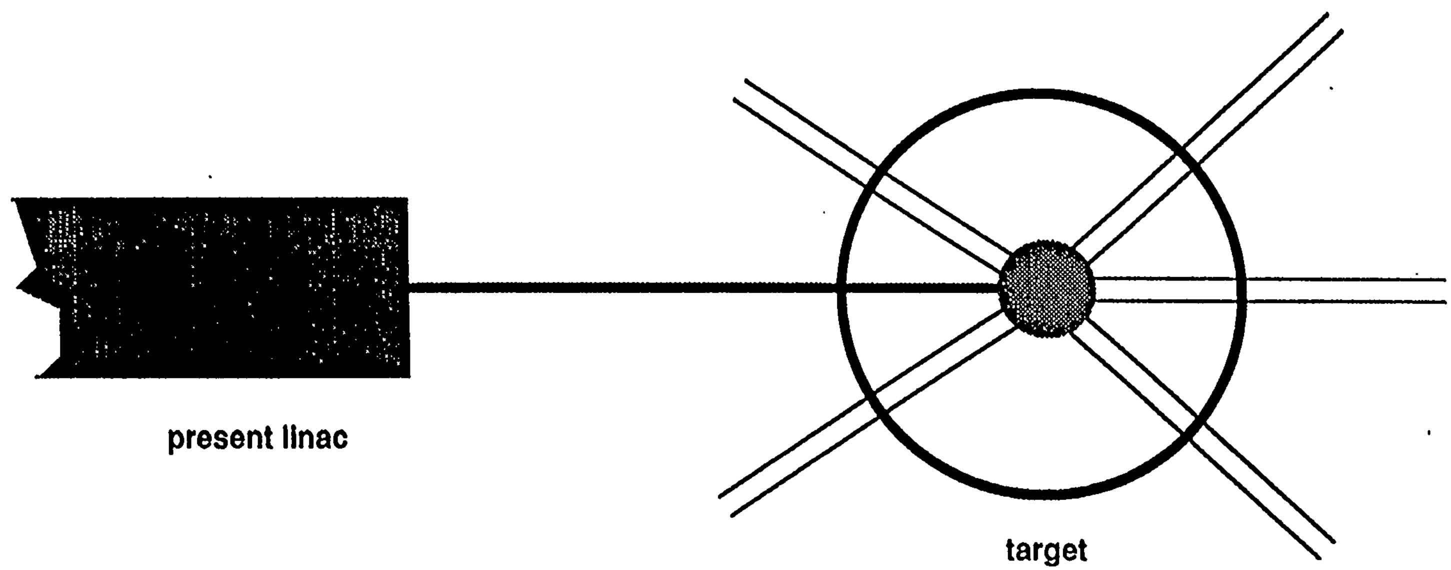
Source Requirements - H^-

- Current 33 mA at RFQ entrance
  40 mA at source
- Chopping 436 ns on, 235 ns off (1.49 MHz)
  < 20 ns rise time (2 ns preferred)
- Duty factor 7.2% at RFQ (60 Hz, 1.2 ms)
  8.6% source (possibly 17.2% if 120 Hz is required)
- Reliability 98%
- Maintenance > 2 weeks
- Emittance (rms, normalized) 0.015 π cm mrad (source) 0.02 π cm mrad (to RFQ)

System Pulse Train

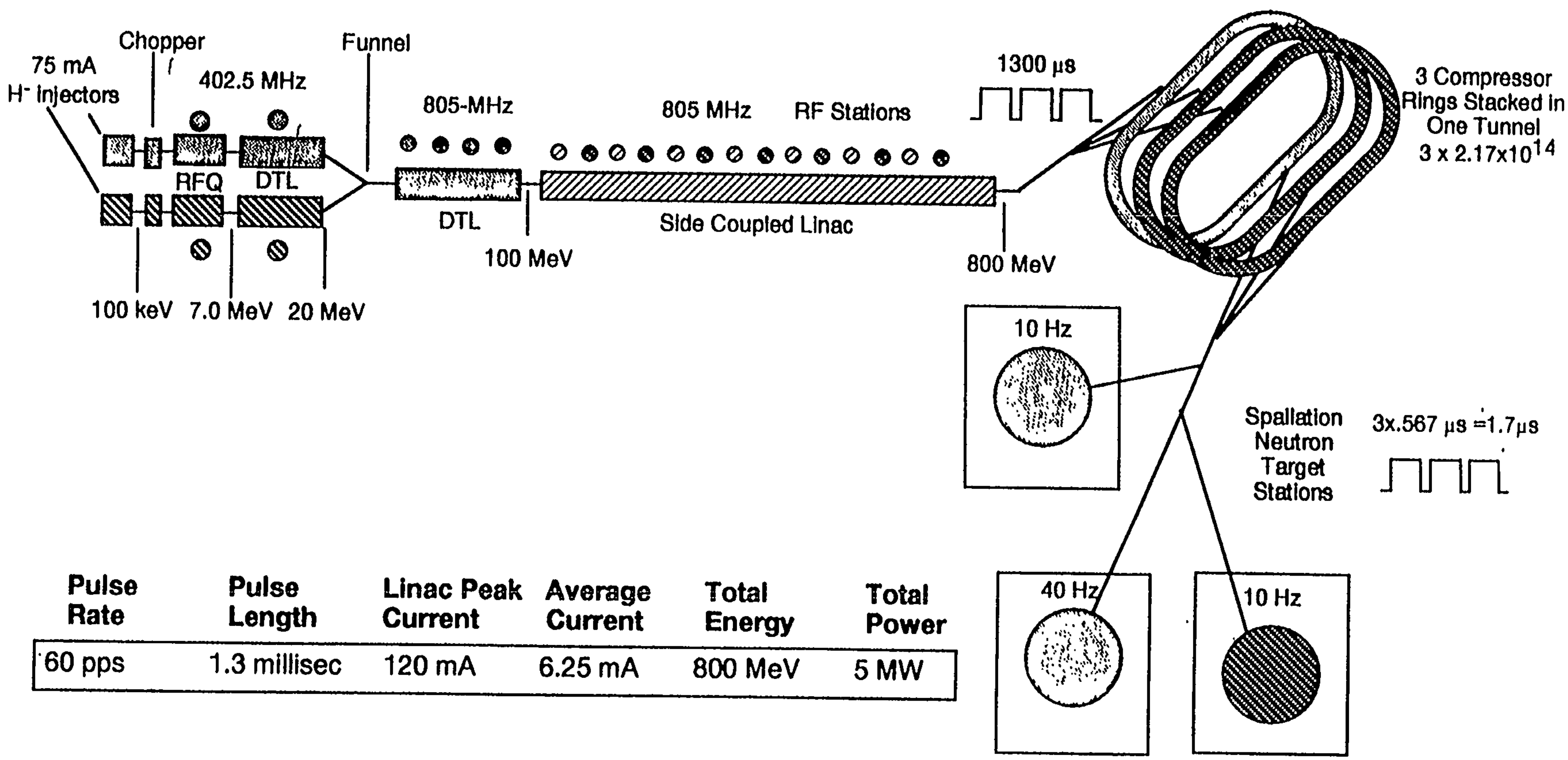


Linac only option
1MW



1/2 to 1 ms 60 Hz
Demonstrated linac performance
Peak currents from 41 to 21 mA

"5 MW" Pulsed Spallation Neutron Source - 800 MeV

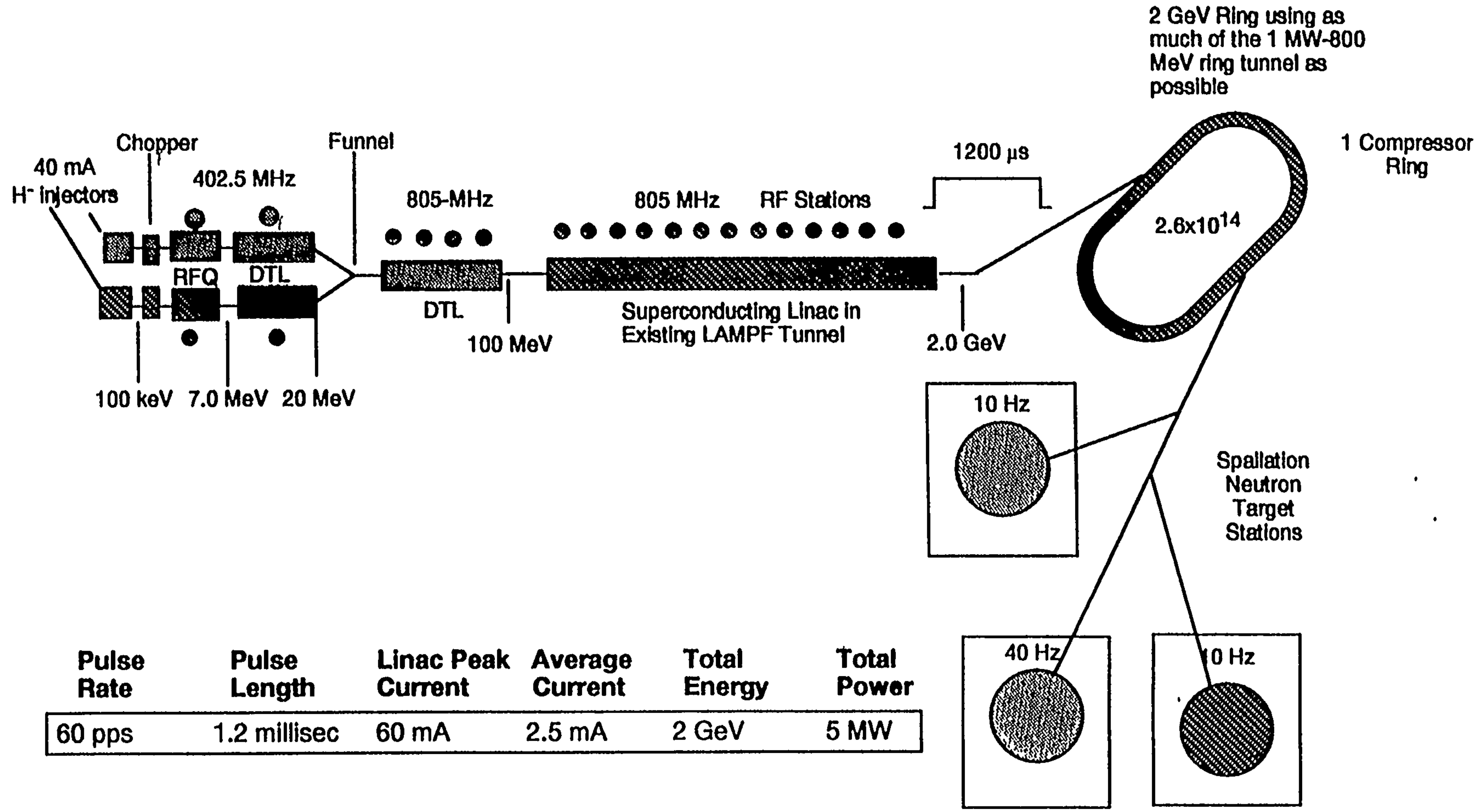


Pulse Rate	Pulse Length	Linac Peak Current	Average Current	Total Energy	Total Power
60 pps	1.3 millisec	120 mA	6.25 mA	800 MeV	5 MW

5 MW Equipment   1 MW Equipment   Original Equipment

A US Department of Energy Laboratory
Los Alamos
NATIONAL LABORATORY

"5 MW" Pulsed Spallation Neutron Source - 2 GeV



Pulse Rate	Pulse Length	Linac Peak Current	Average Current	Total Energy	Total Power
60 pps	1.2 millisec	60 mA	2.5 mA	2 GeV	5 MW

5 MW Equipment   1 MW Equipment   Original Equipment

US Department of Energy Laboratory
Los Alamos
NATIONAL LABORATORY

Source Requirement for IPNS Upgrade

Y. Cho

Argonne National Laboratory

Source Requirement

for

IPNS Upgrade

Y. Cho

October 24, 1994

LBL Ion Source Workshop

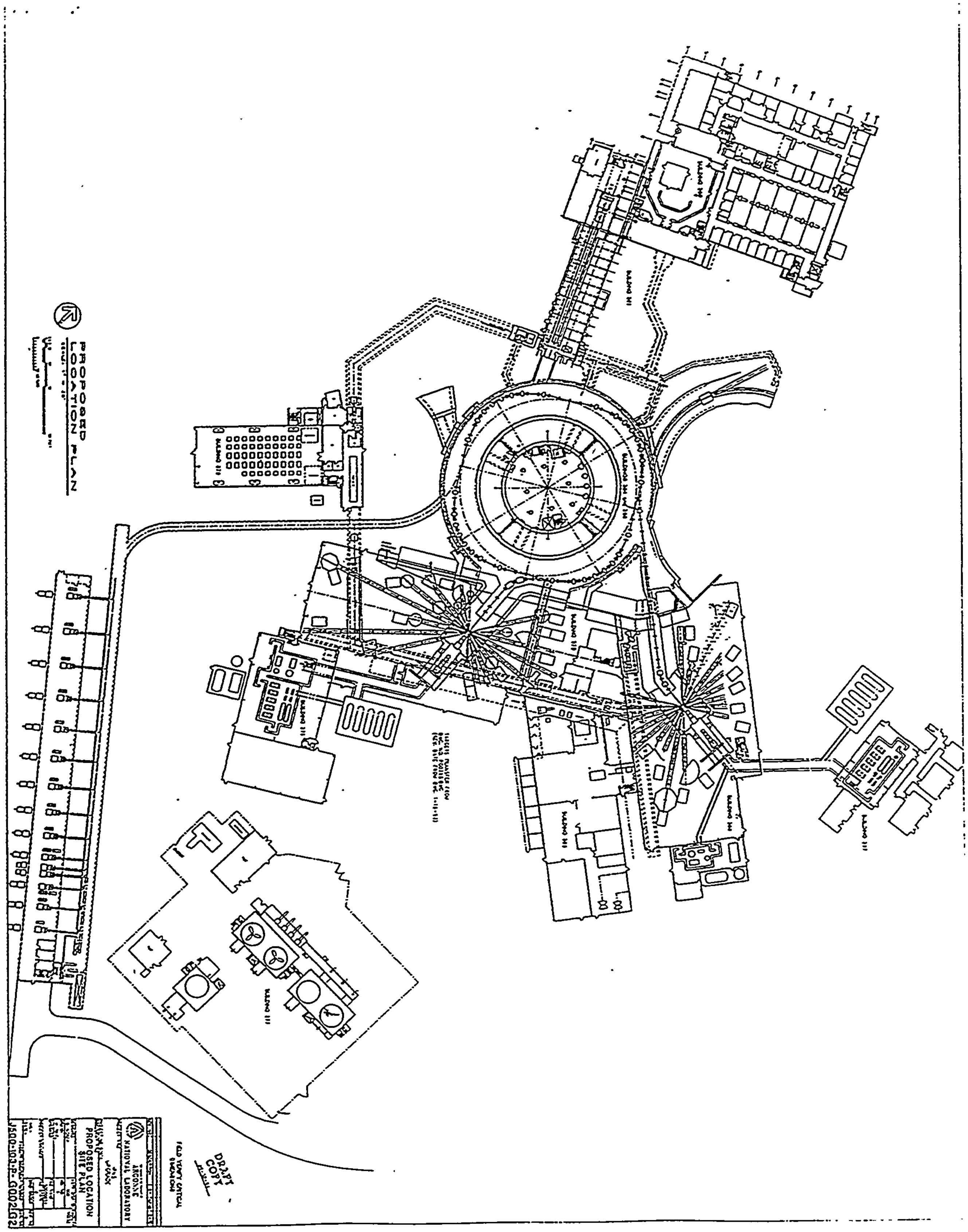
IPNS-Upgrade Proposal

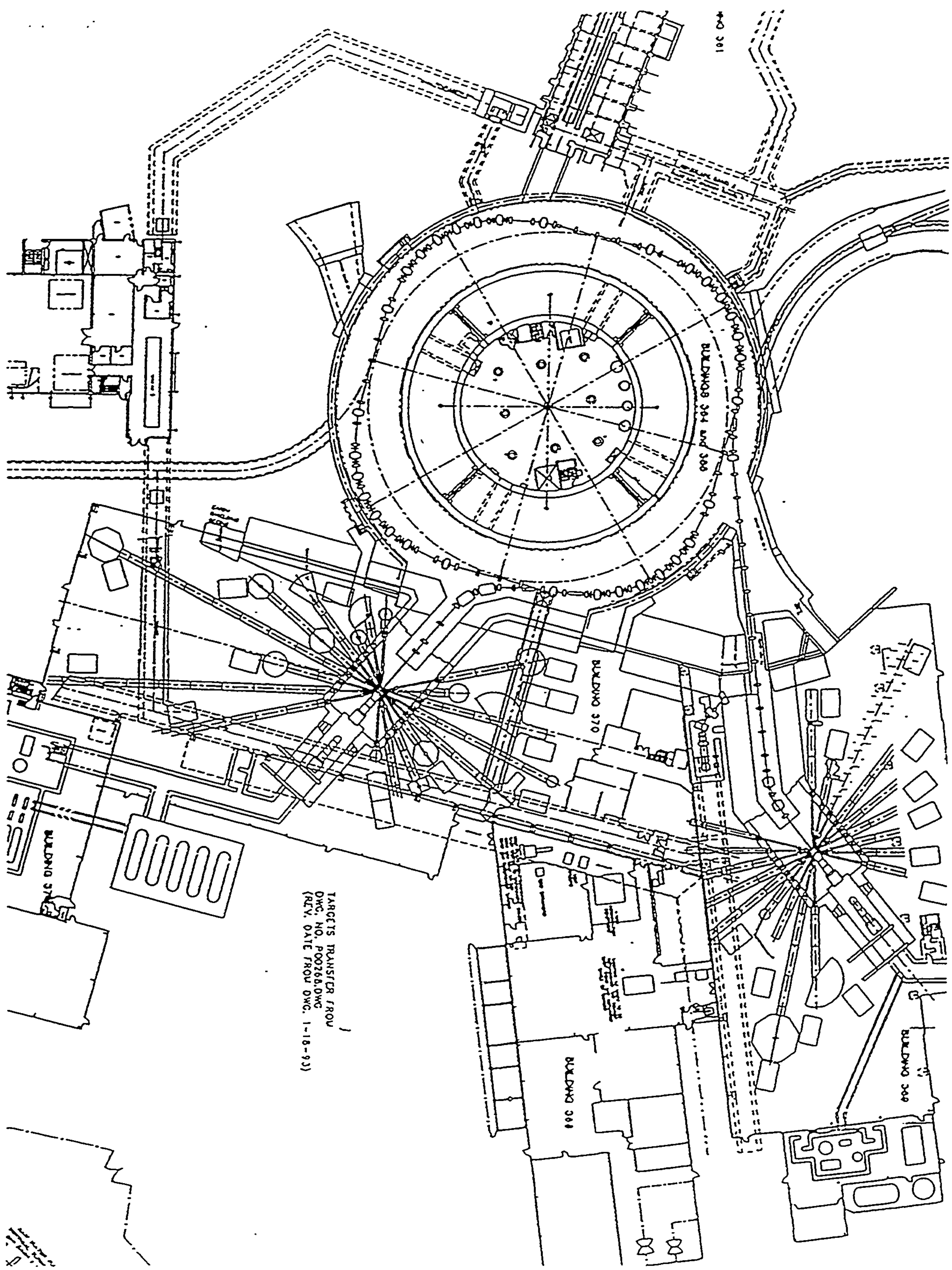
1-MW Pulsed Source using

2- GeV Rapidly Cycling Synchrotron (RCS),

30 Hz Repetition Rate from Users

Former ZGS Tunnel and Other Infra-structure


PROPOSED
LOCATION PLAN
DRAFT
COPY
ARGONNE
NATIONAL LABORATORY
PROPOSED LOCATION
SITE PLAN


BUILDINGS 364 AND 366
BUILDING 370
BUILDING 368
BUILDING 369
TARGETS TRANSFER FROM
DWG. NO. P00268.DWG
(REV. DATE FROM DWG. 1-18-93)

Describe How the Machine Parameters were determined, and

Implications to the Source Parameters

Extraction Energy → Average Current
Repetition Rate → Total Charges/ Pulse
Injection Period → Pulse Current
Acceptance at Injection → Source Emittance

Please Note that Requirements for Pulsed Source are different from Proton-Proton Collider Requirements.

For Colliders -

$\mathcal{L} \sim 1/(\varepsilon_x \varepsilon_y)$ under fixed number of particles. Therefore smaller emittance is highly desirable.

For Pulsed Source -

The requirements are large spot size, large number of particles, and least amount of beam losses. Therefore emittances in both transverse and longitudinal space should be any value comfortable with performance

Extraction Energy of Proton 2 GeV

Choice of Extraction Energy:
Highest Possible Energy so that
Required Current be Minimal.

Also the Ring should fit in ZGS Tunnel
(Circumference ~ 200 m)

Primary Reason for Lowest Possible Current -
Beam Loss Consideration

Secondary Benefit - Easy on Source Requirement

Time Averaged Current - 0.5 mA

Number of Protons per pulse - 1.0 10^{14}
for 30 Hz Operation

Assume Injection without chopping
Injection Period of 0.5 msec > **I_{pulse} = 33 mA**
Injection Period of 0.33 msec > **I_{pulse} = 50 mA**
Duty Factor - 1 ~ 1.5 %
These number will be modified by a chopping factor.

Injection/Capture Simulation Study shows:

25 % Chopping of Linac Beam is needed to eliminate the Capture Losses.

Linac Beam Momentum Spread should be
$\Delta p/p \sim 4\ 10^{-3}$

Therefore I_{pulse} at the Linac Input becomes:

I_{pulse} = 44 mA for 0.5 msec Pulse or
I_{pulse} = 67 mA for 0.33 msec Pulse

Revolution Time of RCS is order of 1 μsec, and harmonic number is 1, therefore the chopping is to be done with 1 MHz chopper.

Injection Energy to RCS - Lowest Possible
Beam Loss Consideration - Most of losses occur during injection and capture, and lower energy losses are easier to handle.

Magnet Aperture -
Acceptance and Beam Stay-Clear (BSC)
BSC - 375 π mm mr for both planes

Injection Energy - 400 MeV
from BSC and Space Charge Tune Shift.

400 MeV H^- Beam - To Paint Transverse Phase Spaces of 375 π mm mr.

Question is What is the Linac Emittance, and therefore the source emittance.

Some 10 years old survey of linac emittances
$\beta\gamma\varepsilon_{rms}$ = 2 π mm mr at linac output
$\beta\gamma\varepsilon_{rms}$ = 1 π mm mr at linac input
$\beta\gamma$ at 400 MeV is ~ 1.

We convert rms to 100 percentile emittance by multiplying with $(6)^{1/2}$ with a note that proton emittance is not a Gaussian.

Therefore we use the linac emittance 2-5 π mm mr 100 percentile.

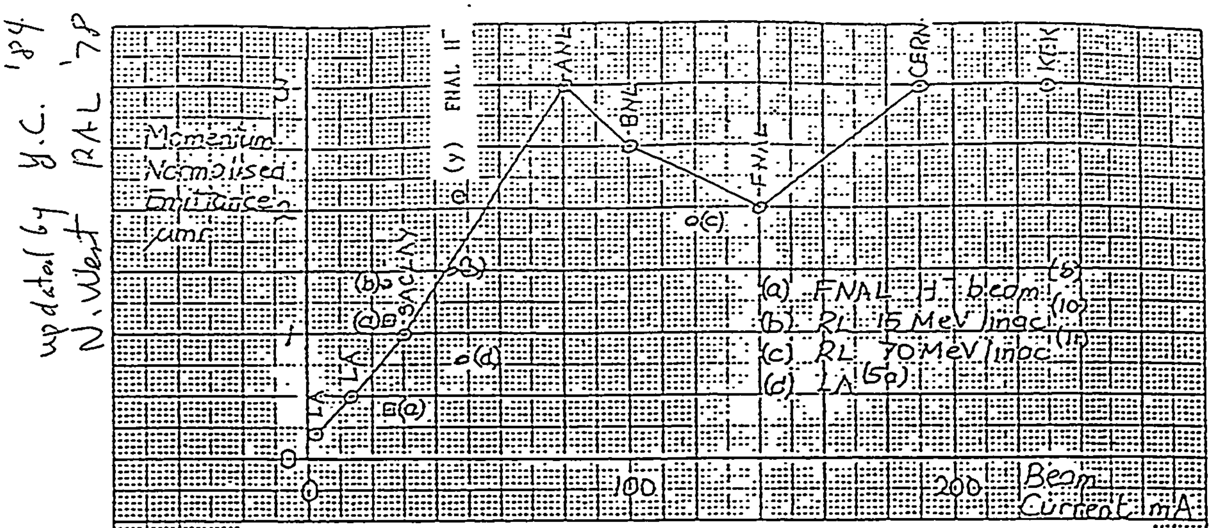


Fig. 1 Measured values of momentum normalised emittance at the input to a linac for 90% of the total beam current.

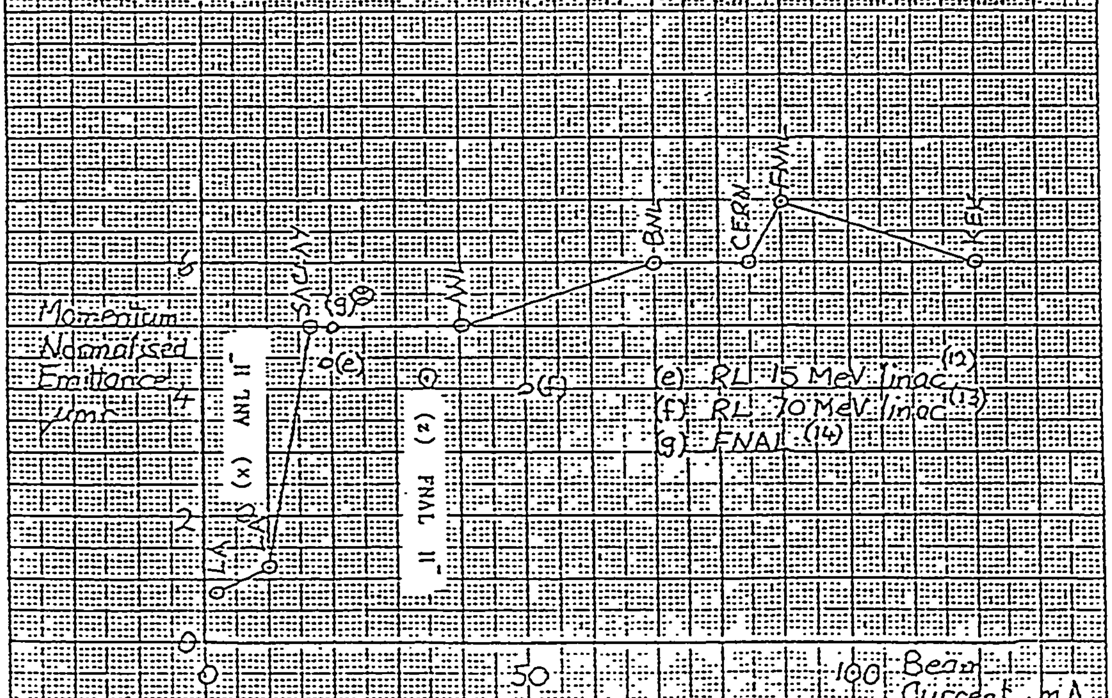


Fig. 2 Measured values of momentum normalised emittance at the output of a linac for 90% of the total beam current.

NOTE Figures obtained by P E Gear from June 78 visit to FNAL give almost identical emittance values in both planes for H beam from linac. 90% of total current figure is plotted above as - ⊗

SUMMARY

Peak Current	44 ~ 67	mA
Pulse Length	0.5 ~ 0.33	msec
Fraction Chopped	25	%
Chopping Frequency	1.1	MHz
RFQ Injection Energy	35	keV
Repetition Rate	30	Hz
Duty Factor	~1.5	%
$\beta\gamma\varepsilon_{rms}$ at linac input	$1\ \pi\ 10^{-6}$	m rad
Flatness during Pulse	<10	%
Repeatability (pulse to pulse)	~5	%
Time between maintenance	Long - 14	days
Time for maintenance	Short - 24	hours
Availability of System	>90	%

Multiple Sources and Quick Interchange Capability

Brookhaven Proposal

J. Alessi

Brookhaven National Laboratory

Brookhaven Proposal

BSNS

J. Alessi, BNL

June, 1994 – Preconceptual Design Study

A. van Steenbergen, Study Coordinator

Table 2-3. General Parameters of the Spallation Neutron Source

Beam Power	5	MW
Final Proton Kinetic Energy	3.6	GeV
Average Proton Beam Intensity	1.4	mA, on Target
Number of Synchrotrons	2	
Synchrotron Repetition Rate	30	Hz
Number of Protons/pulse	1.45×10^{14}	per Synchrotron
Synchrotron Circumference	363	m
Beam Pulse Length on the Target	< 1.24	μs
Linac Energy	600	MeV
Linac Repetition Rate	60	Hz

A conceptual site arrangement of the principal SNS elements is given in Fig. 2.-6.

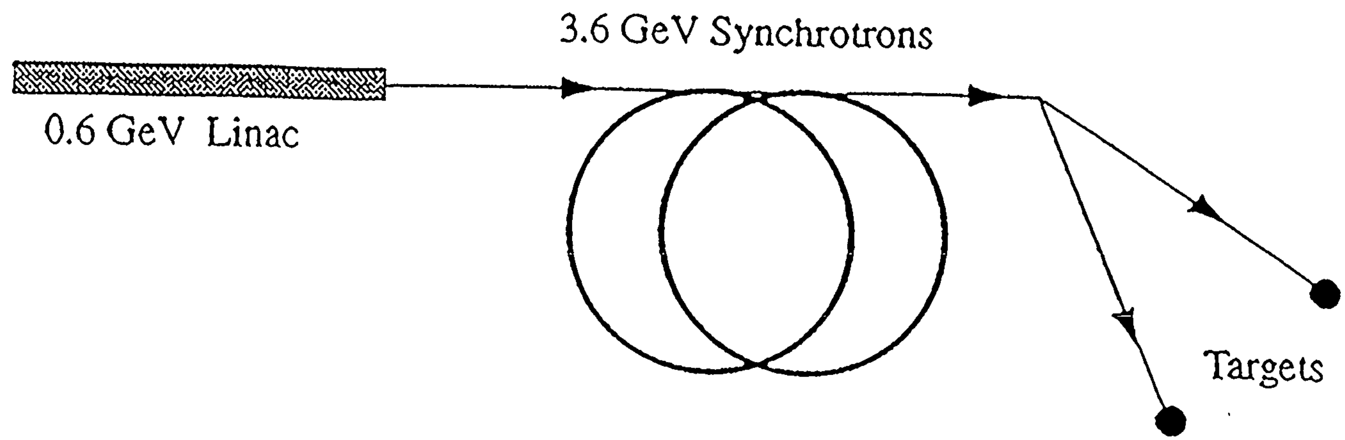


Fig. 2.-5 , Design Concept of the Spallation Neutron Source

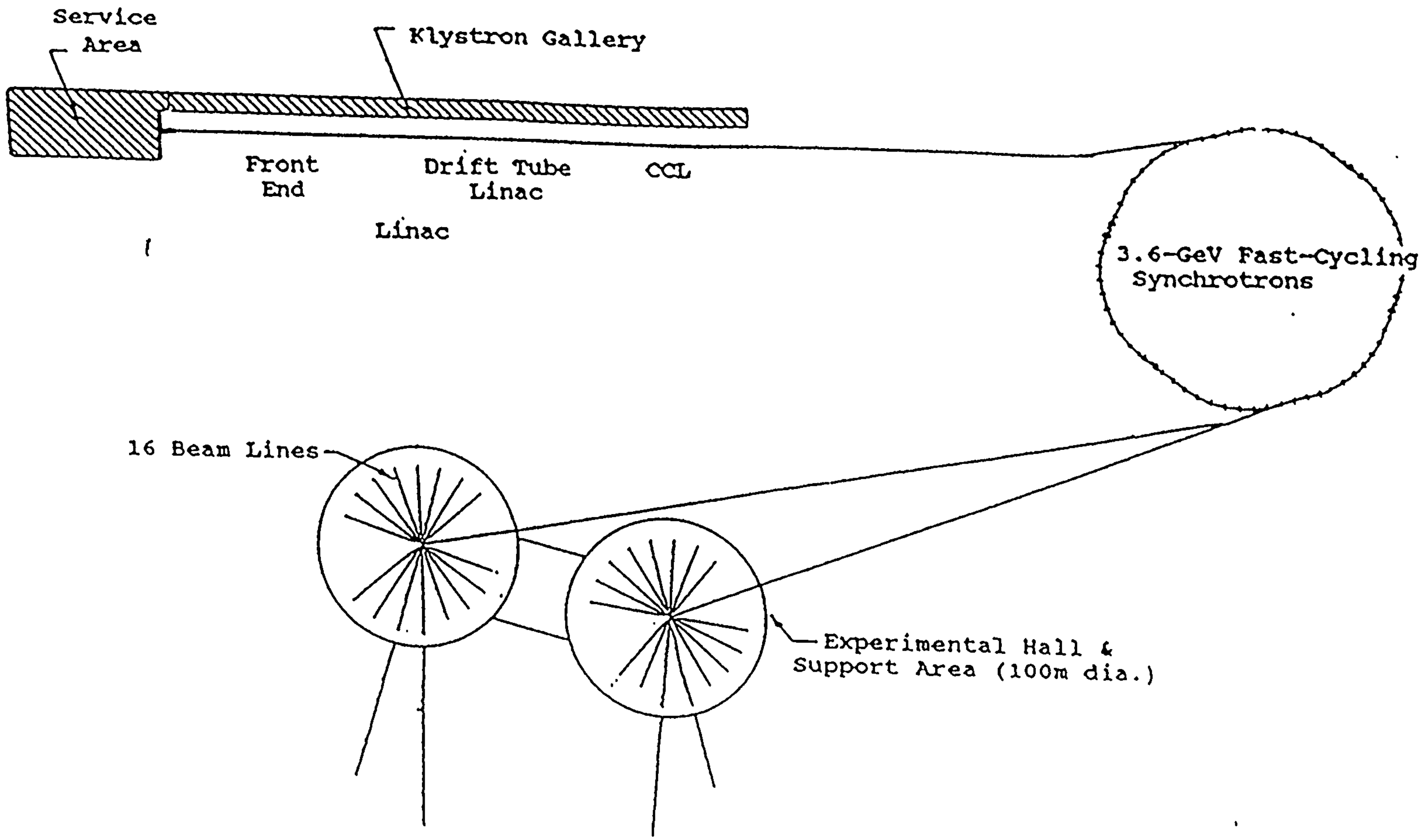
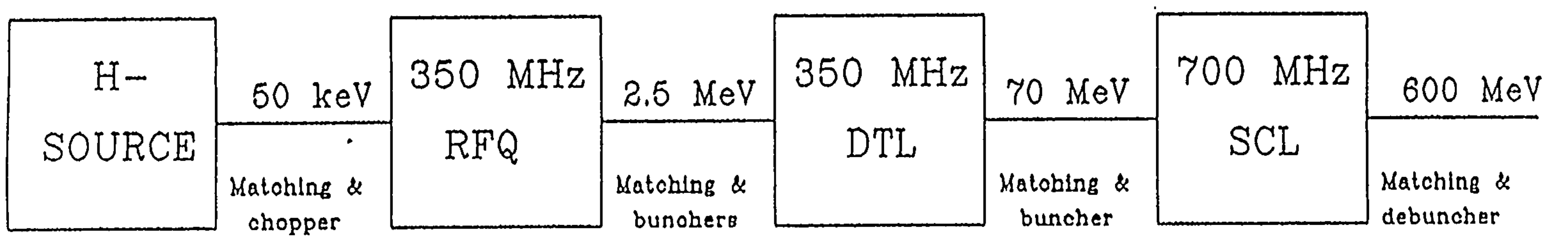


Fig.2.-6, Pulsed Spallation Neutron Source Conceptual Site Arrangement



Rep rate = 60 Hz
Beam width (300 turns) = 450 us
RF width = 500 us
RF duty factor = 3%
H− current = 100 mA (peak)
Chopper duty factor = 50%
Average current = 1.35 mA

Fig. 4.2-1

Table 4.2-1
LINAC BEAM PARAMETERS

<u>H⁻ SOURCE</u>	
Type	Penning surface plasma source
Current	150 mA
Energy	50 keV
Emittance	0.2 π mm mrad (normalized, rms)
<u>RFQ</u>	
Frequency	350 MHz
Energy	
Input	50 keV
Output	2.5 MeV
Current	
Input	125 mA
Output	105 mA
Emittance	
In, transverse	0.2 π mm mrad (normalized, rms)
Out, transverse	0.23 π mm mrad (normalized, rms)
Out, longit.	0.162 π MeV-degrees (rms)
<u>DTL</u>	
Frequency	350 MHz
Energy	
Input	2.5 MeV
Output	70 MeV
Current	
Input	100 mA
Output	100 mA
Emittance	
In, transverse	0.23 π mm mrad (norm., rms)
Out, transverse	0.27 π mm mrad
Out, longit.	0.418 π MeV-degrees (rms)
<u>SCL</u>*	
Frequency	700 MHz
Energy	
Input	70 MeV
Output	600 MeV
Current	
Input	100 mA
Output	100 mA
Emittance	
In, transverse	0.27 π mm mrad (norm., rms)
Out, transverse	0.35 x 0.42 π mm mrad (norm., rms)
Out, longit.	0.800 π MeV-degrees (rms)
$\delta p/p$ (before energy compressor)	$\approx 1.5 \times 10^{-3}$ (full width, full beam)

*The output emittance of the SCL will be improved in the next design iteration.

Parameters assumed for design -
(some flexible)

Source

H^- ions

60 Hz

150 mA (losses and chopping df pessimisti

450 μs (300 turns)

3% duty factor

$\epsilon_{n,rms} = 0.2\ \pi$ mm mrad

Penning seems to fit these requirements
Magnetron ~ok if ϵ requirement relaxed.

Chopping

1.31 MHz

50% duty factor assumed (pessimistic)

→ 380 ns on / 380 ns off

H^- Source for 100 mA ?

LANL "4X" Penning source:

$H^- = 150$ mA @ 180 A, 100 v. discharge

× 3% d.f → 540 watts

They have operated at this avg. power.

$\epsilon_{n,rms} = 0.2\pi$ mm mrad from 5.4 mm ϕ

$e/H \lesssim 1$

Basically, the source exists.

Excellent emittance.

Some development needed:

- Estimate 4 week cathode lifetime
- Extractor erosion uncertain

Chopping

We want ≈ 50 % chopping df --> 375 ns on / 375 ns off

BNL experience in chopping:

At 35 keV, chopping destroyed the space charge neutralization of the beam, distorting the emittance and leading to a poor transmission through the RFQ.

At 750 keV, the chopping works well. No emittance distortion, no loss in transmission. With our chopper, we obtain 10 ns rise and fall times on the beam pulses, and can vary the "micropulses" from ≈ 80 ns to 400 ns (every 400 ns). We can vary the width of each micropulse.

Chopping for SNS (in order of preference)

1. Use an unneutralized, electrostatic transport from the source to RFQ. Electrostatic quadrupoles seem like the best option (U. of Maryland). A voltage can be put on appropriate poles to chop the beam by deflecting out of the RFQ acceptance.

2. If a neutralized transport is used between the source and RFQ (magnetic solenoids), then variation of the energy of the beam by -6 keV (from 35 keV) will prevent acceleration in the RFQ. (Question - how good will rejection be?)

3. If one wants to chop after the RFQ: the beam must be kept small to prevent emittance growth --> can't drift the beam very far (space charge) --> one could build a section with alternating quadrupoles/deflecting plates. Might add 1 meter between RFQ and linac. Not "elegant", but a conventional, safe solution.

Penning Sources for LANSCE II

V. Smith

Los Alamos National Laboratory

Penning Sources for LANSCE II

Vernon Smith

Accelerator Operations and Technology Division
Los Alamos National Laboratory

Presented to the

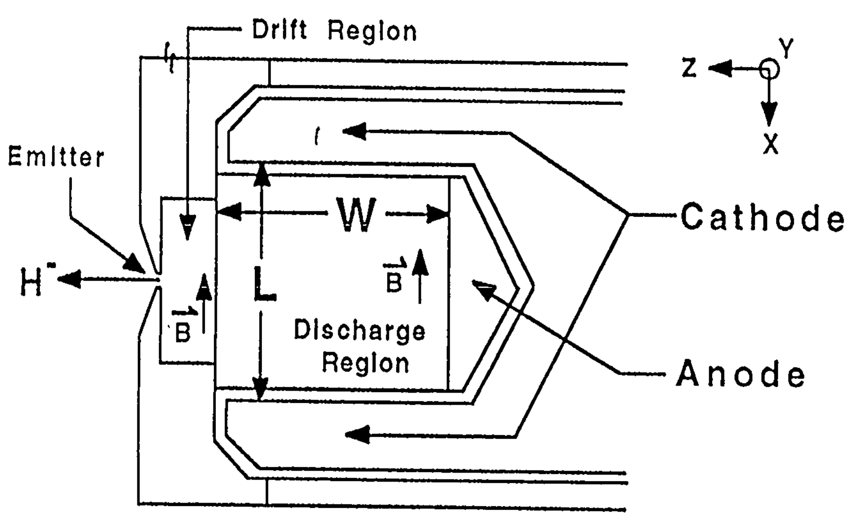
Workshop on Ion Source Issues
Relevant to a Pulsed Spallation Neutron Source

Berkeley, CA

Talk Outline

- Description of Penning SPS
- LANSCE II injector requirements
  - 1 MW option
  - 5 MW option
- Los Alamos Penning SPS performance
  - GTA injector
  - Off-line test stand (HCTS)
- Shortfall between present and required source performance
- Proposed R&D program to bring source performance up to the required levels
- Conclusions

Description of Penning Surface-Plasma Source (SPS) Operation



1X Source	L = 0.43 cm, F_c = 20 kW/cm^2
4X Source	L= 1.7 cm, F_c = 2.2 kW/cm^2
8X Source	L = 3.4 cm, F_c = 1.3 kW/cm^2

- A hydrogen-cesium discharge operates in a magnetic field
- The extracted H^- are formed
  - by resonant-charge exchange of H^-_{fast} with H°_{slow}
  - by H° collisions with cesium-coated anode walls
- Features
  - Produces high-current, low-emittance H^- beams
  - The e^-/H^- ratio is $\leq 1/1$ in the extracted H^- beam
  - No filament or rf-antenna to limit lifetime

LANSCE II Injector Requirements - 1 MW

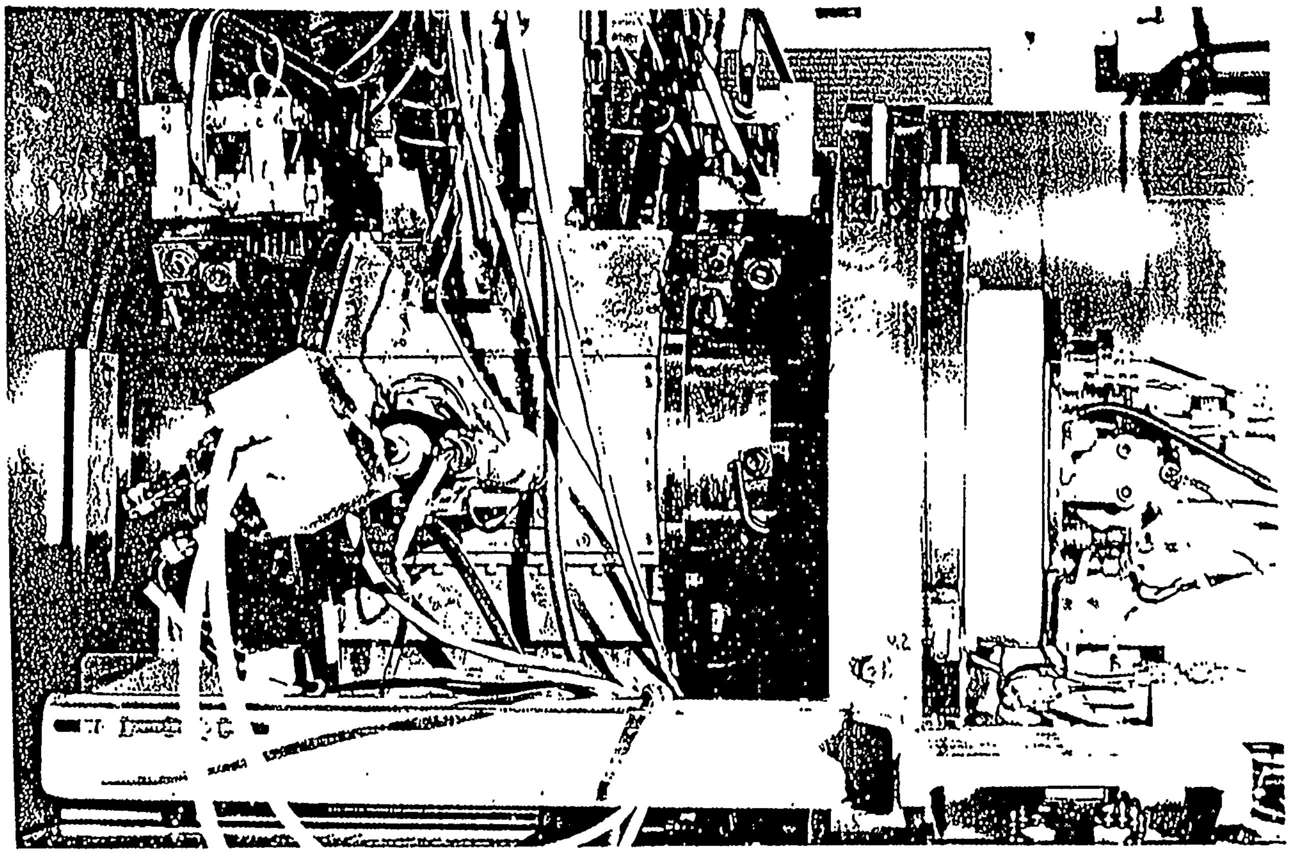
- Beam Current - 33 mA at the RFQ input (40 mA from the ion source)
- Beam Energy - 100 keV
- Pulse Length - 1.2 ms
- Beam Emittance - $\varepsilon_{n,rms}$ = 0.020 π cm mrad at the RFQ match point (0.015 π cm mrad from the ion source)
- RFQ Match Parameters - $\alpha = 0.97$ and $\beta = 0.0034$ cm/mrad
- Pulse Repetition Rate - 60 pps with 40 Hz and 20 Hz interleaved pulse trains at a 120 Hz basic repetition rate
- Beam Turn-on Time - 30 μs with pulse-time modulation after rejection of the initial 200 μs of each beam pulse
- Beam Duty Factor - 8.6% (1.43 ms at 60 pps)
- Chopping - beam off 235 ns / beam on 436 ns for the entire 1.2 ms pulse

LANSCE II Injector Requirements - 5 MW

- Beam Current - 33 mA at two RFQ inputs (40 mA from two ion sources) or 65 mA at one RFQ (80 mA from one ion source)
- Beam Energy - 100 keV
- Pulse Length - 1.2 ms
- Beam Emittance - $\varepsilon_{n,rms}$ = 0.020 π cm mrad at the RFQ match point (0.015 π cm mrad from the ion source)
- RFQ Match Parameters - $\alpha = 0.97$ and $\beta = 0.0034$ cm/mrad
- Pulse Repetition Rate - 60 pps with 40 Hz and 20 Hz interleaved pulse trains at a 120 Hz basic repetition rate
- Beam Turn-on Time - 30 μs with pulse-time modulation after rejection of the initial 200 μs of each beam pulse
- Beam Duty Factor - 8.6% (1.43 ms at 60 pps)
- Chopping - beam off 235 ns / beam on 436 ns for the entire 1.2 ms pulse

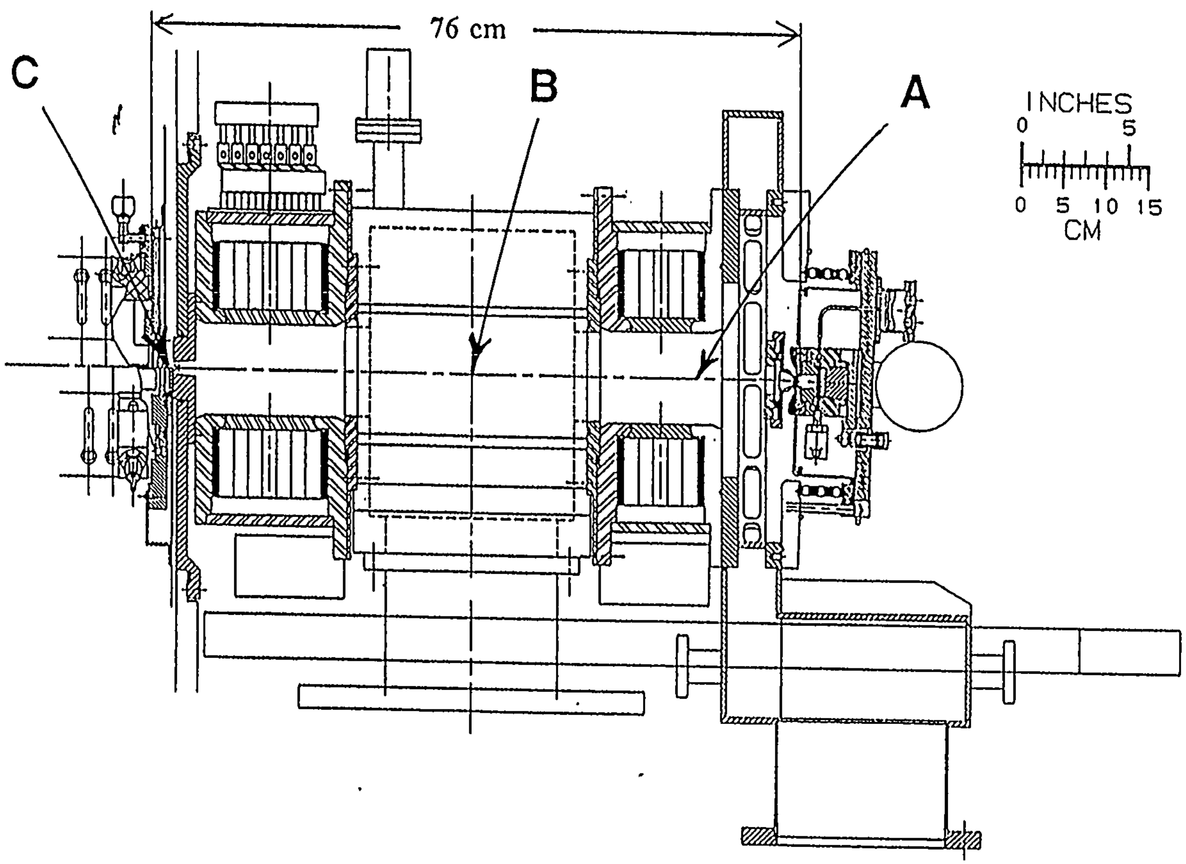
Workshop on Ion Source Issues   October 24-26, 1994   Los Alamos

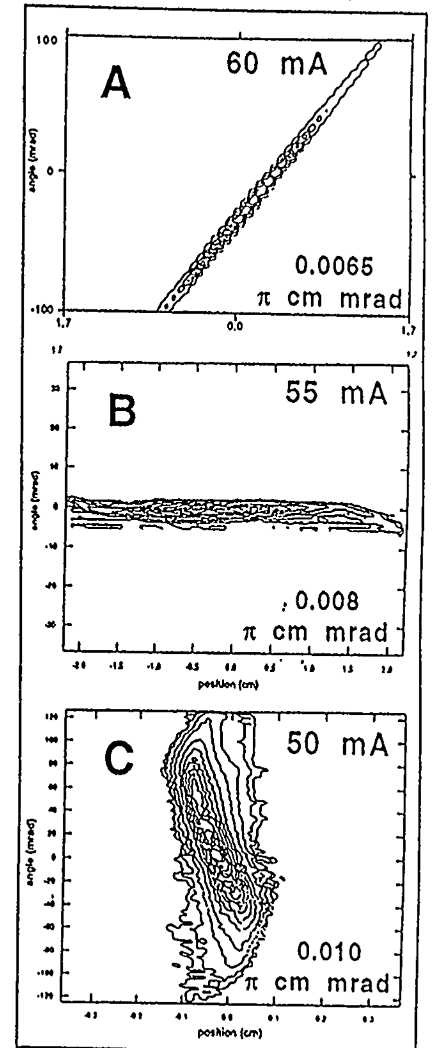
4X Source on the GTA Injector



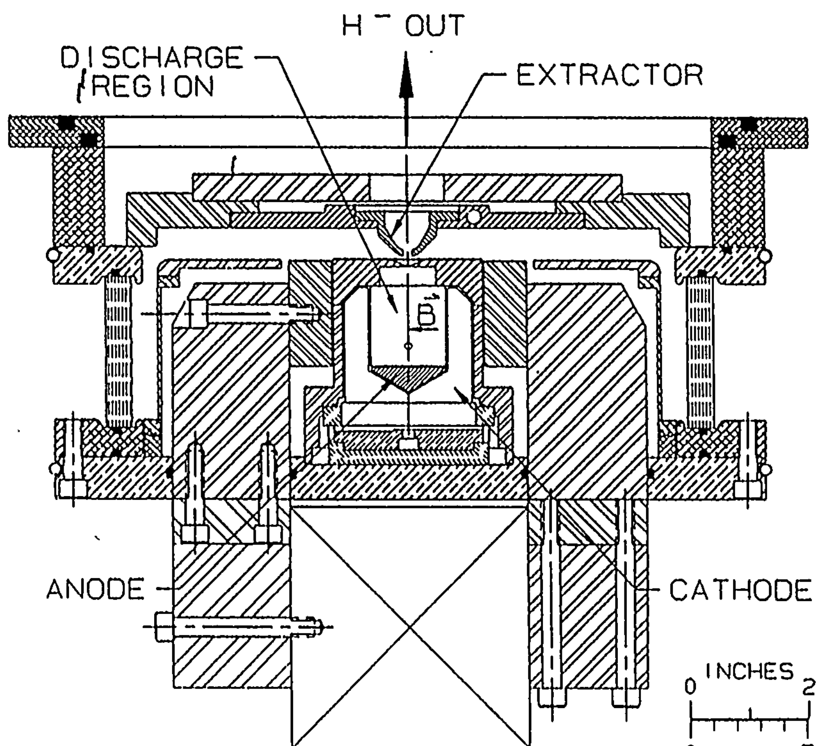
- The 4X source, with a two-solenoid magnetic LEBT, routinely delivered 35-keV, 50-mA, 0.010-π-cm-mrad H^- beams to the ground-test accelerator (GTA) RFQ
- The arc duty factor was typically 1 %; the beam duty factor, 0.15 %

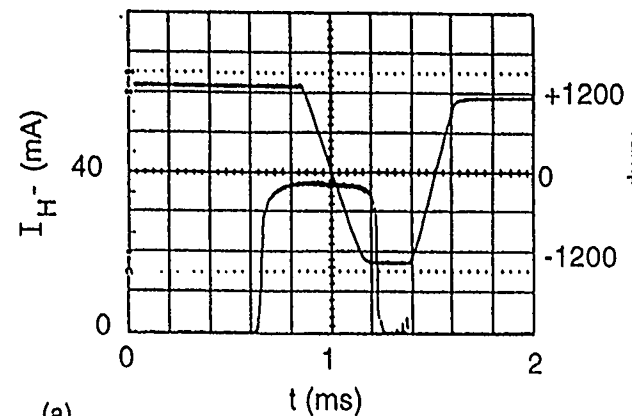
GTA Injector Emittance



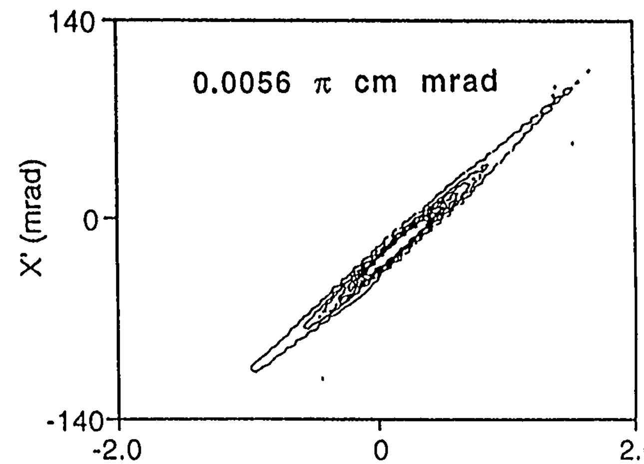


8X Source on the Test Stand





(a)



(b)

Summary of Los Alamos Penning Sources

(0.26-cm-diam Emitters)

	4X Source[1] (test stand)	4X Source[2] (GTA Inj.)	8X Source[1] (test stand)
H^- Current, mA	63	50	40
$\varepsilon_{x,y}$, π cm mrad	0.0063 x 0.0065	0.010 x 0.010	0.0062 x 0.0065
Beam energy, keV	35	35	25
Arc pulse length, ms	2.3	2.0	1.2
Arc duty factor, %	2.3	1.0	0.6
Beam pulse length, ms	2.0	0.3[3]	0.6
Beam duty factor, %	2.0	0.15[3]	0.3

[1] 12 cm from the emitter [2] At RFQ entrance 75 cm from the emitter

[3] Limited by cryogenic accelerator heat loading

Summary of Los Alamos Penning Sources

(0.54-cm-diam Emitters)

	4X Source[1] (test stand)	8X Source[1] (test stand)
H^- Current, mA	150	120
$\varepsilon_{x,y}$, π cm mrad	0.020 x 0.019	0.015 x 0.014
Beam energy, keV	23	30
Arc pulse length, ms	1.1	1.2
Arc duty factor, %	0.5	0.6
Beam pulse length, ms	0.6	0.5
Beam duty factor, %	0.3	0.25

[1] 12 cm from the emitter

LANSCE II Injector Requirements - 1 MW

- Beam Current - 33 mA at the RFQ input (40 mA from the ion source)
- Beam Energy - 100 keV
- Pulse Length - 1.2 ms
- Beam Emittance - $\varepsilon_{n,rms}$ = 0.020 π cm mrad at the RFQ match point (0.015 π cm mrad from the ion source)
- RFQ Match Parameters - $\alpha = 0.97$ and $\beta = 0.0034$ cm/mrad
- Pulse Repetition Rate - 60 pps with 40 Hz and 20 Hz interleaved pulse trains at a 120 Hz basic repetition rate
- Beam Turn-on Time - 30 μs with pulse-time modulation after rejection of the initial 200 μs of each beam pulse
- Beam Duty Factor - 8.6% (1.43 ms at 60 pps)
- Chopping - beam off 235 ns / beam on 436 ns for the entire 1.2 ms pulse

LANSCE II Injector Requirements - 5 MW

- Beam Current - 33 mA at two RFQ inputs (40 mA from two ion sources) or 65 mA at one RFQ (80 mA from one ion source)
- Beam Energy - 100 keV
- Pulse Length - 1.2 ms
- Beam Emittance - $\varepsilon_{n,rms}$ = 0.020 π cm mrad at the RFQ match point (0.015 π cm mrad from the ion source)
- RFQ Match Parameters - α = 0.97 and β = 0.0034 cm/mrad
- Pulse Repetition Rate - 60 pps with 40 Hz and 20 Hz interleaved pulse trains at a 120 Hz basic repetition rate
- Beam Turn-on Time - 30 μs with pulse-time modulation after rejection of the initial 200 μs of each beam pulse
- Beam Duty Factor - 8.6% (1.43 ms at 60 pps)
- Chopping - beam off 235 ns / beam on 436 ns for the entire 1.2 ms pulse

Operational Experience of Penning H^- Ion-Sources at Isis

R. Sidlow

Rutherford Appleton Laboratory

OPERATIONAL EXPERIENCE OF PENNING H^- ION-SOURCES AT ISIS

R. SIDLOW

Rutherford Appleton Laboratory

DESIGN FEATURES OF THE PENNING ION SOURCE

MAGNET ASSEMBLY.

PERMANENT FIXTURE TO THE COLUMN

90° n=1 ANALYSING MAGNET.

POLES HOUSED IN ISOLATED S/S BOX.
PULSED AT 18 KV.
PROVIDES CONNECTION TO EXTRACTOR.
REFRIGERATED TO CONDENSE CAESIUM
SEPARATELY PUMPED AND DECOUPLED FROM COLUMN VACUUM BY DIAPARAGM AND ϕ30 × 120 MM TUBE.

NOTE – PENNING FIELD IS PRODUCED BY 2 POLE TIPS. ATTACHED TO MAGNET.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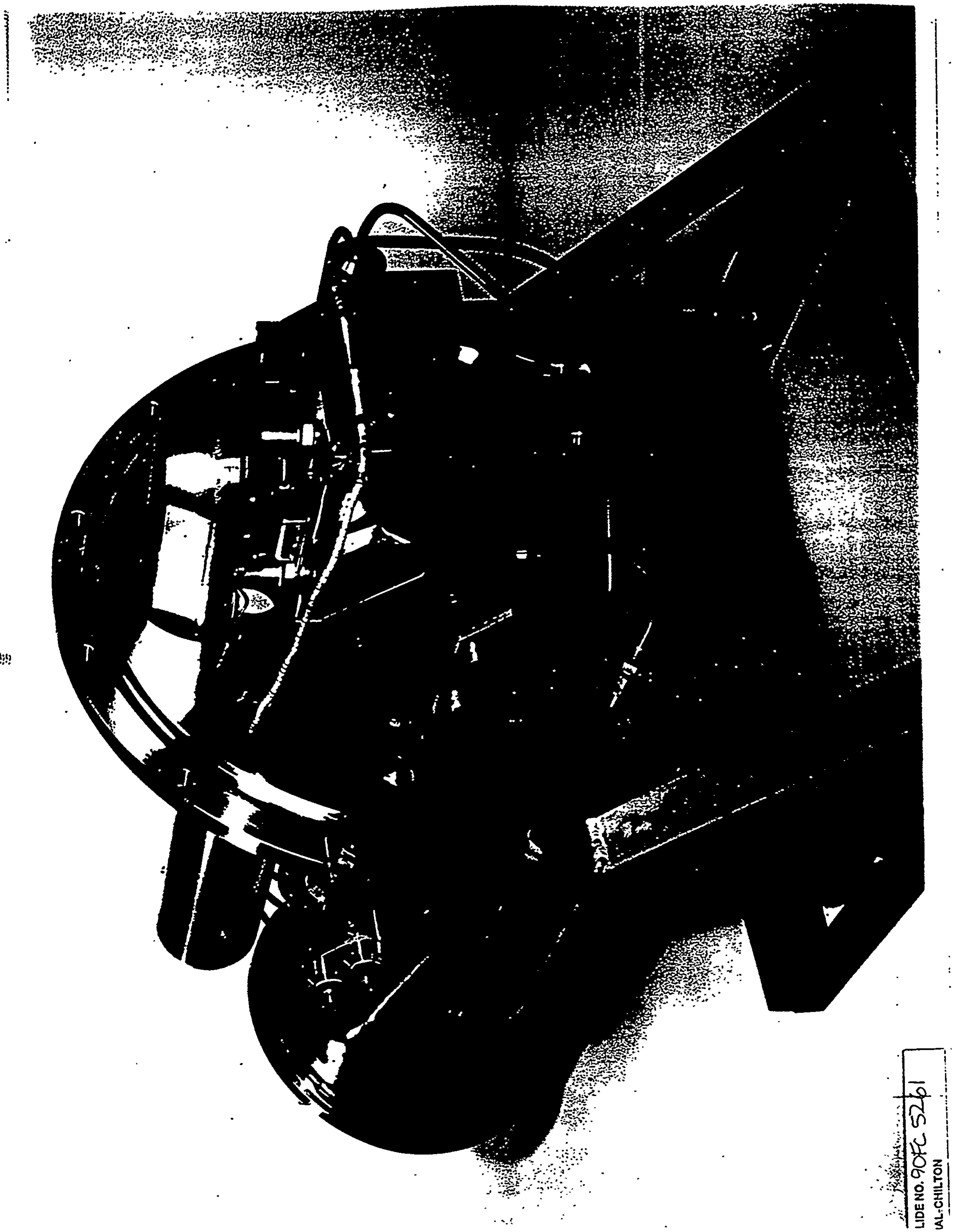
L-CHILTON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ION SOURCE

1. SOURCE IS SEPARATE FROM MAGNET ASSEMI
FOR EASE OF SOURCE CHANGE.

2 IT IS ALIGNED ON A JIG AND DOWELE
TO ENSURE APERTURE/EXTRACTOR ALIGNED TO MAGI

DESIGN FEATURES.

1. S/S BODY. – ~~COOLING TUBES~~.
COOLING TUBES
CAESIUM INLET.
H_2 INLET.

2 MOLYBDENUM ANODE.
TIGHT FIT IN BODY SLOTS.
2 HOLES FOR CAESIUM SUPPLY.
1 HOLE FOR H_2 SUPPLY.
23 x 9 DEEP x 3.5 MM WIDE.
DISCHARGE AREA 10 x 2 MM.

3 MOLYBDENUM CATHODE.
STANDS ON COPPER SPACER AND 0.5 MICA BASI
ANULAR MACOR INSULATOR ALIGNS TO BO

NOTE THERMOCOUPLE POSITION AND INSOLATED B
ALUMINIUM NITRIDE TUBE – CERAMIC –
ELECTRICAL INSULATOR WITH VERY GOOD
THERMAL CONDUCTIVITY.

4 APERTURE PLATE.

0.5 MM THICK WITH 1MM 'RIBS' TO FORM RECESS BETWEEN DISCHARGE AND APERTURE.

APERTURE = 0.6 × 10 MM.

5. EXTRACTOR.

FLAT FACED - BOLTED TO PLATE

2.30 MM GAP.

ALIGNED TO APERTURE.

6 CAESIUM SUPPLY.

COPPER BOILER.

2 GRM GLASS AMPOULE OF CAESIUM METAL

φ6 × 200 MM TRANSPORT TUBE.

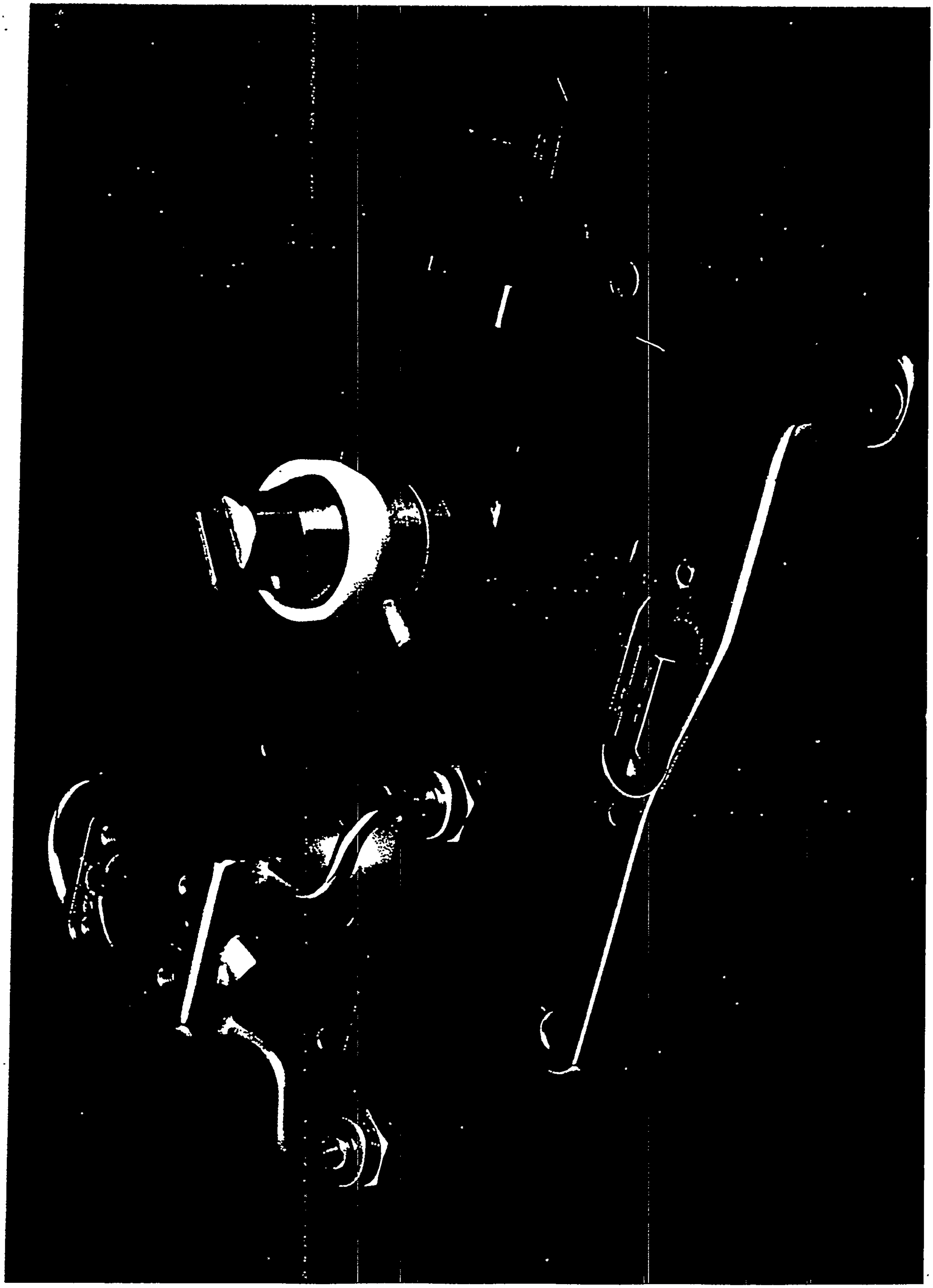
BOILER AND TRANSPORT HAVE SEPARATE CONTROLLED. HEATERS.

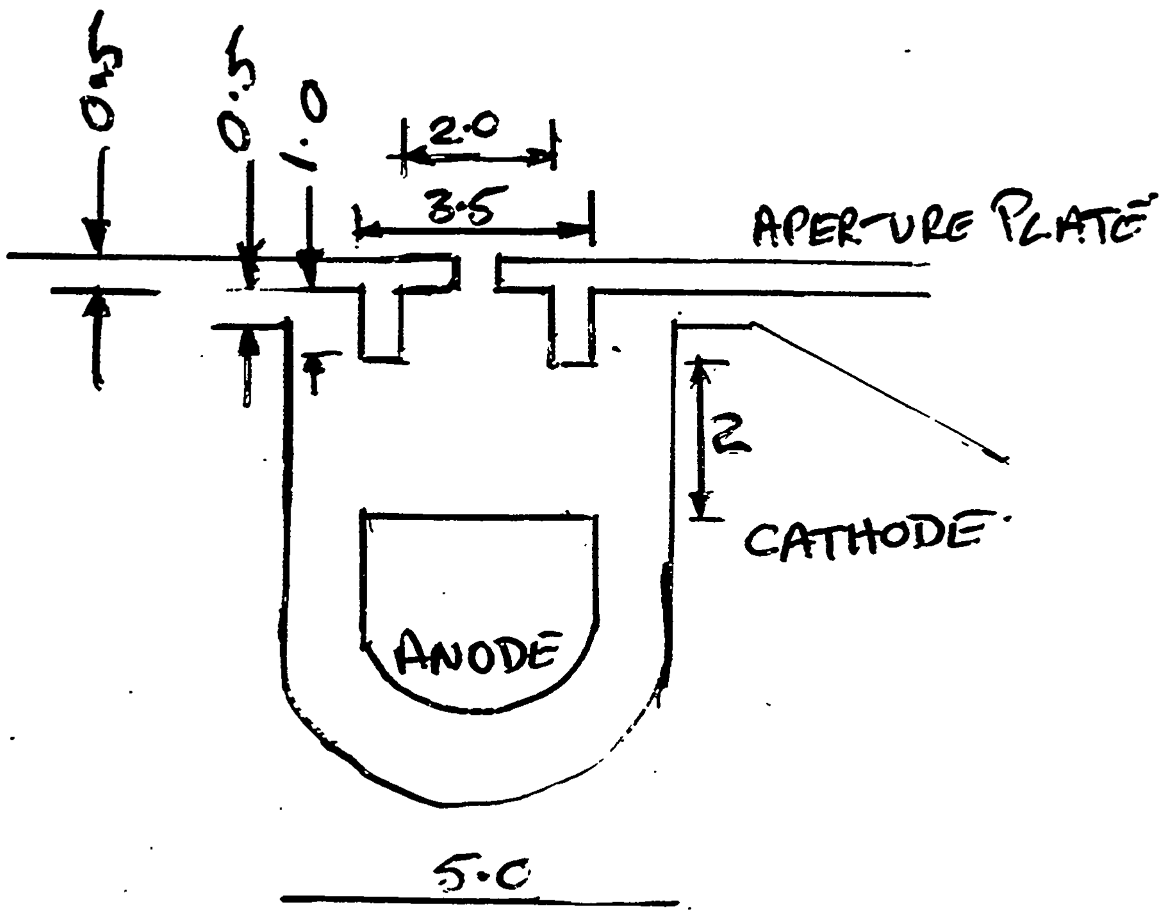
7. HYDROGEN SUPPLY.

MODIFIED 'VEECO' PIEZOELECTRIC VALVE

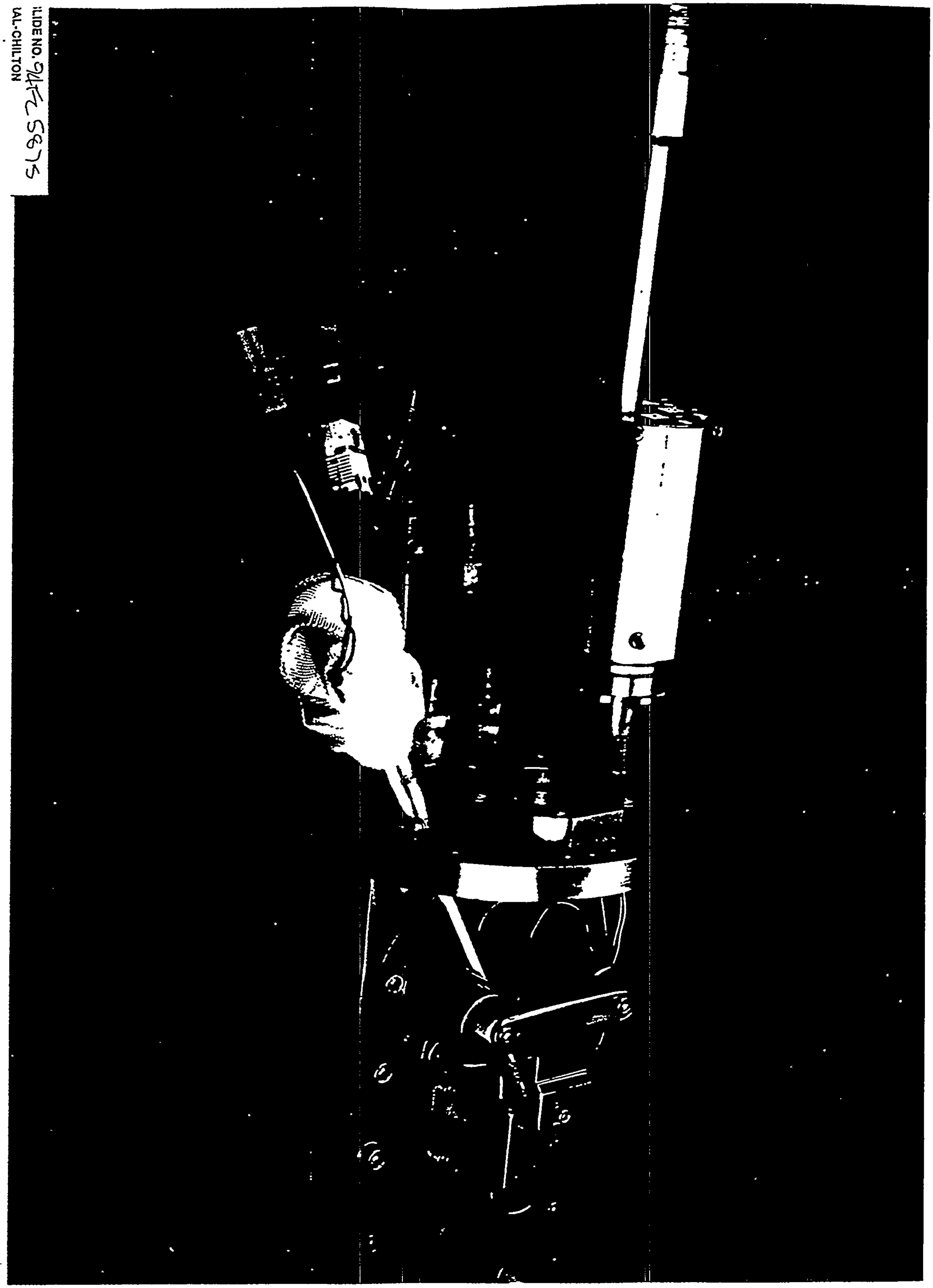
VACUUM PRESSURE SURVO CONTROLLED.

100 μS × 50 Hz PULSED





0.5
0.5
1.0
2.0
3.5
APERTURE PLATE
2
CATHODE
ANODE
5.0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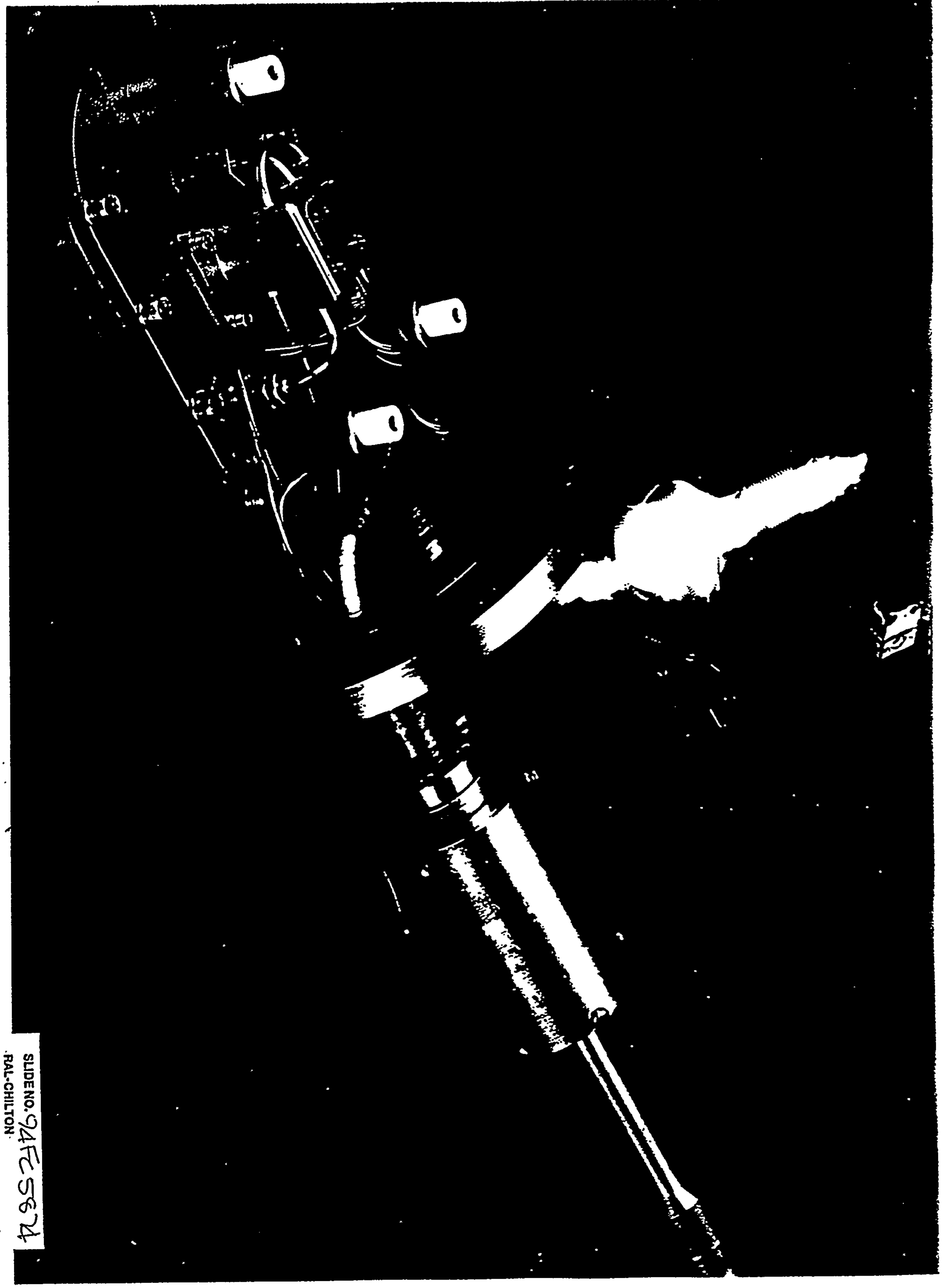
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RAL-CHILTON

Power Supplies

Arc dc supply

- high voltage, low current.

used to get power in source when cold and arc impedance high .

Arc pulsed supply

- intermediate voltage, high current.

switched on after adding caesium to source when low impedance arc obtained.

still need relatively high voltage to get reliable striking of the arc when working at high output current.

Filter in arc supply needed to eliminate interference from an oscillation of the arc discharge.

Extract supply

-current rating increased to 150 mA

to handle spurious discharge between body and poles of magnet.

Extraction slit optimised to 0.6 x 10 mm. Increasing width increases gas flow and produces problems of excessive discharge levels in extraction region.

SOURCE CHANGE.

1. TYPICAL TIME TO CHANGE ~ 2 - 2½ HRS.

a. 1½ HR MECHANICS OF REPLACING SOURCE AND PUMPING DOWN.

b. ~ 1 HR SOURCE WARMUP AND AQUIRING STABLE TEMPERATURES AND PULSED Cs MODE OF DISCHARGE.

NO SUBSEQUENT TUNING OF M/C AFTER A SOURCE CHANGE.

TYPICAL OPERATING PARAMETERS OF THE SOURCE

DISCHARGE CURRENT	35 - 45 A.
PULSE WIDTH	600 - 400 μS.
EXTRACTOR VOLTS	18 KV.
MAGNET CURRENT	10 . 6 A.
CATHODE TEMP.	480 - 510. °C.
SOURCE BODY "	370 - 410. °C
ANODE "	450 - 650 °C
CAESIUM BOILER "	170 - 180. °C.
TRANSPORT	300. °C.
AIR COOLING	6 - 10 L M^{-1}

665 KeV H$^-$ BEAM CURRENT 32 - 36 mA

SOURCE REFURBISHMENT / QUALITY CONTROL.

SIX OPERATIONAL ION SOURCES
REFURBISHED – ALIGNED – TESTED – STORED

EACH SOURCE HAS A NEW:
CATHODE – ANODE – APERTURE PLATE.
CATHODE INSULATOR – 2GRM CAESIUM.
MICA IF NECESSARY.
SOURCE BODY. CAESIUM BOILER & TRANSPORT – REUSE.

COMPONENTS ARE ULTRASONICALLY CLEANED IN.
DETERGENT – DISTILLED WATER – ALCOHOL.

THE SOURCE IS ASSEMBLED – VAC TESTED – ALIGNED AND RUN IN THE PURE HYDROGEN DISCHARGE MODE – STORED UNDER VACUUM.

QUALITY CONTROL.

DISPITE ATTENSION TO DETAIL THERE IS STILL OPERATIONAL DIFFERENCES BETWEEN THE SOURCES AND BETWEEN OPERATIONS OF THE SAME SOURCE.

– STILL LOOKING FOR IMPROVEMENTS!

OPERATIONAL AIMS FOR ISIS REQUIREMENTS

STABILITY.
OUTPUT.
LIFETIME.

STABILITY.

ALL PARAMETERS HAVE AN OPTIMUM MINIMUM VALUE BUT FOR STABILITY SOME BEAM O/P IS SACRIFICED BY RUNNING ABOVE THESE MINIMA

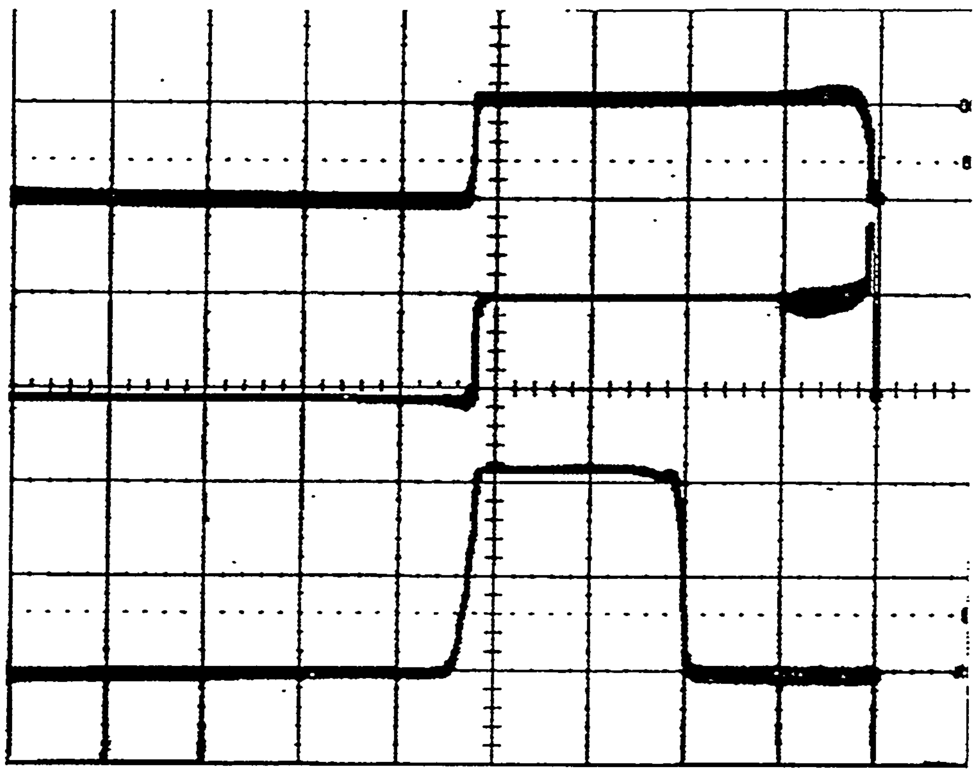
OUTPUT.

ARC CURRENT DETERMINES THE ORDER OF O/P - EMPIRICAL 'TUNING' OF OTHER PARAMETERS DETERMINES THE MINIMUM ARC CURRENT NECESSARY FOR THE REQUIRED O/P.

- THE ARC VOLTAGE SIGNAL IS A GOOD INDECATOR FOR OPTIMUM CONDITIONS.

- A CLEAN NOISELESS PULSE IS AIMED FOR - BOILER TEMPERATURE (CAESIUM FLUX) EFFECTS THIS MOST

- ANY NOISE ON THIS PULSED SIGNAL WHICH INVADES THE EXTRACTION 'WINDOW' IS REFLECTED IN THE H^- BEAM



LIFE TIME

- EXPECT - 21 DAYS FROM A SOURCE - MORE IS A BONU
- PLAN FOR ONE SOURCE CHANGE PER NETRON. CYCLE - 35 DAYS

REALITY - A LARGE SPREAD OF LIFETIMES.

FAILURE MODES.

1. EROSION OF RIBS AND CATHODE DISCHARGE SURFACE GIVES RISE TO DECLINE IN OUTPUT. INCREASED DISCHARGE CURRENT TO COMPENSATE WILL ACCELERATE THE RATE OF EROSION.

2 ABRUPT SHORT CIRCUIT. DEBRIS FROM EROSION OF CATHODE AND ANODE IS DEPOSITED ON THE APERTURE AND S/C OCCURS.
- THIS IS MOST FREQUENT CAUSE OF SOURCE FAILURE - OFTEN PREMATURE.

3. INTERNAL SOURCE BREAKDOWN.
- THIS WILL 'SPUTTER' DEBRIS AND PARTIALLY BLOCK THE APERTURE.
- SOURCE O/P. IS THEN REDUCED TO UNACCEPTABLE LEVEL.

1994 SOURCE OPERATION LIFETIMES.

N° 6	JAN/FEB	34 DAYS	S/C (ERODED)
N° 3		4 DAYS	END OF RUN.
		38	
N° 1		25 DAYS	S/C.
		16 DAYS	
		3 DAYS	END OF RUN.
		44	
N° 2		15 DAYS	S/C.
N° 3		13 DAYS	
N° 6		11 DAYS	END OF RUN.
		39	
N° 5		21 DAYS	EXPEDIENCY.
N° 4	JULY/SEPT	19 DAYS	END OF RUN.
		40	

SOURCE PERFORMANCE HISTORY.

INITIAL SPECIFICATION.

- 40-50 mA, 470 μS at 50 Hz.

THIS ASSUMED 50% TRAPPING EFFICIENCY IN THE RING.

- EARLY DEMONSTRATION OF HIGH TRAPPING EFFICIENCY ~ 90% EVEN AT HIGH INTENSITY.

PRESENT REQUIREMENTS FOR 200 μA

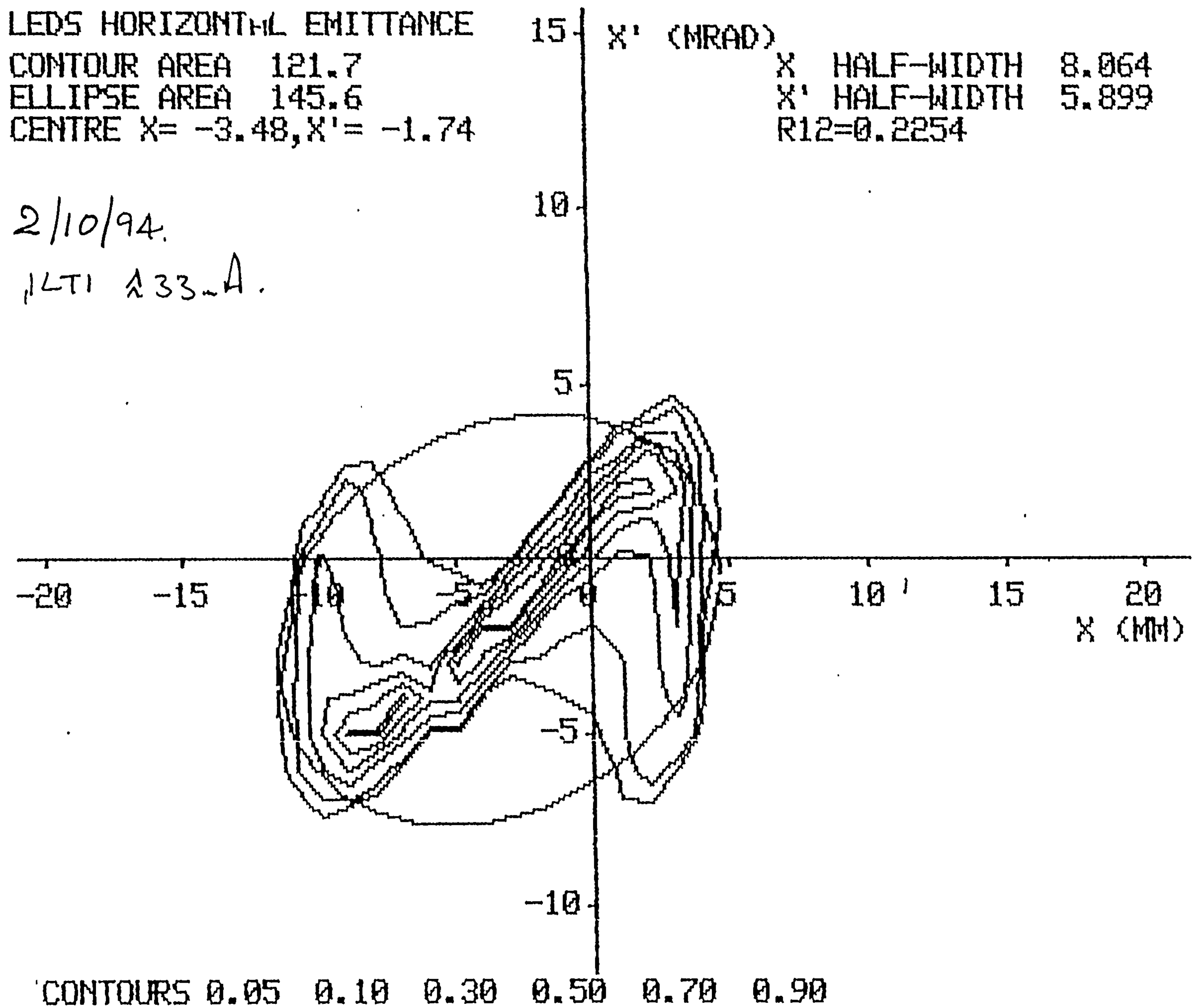
- 35 mA, 250 μS at 50 Hz & 665 KeV

TYPICAL EMITTANCE AT 665 KeV.

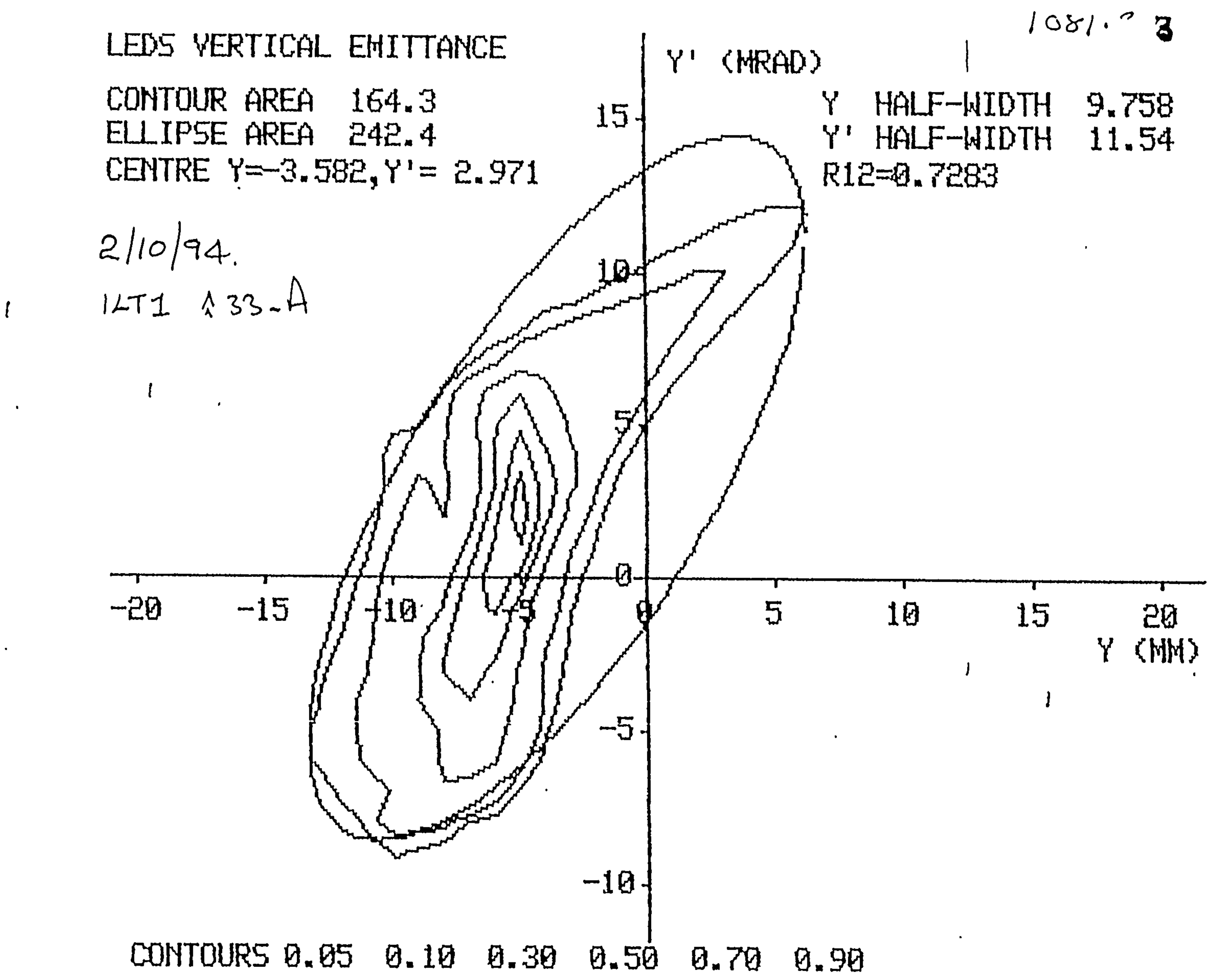
- EMITTANCE = PHASE SPACE AREA / π

ε_H = 145.6 μm. rads.
ε_V = 242.4 μm rads.
} NOT NORMALISED

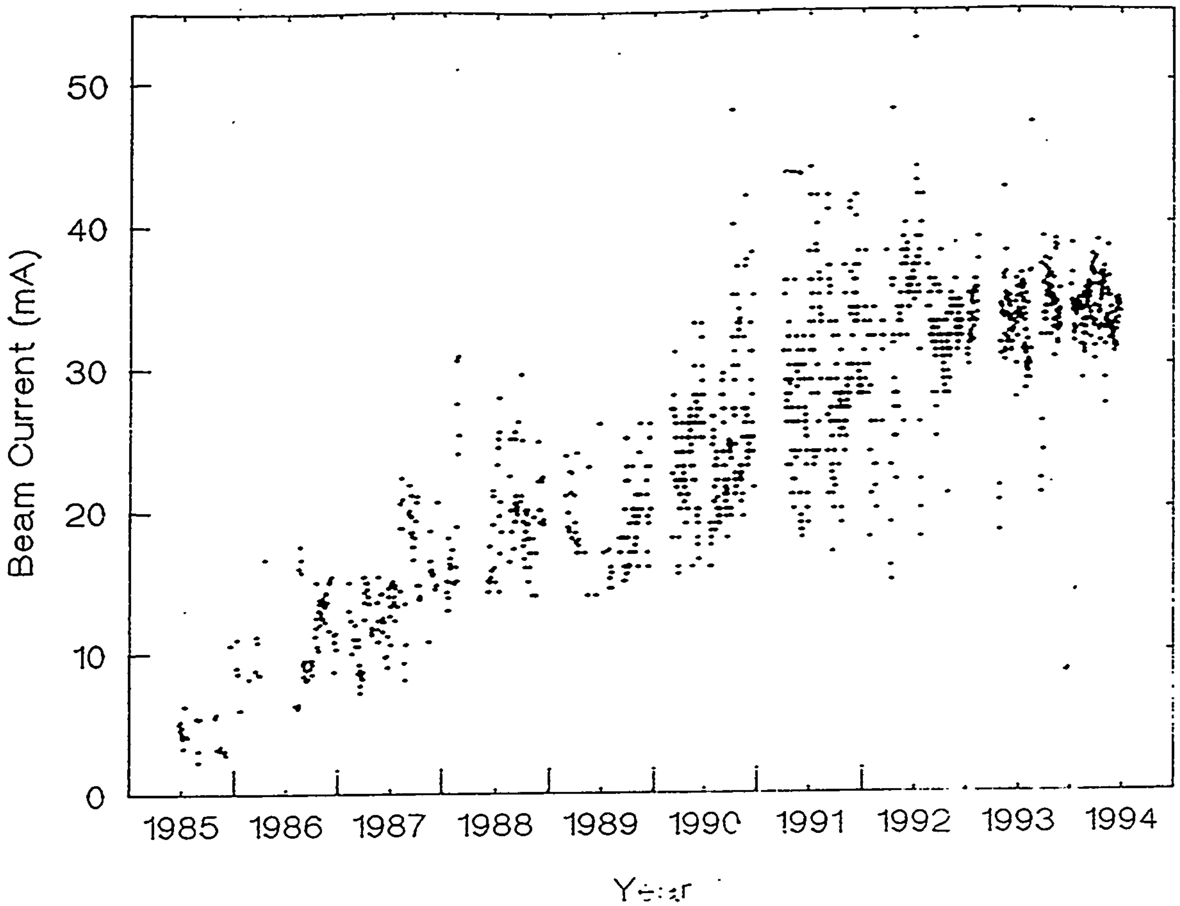
1081.2

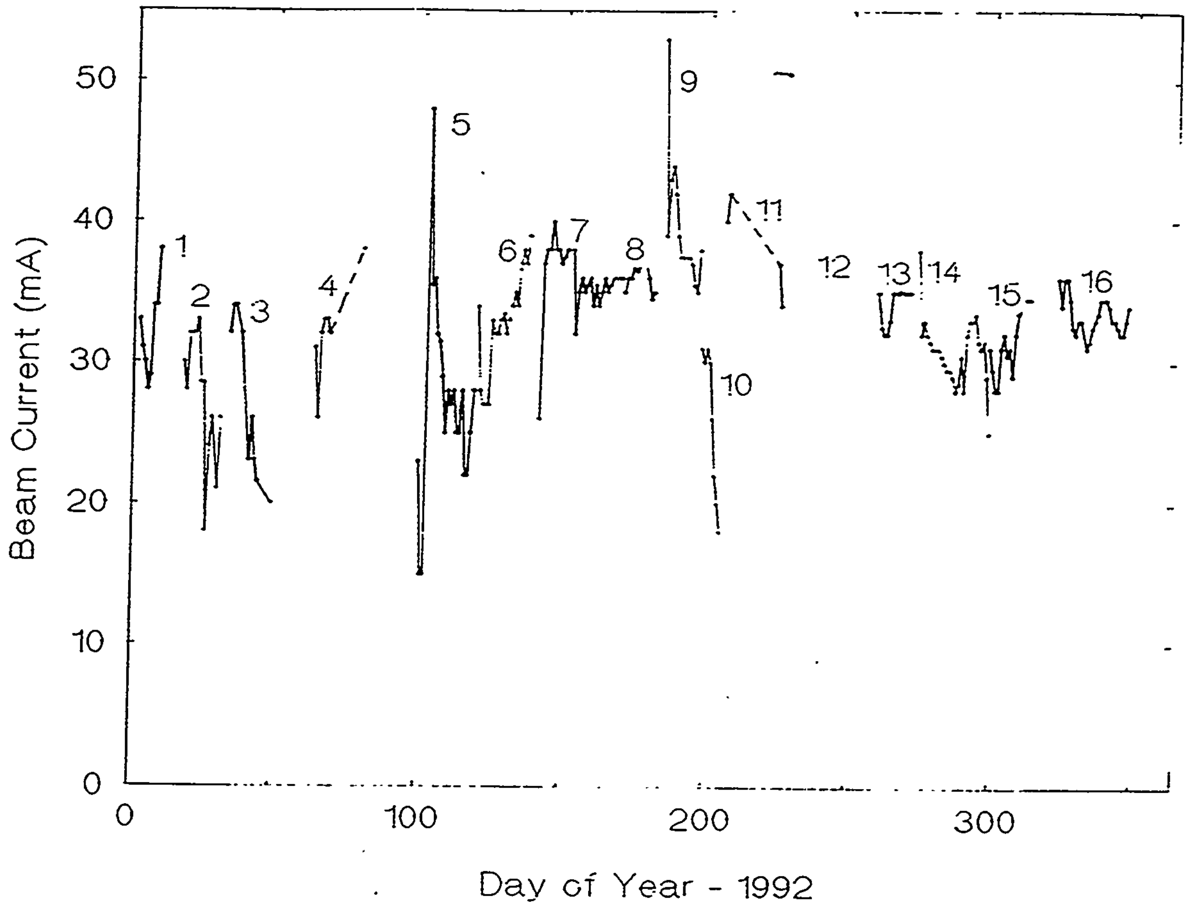


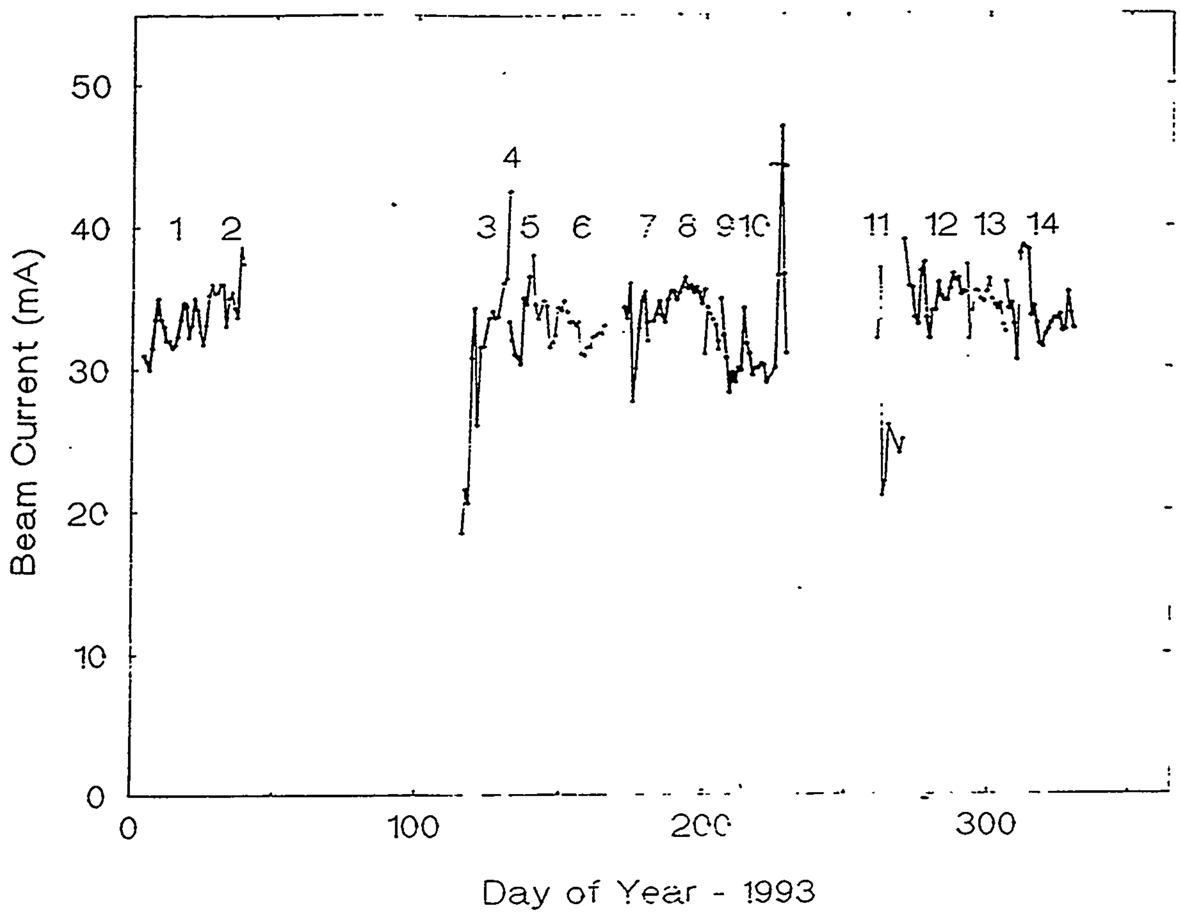
LEDS HORIZONTAL EMITTANCE
CONTOUR AREA 121.7
ELLIPSE AREA 145.6
CENTRE X= -3.48, X'= -1.74
2/10/94.
X' (MRAD)
X HALF-WIDTH 8.064
X' HALF-WIDTH 5.899
R12=0.2254
15
10
5
-5
-10
-20
-15
10
15
20
X (MM)
CONTOURS 0.05 0.10 0.30 0.50 0.70 0.90



LEDS VERTICAL EMITTANCE
CONTOUR AREA 164.3
ELLIPSE AREA 242.4
CENTRE Y=-3.582, Y'= 2.971
2/10/94.
ILT1 A33-A
1081.? 3
Y' (MRAD)
Y HALF-WIDTH 9.758
Y' HALF-WIDTH 11.54
R12=0.7283
15
10
5
0
-5
-10
-20
-15
-10
-5
0
5
10
15
20
Y (MM)
CONTOURS 0.05 0.10 0.30 0.50 0.70 0.90


Beam Current (mA)
50
40
30
20
10
0
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
Year


Beam Current (mA)
Day of Year - 1992
0
10
20
30
40
50
0
100
200
300
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16



Beam Current (mA)
50
40
30
20
10
0
0
100
200
300
Day of Year - 1993
1
2
3
4
5
6
7
8
9
10
11
12
13
14

FINALLY.

THIS SOURCE IS ADEQUATE FOR THE NEEDS OF ISIS. BUT WE ARE ALWAYS CONSIDERING IMROVEMEN WHICH WILL EFFECT THE

QUALITY CONTROL.

STABILITY.

LIFE TIME

Penning Source R&D for ESS

C. Planner

Rutherford Appleton Laboratory

PENNING SOURCE R+D FOR ESS

C. W. PLANNER.

WITH ACKNOWLEDGEMENTS TO

G. DEREVYANKIN

R. SIDLOW

ION SOURCE PERFORMANCE IN RELATION TO ACCELERATORS

- EMITTANCES — NOT ALWAYS QUOTED FOR ELLIPTICAL CONTOUR

BEAM ACCEPTANCE FOR MOST ACCELERATORS – ELLIPTICAL IN SHAPE

- CONSTANCY OF OUTPUT OVER OPERATIONAL LIFE
- CONSISTANCY ION-SOURCE TO ION SOURCE
- LOW NOISE

DYNAMIC STABILITY OF VERY HIGH INTENSITY BEAMS IN ACCELERATORS + COMPRESSOR RINGS VERY SENSITIVE TO FLUCTUATIONS IN INTENSITY

- LOW MOMENTUM / ENERGY SPREAD

PULSED EXTRACTION SYSTEMS – DIFFICULT TO GET HIGH STABILITY + REGULATION PARTICULARLY WITH ADDITIONAL HIGH ELECTRON LOADING.

RFQ'S HAVE LARGE MOMENTUM/ENERGY ACCEPTANCE BUT SOLENOID FOCUSING IS CHROMATIC + RESULTS IN TRANSVERS_ MISMATCH TO RFQ FOR LARGE — MOMENTUM PARTICLES.

- BEAM LOSS + QUALITY DETERIORATION HAVE A LARGE IMPACT ON ION SOURCE SPECIFICATION.

  ACCELERATION EFFICIENCIES.

  INJECTION EFFICIENCY.

  TRANSPORT EFFICIENCIES.

  TIME VARIATION OF FOCUSING DURING NEUTRALISATION.

  CHROMATIC + SPHERICAL ABERRATIONS IN EXTRACTION + FOCUSING SYSTEMS.

- BEAM CHOPPING

  NECESSARY TO MINIMISE HIGH ENERGY BEAM LOSS IN RINGS DURING INJECTION, ACCELERATION + EXTRACTION – BUT INCREASES DUTY CYCLE OF SOURCE.

- ENGINEER DESIGN OF SOURCE + COMPONENTS TO BE SELF ALIGNING.

  RFQ TRANSMISSION/ACCELERATION EFFICIENCY VERY SENSITIVE TO BEAM ALIGNMENT.

SOME CONSIDERATIONS FOR CHOICE OF ION-SOURCE

TYPE

VOLUME SOURCE ?

MAGNETRON / PLANATRON / SEMI-PLANATRON ?

PENNING ?

ALL Cs CATALYSED FOR HIGH H^- EMISSION CURRENT

SCALING ?

AXIAL SYMMETRY OR SLIT GEOMETRY ?

ELECTRON EMISSION.

VOLUME PRODUCTION.

H^- IONS PRODUCED IN DISSOCIATIVE ATTACHMENT COLLISIONS OF HIGH VIBRATIONAL STATE ($\nu > 5$) HYDROGEN MOLECULES WITH THERMALISED PLASMA ELECTRONS.

∴ INITIAL TEMP AND ENERGY SPEAD ~1eV

TO OBTAIN EMISSION CURRENT DENSITY ~ 1A/cm²

NEED NEGATIVE ION DENSITY $> 10^{13}/cm^3$

PLASMA DENSITY $\sim 10^{14}/cm^3$

HIGH DENSITIES REDUCE DENSITY OF HIGH EXCITATION STATES OF HYDROGEN MOLECULES

LIMITS $j_{H^-} \sim 100 - 200\ mA/cm^2$

In practice 20-30 mA/cm² MORE TYPICAL

LARGE VOLUME — LARGE GAS + Cs CONSUMPTION

REQUIRE HIGH POWER ELECTRON GENERATOR.

FILAMENT
RF.

LOWER POWER GENERATORS MAY BE POSSIBLE

- PHOTOEMISSION ?
- FERROELECTRIC EMISSION?

LARGE e^-/H^- RATION 30-50

CAN BE REDUCED WITH SUPPRESSOR ELECTRODES.
MAGNETIC FILTER

MAGNETRON / PLANATRON / SEMI-PLANATRON.

SURFACE PLASMA SOURCE WITH DIRECT EXTRACTION OF SURFACE PRODUCED H^- BY NEGATIVE IONISATION ON A METAL SURFACE.

j_{H^-} ~1-2A/cm² CAN BE OBTAINED

BUT TRANSVERSE ION TEMPERATURE > 10 eV

ENERGY SPREAD > 100 eV

DIFFICULT TO OPTIMISE H^- ION DENSITY AT PLASMA BOUNDARY — REQUIRE:

FIELD EACH SIDE OF BOUNDARY ZERO

ION VELOCITY EACH SIDE ZERO OR VERY SMALL.

HIGH ENERGY OF IONS RESULTS IN PENETRATION OF PLASMA BOUNDARY BY EXTRACTION FIELD — PRODUCES STRONG ELECTROSTATIC LENS EFFECT + SIGNIFICANT SPHERICAL + CHROMATIC ABERRATION.

LIMITS BRIGHTNESS 10-100 mA/mm²/mrad²

MAGNETRON COOLING - DIFFICULT

SEMI-PLANATRON MORE EASILY COOLED

BOTH MORE EFFICIENT THAN PENNING AT 20-30A DISCHARGE CURRENTS BUT SIMILAR TO PENNING AT HIGH DISCHARGE CURRENTS.

(MAGNETRON SHOWS SATURATION ~100 A DISCHARGE)

PENNING SOURCE

HIGH BRIGHTNESS H^- BEAM IS OBTAINED FROM SECONDARY NEGATIVE IONS PRODUCED NEAR THE EMISSION APERTURE AS A RESULT OF RESONANT CHARGE EXCHANGE OF FAST SURFACE PRODUCED H^- IONS WITH SLOW NEUTRAL ATOMS.

$j_{H^-} \sim 1-2\ A/cm^2$

low ion temperature ~1eV

low energy spread

RELATIVELY EASY TO OPTIMISE PLASMA BOUNDARY FOR EXTRACTION GEOMETRY + VOLTAGE.

SMALL VOLUME - SMALL GAS CONSUMPTION WITH PULSED GAS VALVE POSSIBLE.

LOW Cs CONSUMPTION - IMPORTANT FOR LIFETIME + MINIMISATION OF DOWNSTREAM CONTAMINATION OF COMPONENTS (RFQ etc.)

LOW ELECTRON EMISSION $e/H^- \leq 1$

PENNING SOURCES HAVE AN EXCELLENT TRACK RECORD AS OPERATIONAL SOURCES

	BUDKER	RAL
DUTY CYCLE	2.5%	2.5%
ARC PULSE	250 µs	500 µs
H^- ion CURRENT	100 mA	35 mA (@ 665 KeV)
LIFETIME	300 h	500 h
PULSE REP RATE	100 Hz	50 Hz.

Scaling.

MAIN OBJECTIVE - REDUCE CATHODE POWER DENSITY

(SUCCESSFULLY DEMONSTRATED V. SMITH LANL)

BUT INCREASES ELECTRON EMISSION e^-/H^-

DISCHARGE VOLUME

GAS + Cs THROUGHPUT.

GEOMETRY

AXIAL SYMMETRY – SIMPLIFIES MATCHING TO RFQ

– EQUIPARTITIONS ENERGY IN TRANSVERSE PHASE PLANES.

– FOR LARGE EXTRACTED H^- CURRENTS REQUIRE LARGE APERTURE → LARGE SPHERICAL + CHROMATIC ABERRATIONS → LARGE EMITTANCE (MEASUREMENTS REQUIRED)

SLIT GEOMETRY – LARGE EXTRACTION AREA WITH MINIMUM OPTICAL ABERRATIONS.

– UNEQUAL PARTITION OF ENERGY IN TRANSVERSE PHASE PLANES → EMITTANCE GROWTH DUE TO EQUALISATION.

– MATCHING TO RFQ STILL POSSIBLE USING MORE THAN TWO SOLENOIDS.

DEVELOPMENT PROGRAMS.

AT RAL.

CONTINUE DEVELOPMENT OF ISIS SOURCE TO HIGHER CURRENTS + PULSE LENGTHS.

70mA 2ms 50Hz.

DEVELOP OFF-LINE TEST STAND WITH FAST DIAGNOSTICS SYSTEM.

SEARCH FOR IMPROVEMENTS IN QUALITY CONTROL OF ENGINEERING COMPONENTS AND ASSEMBLY

APPRAISAL OF ENGINEERING DESIGNS TO IMPROVE SELF ALIGNMENT OF COMPONENTS ON ASSEMBLY

SOME ASPECTS OF SOURCE DEVELOPMENT ARE MAINLY DETAIL CONSTRUCTION CHANGES.

INCREASE DISCHARGE VOLUME WHILE AT THE SAME TIME REDUCING 'UNUSED' TRAPPING VOLUMES

- Cs TRANSFER LINE
- GAS VALVE CONSTRUCTION
- HYDROGEN TRANSPORT.

IMPROVE THERMAL CONTACTS OF ELECTRODES AND ELECTRODE TEMPERATURE CONTROL

GROOVED ANODE — REDUCE ELECTRODE SPUTTERING

SHAPED CATHODE — MINIMISE PARASITIC PENNING DISCHARGES INSIDE SOURCE.

'MAGNETIC' EXTRACTION ELECTRODE TO MINIMISE PARASITIC PENNING DISCHARGE OUTSIDE SOURCE

IMPROVE DESIGN OF Cs COLD BOX TRAP TO INCREASE PUMPING IN EXTRACTION REGION REDUCE PARASITIC PENNING DISCHARGE.

DEVELOPMENT PROGRAM COLLABORATION.

BUDKER INSTITUTE / RAL / U. FRANKFURT.

SEEKING FUNDING FROM INTAS.

(INTERNATIONA ASSOCIATION FOR THE PROMOTION OF CO-OPERATION WITH SCIENTISTS FROM THE INDEPENDENT STATES OF THE FORMER SOVIET UNION).

- DEVELOP 100mA, 2ms, 50Hz source (H^-) WITH AXIAL EXTRACTION GEOMETRY
- DEVELOP FAST DATA ACQUISITION SYSTEM + ON LINE EMITTANCE MEASUREMENT SYSTEM.
- STUDY DISCHARG OSCILLATION MODES AND PARAMETERS AFFECTING QUIET STABLE PLASMA FORMATION
- EXTEND STUDIES OF FORMATION AND TRANSPORTATION OF INTENSE H^- ION BEAMS + MATCHING INTO RFQ
- SEARCH FOR NEW EFFECTIVE EMITTER MATERIAL FOR SURFACE PLASMA SOURCES.

BNL Magnetron H^- Sources

J. Alessi

Brookhaven National Laboratory

BNL Magnetron H^- Source

J. Alessi

H^- = 70 – 100 mA

e/H^- = 0.5 – 1.0

35 keV

50 – 60 mA out of 750 keV RFQ

This source has been used for high energy physics program at AGS for ~14 years.

Used with RFQ for ~6 years.

~6 month/yr operation, 24 hr/day

~Identical to source used at FNAL.

Magnetron H^- Source

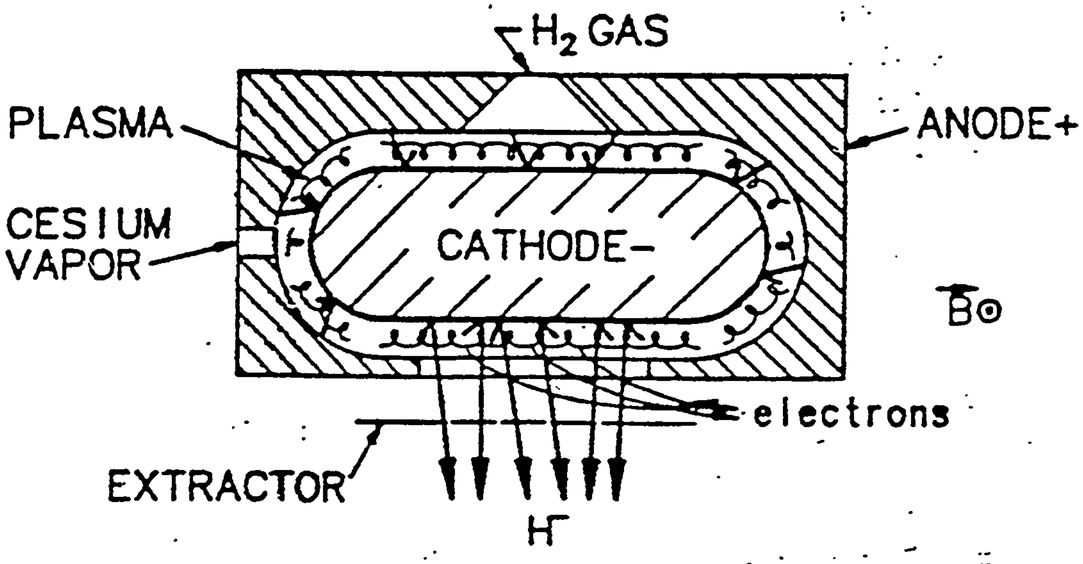
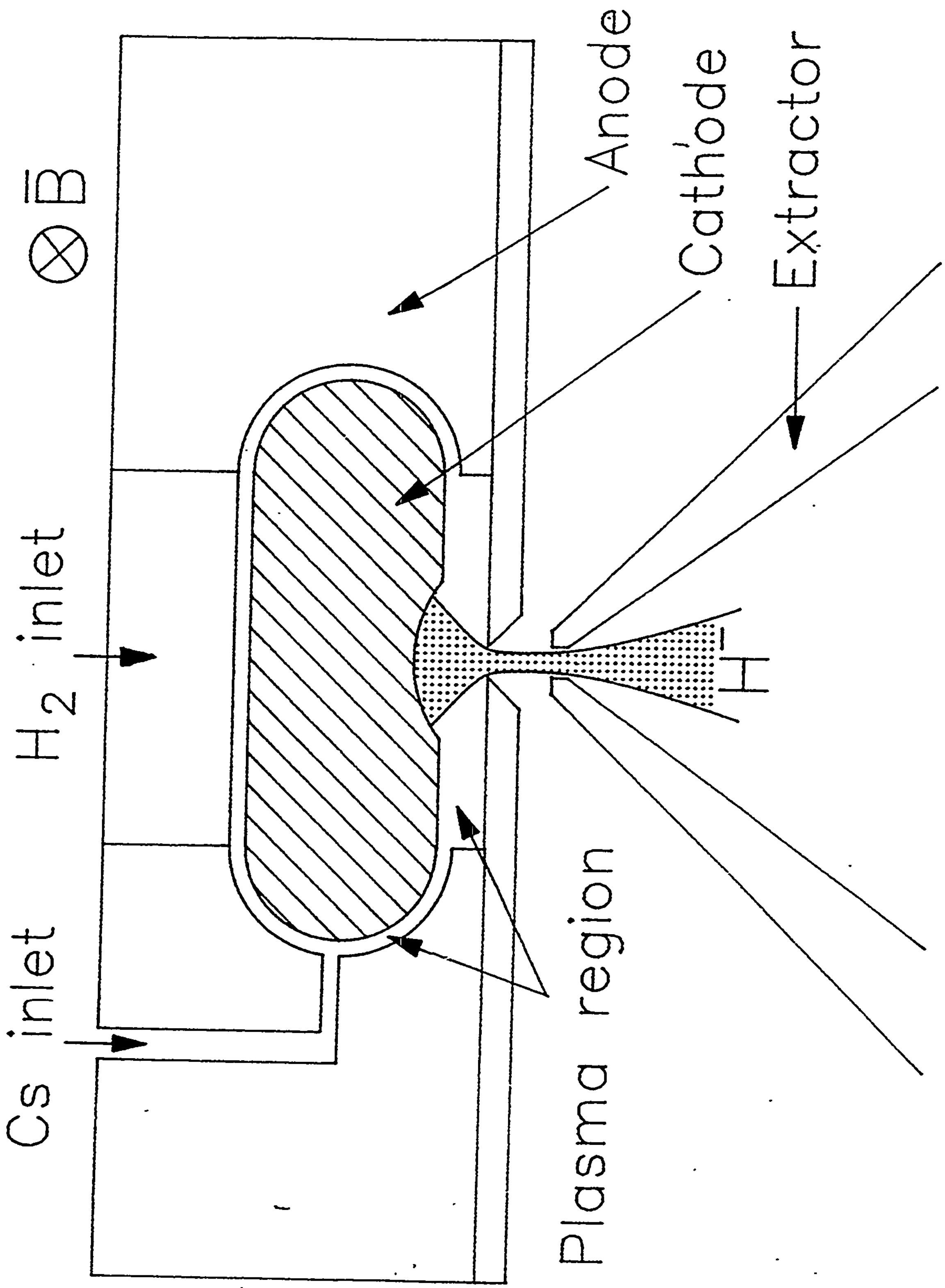
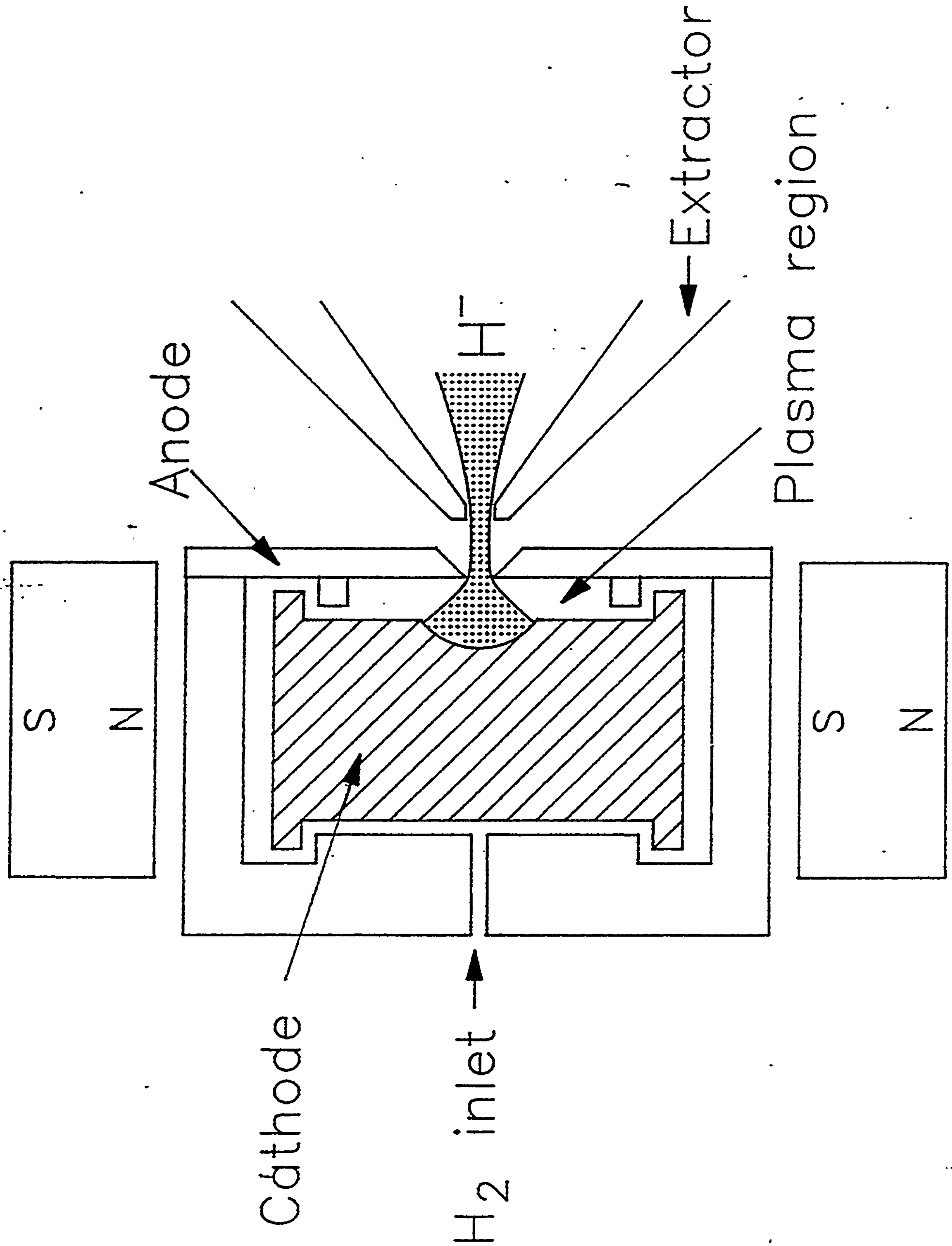
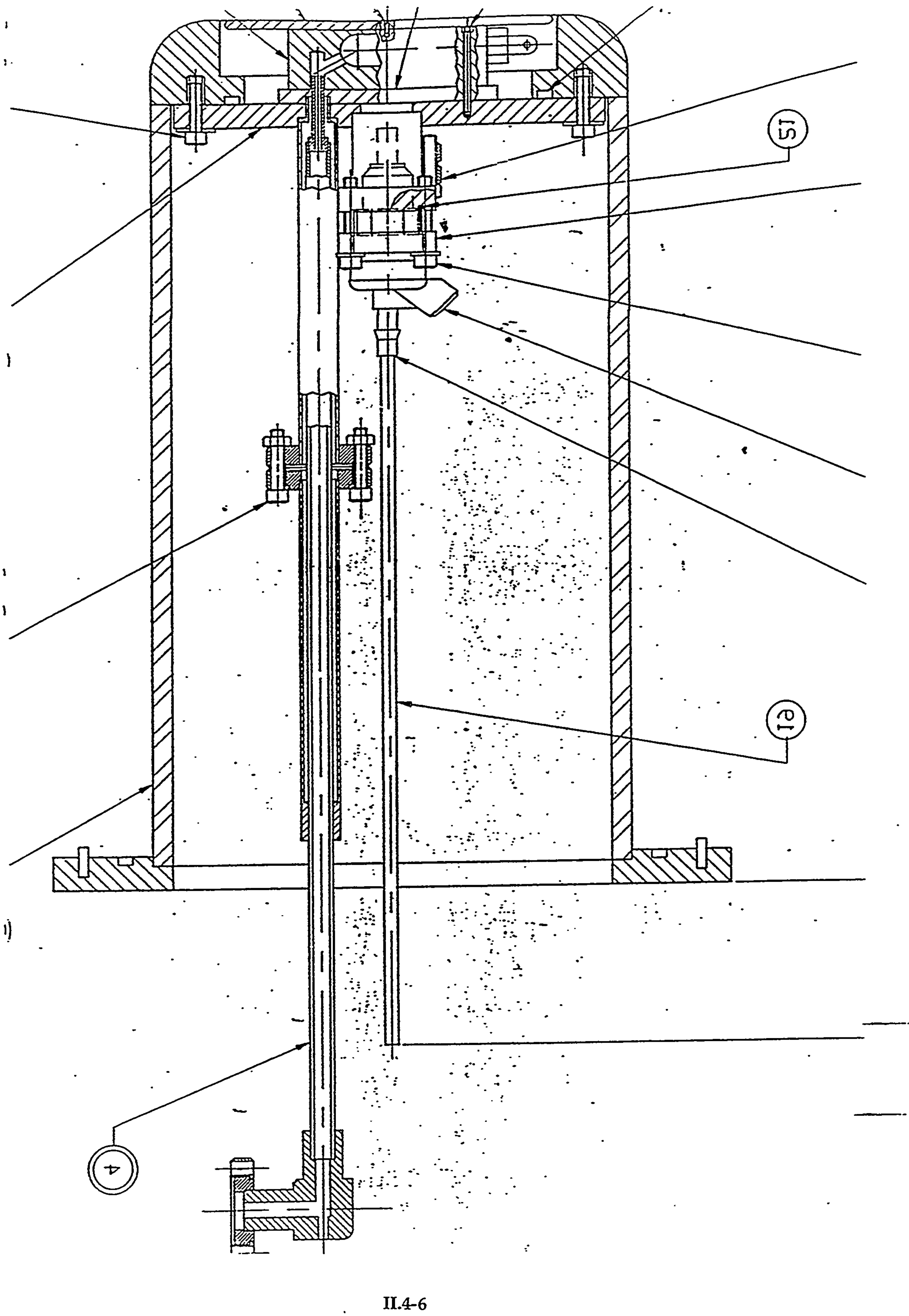
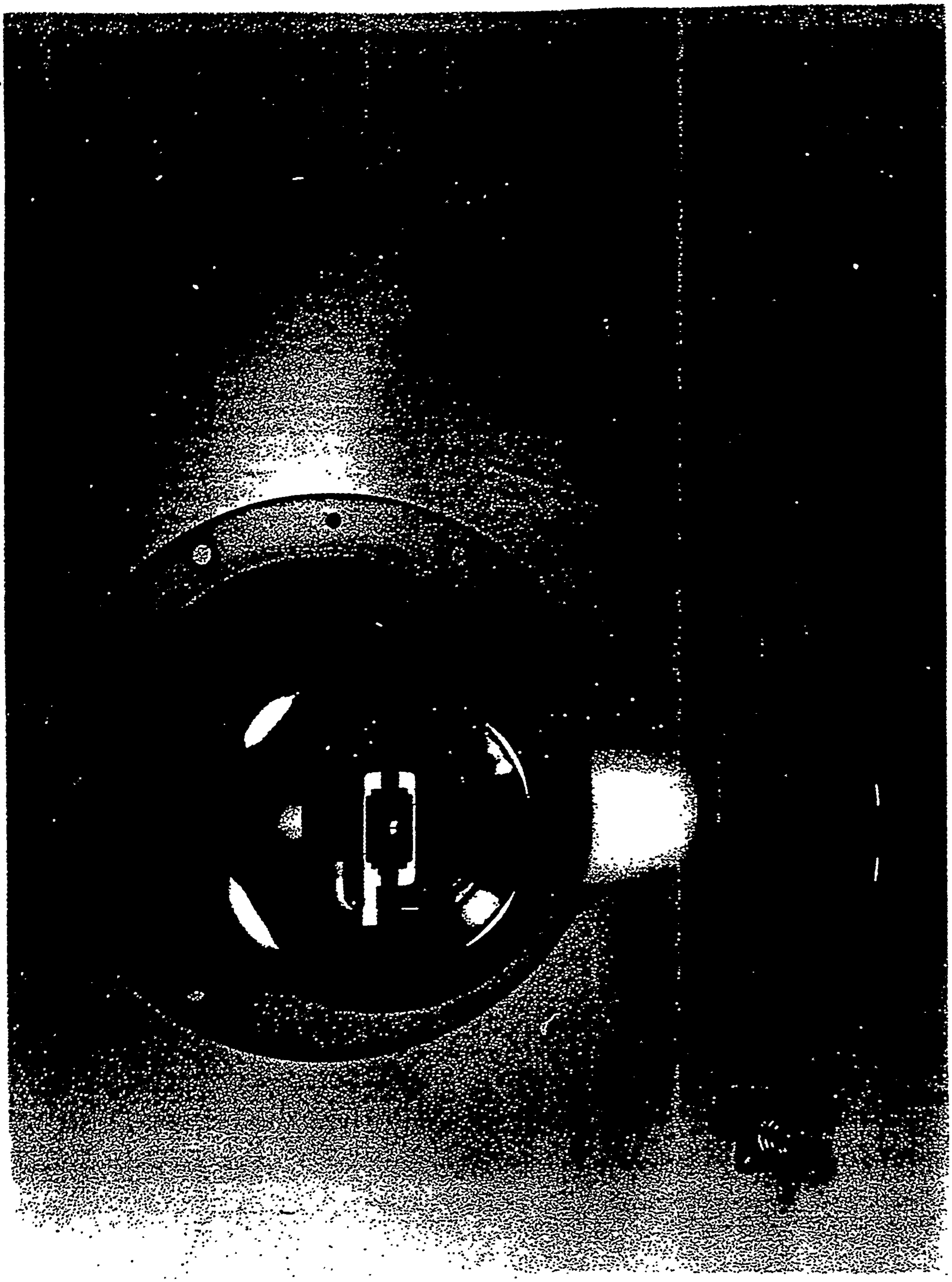


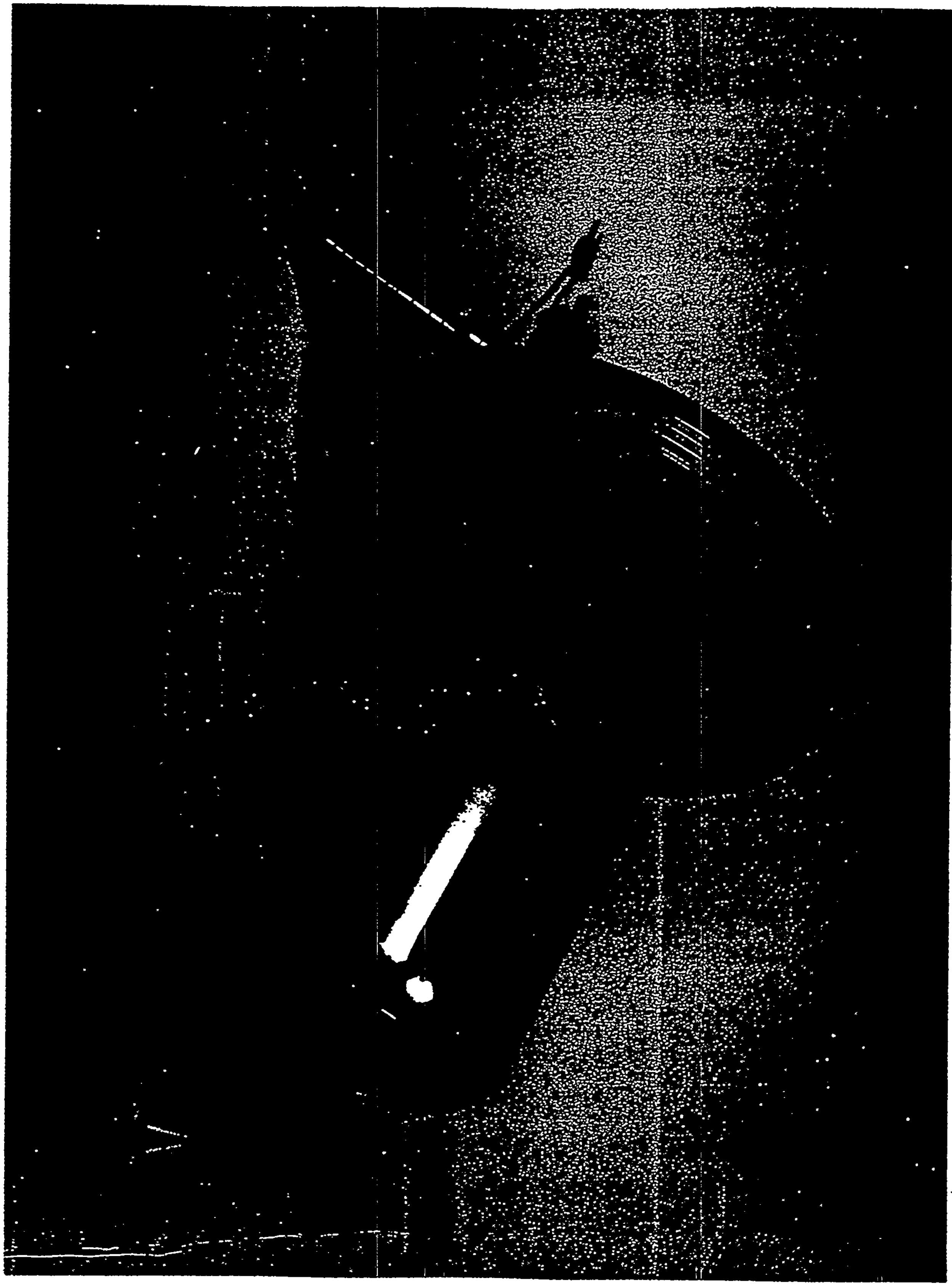
Fig. 3. Basic magnetron source configuration.

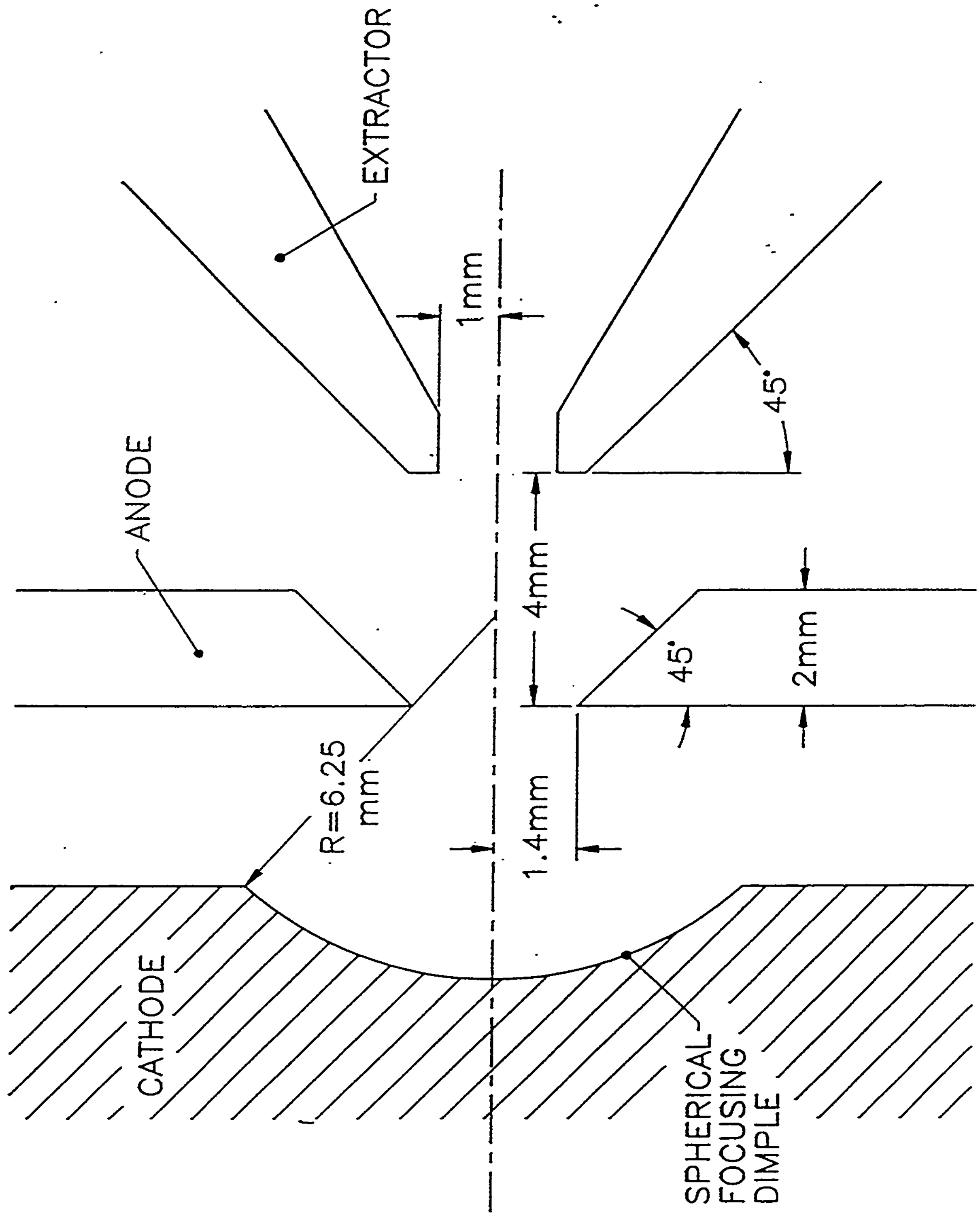

Anode
Cathode
Extractor
⊗ B̄
H_2 inlet
Cs inlet
Plasma region
H^-


Extractor
Plasma region
H^-
Anode
S
N
S
N
Cathode
H_2 inlet








EXTRACTOR
1mm
45°
ANODE
4mm
45°
2mm
R=6.25 mm
1.4mm
CATHODE
SPHERICAL FOCUSING DIMPLE

Typical Magnetron Source Performance

Extraction voltage	35 keV
Pulse width	700 μs
Rep rate	5 Hz 0.35% df
H^- current	70 – 100 mA
Current density	1.1 – 1.6 A/cm^2
Discharge current	12 – 15 A
Discharge voltage	145 – 165 V $\bar{P} \sim 7.5$ W
electron/H^-	0.5 – 1.0
E(N, 90%)	1.1 – 1.5 π mm–mrad
E(N, RMS)	0.3 – 0.4 π mm–mrad
Average gas flow	< 1 sccm
Cs consumption	~ 0.5 mg/hr

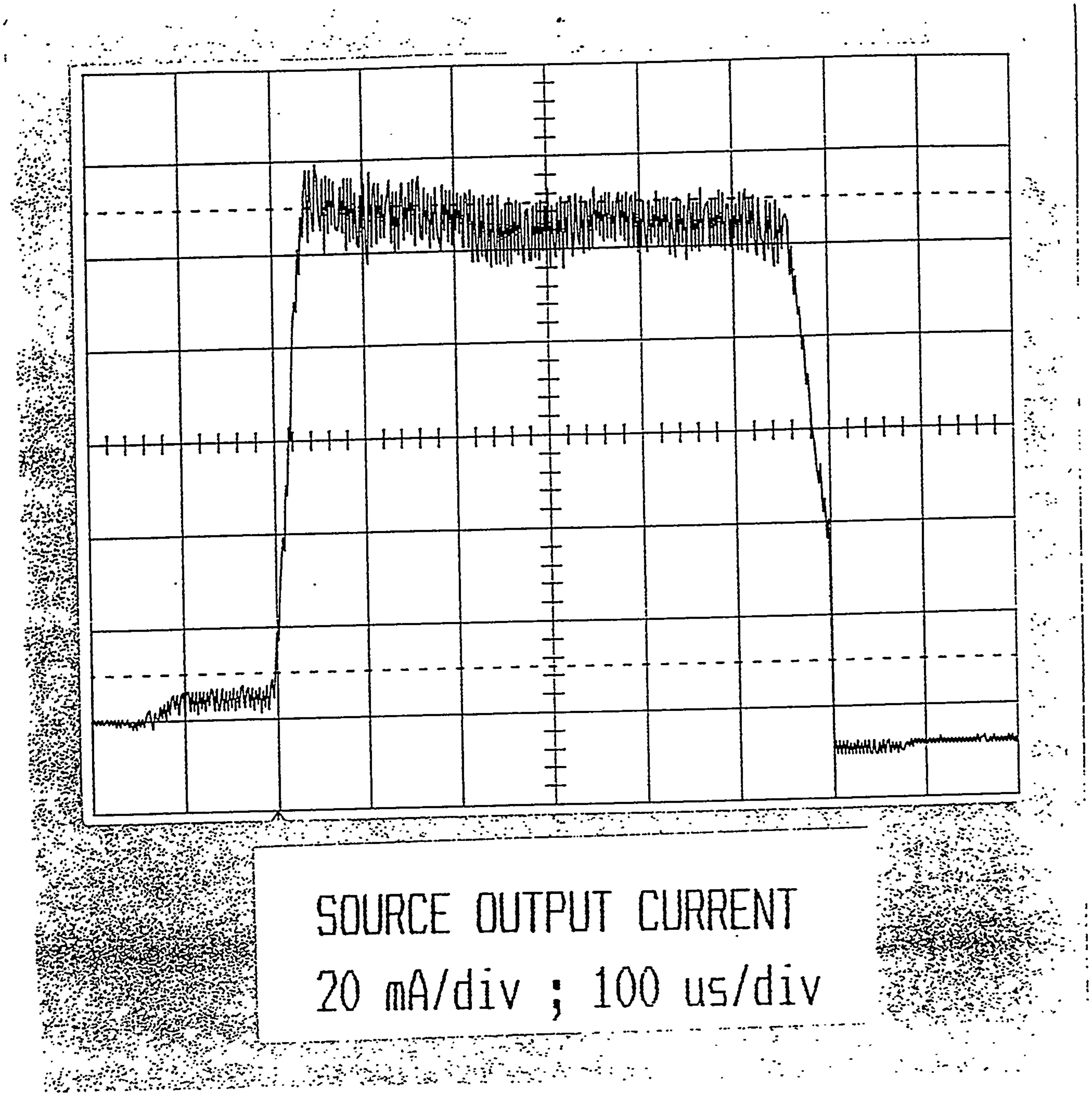
P(source box) ~ 2.5×10^{-6} T (gauge)

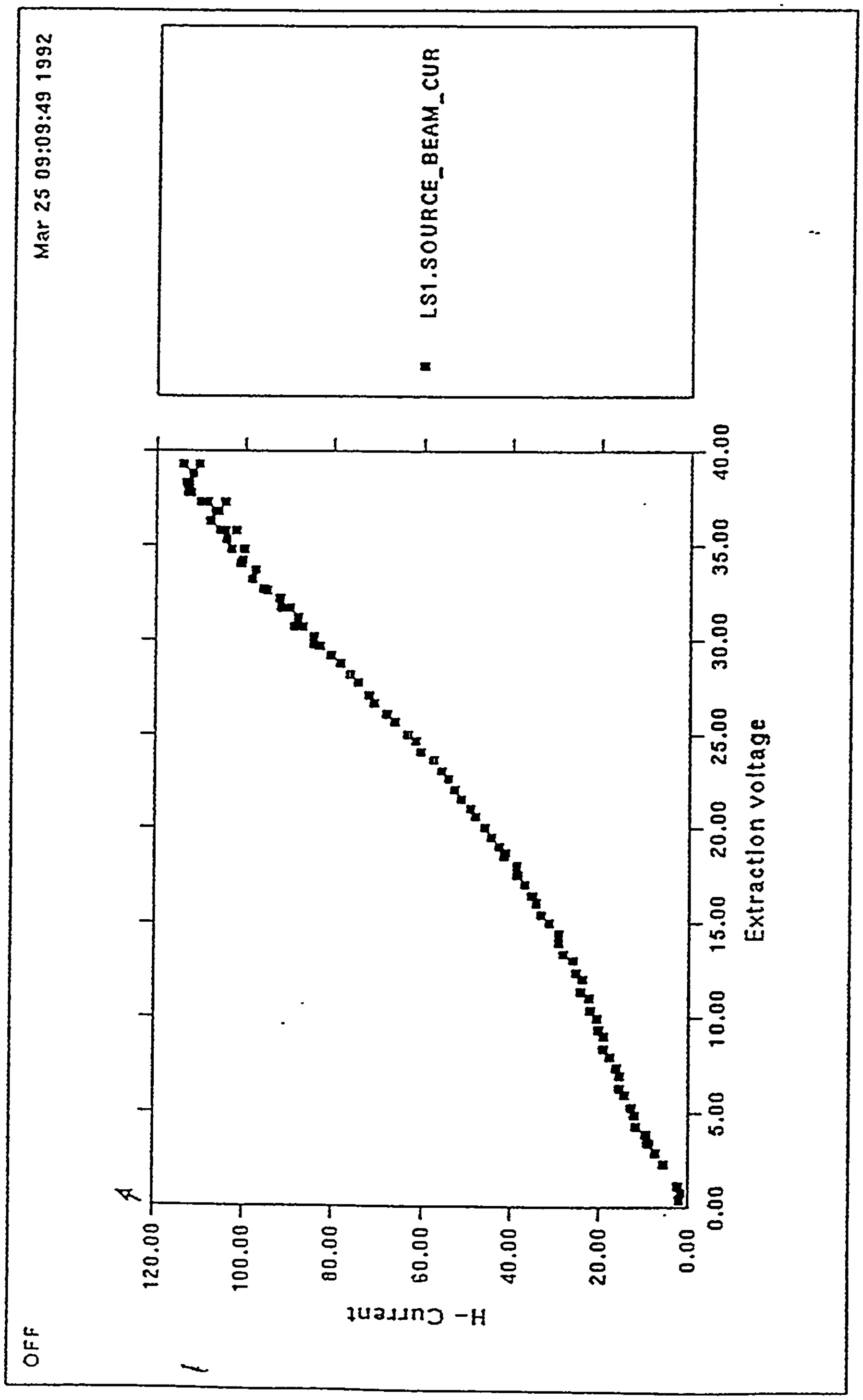
This source was operated for ~ 4 years at $\bar{P}$ = 68 W!

(150 V, 150 A, 5 Hz, 600 μs)

⇒ could run at 3–2% now

(Extractor cooling, etc)


SOURCE OUTPUT CURRENT
20 mA/div ; 100 us/div


Mar 25 09:09:49 1992
LS1.SOURCE_BEAM_CUR
OFF
H- Current
0.00
20.00
40.00
60.00
80.00
100.00
120.00
Extraction voltage
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00

H- Volume Sources at TRIUMF

P. Schmor

TRIUMF

H-minus VOLUME SOURCES at TRIUMF

LBL WORKSHOP
on
ION SOURCES
for a
PULSED SPALLATION NEUTRON SOURCE

P.W. SCHMOR
TRIUMF

TRIUMF H^- ACCELERATORS

- 500 MeV @ < 200 uA
  VOLUME CUSP
  ([redacted] mA H^- @ [redacted] keV)
  1 12
- 30 MeV @ < 550 uA
  VOLUME CUSP
  ([redacted] mA H- @ [redacted] keV)
  5 25
- 13 MeV @ < 100 uA
  VOLUME CUSP
  (1 mA H^- @ 25 keV)
- 1 MeV @ < 1.1 mA
  VOLUME CUSP
  (12 mA H^- @ 25 keV)
- 42 MeV @ < 150 uA
  Internal PIG

TESTSTANDS

- 1 MeV INJECTOR
  25 keV Bias
  Filament driven
  1.4 meter length
  Solenoid + magnetic quads

- Stand #2
  25 keV Bias
  Filament driven
  2 meter length
  Solenoid focussing

- Stand #3
  25 keV Bias
  micro-wave driven (2.45 Ghz)
  2 meter length
  solenoid focussing

INJECTION OPTICS
(SIMPLIFY TUNING)
cyclotron

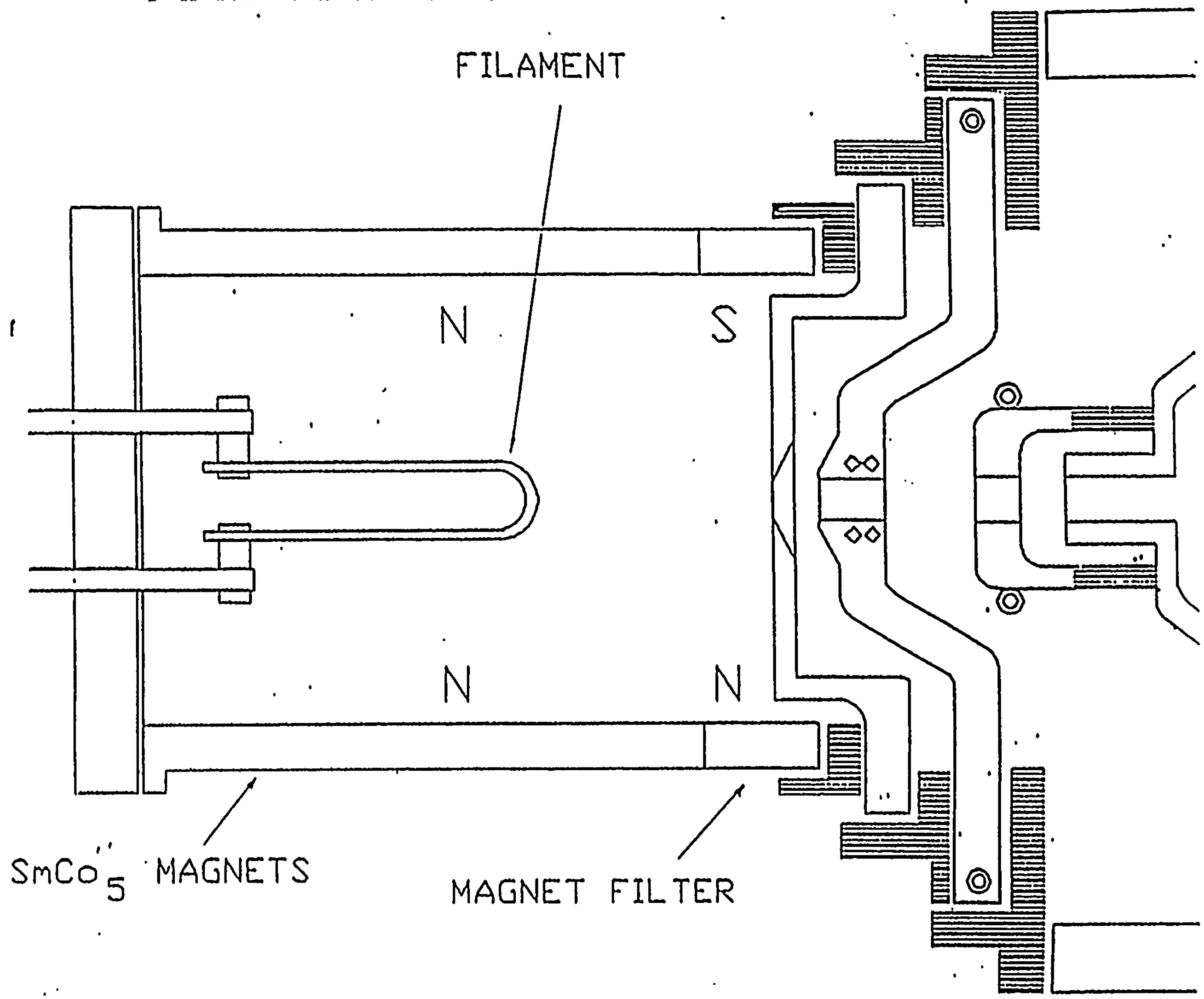
- ELECTROSTATIC
  VARIABLE DUTY CYCLE PULSER
  PEAK CURRENT CONSTANT

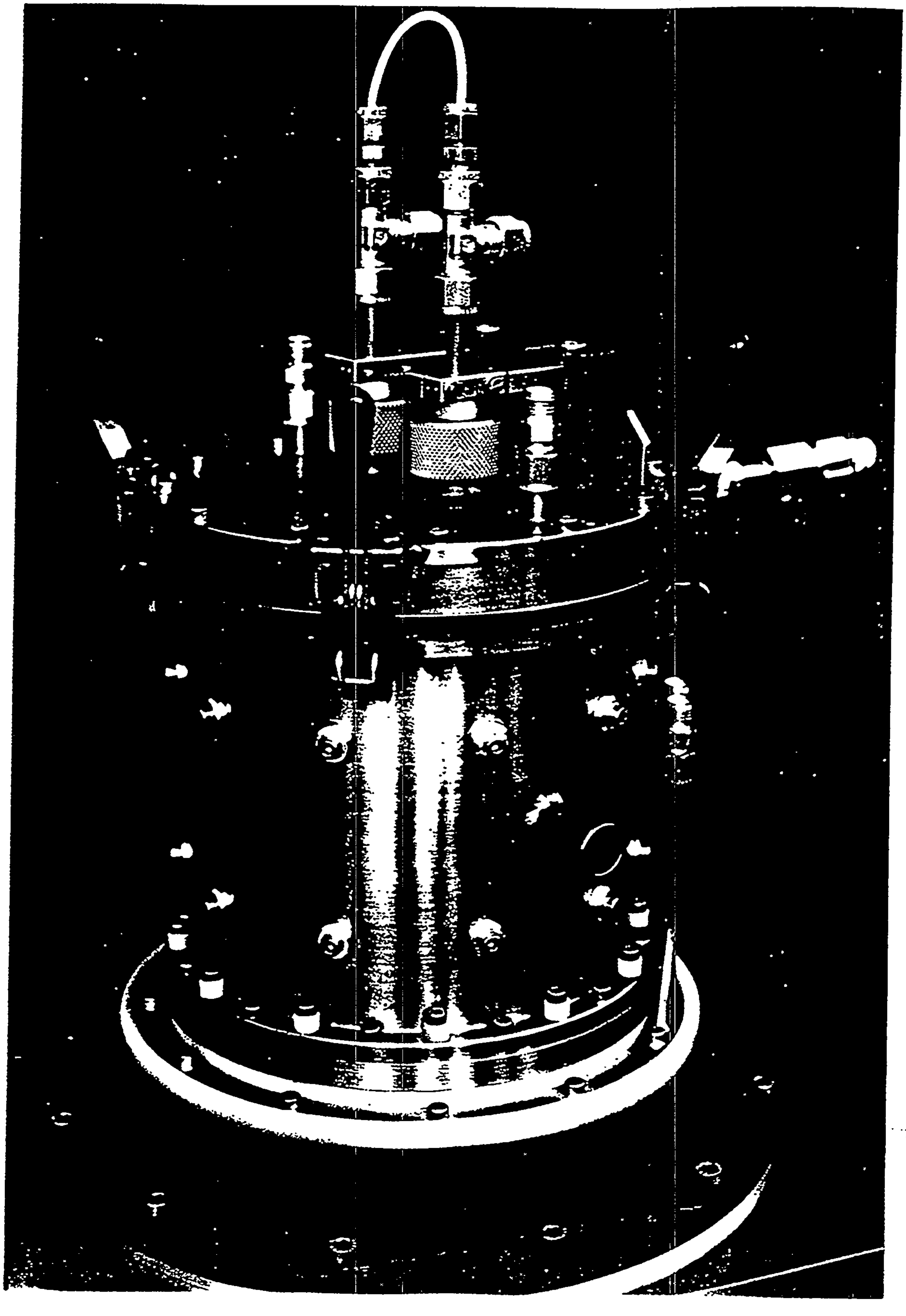
- MAGNETIC
  CURRENT VARIED WITH ARC POWER

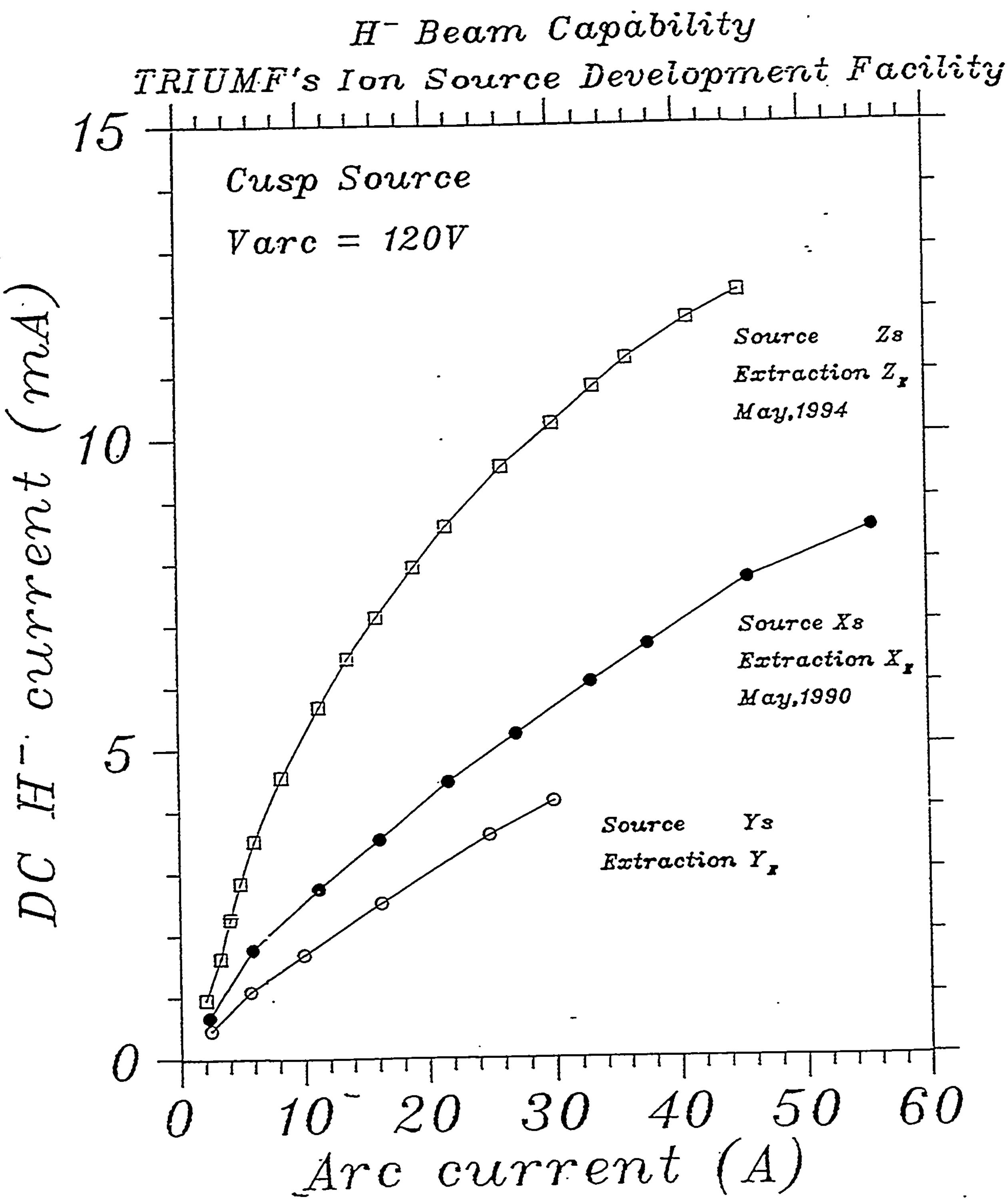
SOURCE & EXTRACTION

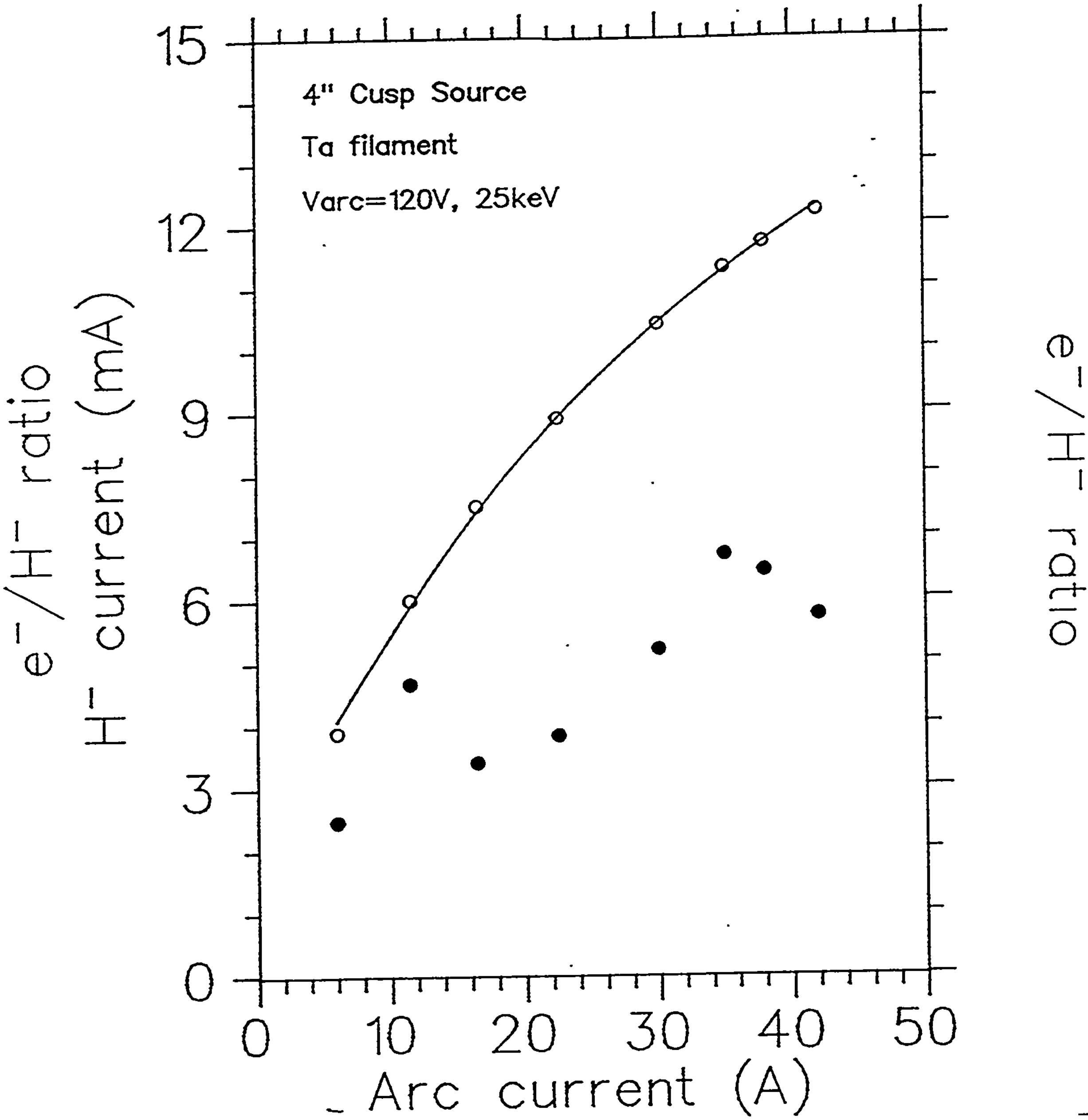
- BODY
  - 10 cm diameter
  - filament(s)
  - micro waves
- dc beams extracted
- TRIODE EXTRACTOR
- DIFFERENTIAL PUMPING
  - TMP at lens
  - Cryopump on beam line

TRIUMF CUSP ION SOURCE AND EXTRACTION SYSTEM

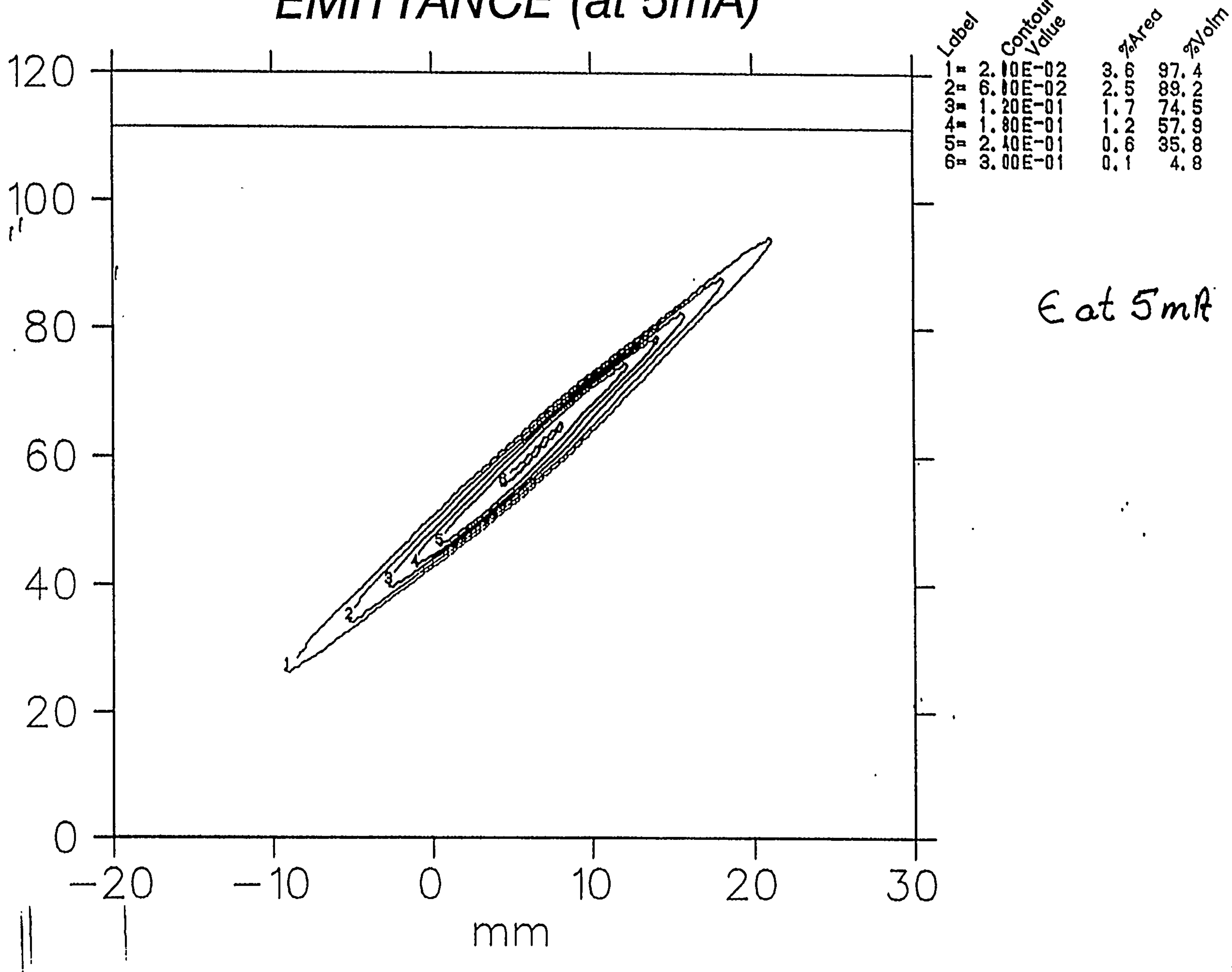


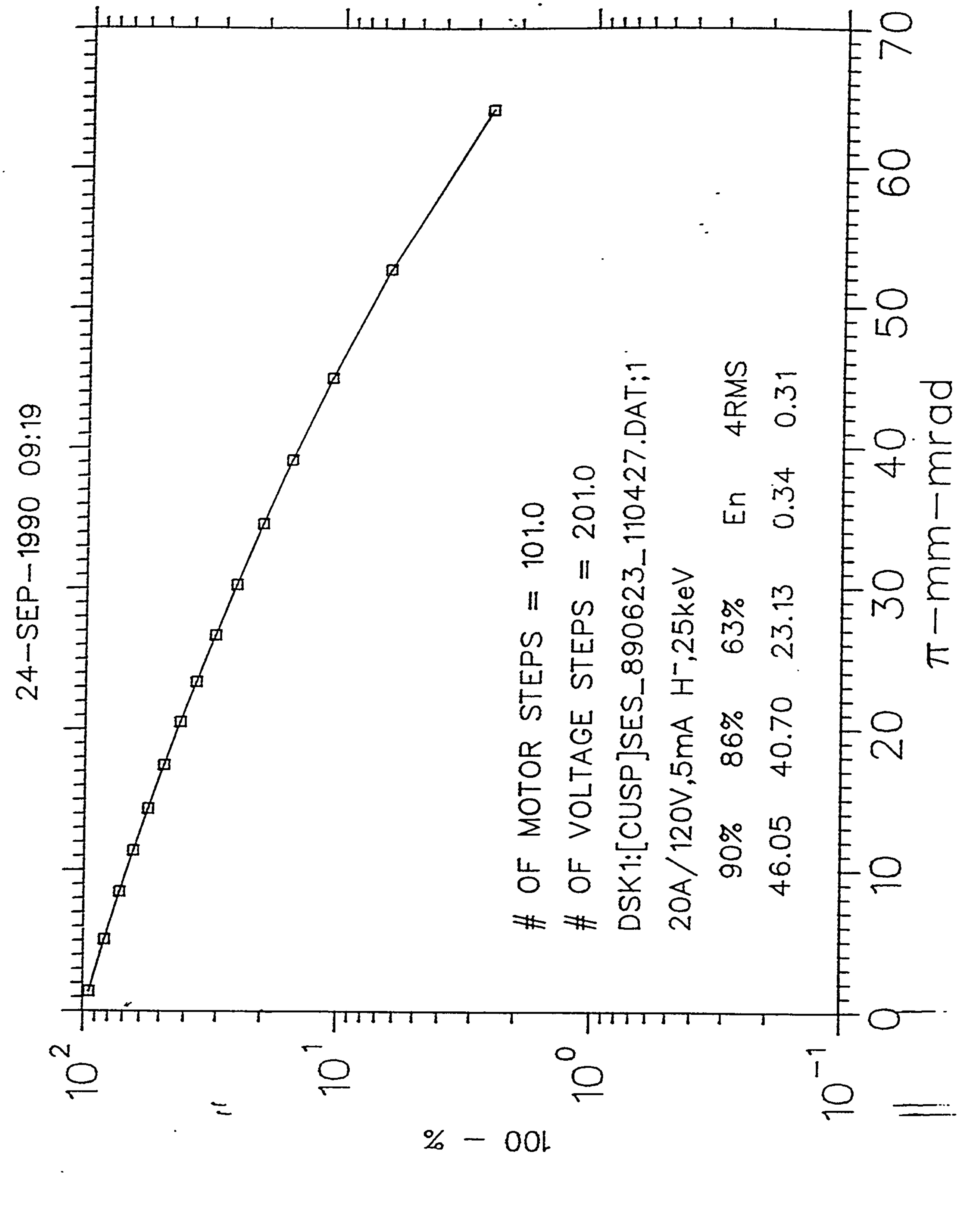


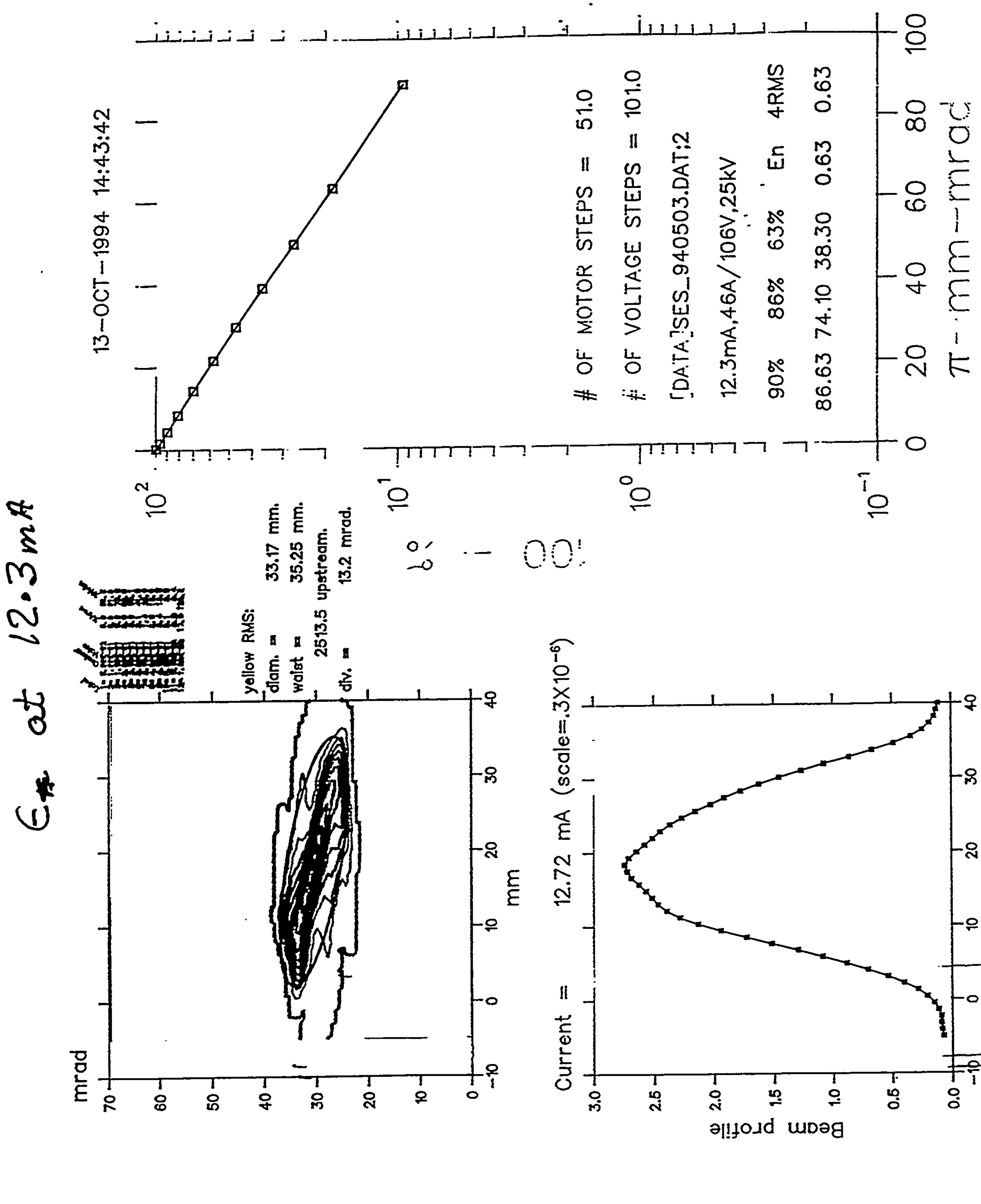

H⁻ Beam Capability
TRIUMF's Ion Source Development Facility
Cusp Source
Varc = 120V
Source Zs
Extraction Z₁
May,1994
Source Xs
Extraction X₁
May,1990
Source Ys
Extraction Y₁
DC H⁻ current (mA)
Arc current (A)
0
5
10
15
0
10
20
30
40
50
60

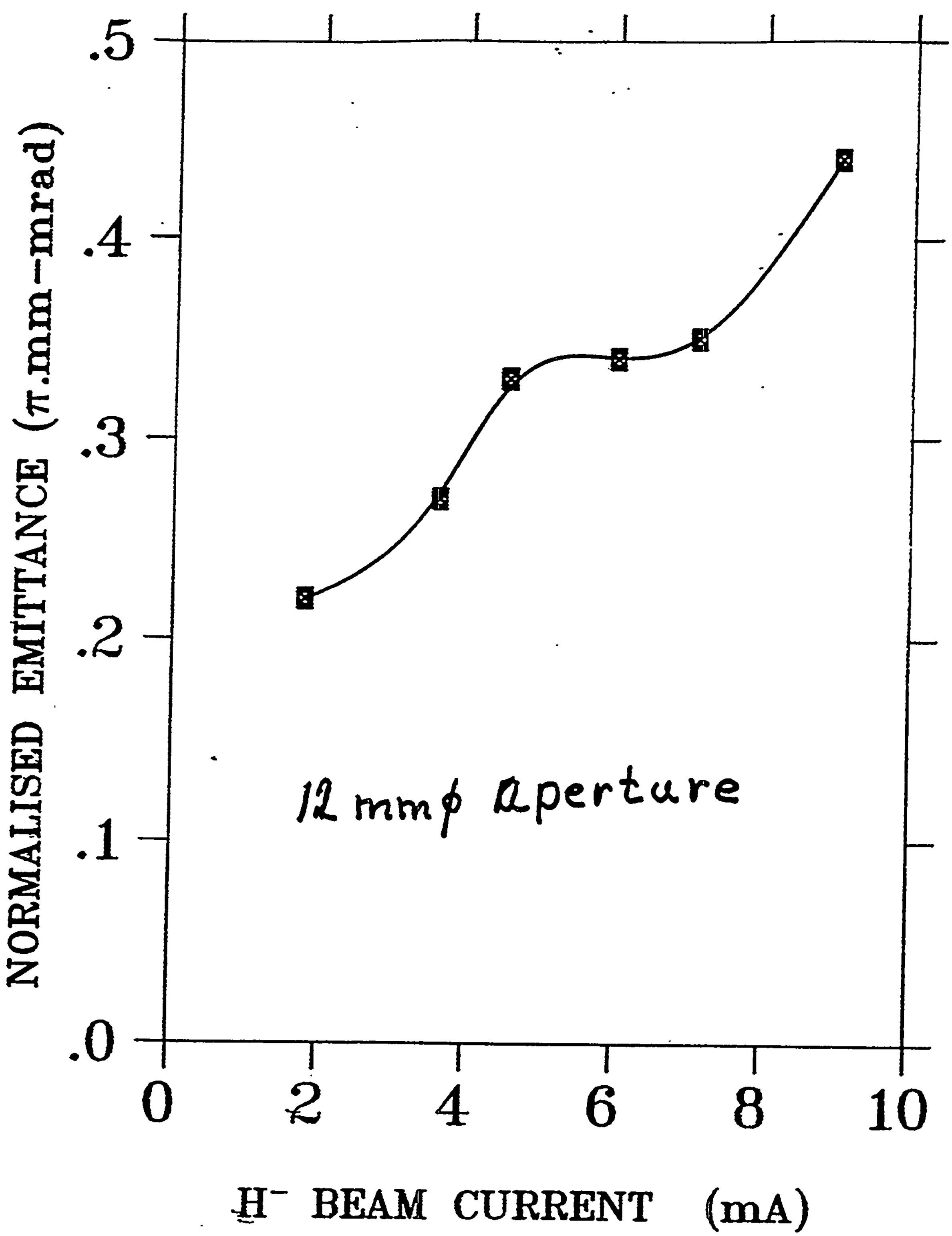

4" Cusp Source
Ta filament
Varc=120V, 25keV
e⁻/H⁻ ratio
H⁻ current (mA)
e⁻/H⁻ ratio
Arc current (A)
0
3
6
9
12
15
0
10
20
30
40
50

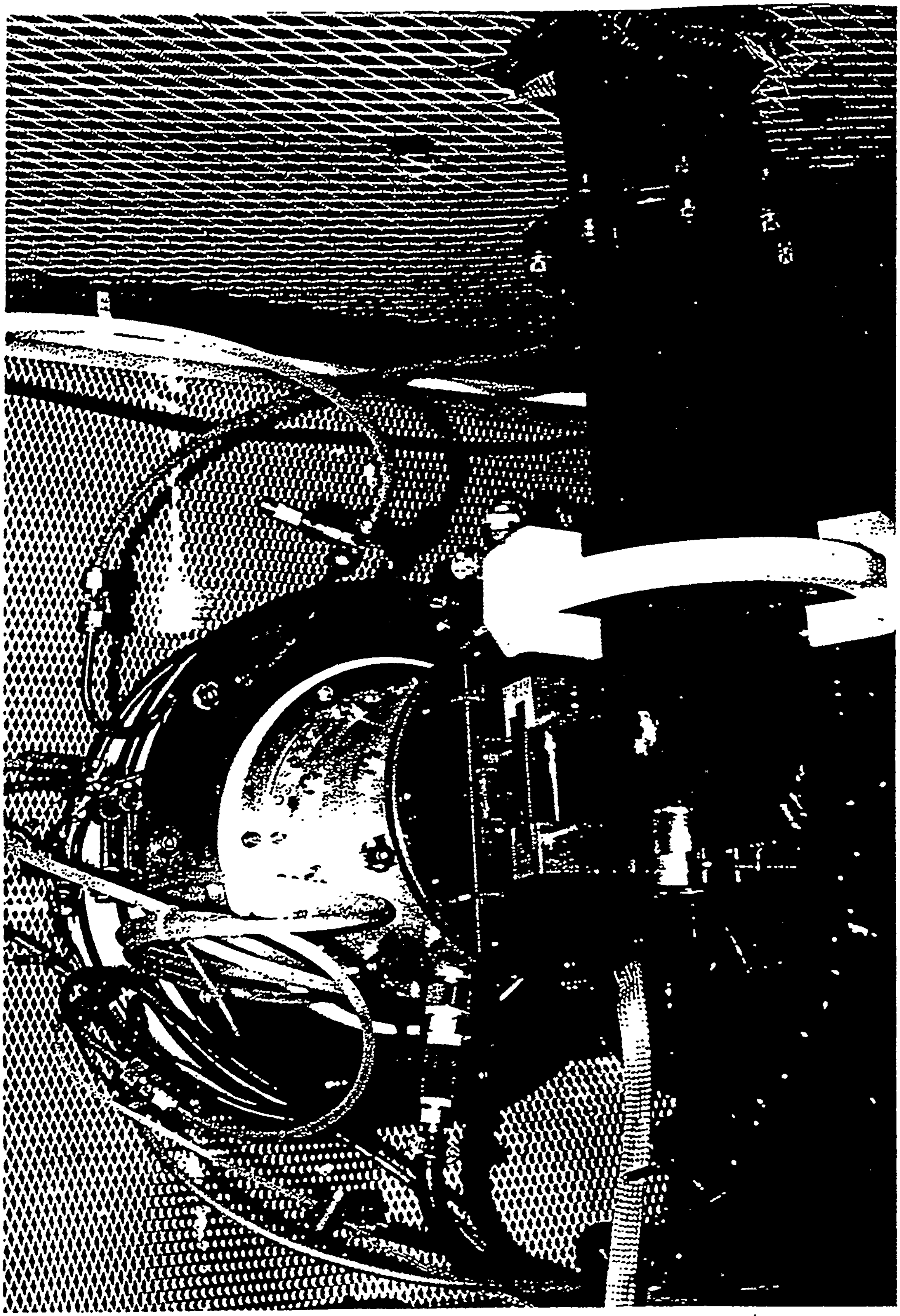
TRIUMF CUSP ION SOURCE EMITTANCE (at 5mA)



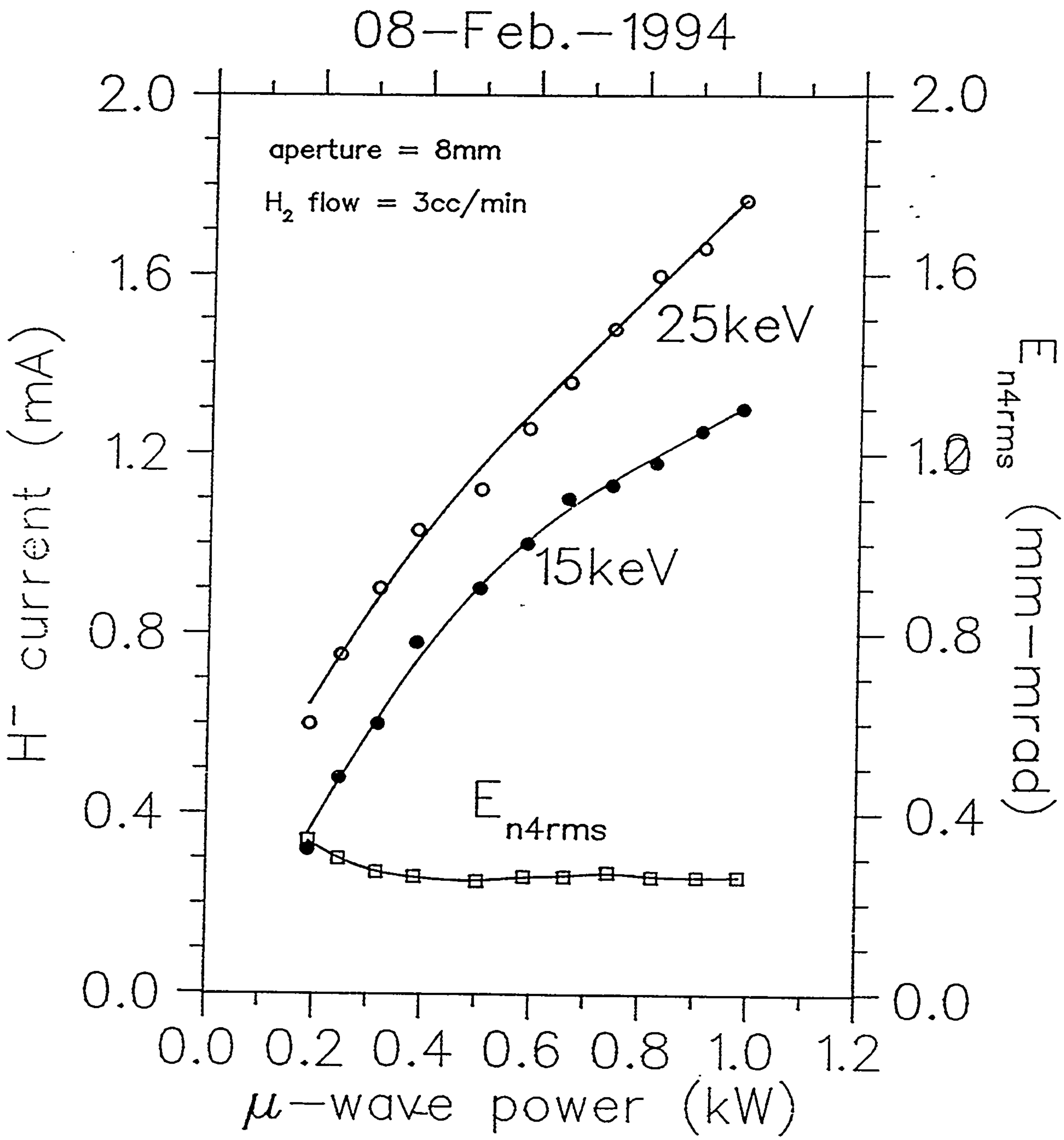

24-SEP-1990 09:19
OF MOTOR STEPS = 101.0
OF VOLTAGE STEPS = 201.0
DSK1:[CUSP]SES_890623_110427.DAT;1
20A/120V,5mA H⁻,25keV
90% 86% 63% En 4RMS
46.05 40.70 23.13 0.34 0.31
100 - %
10^2
10^1
10^0
10^-1
0
10
20
30
40
50
60
70
π-mm-mrad


E* at 12.3mA
13-OCT-1994 14:43:42
OF MOTOR STEPS = 51.0
OF VOLTAGE STEPS = 101.0
[DATA]SES_940503.DAT;2
12.3mA,46A/106V,25kV
90% 86% 63% En 4RMS
86.63 74.10 38.30 0.63 0.63
π - mm - mrad
yellow RMS:
diam. = 33.17 mm.
waist = 35.25 mm.
2513.5 upstream.
div. = 13.2 mrad.
mrad
mm
Current = 12.72 mA (scale=.3X10^-6)
Beam profile
mm

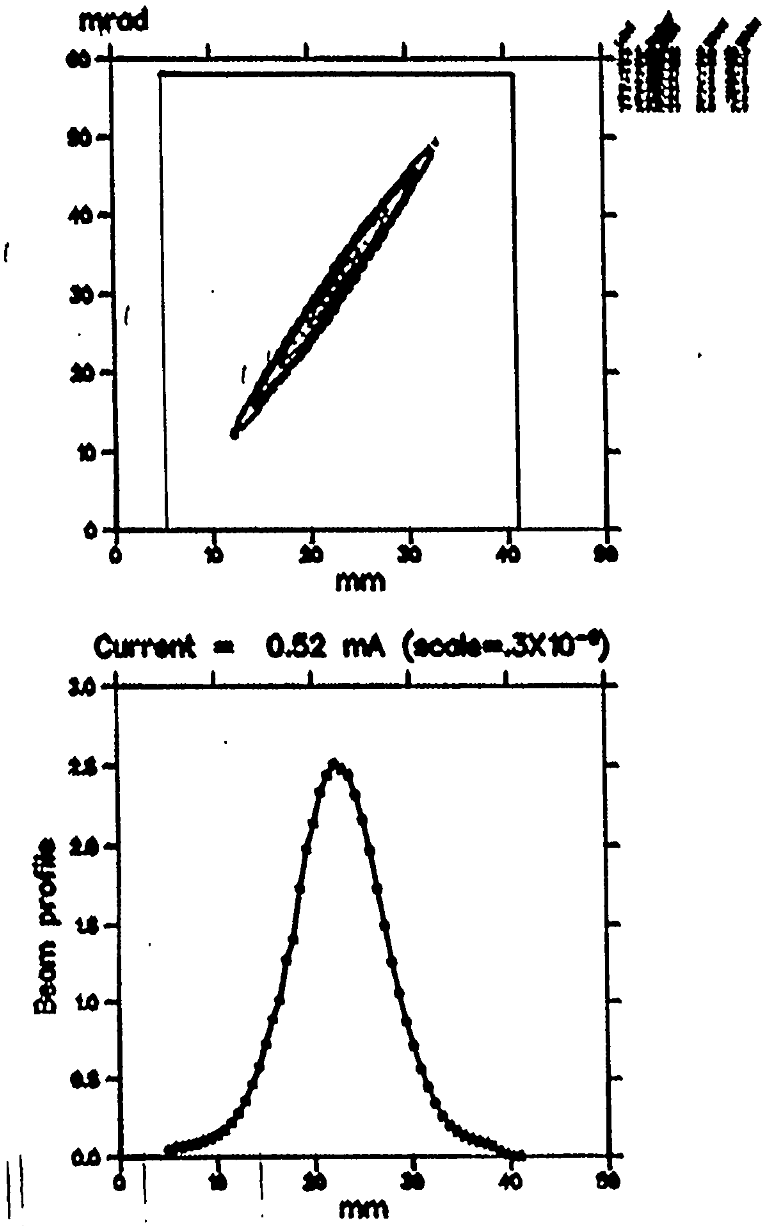

.5
.4
.3
.2
.1
.0
0
2
4
6
8
10
NORMALISED EMITTANCE (π.mm-mrad)
12 mmφ aperture
H⁻ BEAM CURRENT (mA)

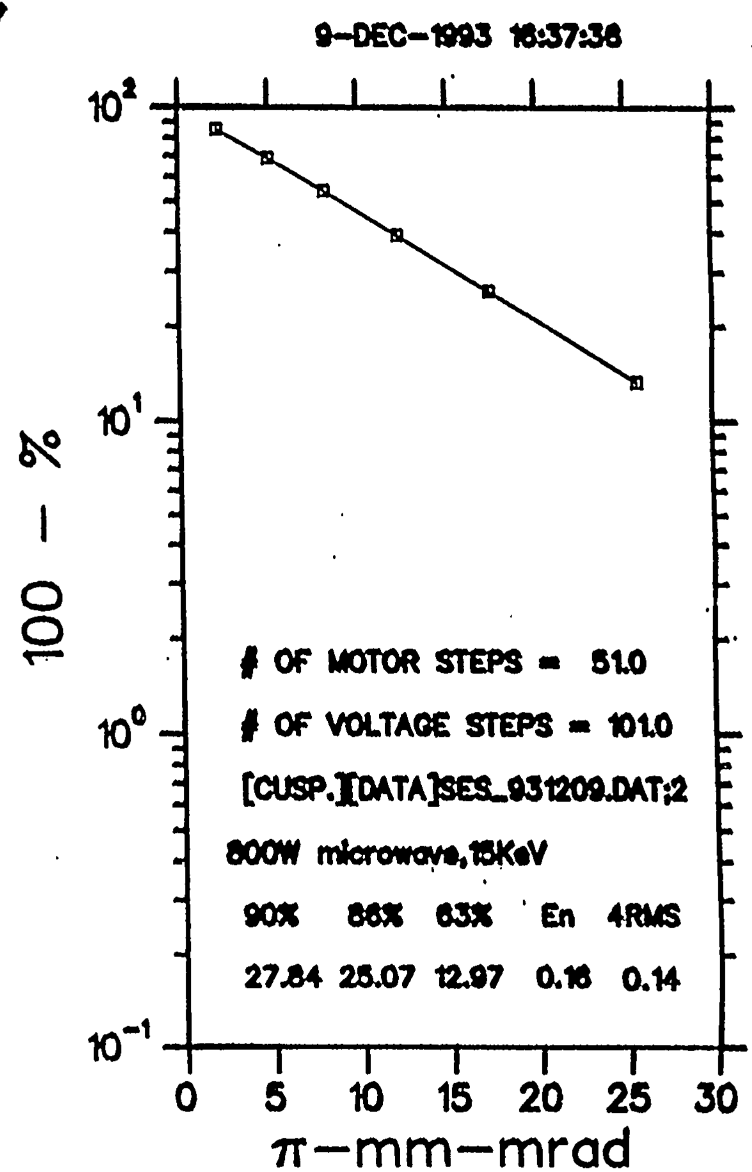


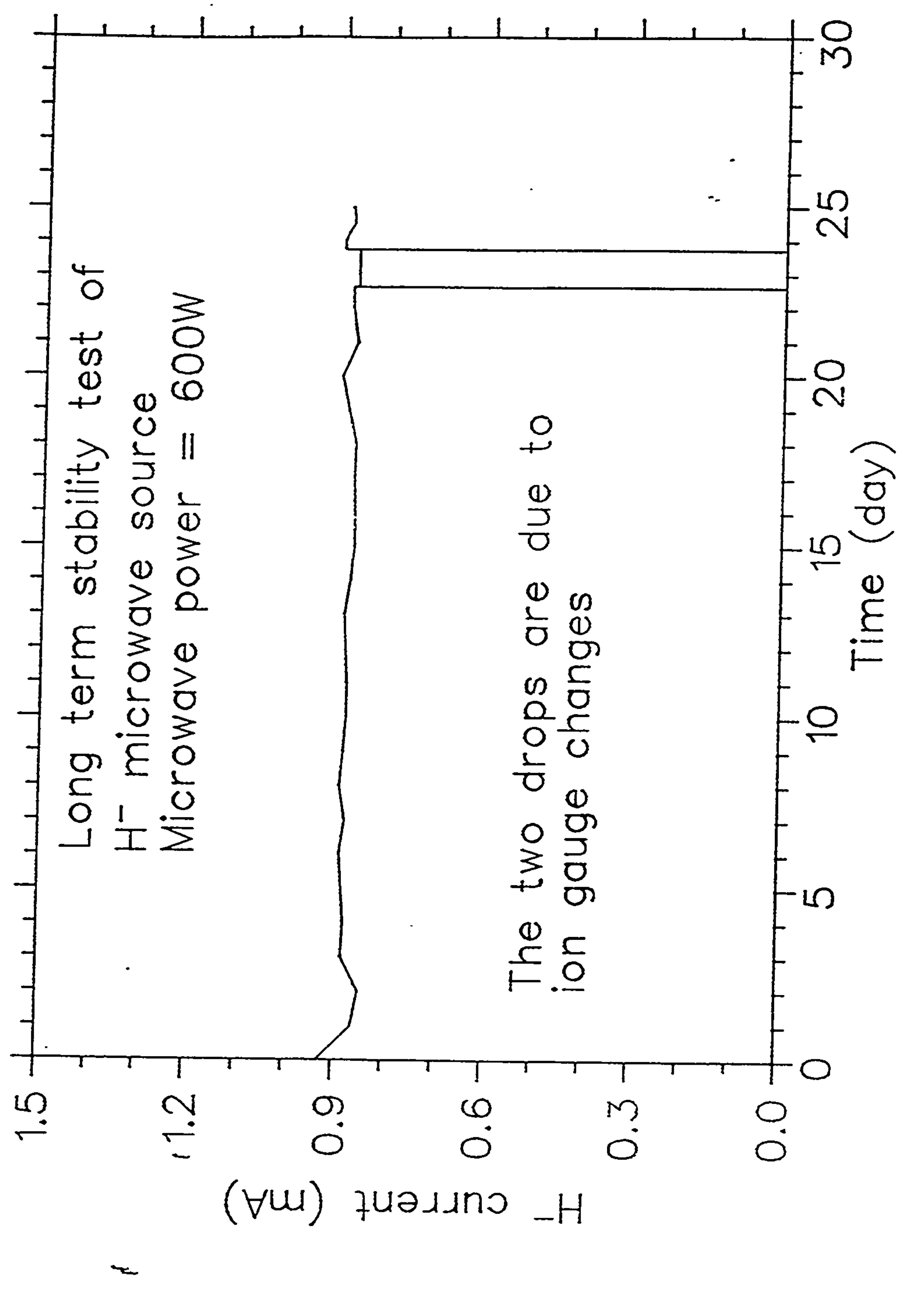
μ-wave Source, dc current



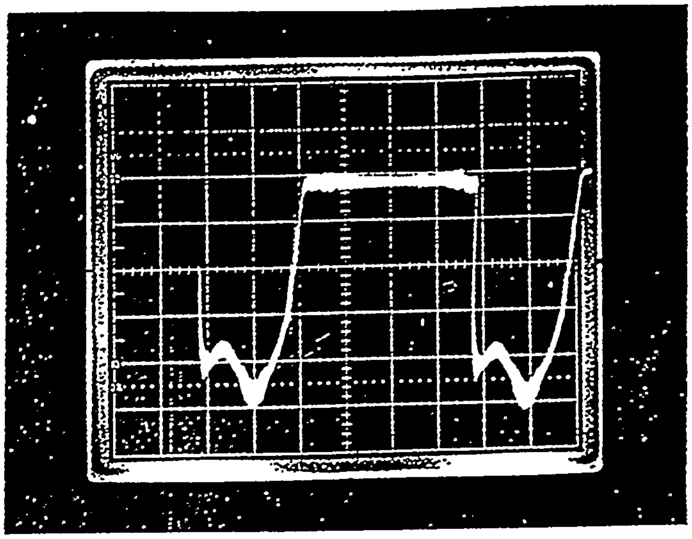
Emittance of µ-wave source







Long term stability test of
H⁻ microwave source
Microwave power = 600W
The two drops are due to
ion gauge changes
H^- current (mA)
Time (day)
1.5
1.2
0.9
0.6
0.3
0.0
0
5
10
15
20
25
30

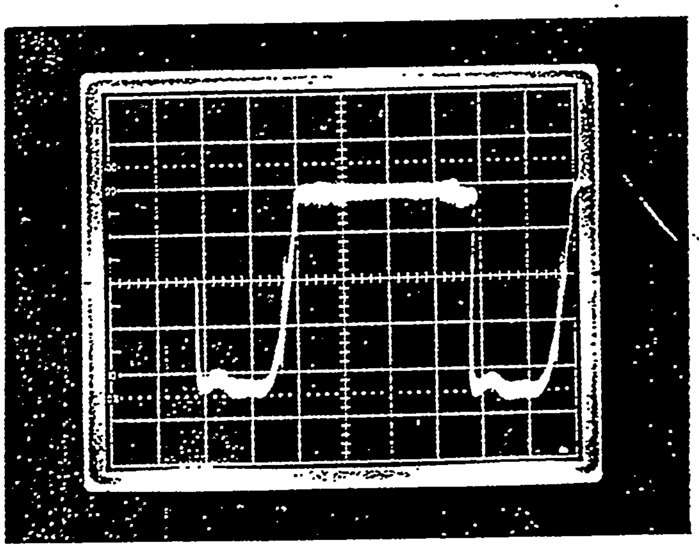


60 Hz pulse

0.4 mA/div

0 —

~1.6mA -



60 Hz pulse

0.4 mA/div

H^- current from μ-wave source driven by Panasonic oven magnetron

BNL Volume Sources

J. Alessi

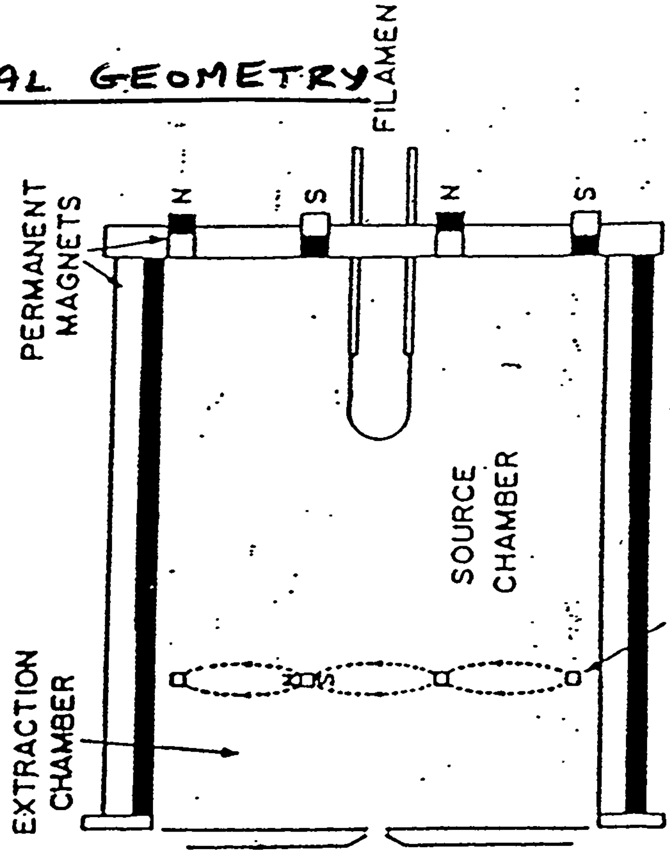
Brookhaven National Laboratory

ENL VOLUME H⁻ SOURCES

J. Alessi

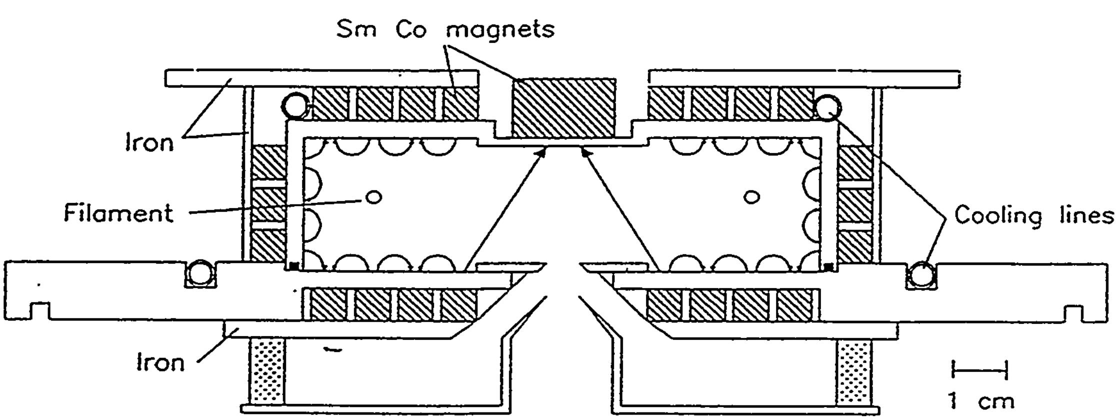
K. Prelec
D. McCafferty

~TYPICAL GEOMETRY

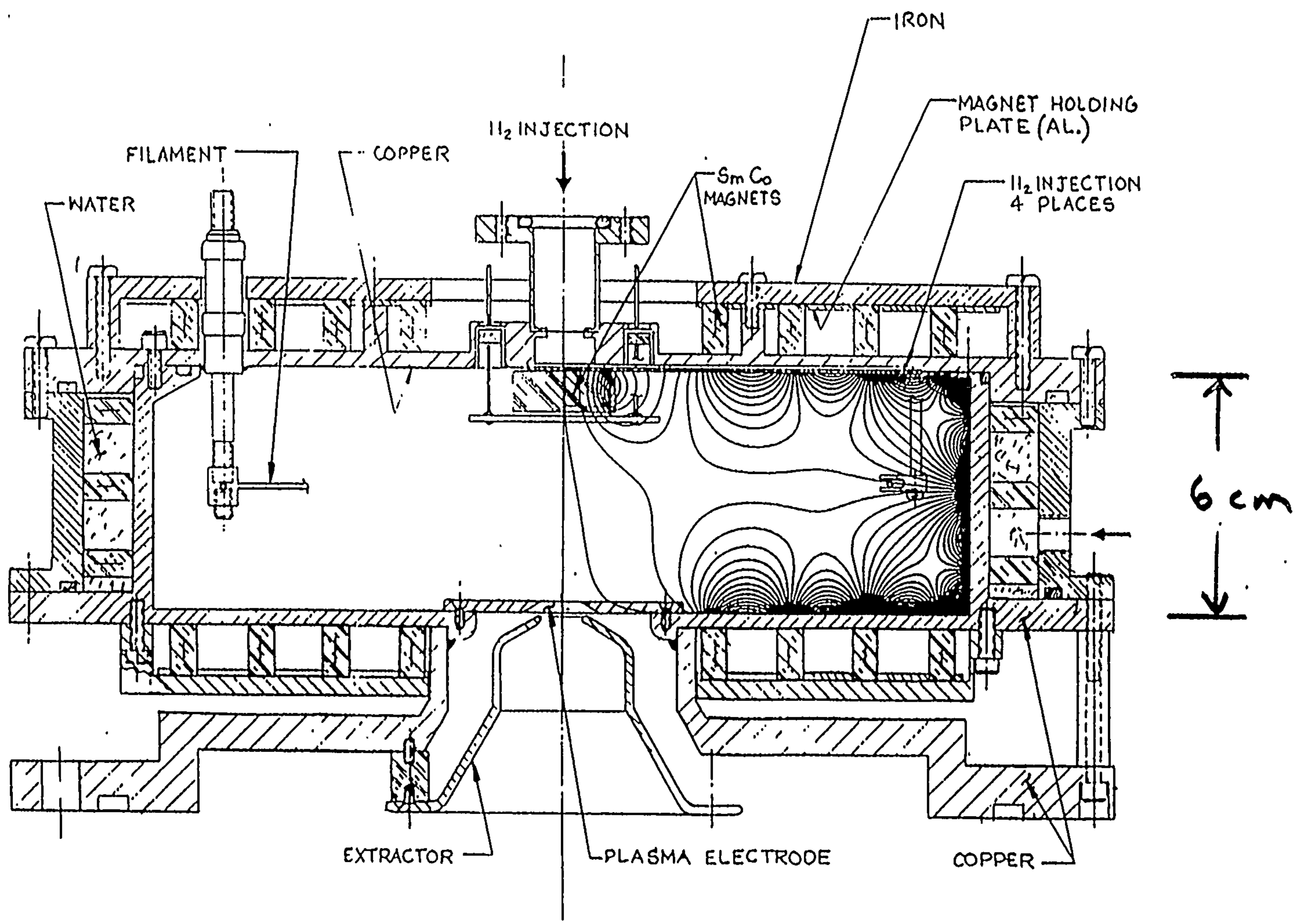


12. Basic H^- volume source.

BNL TOROIDAL GEOMETRY / CONICAL FILTER

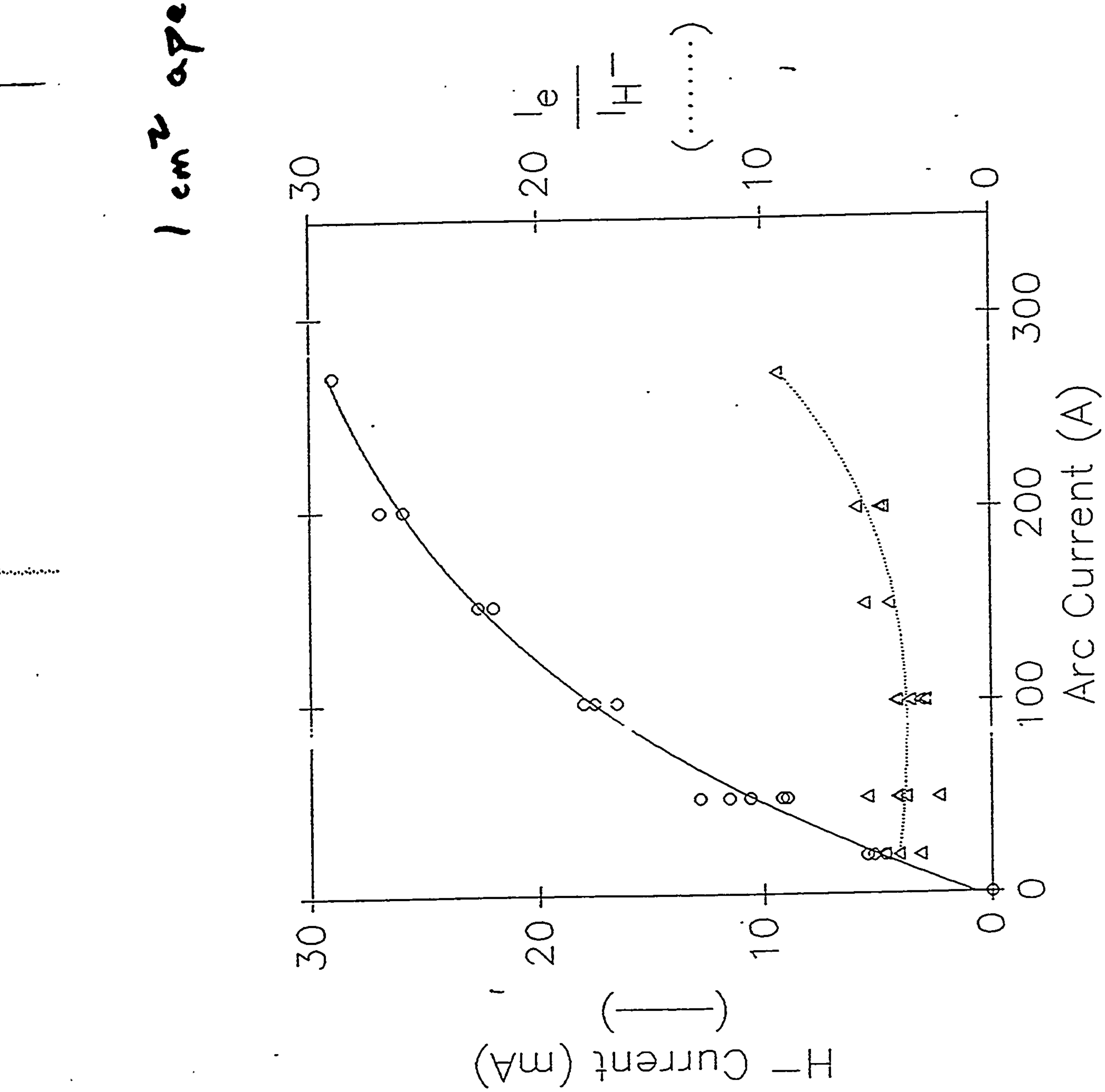


LARGE SOURCE

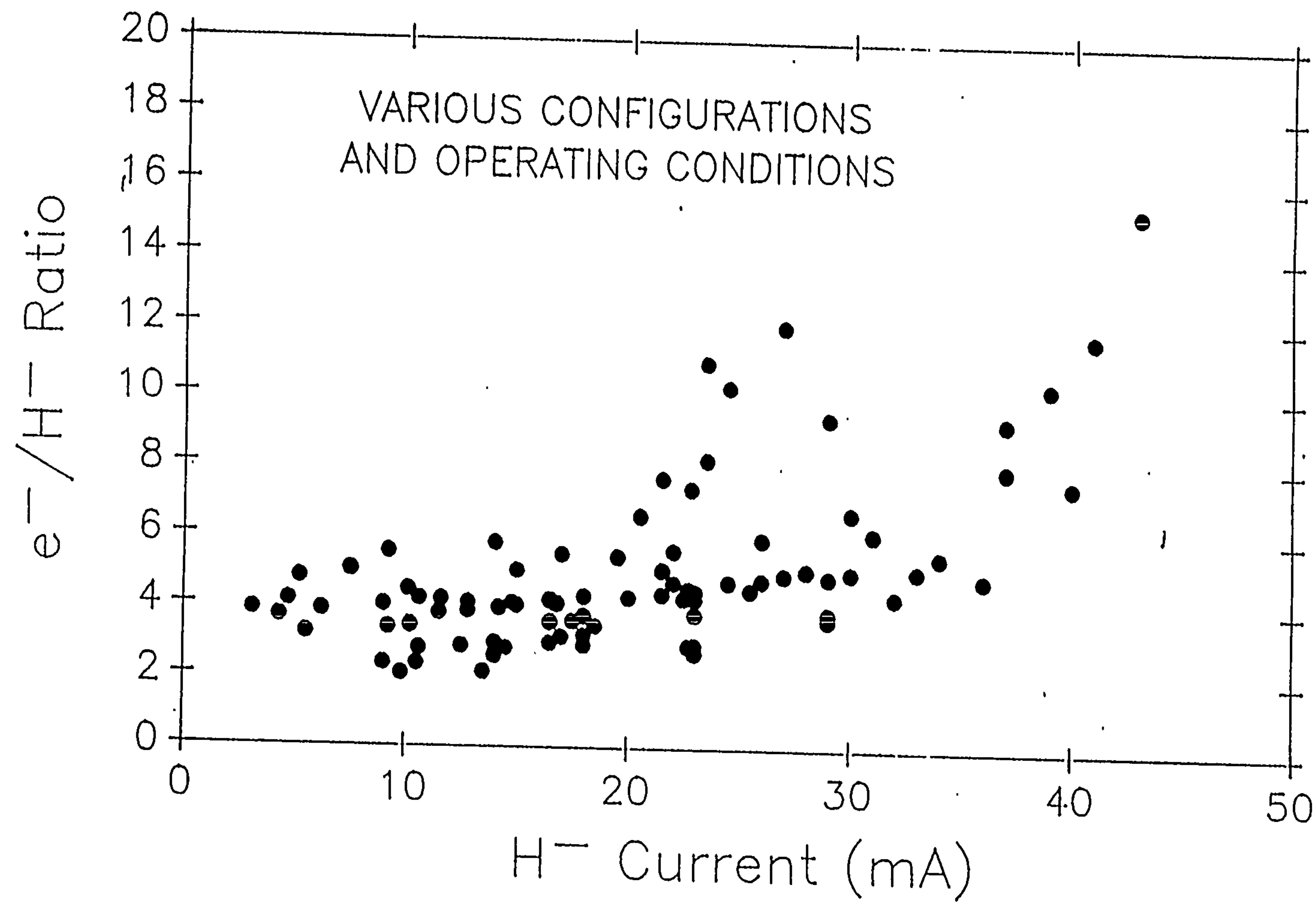


20 cm I.D.

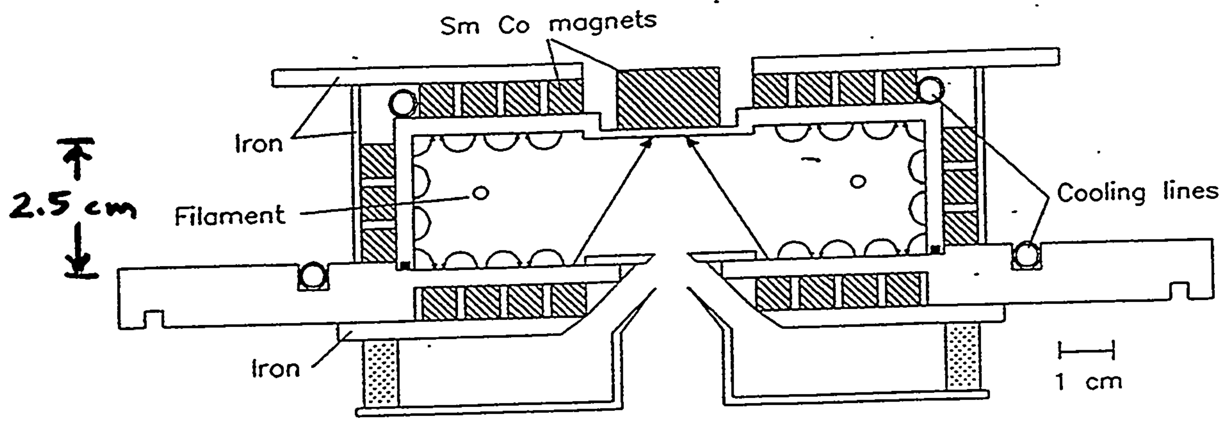
1 cm² aperture

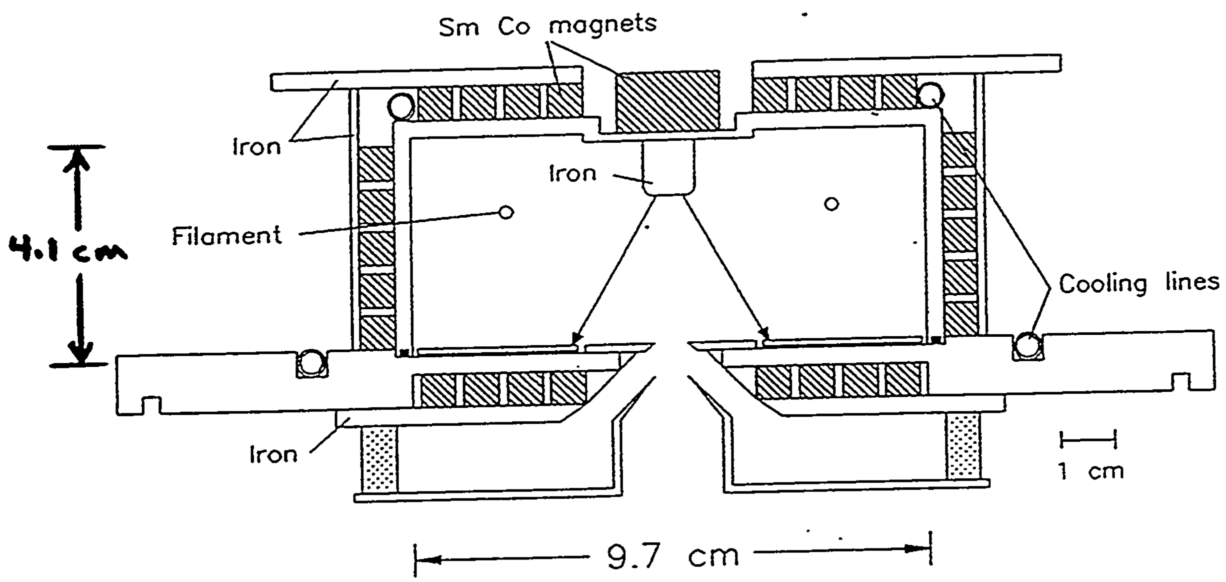


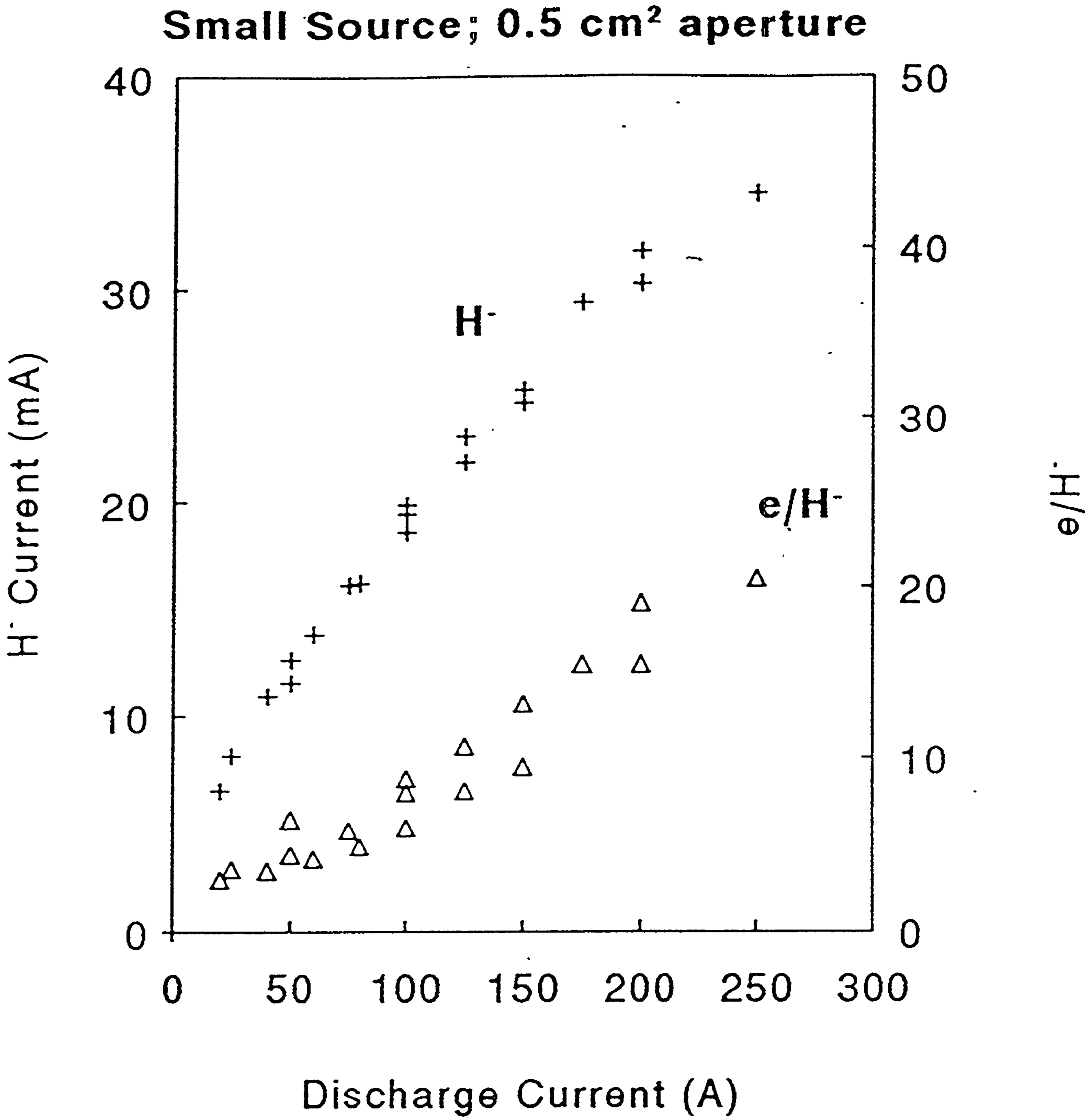
LARGE SOURCE

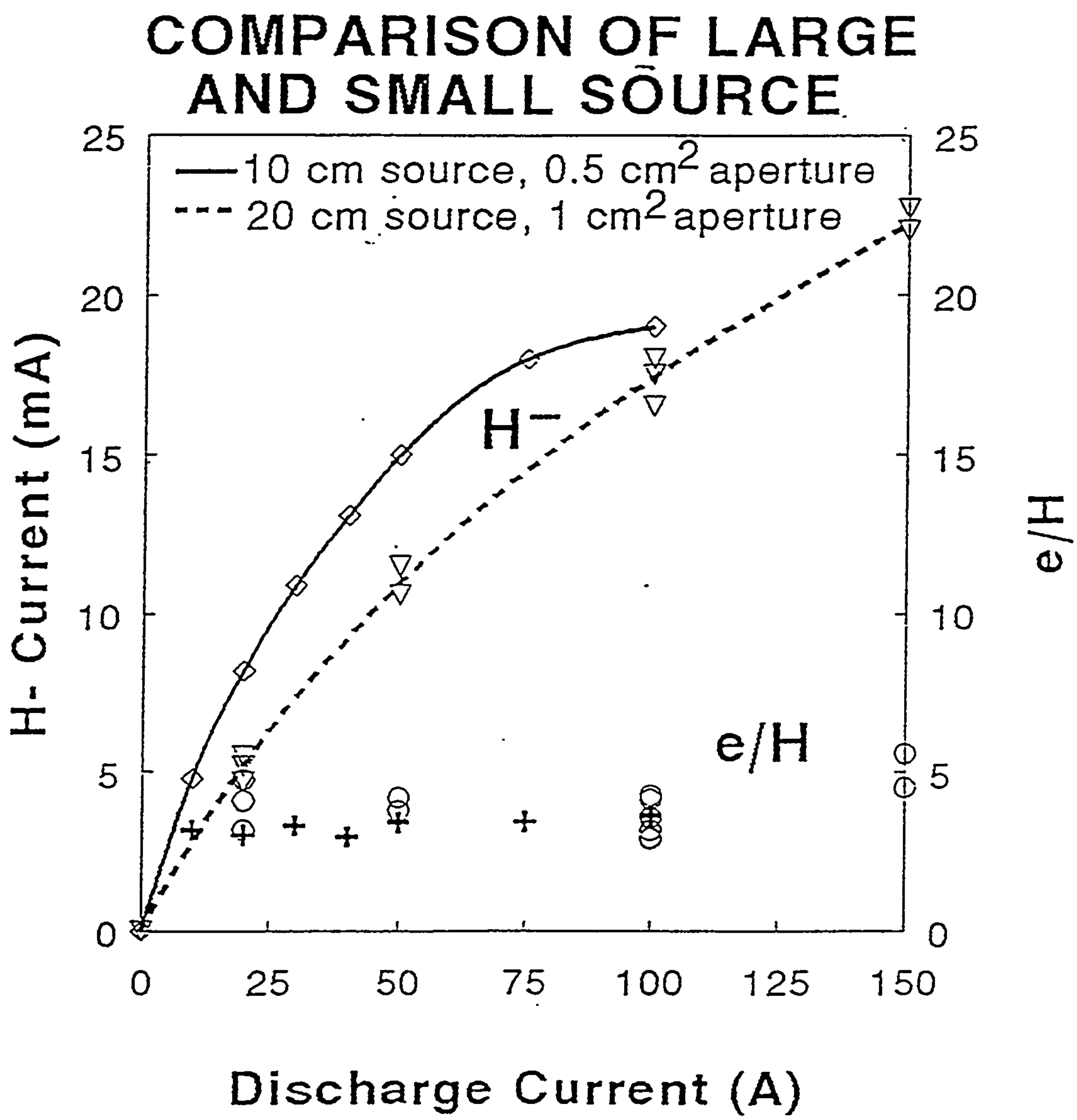


SCHEMATIC OF SMALL SOURCE



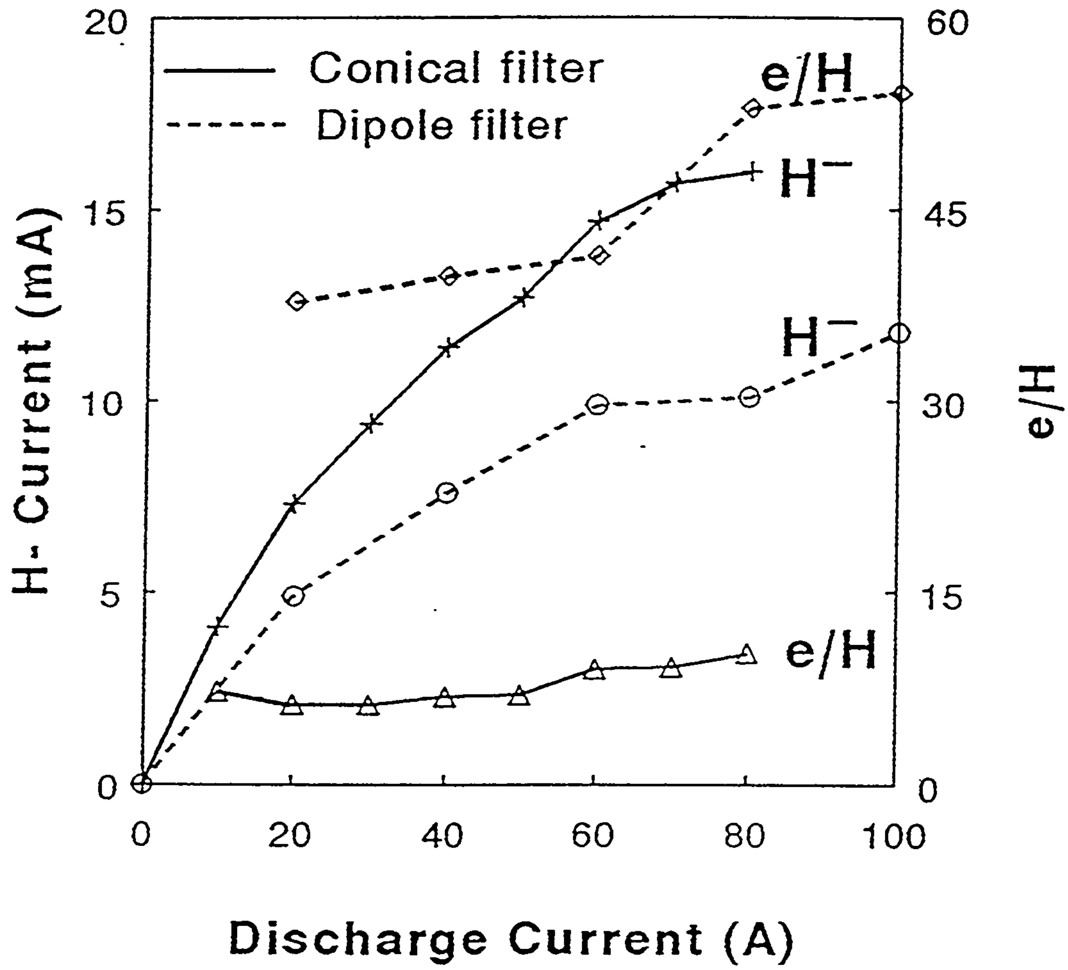



Small Source; 0.5 cm² aperture
40
30
20
10
0
50
40
30
20
10
0
H⁻
e/H⁻
H⁻ Current (mA)
e/H⁻
0
50
100
150
200
250
300
Discharge Current (A)

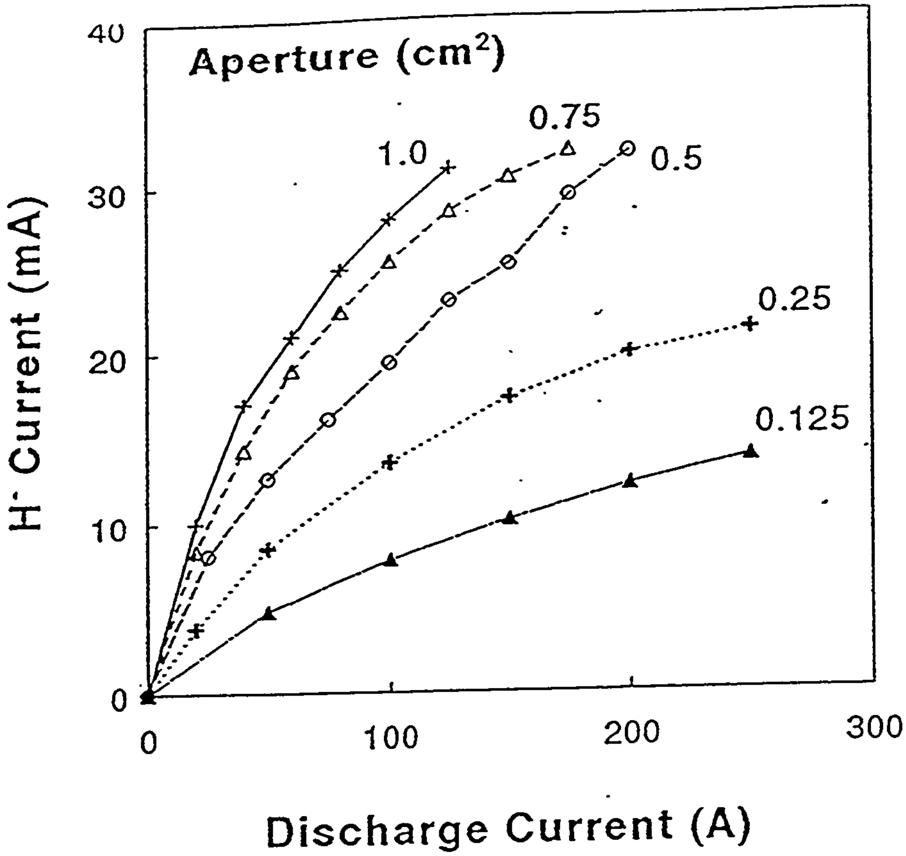


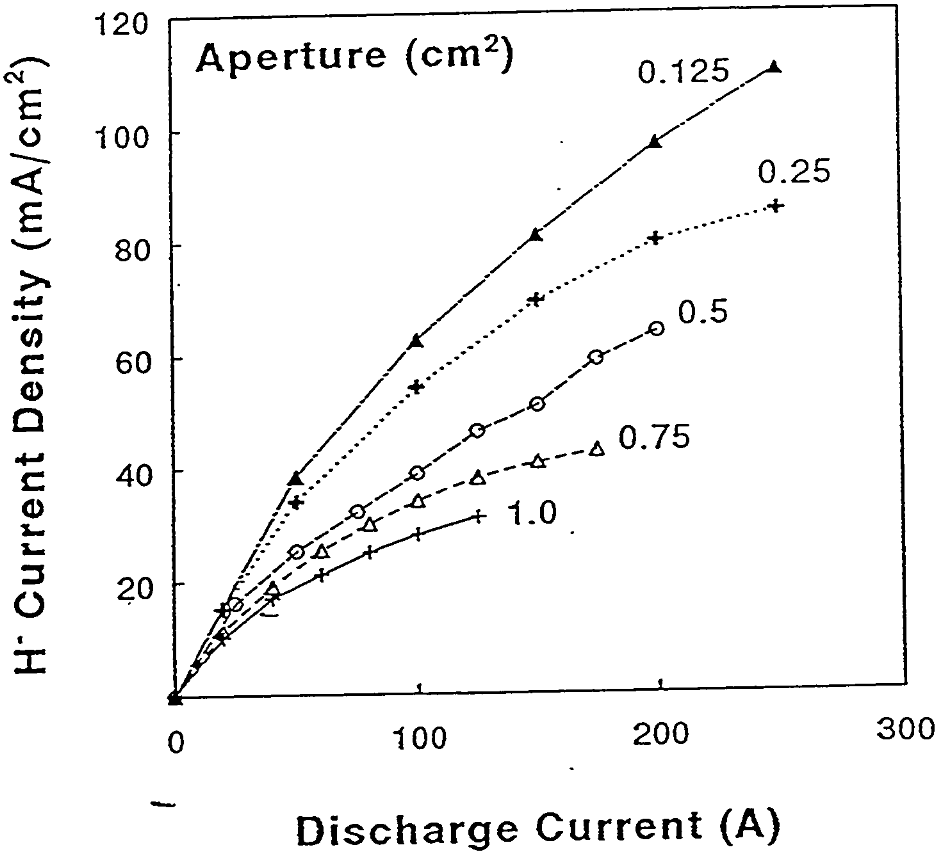
COMPARISON OF LARGE AND SMALL SOURCE
10 cm source, 0.5 cm2 aperture
20 cm source, 1 cm2 aperture
H-
e/H
H- Current (mA)
e/H
Discharge Current (A)
0
5
10
15
20
25
0
25
50
75
100
125
150

CONICAL VS. DIPOLE FILTER FIELD



Small Source





FILTER FIELD STRENGTH

LARGE

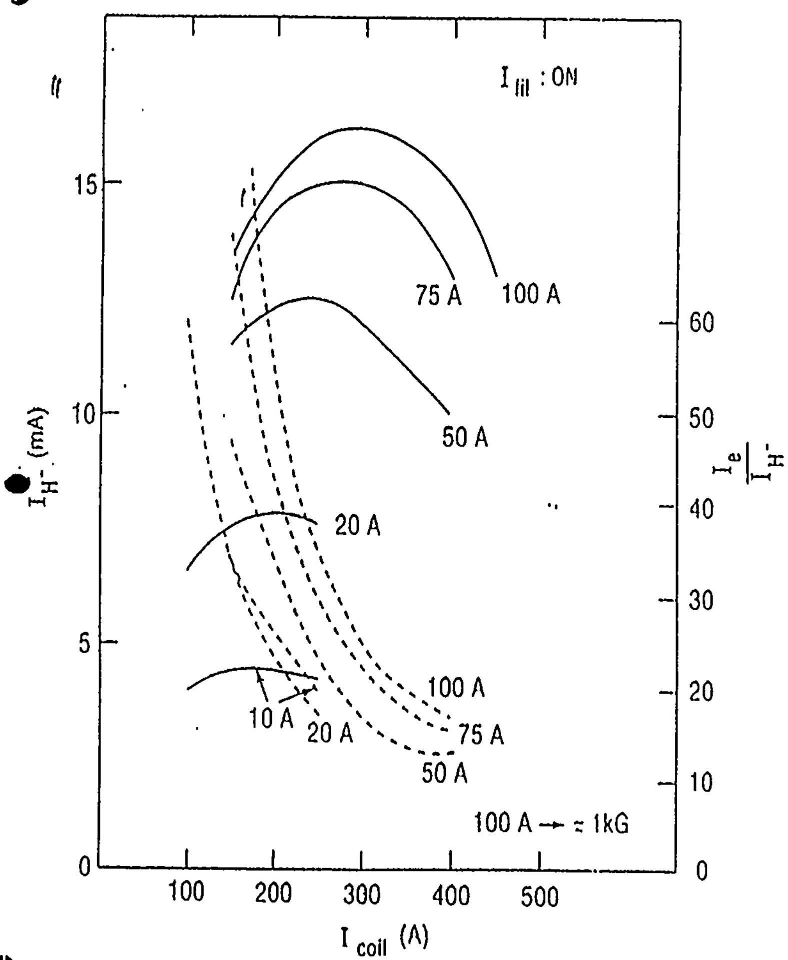
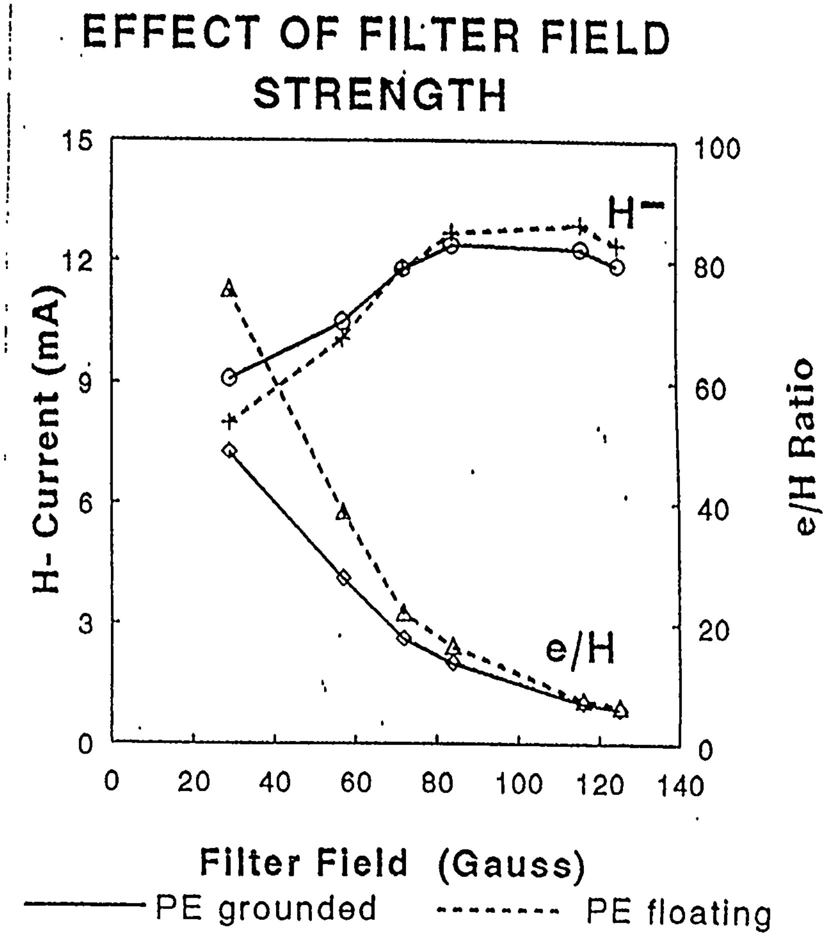
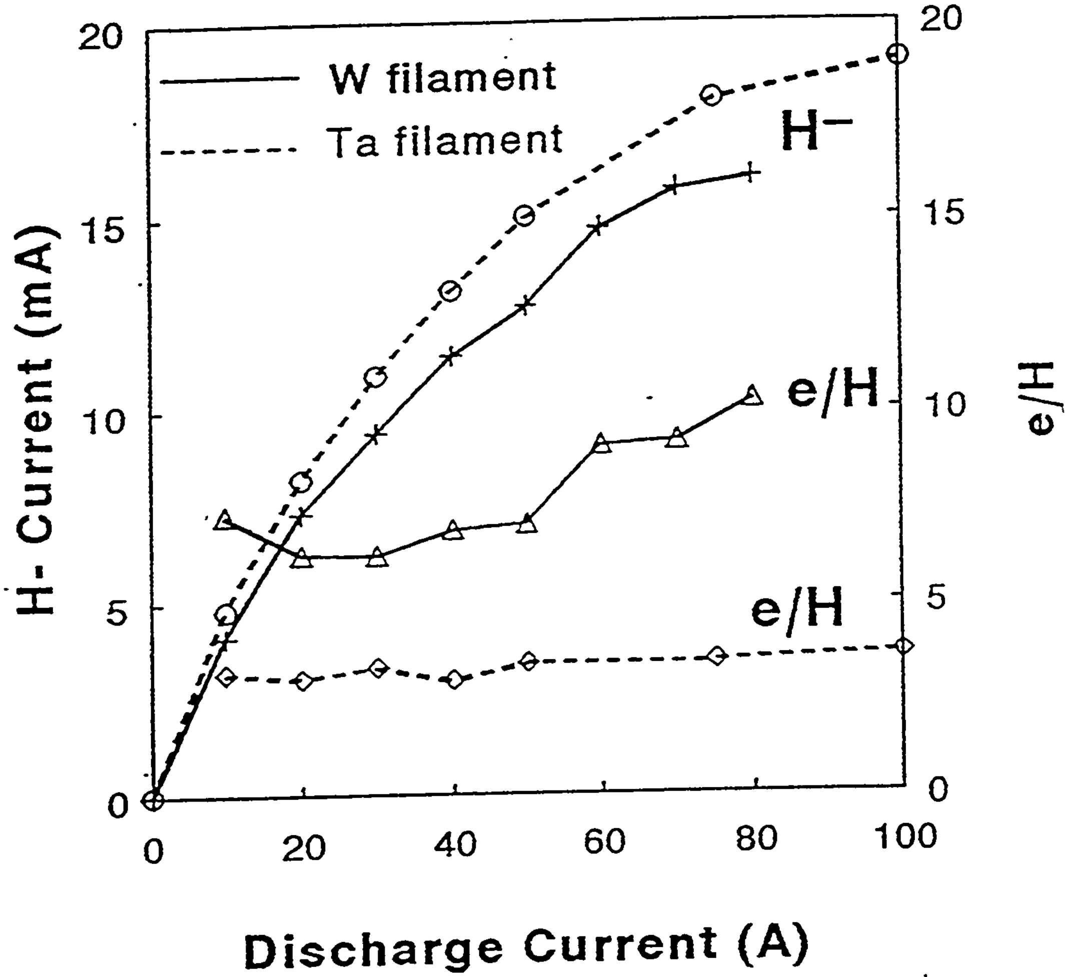


Fig. 6 H^- yield (full lines) and the ratio I_e/I_{H^-} as function of the conical field strength for several values of the arc current; I_{fil} ON.

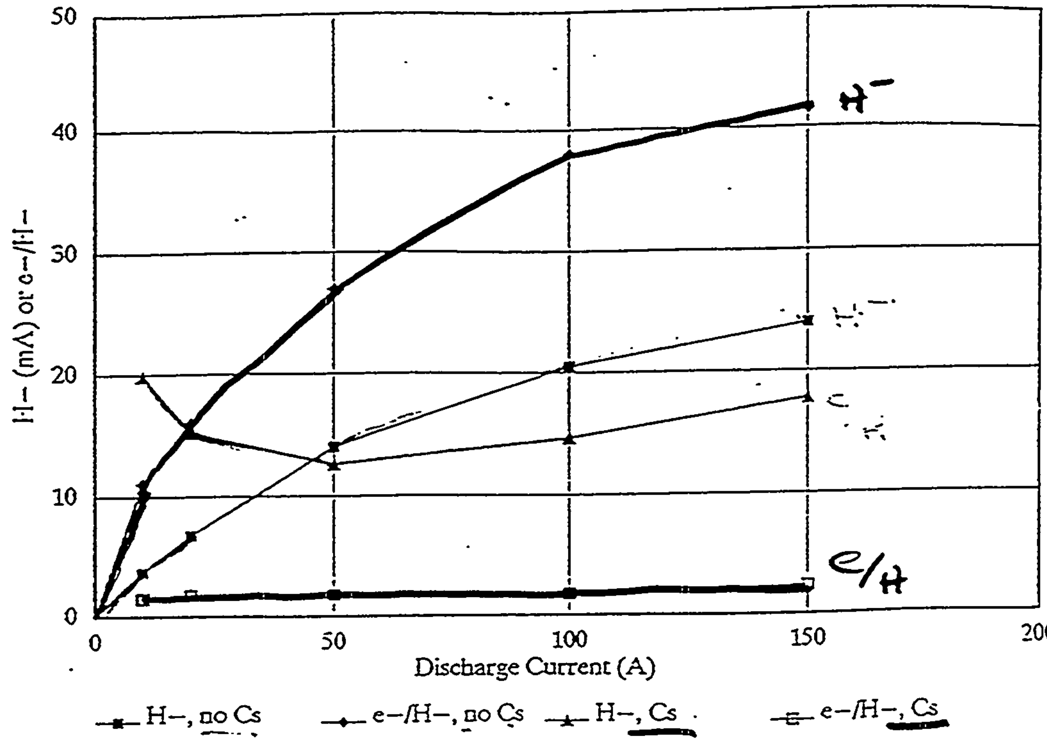
SMALL

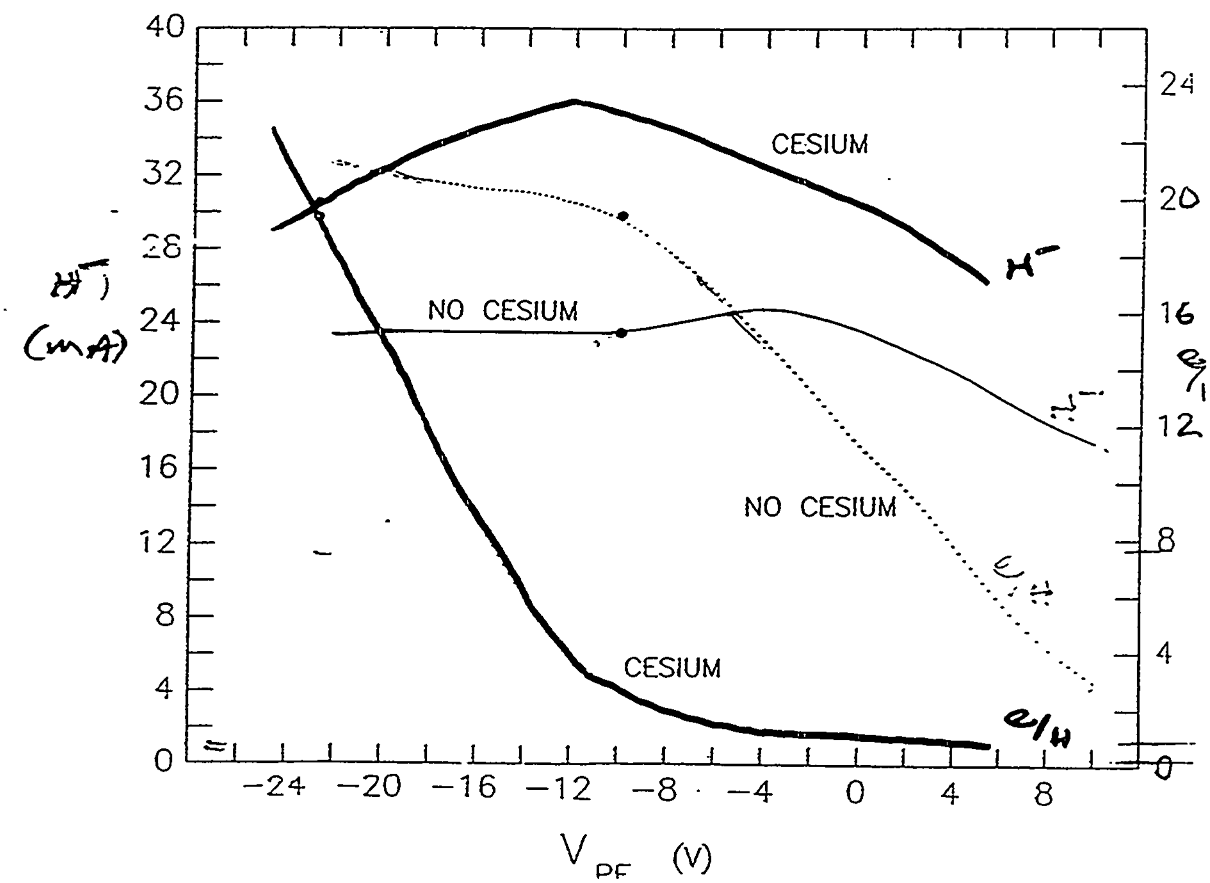


COMPARISON OF TUNGSTEN VS.TANTALUM FILAMENTS

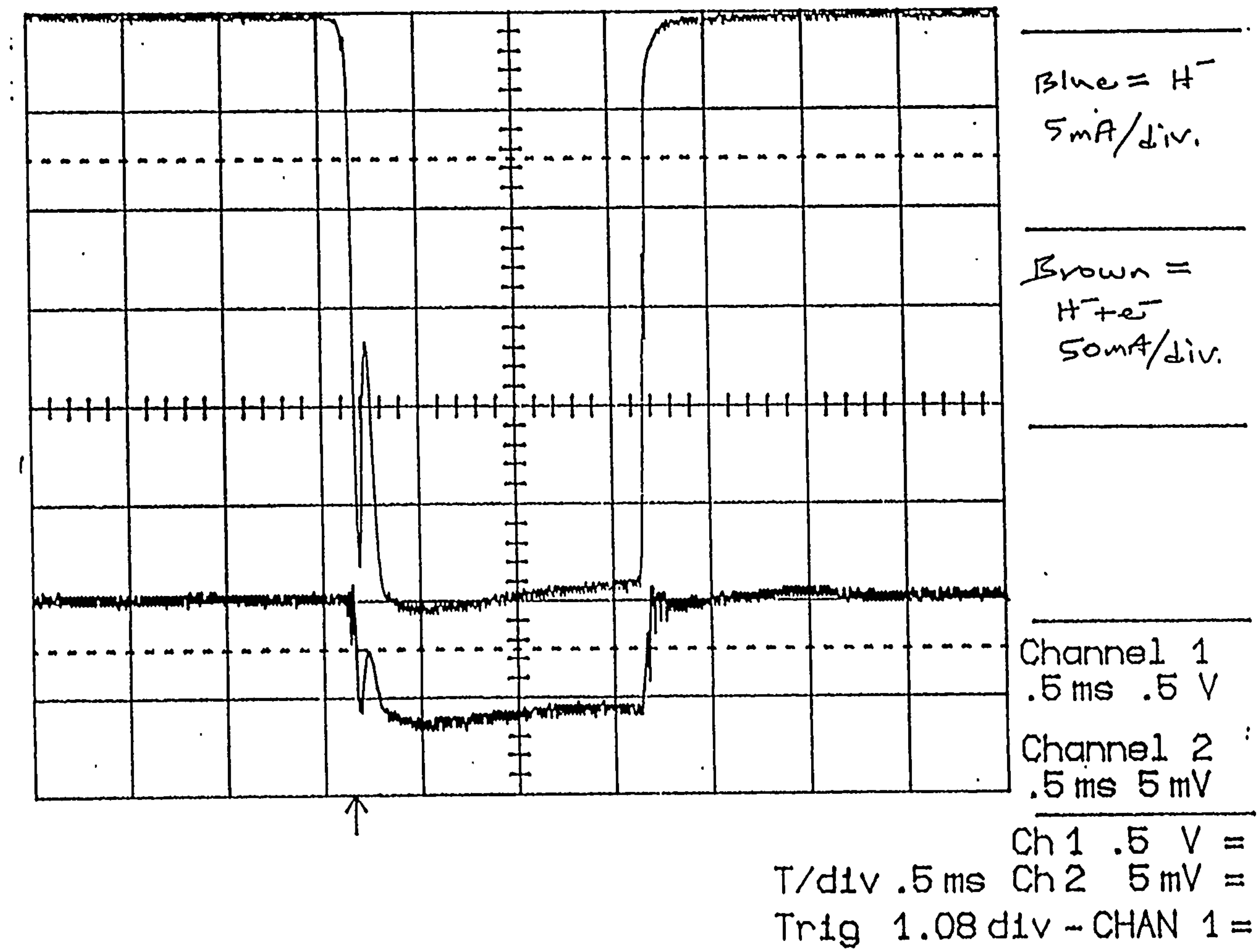


Cesium in Large Source

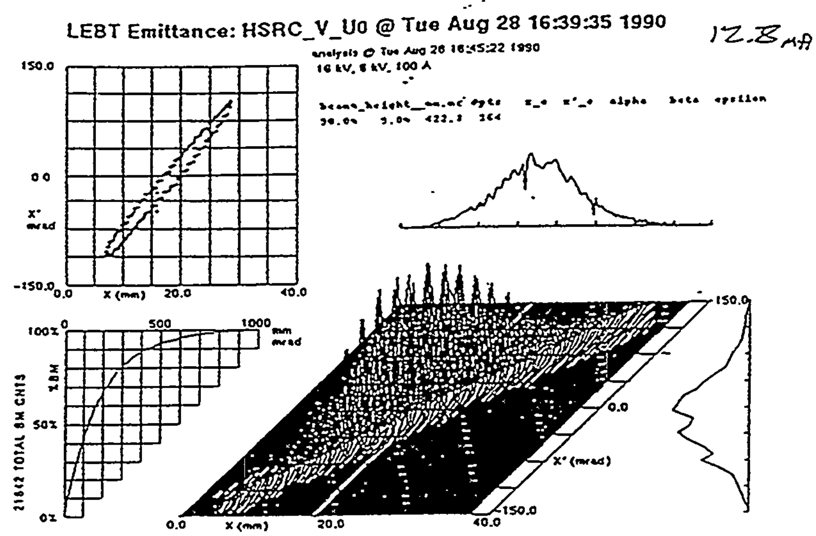


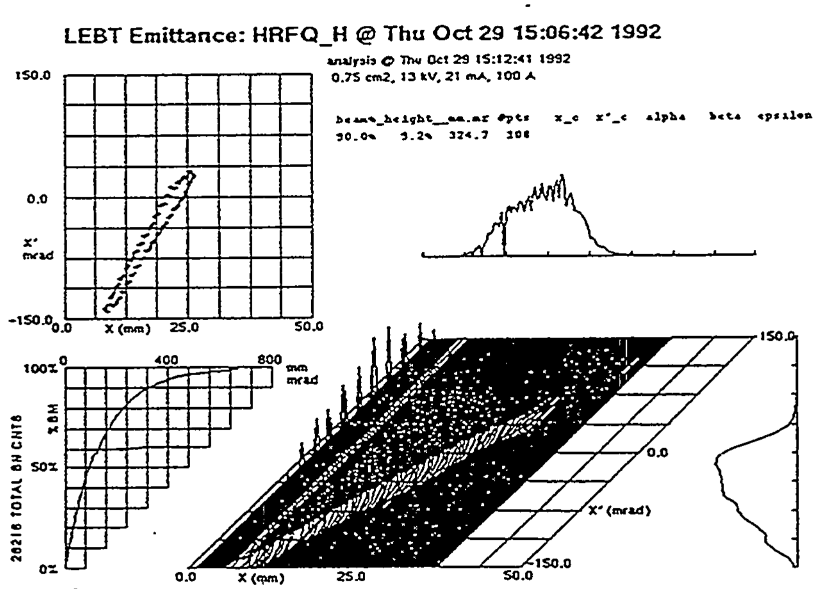


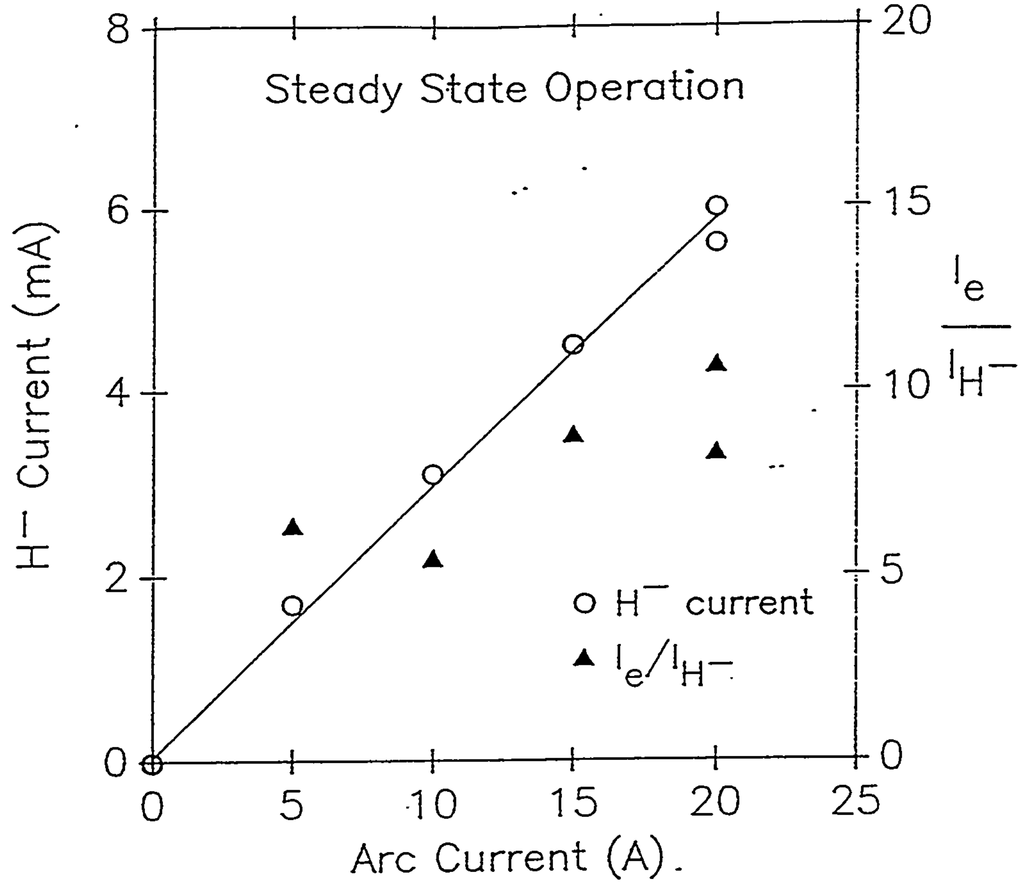
(a)



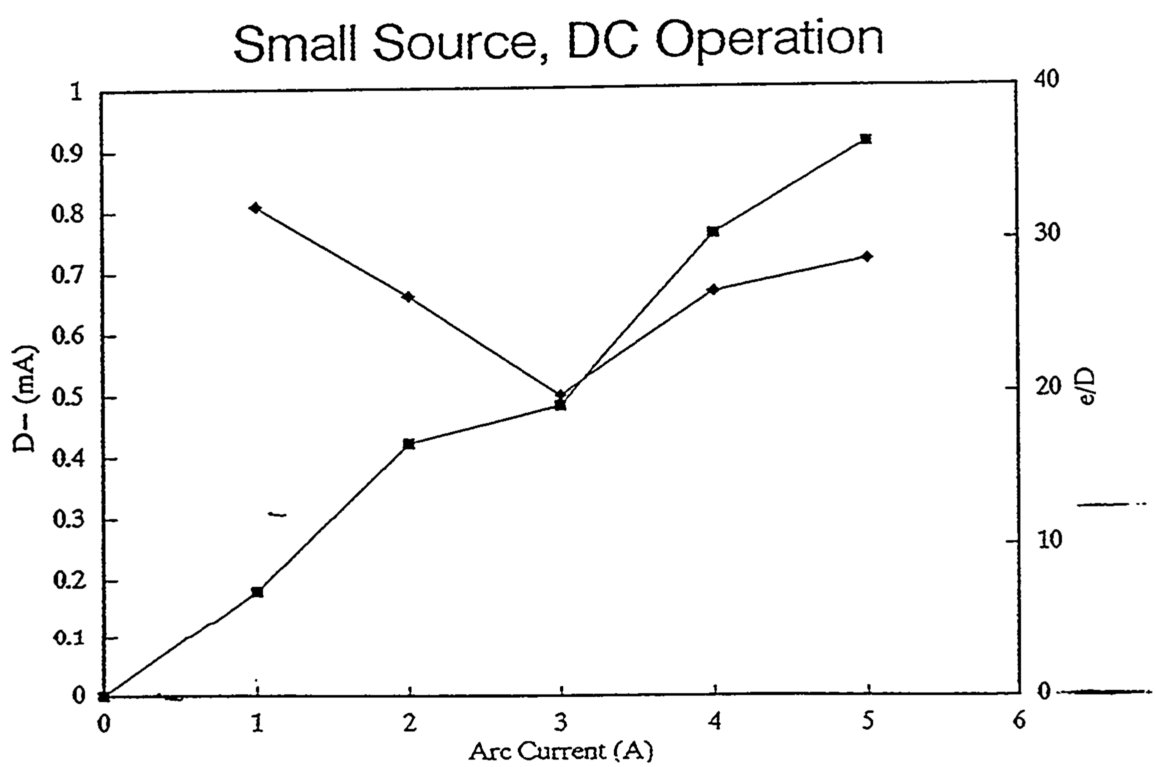
H^- CURRENT AND TOTAL EXTRACTOR P.S. LOAD ($I_{H^-} + I_e$), WITH CESIUM ADDED


LEBT Emittance: HSRC_V_U0 @ Tue Aug 28 16:39:35 1990
12.8 mA
analysis @ Tue Aug 28 16:45:22 1990
16 kV, 8 kV, 100 A
beam_height__mm.mr #pts x_c x'_c alpha beta epsilon
150.0
0.0
X' mrad
-150.0
0.0
X (mm)
20.0
40.0
100%
0
500
1000
mm mrad
%BM
50%
0%
21642 TOTAL BM CNTS
X' (mrad)
-150.0
150.0


LEBT Emittance: HRFQ_H @ Thu Oct 29 15:06:42 1992
analysis @ Thu Oct 29 15:12:41 1992
0.75 cm2, 13 kV, 21 mA, 100 A
beam_height__mm.mr #pts x_c x'_c alpha beta epsilon
150.0
0.0
X' mrad
-150.0
0.0
X (mm)
25.0
50.0
100%
0
400
800
mm mrad
%BM
50%
0%
28218 TOTAL BM CNTS
X' (mrad)
-150.0
150.0



Steady State Operation
H⁻ Current (mA)
I_e / I_{H^-}
○ H⁻ current
▲ I_e/I_{H^-}
Arc Current (A)
0
2
4
6
8
0
5
10
15
20
0
5
10
15
20
25



Small Source, DC Operation
D– (mA)
e/D
Arc Current (A)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
0
1
2
3
4
5
6

SUMMARY

LARGE SOURCE	SMALL SOURCE
20 cm diameter 6 cm deep Volume = 1885 cm^3	9.7 cm diameter 4.1 cm deep (2.5) Volume = 303 cm^3 (185)

Pulsed Operation

LARGE SOURCE	SMALL SOURCE
30 mA from 1 cm^2 50 mA from 1.87 cm^2	35 mA from 0.5 cm^2

Emittance

LARGE SOURCE	SMALL SOURCE
13 mA, 1 cm^2 $\epsilon(n, 90\%) = 0.32\pi$ mm mrad $\epsilon(n, rms) = 0.07\pi$ mm mrad (KT = 0.57 eV)	23 mA, 0.5 cm^2 $\epsilon(n, 90\%) = 0.4\pi$ mm mrad $\epsilon(n, rms) = 0.08\pi$ mm mrad (KT = 1.4 eV)
19 mA, 1 cm^2 $\epsilon(n, 90\%) = 0.44\pi$ mm mrad	35 mA, 0.5 cm^2 $\epsilon(n, 90\%) = 0.65\pi$ mm mrad

Isotope Effect

LARGE SOURCE	SMALL SOURCE
$I(D^-) \sim (0.5-0.6) \times I(H^-)$ $e/D^- \sim (4-5) \times e/H^-$	$I(D^-) \sim 0.6 \times I(H^-)$ $e/D^- \sim (3-4) \times e/H^-$

Addition of Cesium

LARGE SOURCE	SMALL SOURCE
~ doubles H^- $e/H < 1$ Pressure reduced by factor of 2	

dc Operation

LARGE SOURCE	SMALL SOURCE
1 cm^2, 6 mA H^- @ 20 A, 150 V (same as pulsed)	0.5 cm^2, 0.[illegible]1 mA D^- @ 5 A, [illegible]90 V
$e/H \sim (2-3) \times$ pulsed value 15–30 sccm	$e/D^- = 2$[illegible] 8–10 sccm

	Large	Small
Have operated d.c. at:	20 A, 150 V. = 3000 W	5 A, 90 V. = 450 W

Assuming the same average power, try and infer duty factor for pulsed operation —

7.5 mA	200 A, 180 V. ⇒ 8% d.f.	150 A, 180 V. ⇒ 1.7% d.f.
30 mA		200 A, 180 V. ⇒ 1.2% d.f.

LANL Source Experience

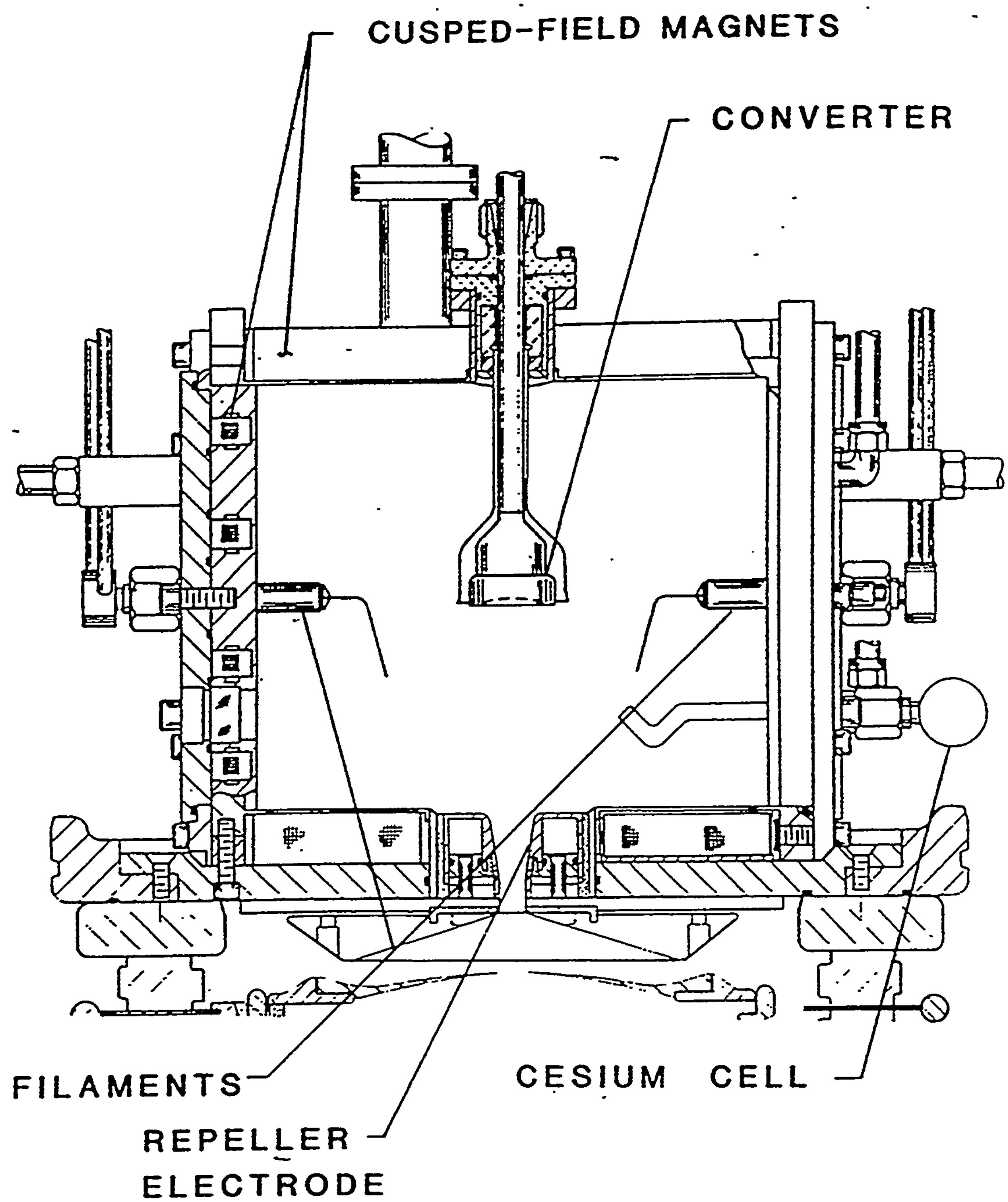
R. York

Los Alamos National Laboratory

LANL SOURCE EXPERIENCE

Rob L. York

- Present LAMPF H^- Source
- Operational Considerations
- Brighter H^- Sources
  - Berkeley Volume H^- Source
  - Brookhaven Volume H^- source
- Conclusion


CUSPED-FIELD MAGNETS
CONVERTER
FILAMENTS
CESIUM CELL
REPELLER
ELECTRODE

Surface Production Multicusp H^- Source

Intensity:20 mA

Emittance:0.08 cm-mrad at 95% beam fraction

Duty Factor: 10% 1msec pulse at 120Hz

Gas Pressure:3 mTorr

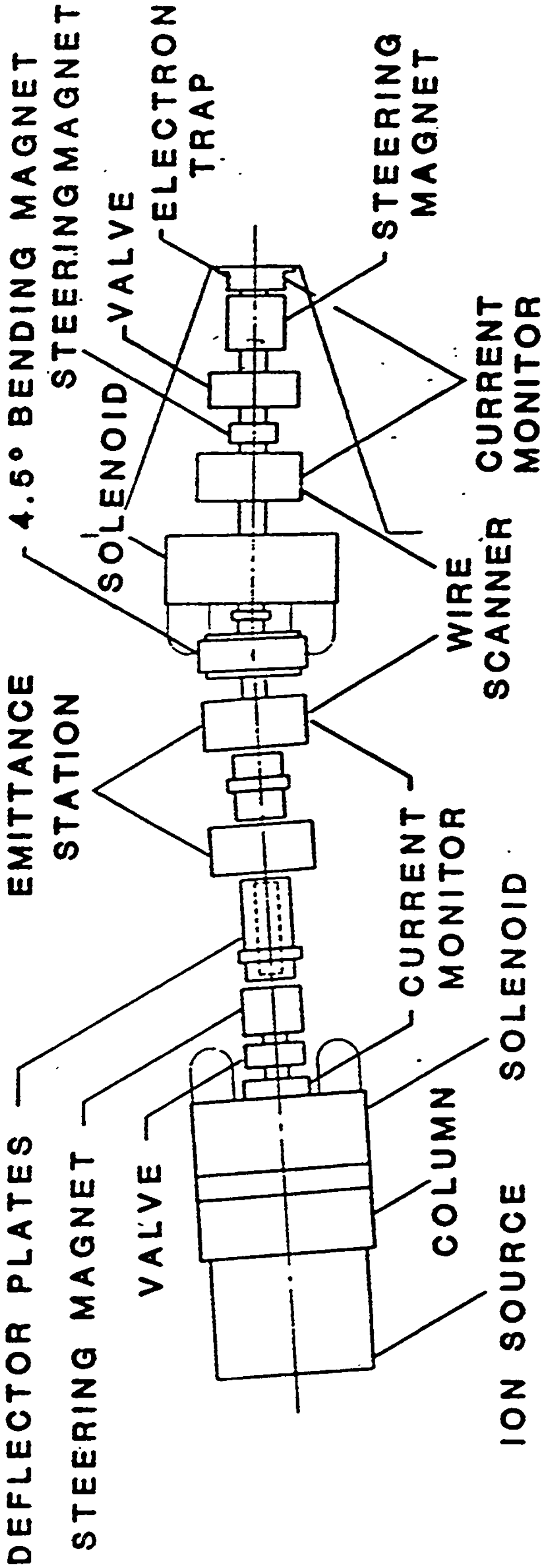
Size: 20 cm diameter and 23 cm long

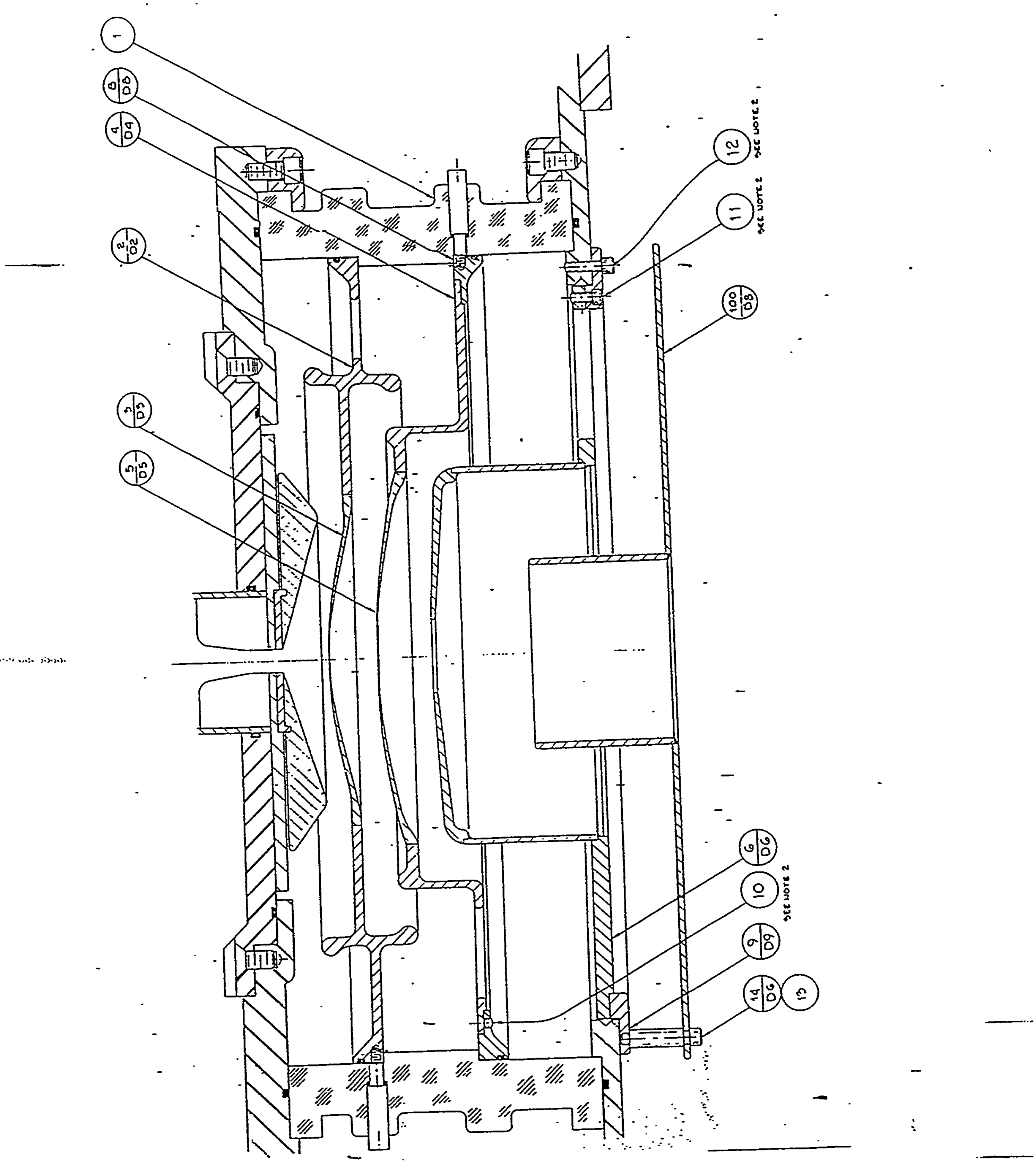
Lifetime: 38 days run contiuously with 95% reliability

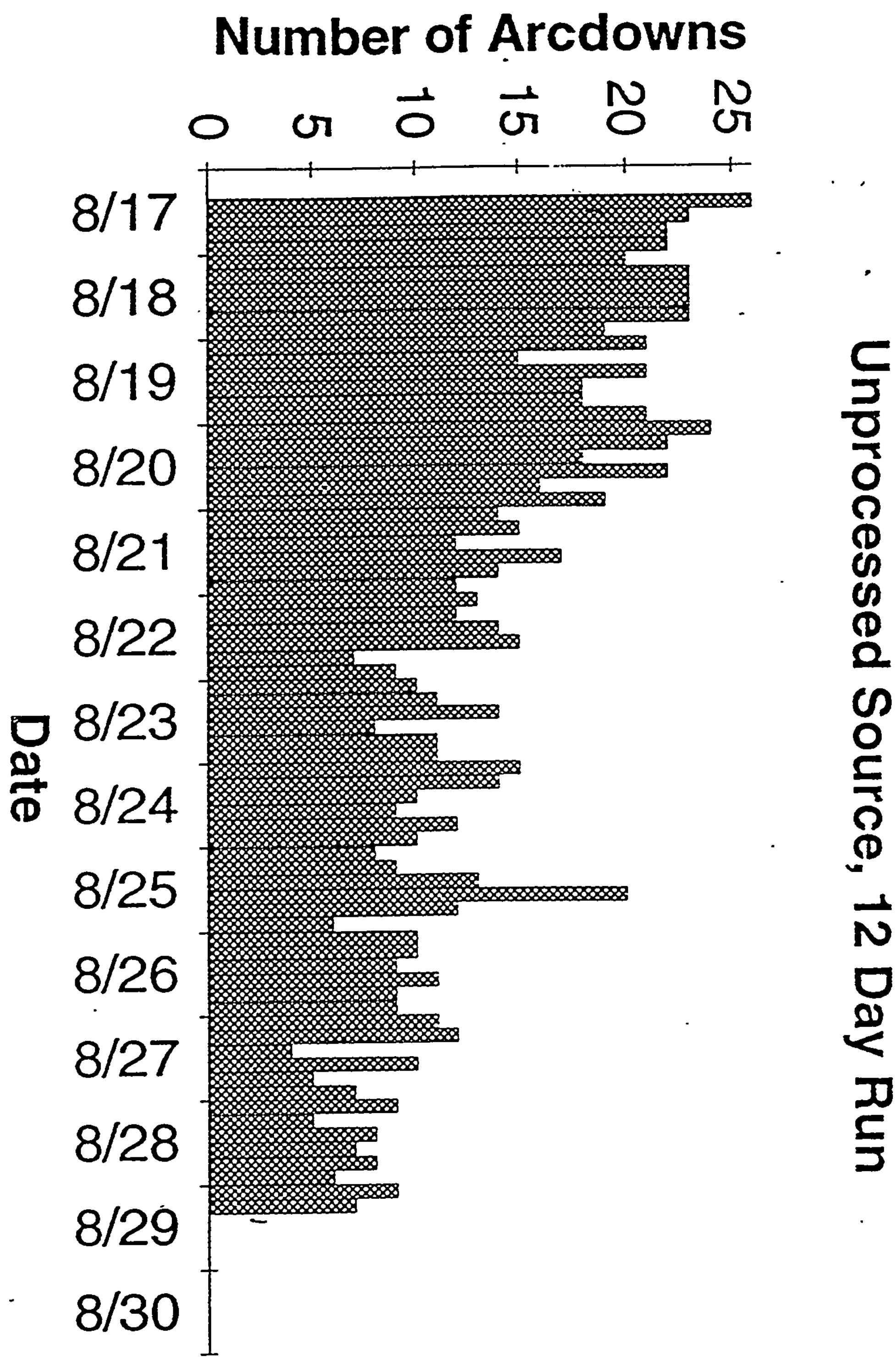
Energy: 80 keV or 750 kev

Plasma Density: 3×10^{12}

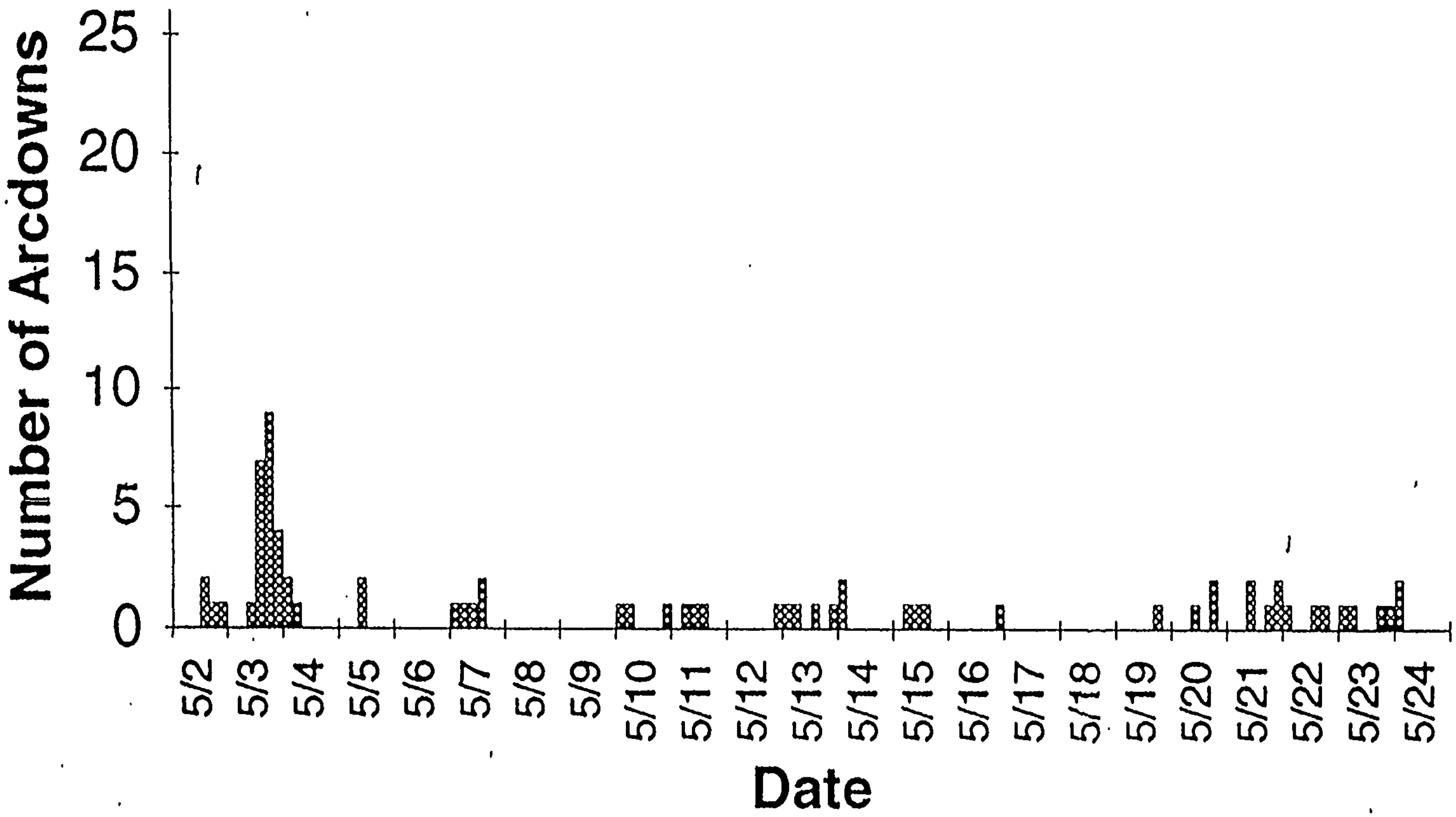
Converter: 3.8 cm

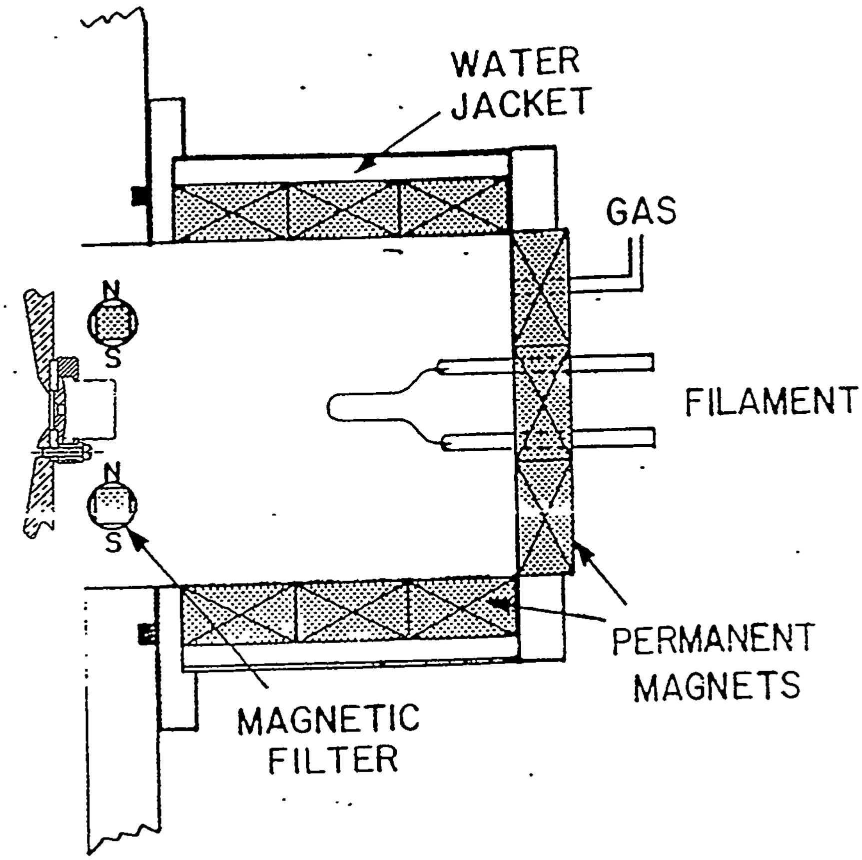

DEFLECTOR PLATES
STEERING MAGNET
VALVE
ION SOURCE
COLUMN
SOLENOID
CURRENT MONITOR
SOLENOID
EMITTANCE STATION
CURRENT MONITOR
WIRE SCANNER
4.5° BENDING MAGNET
SOLENOID
STEERING MAGNET
VALVE
ELECTRON TRAP
STEERING MAGNET
CURRENT MONITOR
WIRE SCANNER

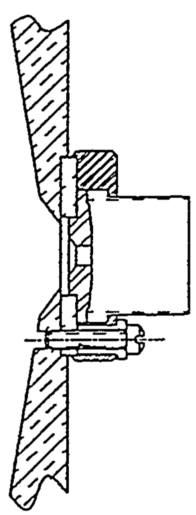

1
8/D8
4/D4
2/D2
3/D3
5/D5
12
SEE NOTE 2
11
SEE NOTE 2
100/D8
6/D6
10
SEE NOTE 2
9/D9
14/D6
13

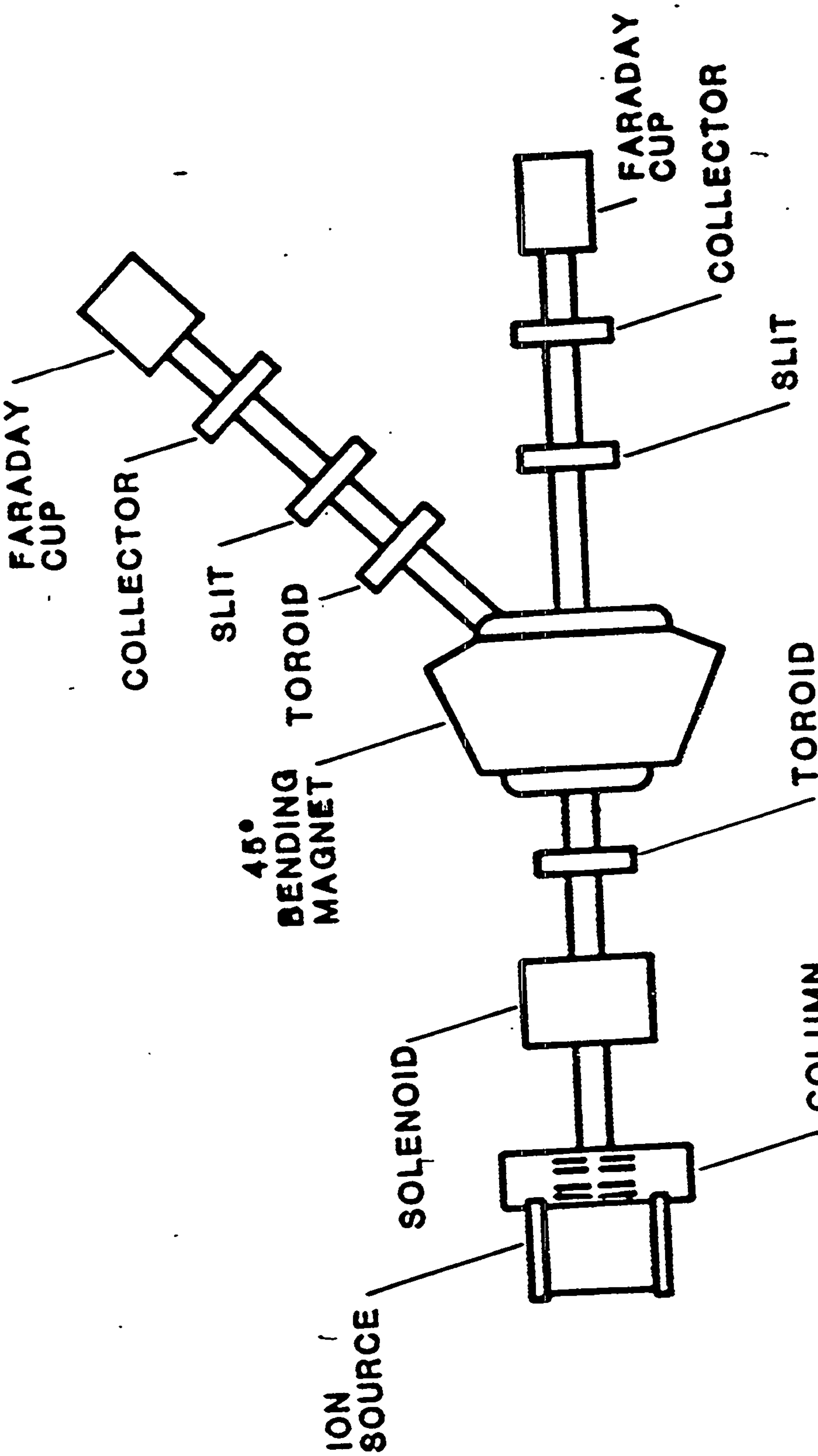

Unprocessed Source, 12 Day Run
Number of Arcdowns
0
5
10
15
20
25
Date
8/17
8/18
8/19
8/20
8/21
8/22
8/23
8/24
8/25
8/26
8/27
8/28
8/29
8/30

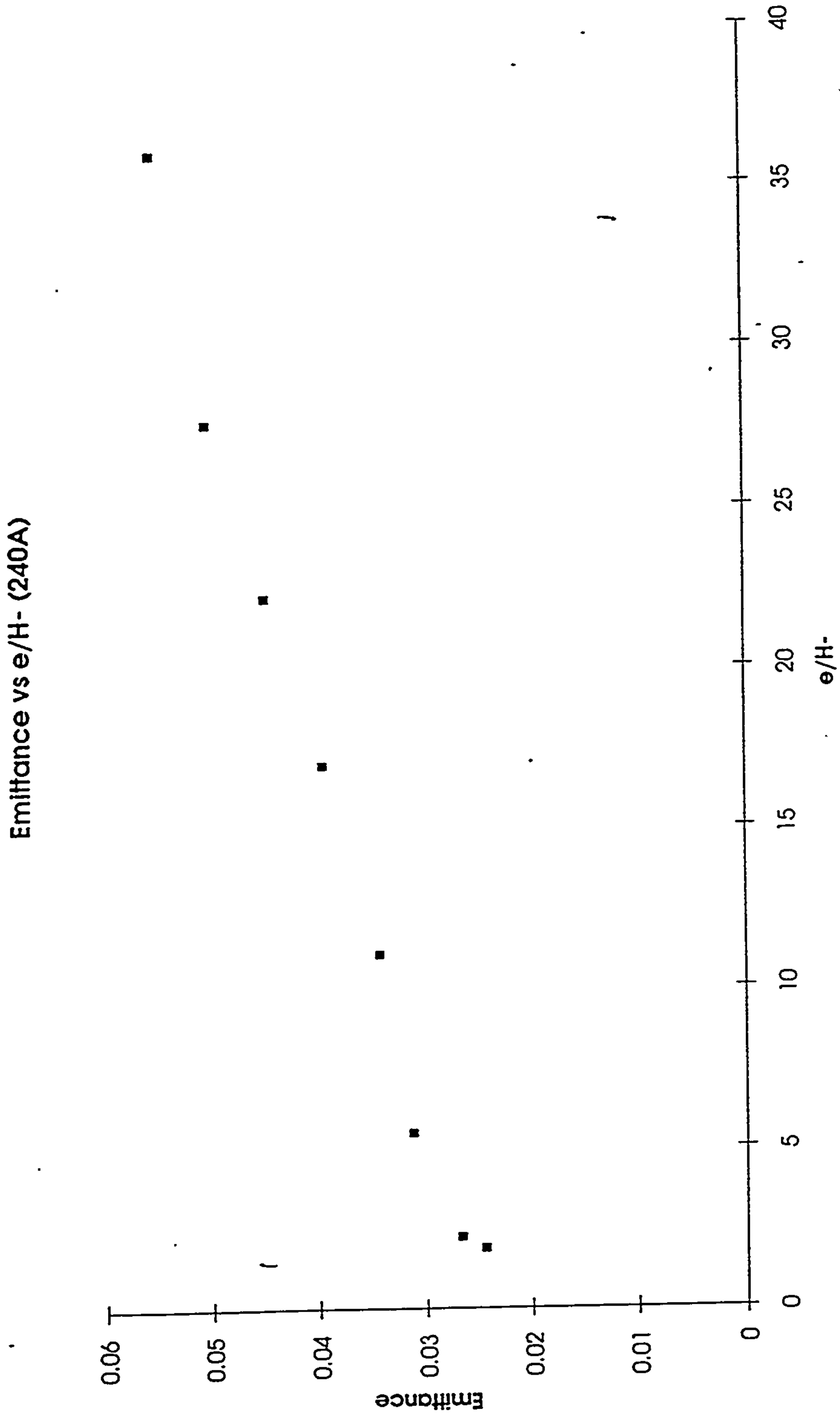
Processed Source with Optimized Repeller

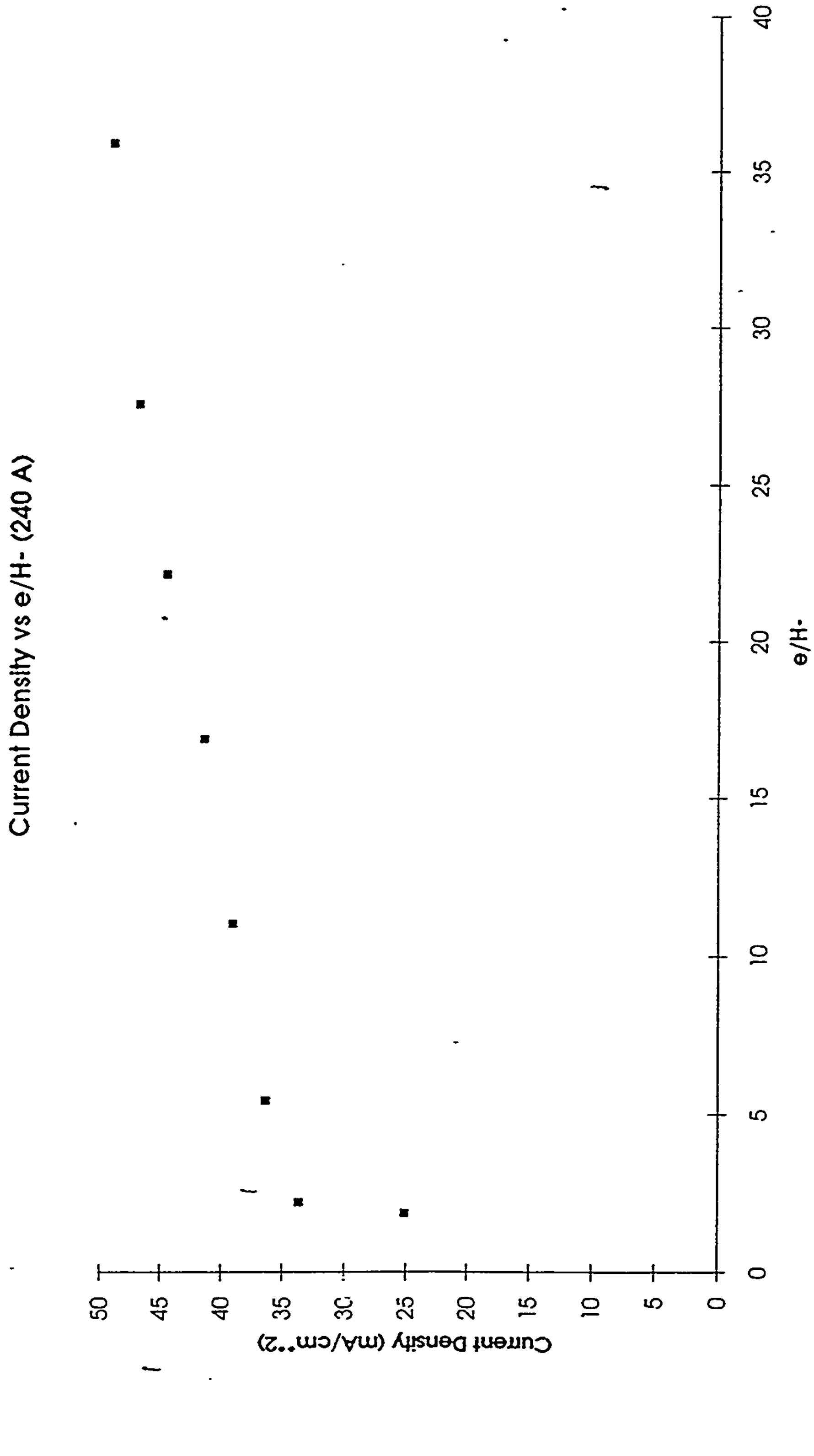


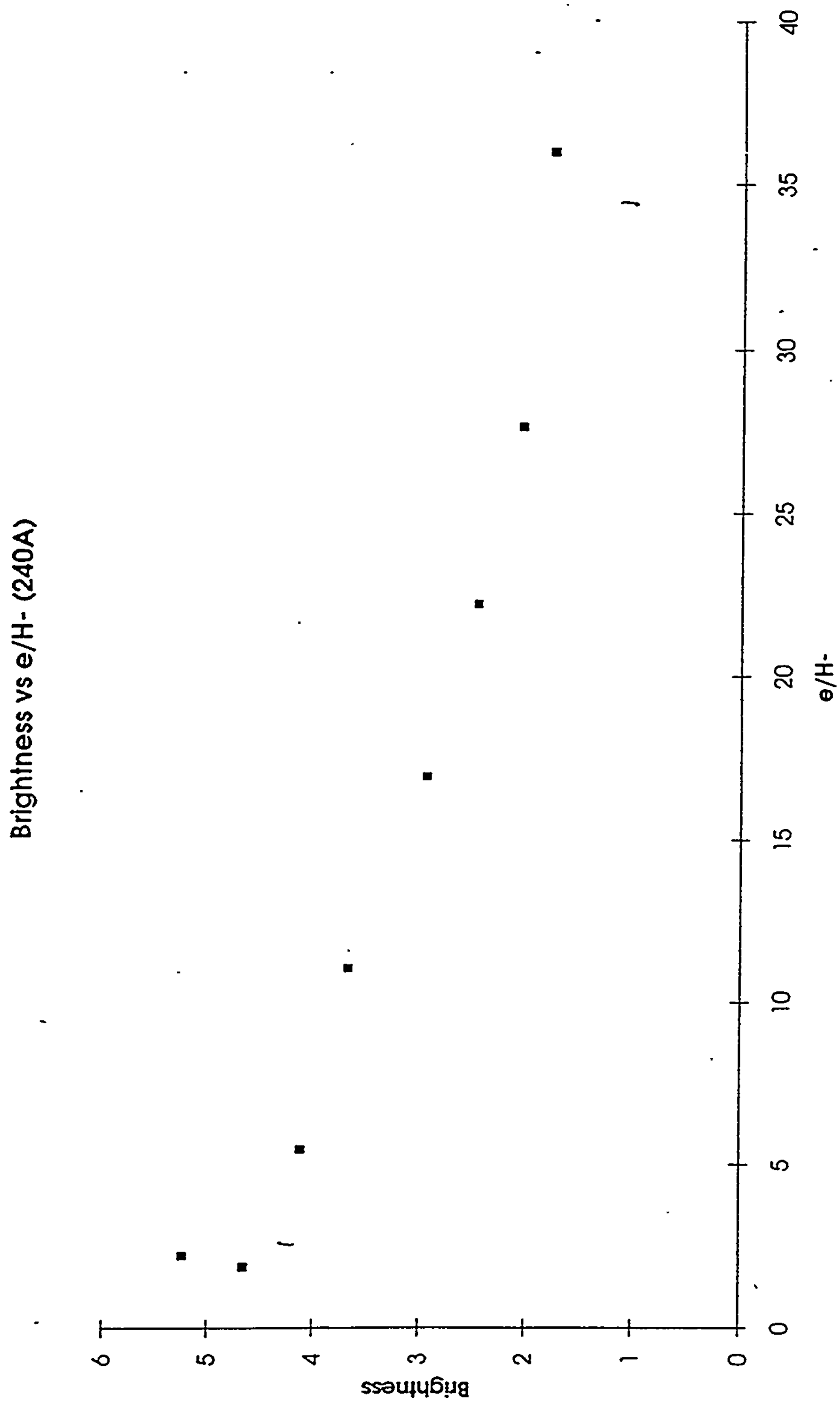

WATER
JACKET
GAS
N
S
FILAMENT
N
S
PERMANENT
MAGNETS
MAGNETIC
FILTER



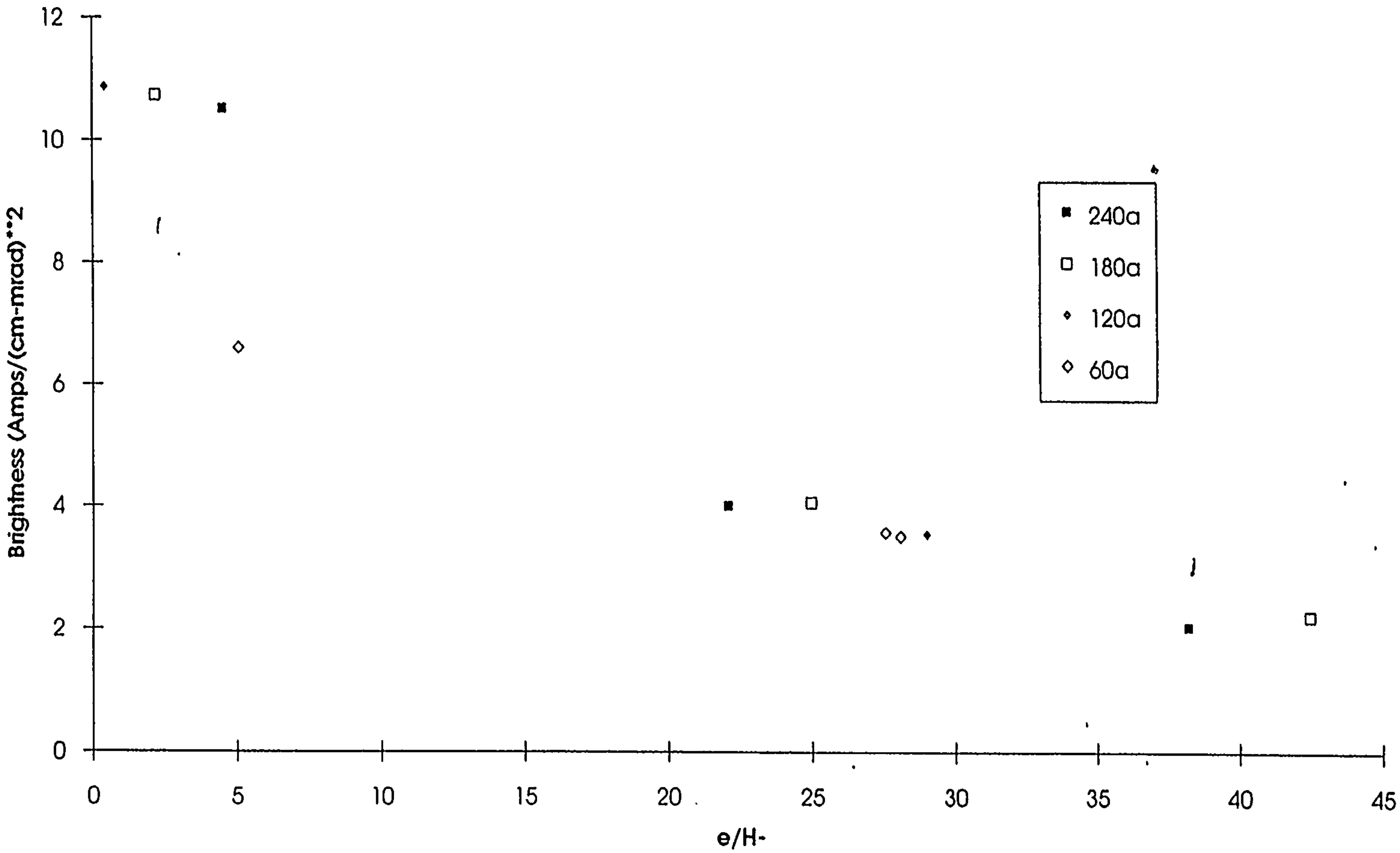

FARADAY CUP
COLLECTOR
SLIT
TOROID
45° BENDING MAGNET
FARADAY CUP
COLLECTOR
SLIT
TOROID
TOROID
SOLENOID
COLUMN
ION SOURCE

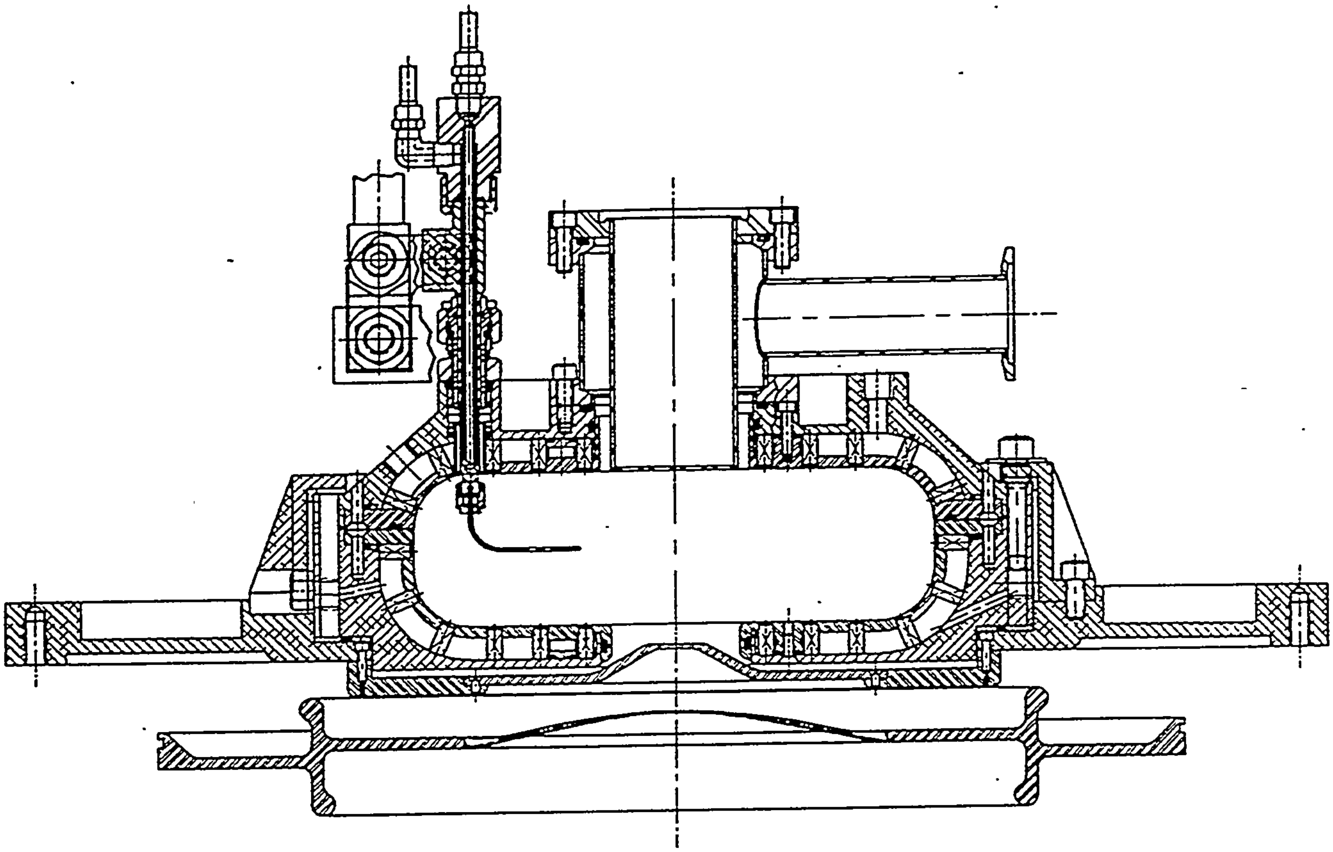

Emittance vs e/H- (240A)
Emittance
0.06
0.05
0.04
0.03
0.02
0.01
0
e/H-
0
5
10
15
20
25
30
35
40

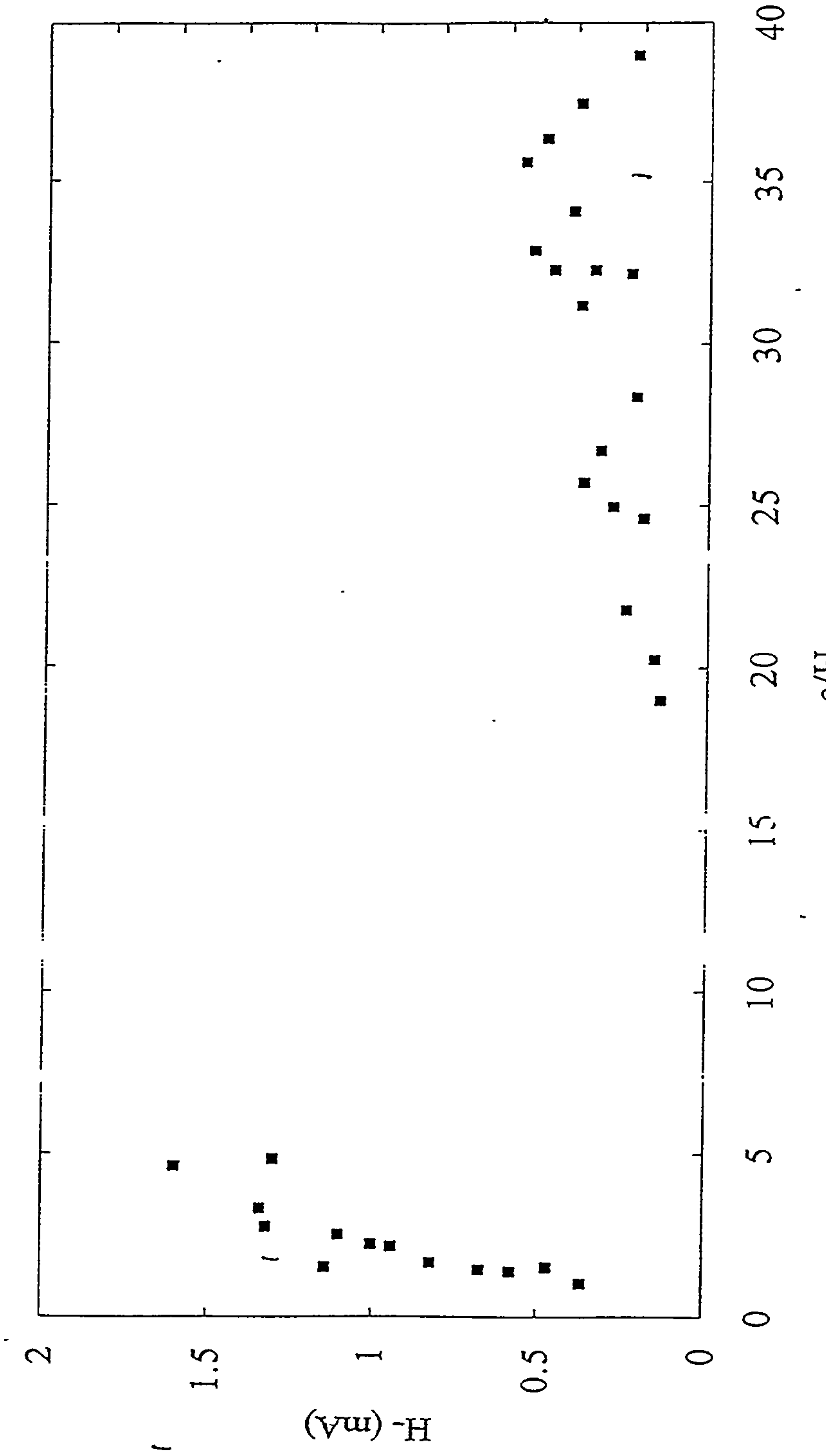

Current Density vs e/H- (240 A)
Current Density (mA/cm**2)
e/H-
0
5
10
15
20
25
30
35
40
45
50


Brightness vs e/H- (240A)
Brightness
0
1
2
3
4
5
6
e/H-
0
5
10
15
20
25
30
35
40

ASP21.DAT Chart 2

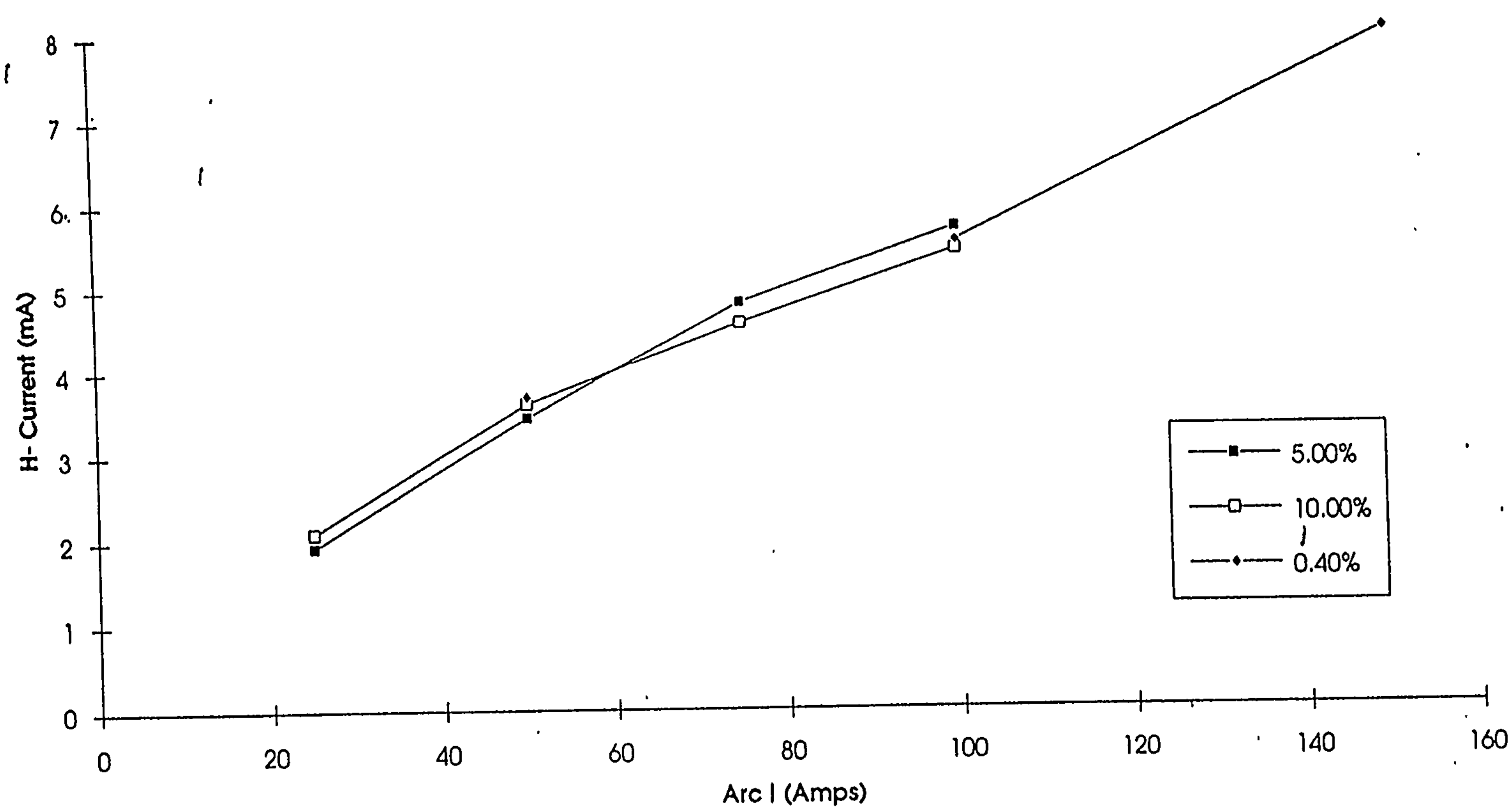




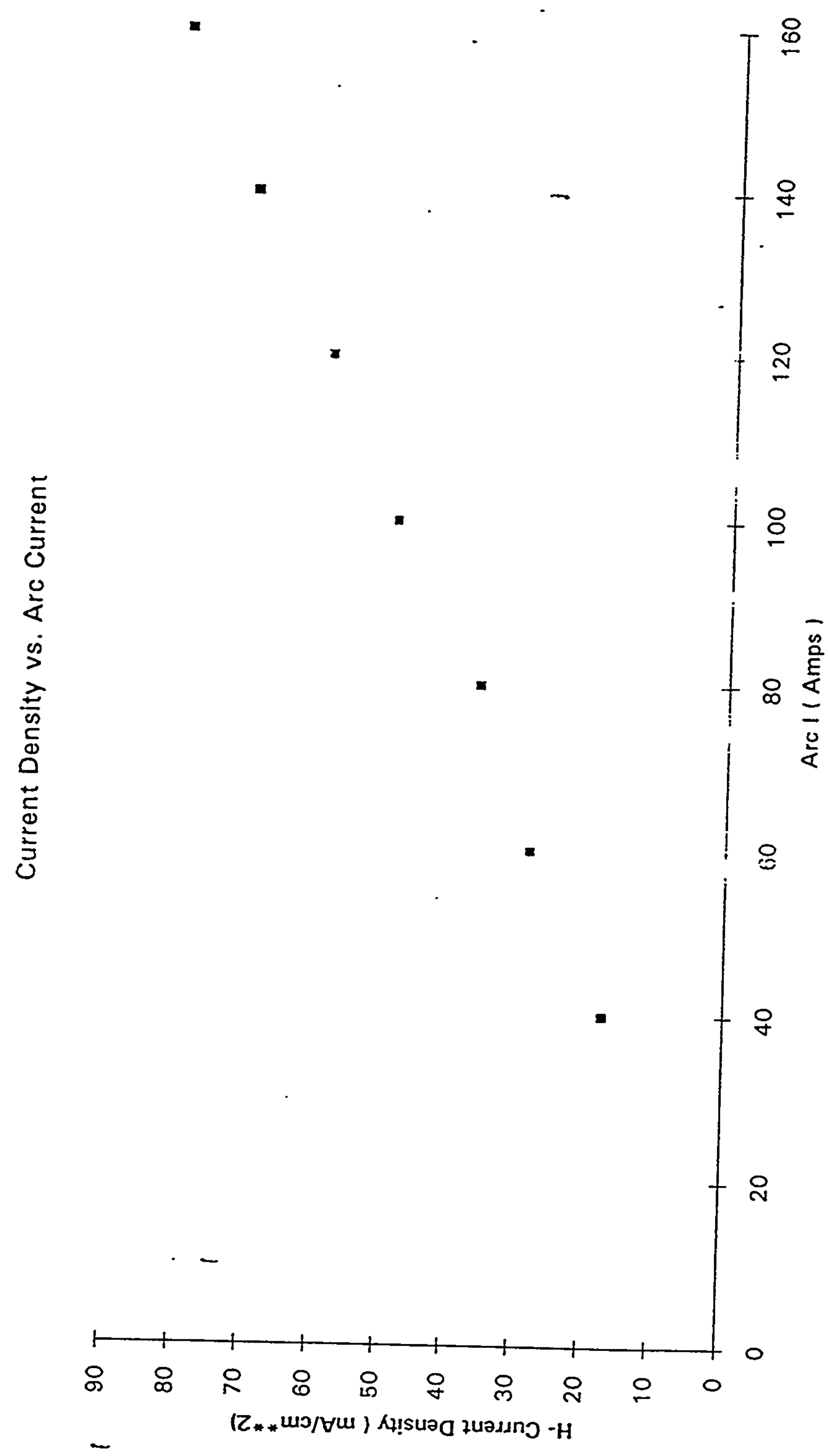

H- (mA)
e/H-
0
0.5
1
1.5
2
0
5
10
15
20
25
30
35
40

Sheet1 Chart 1

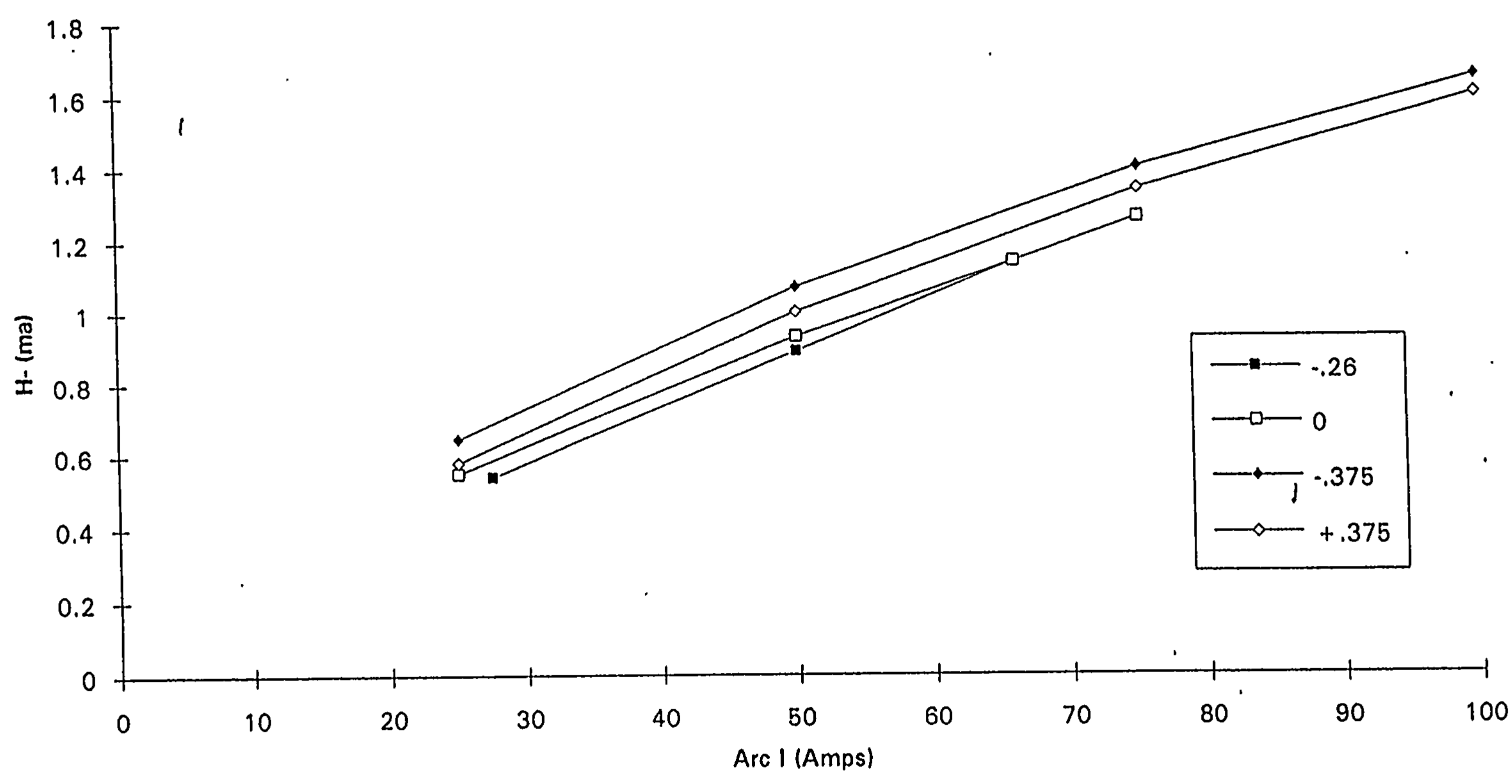
Duty Factor Comparaison



Page 1

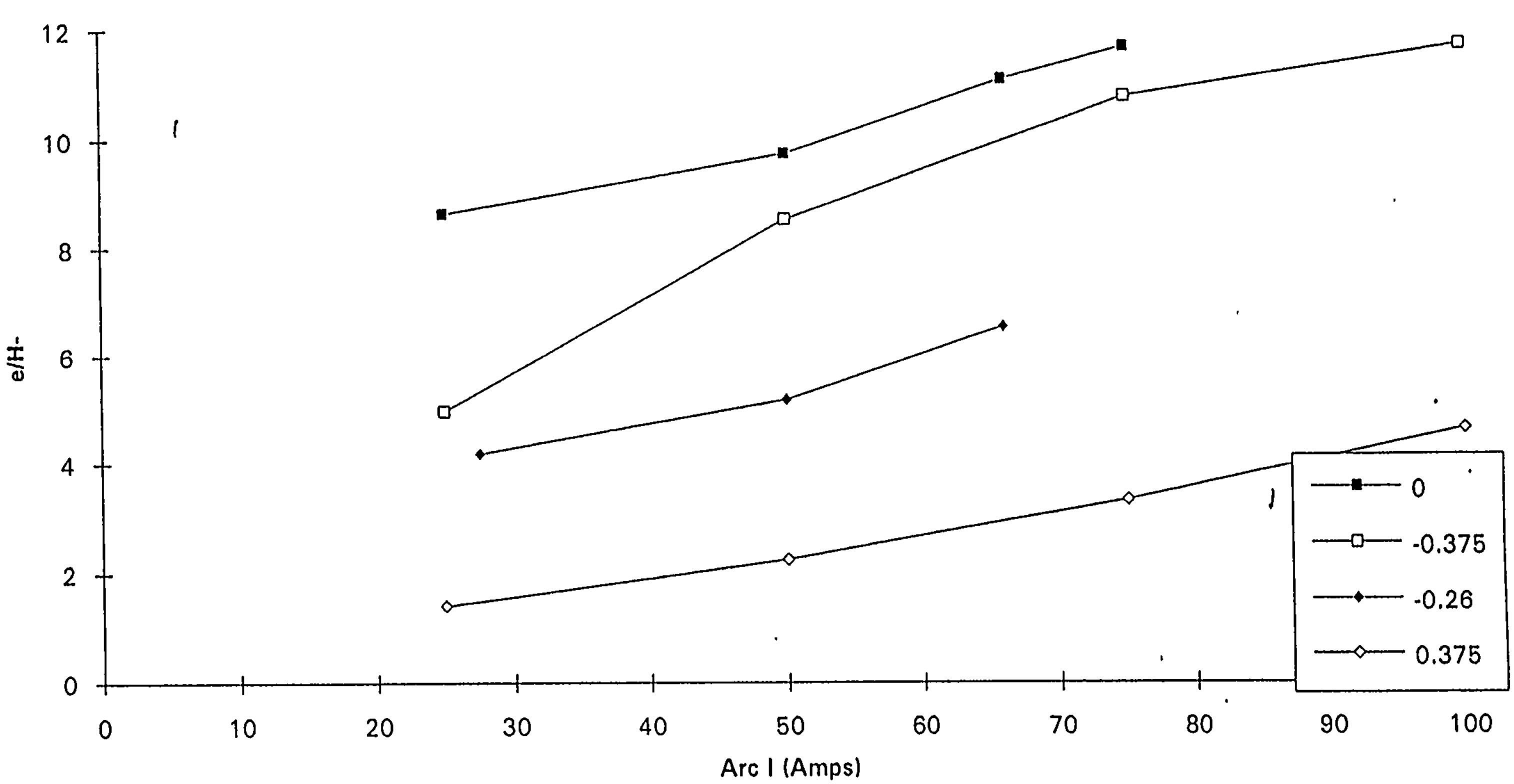

Current Density vs. Arc Current
H- Current Density (mA/cm**2)
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
Arc I (Amps)

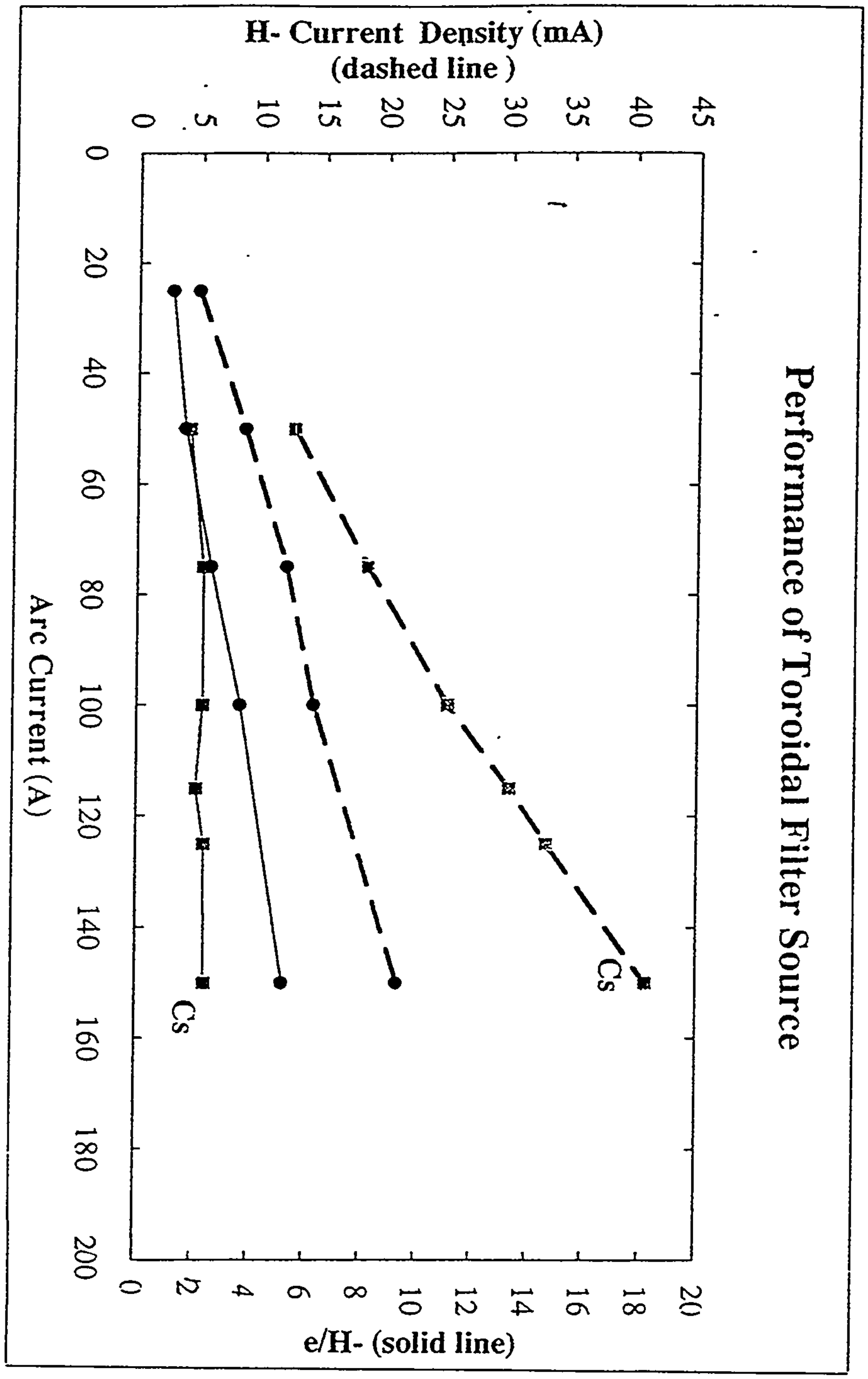
Plasma Electrode Position



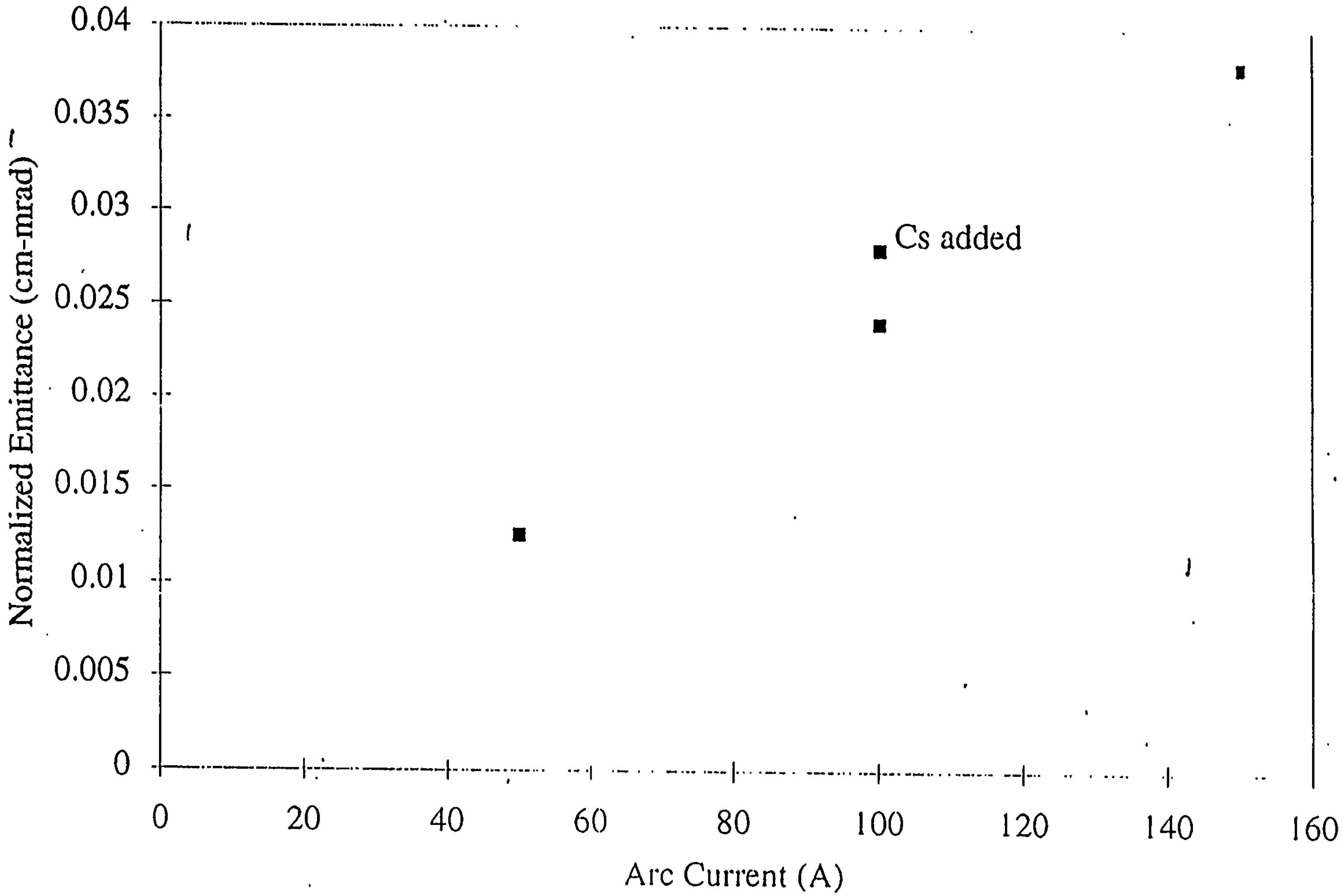
BNL3.DAT Chart 8

Plasma Electrode Position

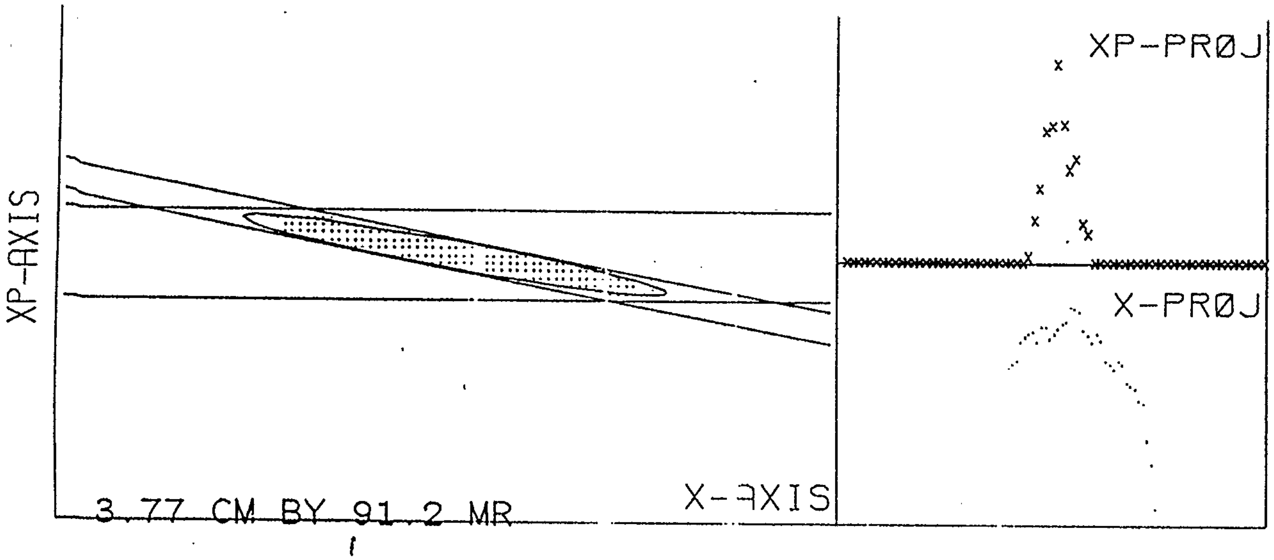


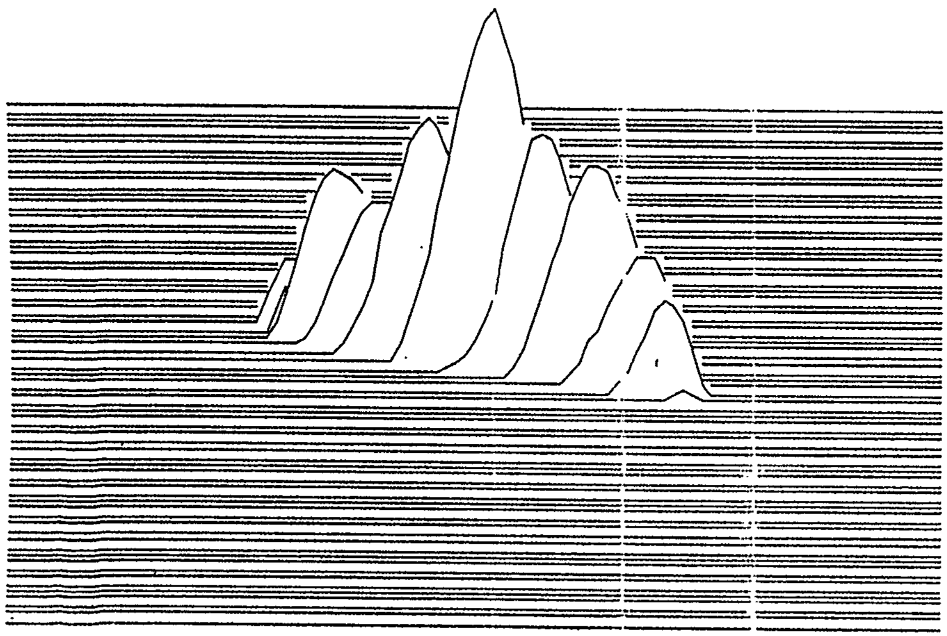

Performance of Toroidal Filter Source
H- Current Density (mA)
(dashed line)
e/H- (solid line)
Arc Current (A)
Cs
Cs

EMIT.XLC

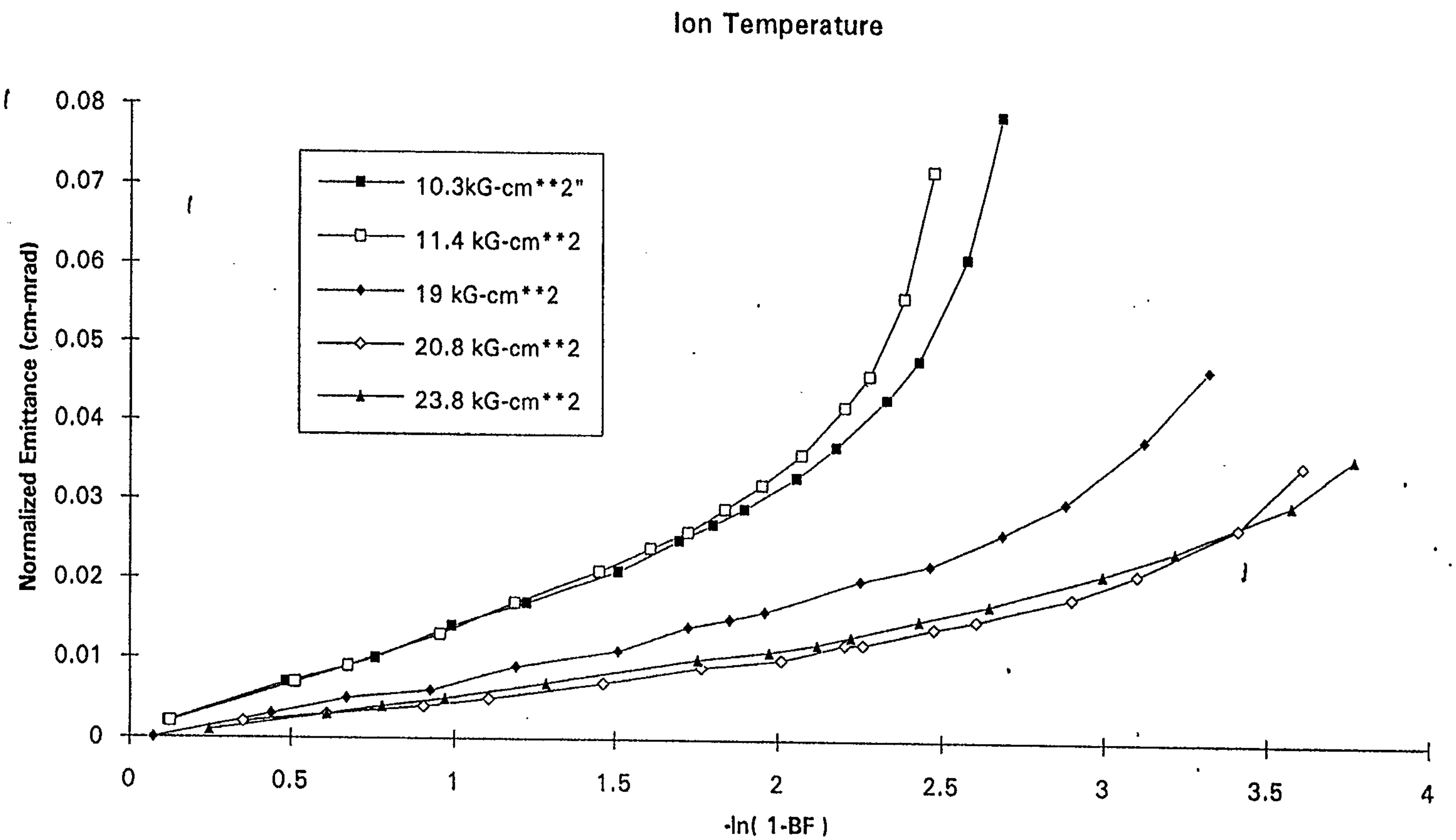


0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Normalized Emittance (cm-mrad)
Cs added
0
20
40
60
80
100
120
140
160
Arc Current (A)

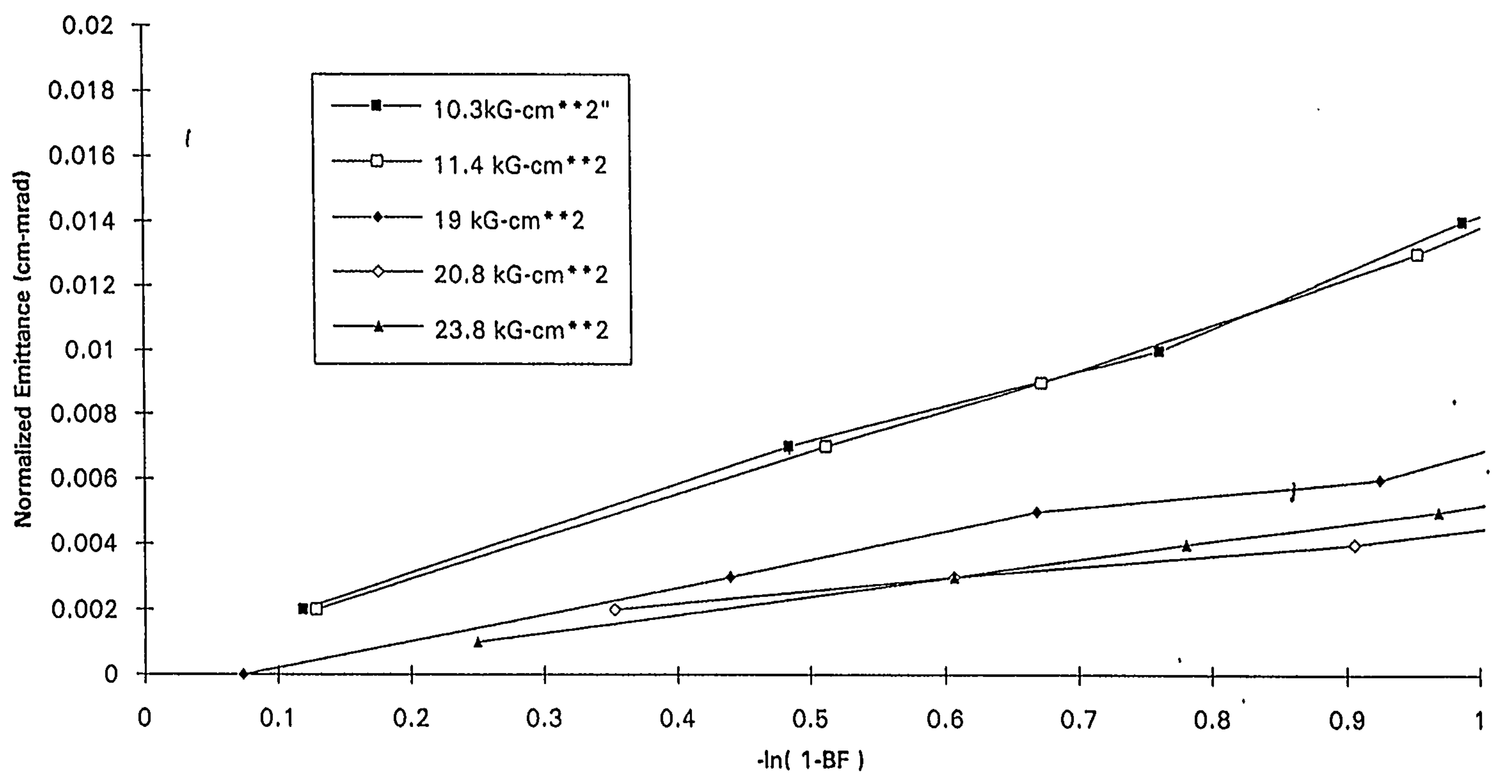




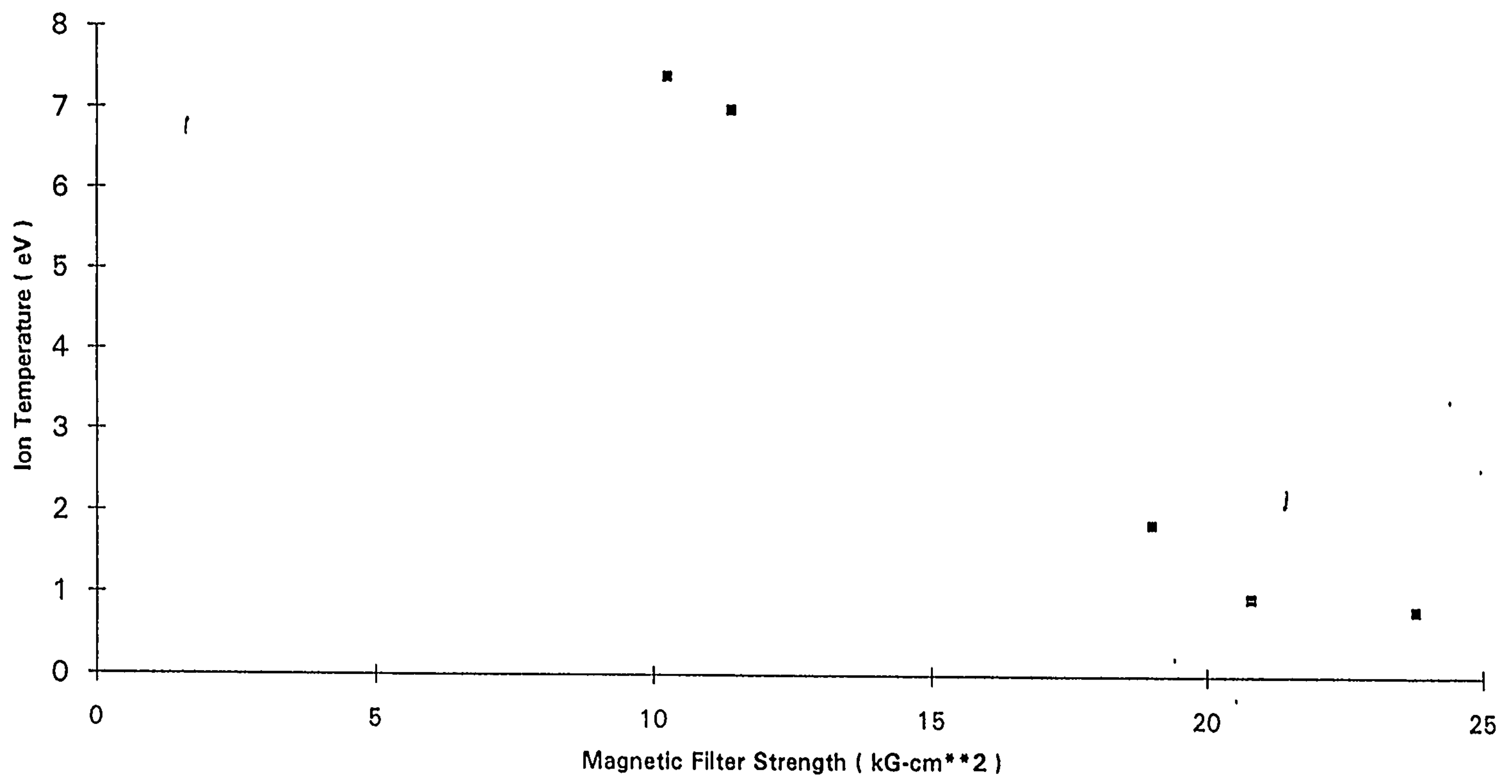
```
Run: 3559   STN.: IBEM1-H
 5-APR-93      16:02:05
    BEAM: H-
E(TOTAL)=    2.516 pi
E(Edge) =    2.054 pi
E(RMS)  =    0.464 pi
ETOT/RMS=    5.42
 ALPHA   =    2.645
 BETA    =    0.430
4*E(RMS) =    1.858 pi
    C    =    0.057 cm
    CP   =    0.804 mr
X SIGMA =  0.4467 cm
XP SIGMA=  2.9407 mr
 THOLD   =  10.0 PERCENT
 THOLD   =  119 CNTS
 MAXIMUM COUNTS =     1191
BEAM THRU THRESH=    65188
     TOTAL BEAM =    68530
CLCTR POS=     812   1369
JAW POS =   1102   1655
```


Ion Temperature
Normalized Emittance (cm-mrad)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
3
3.5
4
-ln(1-BF)
10.3kG-cm**2"
11.4 kG-cm**2
19 kG-cm**2
20.8 kG-cm**2
23.8 kG-cm**2

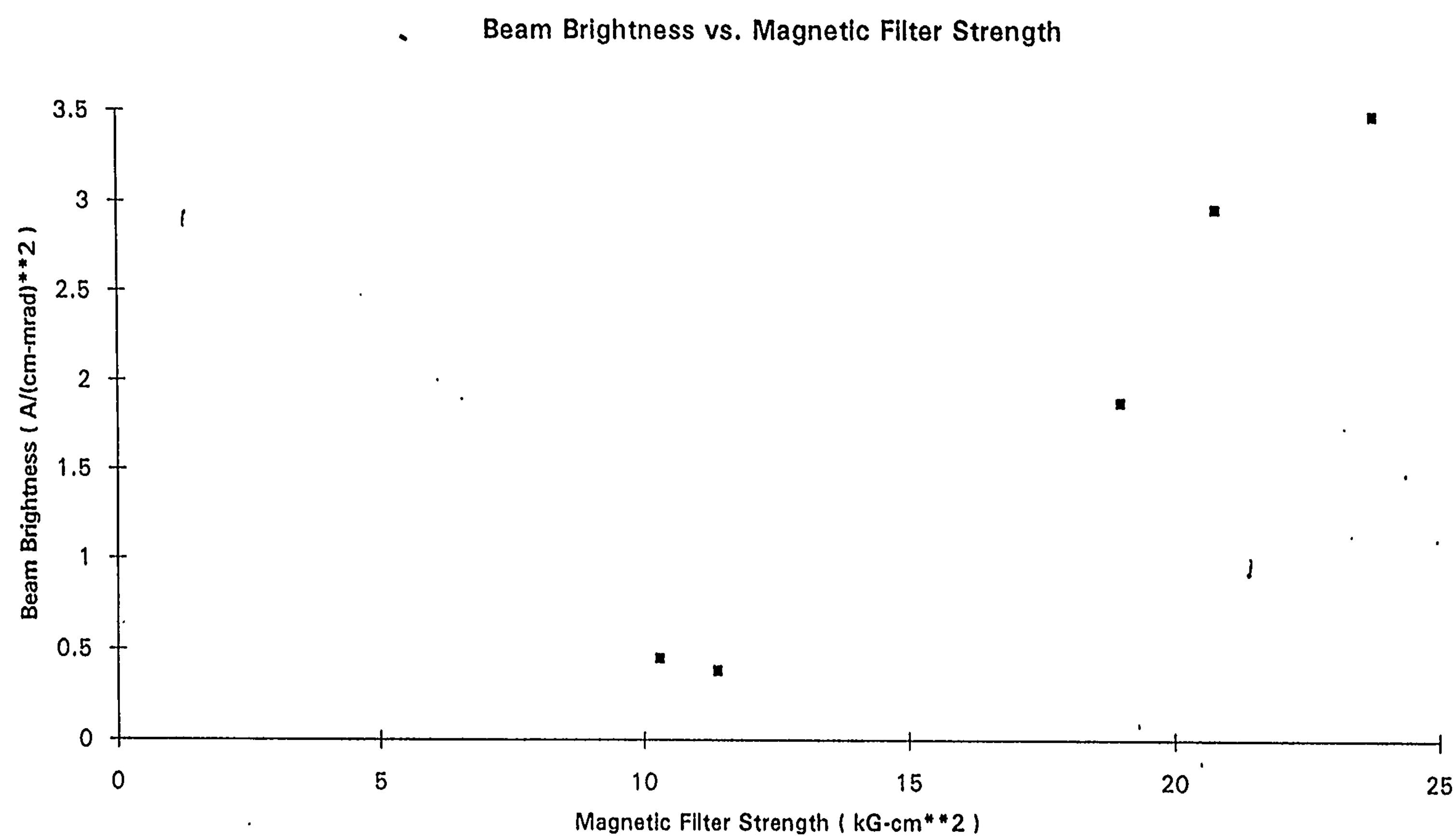
Ion Temperature



Ion Temperature vs. Magnetic Filter Strength



ITEMP.DAT Chart 6



Page 1

Conclusions

1. The electron to H^- ratio effects the quality of the beam and the operational reliability of the source.
2. Volume H^- sources are capable of producing beams of the required intensity and emittance but, reliability questions must be studied.
3. Transporting these high intensity beams is a significant problem and requires careful study.

Volume H^- Sources at LBL

K. Leung

Lawrence Berkeley Laboratory

Volume H^- Sources at LBL

Ka-Ngo Leung

Lawrence Berkeley Laboratory

Workshop on Ion Sources Issues Relevant to a Pulsed Spallation Neutron Source

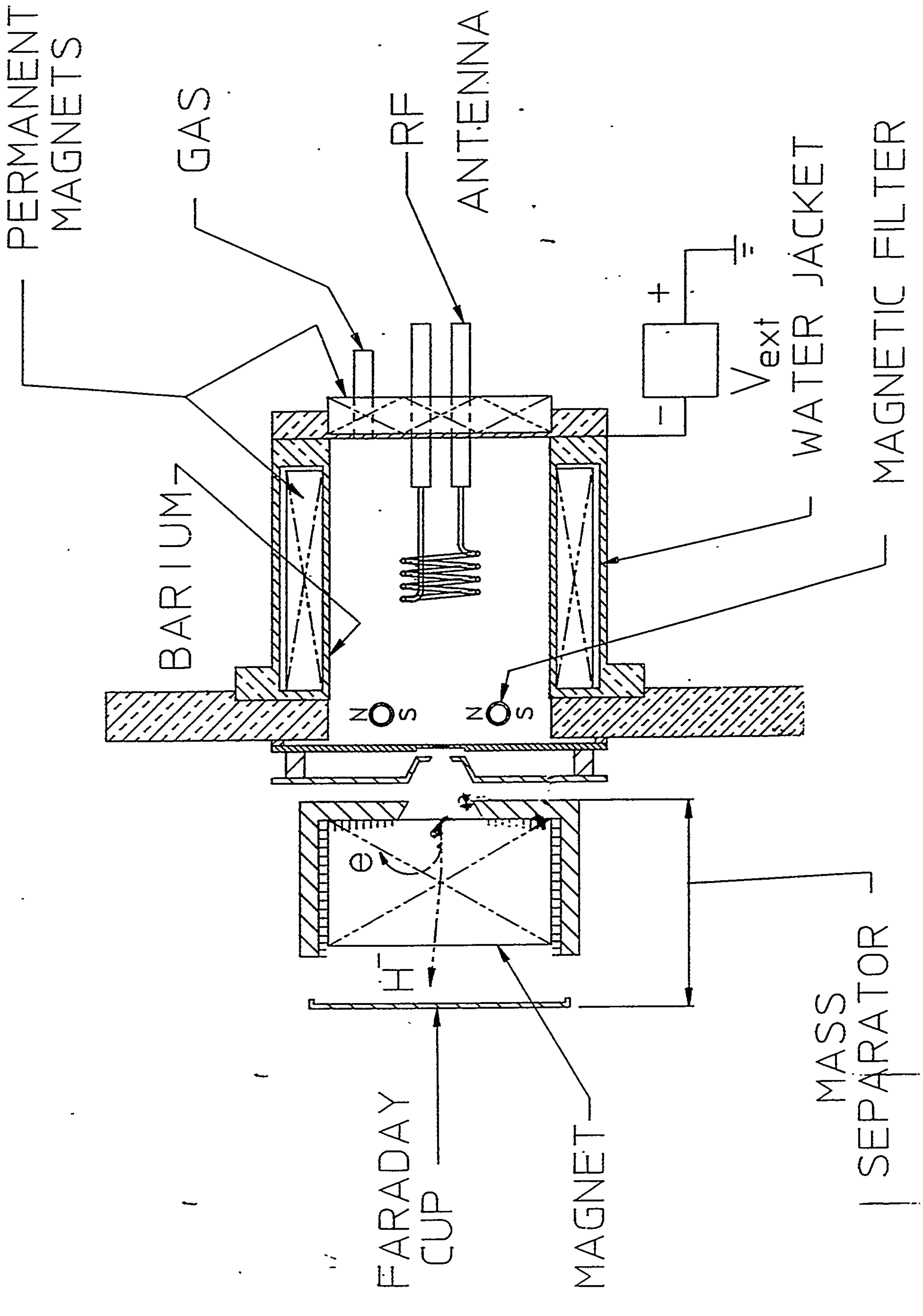
LBL (Oct 24-26, 1994)

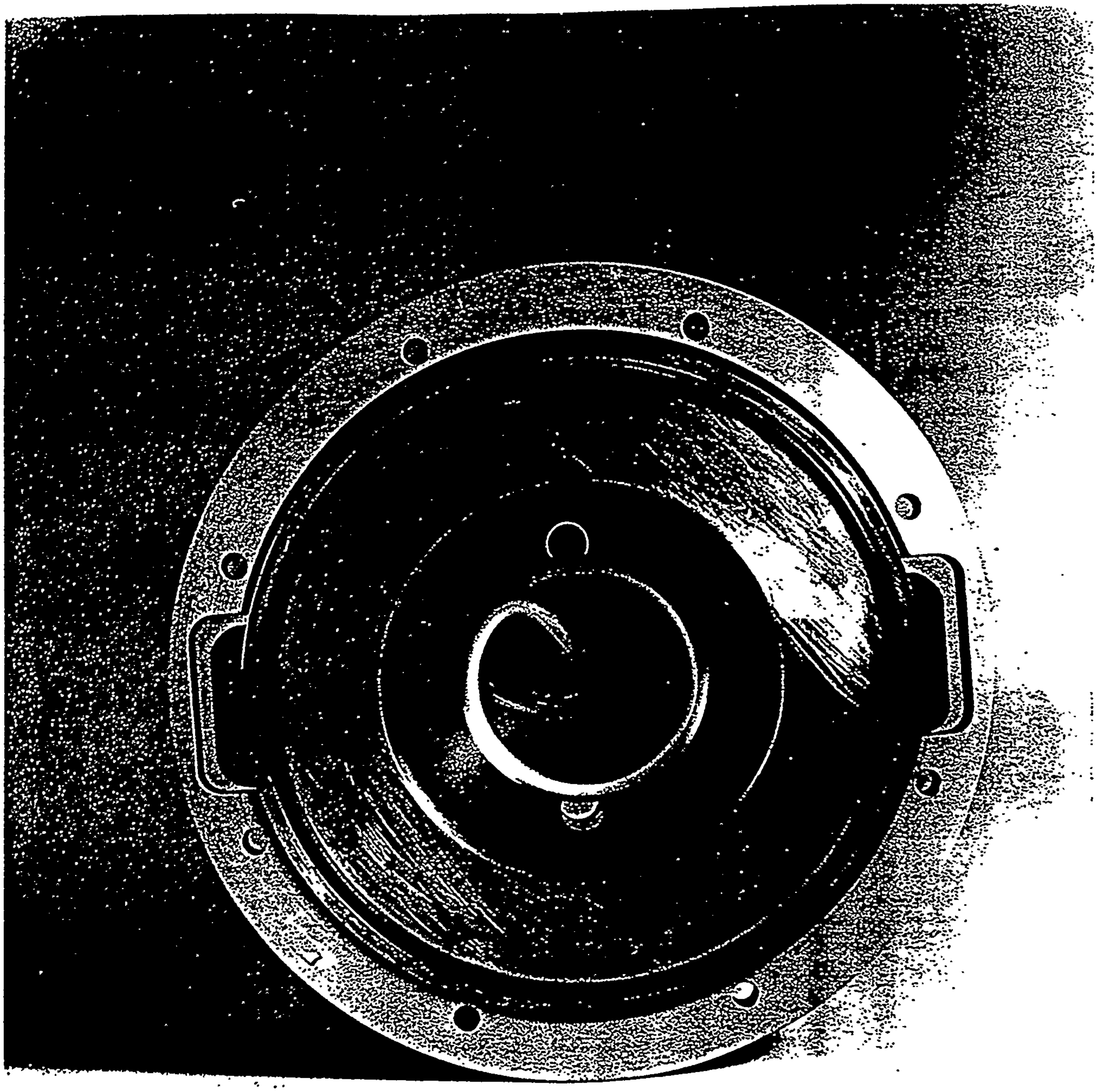
- RF driven H^- source operation without cesium

- RF driven H^- source operation with cesium

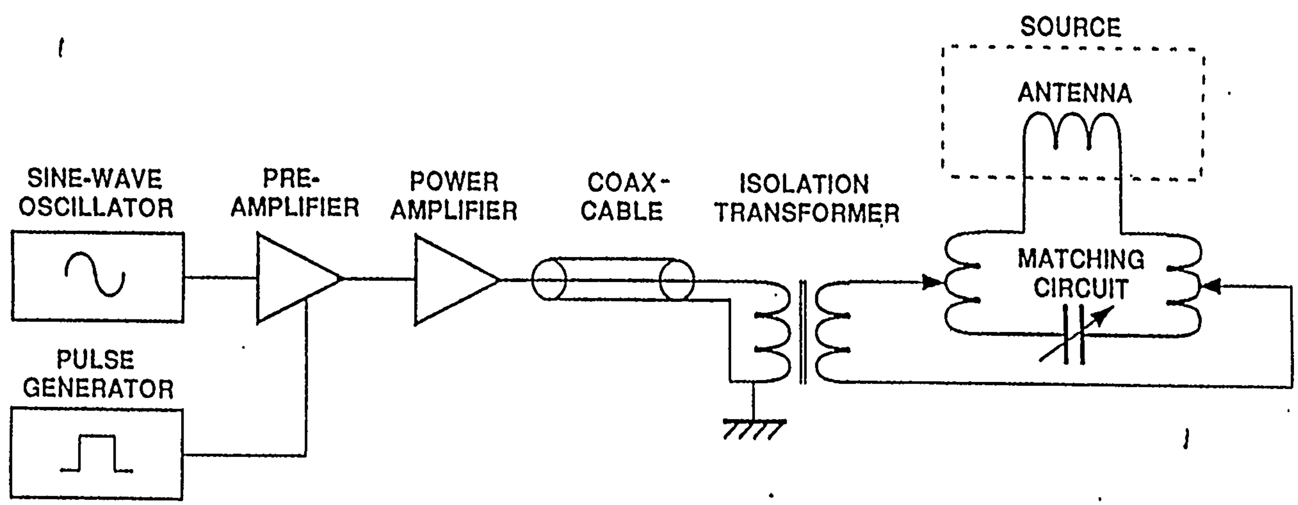
- Start-up of rf plasma
  - tungsten filament
  - laser
  - flash lamp

- Antenna lifetime for high power operation

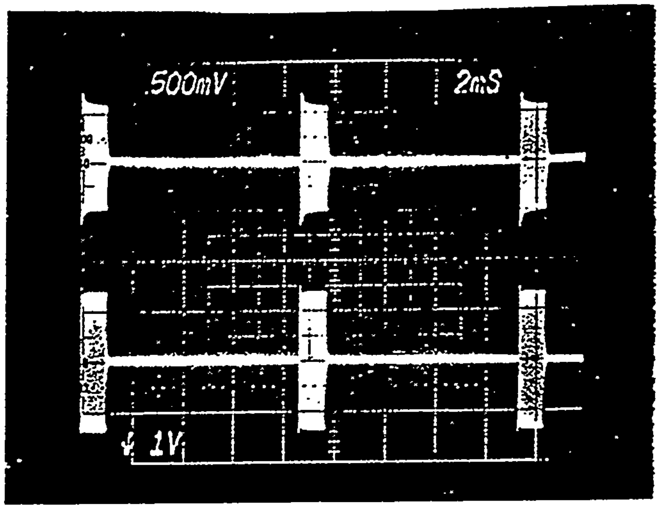

PERMANENT
MAGNETS
GAS
RF
ANTENNA
+
−
V_{ext}
WATER JACKET
MAGNETIC FILTER
BARIUM
N
S
e
H^-
FARADAY
CUP
MAGNET
MASS
SEPARATOR



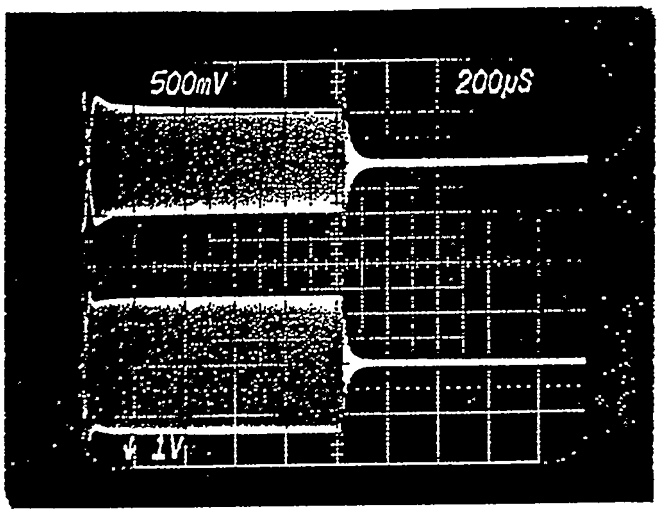
Porcelain-coated antenna coil of the rf driven H^- source.



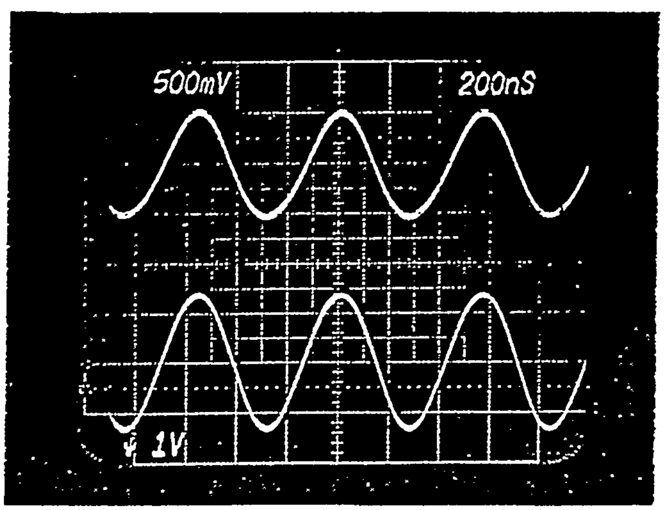
Schematic diagram showing the coupling of RF power into the ion source.



111 rf pulses/sec



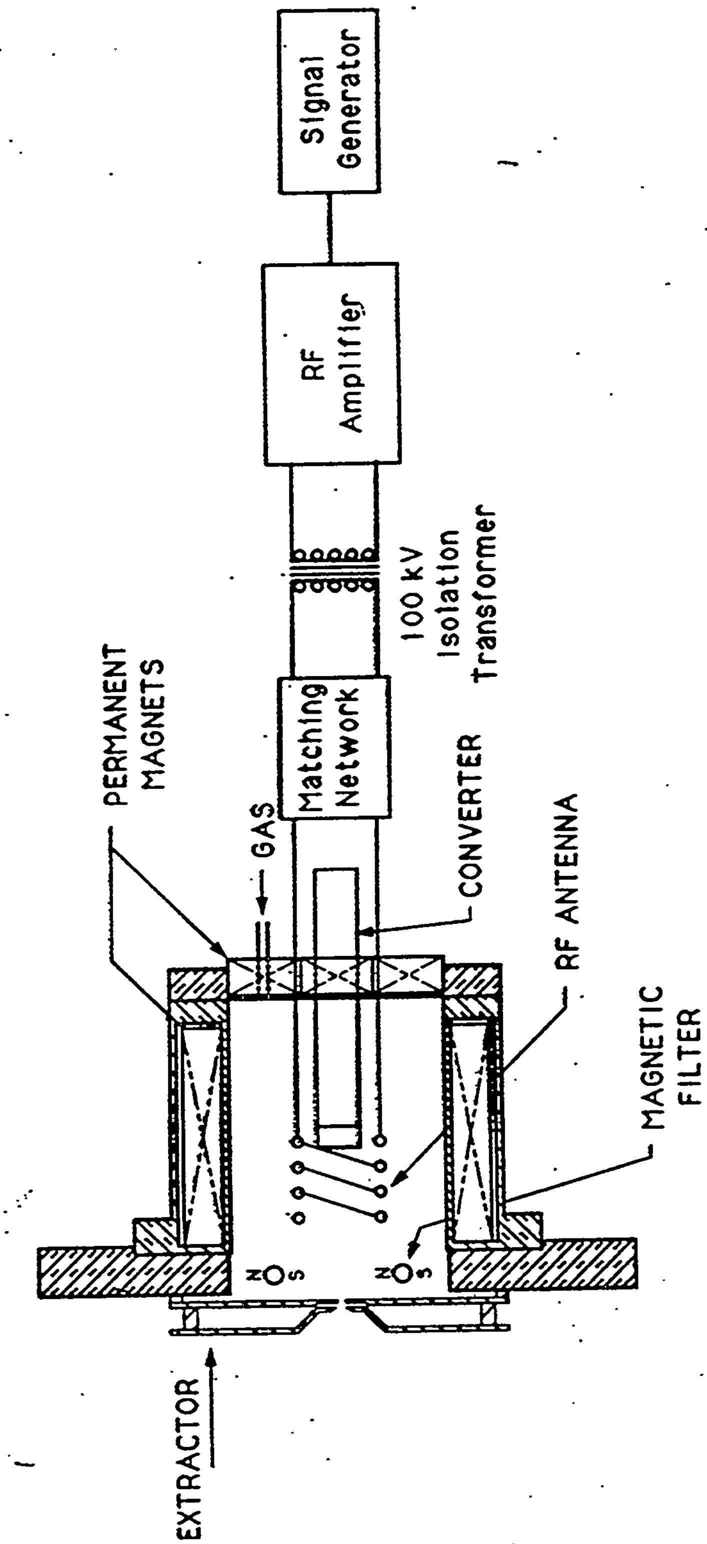
1 ms rf pulse

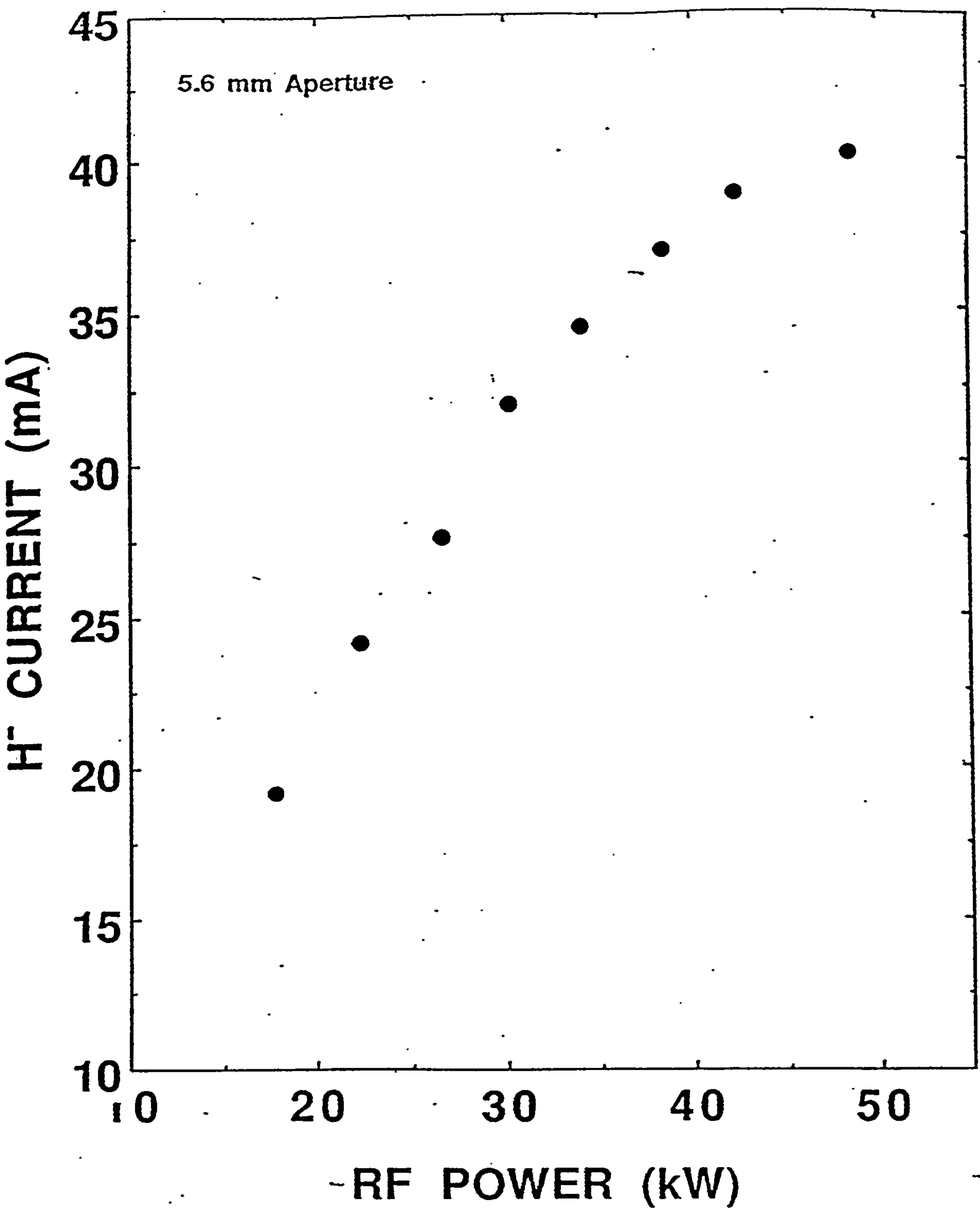


top : rf voltage

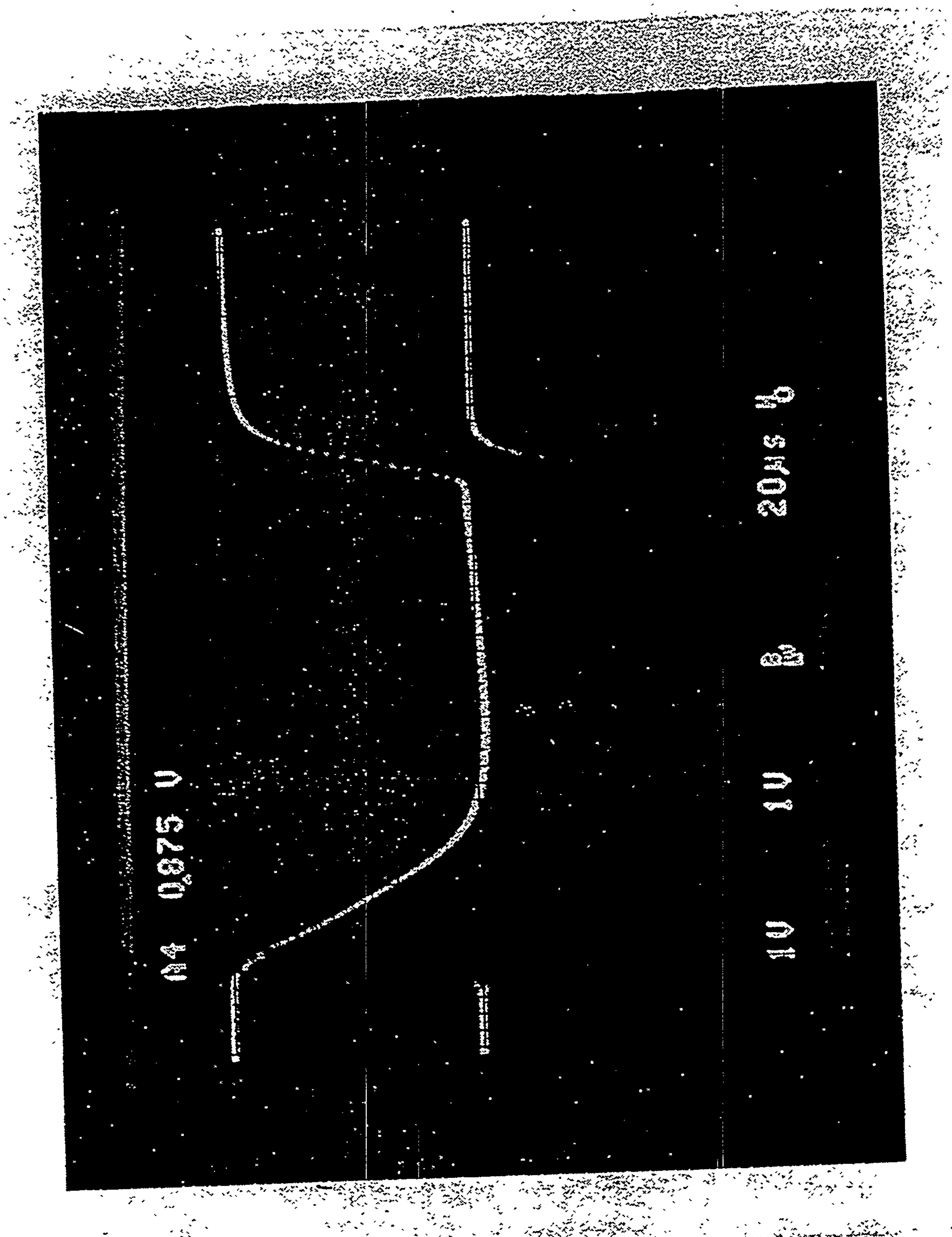
bottom : rf current

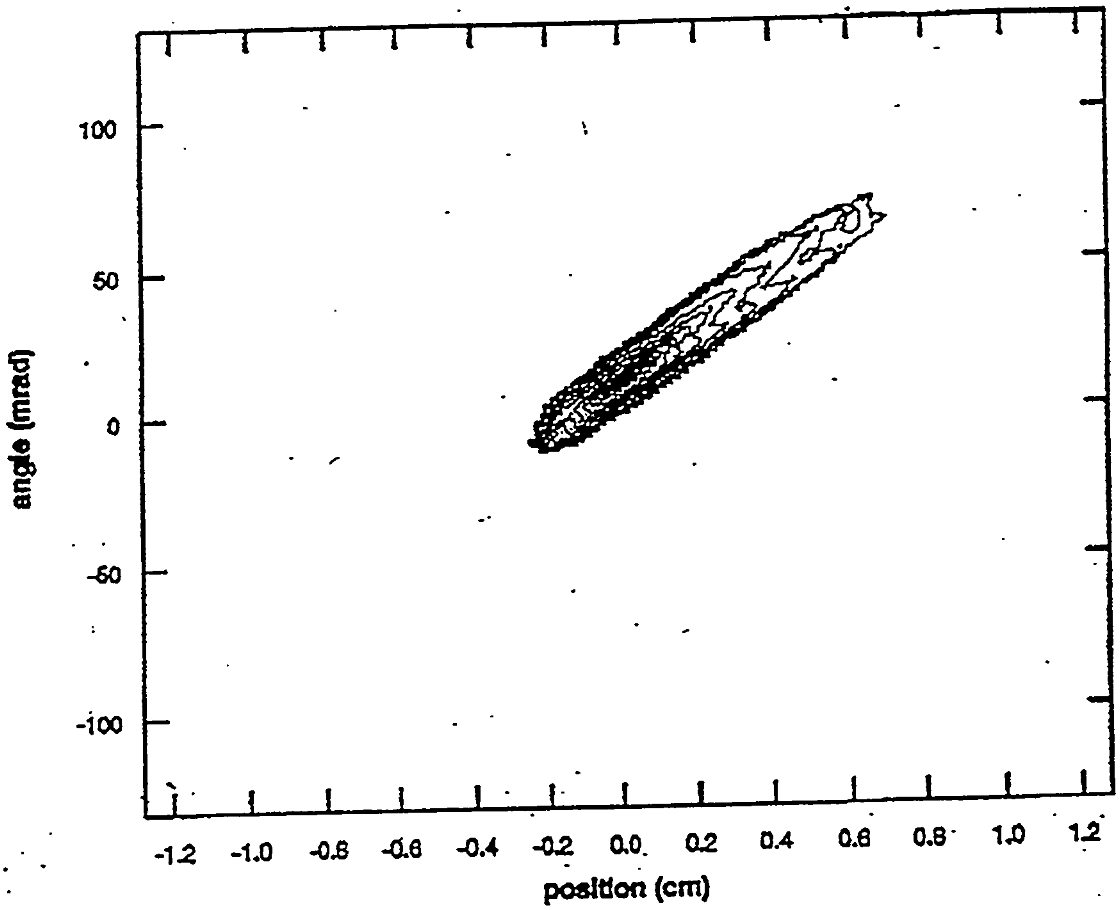
Oscilloscope traces showing the 1.[illegible] MHz RF


Signal Generator
RF Amplifier
100 kV Isolation Transformer
Matching Network
PERMANENT MAGNETS
GAS
CONVERTER
RF ANTENNA
MAGNETIC FILTER
EXTRACTOR
N
S
N
S



Extracted H^- current as a function of RF power


0,875 V
1V 1V
20µs



d = 9 mm
r = 3 mm
V = 35 kV
L_i = 91%
I_i = 1.0 A

$\varepsilon = 0.06\ \pi$ mm mr
divergence = 90 mr
diameter = 0.95 cm

Cesium Delivery System

- In the past, we used a cesium oven with a needle-valve and a hot delivery tube. This system has the advantage of a large cesium reservoir, but it is complicate to operate.

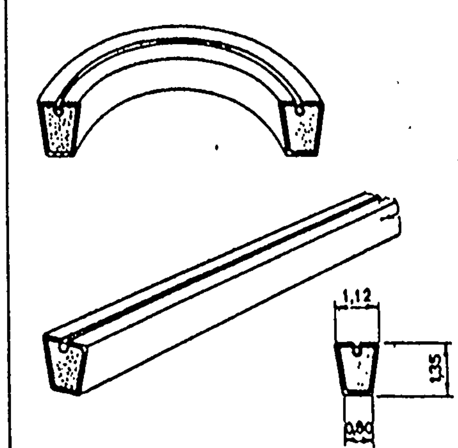
- At present, we are using a cesium getter dispenser delivery system because the amount of cesium required is very small for rf discharge operation. Dispensers are simple in design and easy to operate. Dispensers are also more efficient in cesium consumption thus produce less waste.

SAES high-yield dispensers in custom cut lengths or continuous wire are suitable for the synthesis of all types of photocathode and are of particular value for the fabrication of appendage generator bulbs, where the remote possibility of loose particles is unimportant, but accurate reproducibility is still necessary. It should be noted that there is a protection wire behind the slot so that no particles can be lost at this point, but here no terminals are fitted so that distortion of the ends when mounting is always a possibility, occasionally leading to some particle loss. Identification is by the appropriate chemical symbol on the packing.

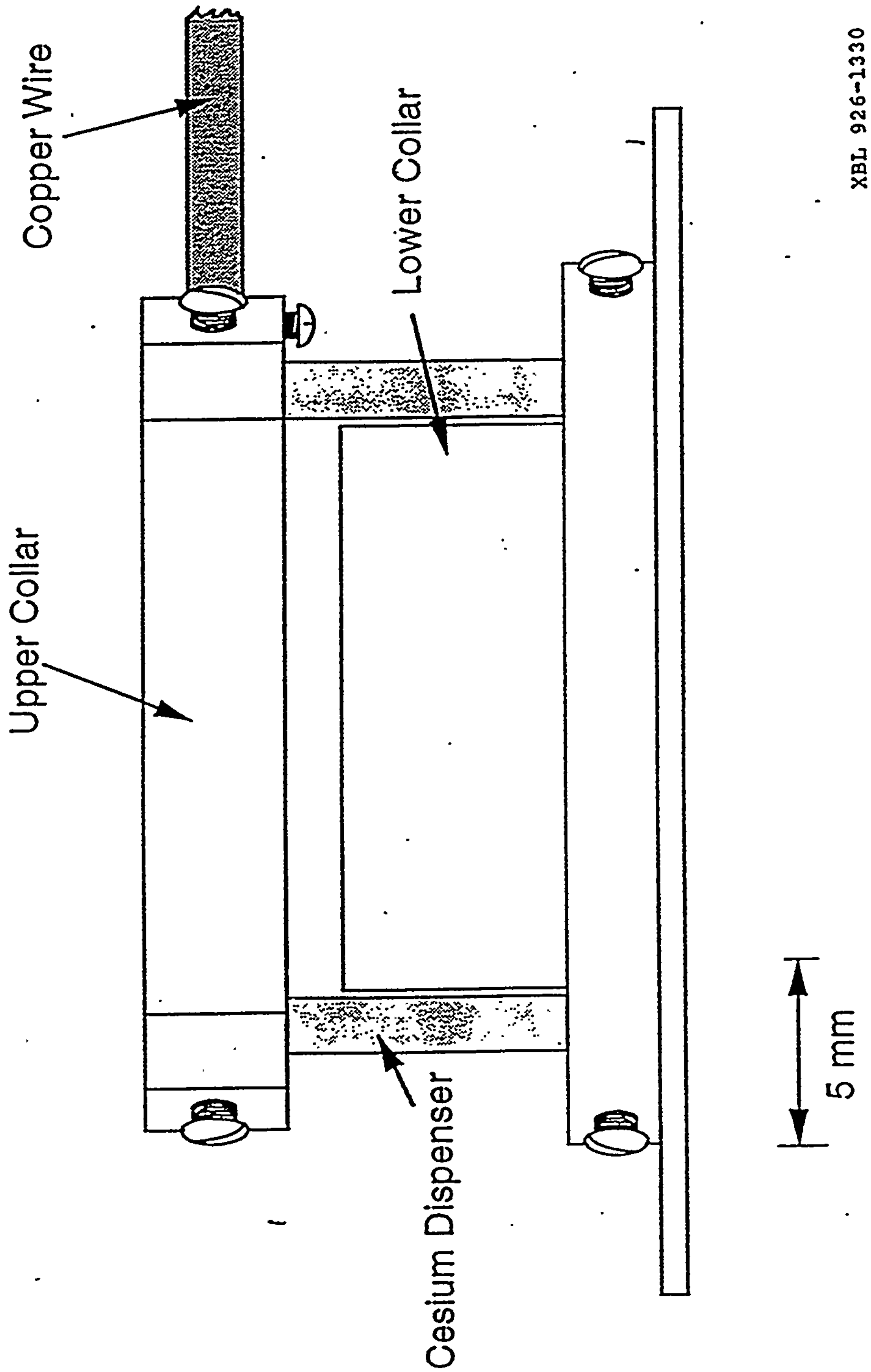
Specification

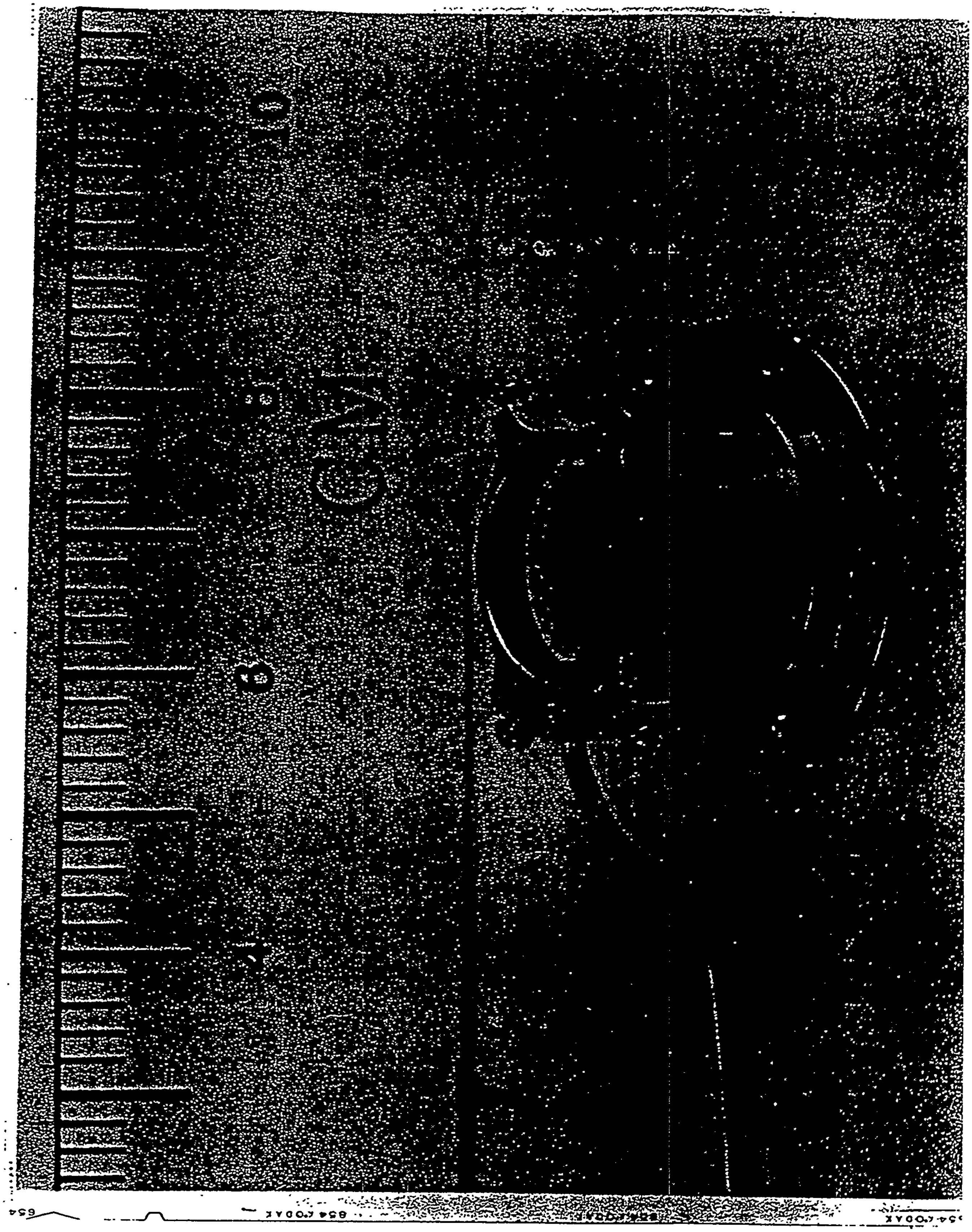
Activation current	4.5-7.5 A
Max degassing temperature	500°C
Standard lengths	cut in lengths as required or as continuous wire
Minimum bending radius	40 mm

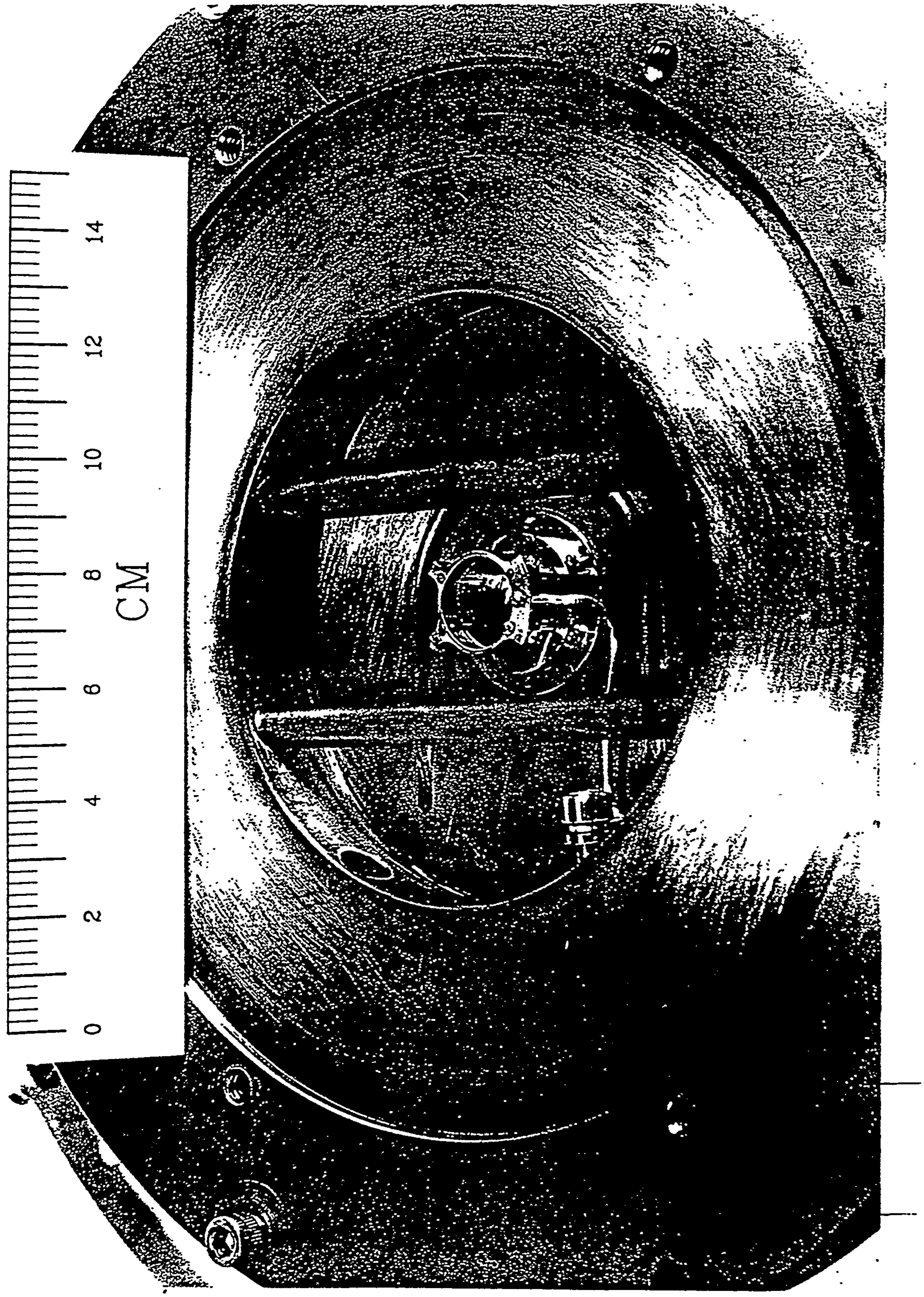
Note:
Cut lengths can be supplied bent to a specified radius with the slot internal, external, or even normal to the plane of curvature.

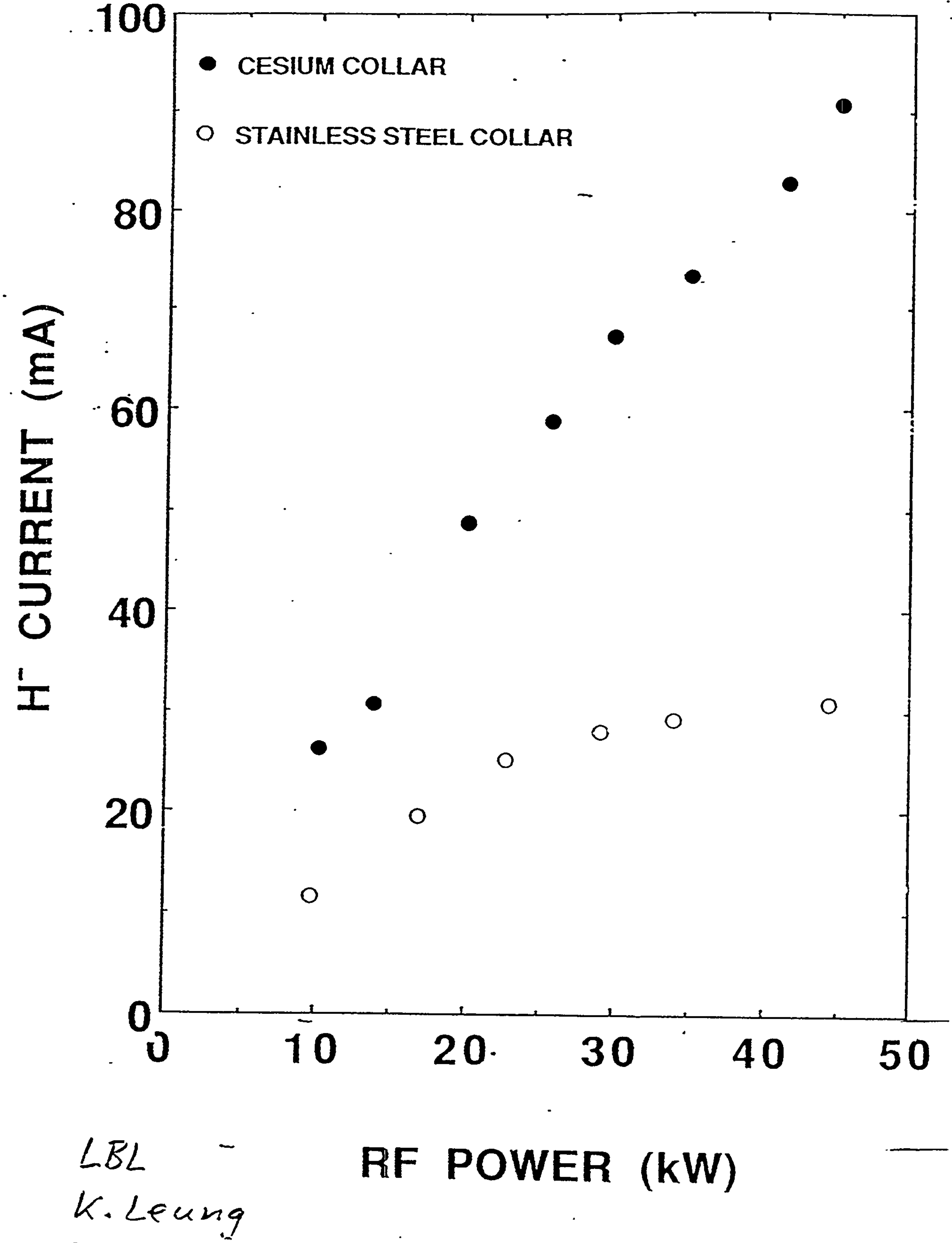


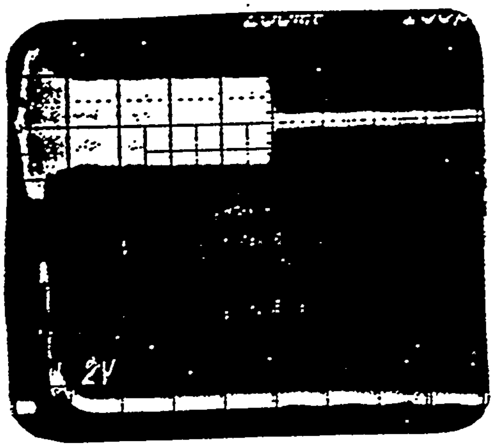
All dimensions in millimetres.

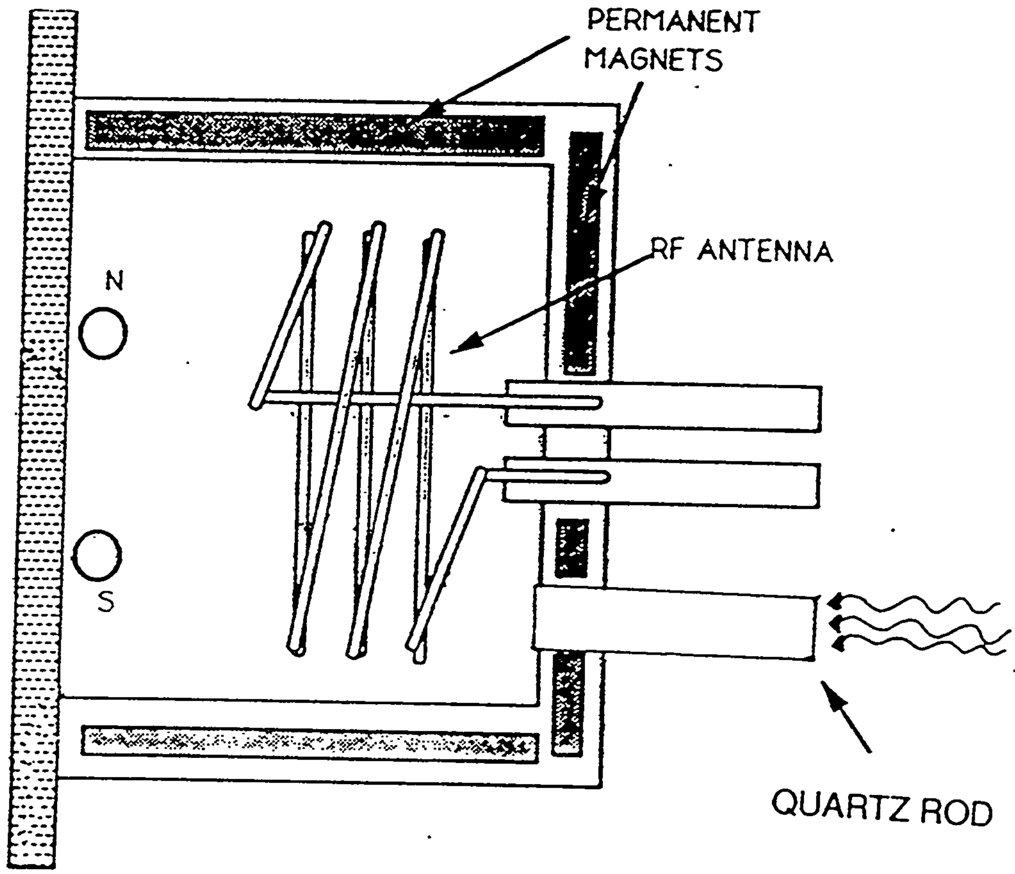

Copper Wire
Lower Collar
Upper Collar
Cesium Dispenser
5 mm
XBL 926-1330



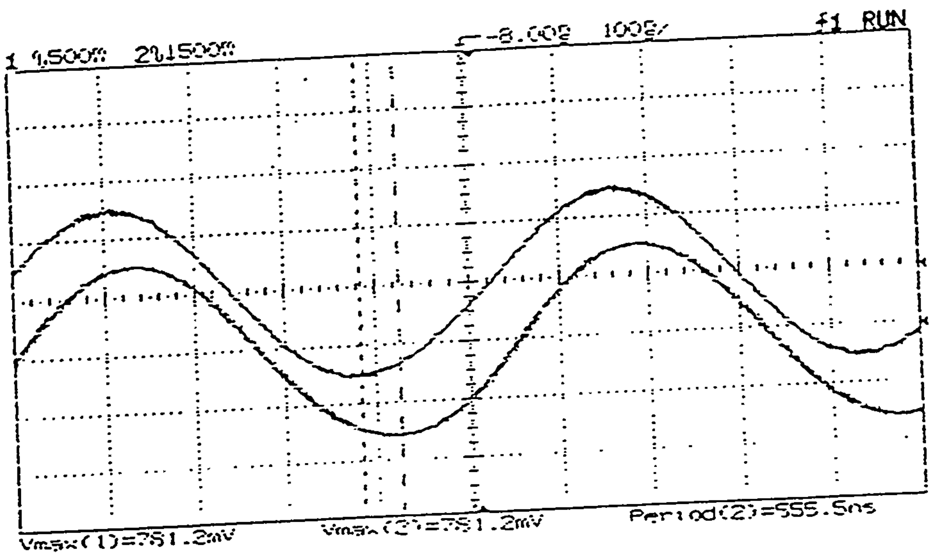

CM
0 2 4 6 8 10 12 14


100
80
60
40
20
0
CESIUM COLLAR
STAINLESS STEEL COLLAR
H⁻ CURRENT (mA)
0
10
20
30
40
50
RF POWER (kW)
LBL
K. Leung


rf pulse
laser pulse

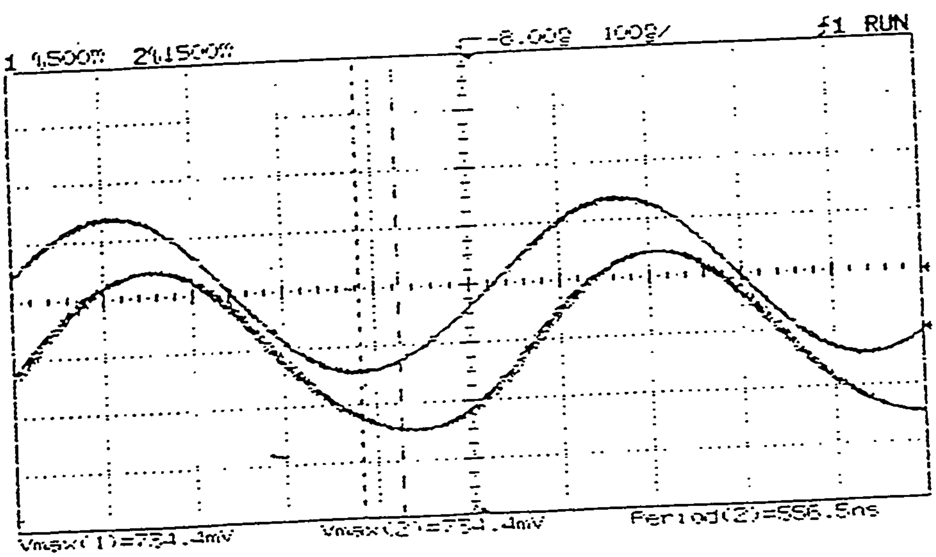

PERMANENT
MAGNETS
RF ANTENNA
N
S
QUARTZ ROD

No cooling of the isolation transformer



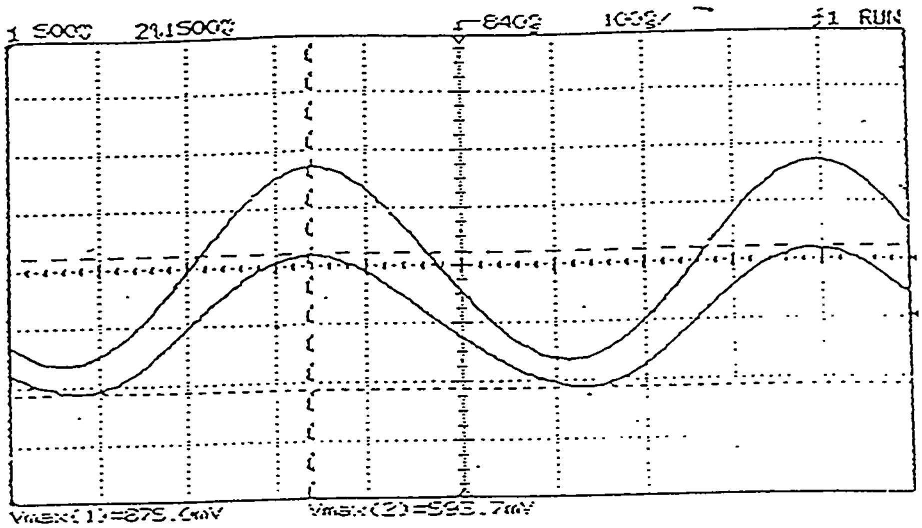
rf voltage

rf current



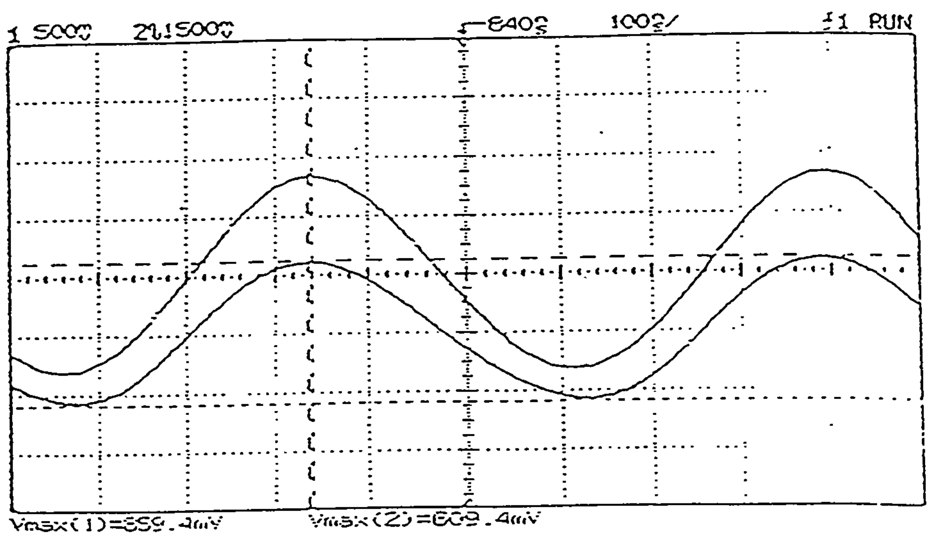
after 20 min
of operation

Isolation transformer was air-cooled

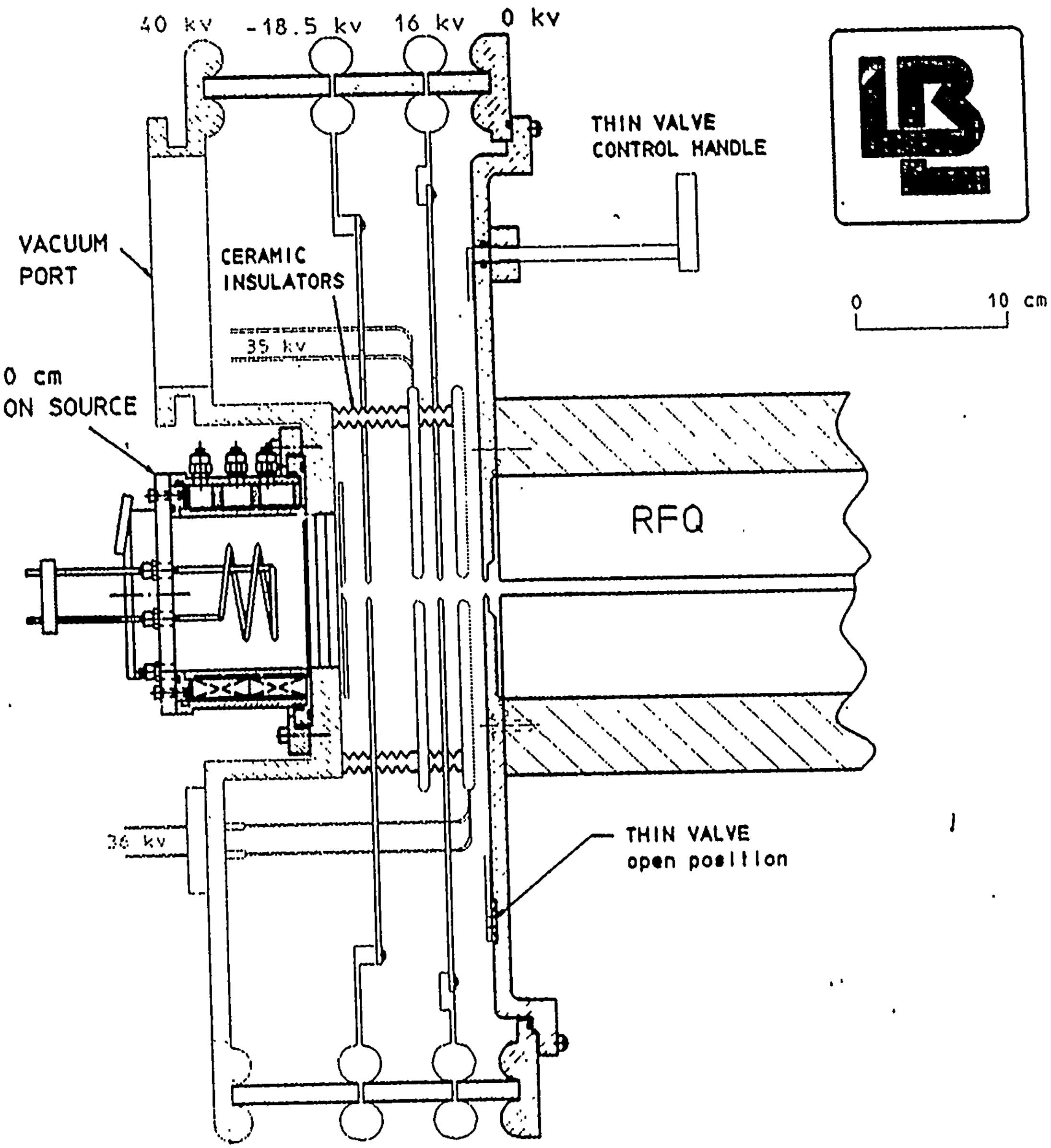


rf voltage

rf current



after 110 min of operation



ELECTROSTATIC LEBT

for injection of H^+
ion beam into an RFQ

Recent Developments with Multicusp Ion Sources at Grumman

S. Melnychuk

Grumman

ATD

RECENT DEVELOPMENTS WITH MULTICUSP ION SOURCES AT GRUMMAN

S.T. MELNYCHUK, G. GAMMEL,
T. W. DEBIAK, J. J. SREDNIAWSKI

GRUMMAN

Accelerator Technology Development

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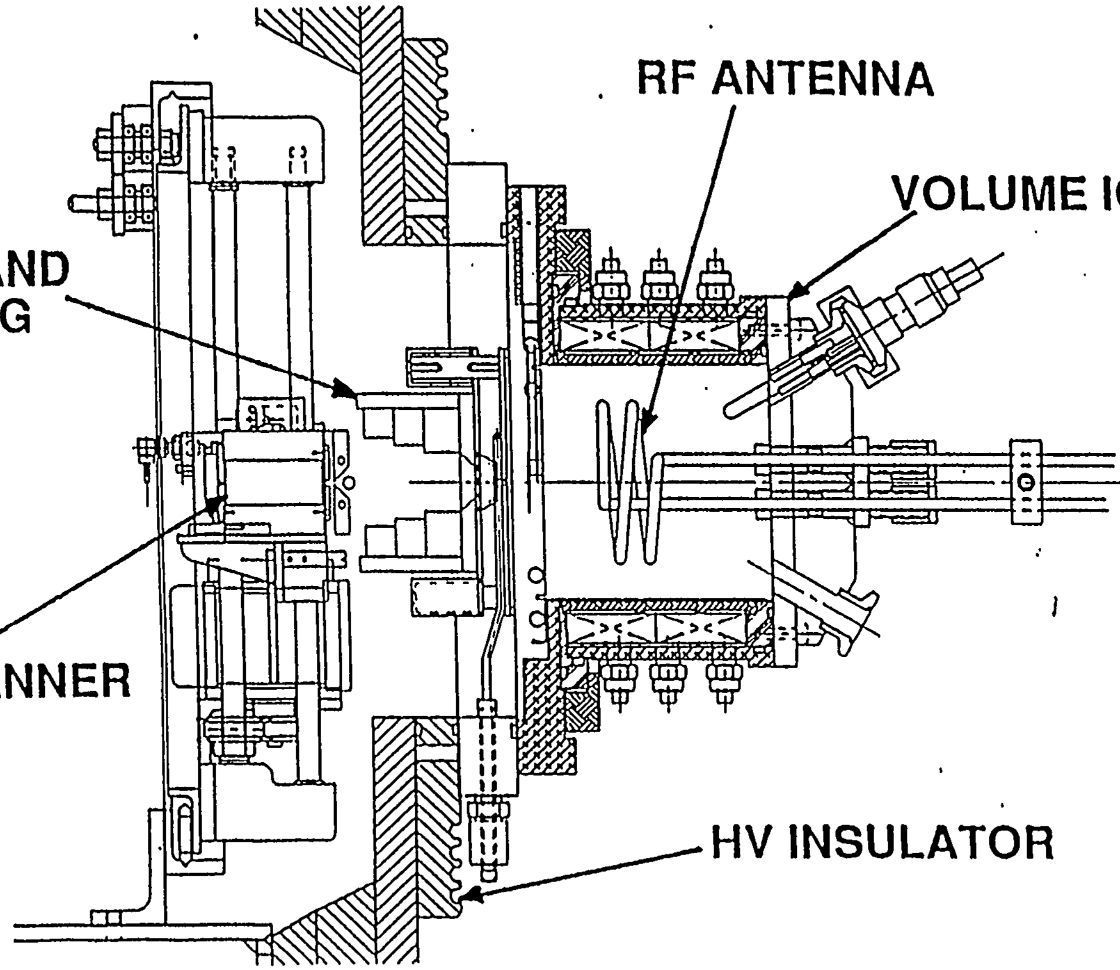
TEST SETUP FOR H⁻ BEAM CHARACTERIZATION



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RF Driven Ion Source

10 cm diameter by 10 cm deep multicusp chamber with 20 columns of Sm-Co magnets designed to handle 2.5 kW of steady state power.

2 pairs of filter rods providing a variable magnetic filter field. (Typically 215 G for H- extraction)

2.5 turn porcelain coated induction antenna
6.9 cm coil OD made from 4.7 mm Cu tubing

8.0 mm plasma aperture
8.0 mm ground electrode aperture

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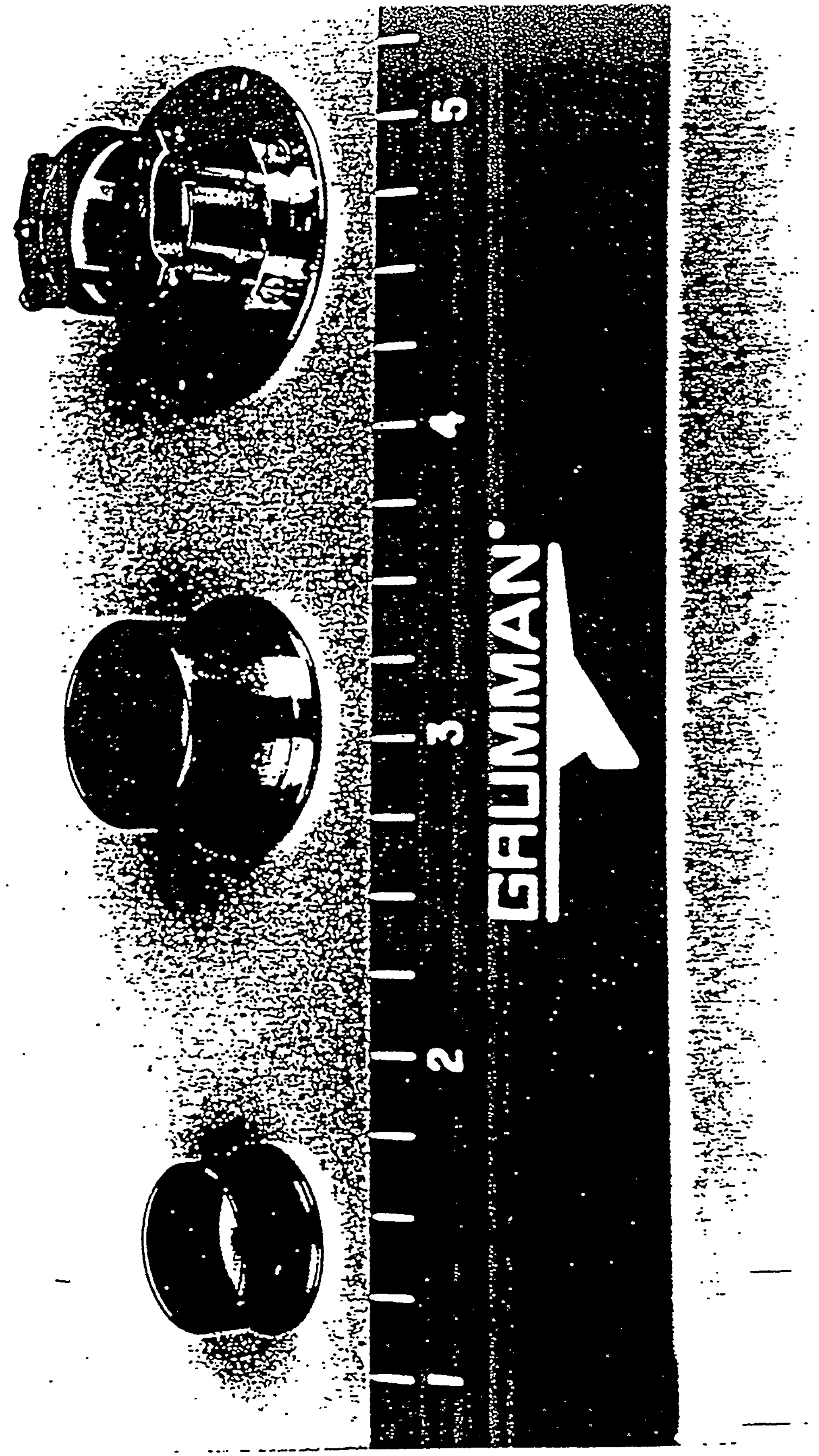
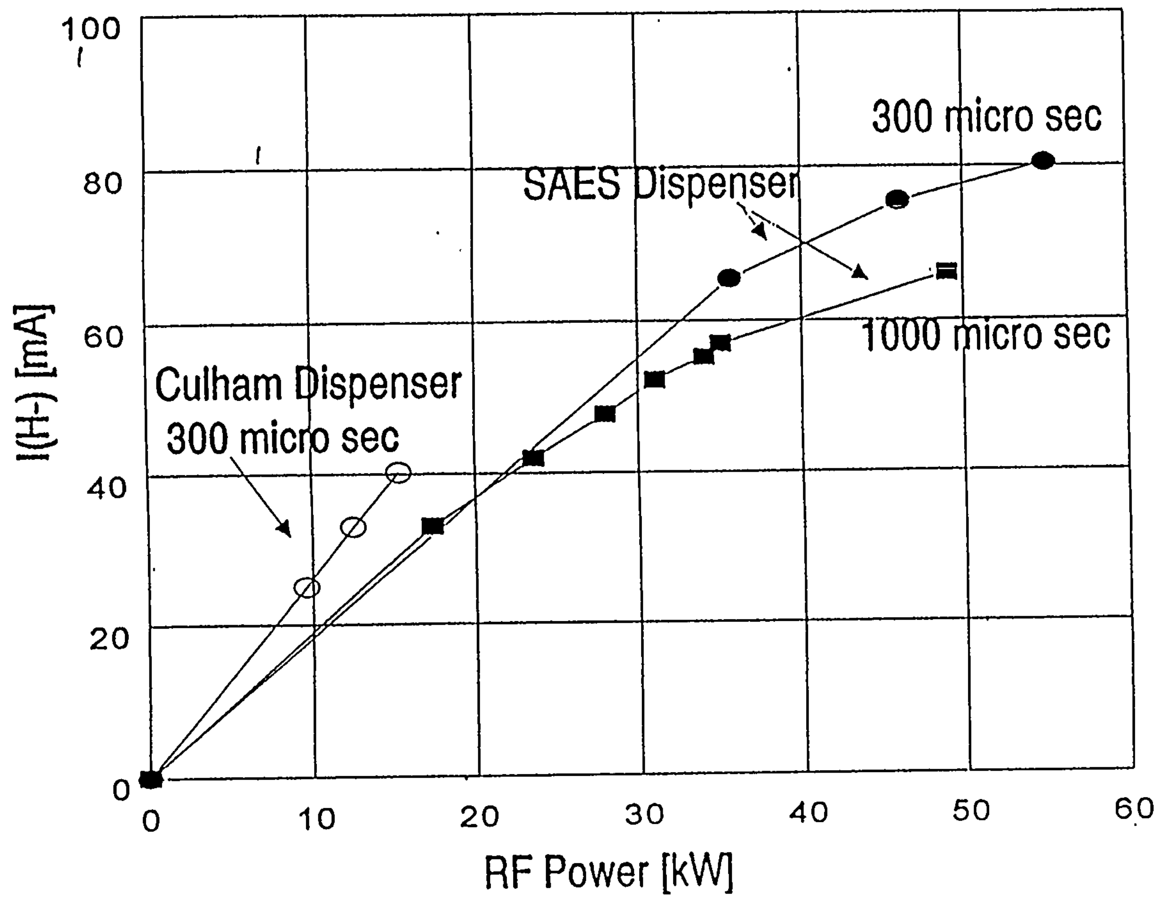

GRUMMAN
2
3
4
5

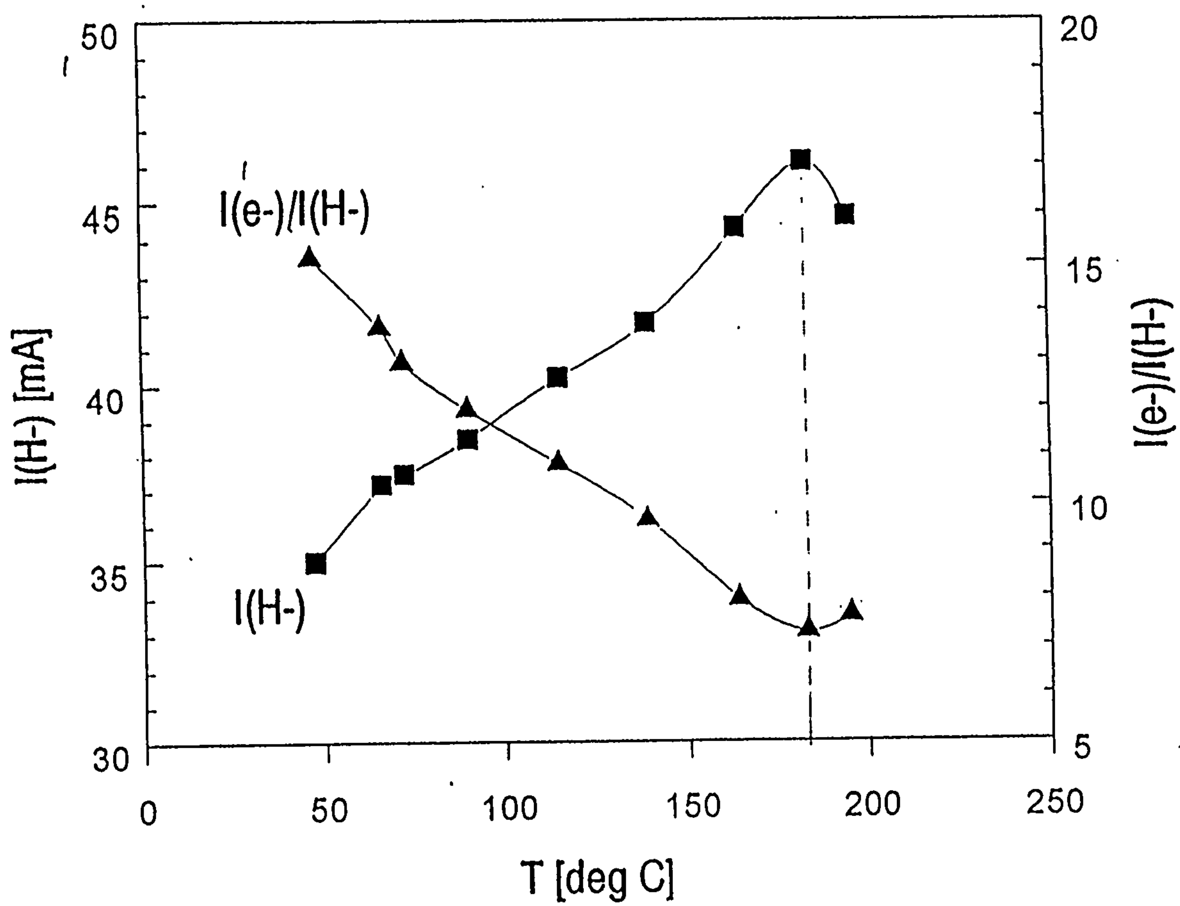
H- Current vs. RF Power



- 40 mA of H- (e-/H- =10) extracted at15 kW of RF input power with Culham dispenser.
- 80 mA of H- extracted at 55 kW of RF input power with SAES collar.
- 80 mA current level was reproducible after 40 days with no degradation in performance

Duty Factor
0.3% to 1.0%

ATD I(H-) and (e-/H-) Ratio vs. Collar Temperature



Collar wall temperature measured with a thermo-couple spot-welded to the collar.

Collar heating done by passing 3 - 4 A of current through the SAES strips. At these strip currents no Cs is dispensed.

At approximately 170 C the extracted H- current reached a maximum and the e-/H- ratio was minimum.

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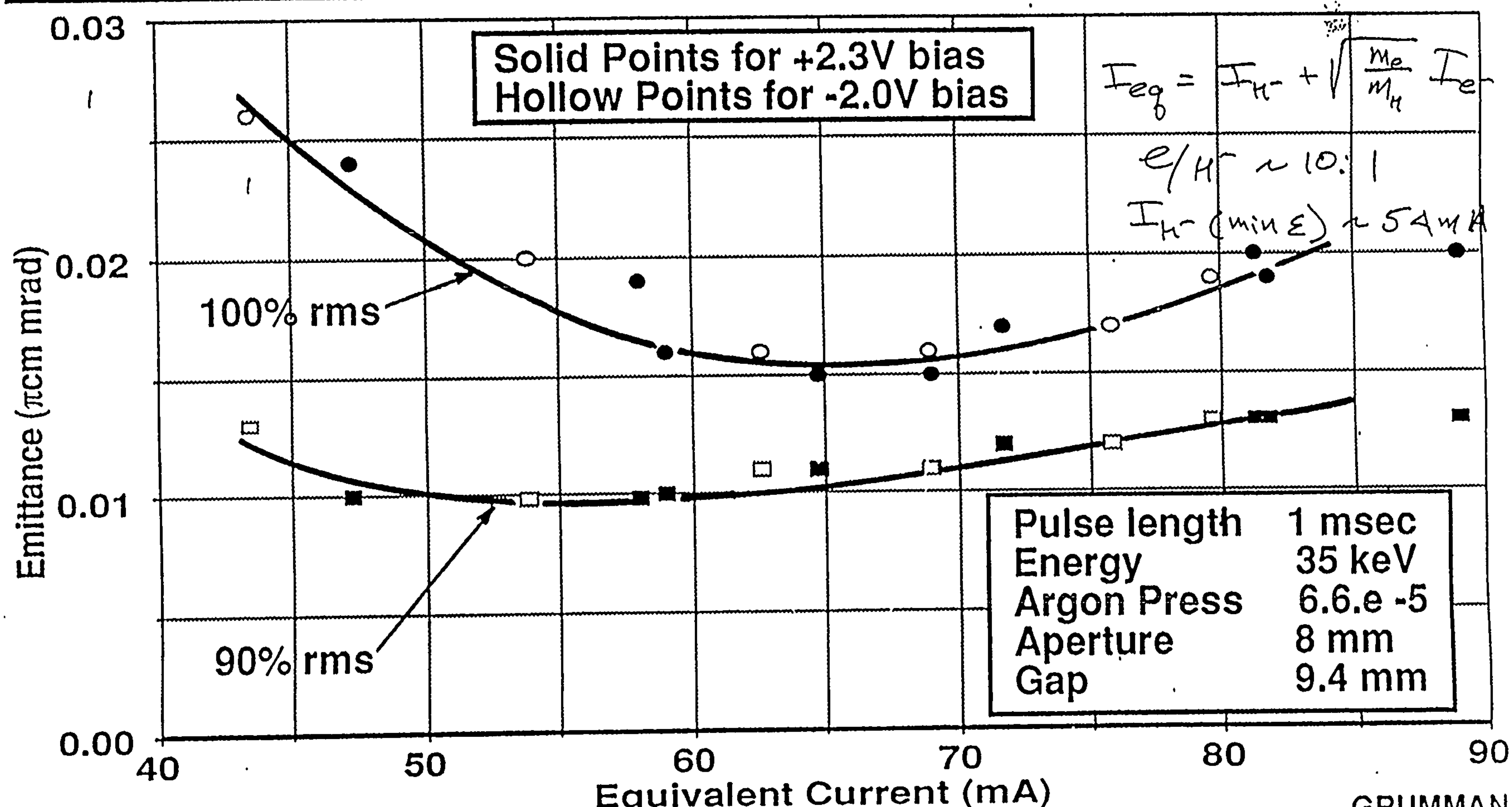
Emittance vs Equivalent Current



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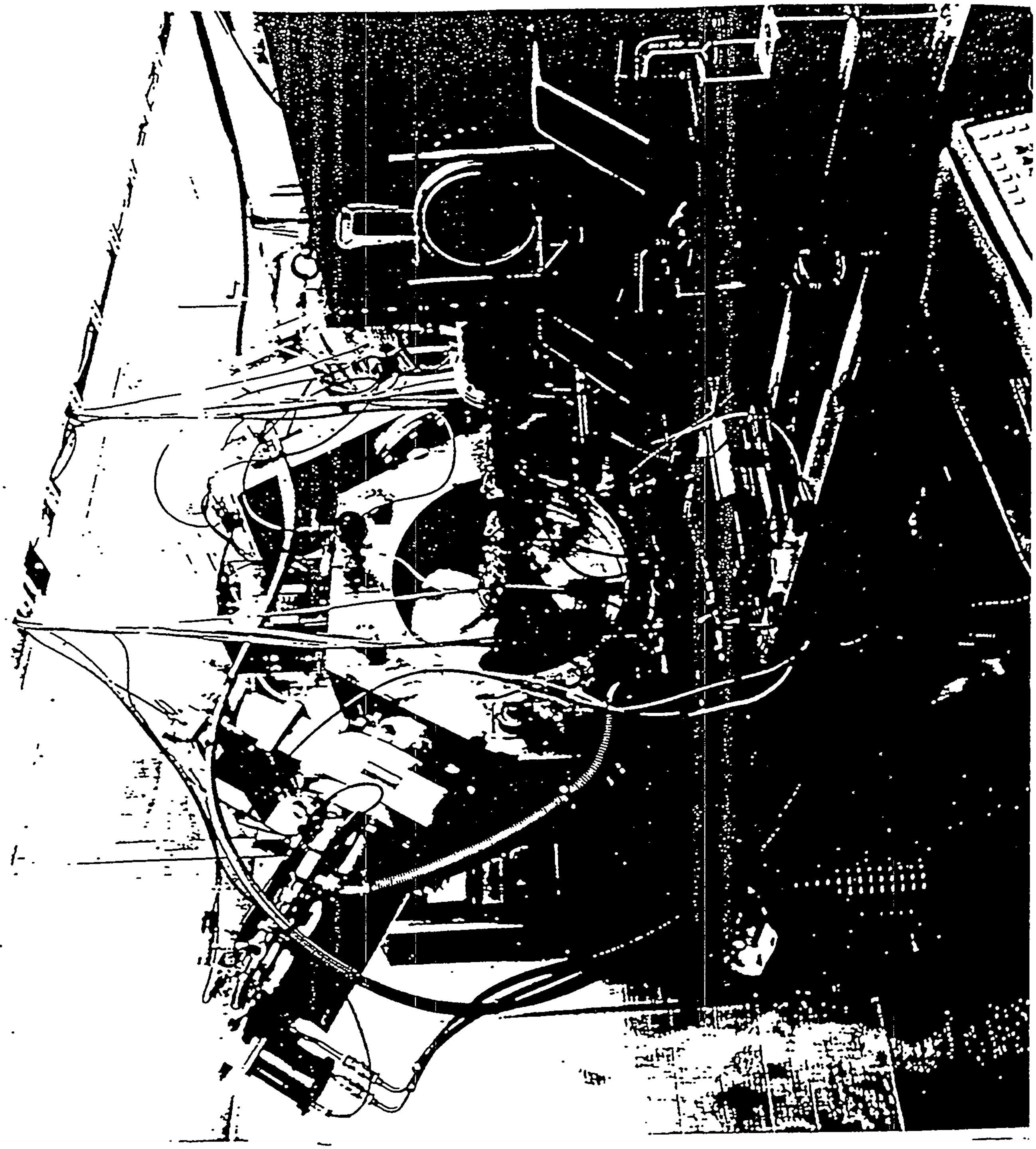
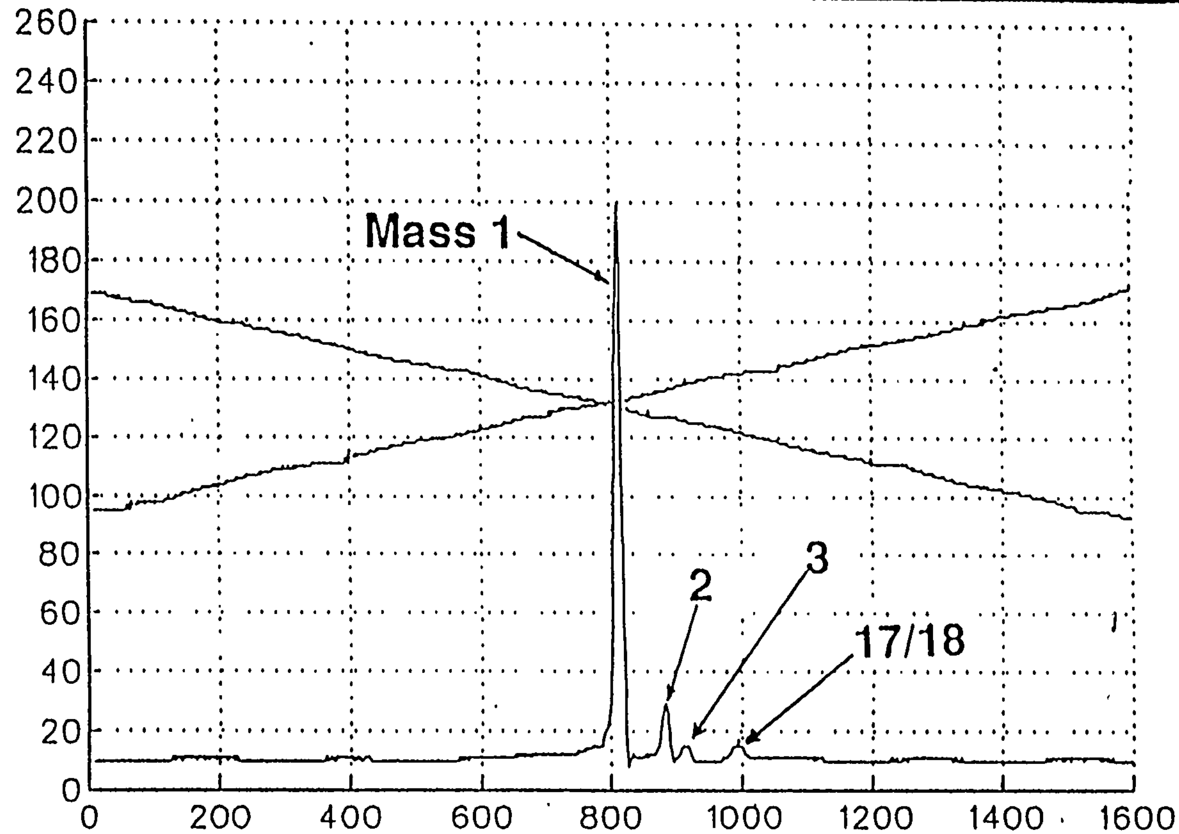
CW SOURCE OPERATION
(POSITIVE ION EXTRACTION)



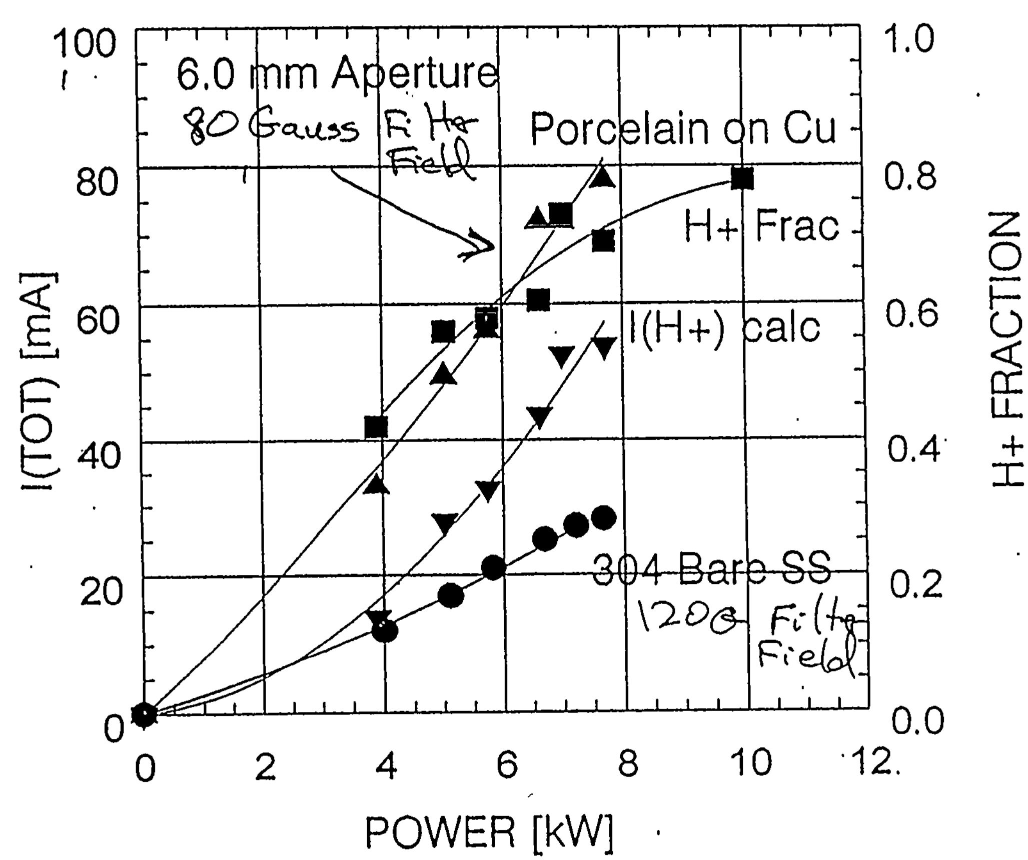
SEPARATION OF SPECIES



An electrostatic emittance scanner coupled with a beam bending magnet have been used to separate ion beam species.

ATD

CW Positive Ion Current vs. RF Power



80 mA of total beam current extracted at 7.5 kW of CW RF input power.

H+ fractions determined from low power pulsed experiments.

100 mA of H+ may be possible at 6kW with a 10 mm diameter plasma aperture (assuming constant current density).

CW diagnostics currently being designed.

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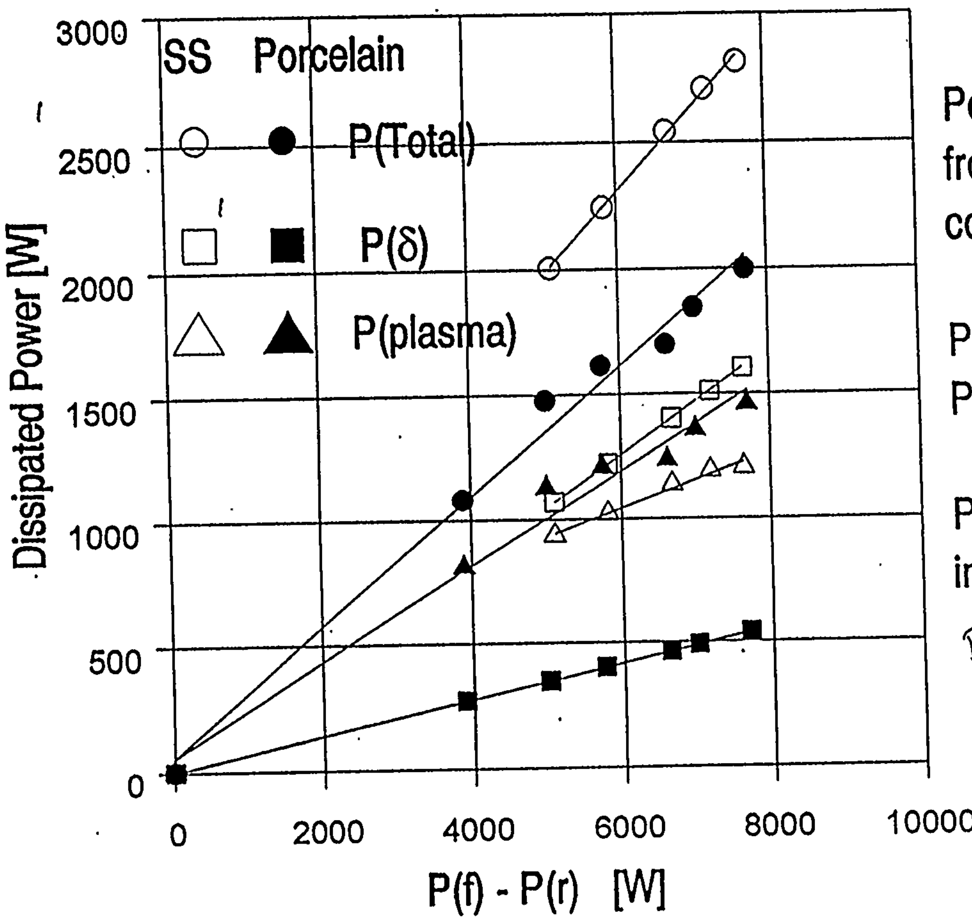
POWER DISSIPATED IN ANTENNA



Power dissipated by antenna was determined from the temperature rise of the antenna cooling water.

$P(water) = Q * C * \Delta T = P(\delta) + P(plasma)$
$P(water) = 66$ Watts/deg C

$P(\delta)/L = I**2/(4\pi r\delta\sigma)$ = power dissipated in one skin depth.

P_{Plasma} = Power incident on antenna from plasma

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ANTENNA LIFETIME

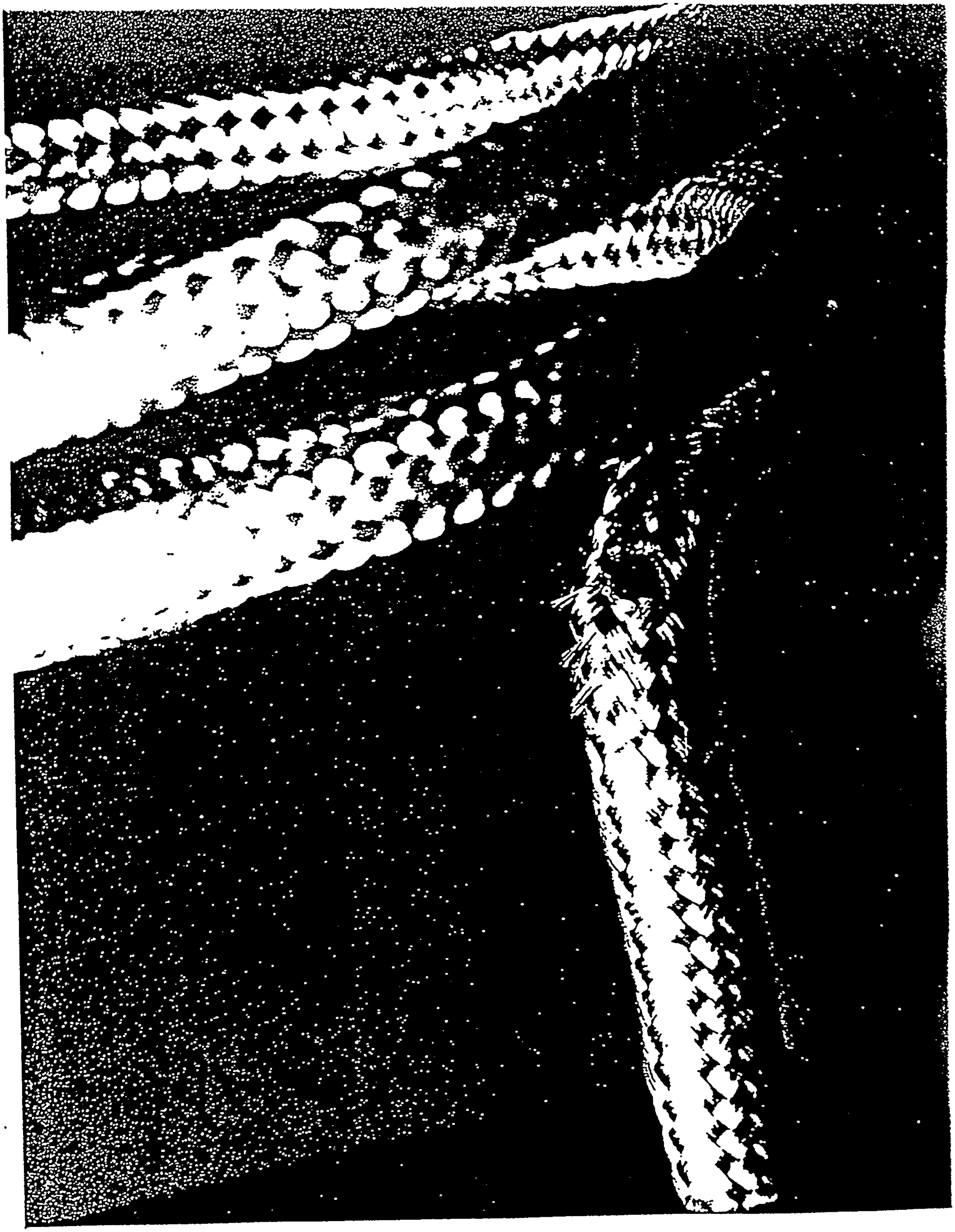
Two failure modes observed:

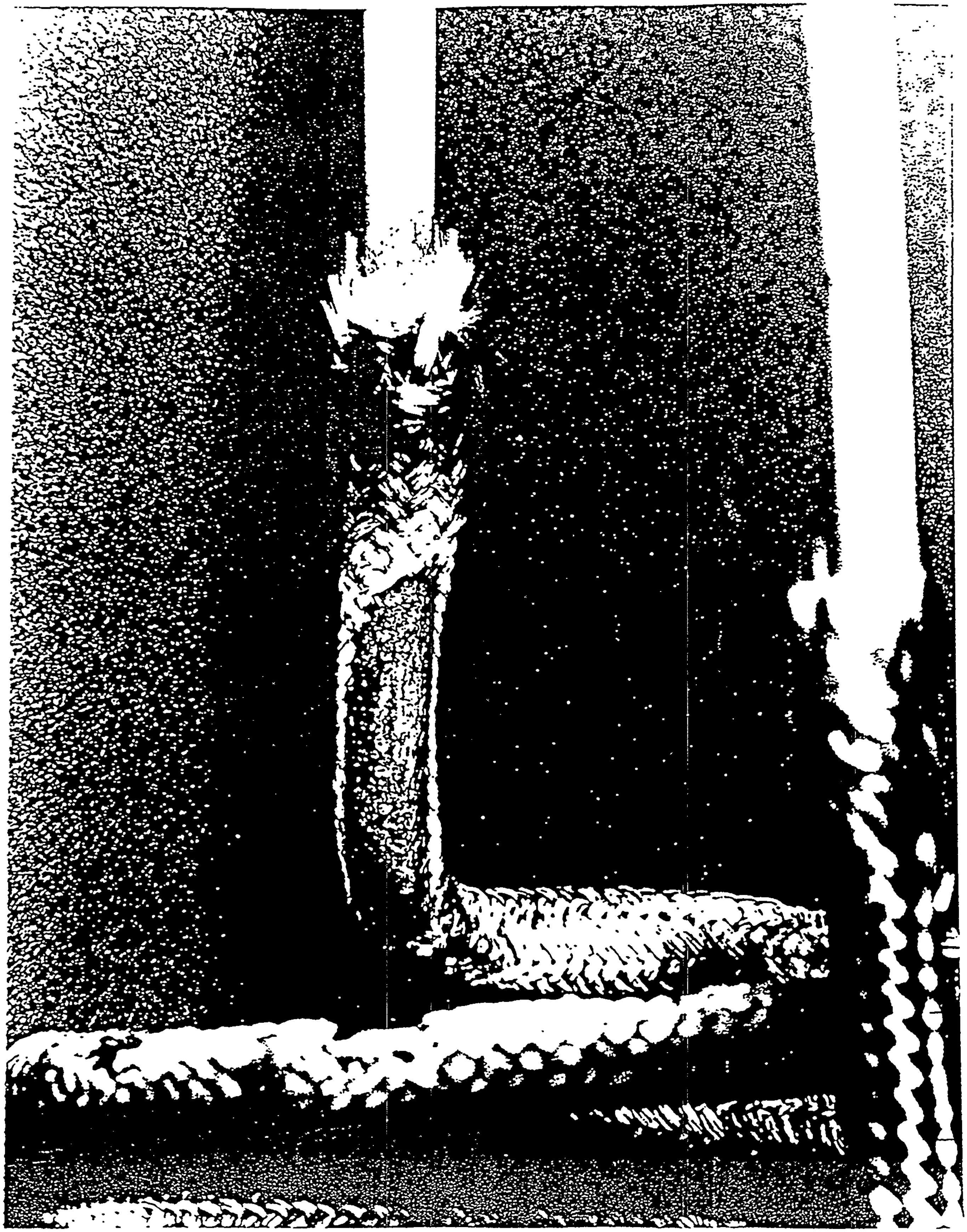
-- Single spot arcing:

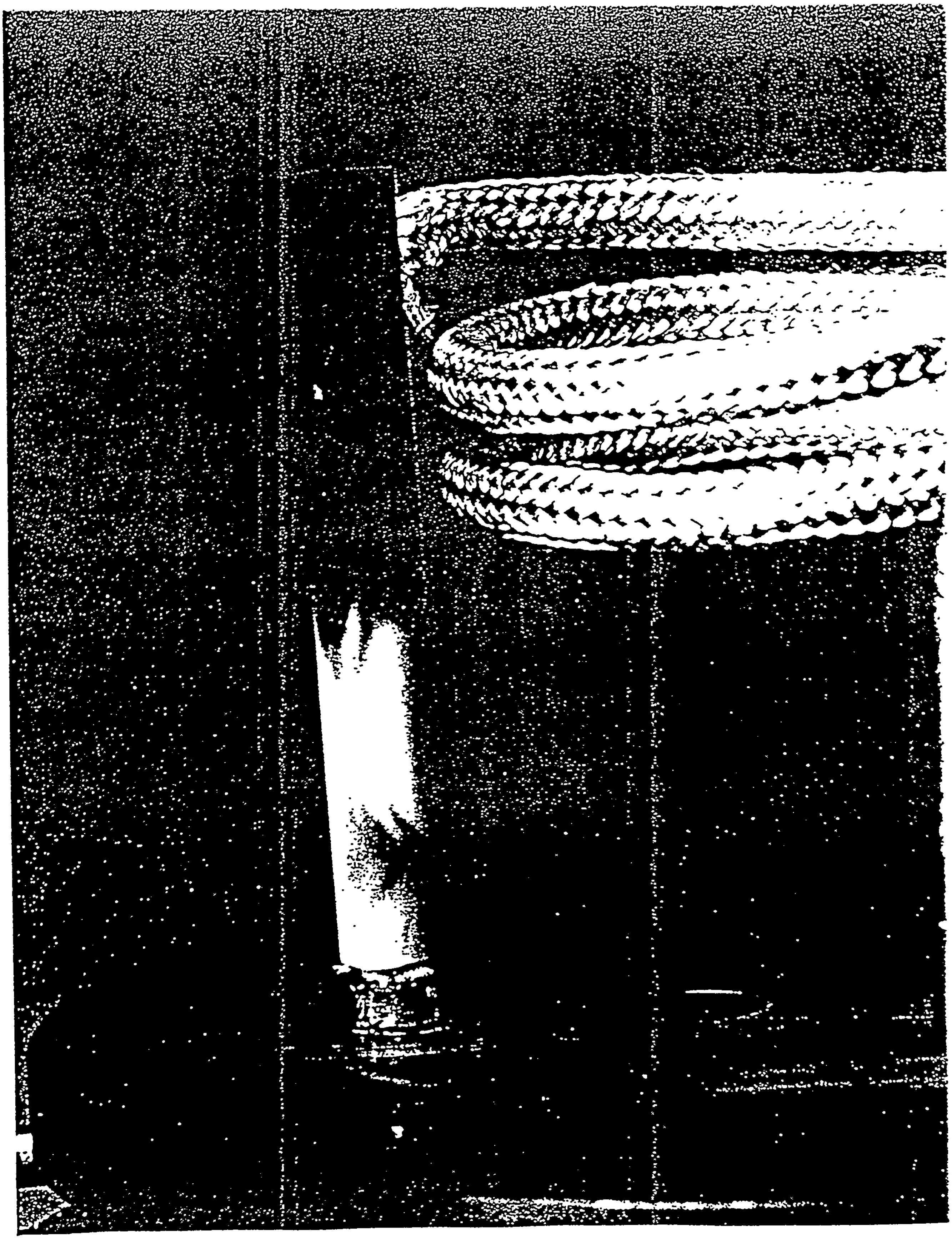
  -- Power spikes during initial turn on causing pinhole damage

-- Distributed erosion pattern:

  -- Atomic hydrogen enhanced sputtering of the oxide coating







SPUTTERING OF THE ANTENNA COATING

Erosion rate:

$$dx/dt = (2 * J(P,m) * Y(V,m) * m) / (e * N * \rho)$$

P = RF power

eV = Ion energy ; $V = (2 * P * Z)^{0.5}$ = V(primary)/ # of turns

J = ion current density striking the antenna (extracted current)

Y = sputter yield = # of atoms removed/incident ion

m = atomic mass

e = electron charge

N = 6.02 E 23

ρ = mass density

5. Sputtering

The sputtering yield of different coatings under H, D and He irradiation was measured in the 100 eV to 8 keV energy range. All data were obtained by the weight loss method, which is limited to high fluences (10^{19} ions/cm^2) [16]. The data for the coating were in good agreement with values measured on massive materials.

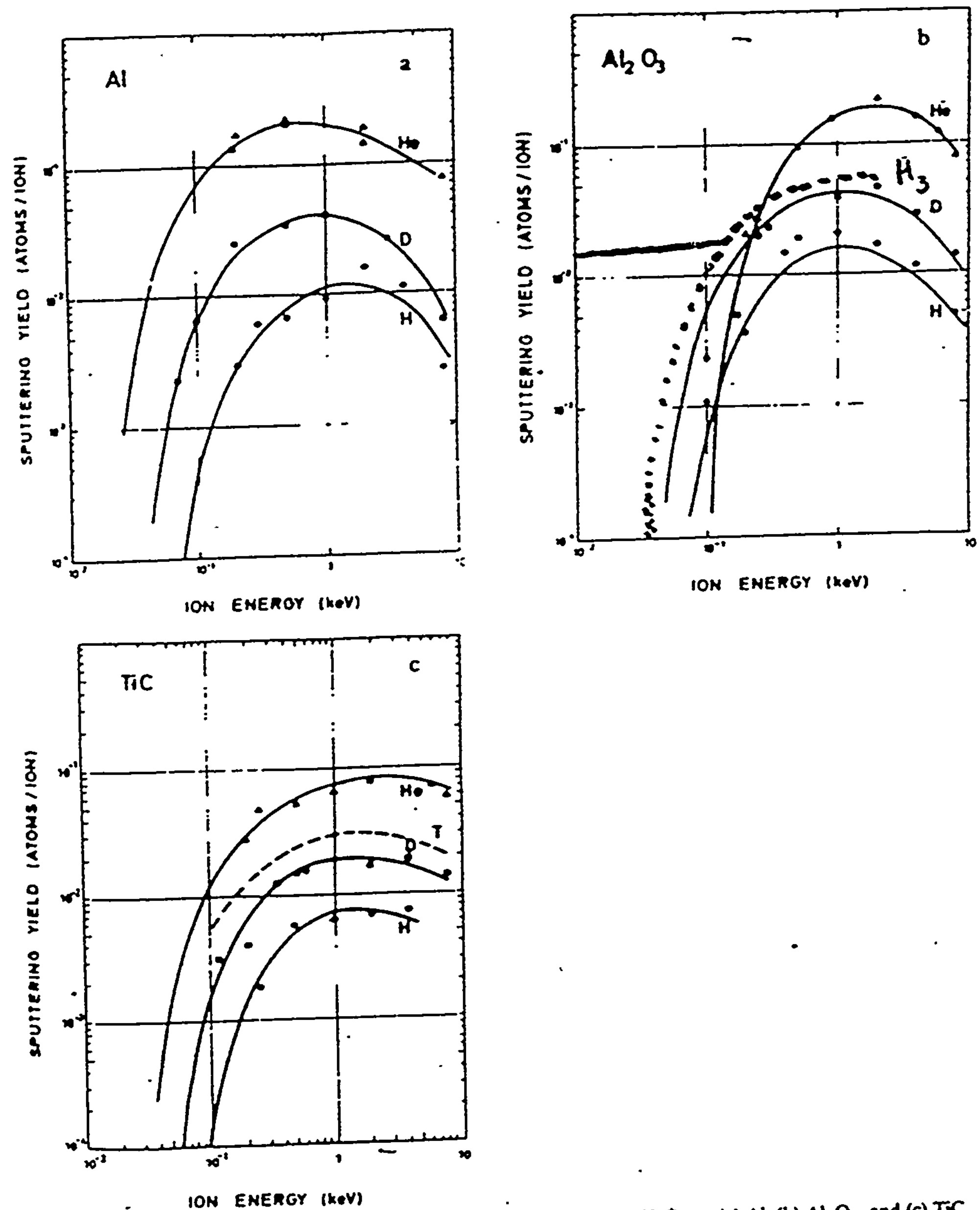


Fig. 7. Energy-dependence of the sputtering yield produced by H^+, D^+ and He^+ on: (a) Al, (b) Al_2O_3, and (c) TiC.

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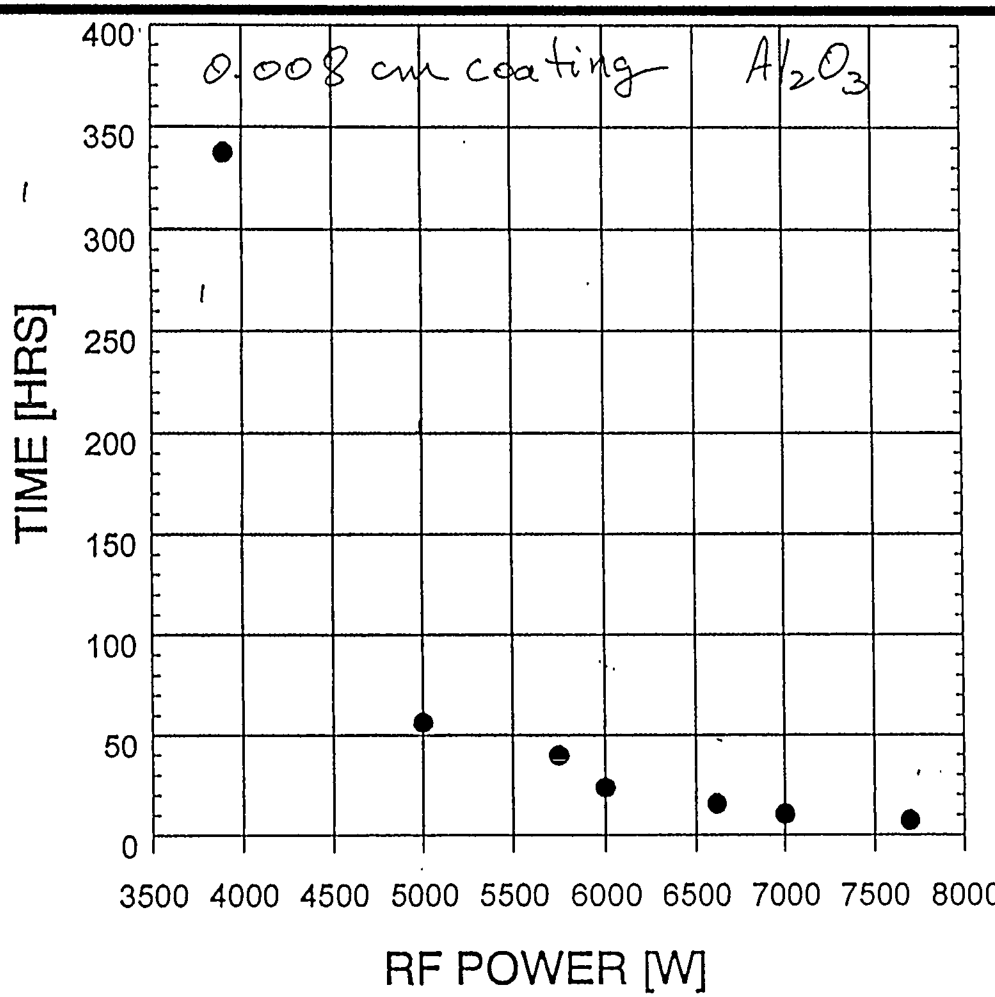
NORMALIZED ANTENNA LIFETIME VS POWER



Antenna coating thickness: 0.008 cm

Sputter yield for H(3) on Alumina

$\rho = 4$ gm/cm^3

Point at 6 kW corresponds to our measured lifetime

We have operated at 4.9kW with a 0.016 cm coating for 60 hrs with no deterioration in performance

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Accelerator Technology Development

Estimate of Antenna Lifetime at 15 kW

15 kW → $V^{RF}_{peak} \sim 225\,V$ → $V_{rms} \sim 160\,V$

From I_+ vs P_{RF} → $J_+ \sim 500\,mA/cm^2$

Sputter Yield for Al_2O_3 at 160 V

$Y_{m=3} \sim .013$ * Consider H_3^+ only *

$$\frac{\Delta L}{\Delta t} = \frac{Y * J * M}{e * N_A * \rho} * \frac{1}{2} * f_3$$

($\frac{1}{2}$ → ½ of full RF cycle; f_3 → H_3 fraction)

$$= \frac{(.013)(0.5)(102)}{(1.6E-19)(6.02E23)(4)} * \frac{1}{2} * \frac{1}{2} = 4.2E-7 \left(\frac{cm}{s}\right)$$

for Coating $L \sim .05$ cm = .02"

$$t = \frac{L}{\left(\frac{\Delta L}{\Delta t}\right)} \sim 33\,h$$

DF ~ 10%

$$\frac{t}{DF} \sim 13.7 \text{ Days}$$

A High Current H^- Volume Ion Source

K. Saadatmand

Superconducting Super Collider Laboratory

A High Current H^- RF Volume Ion Source

K. Saadatmand

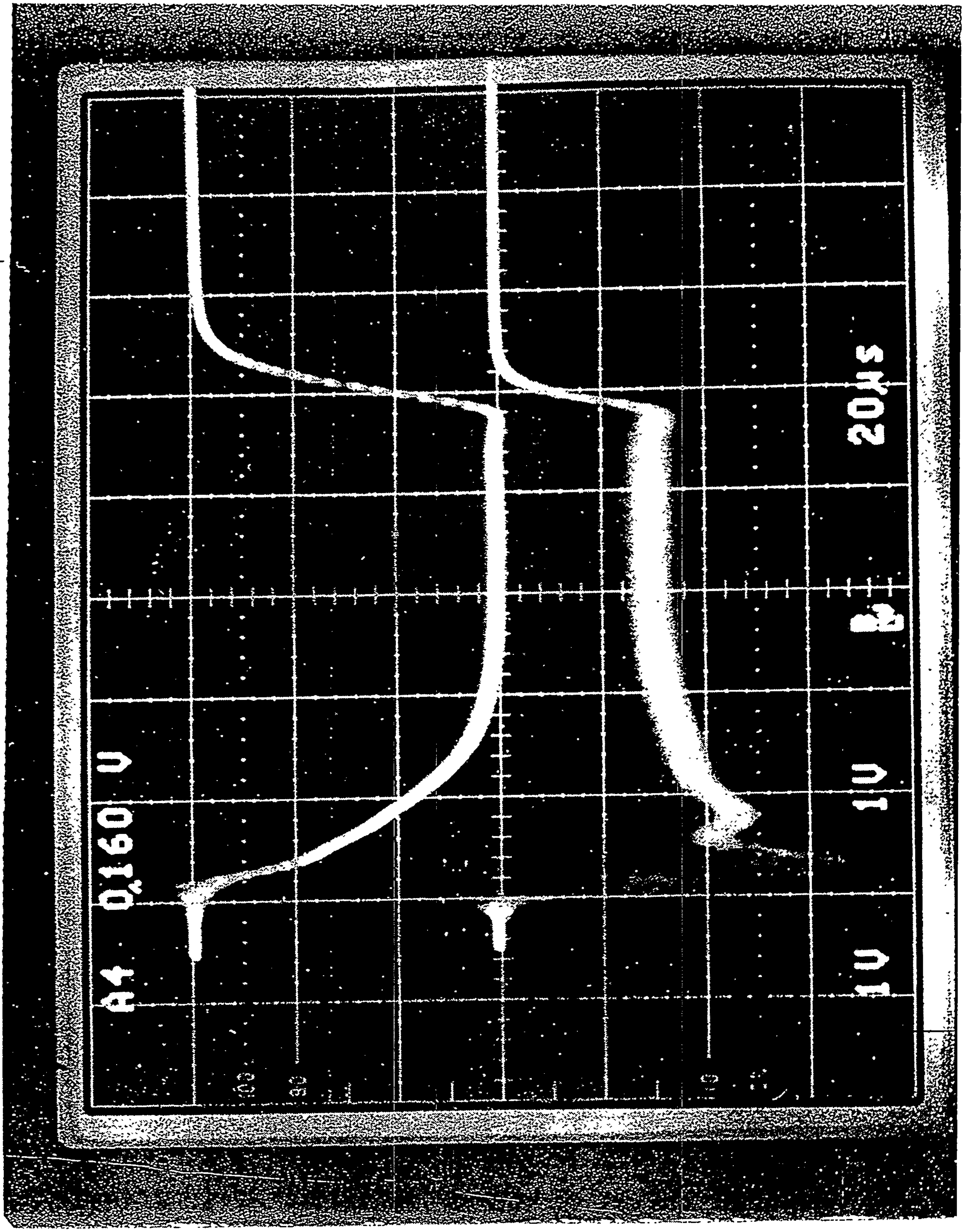
Superconducting Super Collider Laboratory
2550 Beckleymeade Avenue
Dallas, TX 75237-3946

SSC RF-driven volume ion source

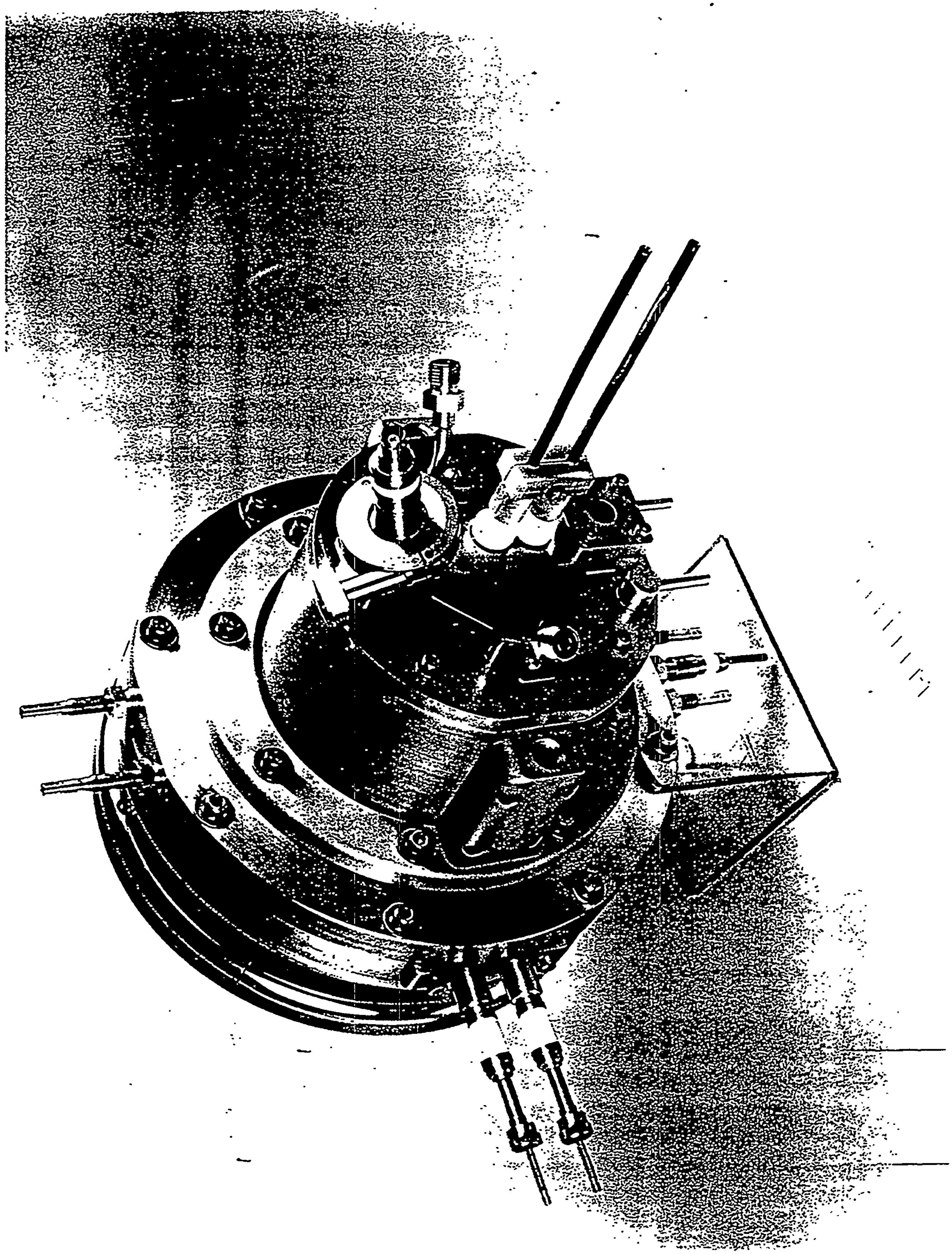
$\geq$ 30 mA H^- beam @ 35 kV

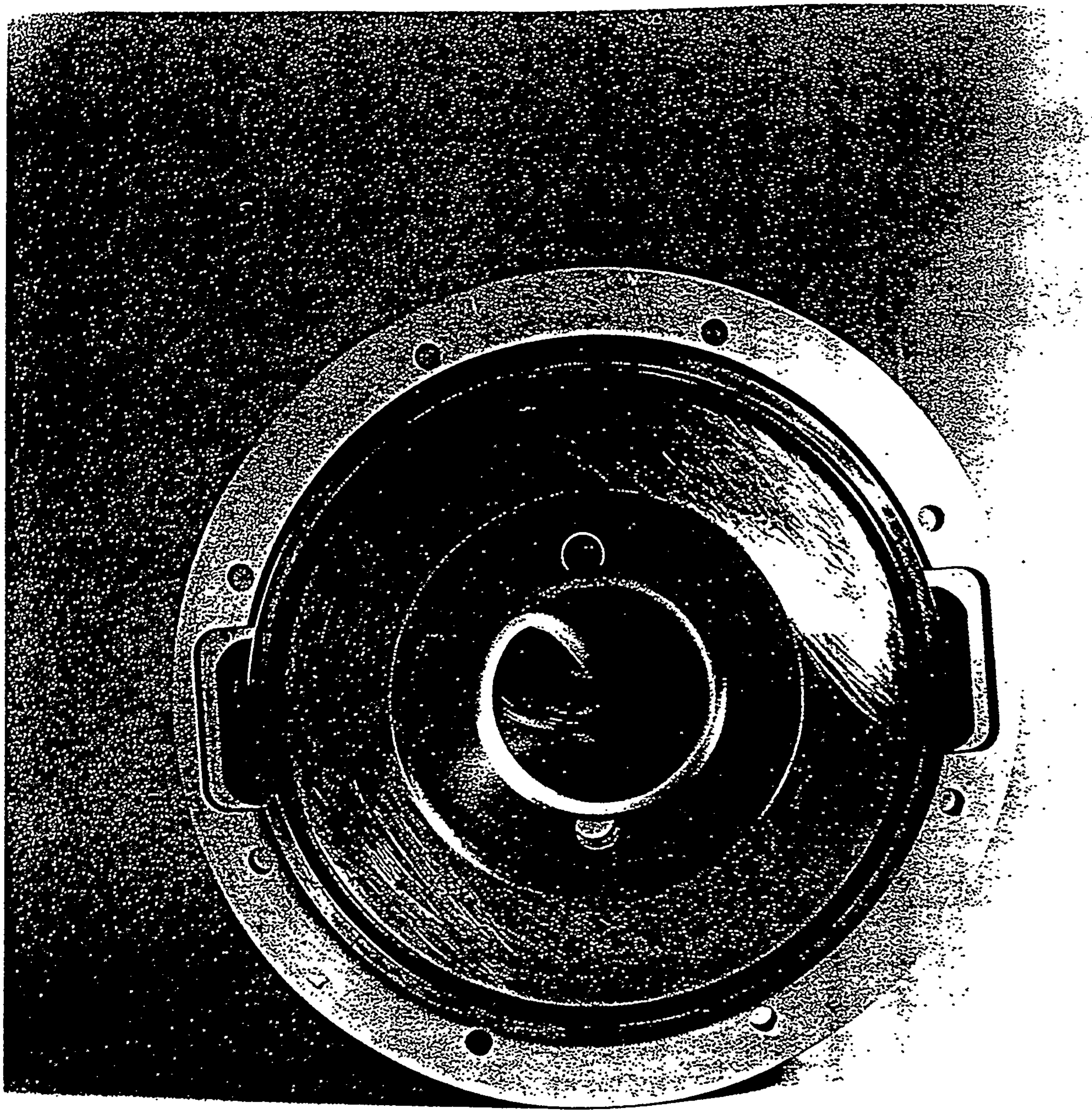
100 μs pulse width @ 10 Hz repetition rate

$\varepsilon_{n\text{-rms}} < 0.1\ \pi$ mm-mrad


A4 0.160 V
1V
1V
20µs

VMS 93-12-15-24
8-19-93
Ion Source





Porcelain-coated antenna coil of the rf driven H^- source.

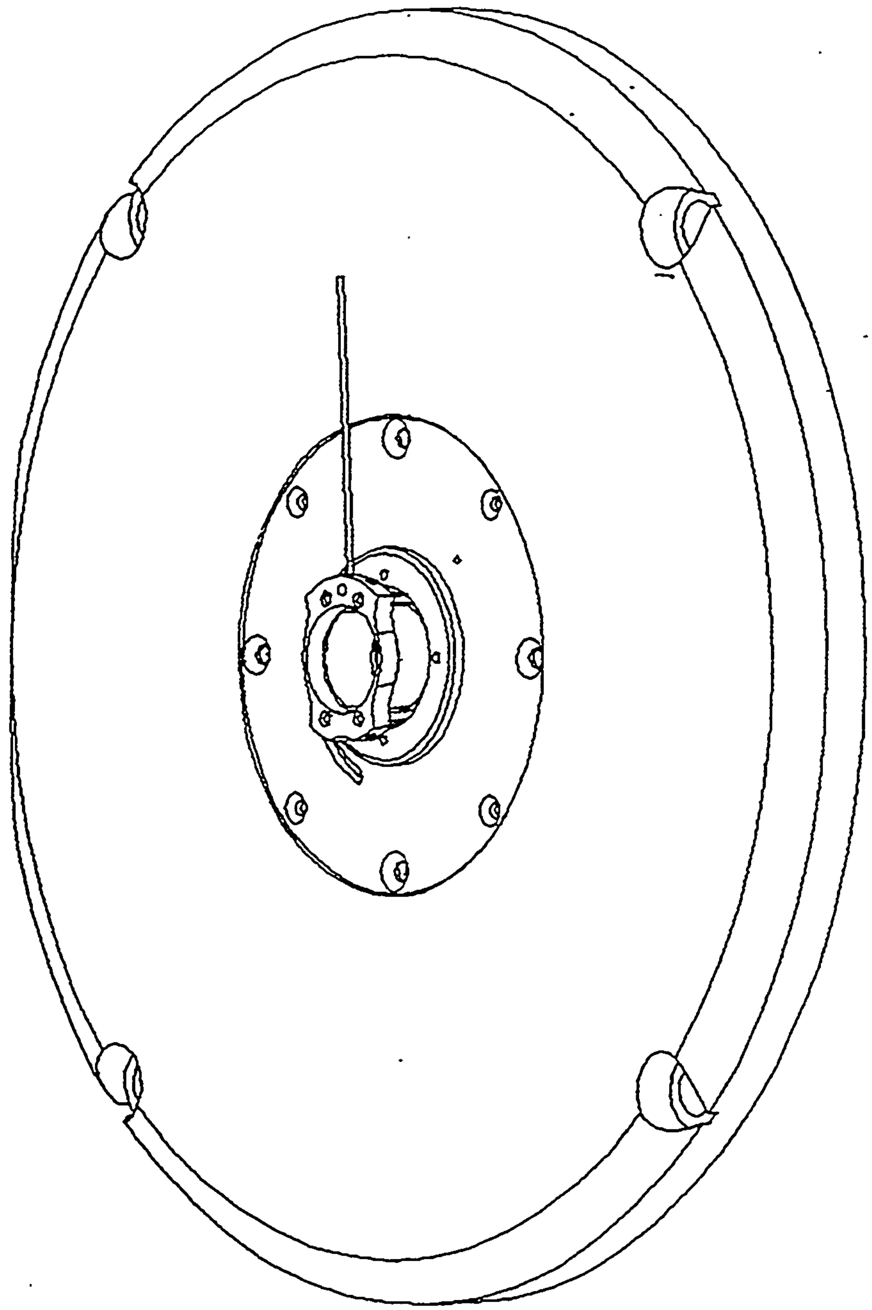
H^- beam current enhancement

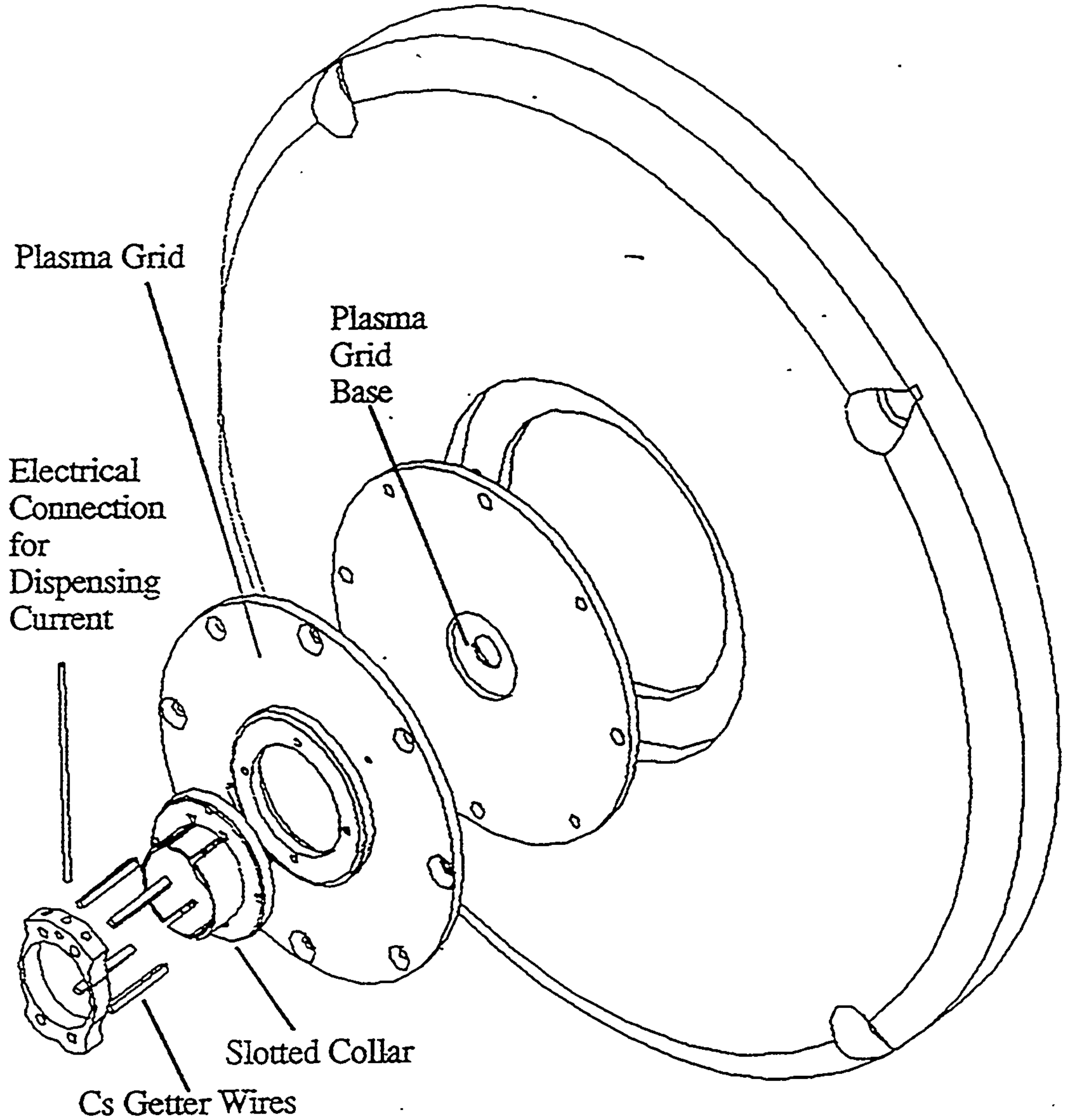
- The ion source was modified with a dispenser to introduce a trace amount of cesium into the plasma grid collar.

- Four cesium getter wires (1.5 cm long each) are placed in vertical cuts around the collar

- Cesium is usually introduced into the source collar area by conducting a high electrical current through the getter wires (10-12 A per wire is required).

- We were able to reach high H^- currents (70-80 mA) but were unable to maintain it for more than a couple of hours.




Plasma Grid
Plasma
Grid
Base
Electrical
Connection
for
Dispensing
Current
Slotted Collar
Cs Getter Wires

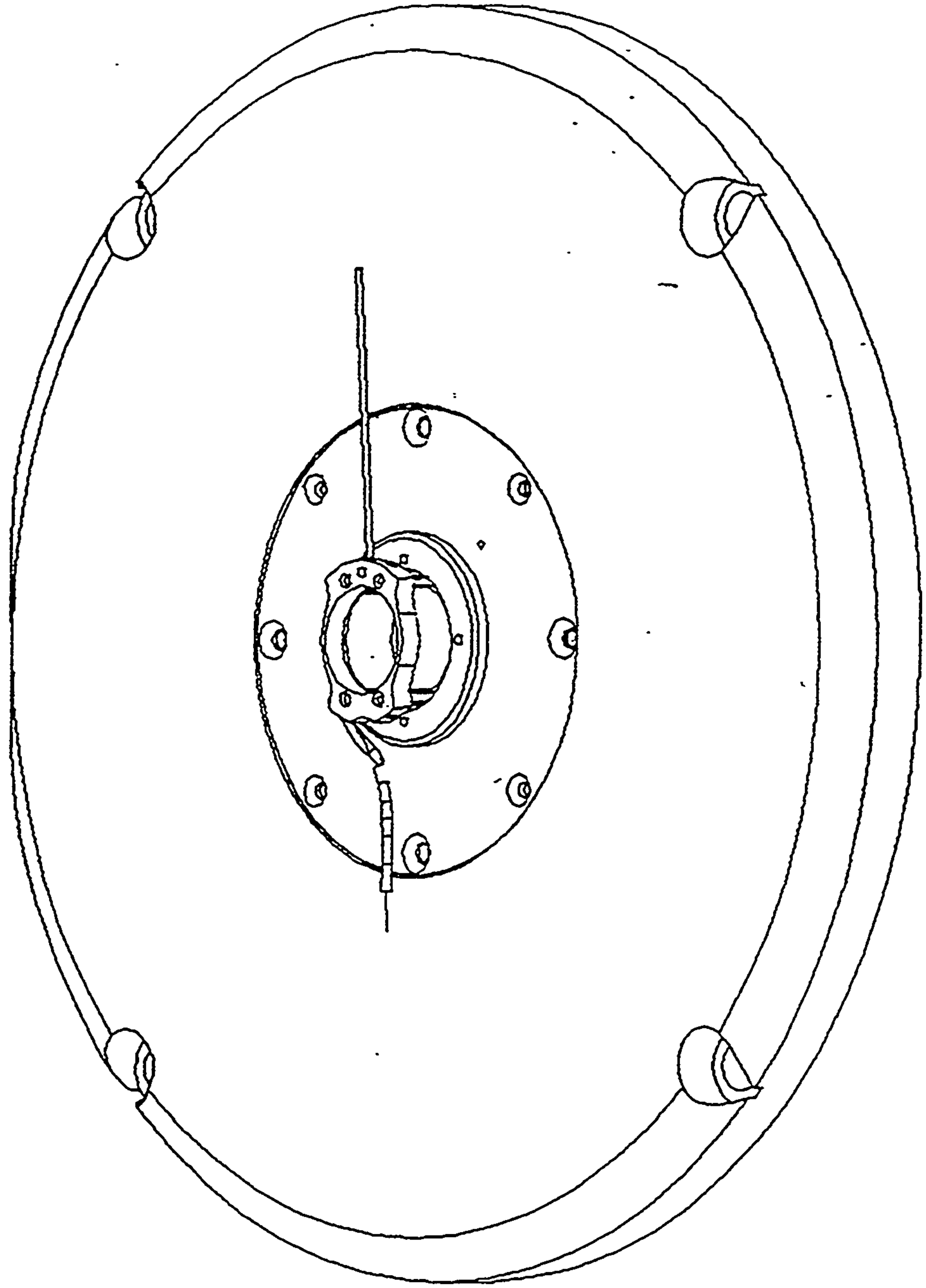
Plasma grid heater

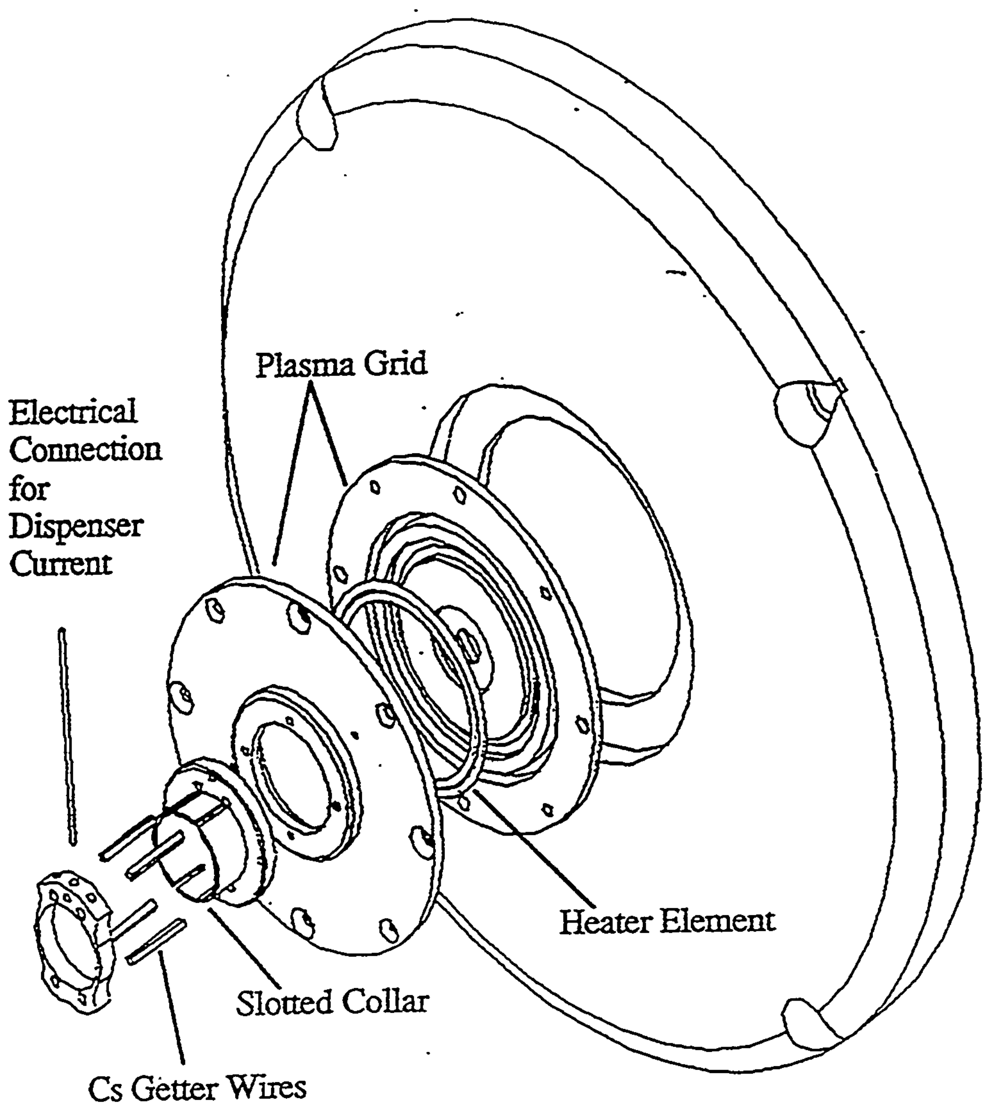
-we placed a heater wire in the base of the plasma grid insert. 56 W of power (up to 8 Amps at 7 Volts)

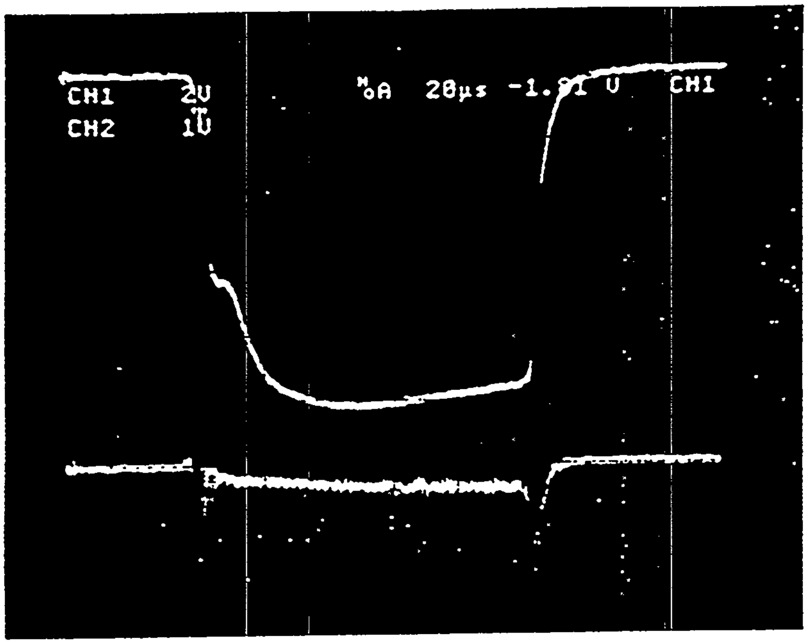
-This arrangement allowed us to control the collar temperature independent of Cs dispensing and gave us better control over the source operation.

Cs dispenser current of 40 Amps and grid heater current of 8 Amps.

- H^- current 102 mA and with 125 mA electrons
- the electron current to H^- ratio was close to unity
- maintained an H^- current of 100+ mA for 40 minutes before the heater element failed




Plasma Grid
Electrical Connection for Dispenser Current
Heater Element
Slotted Collar
Cs Getter Wires



TOP TRACE : H^- 20mA /DIV

BOTTOM TRACE : ELECTRONS 500mA/DIV

Plasma grid heater

- A two turn heater element to supply up to 100 W of power (up to 7.5 Amps at 13.3 Volts) to the plasma grid insert and collar assembly.

- reduced the thermal contact between the plasma grid insert and the plasma grid.

- By first applying high currents (30-40 A) to the Cs dispenser wires for a short period of time, we introduced Cs in the area of interest.

- By controlling the plasma grid temperature independently we could control the Cs coating in the collar area which gave us very good control over H^- production.

With this change, achieving beam currents of 50-60 mA were routine and quick (within 30 minutes) every day.

New Mode of Operation

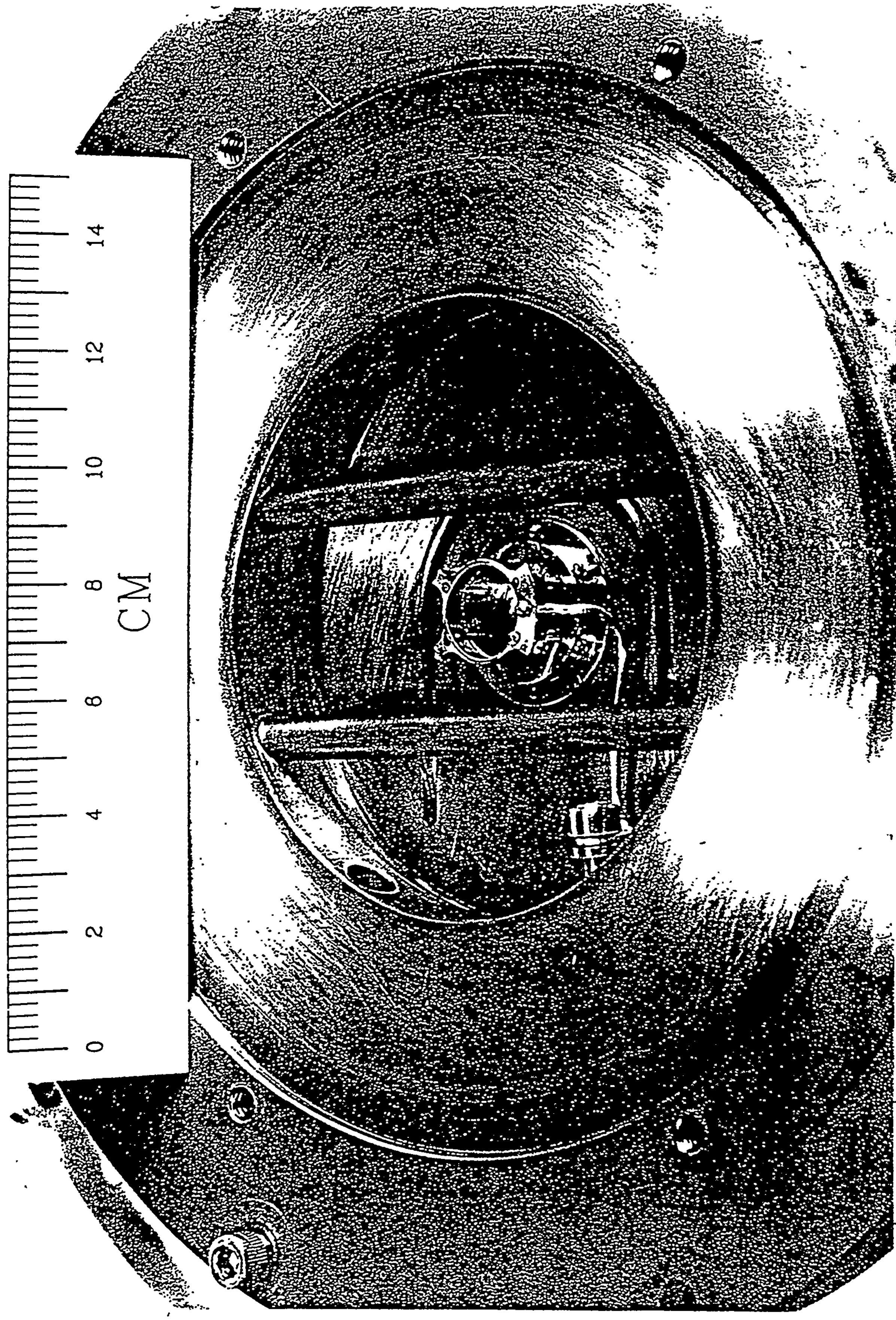
- We realized an H^- beam enhancement by using only the plasma grid heater. (only a trace amount of cesium is required for H^- enhancement)
- the initial start up was somewhat slower ($\geq$ 1 hrs)
- longer operational lifetime since we did not release excess Cs into the source.

-The H^- current enhancement was controlled by the plasma grid heater current which in turn regulated the collar area temperature and Cs dispensing rate.

At heater current of 3.5 A,

- We maintained the 60+ mA (70+ at max RF power) operation, with e/H^- ratio < 10

We repeated this type of operation for 13 consecutive days.


0 2 4 6 8 10 12 14
CM

Final Set-up

To provide more cesiation at lower temperatures:

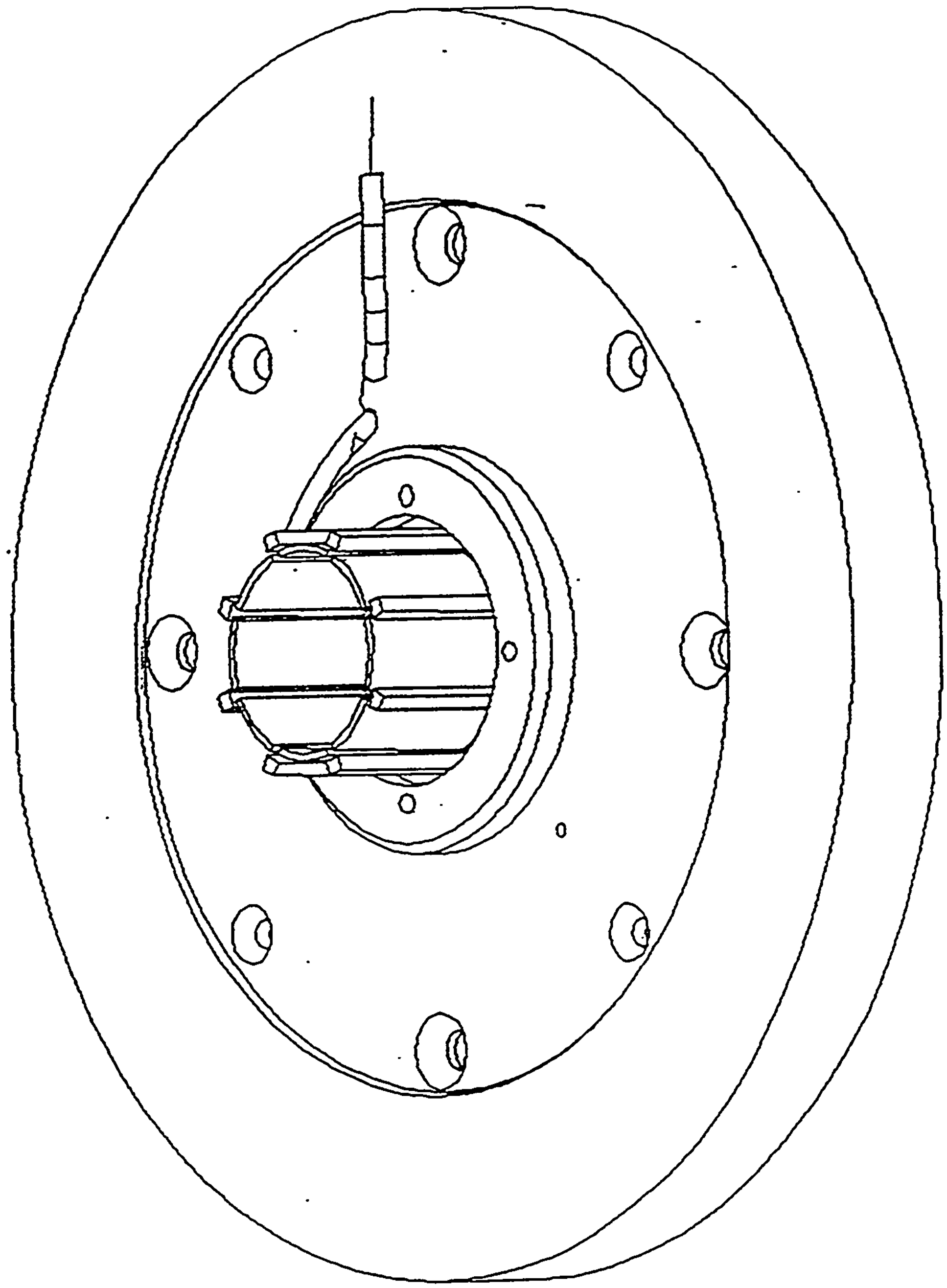
-we modified the collar assembly to provide for eight Cs getter wires
-removed the now unnecessary Cs dispenser power connections

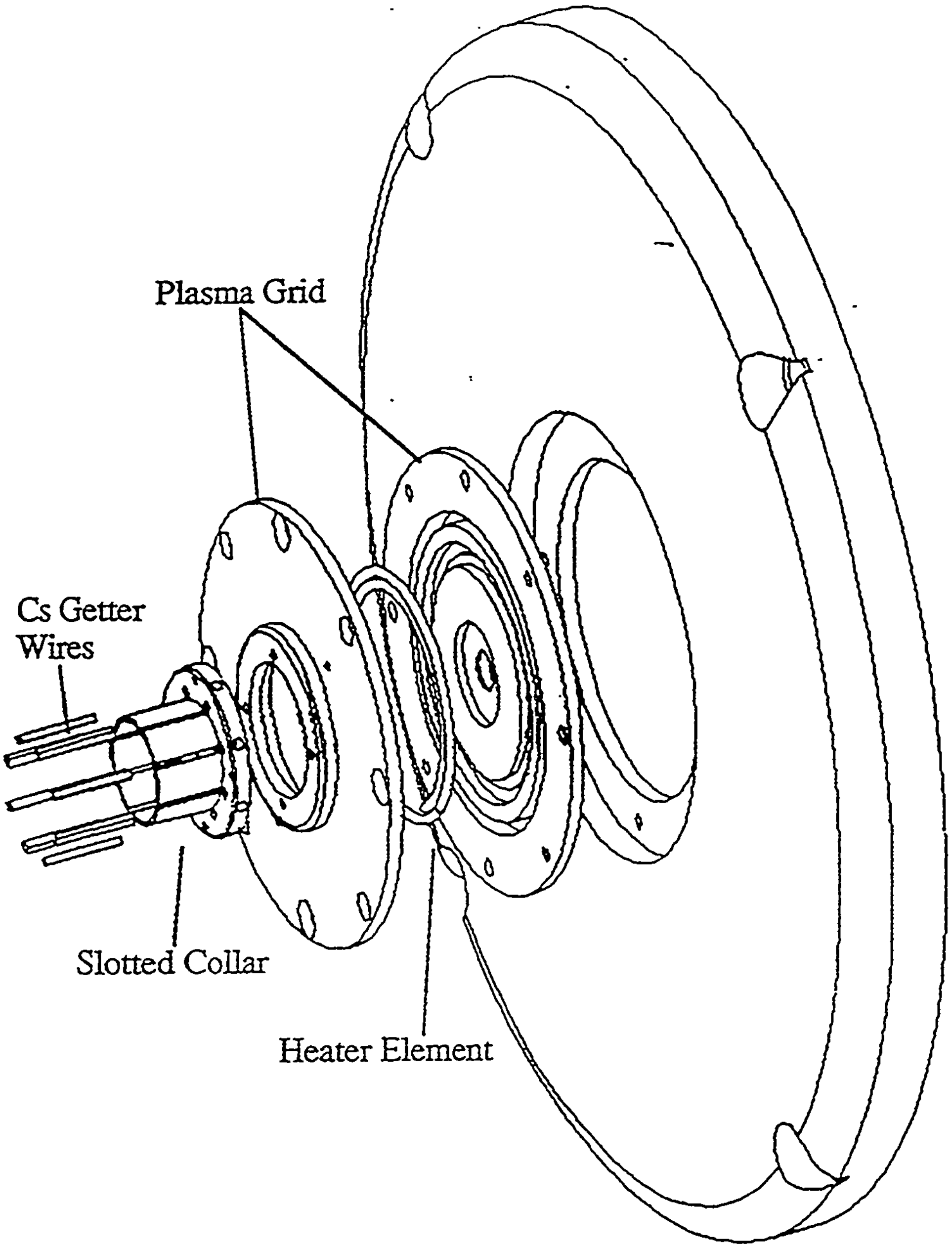
Plasma grid heater @ 3.5 A
60 mA of H^- current (500 mA electrons) in approximately one hour.

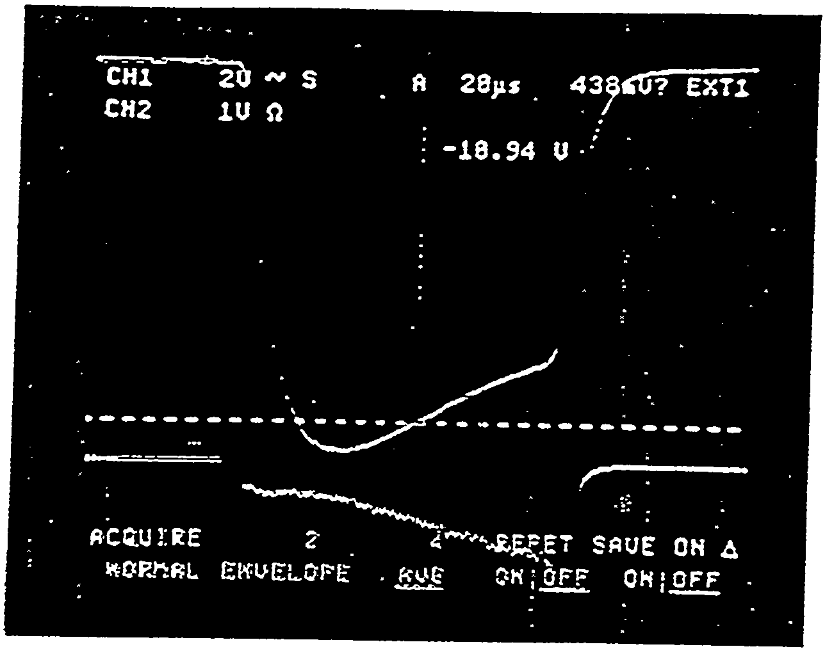
plasma grid heater @ 5 A
109 mA of H^- current with an e/H^- ratio of approximately 2:1

We experimented with this setup for 5 consecutive days,
-we were able to achieve 60 mA operation within 1/2 hour
- over 70 mA every day,
- over 80 for 3 days
- over 90 for 2 days.

- we could arbitrarily choose between these current ranges as an operating point. Setting the plasma grid heater current at 5 - 5.5 A would allow sufficient Cs to dispense to reach the desired range. Once at the chosen H^- current, reducing the heater current to approximately 4.5 A would maintain that range.




Plasma Grid
Cs Getter
Wires
Slotted Collar
Heater Element



TOP TRACE : H⁻ 20mA/DIV
BOTTOM TRACE : ELECTRONS 500mA/DIV

Emittance Measurements

at 6 cm downstream of the extraction aperture

uncesiated source

30 mA H^- beam @ 35 keV (electron current of 750 mA)
- small (0.5-0.6 cm radius),
- low divergence (100 mrad envelope divergence),
- εt-n-rms = 0.09-0.10 π mm-mrad
- εt-n-rms = 0.06 π mm-mrad in the presence of Xe

cesiated source

70 mA H^- @ 35 keV beam (electron current of 700 mA)

- radius = 0.8-0.9 cm
- envelope divergence = 150 mrad
- εt-n-rms = 0.11- 0.12 π mm-mrad.

Emittance Measurements

cesiated source

91 mA H^- @ 35 keV beam (electron current of 500 mA) is somewhat elliptical.

In the horizontal plane:

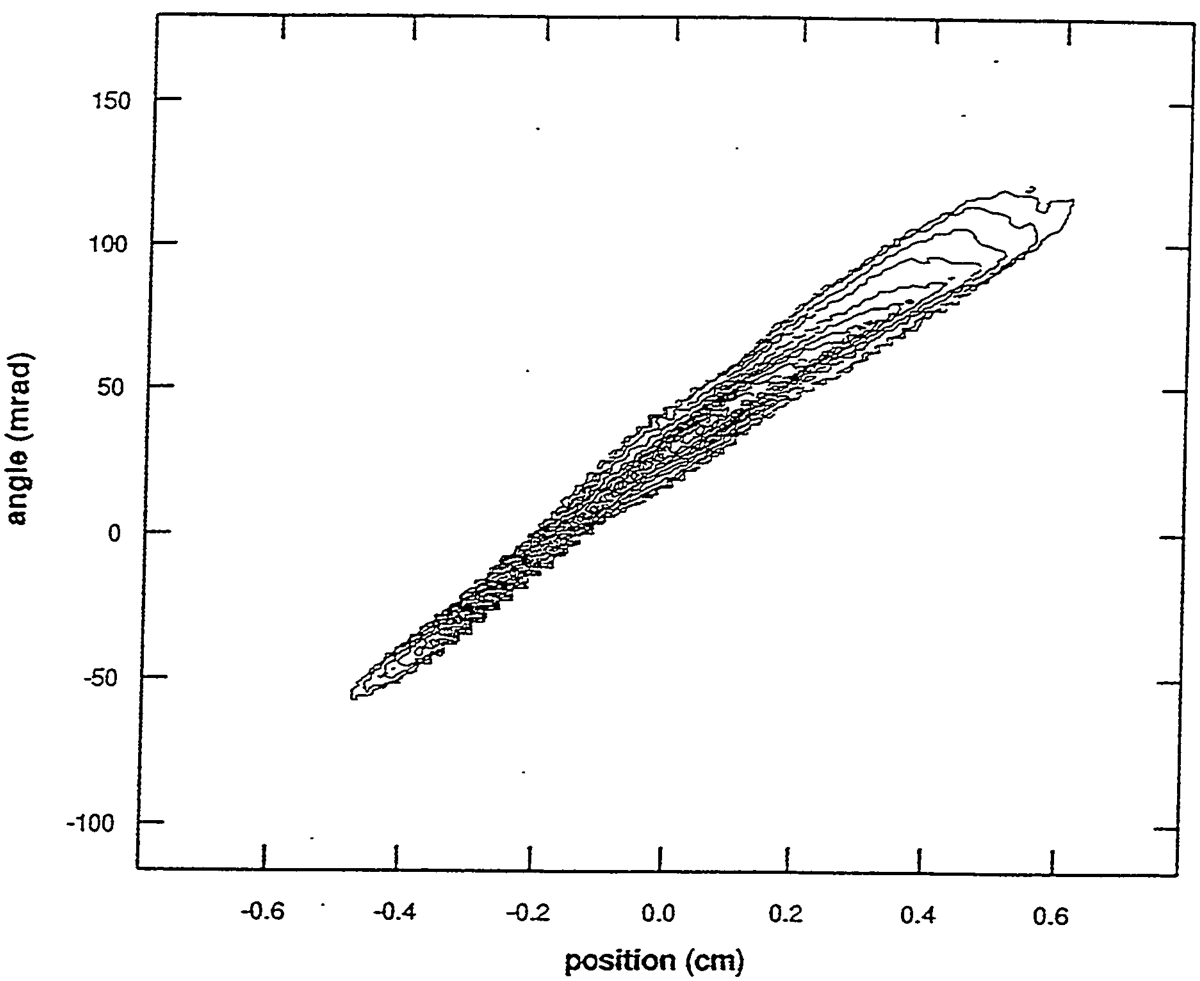
- radius = 1.0 cm
- envelope divergence = 180 mrad
-ε_x-n-rms = 0.14 π mm-mrad.

In the vertical plane:

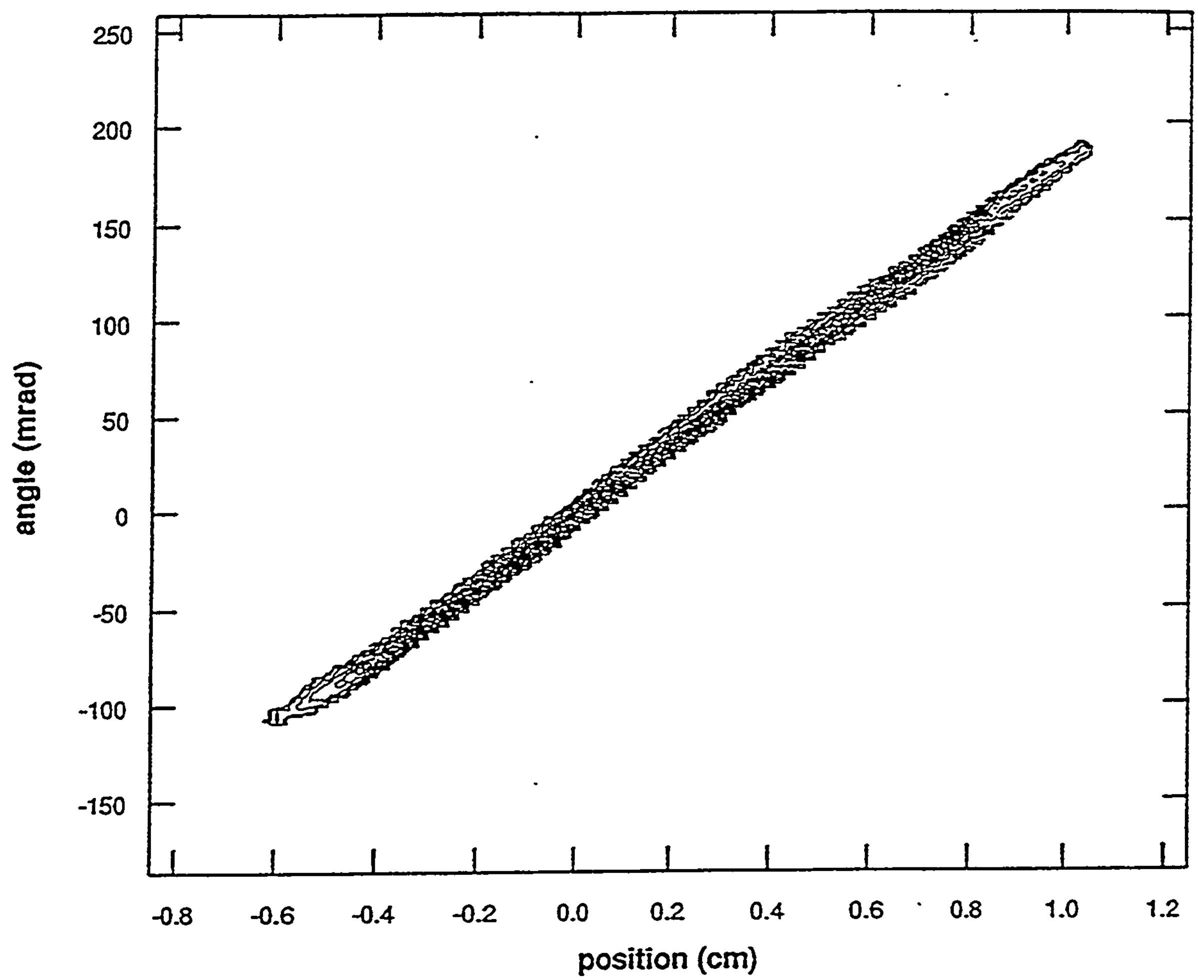
- radius = 0.8 cm
- envelope divergence = 150 mrad
-ε_y-n-rms = 0.11 π mm-mrad.

- 20% to 40 % emittance growth relative to the uncesiated source.
-expect improved beam quality with further optimization of extraction optics.

poct211556y.rea run Wed Oct 12 08:30:42 1994



paug161331y.rea run Wed Oct 12 09:15:12 1994



Repeatability and lifetime

Under the constraint of working five days per week, eight hours per day, we routinely operated at stable and high currents ($H^- > 50$ mA) for more than a month.

H^- currents > 60 mA for as many as 7 consecutive days,

H^- currents > 70 mA for as many as 11 days,

H^- currents > 80 mA for at least 4 days.

The electron to H^- current ratio was also down, ranging between 2-10.

Conclusion

With the dispensing mechanism described in this paper, the enhancement of beam current from the introduction of only a trace amount of cesium is quite remarkable.

We could quickly achieve and maintain high H^- currents (100+ mA).

This enhancement in H^- beam current is accompanied by a dramatic reduction of electron current.

to extract the maximum H^- current, a plasma grid bias voltage of order of -10 to -15 volts is required, instead of usual -2 to -5 volts, in agreement with previous report.

This enhanced, very reliable, source is a strong candidate for high current H^- accelerators.

Volume H^- Sources for ESS

K. Volk

U. Frankfurt

Volume H^- sources for ESS

K. Volk
A. Lakatos
A. Maaser
(M. Weber)

presented by:
K. Volk
Universität Frankfurt
Institut für Angewandte Physik

Berkeley / USA
October 1994

Negative ion production

negative ions are made by:

dissociative recombination

$$e^- + H_2^+ \rightarrow H^- + H^+$$

dissociative attachment

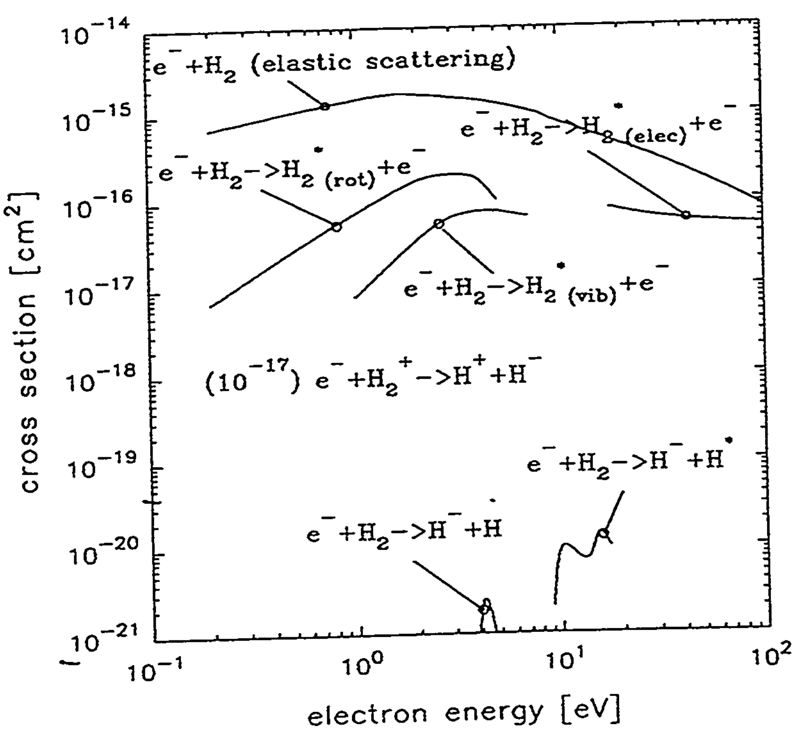
1. step $e^-_{fast} + H_2(\nu=0) \rightarrow H_2(\nu>0) + e^-$
2. step $e^-_{slow} + H_2(\nu>0) \rightarrow H^- + H$

$$e^- + H_2 \rightarrow H^- + H^*$$

$$e^- + H_2 \rightarrow H^- + H$$

polar dissociation

$$e^- + H_2 \rightarrow H^- + H^+ + e^-$$



Negative ion destruction

negative ions are destroyed by:

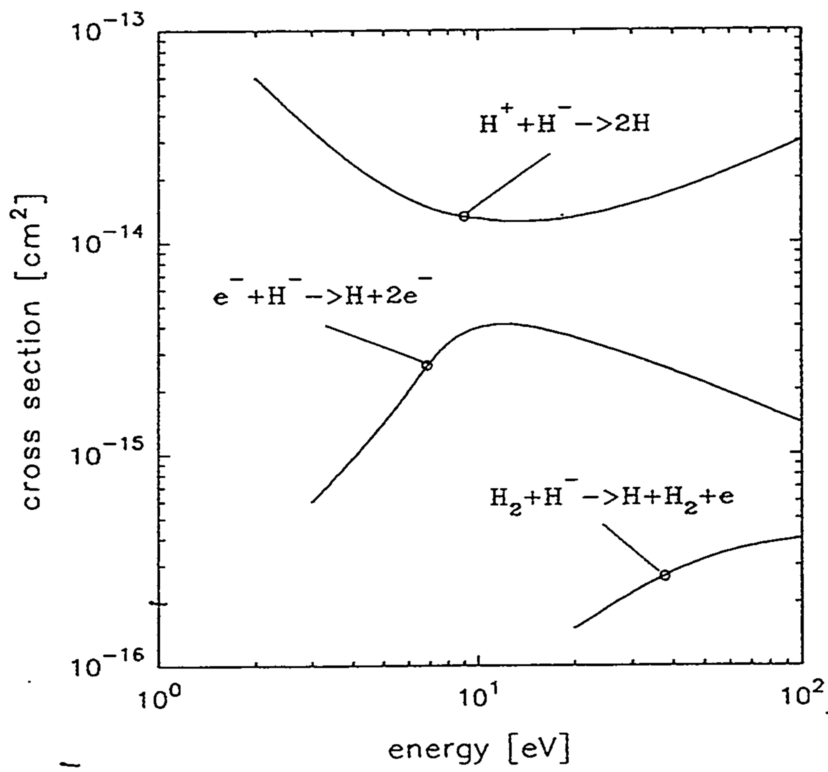
ion-ion recombination

$$H^+ + H^- \rightarrow 2H$$

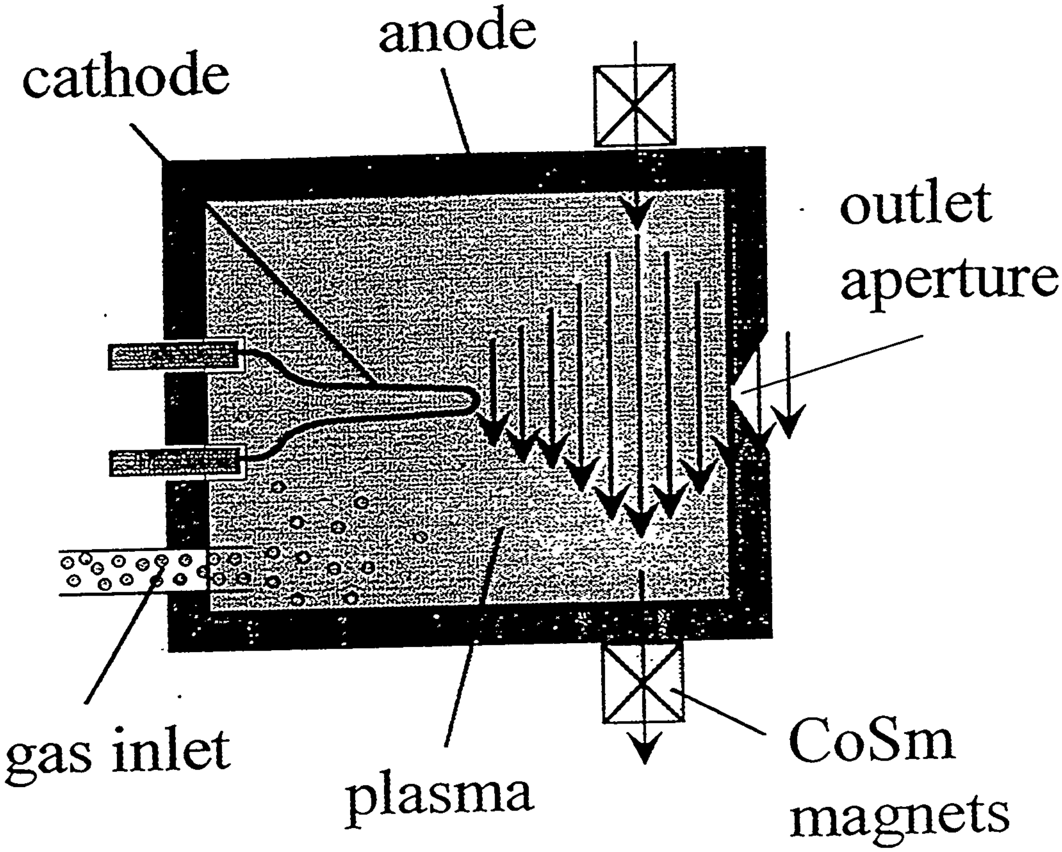
collisional recombination

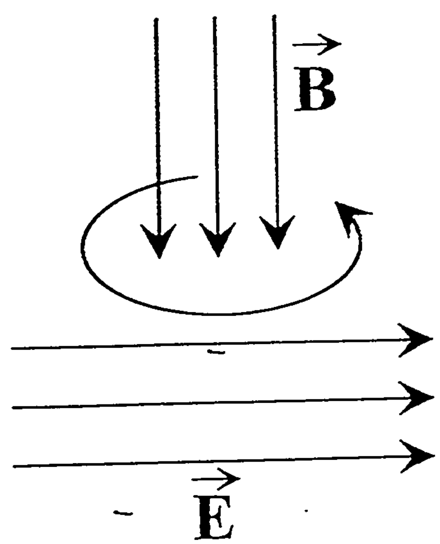
$$e^- + H^- \rightarrow H + 2e^-$$

$$H_2 + H^- \rightarrow H + H_2 + e$$



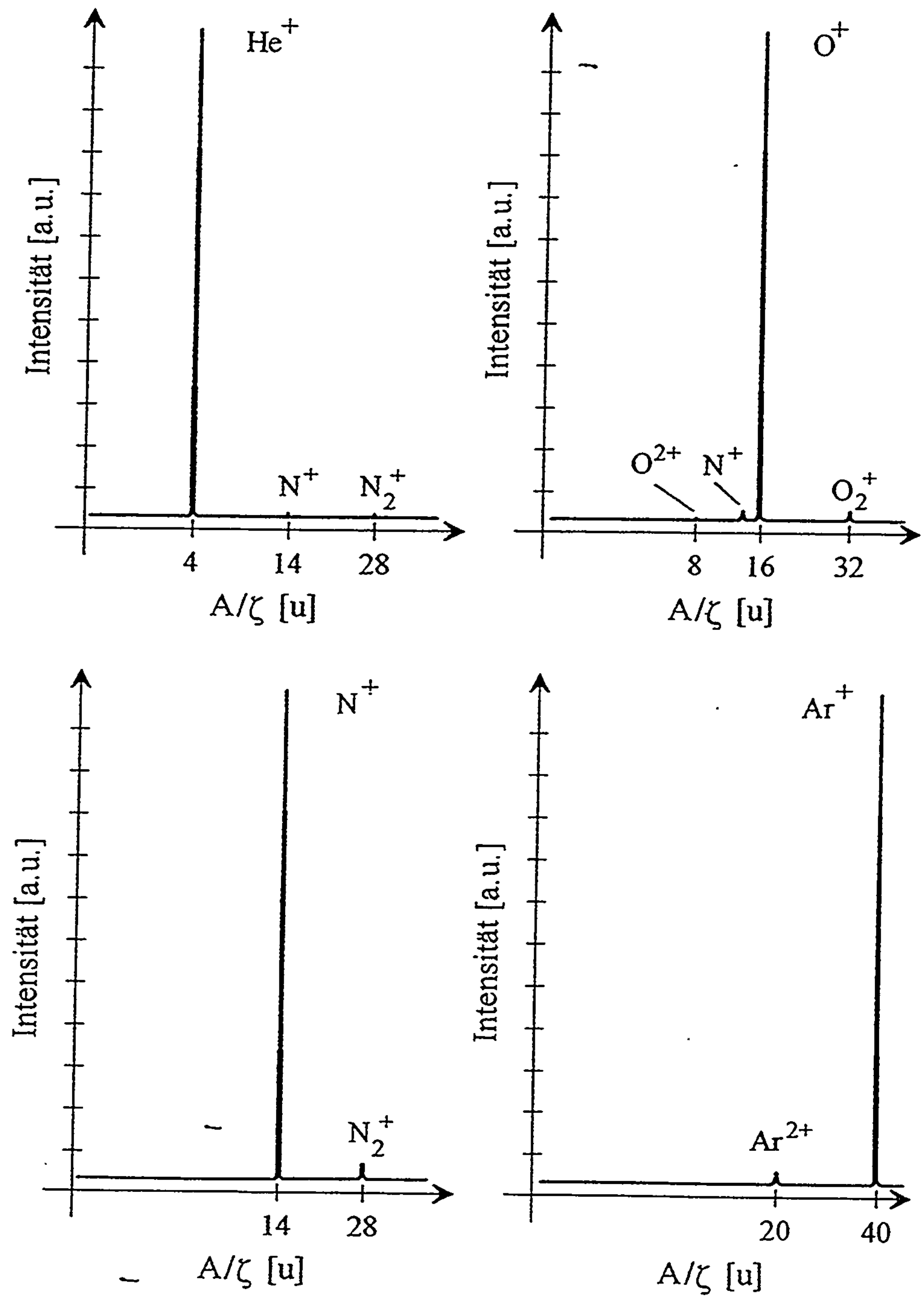
Principle of the magnetic filter





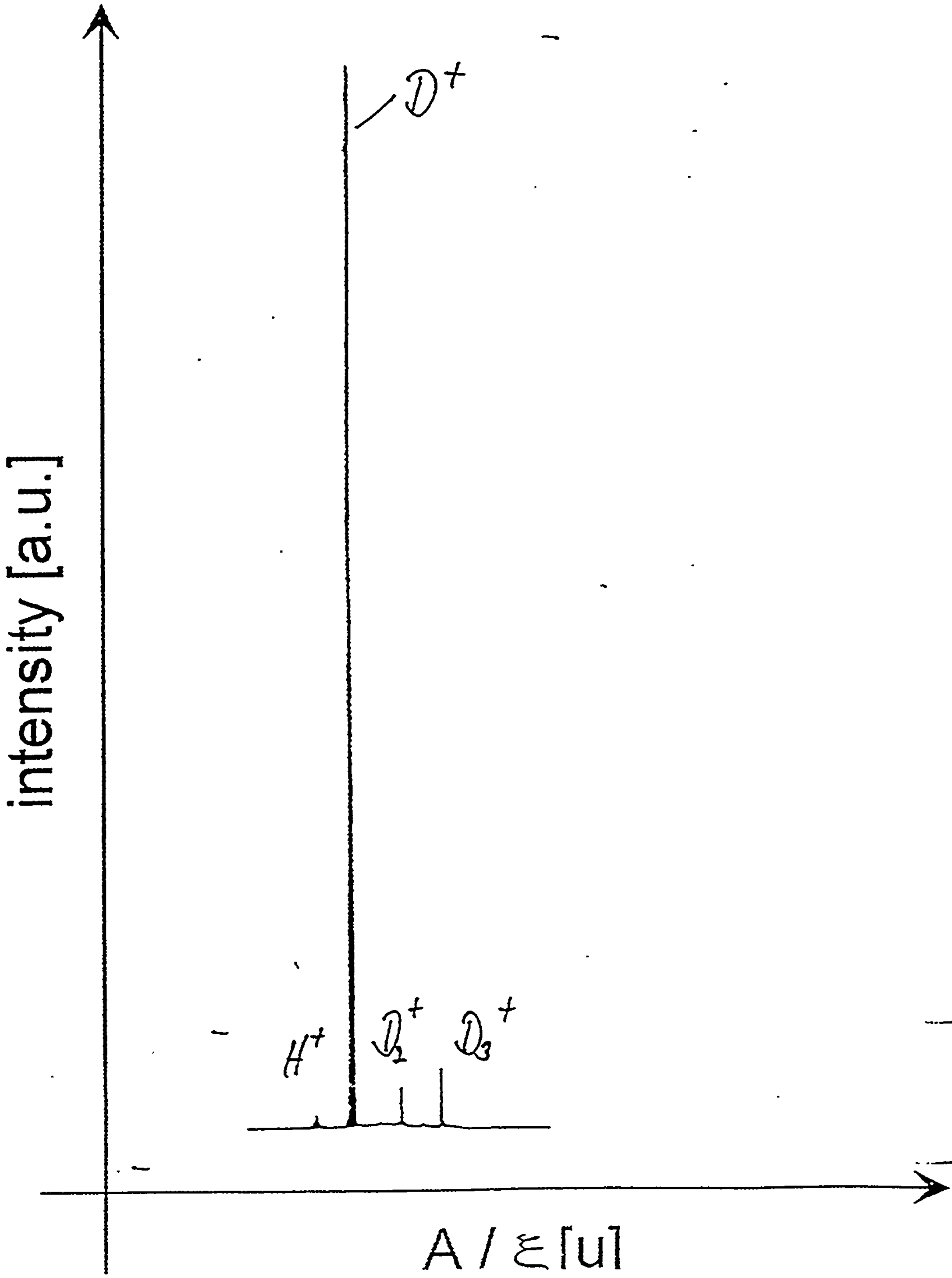
$$eU = -e \int \vec{E}\, \vec{ds}$$

Mass charge spectra of the HIEFS

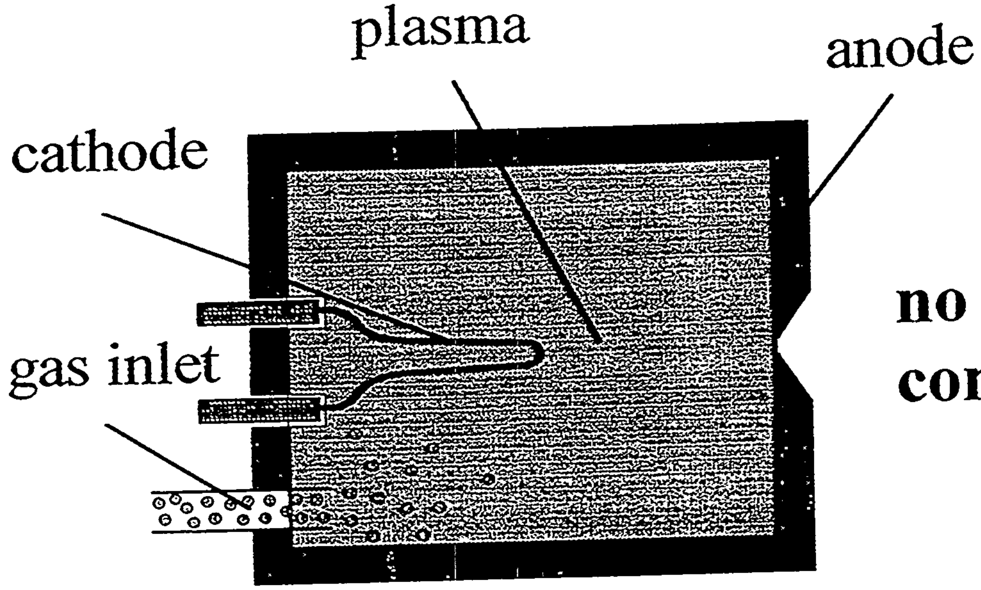


D^+ spectra

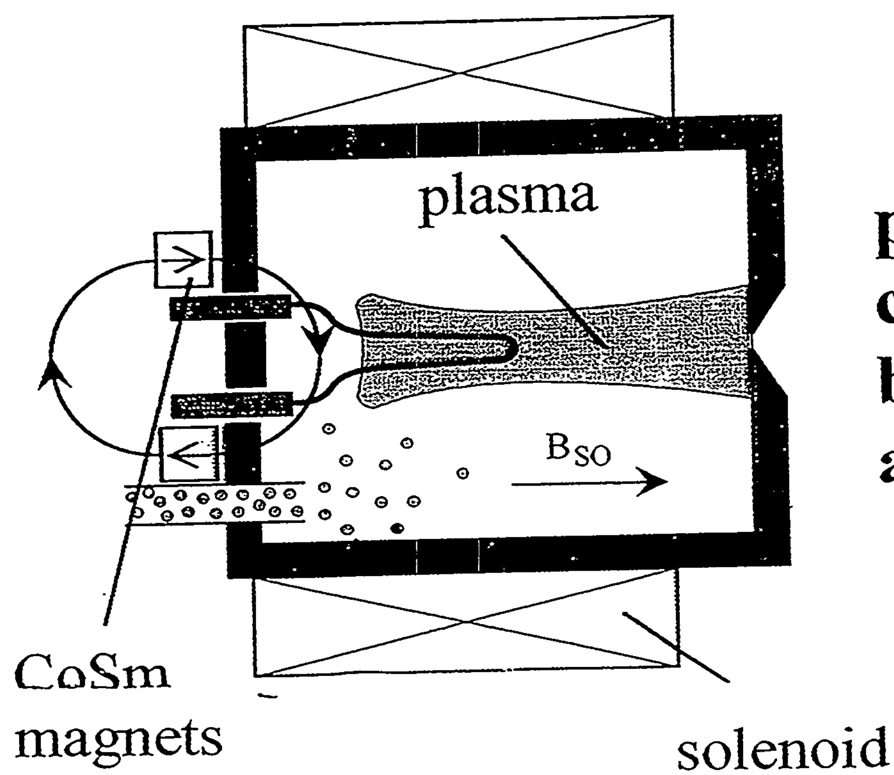
$U_{EX} = 20kV \quad I_{EX} = 20mA$



Principle of the plasma confinement

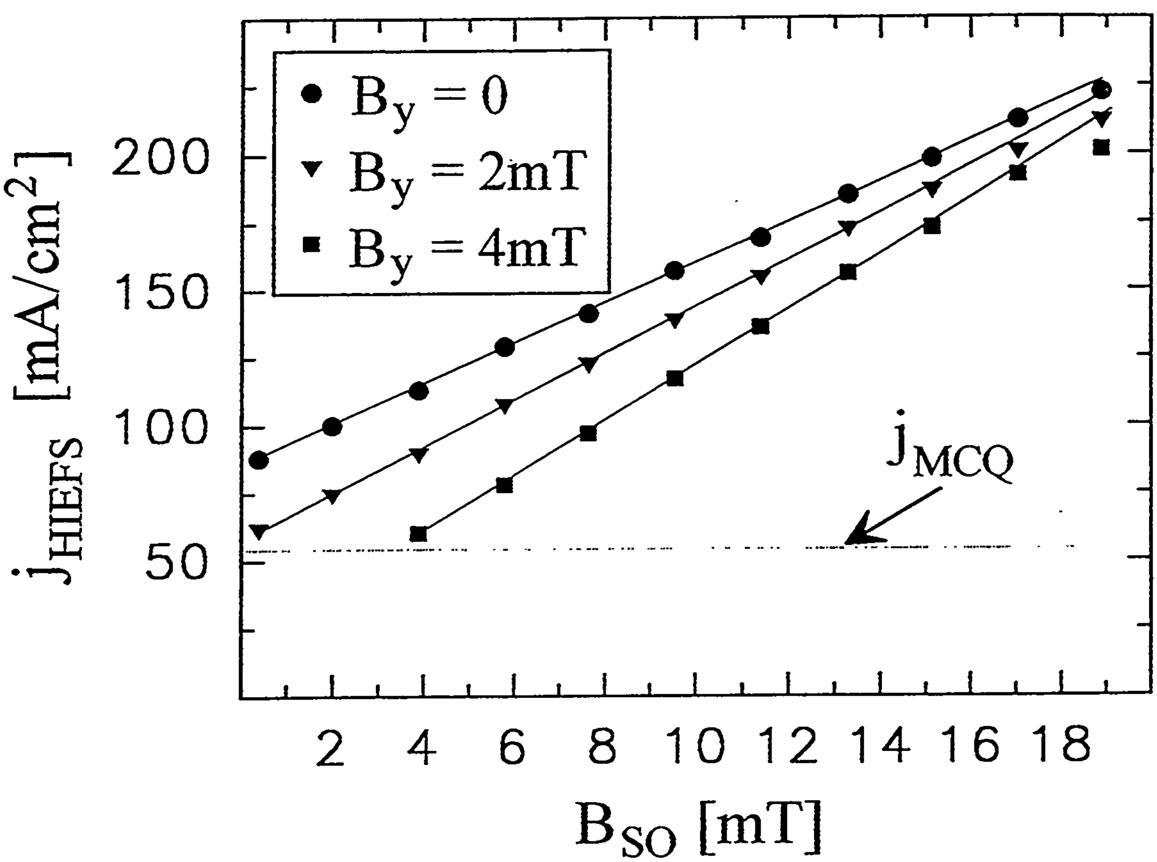


no plasma confinement

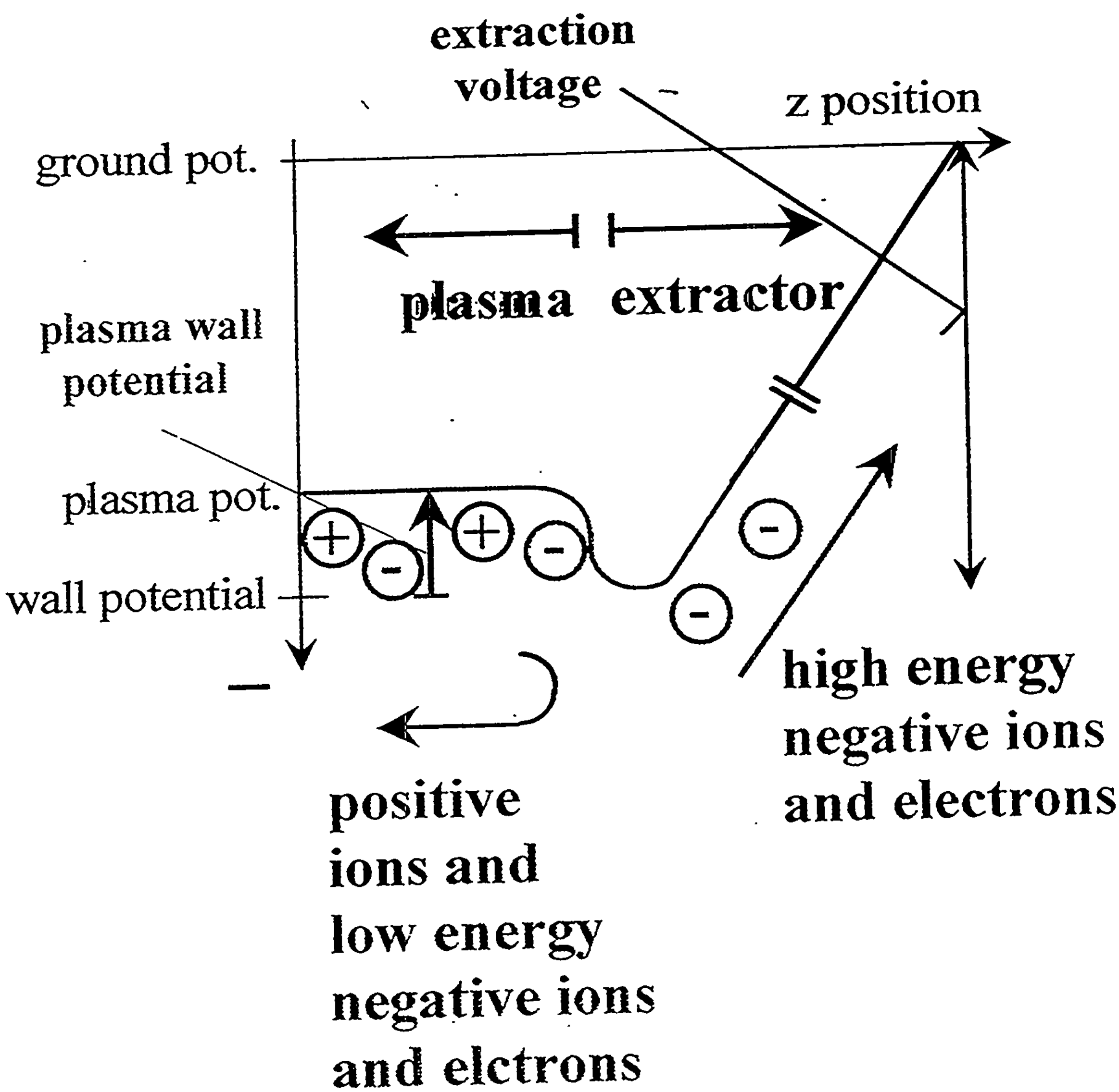


plasma confinement by means of a solenoid

Extracted current density of the HIEFS as function of the longitudinal field strength

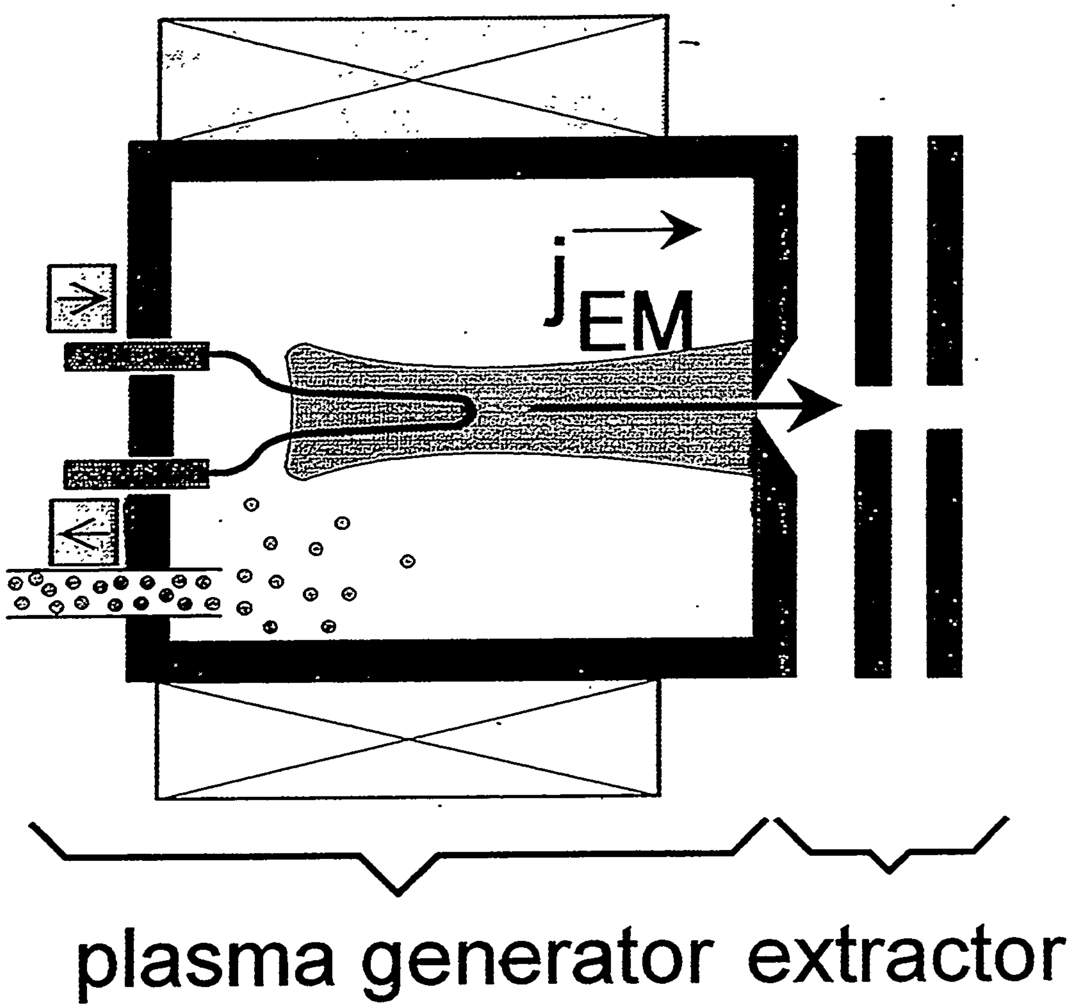


Principle of negative ion extraction



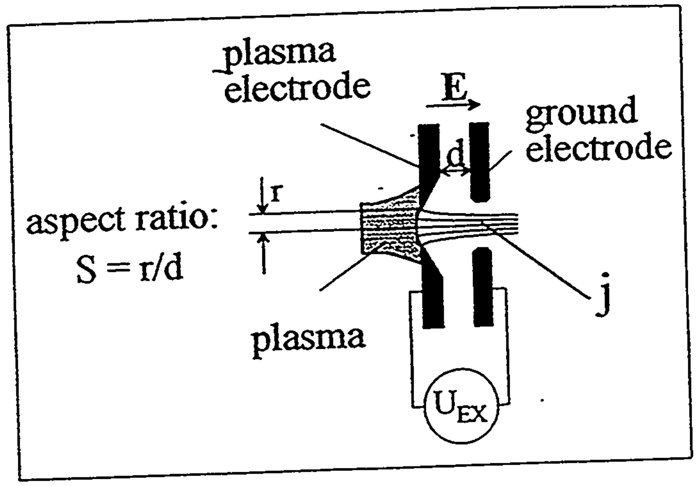
not scaled !

Emission current density



$$j_{EM} = e\, n_I\, v_I$$

Maximum current density at ion sources with triode extraction systems



Child-Langmuir:

$$j_{CL} = 4/9\ \varepsilon_0 \sqrt{\frac{2e\zeta}{m}} \sqrt{\frac{S}{r}}\ E^{3/2}$$

R. Keller:

$$j_K = 4/9\ \varepsilon_0 \frac{0{,}279}{(1+3S^2)} \sqrt{\frac{2e\zeta}{m}} \sqrt{\frac{S}{r}}\ E^{3/2}$$

with: $d = 4{,}4721 \cdot 10^{-10}\ U^{3/2}$ ***(Kilpatrik),*** and with: $S = 0{,}58$

$$j_K = \frac{98\text{mA}}{\text{cm}} \sqrt{\frac{\zeta}{A}} \frac{\mathbf{1}}{\mathbf{r}} \qquad [\text{mA/cm}^2]$$

$[r]$ = cm, $[A]$ = mass number, $[\zeta]$ = charge state

Extractions systems calculated with IGUN

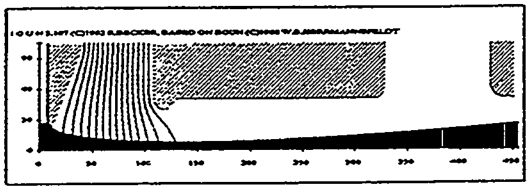
I_{H^-} [mA]	**35**	**70**	**140**
U_{EX} [kV]	**35**	**55**	**88**
P [$A/V^{3/2}$]	5.4×10^{-9}	5.4×10^{-9}	5.4×10^{-9}
r [cm]	0.25	0.4	0.63
d [cm]	0.7	1.1	1.76
S = r/d	0.36	0.36	0.36
E [kV/mm]	5	5	5
A_{EX} [cm^2]	**0.2**	**0.5**	**1.25**
j [mA/cm^2]	**178**	**140**	**112**

It should be:

$$j_{EM} \geq j_{CL\,(max)}$$

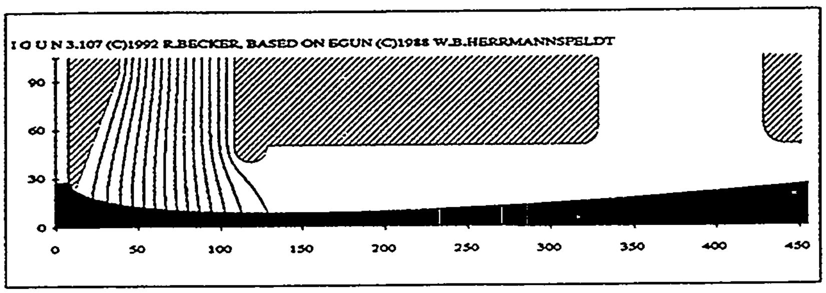
Beam formation in the extractor

$U_{EX} = 35kV$ $I_{EX} = 35mA$ $j = 178mA/cm^2$

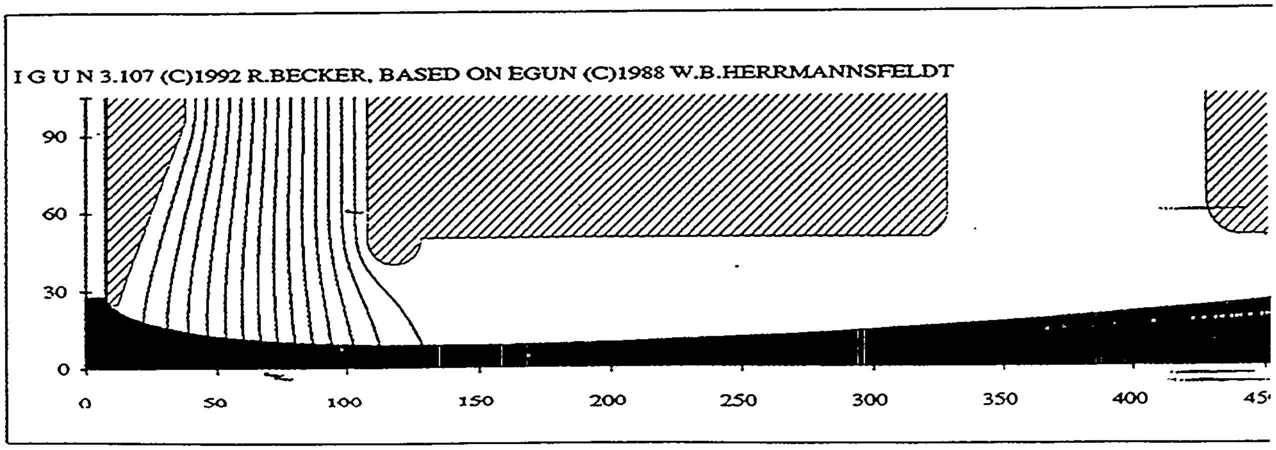


2,5cm

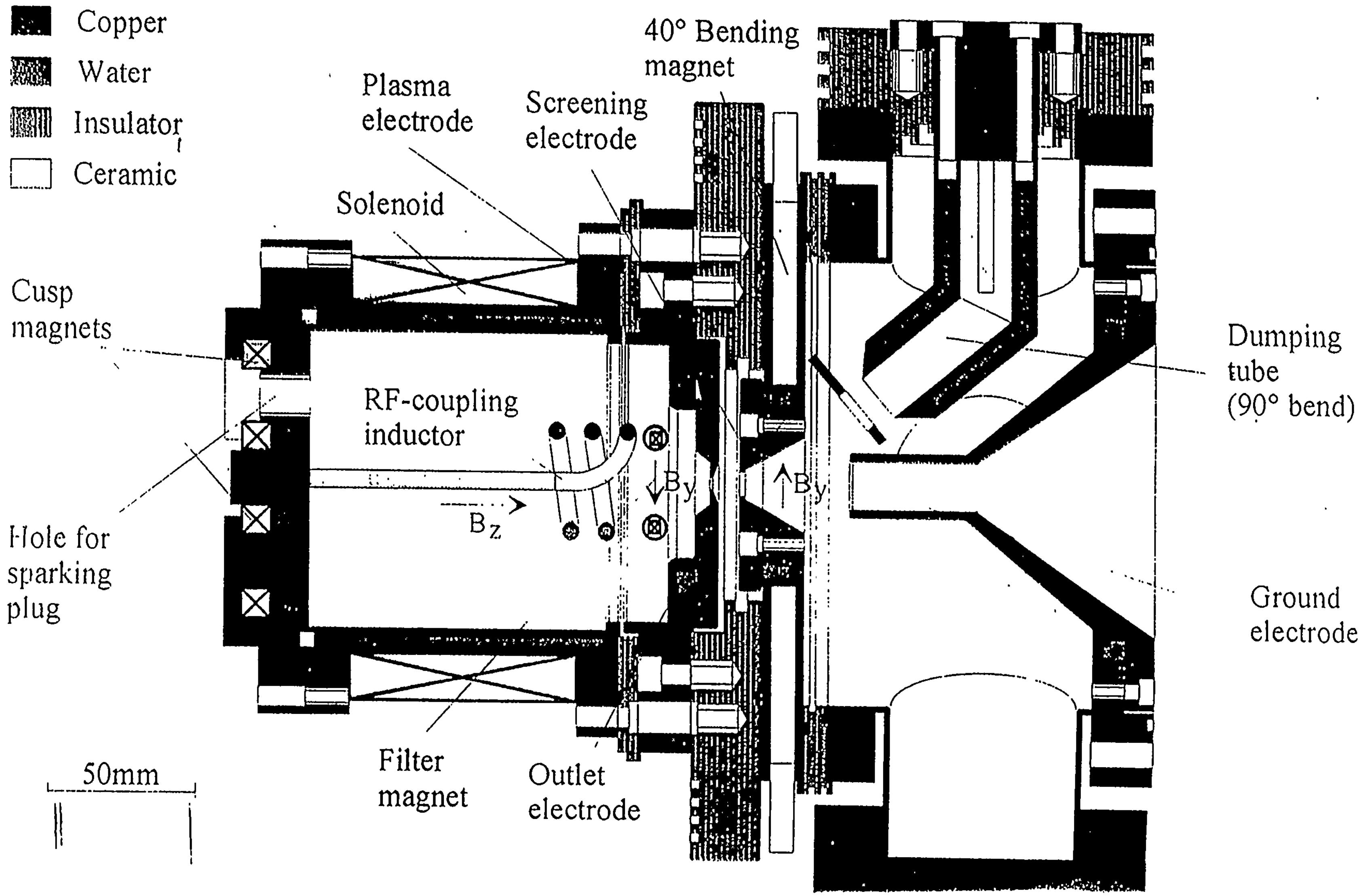
$U_{EX} = 55kV$ $I_{EX} = 70mA$ $j = 140mA/cm^2$



$U_{EX} = 88kV$ $I_{EX} = 140mA$ $j = 112mA/cm^2$



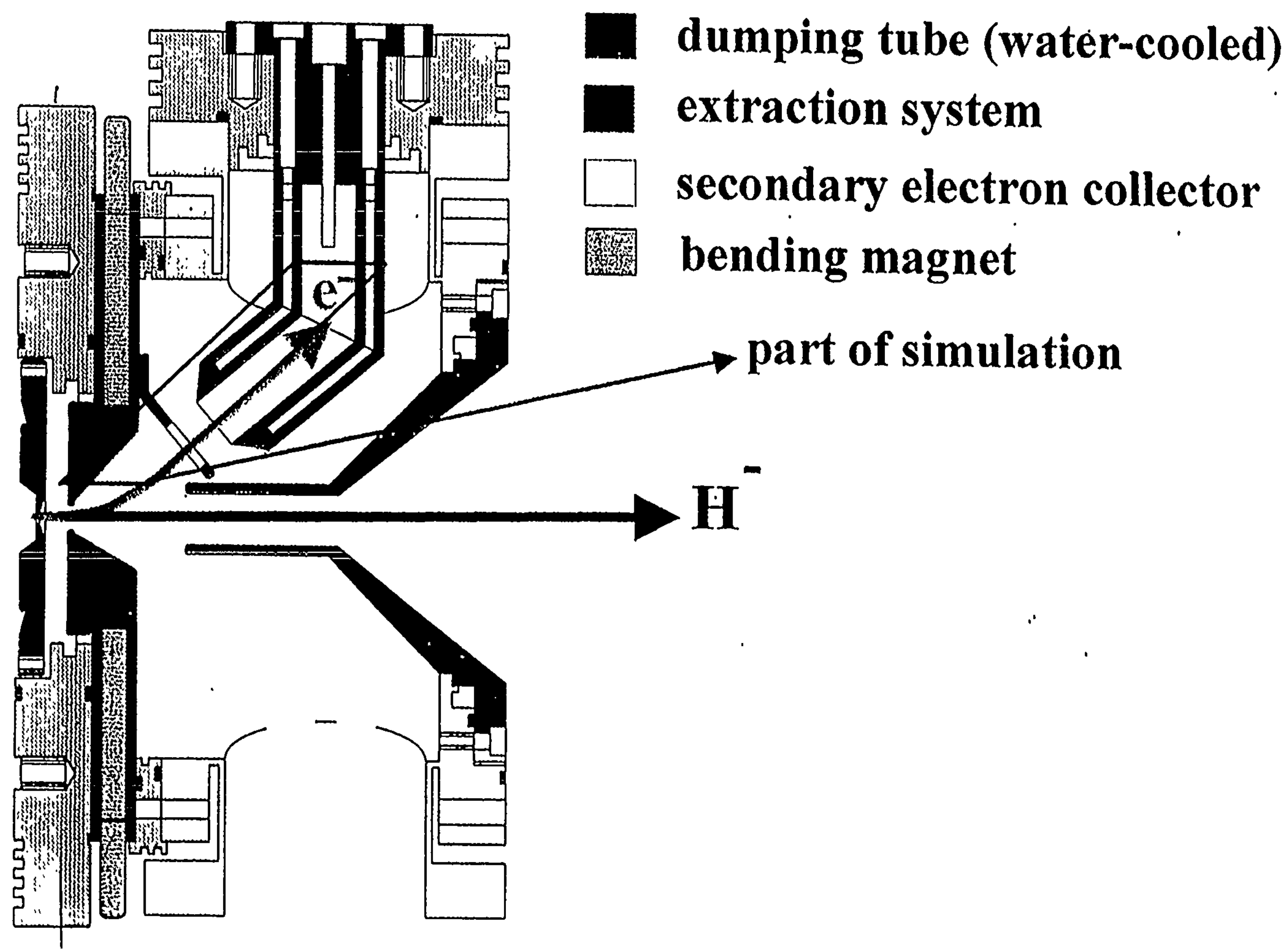
Schematic drawing of the H^- source



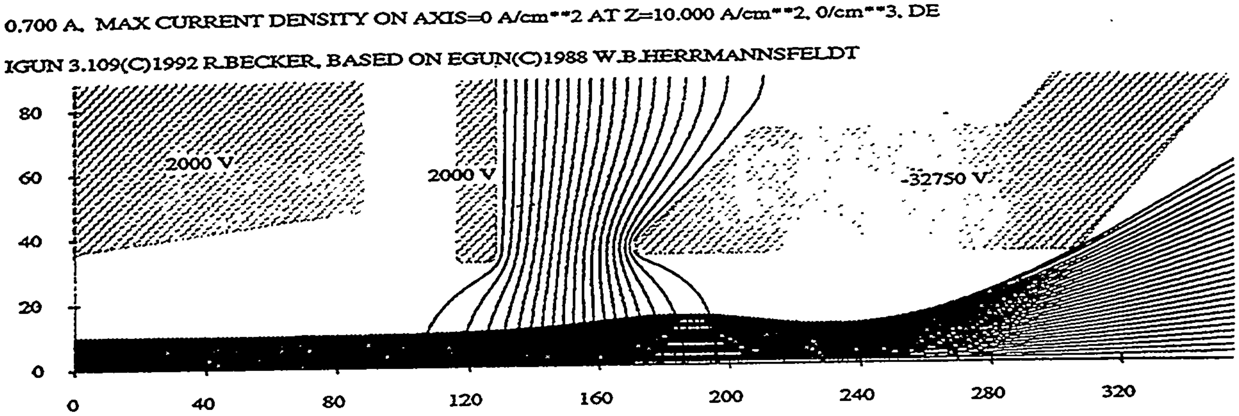
Institut für Angewandte Physik, Universität Frankfurt

A. Lakatos

Schematic drawing of the dumping system



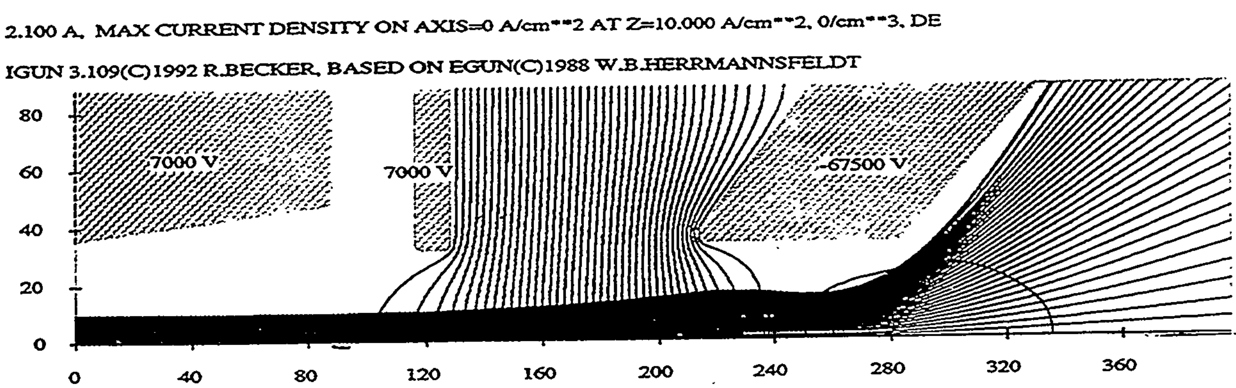
Electron trajectories in electron dump for a 700mA 35kV



1:20 700mA electron beam

ratio	kinetic energy	thermical stress [W/cm²](pulse 10%)
1:20 (0.7 A)	2250 V	22.3

and for a 2100mA 70kV



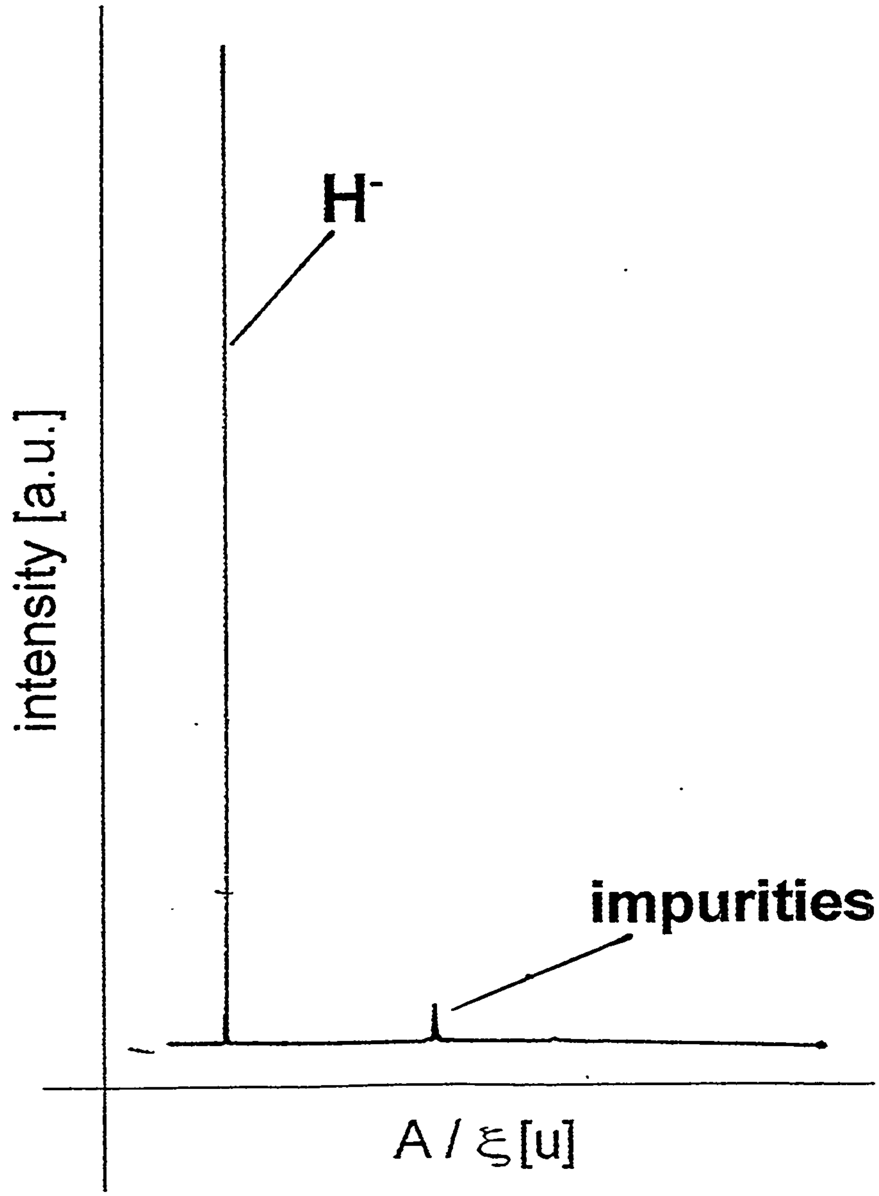
1:20 2.1A electron, beam 4 units=1mm

ratio	kinetic energy	thermical stress [W/cm²](pulse 10%)
1:20 (2.1 A)	2500 V	30.2

Our first H^- spectra

U_{EX} = 8kV

I_{EX} = 10mA



A High Brightness Hydrogen Ion Source for The BTA

H. Oguri

JAERI

A HIGH BRIGHTNESS HYDROGEN ION SOURCE FOR THE BTA

H. Oguri, Y. Okumura, J. Kusano, M. Mizumoto,
K. Hasegawa, N. Ito, M. Kawai and T. Ono

Japan Atomic Energy Research Institute

Workshop on Ion Source Issues Relevant to
a Pulsed Spallation Neutron Source
(at Berkeley)
October 25, 1994

INTRODUCTION

A hydrogen ion source has been developed for a high intensity proton linear accelerator (BTA; Basic Technology Accelerator).

The beam test was performed at an acceleration voltage of 100 kV.

Measurement

Beam Profile :	Multi-channel wire monitor
	Multi-channel calorimeter
Emittance :	Double slit system
Proton Yield :	Doppler shifted spectroscopy

DESIGN PARAMETERS

Acceleration Voltage	:	100 kV
Acceleration Current	:	120 mA
Duty Factor	:	CW
Normalized Emittance	:	0.5 πmm.mrad (100 %)
Proton Yield	:	>90 %
Impurity	:	< 1 %

FEATURE

Type : Multi-cusp Type Ion Source

Plasma Chamber

Production : Arc Discharge (Tungsten Filaments)

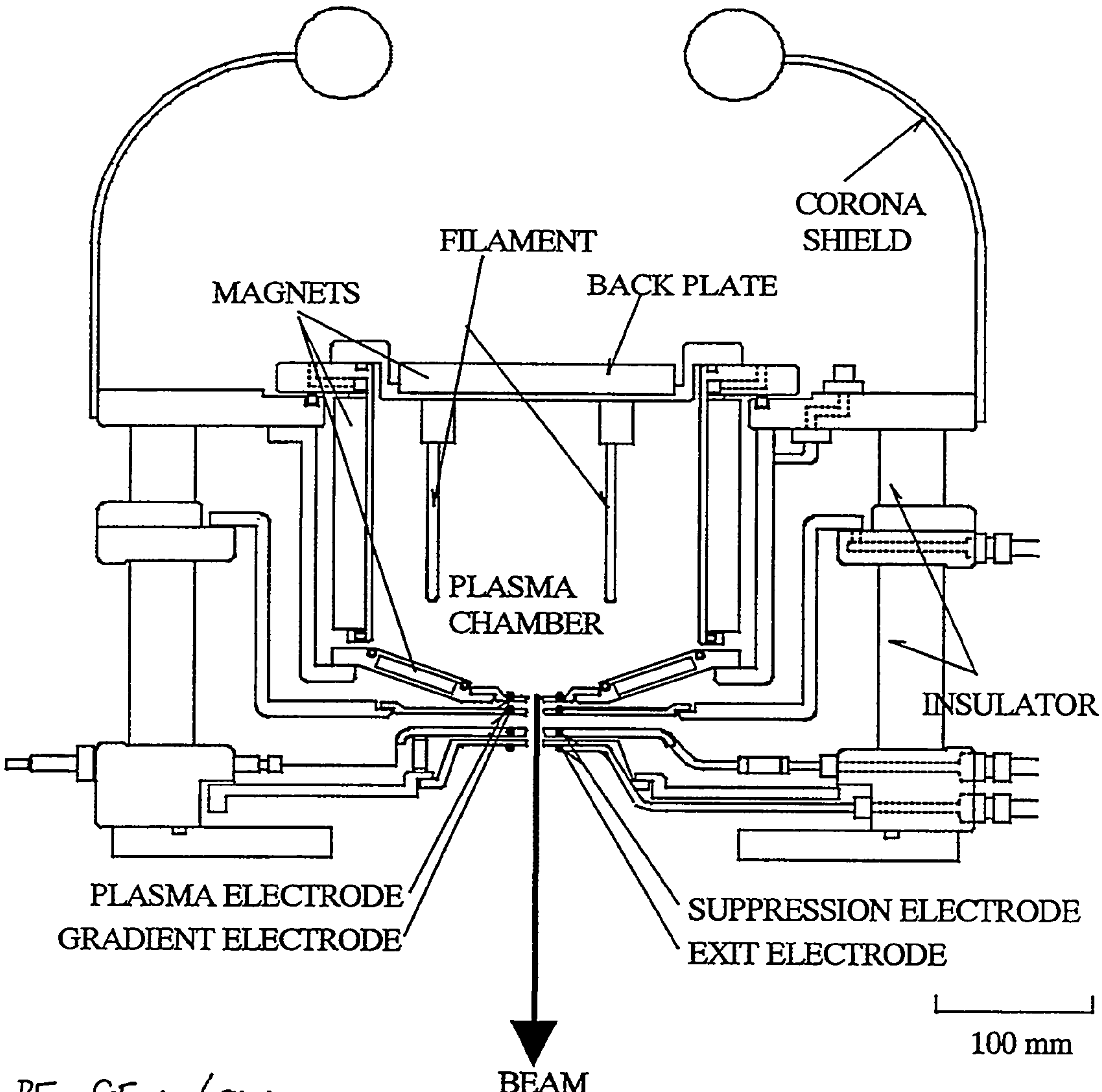
Confinement : Multicusp Magnetic Field (Permanent Magnets)

Beam Extractor

Aperture : 10 mmϕ, Single

Electrode : Two Stage Extraction System

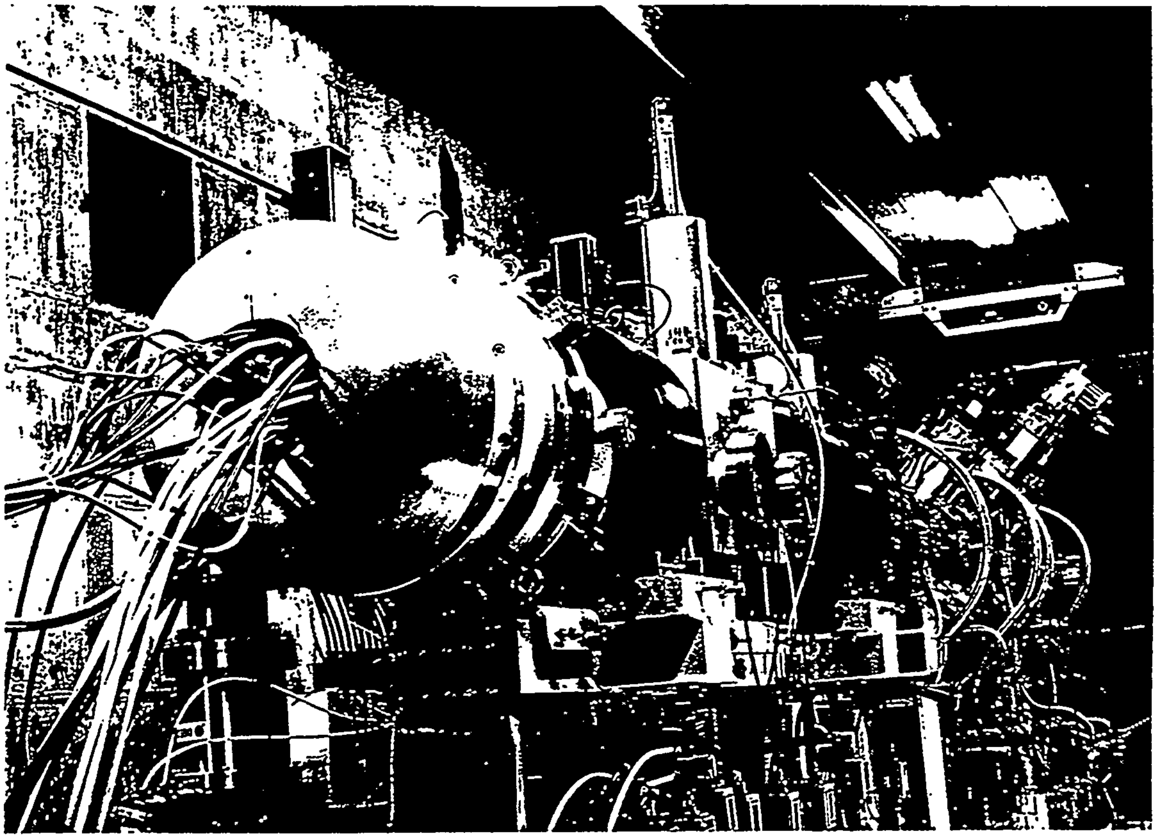
Cross sectional view

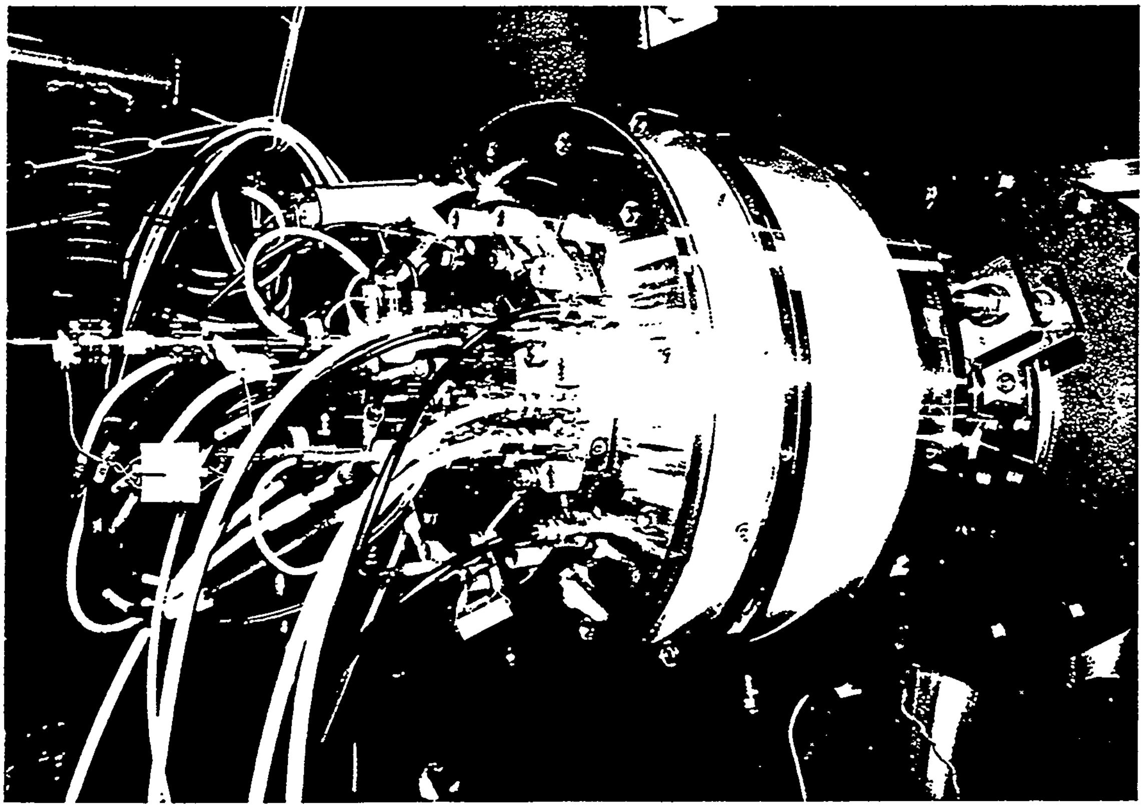


PE~GE : 6mm

GE~SE : 8mm

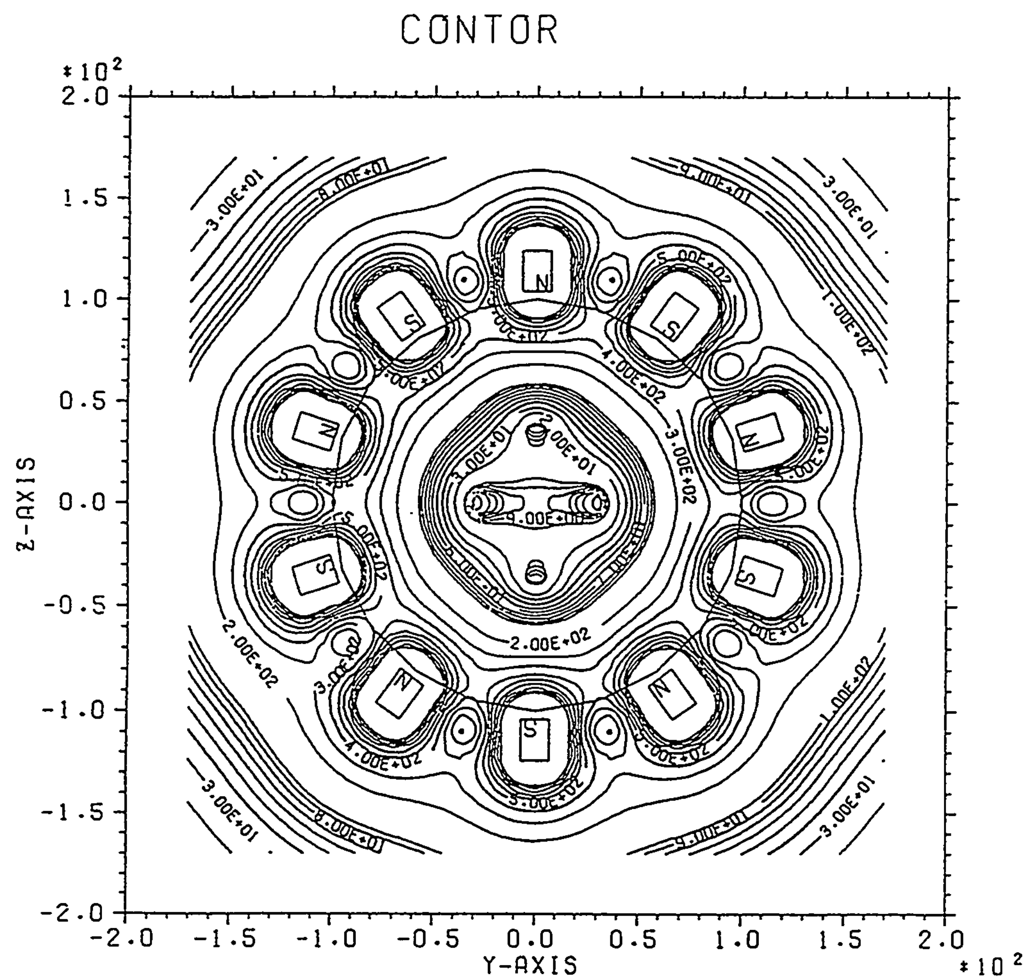
SE~EE : 2mm





Magnetic field in the plasma chamber

(Calculation result by a computer code)

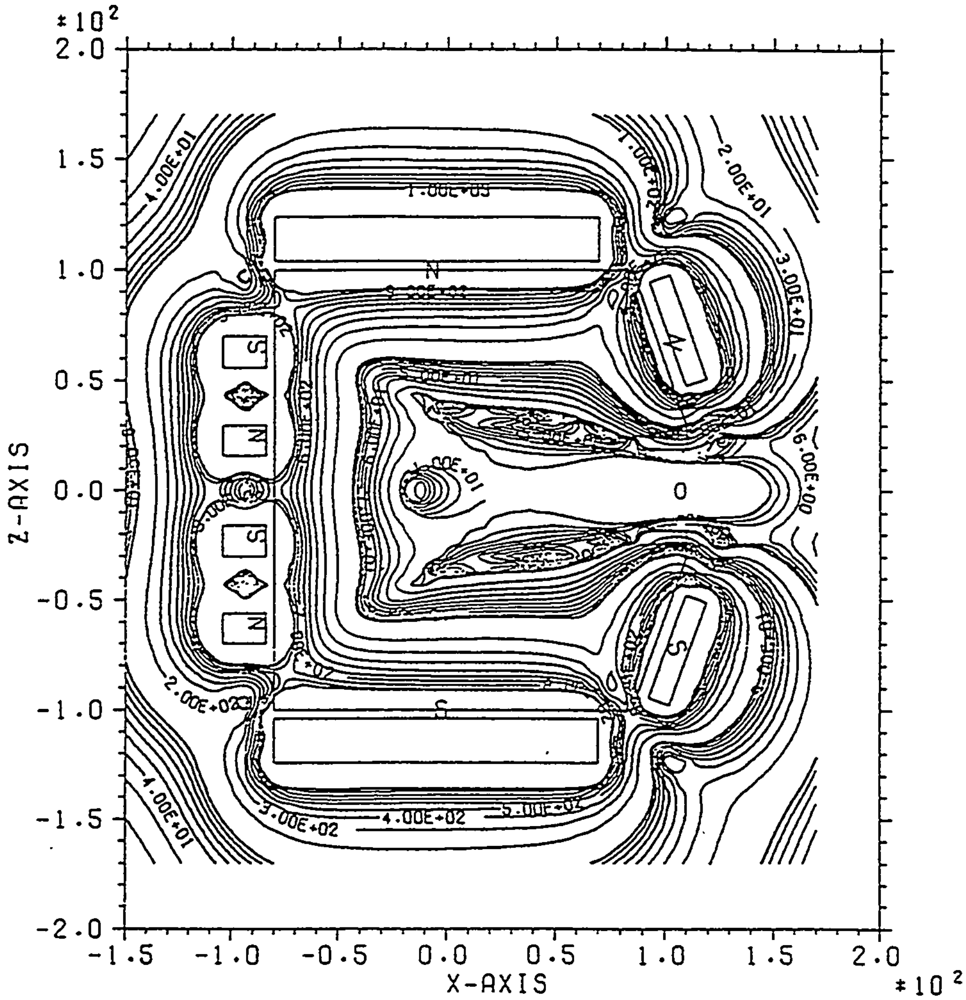


(plain view)

The magnetic field around the inner surface of the chamber was more than 2 kG. The magnetic field decreased to less than 30 Gauss within the central region of about 5 cm in diameter, where the beam extraction aperture exits.

Magnetic field in the plasma chamber

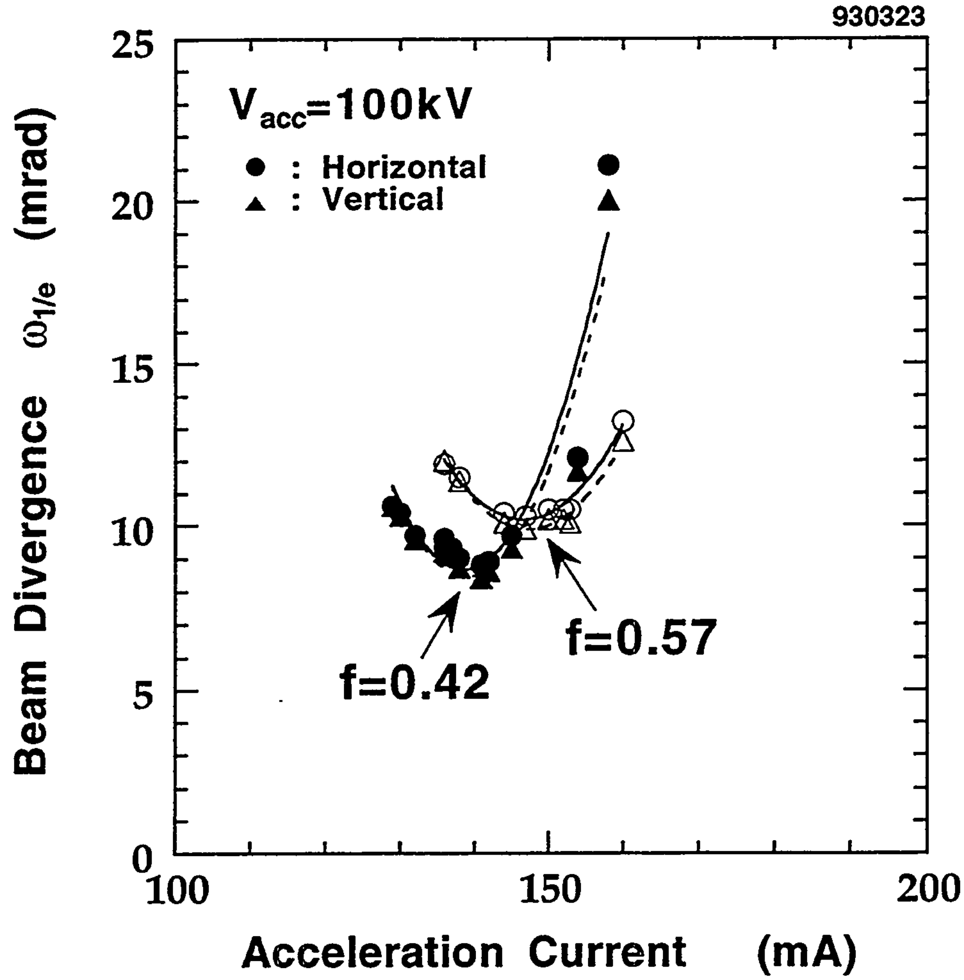
(Calculation result by a computer code)



(Cross-sectional view)

The magnet columns around the inner surface are connected at a back plate by four rows of magnets. The open end of the chamber is enclosed by a plasma electrode, where additional 10 rows of magnets are installed except for the central extraction region.

Field intensity ratio f of the two-stage extractor

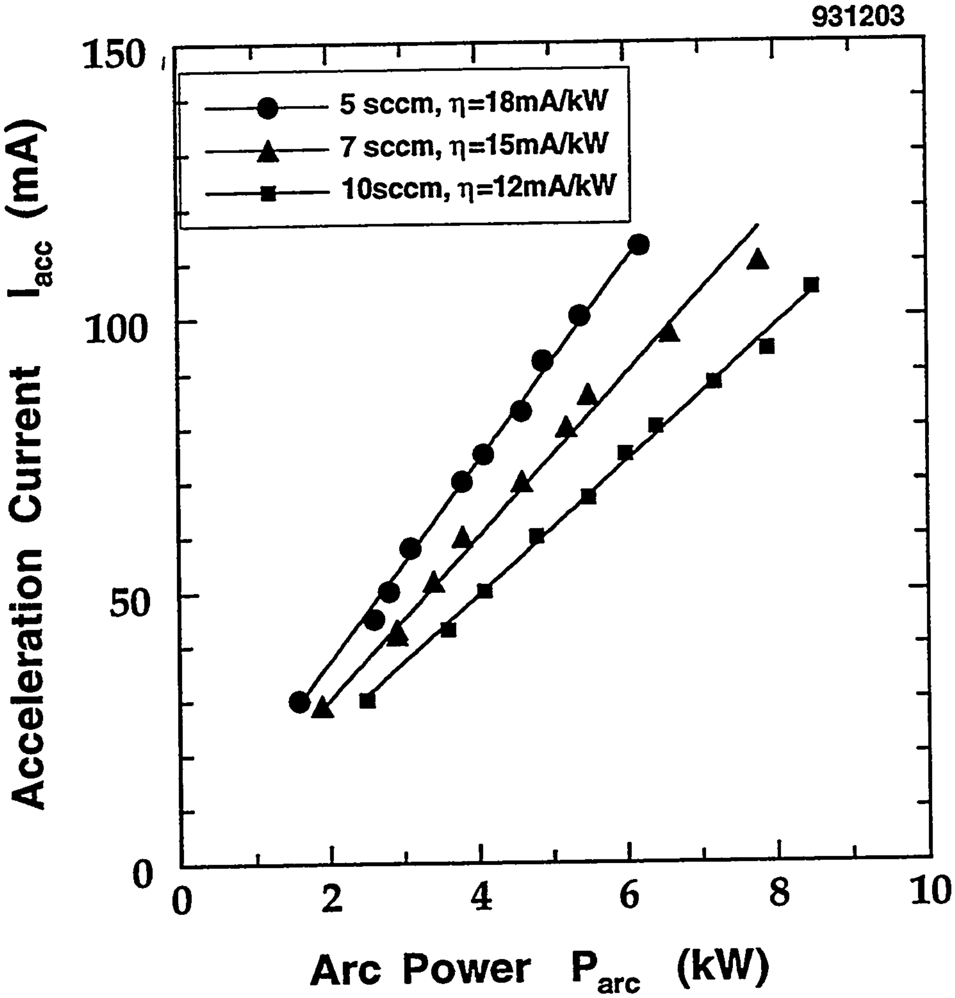


A field intensity ratio f is defined as :

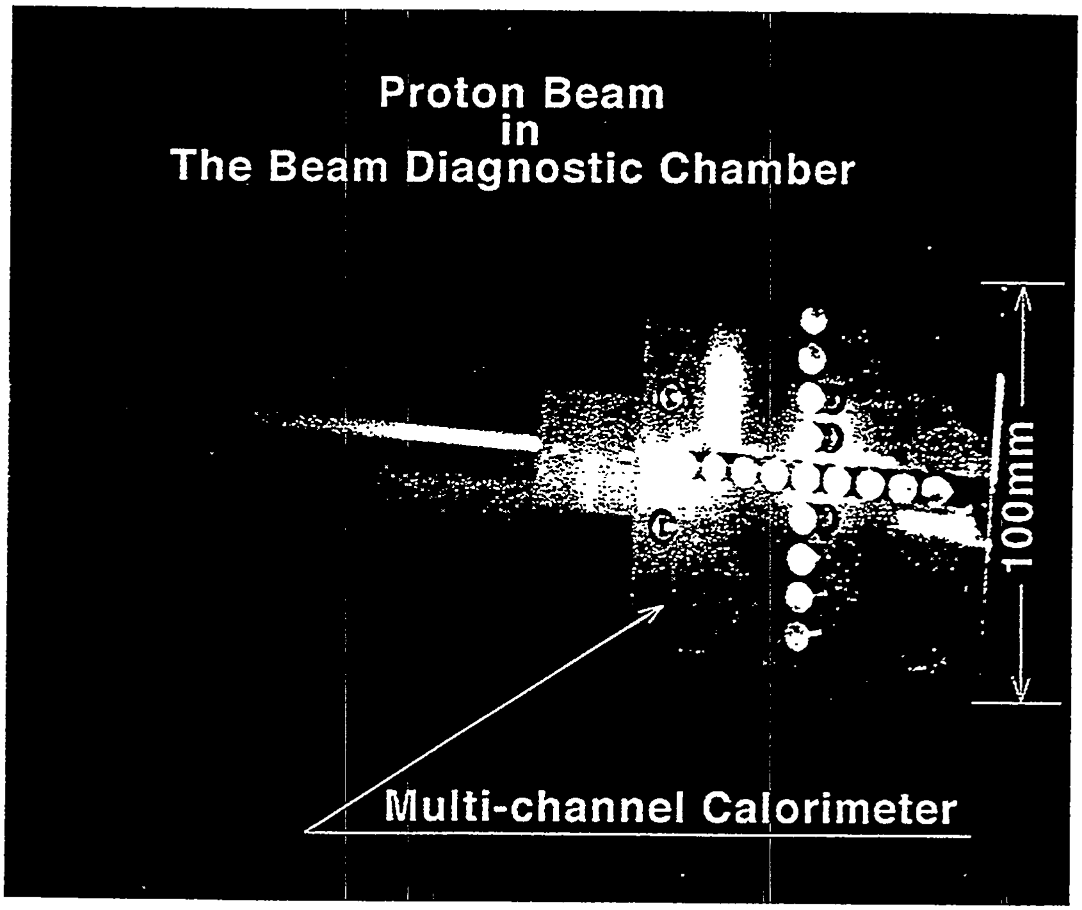
$$f = E_1 / E_2$$

, where E_1 : electric field at the first stage
E_2 : electric field at the second stage.

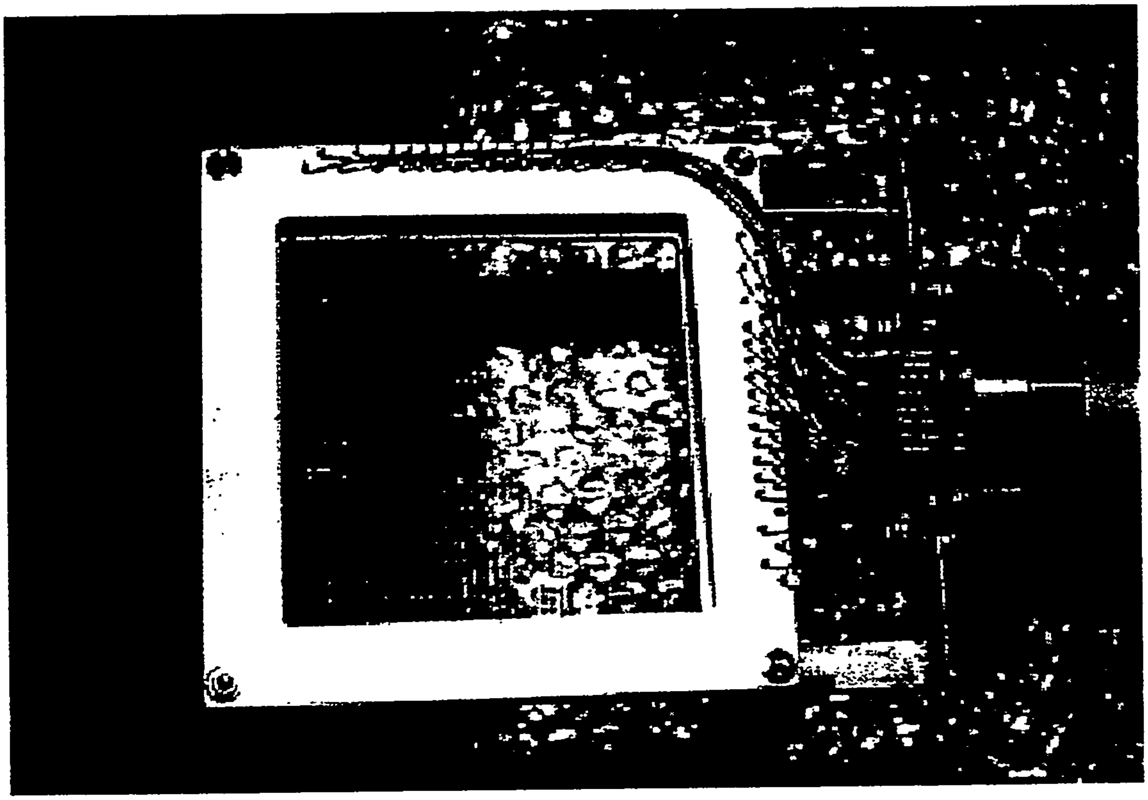
Arc efficiency



An arc efficiency η, ($\eta = I_{acc} / P_{arc}$), was high when the neutral hydrogen gas flow rate injected into the ion source was low. It reaches 18 mA/kW at 5 SCCM.

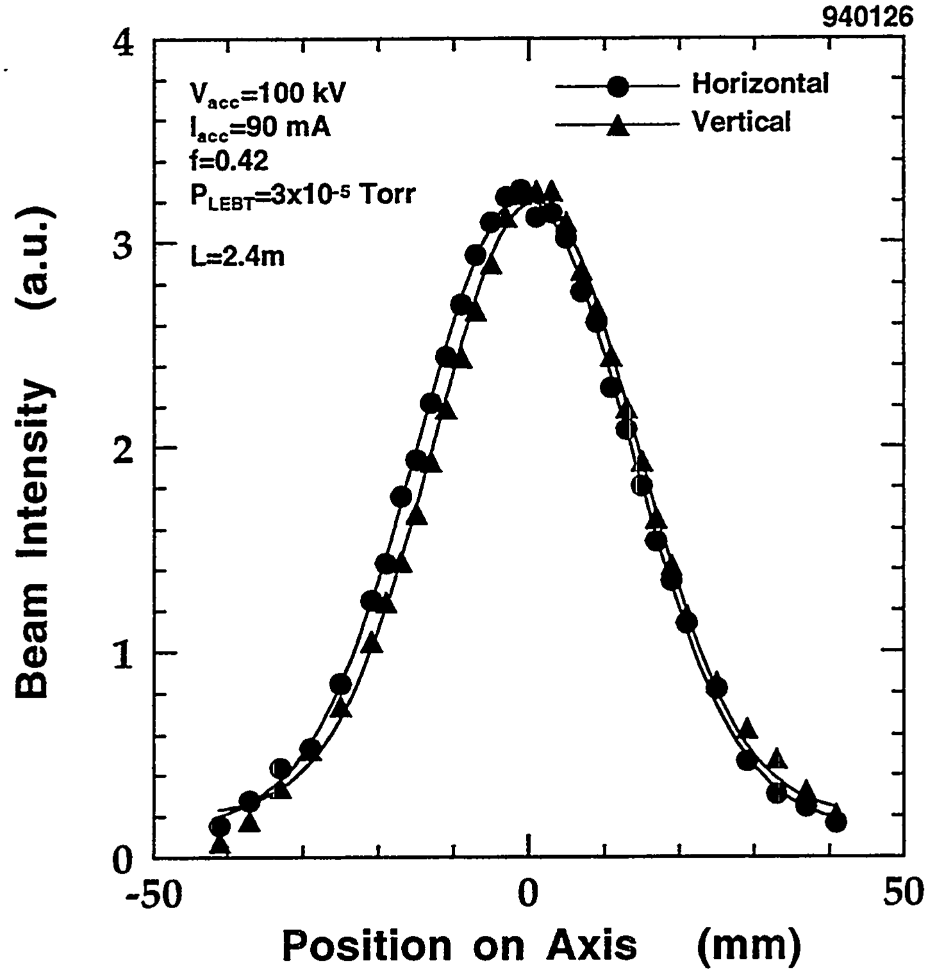

Proton Beam
in
The Beam Diagnostic Chamber
100mm
Multi-channel Calorimeter

Multi-Channel Wire Monitor



32 channels	X-Y each
0.1 mm in diam.	Tungsten wire
Central region	2 mm mesh
Outer region	4 mm mesh

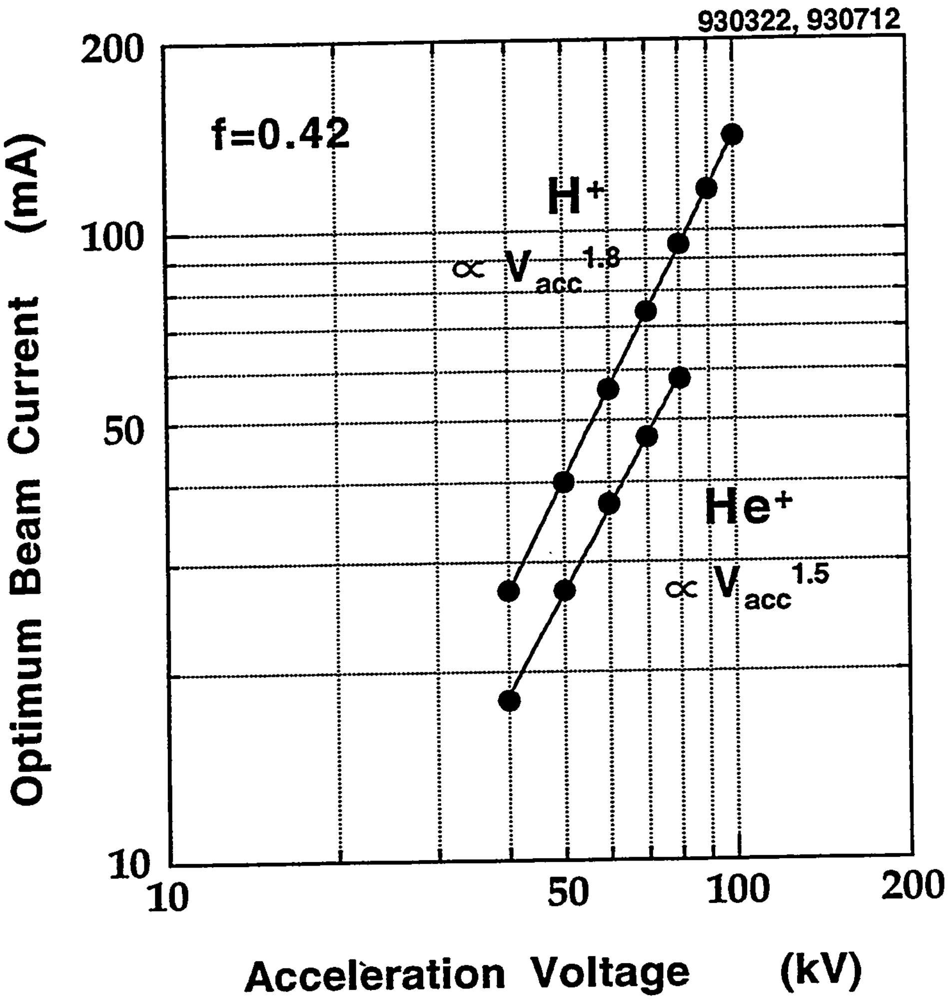
Typical beam profile



A beam profile was measured by a two dimensional 32 channels wire type monitor installed in the vacuum chamber at 2.4 m downstream from the ion source.

Two solid lines show the Gaussian fitting results. The fitting curves reproduce well the data with the beam divergence of 8.5 mrad.

Optimum beam current

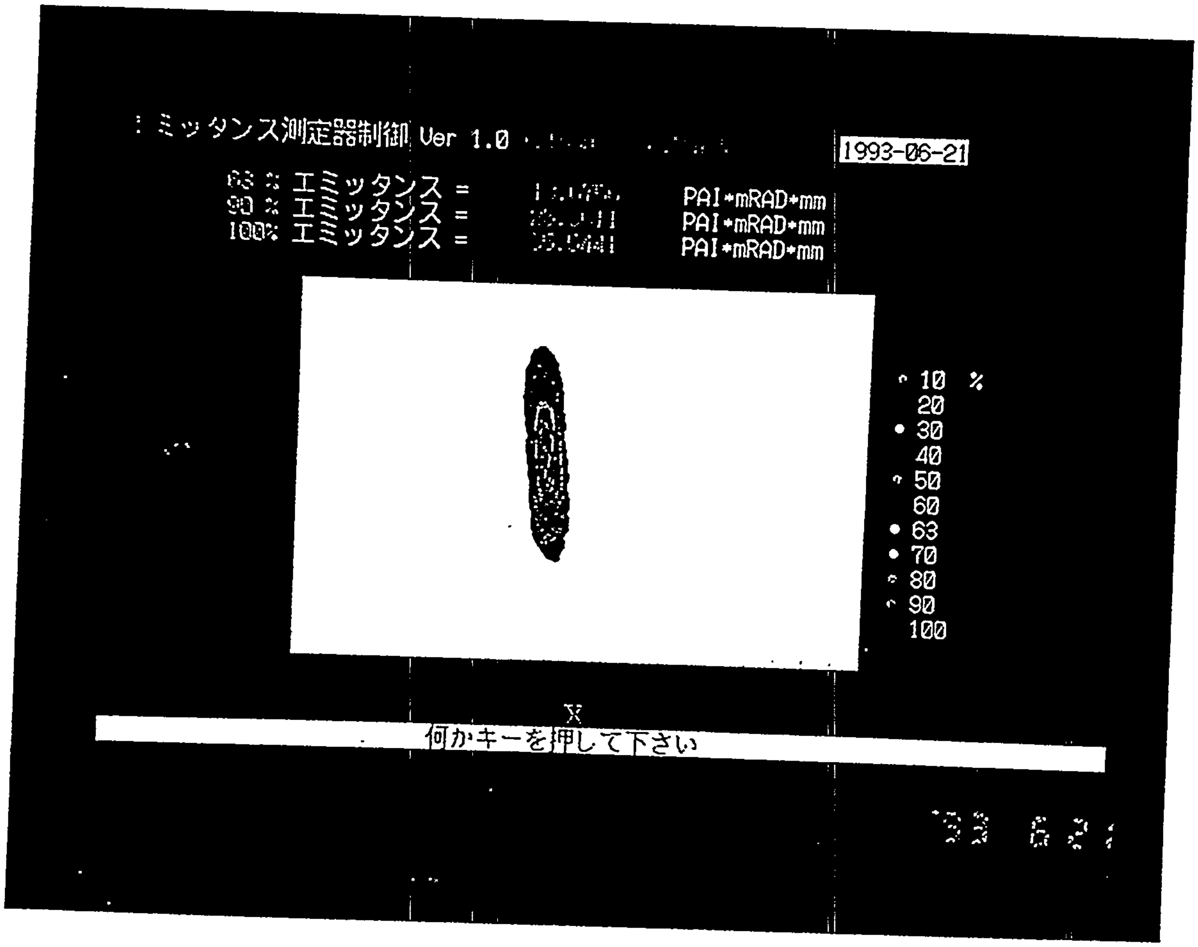


The red circles and green ones show the hydrogen and helium data, respectively.

The hydrogen optimum beam current, which gives the minimum beam divergence, reached 140 mA at 100 kV.

Emittance diagram

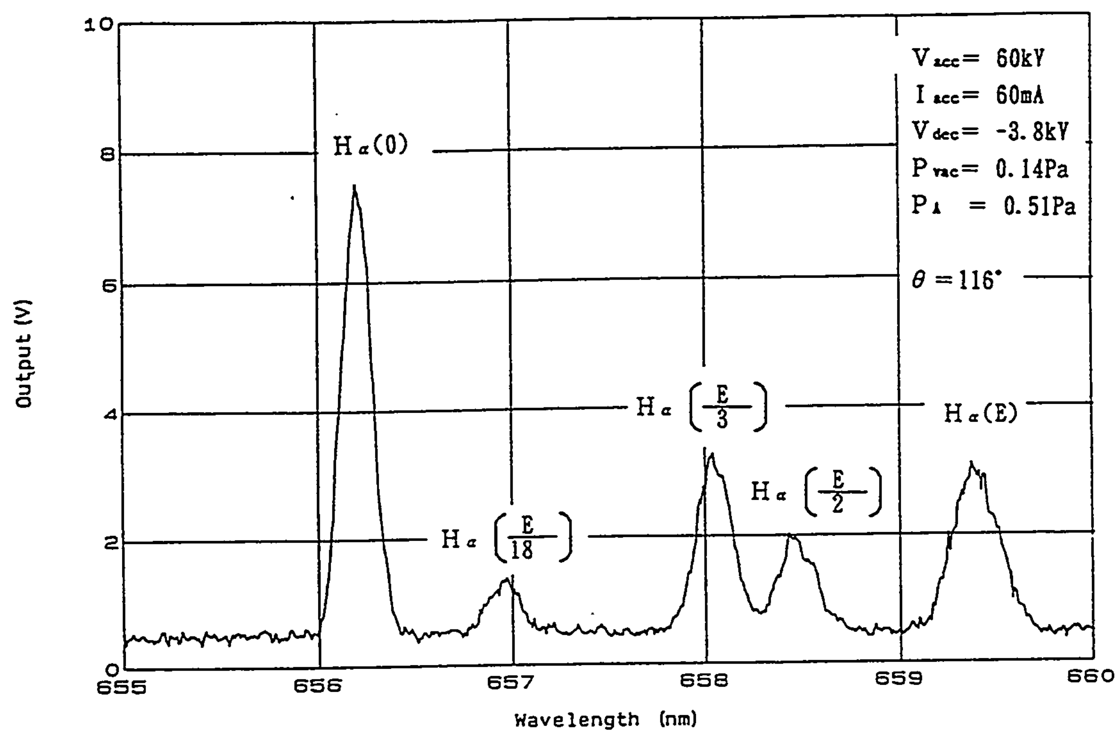
$V_{acc} = 60$ kV, $I_{acc} = 52$ mA, f = 0.42



63 % norm. emittance = 0.15 πmm.mrad
90 % norm. emittance = 0.29 πmm.mrad
100 % norm. emittance = 0.40 πmm.mrad

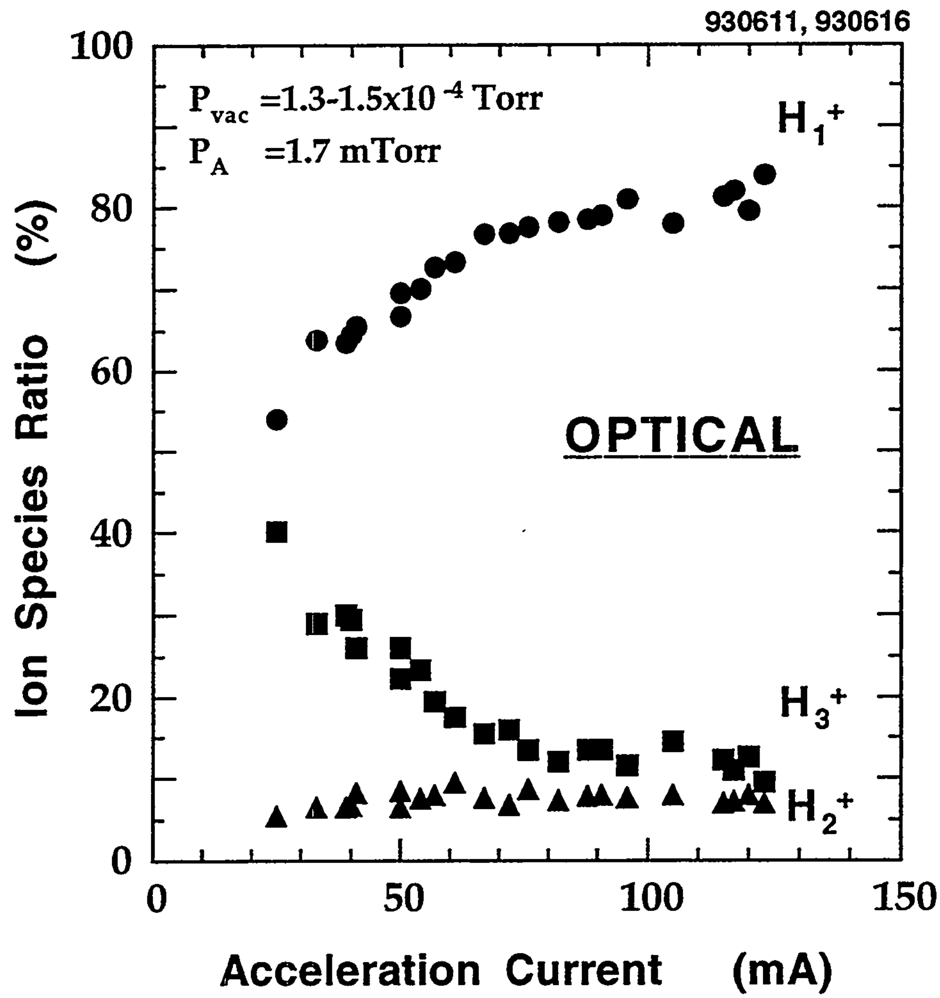
The emittance was measured by a double slits monitor. The distance between the two slits is 300 mm. The size of the first and second slits are 0.5mm ×30mm and 0.5mm ×42mm, respectively.

Typical spectrum of Balmer-alpha light



The highest peak at 656.3 nm is the Balmer-alpha light emitted from hydrogen atom in the beam plasma. The four peaks above 656.3 nm are the Doppler-shifted lights emitted from the accelerated hydrogen atoms. These correspond to the peaks due to the H_1^+, H_2^+, H_3^+ and H_2O^+ ions from the right side of the spectrum .

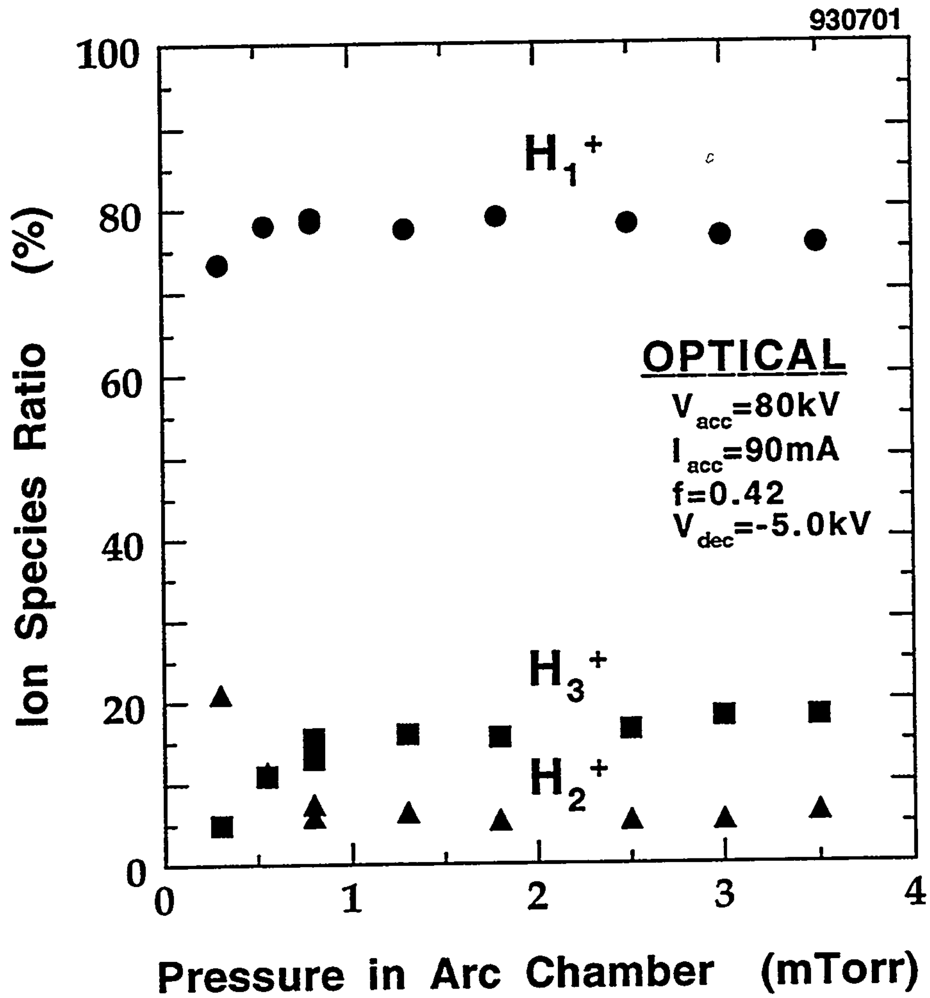
Ion species ratio vs. acceleration current



The ion species ratio in the hydrogen beam was measured by observing the Doppler-shifted Balmer alpha radiation emitted from fast hydrogen atoms.

The proton yield increased with the acceleration current and reached more than 85 % at 120 mA.

Ion species ratio vs. pressure in arc chamber



The proton yield had weak dependence on the pressure in the arc chamber.

CONCLUSION

Results of the beam test

Opt. Beam Current	:	140 mA (100 kV)
Norm. Emittance	:	0.5 πmm.mrad (90 %)
		(100 kV, 133 mA)
Proton Yield	:	>85 % (120 mA)
Impurity	:	< 1 %
Arc Efficiency	:	18 mA/kW (5 SCCM)

SUBJECTS FOR THE FUTURE STUDY

Plasma Production without Filament
: ECR, RF- driven

Further Enhancement of the Proton Yield
: Magnetic filter

Precise Emittance Measurement

Extraction of Negative Hydrogen Ion

Rf H^+ Ion Source Development at LBL

L. Perkins

Lawrence Berkeley Laboratory

Rf H^+ ion source development at LBL

Components and Characteristics of Induction Discharges
Antenna
Matching Network
Starter

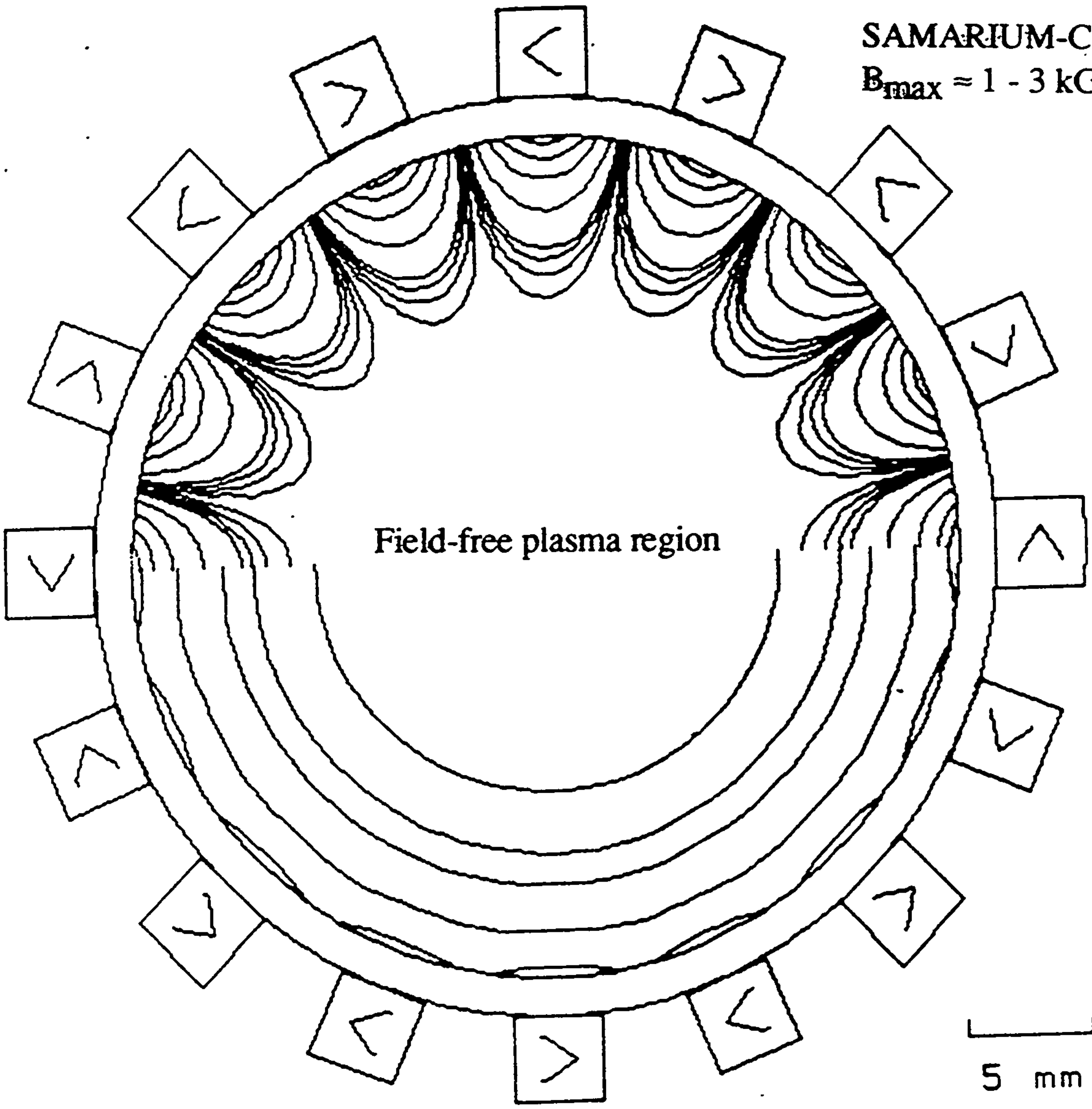
Experimental Results
Source size
Pulsed and CW
Species and current

Summary

Luke Perkins
Department of Nuclear Engineering
University of California Berkeley

[MULTICUSPS ION SOURCE]

Magnet Periods= 8   Magnets per Period= 2



FIELD LINES.0(025,05,075,1,25,5,75),.1KG-CM FIELD INTENSITY .01,.05,.1,.25,.5KG

THE MAGNETIC FIELD DISTRIBUTION AND FIELD LINES

Large source (original)

Applications:

Neutral beam injection systems and particle accelerators (cyclotrons).

Specifications:

Copper or stain-less steel "bucket" with a water-cooled jacket
20 cm dia. x 24 cm long
10 cm dia. x 10 cm long
with a multi-port back flange (for various inlets)

Rf operatioal Performance:
(see graphs)

Small (subcompact) source

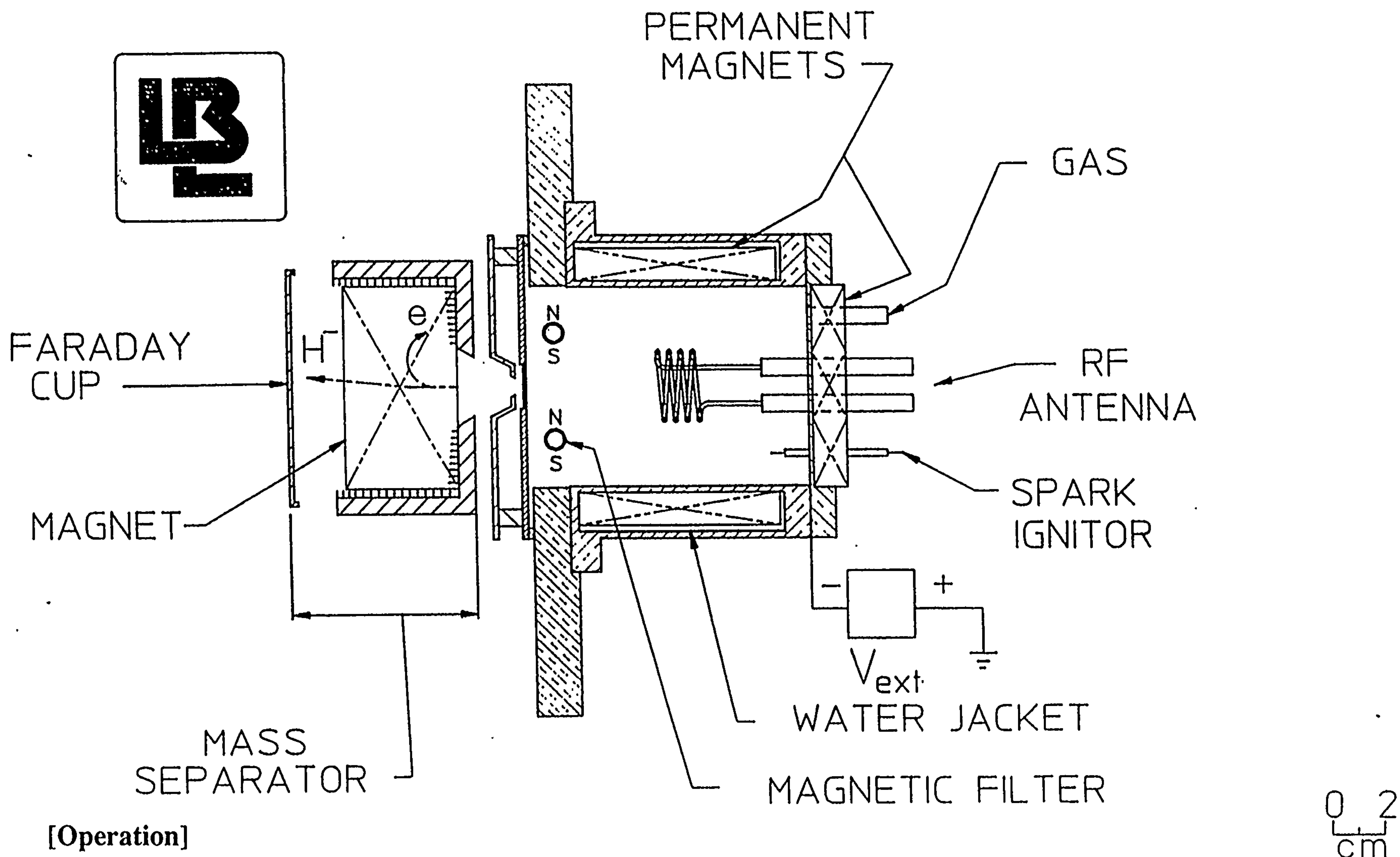
Applications :

Neutron generation for oil-well logging and medical purposes.
[Ion source coupled to accelerator and tritium target are housed in 3 cm dia x 30 cm long glass tube]

Specifications :

3 cm dia. x 5 cm long
4 cm dia. x 6 cm long

Rf operatioal Performance:
Only pulsed operation (<1% duty factor)
(see graphs)



[Operation]
Pulsed or *CW* mode.

[Diagnostics]
Species: 180° focusing magnetic deflection mass spectrometer. 5.6mm / 1mm

Induction discharges

Antenna:

Porcelain coated made of copper tubing.

A good antenna coating is <u>critical</u> (especially for CW operation).

- Must be flexible ; crack / sputter resistant.
- Must withstand high potential gradient between the plasma and the antenna.

=> Optimization of number of turns, diameter of turns, position of antenna is required.

Matching Network:

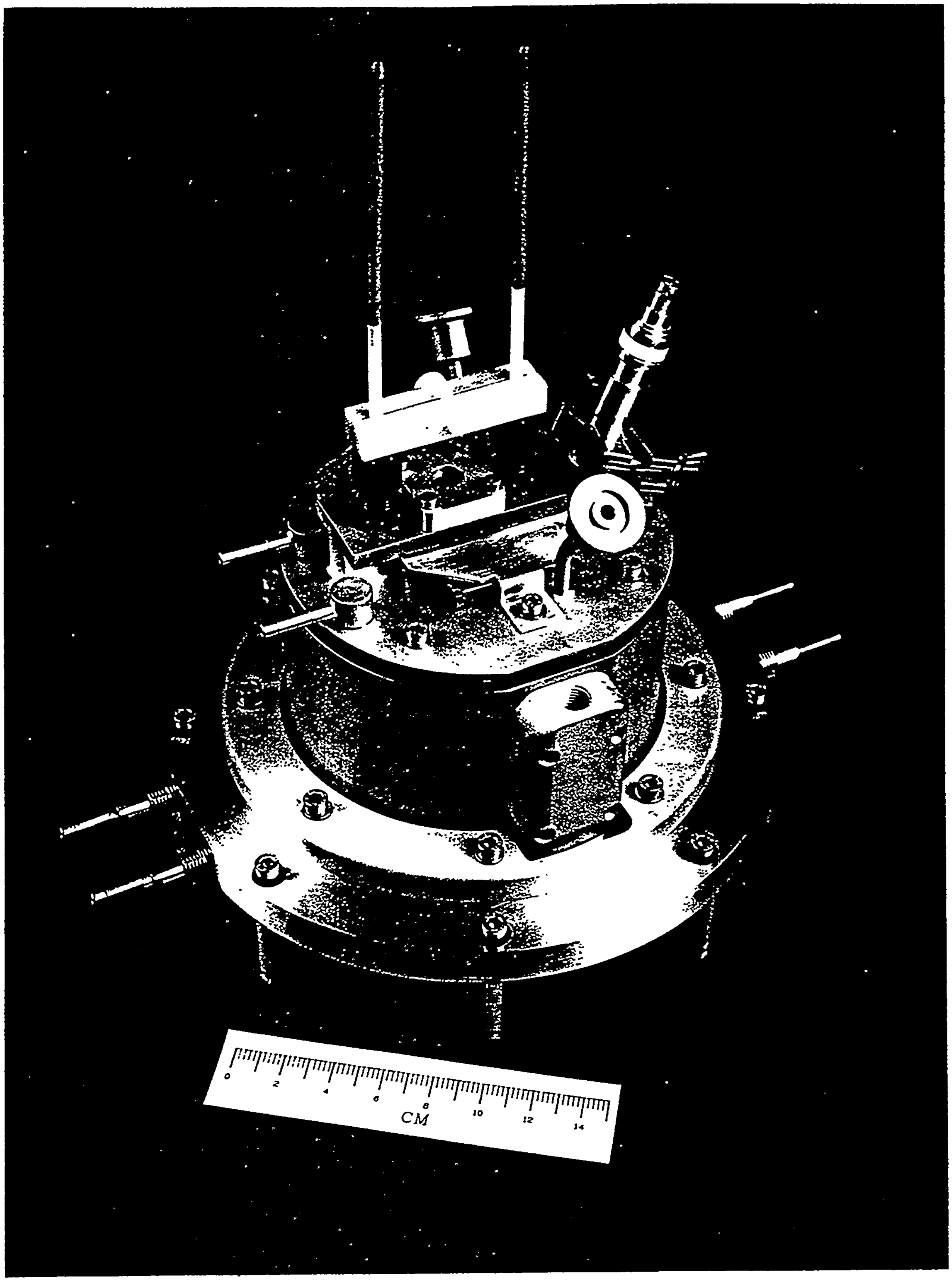
Inductor and variable capacitor in series with antenna (RLC circuit).
Rf power from amplifier is delivered via a step-down isolation transformer.

- Must have adequate cooling (especially for CW operation)
- Must have good cores in isolation transformer to minimized loses (and phase shifting)
- Must be tuned initially to first order ($\approx$ 2 MHz) using a vector impedance meter to minimize phase difference between current and voltage
  => maximize power transfer. Additional fine tuning is done with the frequency generator during operation.

Starter:

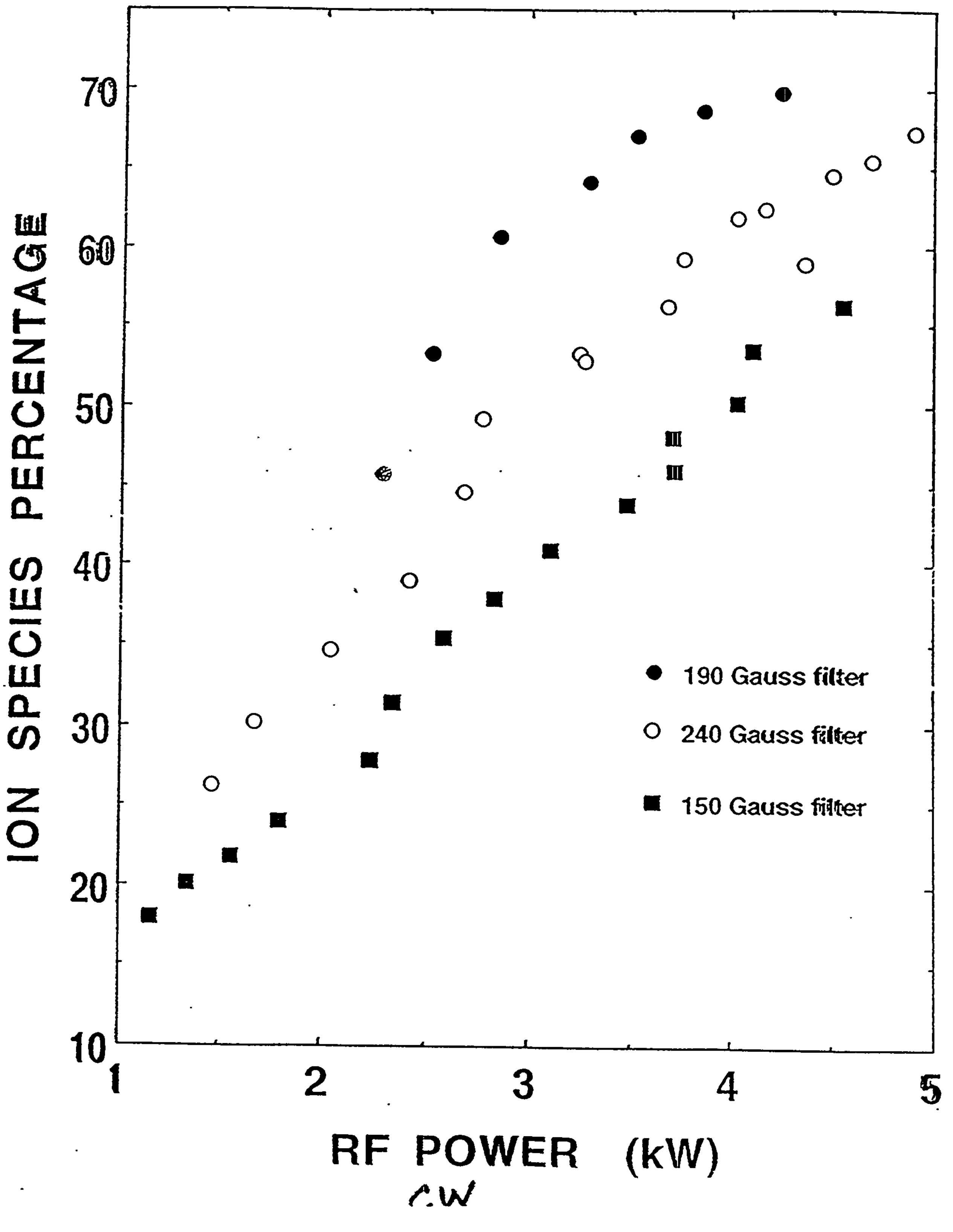
Need for initial break down starter cathode (filament, laser, flash-lamp, etc.) (alternative: start at higher pressure but can incur large reflected power).

Advantages: Long life-time, clean operation (no impurities in beam)
Disadvantages: equipment requirement, starter requirement, rf shielding.


CM

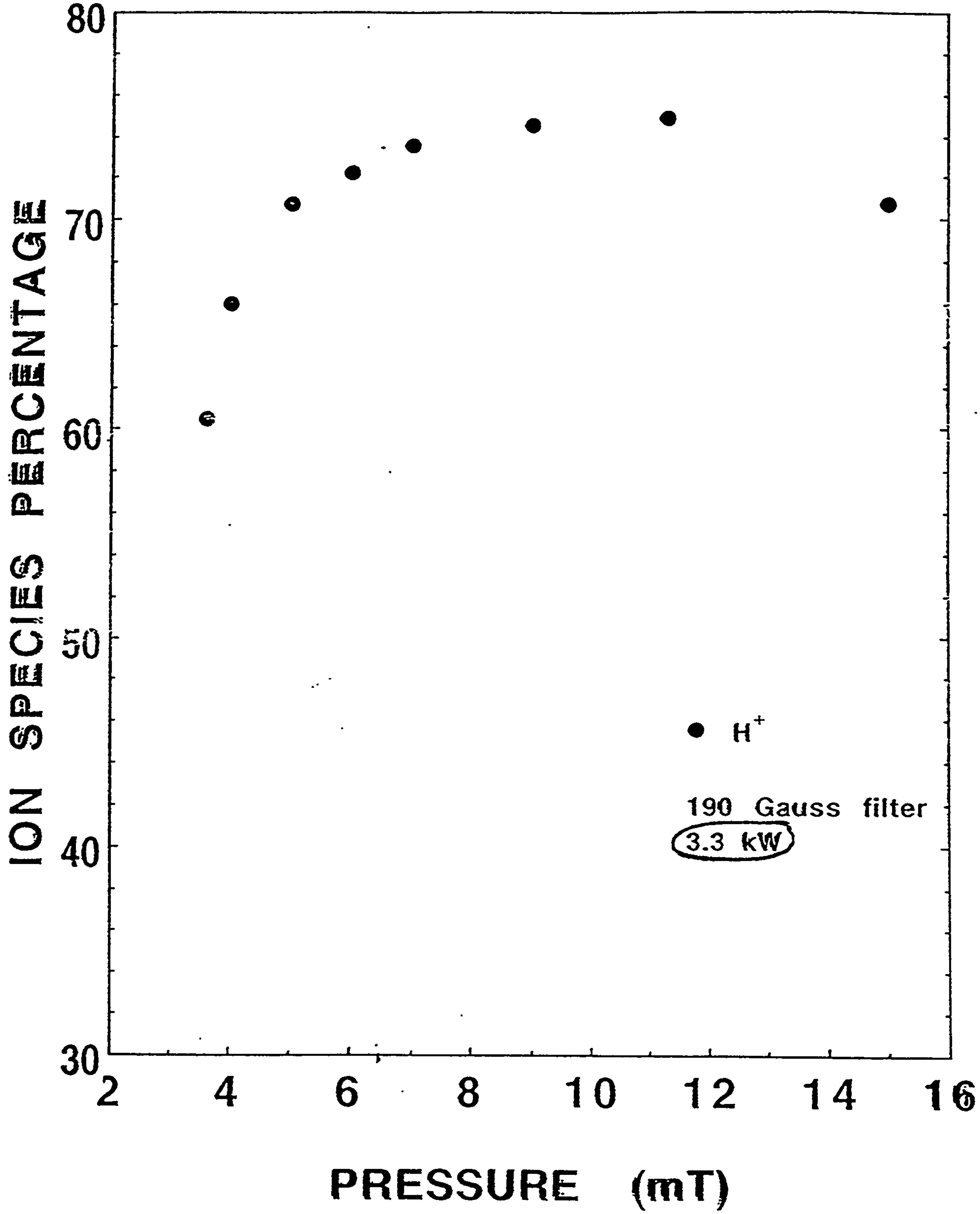
LARGE SOURCE
CW OPERATION

[OPTIMAL FILTER STRENGTH]

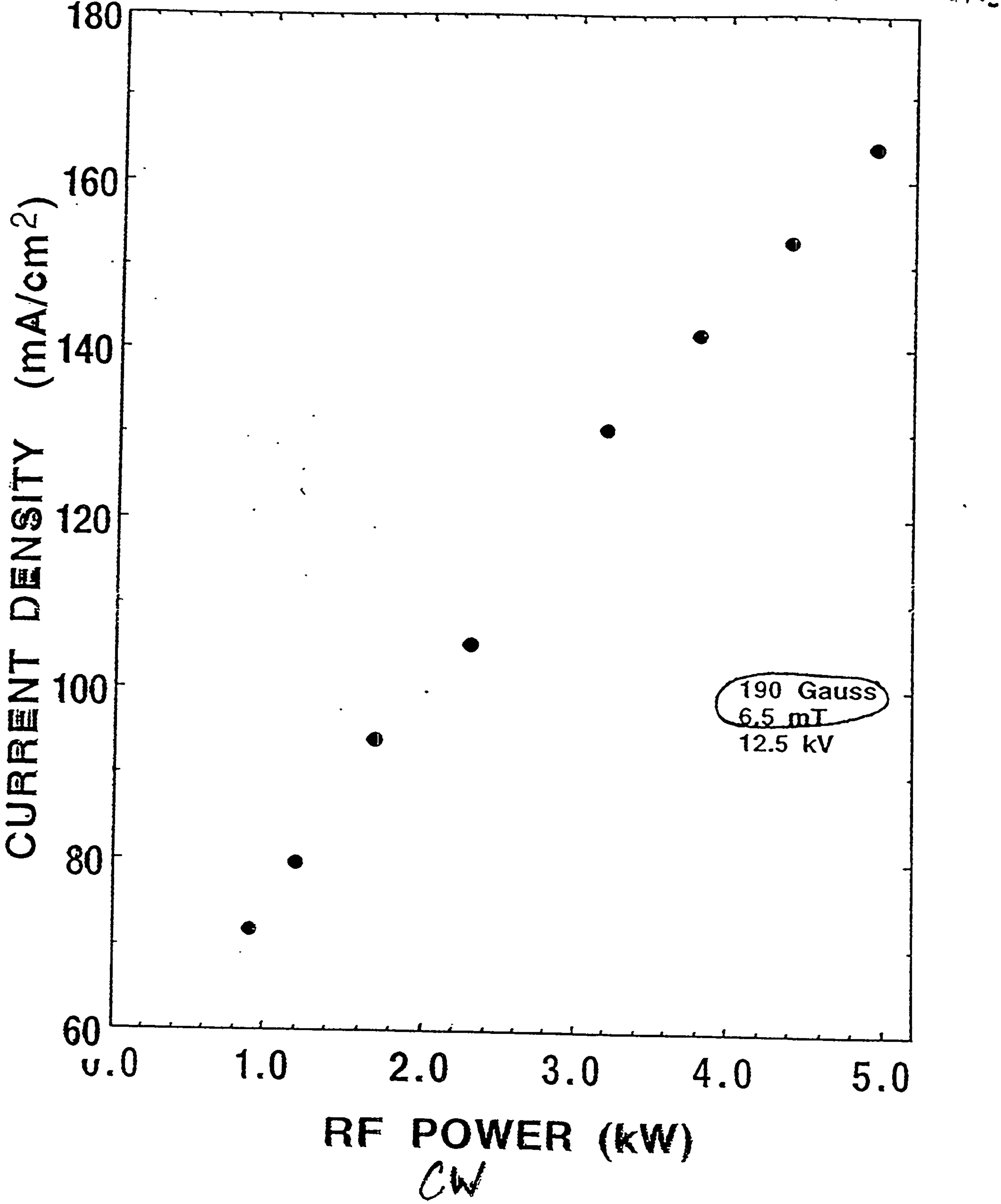


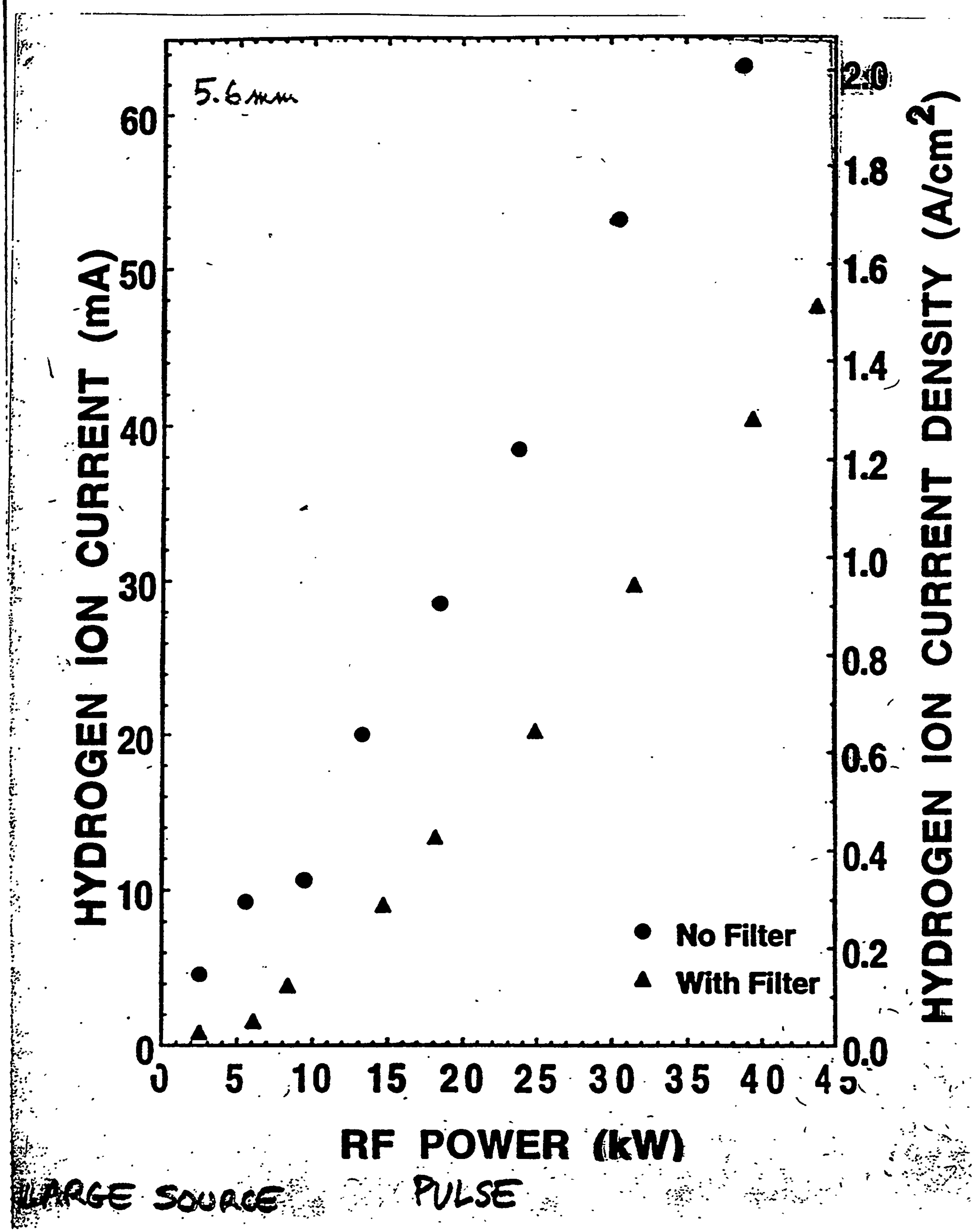
LARGE SOURCE
CW OPERATION

[OPTIMAL PRESSURE]

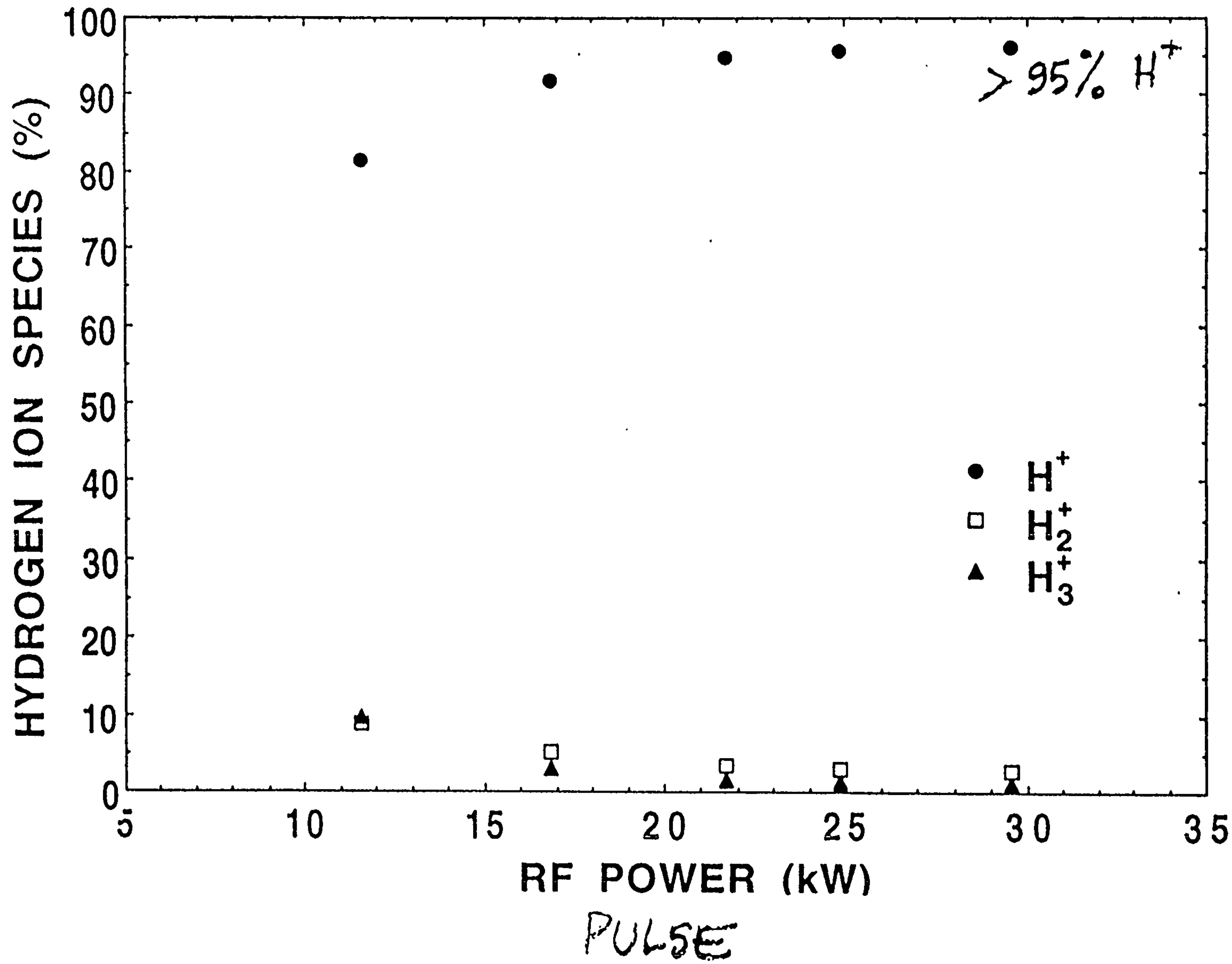


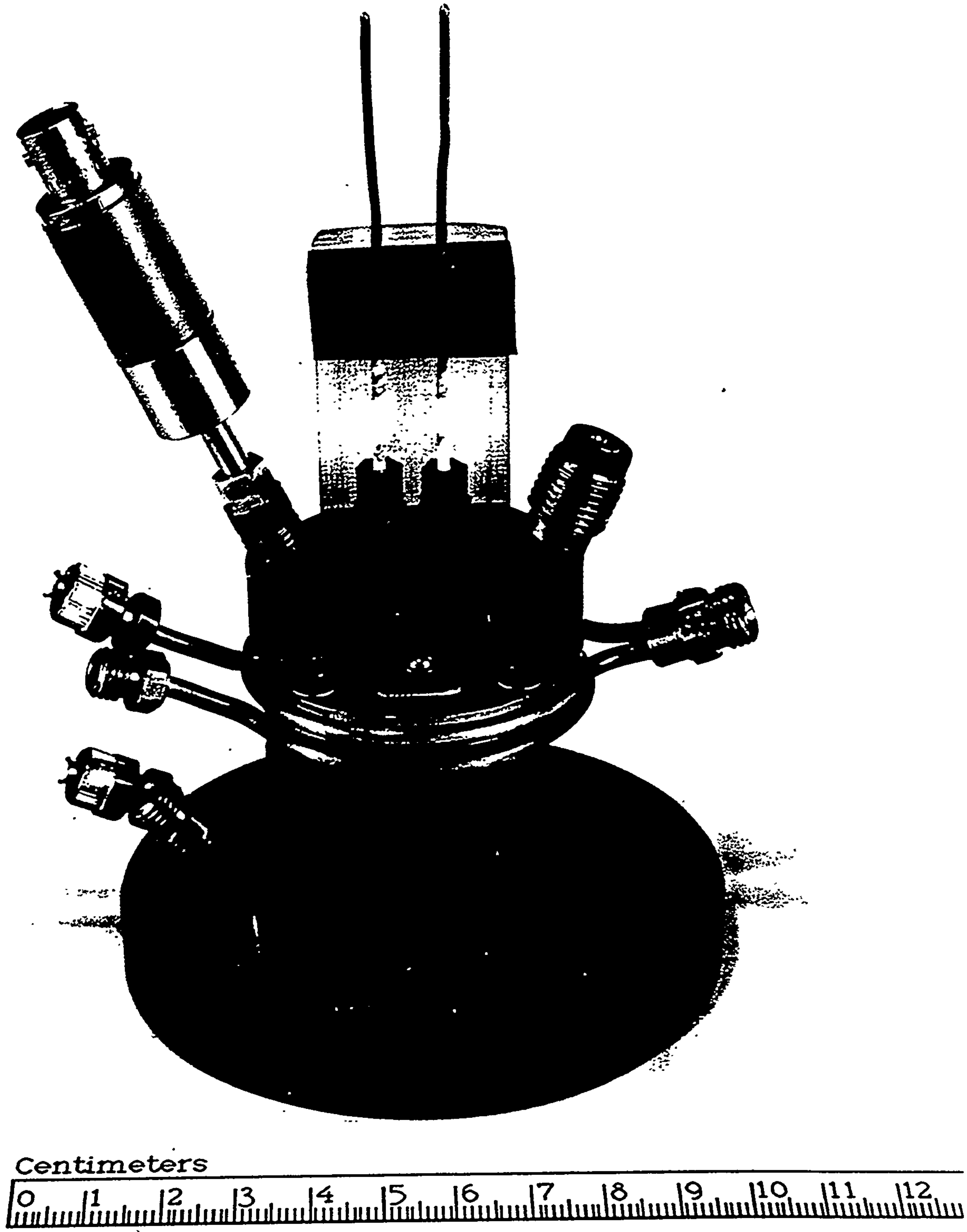
TOTAL ION CURRENT DENSITY UNDER OPTIMAL CONDITIONS



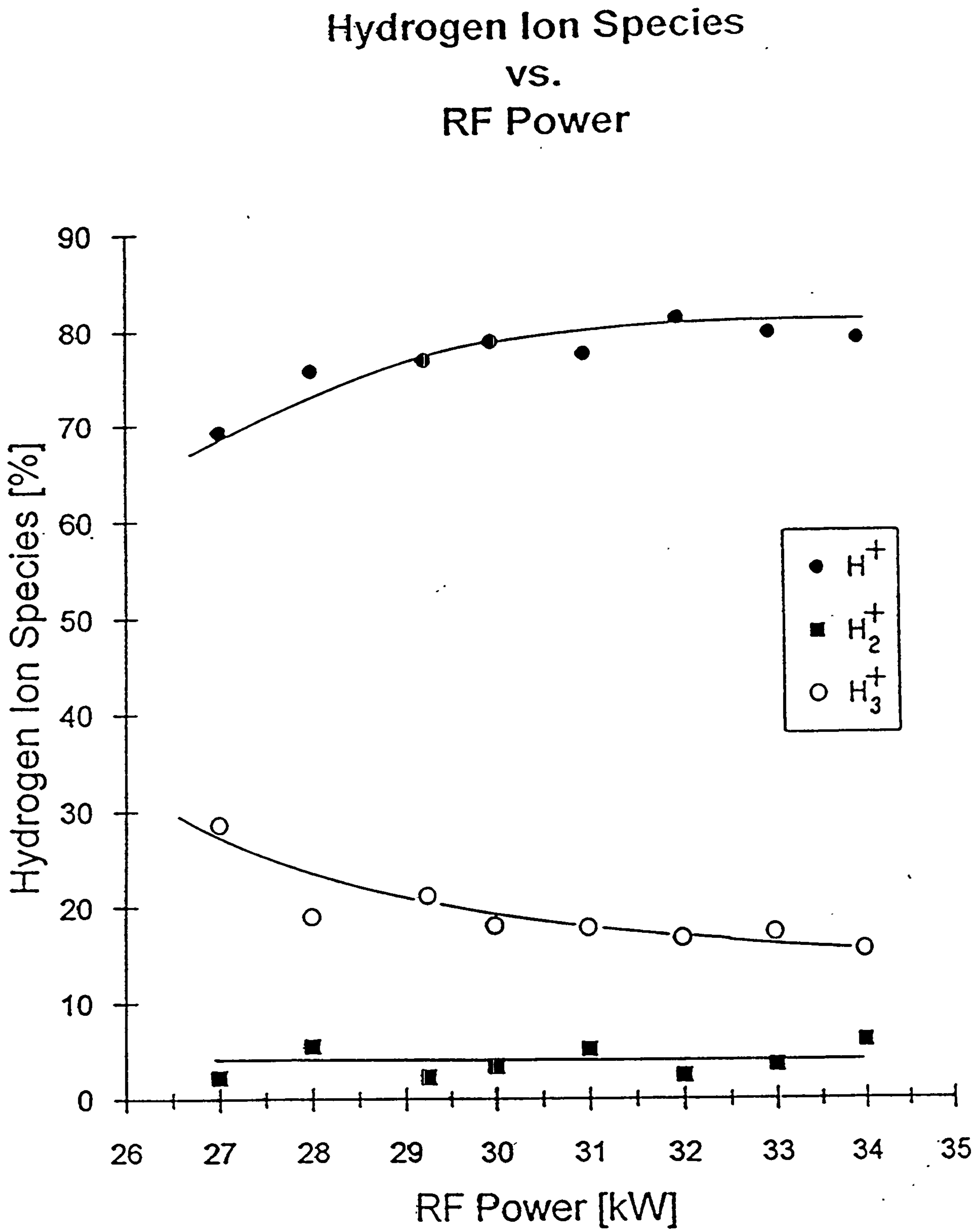

5.6 mm
HYDROGEN ION CURRENT (mA)
HYDROGEN ION CURRENT DENSITY (A/cm2)
RF POWER (kW)
No Filter
With Filter
0
10
20
30
40
50
60
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
5
10
15
20
25
30
35
40
45
LARGE SOURCE
PULSE

LARGE SOURCE
PULSE OPERATION

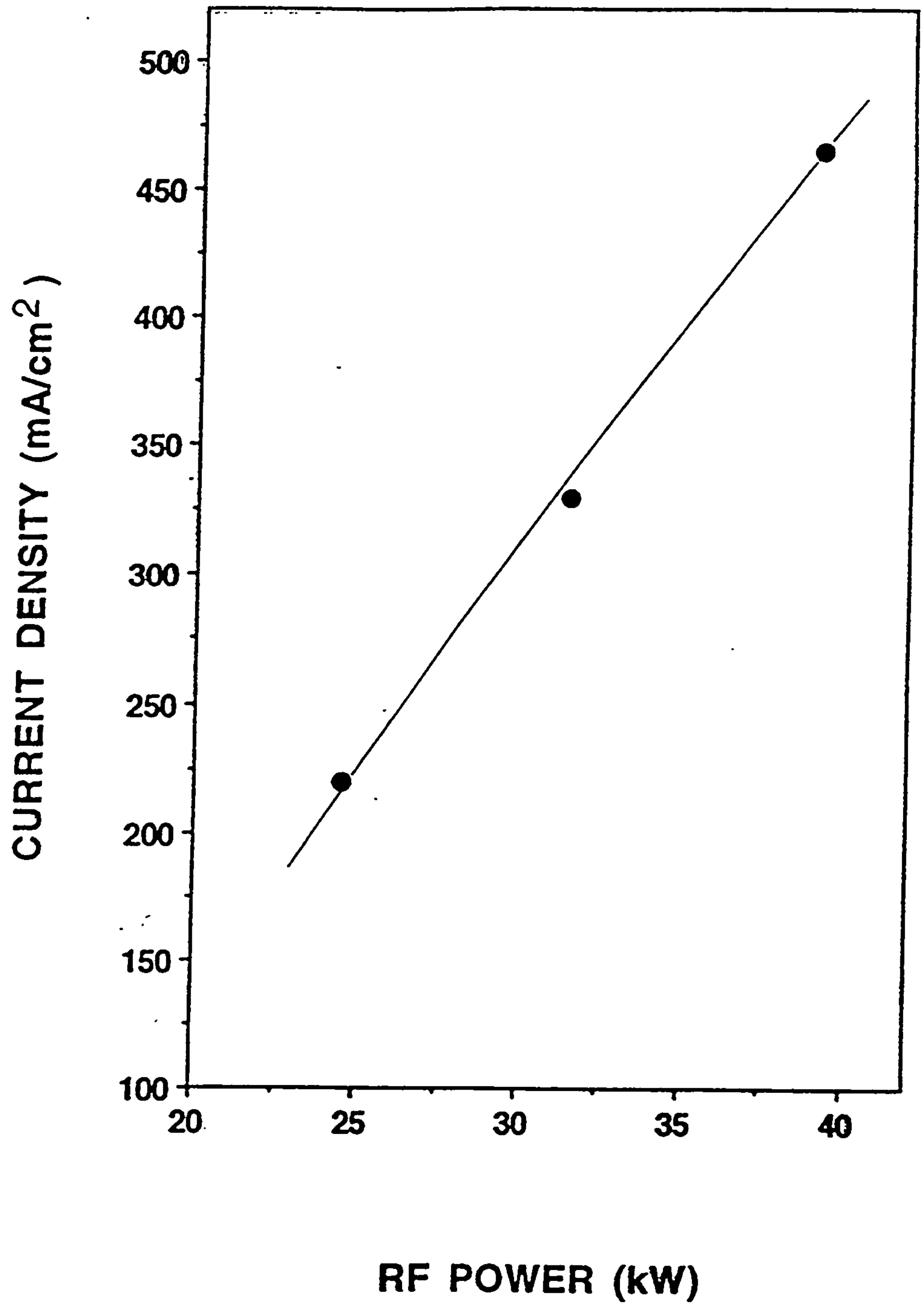



Centimeters
0 1 2 3 4 5 6 7 8 9 10 11 12

Species for small source, pulsed operation.



Total ion current density for small source, pulsed operation



Extracted hydrogen ion current density as function of rf input power for the 2.5-cm-diam source.

Summary

- Source parameters must be optimized (including filter field strength and pressure)
- Duty factor doesn't affect on a first order source output.
- 1 kw ≈ 1mA (high power — through 5.6mm dia. aperture)
- Can achieve > 80 - 95% H^+
- Larger sources are more efficient.

Positive Ion Sources
Volume Sources at PSI

M. Olivo

Paul Scherrer Institute

POSITIVE ION SOURCES

VOLUME SOURCES AT PSI

MIGUEL OLIVO

PAUL SCHERRER INSTITUTE

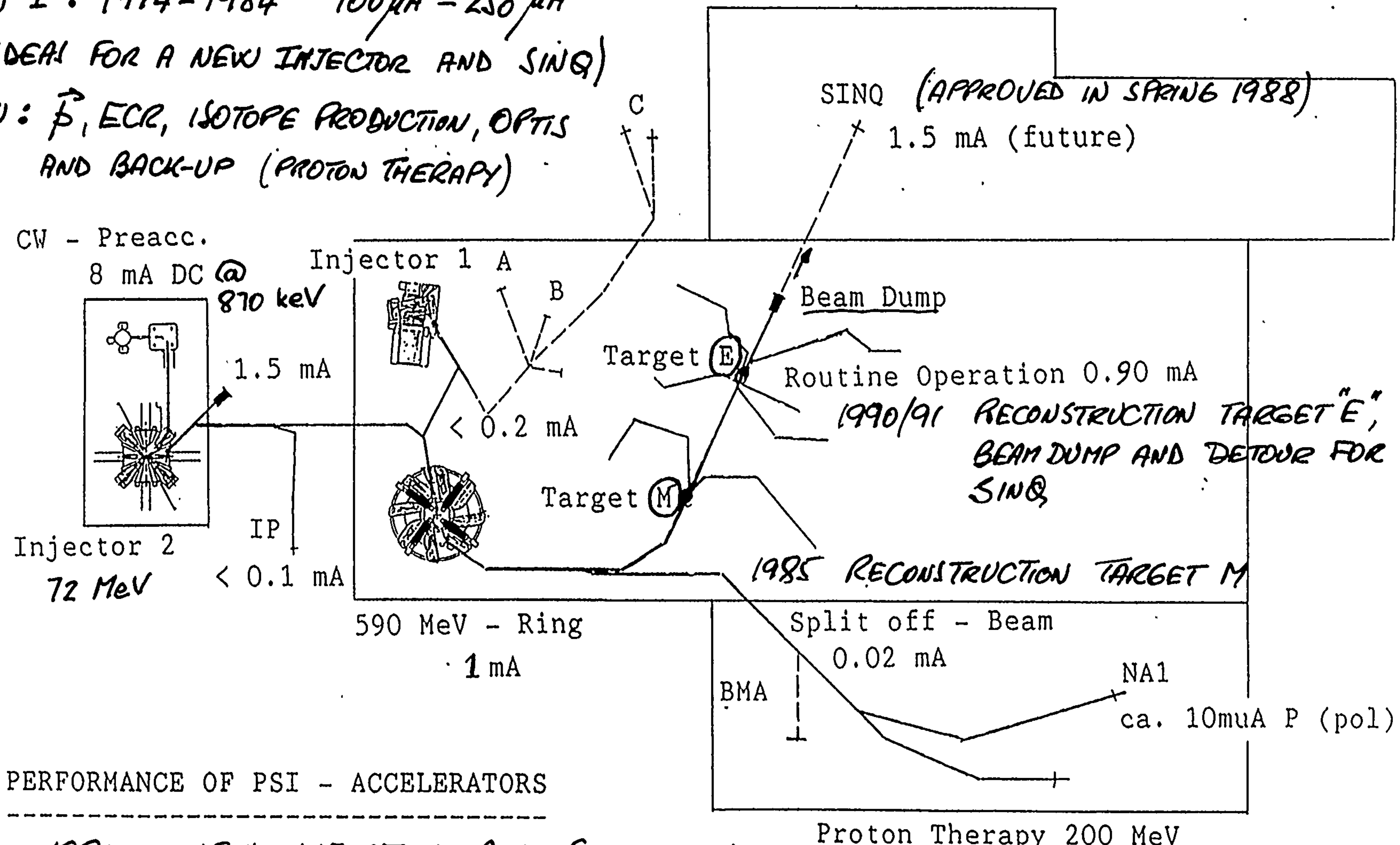
OCTOBER 25, 1994

MESON FACILITY IN OPERATION SINCE 1974 (SIN)

INJ I : 1974-1984 100 μA - 250 μA

(IDEAL FOR A NEW INJECTOR AND SINQ)

NOW : $\vec{p}$, ECR, ISOTOPE PRODUCTION, OPTIS AND BACK-UP (PROTON THERAPY)



PERFORMANCE OF PSI - ACCELERATORS

1992 NEW INJECTION AND EXTRACTION ELEMENTS FOR THE RING MACHINE

ION SOURCE

(OPERATIONAL VALUES FOR A 1.5 mA PROTON BEAM AT 72 MeV
OR 1.0 mA AT 590 MeV

MULTI-CUSP (CULHAM DESIGN)

ARC CHAMBER: 10 cm × 10 cm × 10 cm Cu - H_2O COOLED

4 ROWS (PLUS BACK) OF 3.5 KG Sm-Co MAGNETS

4 (2×2) FILAMENTS* W-1.5% ThO_2 ϕ1.5 mm L = 10 cm (6V, 2×95A,

GAS FLOW: 3 sccm H_2; ARC CHAMBER PRESSURE: 4.7 mT

ARC DISCHARGE: 40 V, 24 A (TYPICALLY $1.5 \leq Z \leq 1.7\ \Omega$)

TETRODE EXTRACTION CONFIGURATION: 60 kV/52 kV/-2 kV

EXTRACTION APERTURE: ϕ 7 mm $\Rightarrow$ 0.38 cm^2

TOTAL ION EXTRACTION CURRENT: 36 mA d.c. (95 mA/cm^2)

H_1^+ = 12 mA (~33% PROTON EFFICIENCY)

H_1^+ = 8.6 mA THROUGH 810 kV ACC. TUBE
(3.4 mA LOST IN 60 keV B.T.S. COLLIMATORS)

	NORMALIZED EMITTANCE [π mm mrad] [86%]
8.6 mA @ 60 keV (BEFORE TUBE)	= 0.18
8.6 mA @ 870 keV (AFTER TUBE)	= 0.30
8.1 mA @ 870 keV (AXIAL INJ. SYS) TO INJ. II	= 0.50
(0.5 mA LOST ($H_2^+ + H_3^+$) IN 870 keV B.T.S.)	
0.5 mA @ 72 MeV (B.T.S. TO RING)	= 1.2
1.5 mA @ 72 MeV (B.T.S. TO 3 mA, 72 MeV BEAM DUMP)	= 5.0 (?)
1.0 mA @ 590 MeV (B.T.S. TO TARGETS)	= 2.0

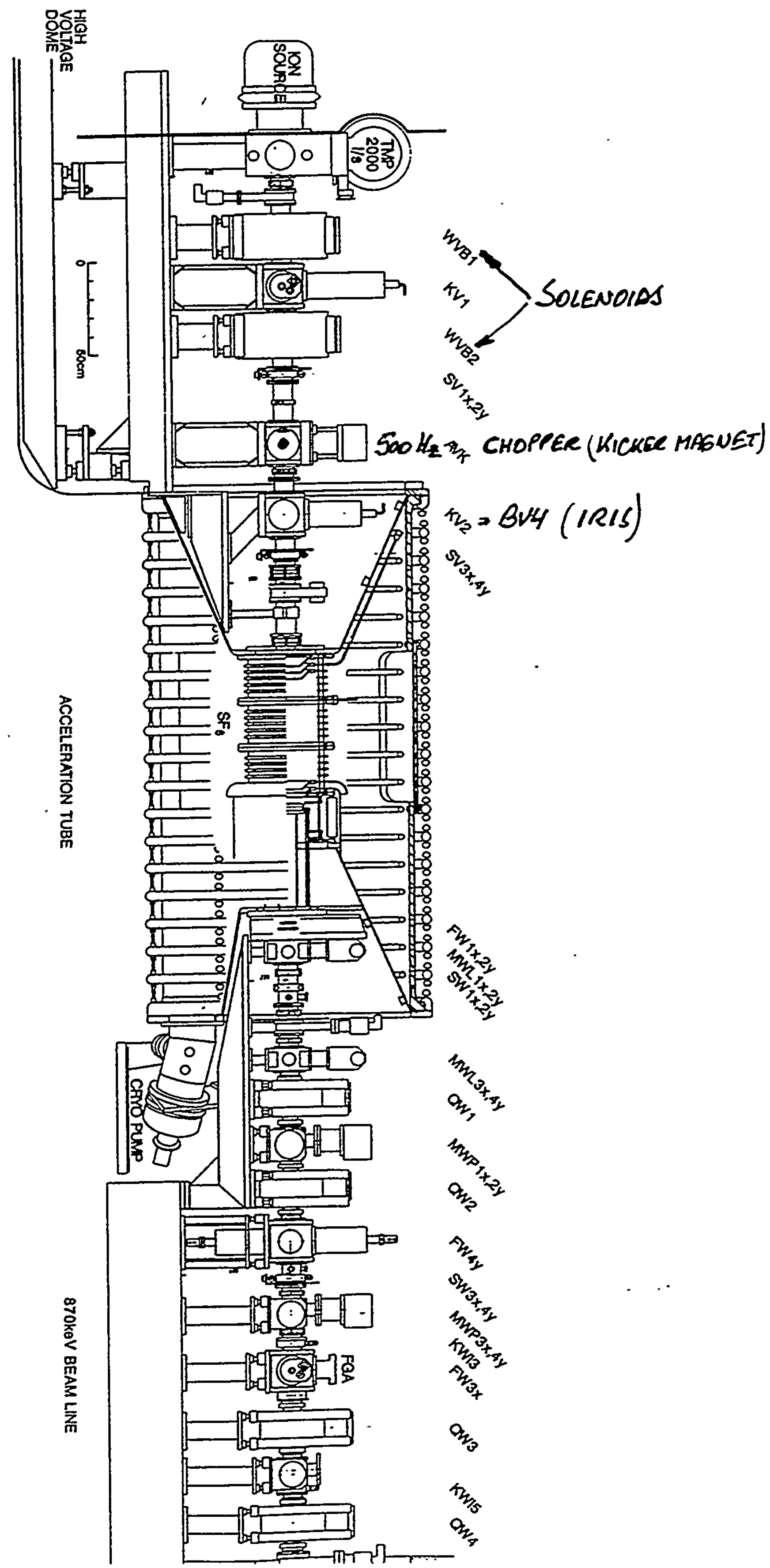
[30 DAYS @ 24h/day]

INJECTION INTO INJ. II:

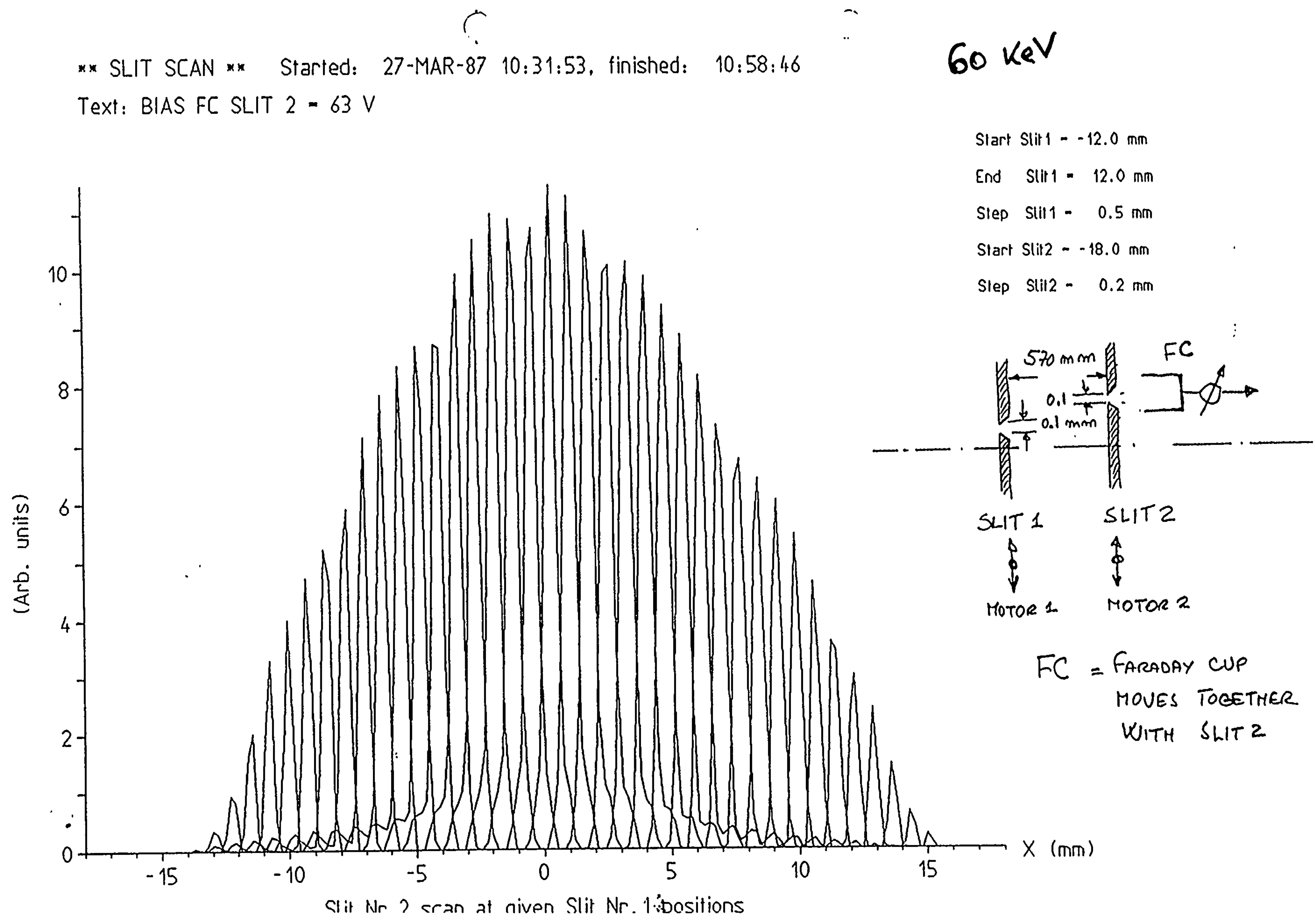
$\Delta\phi \simeq 24°$ $B_f \simeq 3.7$ $\langle I \rangle = \frac{8.1 \times B_f \times \Delta\phi}{360} \simeq 2$ mA

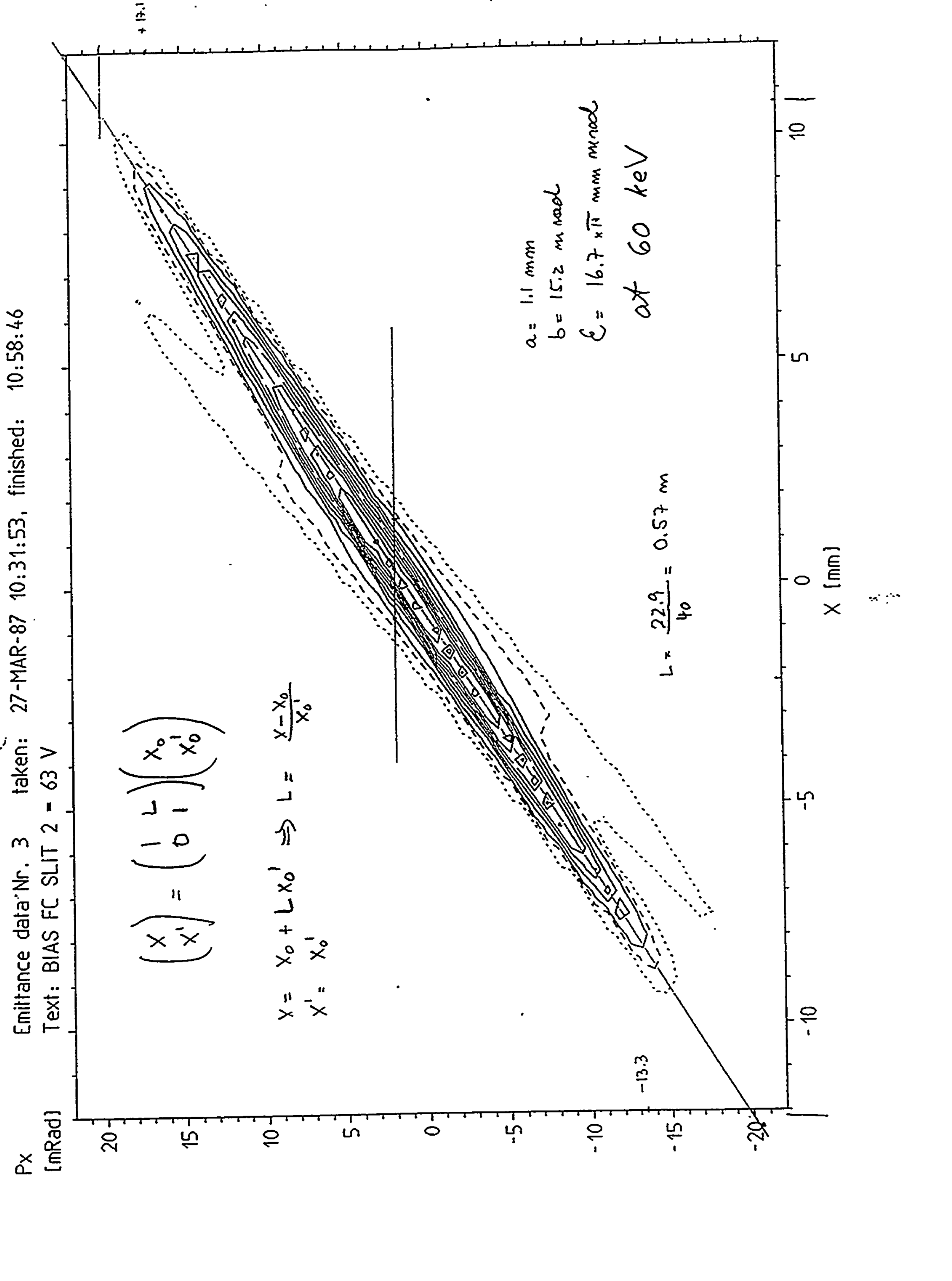
$\hat{I} \simeq 4?$ mA

$\langle I \rangle$ @ 72 MeV = 1.5 mA [0.5 mA LOST IN COLLIMATORS (V+h) IN FIRST 4 TURNS INJ. II)
($\Delta\phi \simeq 12° \equiv 0.7$ ns)



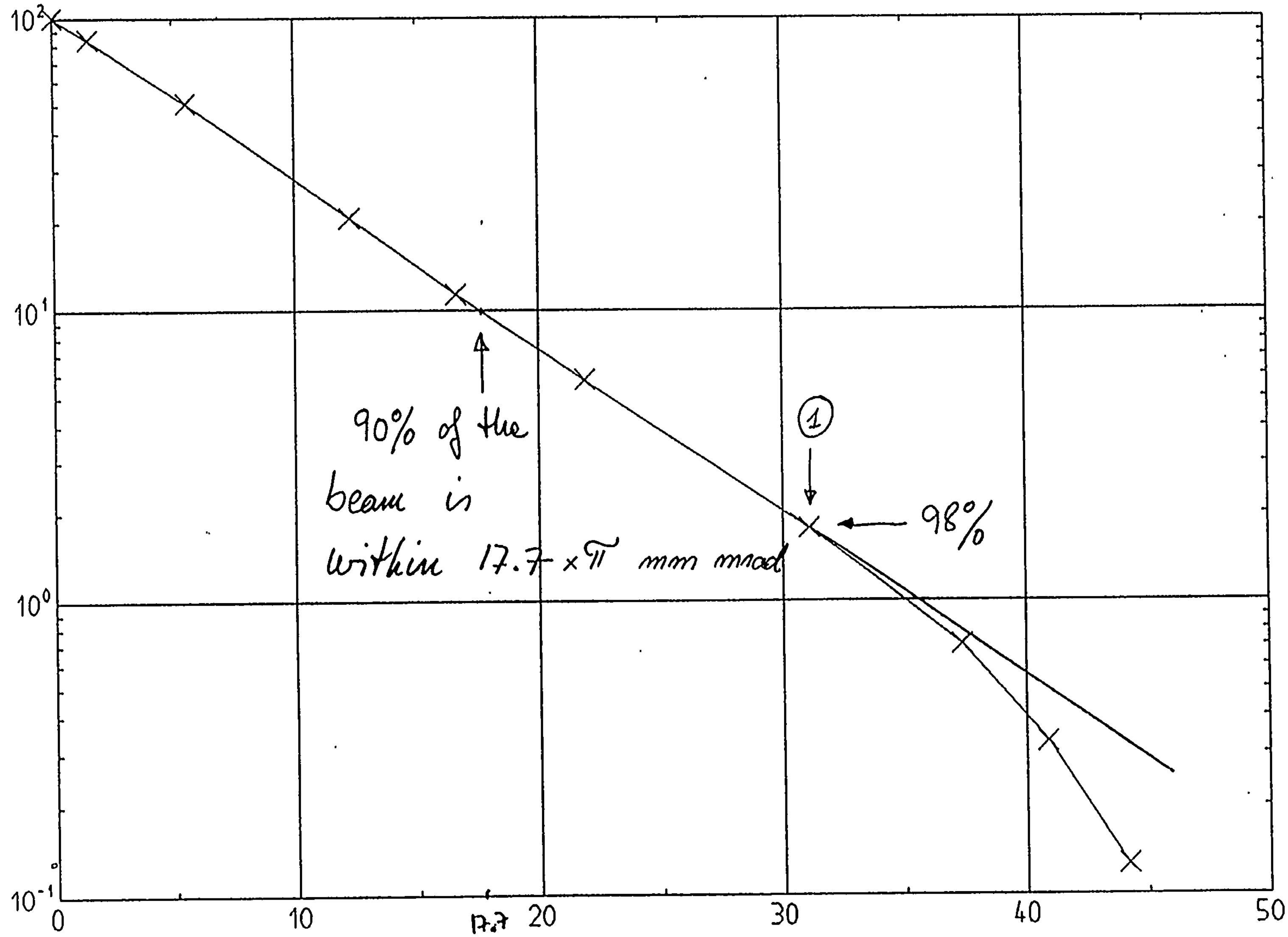
HIGH VOLTAGE DOME
ION SOURCE
TMP 2000 l/s
0
60cm
WVB1
KV1
WVB2
SOLENOIDS
SV1x,2y
500 Hz
CHOPPER (KICKER MAGNET)
KV2 = BV4 (IRIS)
SV3x,4y
SF6
ACCELERATION TUBE
FW1x,2y
MWL1x,2y
SW1x,2y
CRYO PUMP
MWL3x,4y
QW1
MWP1x,2y
QW2
FW4y
SW3x,4y
MWP3x,4y
KWI3
FW3x
FGA
QW3
KWI5
QW4
870keV BEAM LINE

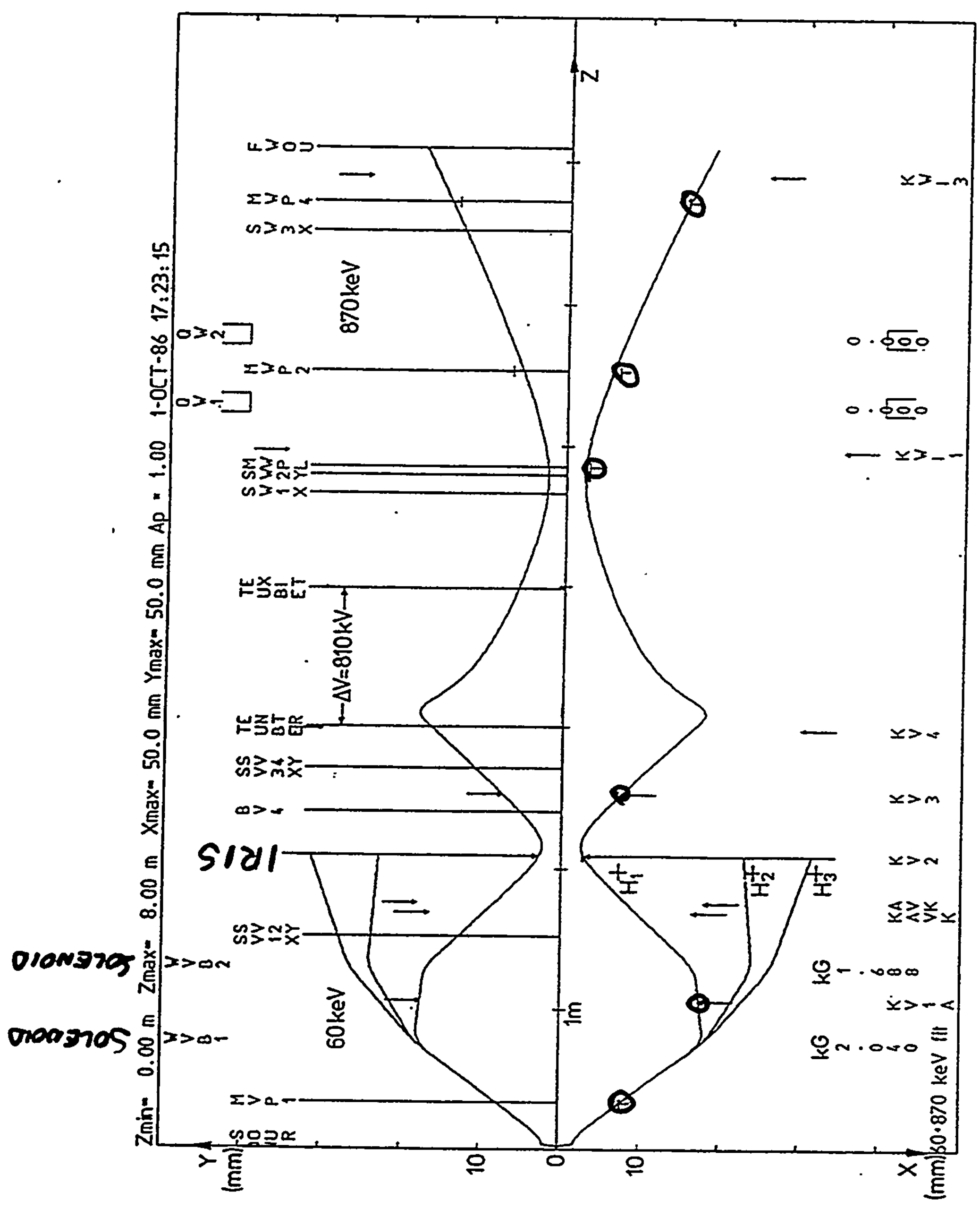

** SLIT SCAN ** Started: 27-MAR-87 10:31:53, finished: 10:58:46
Text: BIAS FC SLIT 2 = 63 V
60 KeV
Start Slit1 = -12.0 mm
End Slit1 = 12.0 mm
Step Slit1 = 0.5 mm
Start Slit2 = -18.0 mm
Step Slit2 = 0.2 mm
570 mm
0.1
0.1 mm
FC
SLIT 1
SLIT 2
MOTOR 1
MOTOR 2
FC = FARADAY CUP MOVES TOGETHER WITH SLIT 2
(Arb. units)
X (mm)
Slit Nr 2 scan at given Slit Nr. 1 positions


Emittance data Nr. 3 taken: 27-MAR-87 10:31:53, finished: 10:58:46
Text: BIAS FC SLIT 2 = 63 V
Px [mRad]
20
15
10
5
0
-5
-10
-15
-20
X [mm]
-10
-5
0
5
10
+17.1
-13.3
(X X') = (1 L 0 1)(X₀ X₀')
X = X₀ + L X₀' ⇒ L = (X − X₀)/X₀'
X' = X₀'
a = 1.1 mm
b = 15.2 mrad
ε = 16.7 × π mm mrad
at 60 keV
L ≈ 22.9/40 = 0.57 m

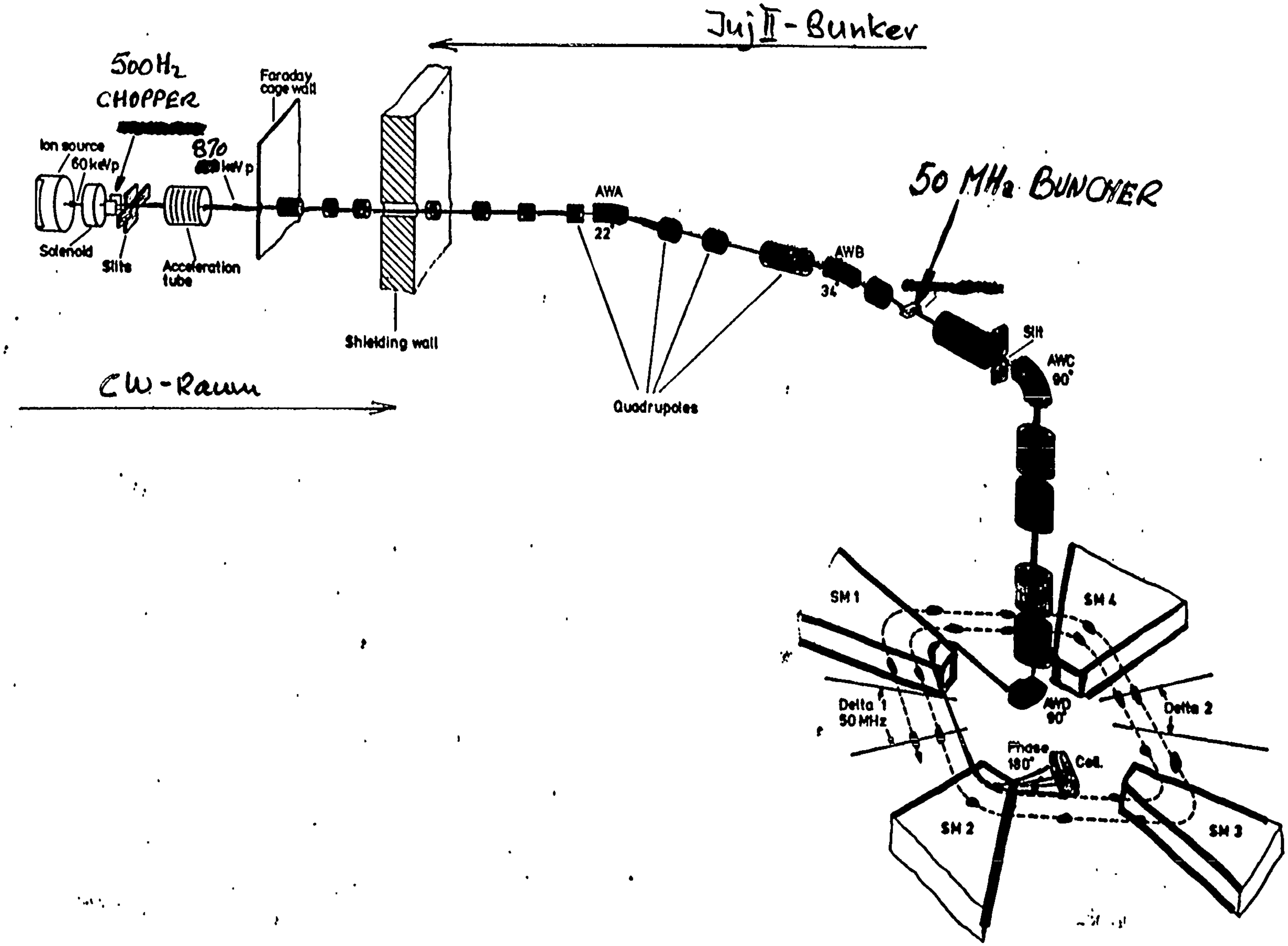
Emittance data Nr. 3 taken: 27-MAR-87 10:31:53, finished: 10:58:46

Text: BIAS FC SLIT 2 = 63 V





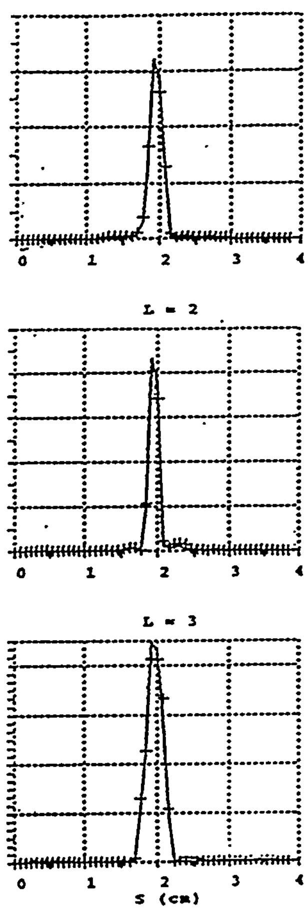
"TRANSPORT" FIT

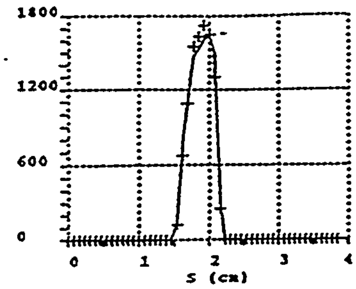

Juj II - Bunker
500 Hz
CHOPPER
Faraday cage wall
Ion source
60 keVp
870 keV p
Solenoid
Slits
Acceleration tube
Shielding wall
CW - Raum
AWA
22°
Quadrupoles
AWB
34°
50 MHz BUNCHER
Slit
AWC
90°
SM 1
SM 4
AWD
90°
Delta 1
50 MHz
Delta 2
Phase
180°
Coll.
SM 2
SM 3

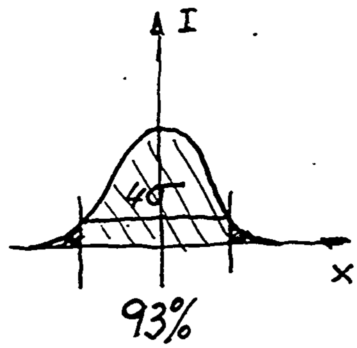
STRAHLTOMOGRAPHIE

(870keV - Strahl, 8mA, 13.11.1991)

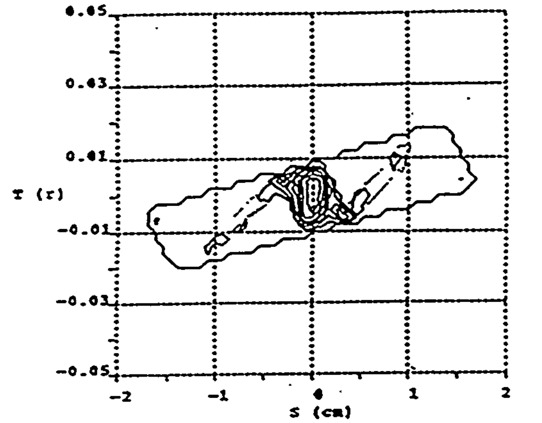
vertikale Strahlprofile

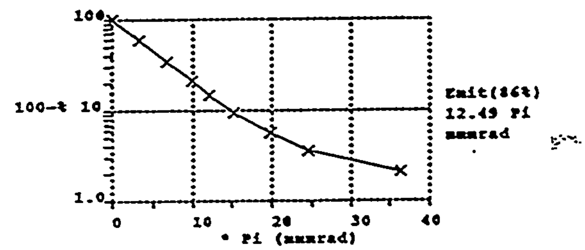


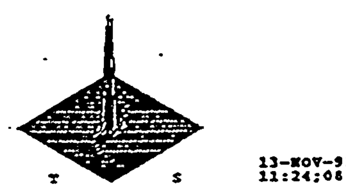


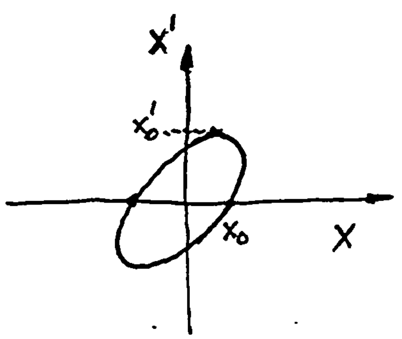


Emittanzfläche



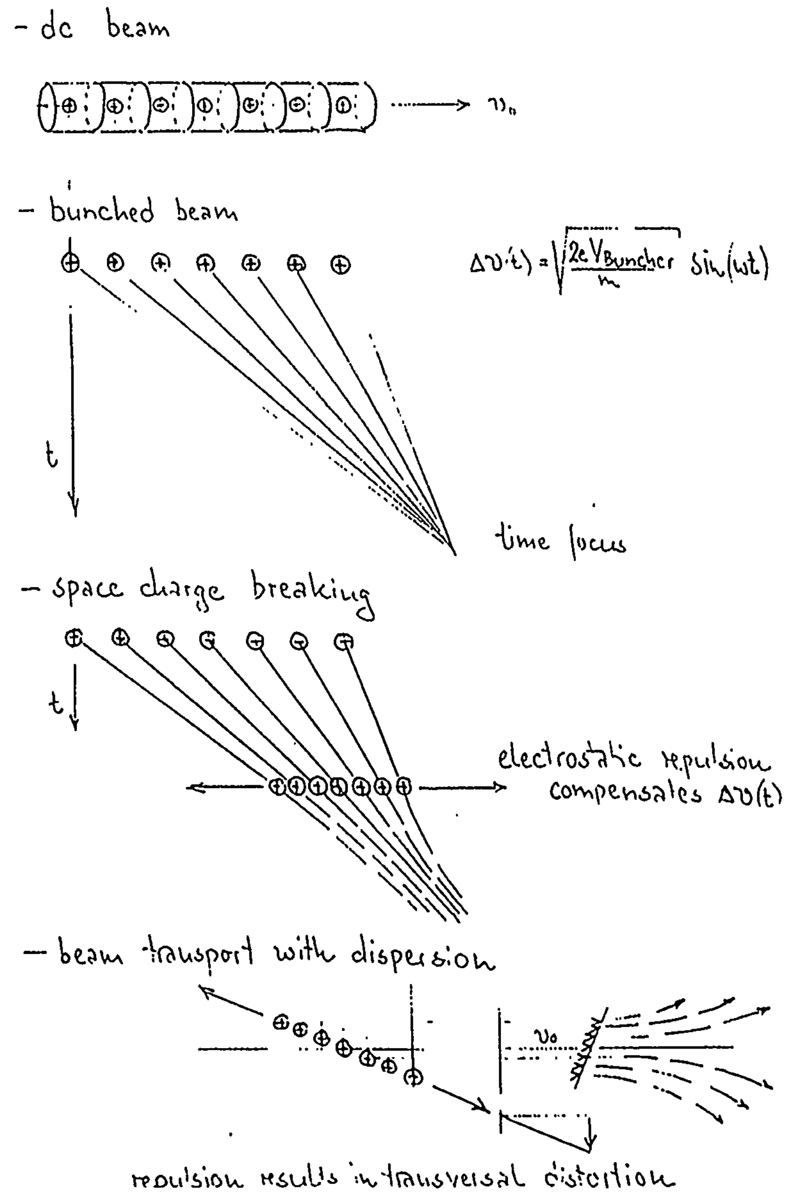




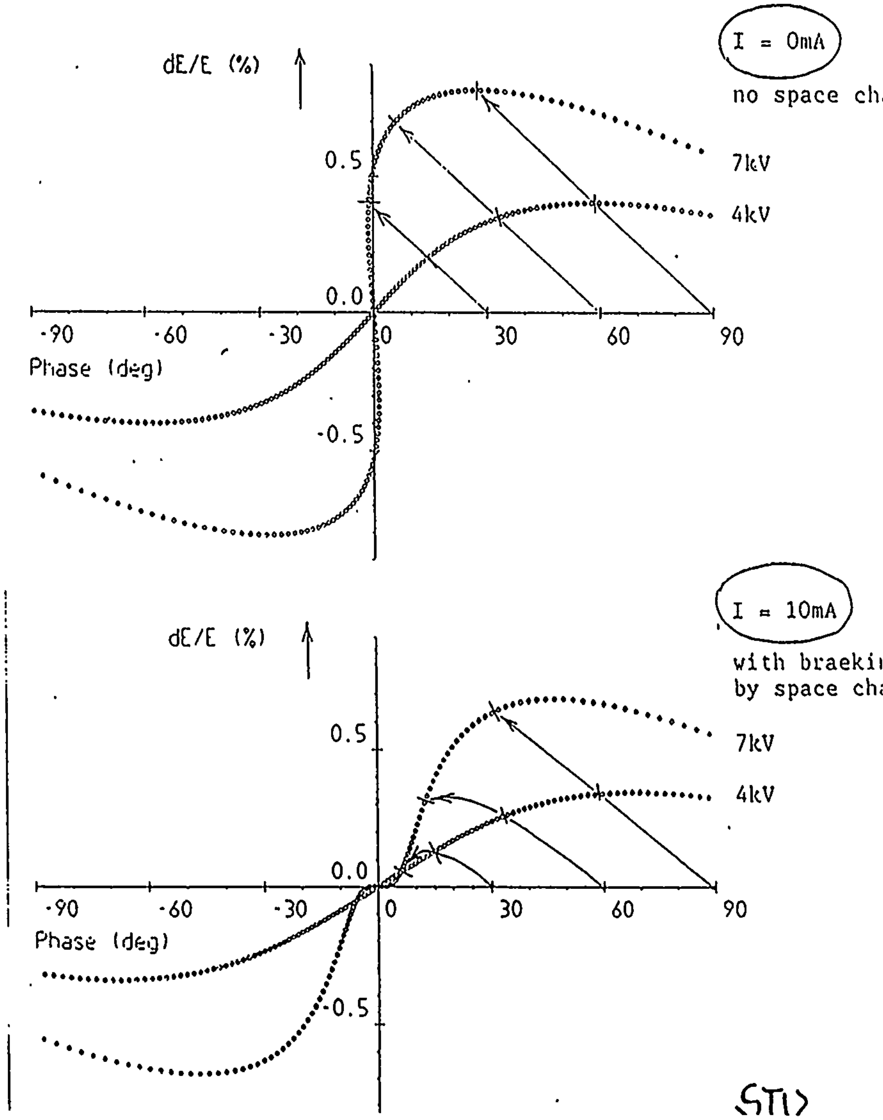


$\varepsilon = \pi x_0 \cdot x_0'$ [86%]

STI2

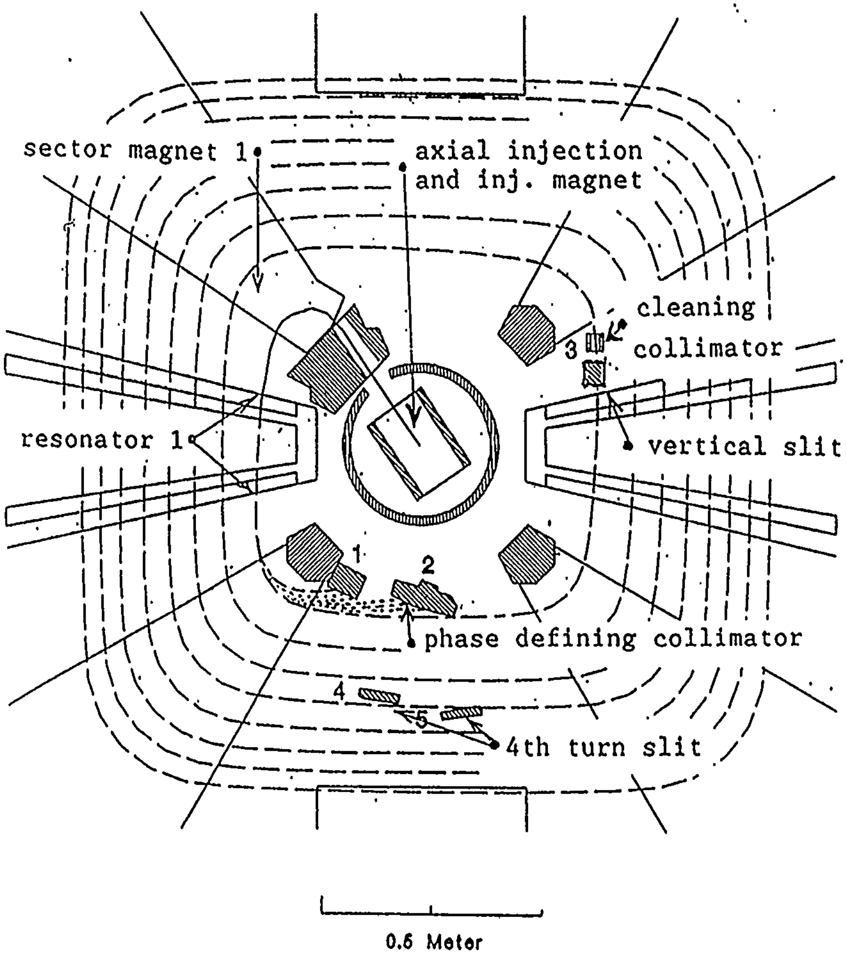


ENERGY SPREAD in a BUNCHED BEAM



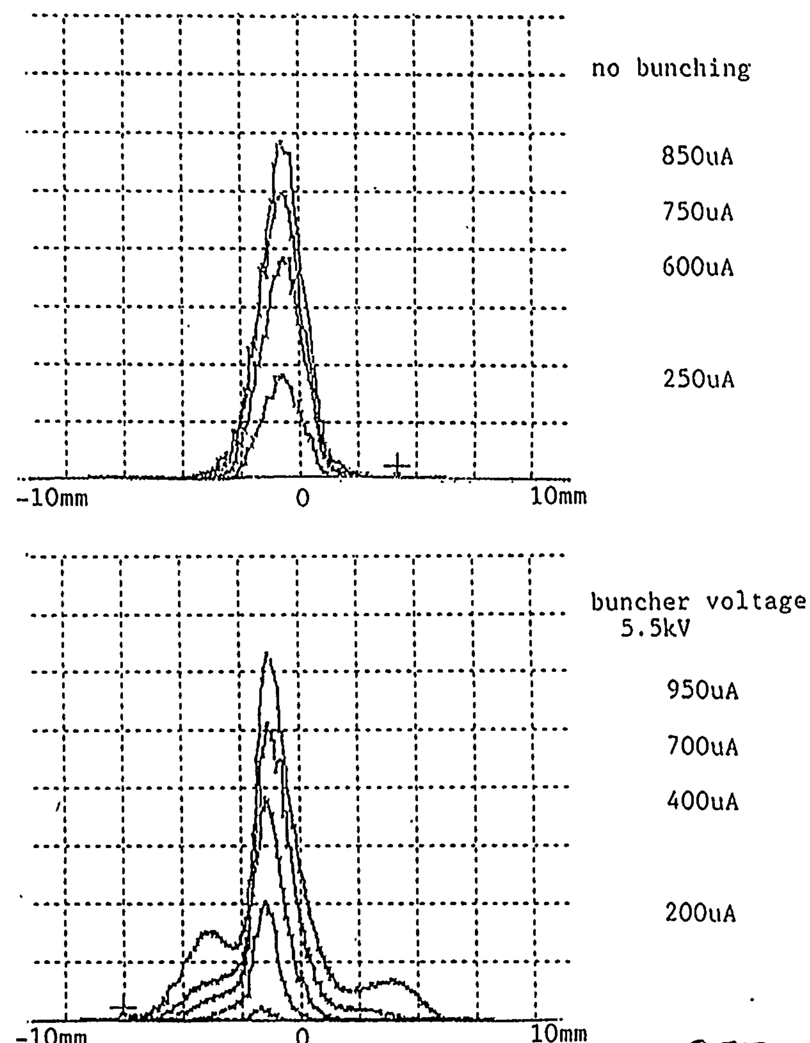
STI

CENTER REGION INJECTOR 2



EFFECT of BUNCHING on the VERTICAL BEAM PROFILES

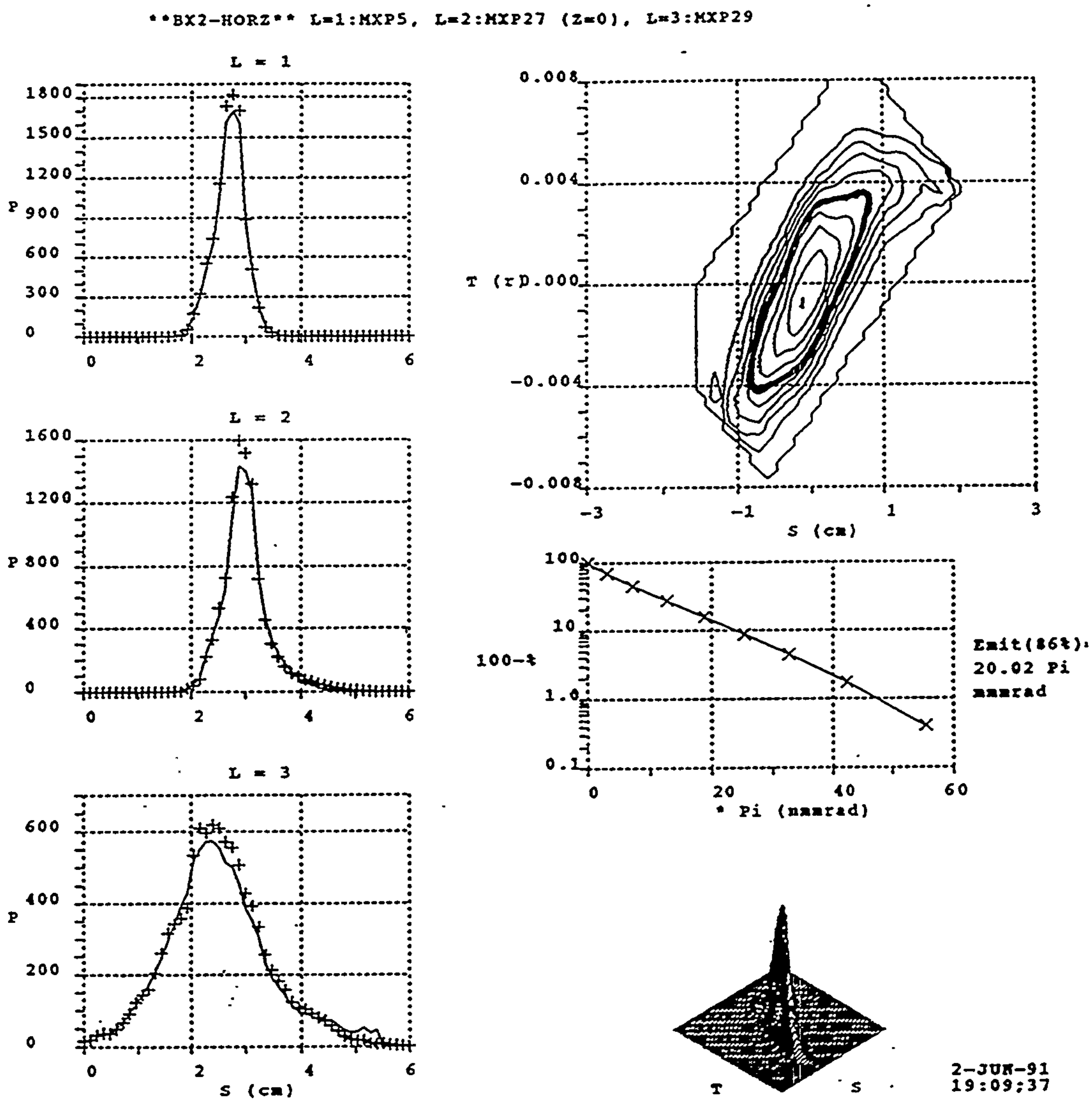
1st orbit in Injector 2



ST12

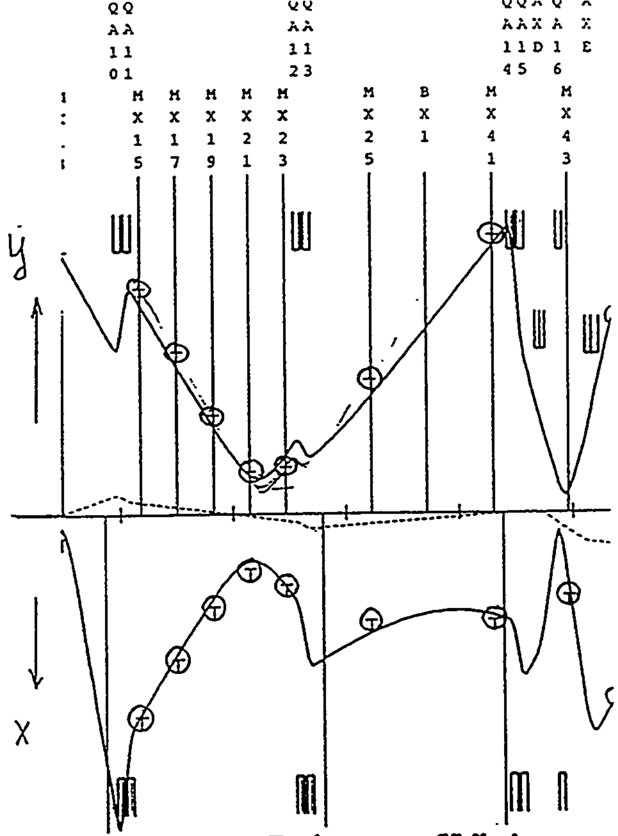
INJ.2 STRAHLTOMOGRAPHIE bei 1.5mA

2.6.1991



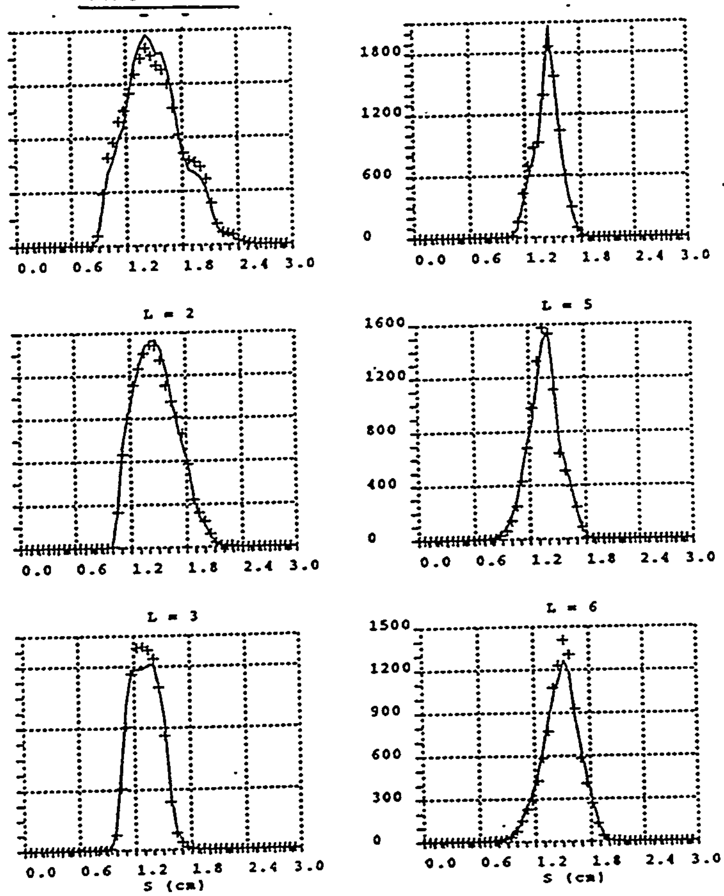
ST12

TOMOGRAPHIE - STRECKE
im
72MeV INJEKTIONSWEG

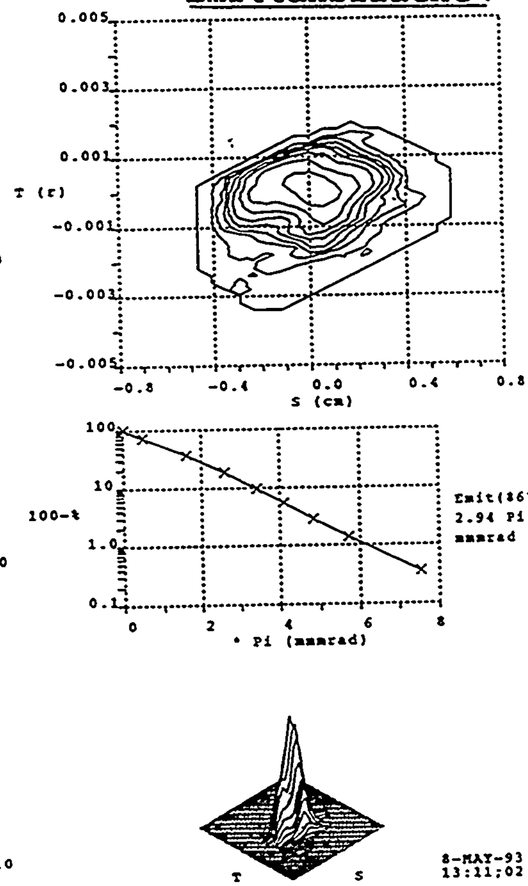


500μA, 8.Mai 1993

Profile:



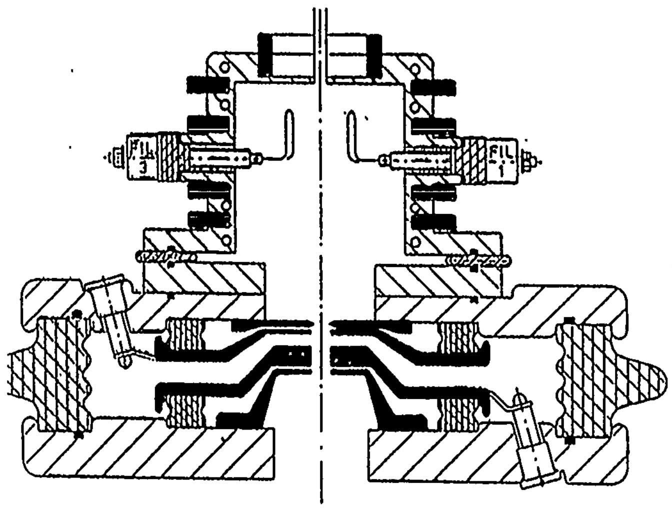
Emittanzfläche:



ST12

CULHAM

FILAMENT DRIVEN



E_{EXTR} = 60 kV

I_{TOTAL} = 55 mA d.c.

EXTR. APER. = 7 mm ø $j \simeq$ 140 mA/cm²

$I_{H_1^+}$ = **21** mA (~38%)

I_{ARC} = 34 A

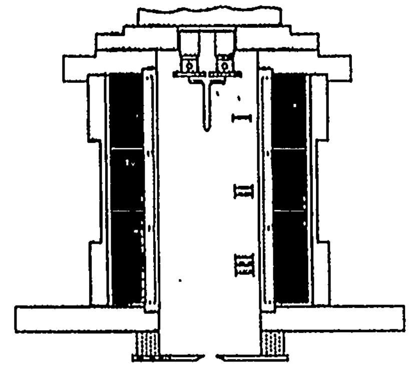
V_{ARC} = 51 V   Z = 1.5 Ω

GAS FLOW = 3 sccm (H_2)

[illegible]

PSI

FILAMENT DRIVEN



E_{EXTR} ≈ 55 kV

I_{TOTAL} ≈ 50 mA d.c.

j ≈ 130 mA/cm²

$I_{H_1^+}$ = 31 mA (~62%)

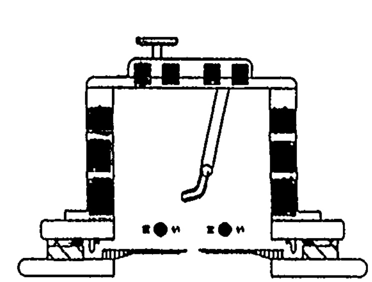
I_{ARC} = 85 A

V_{ARC} = 61 V   Z ≈ 0.7 Ω

GAS FLOW = 3 sccm

LBL

TO BE DRIVEN WITH AN ANTENNA (2 MHz) TESTED WITH FILAMENTS



E_{EXTR} = 30 kV

I_{TOTAL} = 21 mA d.c.

$I_{H_1^+}$ = 14 mA (68°)

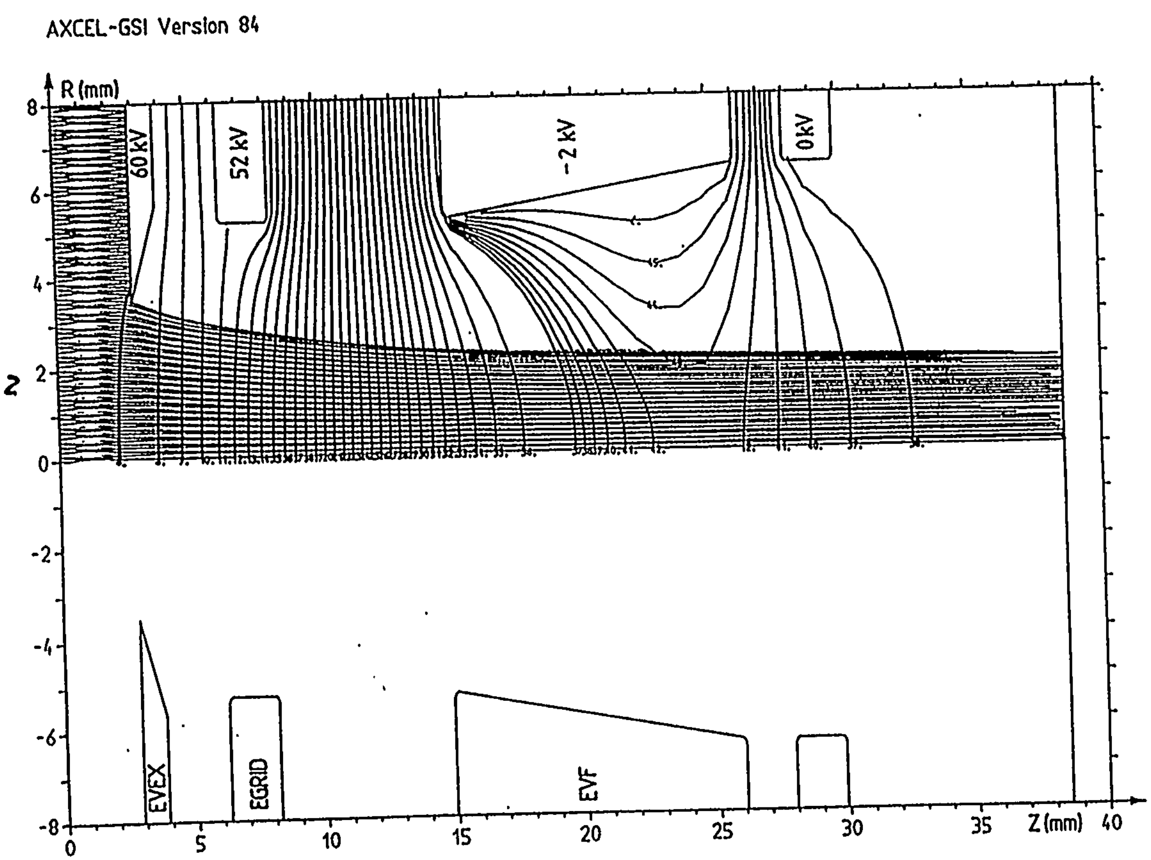
I_{ARC} = **70** A

V_{ARC} = 91 V   Z ≈ 1.3 Ω

GAS FLOW = 3 sccm

j = 55 mA/cm²

PSI EXTRACTION GEOMETRY



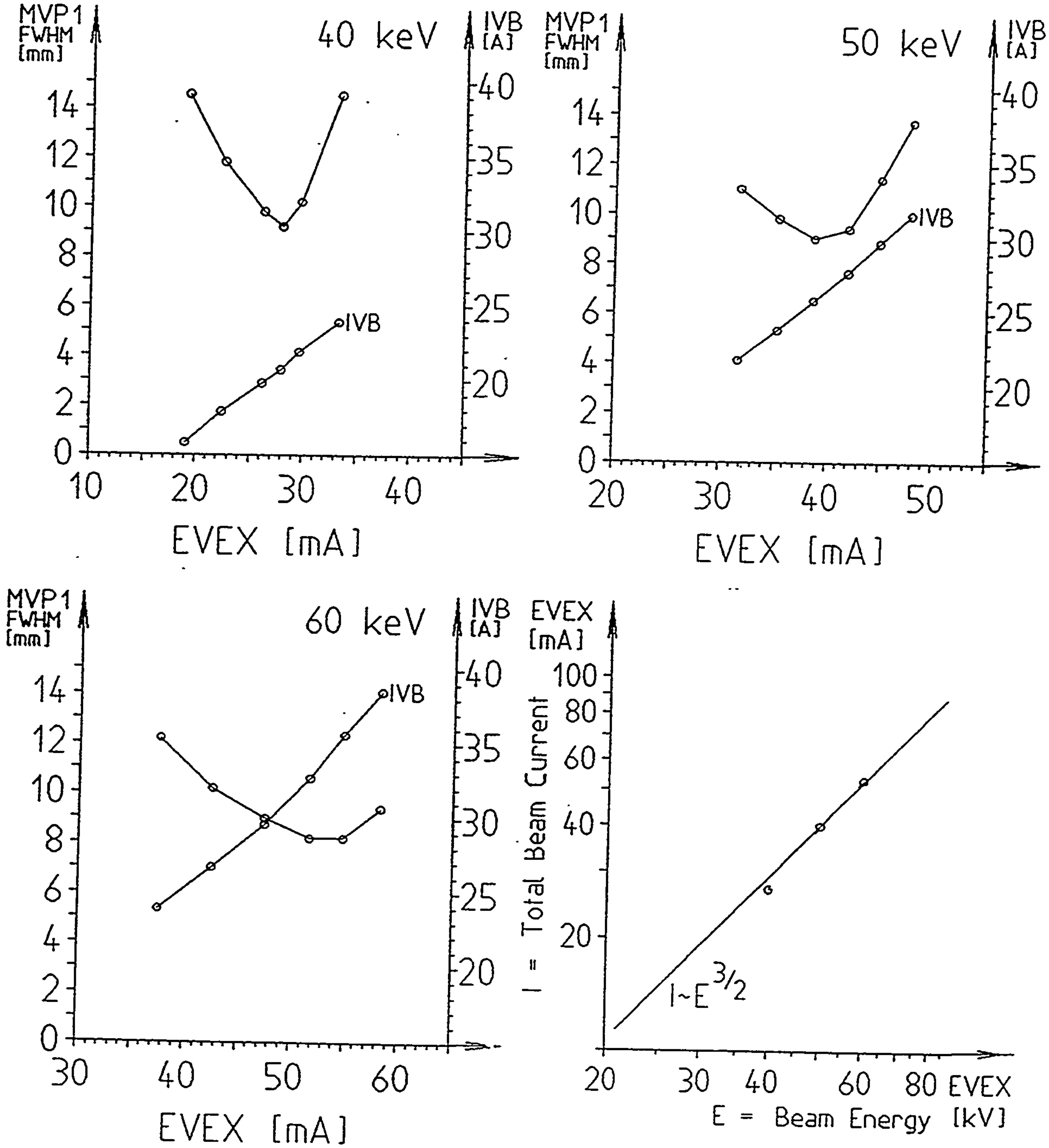
$j = 140\ mA/cm^2$

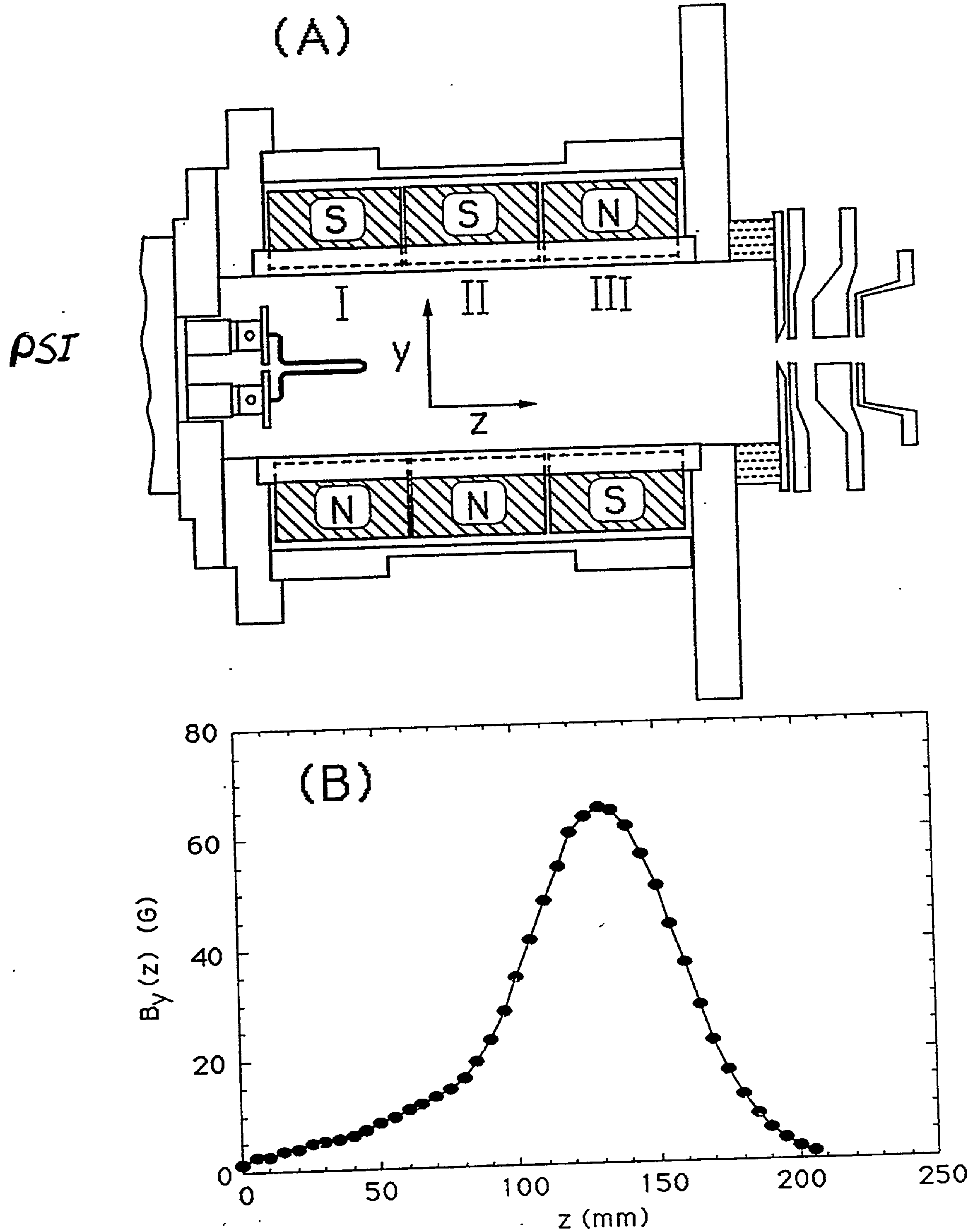
$T_e = 5\,eV$

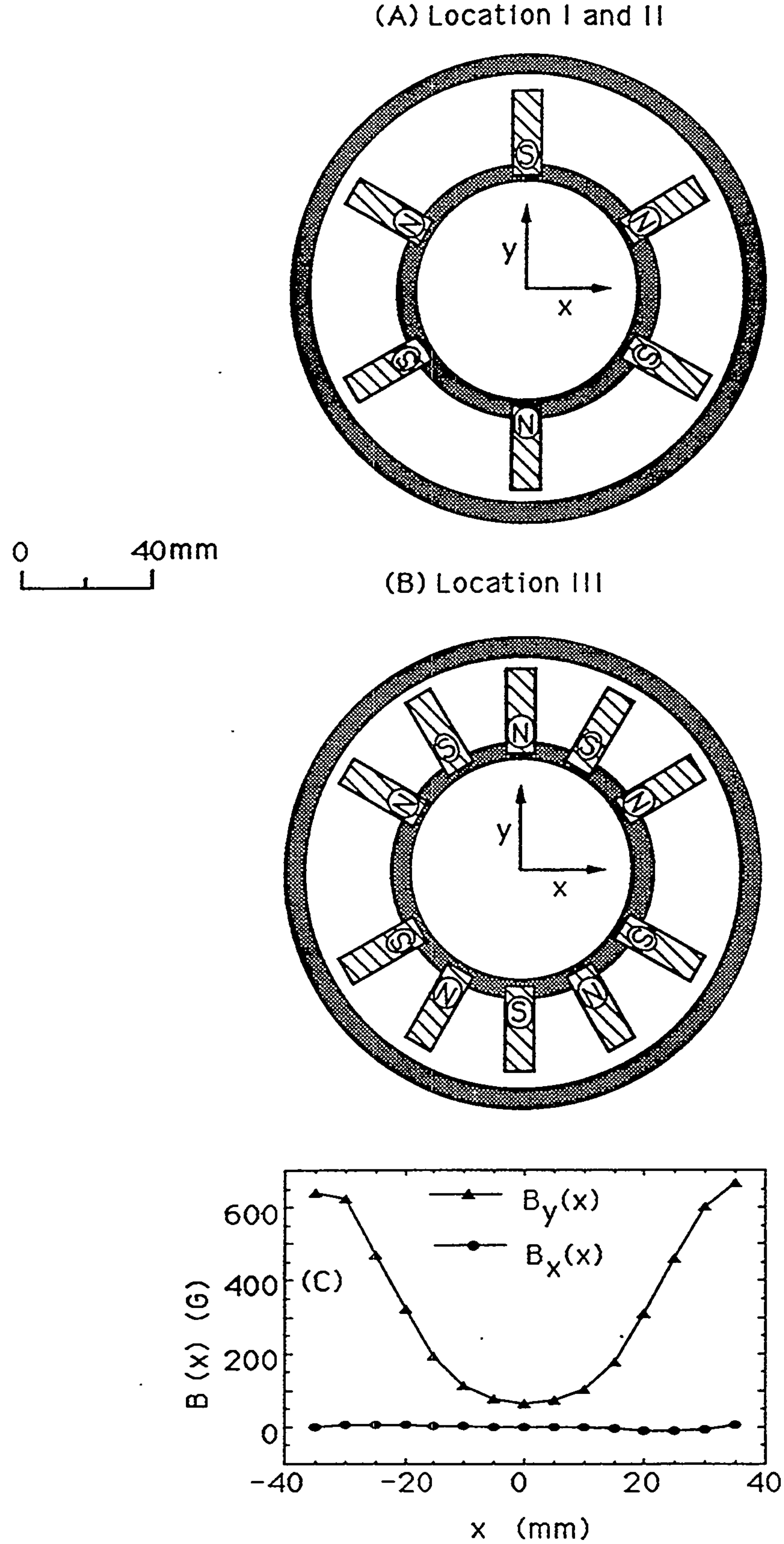
$T_i = 0.6\,eV$

$\left\langle \frac{M}{Z} \right\rangle = 1.78$

CULHAM

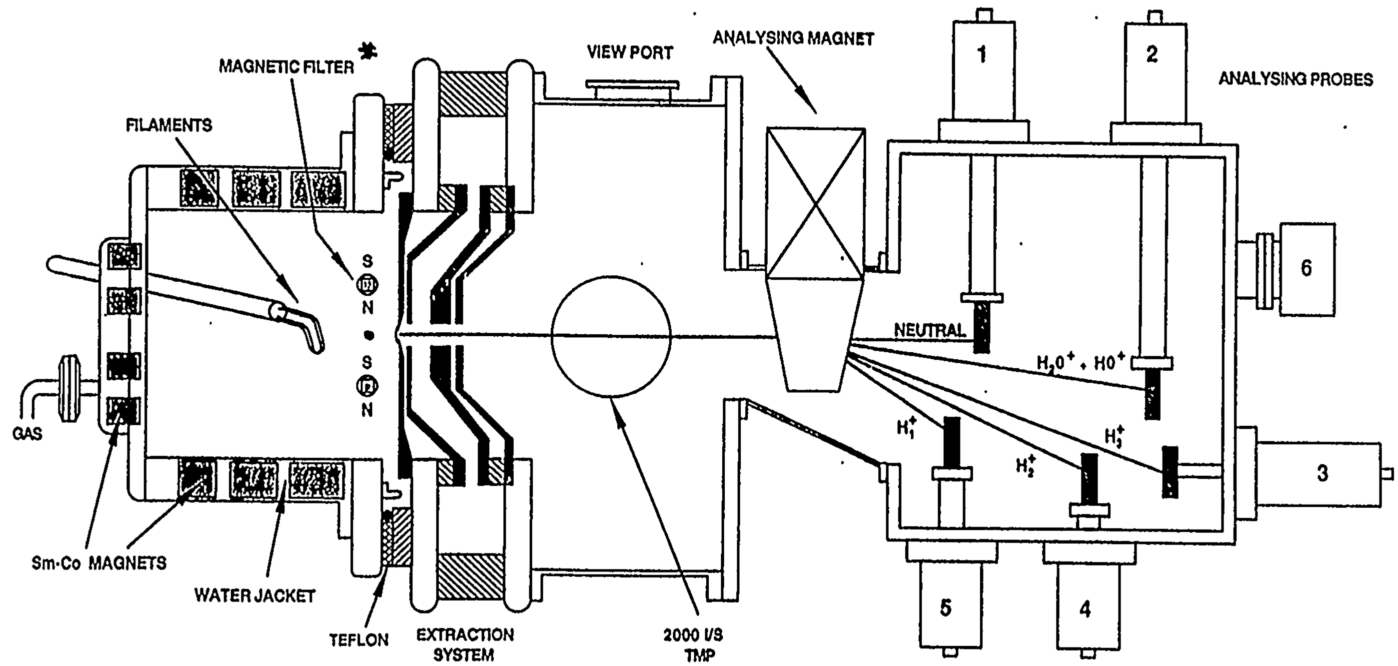

MVP1 FWHM [mm]
40 keV
IVB [A]
IVB
EVEX [mA]
50 keV
60 keV
EVEX [mA]
I = Total Beam Current
I~E^3/2
E = Beam Energy [kV]


(A)
S
S
N
I
II
III
PSI
y
z
N
N
S
(B)
80
60
40
20
0
$B_y(z)$ (G)
0
50
100
150
200
250
z (mm)


(A) Location I and II
S
N
N
S
S
N
y
x
0
40mm
(B) Location III
N
S
S
N
N
S
S
N
S
N
y
x
By(x)
Bx(x)
(C)
600
400
200
0
B (x) (G)
-40
-20
0
20
40
x (mm)

* B-FIELD = 190 GAUSS (AT MIDPLANE; ON SOURCE AXIS) "•"

LBL



The PSI 590 MeV - 1.5 mA proton accelerator facility consists of a 72 MeV isochronous injector cyclotron and a 590 MeV isochronous ring cyclotron.
The design goal calling for a 1.5 mA beam at 72 MeV has been reached by the injector cyclotron
An 870 keV - 8 mA d.c. beam from a Cockcroft-Walton pre-injector drives the injector cyclotron. Strong bunching at 870 keV is required to achieve the 1.5 mA at 72 MeV.

The pre-injector consists of an ion source, a 60 keV BTS, and an 810 kV acceleration column. The ions are generated in a filament driven multicusp volume source (Culham design) and extracted through a 7 mm dia. aperture using a four-electrode configuration
The ion source characteristics and operation values to produce an 8 mA proton beam at 870 keV are:

(2)

MULTICUSP VOLUME SOURCE

ARC CHAMBER : 10 cm × 10 cm × 10 cm

4 ROWS OF 3.5 kG FACE FIELD Sm-Co MAGNETS

4 (2×2) FILAMENTS W-1.5% ThO₂ 1.5 mm dia., 10 cm LONG

OPERATED TYPICALLY AT 6V, 2×95A

GAS FLOW : 3 sccm H_2 ; ARC CHAMBER PRESSURE: 4.7 mT

ARC DISCHARGE : 40 V, 24 A

TETRODE EXTRACTION CONFIGURATION : 60 kV/52 kV/-2 kV/0

EXTRACTION APERTURE : 7 mm dia. ⟹ 0.38 cm^2

TOTAL ION EXTRACTION CURRENT : 36 mA d.c. (95 mA/cm^2)

H_1^+ = 12 mA (~33% PROTON EFFICIENCY)

H_1^+ = 8.6 mA THROUGH 810 kV ACC. TUBE

(3.4 mA ARE REMOVED IN THE 60keV-B.T.S. COLLIMATORS)

NORMALIZED EMITTANCES [π mm mrad] [90%]

8.6 mA @ 60 KeV (BEFORE TUBE) = 0.2

8.6 mA @ 870 KeV (AFTER TUBE) = 0.35

8.1 mA @ 870 KeV (AT BUNCHER) = 0.55

(0.5 mA, MOSTLY $H_2^+ + H_3^+$, ARE REMOVED IN THE 870 keV-B.T.S.)

The lifetime of the two pairs of filaments is about 1 month of continuos operation.

The arc power supply is current regulated. The power in the discharge is kept constant via regulation in the filament supply.

—o—

The beam intensity stability is better than 0.2%. The beam reproducibility after e.g. filament changes is excellent. The "noise" in the beam, typically in the 100 kHz, ~~[illegible]~~ is less than 5% peak to peak. (The stability of the source IS VERY IMPORTANT when you deal with a MW beam). LOSSES!! ⇒ ACTIVATION!!

In 1995, after completion of the power upgrade program in the R.F. system of the ring cyclotron, a 1.5 mA beam at 590 MeV (0.9 MW) is anticipated.

After traversing the PSI meson production targets, and subsequent collimation, 0.9 mA at 570 MeV (~0.5 MW) will be available at the spallation neutron production target (SINQ). The SINQ facility is expected to go into operation early in 1996.

An increase in the beam power delivered to SINQ from 0.5 MW to 0.7 MW is readily made by reducing ~~[illegible]~~ the thickness of the second meson target (a beam of

about 1.2 mA at 580 MeV for SINQ)
A second step, from 0.7 MW to about 0.9 MW, may require major changes in the Ring acceleration system (new cavities), further beam development to circumvent the detrimental space charge effects, mainly in the injector cyclotron, and an increase in the beam intensity delivered by the 870 keV Cockcroft-Walton pre-injector by a factor of ~2.5.
The last step is of course the easiest to achieve.

M. OLIVO
BERKELEY, OCT 21, 1994

Proton Ion Sources for LANSCE II

R. Stevens

Los Alamos National Laboratory

PROTON ION SOURCES for LANSCE II

Presented by Ralph R. Stevens, Jr.
October 25, 1994

Topics

- LAMPF duoplasmatron ion source
- CRL cw microwave proton ion source
- Development of a 75 keV, 140 mA injector for high current linacs.

Los Alamos

Beam Requirements for LANSCE II Linac-Only Mode

- Pulse lengths between 0.5 and 1.0 ms
- 60 Hz repetition rate

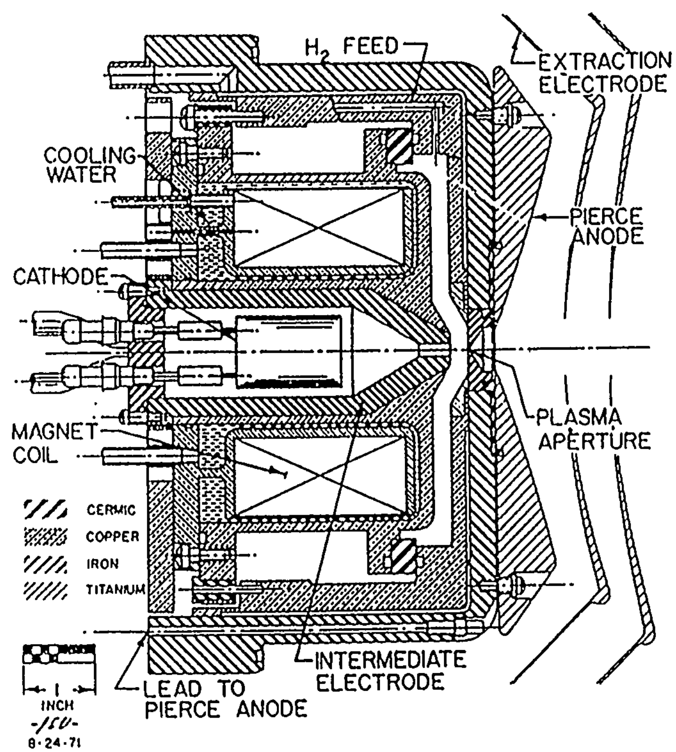
1 MW Option

- Peak H+ beam currents on target of:
  - For 800 MeV beams, 42 mA/21mA for 0.5/1.0 ms pulse lengths

5 MW Option

- Peak H+ beam currents on target of:
  - For 800 MeV beams, 210 mA/105mA for 0.5/1.0 ms pulse lengths
  - For 2 GeV beams, 84mA/42mA for 0.5/1.0 ms pulse lenghs
- Required ion source currents will be 25% to 50% larger depending on the choice of ion source and capture efficiency of the accelerator.

LAMPF Duoplasmatron Ion Source



- 30 mA of protons at 12% duty factor (1000 μs at 120 Hz)
- High gas and arc efficiency - source operates with 8A Arc and 1 sccm
- Normalized, rms emittance of 0.0065 πcm-mrad at input to linac
- Lifetime of source under operating conditions is >5000 hours
- Beam stability and noise meet LAMPF requirements

Los Alamos

Line Drawing of Microwave Proton Source*

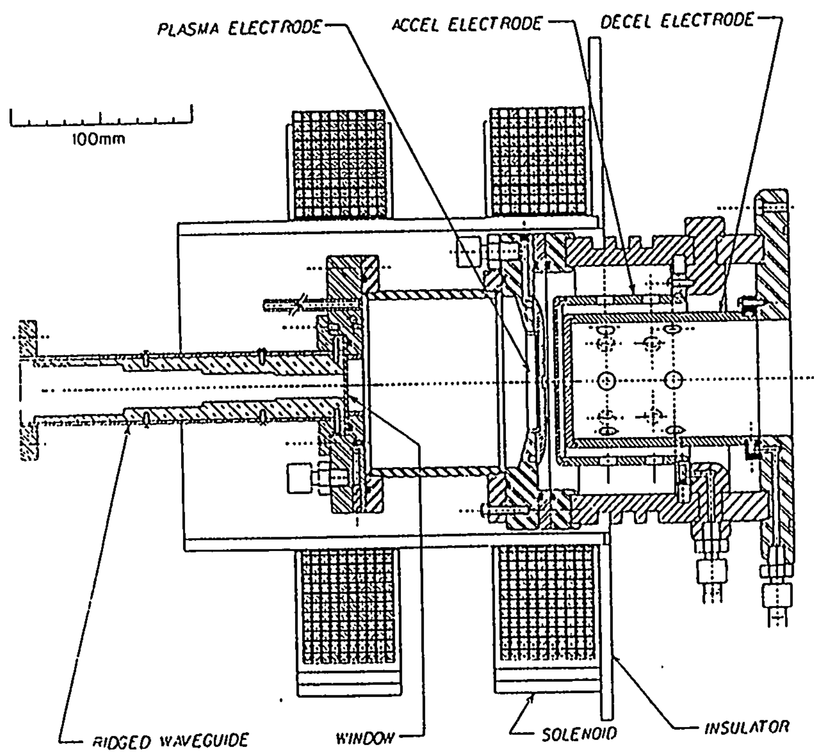


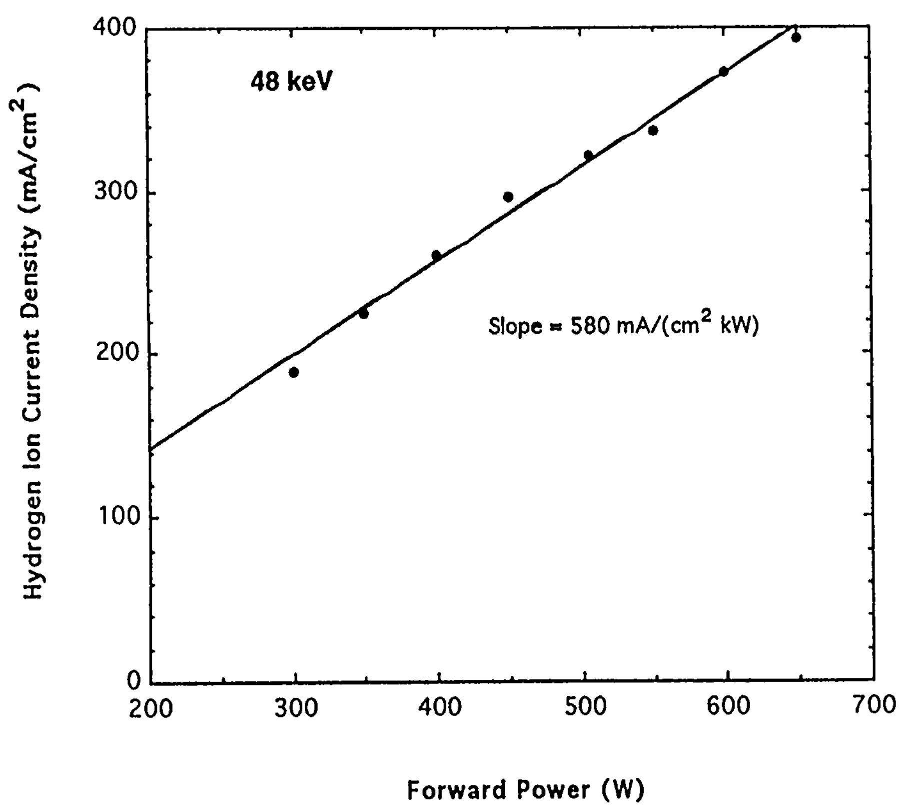
Fig. 2. High-current low-emittance microwave proton source.

- Solenoids establish ≈ 900 G on axis field.
- 2.45 GHz microwaves provide ≈ 600 W power to the hydrogen discharge.
- The discharge is self-igniting at 300 W power with the source pressure at 1 - 3 mTorr

*Terence Taylor and Jozef Mouris, Nucl. Instrum. and Methods in Phys. Res., A336 (1993), 1-5.

Los Alamos

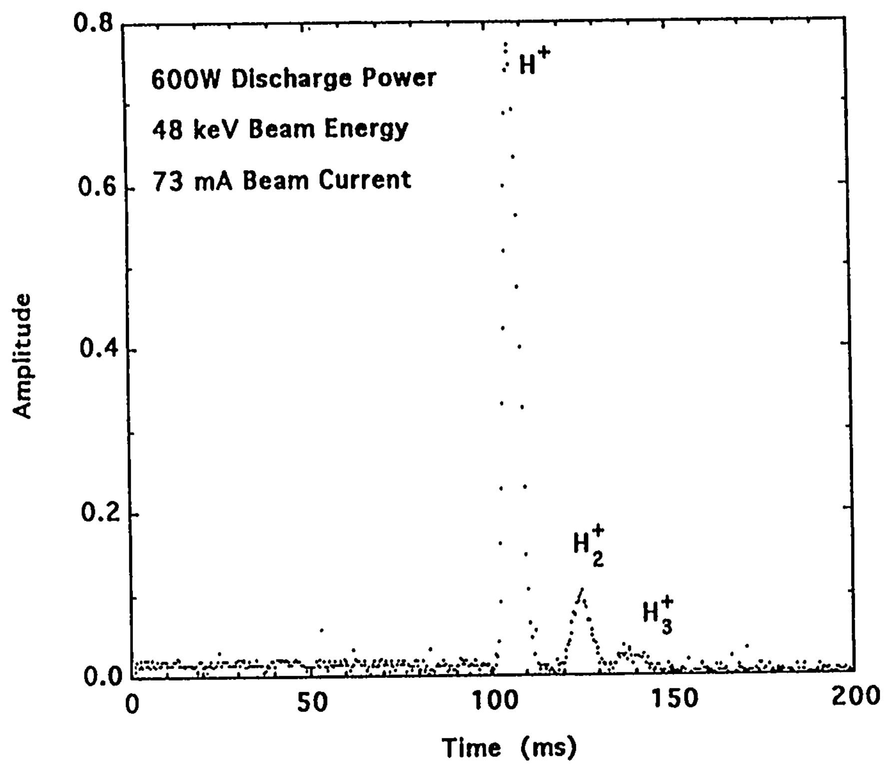
Hydrogen Ion Current Density vs. Forward Power



- Measurements made at Los Alamos in dc mode.
- Typical operation used 600 - 700 W forward power, yielding 75 mA hydrogen ion beam.
- Consistency among most of the beam current measurements is ≤ 5%.
- Proton beam efficiency = proton beam fraction X 580 = 480 mA/(cm^2kW)

Los Alamos

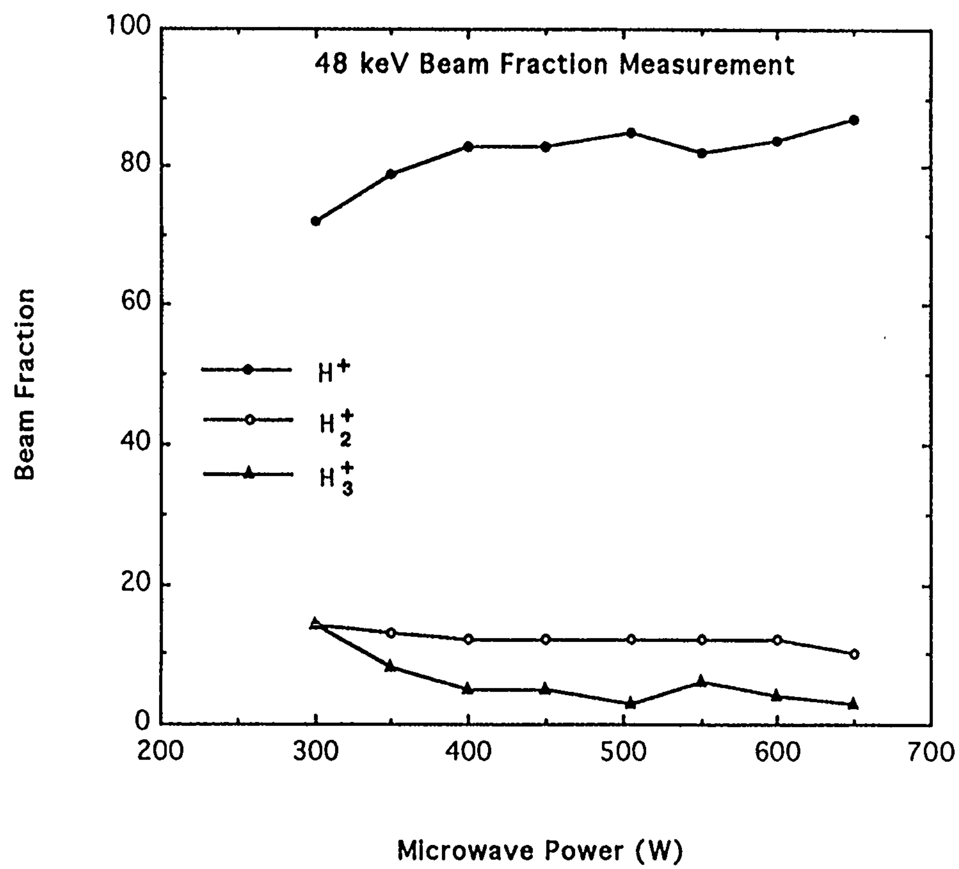
Hydrogen Ion Beam Species Measurement



- Beam is sampled after the emittance measuring unit(EMU) main slit.
- Beam is analyzed by a ramped dipole magnetic field, and the H^+, H_2^+, and H_3^+ species currents are collected in a Faraday cup 30.5 cm from the main slit.
- Measured beam fraction: H^+:H_2^+:H_3^+ = 84:12:4%.
- The LEBT solenoid is turned off to ensure a homogeneous hydrogen ion beam.

Los Alamos

Measured Beam Fraction as Function of Discharge Power



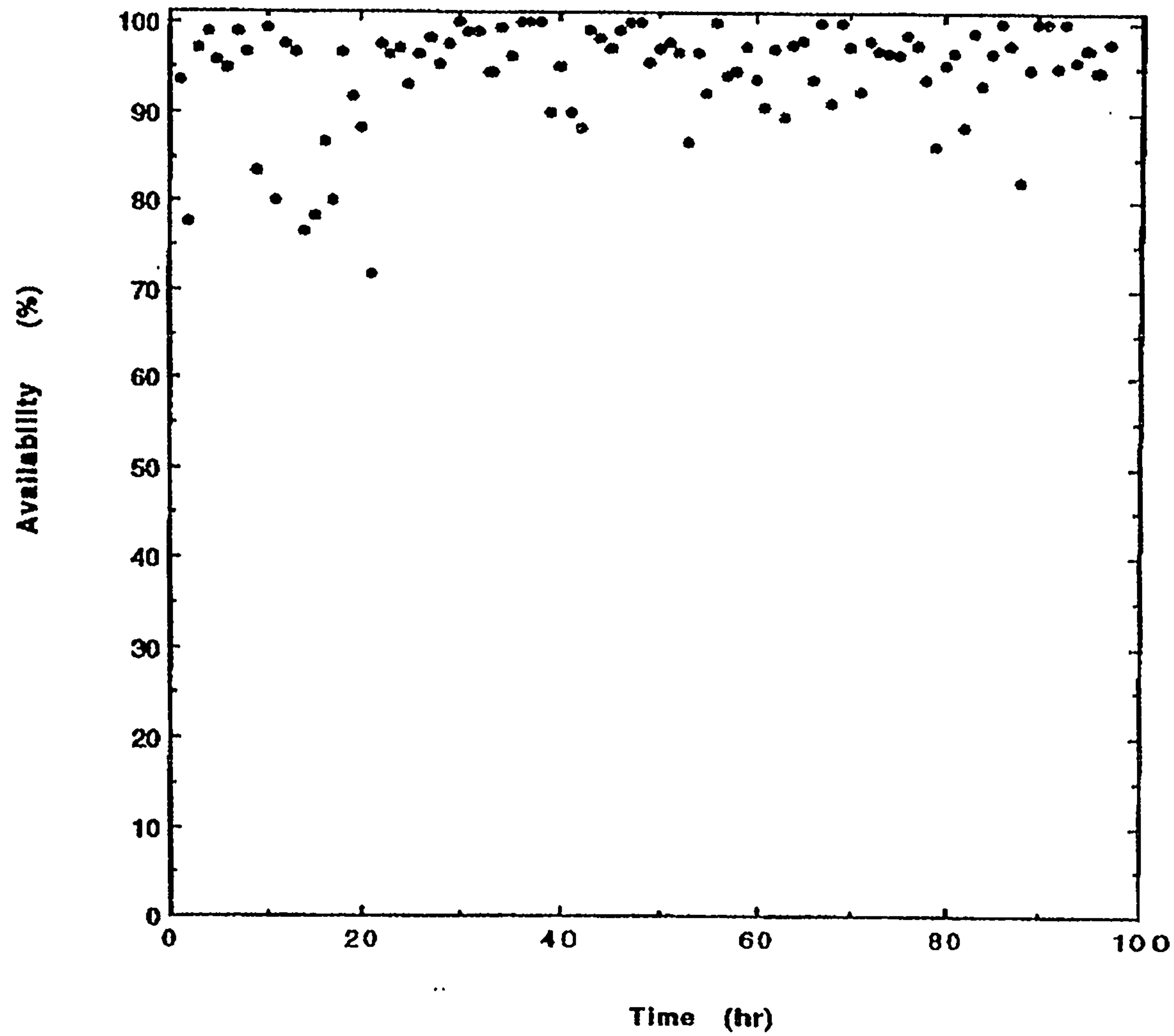
- Beam fractions are measured as a function of 2.45 GHz microwave power.
- A ramped dipole magnetic field was used to separate the hydrogen ion species.
- The H^+ beam fraction increases slowly with discharge power.

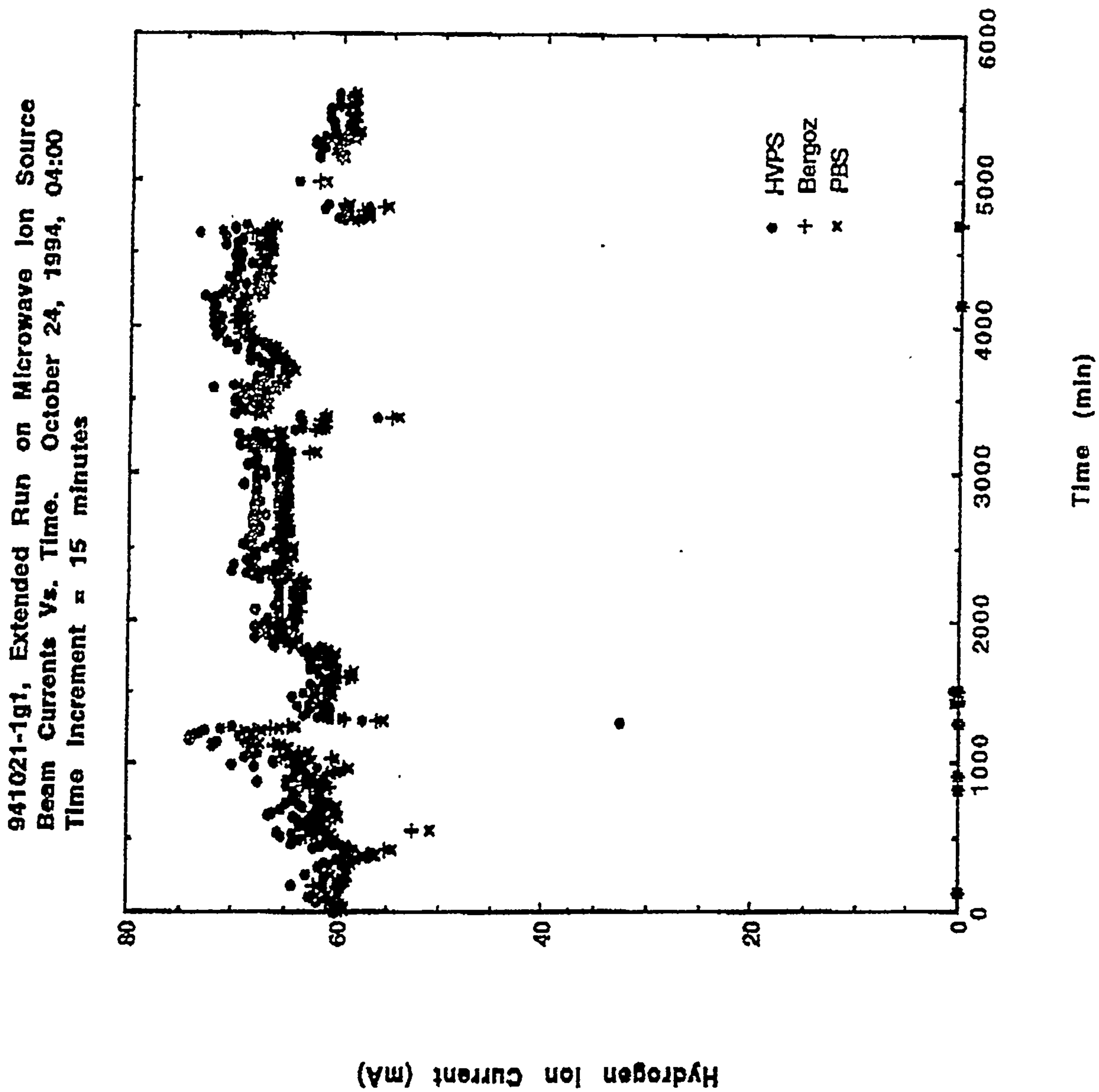
Microwave Ion Source Performance at CRL and Los Alamos (dc mode)

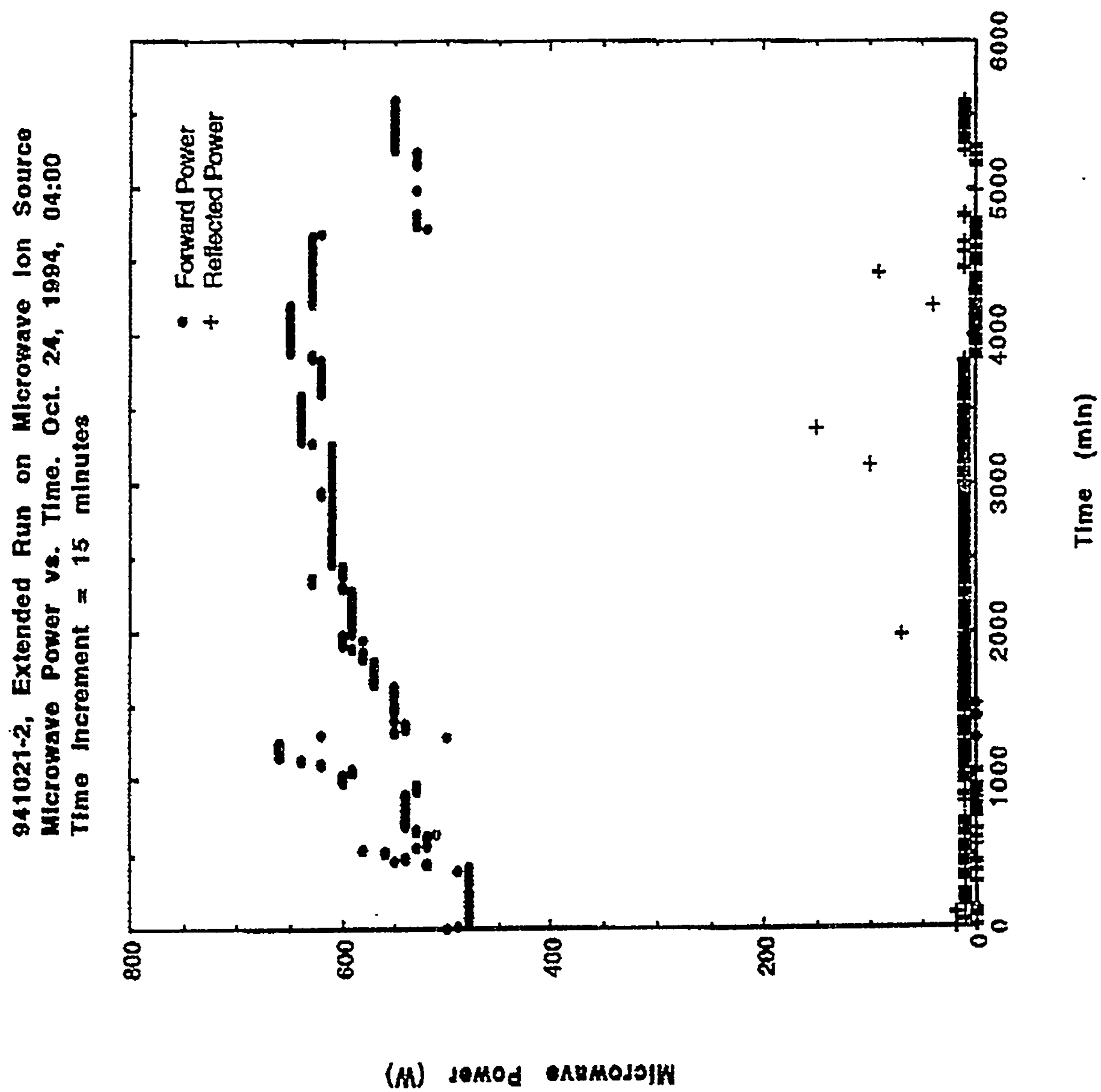
- Demonstrated operation:
  - 100 - 200 hours dc operation at CRL for RFQ development (80 mA).
  - 60 hours LANL, LEBT measurements (60 - 80 mA).
- Measured dc mode emittance: 0.12 πmm-mrad @ 80 mA
  - emitter radius = 2.5 mm
  - extraction gap = 5 mm
- Beam fraction = $H^+:H_2^+:H_3^+$ 84:12:4% (@600W, Q = 2 sccm)
- Beam noise: $\leq 2\%$
- Power efficiency = $j_{H^+}(mA/cm^2)/P_d(kW)$ = 500 mA/(cm^2-kW)
- Gas efficiency = $6.95 i_{H^+}(A)/Q_{H2}(sccm)$ = 0.3

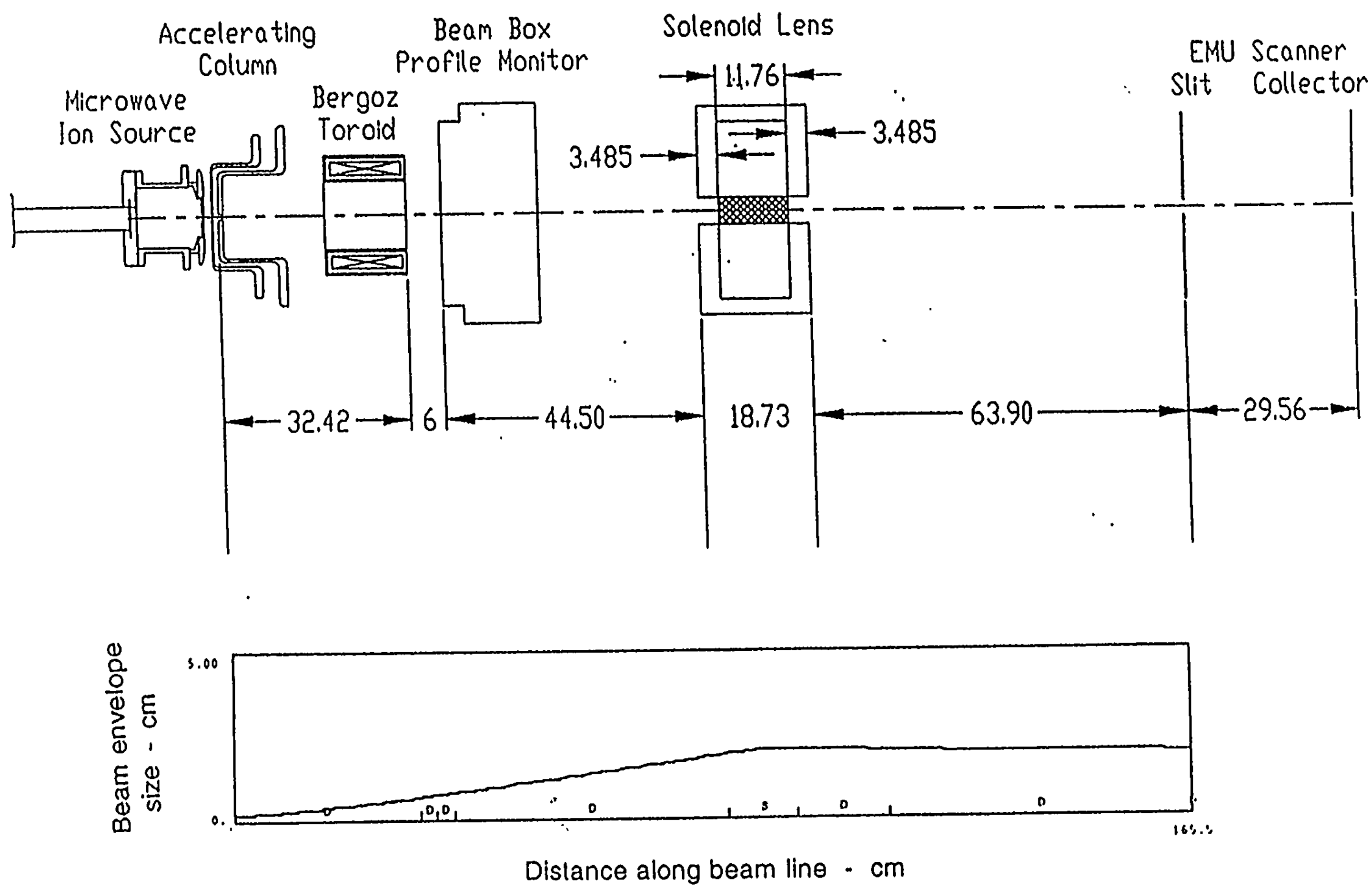
Los Alamos

941020-1g1 Beam Availability Data for Microwave Proton Source
Require > 47 kV, 60 mA. Recorded Hourly.
October 24, 1994, 0800.



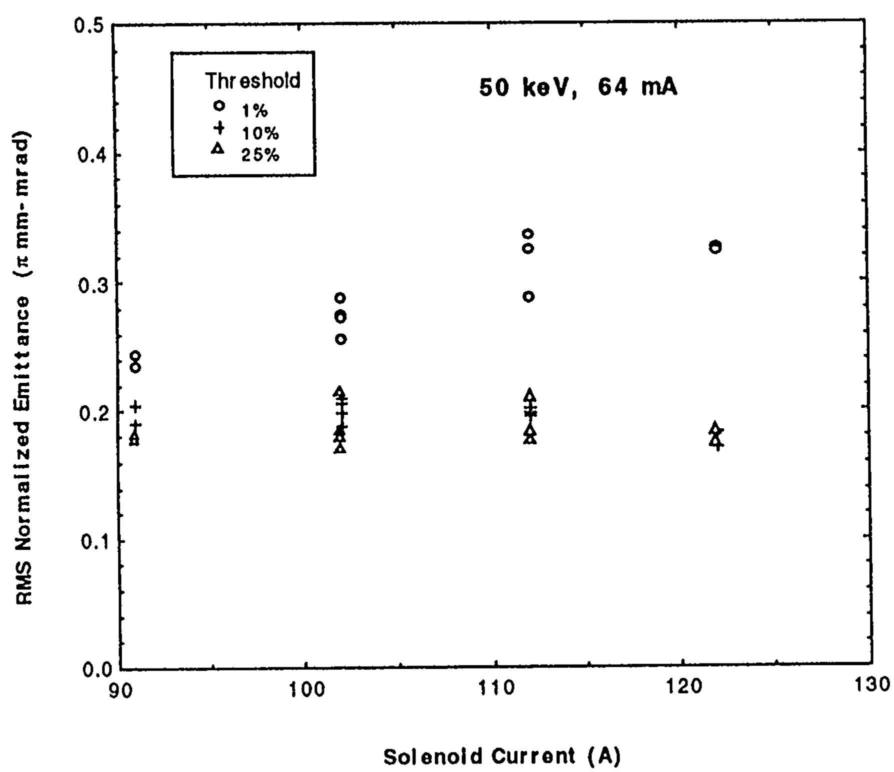

941021-1g1, Extended Run on Microwave Ion Source
Beam Currents Vs. Time. October 24, 1994, 04:00
Time Increment = 15 minutes
Hydrogen Ion Current (mA)
Time (min)
0
20
40
60
80
1000
2000
3000
4000
5000
6000
HVPS
Bergoz
PBS


941021-2, Extended Run on Microwave Ion Source
Microwave Power vs. Time. Oct. 24, 1994, 04:00
Time Increment = 15 minutes
Forward Power
Reflected Power
Microwave Power (W)
Time (min)
0
200
400
600
800
1000
2000
3000
4000
5000
6000



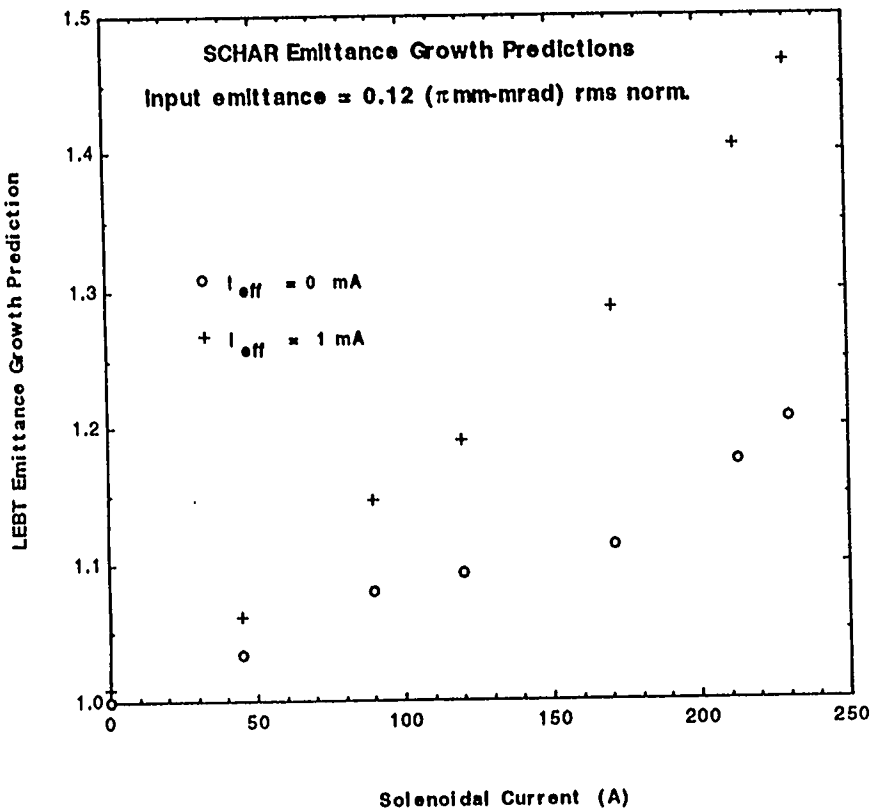
Schematic layout of the single-solenoid LEBT system for beam transport to the EMU. The TRACE envelope simulation for a 50-keV proton beam and 102 A solenoid excitation and with an effective current of 1 mA is shown below.

Summary of LEBT Emittance Measurements



- Normalized rms proton emittances are plotted vs. the LEBT solenoid current at the 1%, 10%, and 25% EMU current thresholds for a 50 keV, 64 mA beam.
- For solenoid currents less than 90 A, not all of the proton current is scanned by the EMU.
- Emittances at 10% and 25% threshold are clustered at 0.2 (πmm-mrad) whereas the 1% threshold emittances are up to 50% greater because of inclusion of H_2^+ and H_3^+ species.
- Ion source only measurements at CRL give rms normalized emittance of 0.12 (πmm-mrad), thus indicating a 70% emittance growth in the LEBT.

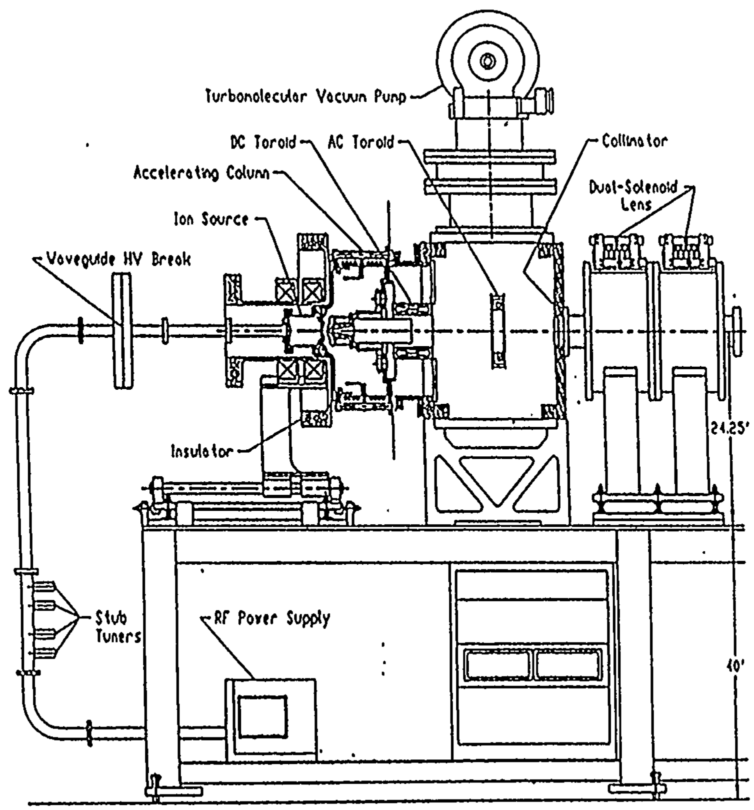
SCHAR Emittance Growth Predictions



- Beam input emittance from CRL ion source alone measurements.
- Beam envelope size and divergence determined from emittance measurements at Los Alamos.
- Emittance growth is observed as the solenoid current is increased. Expect to run RFQ experiments at 213 A solenoid current.
- Inclusion of 1 mA effective current approximately doubles the predicted emittance growth.

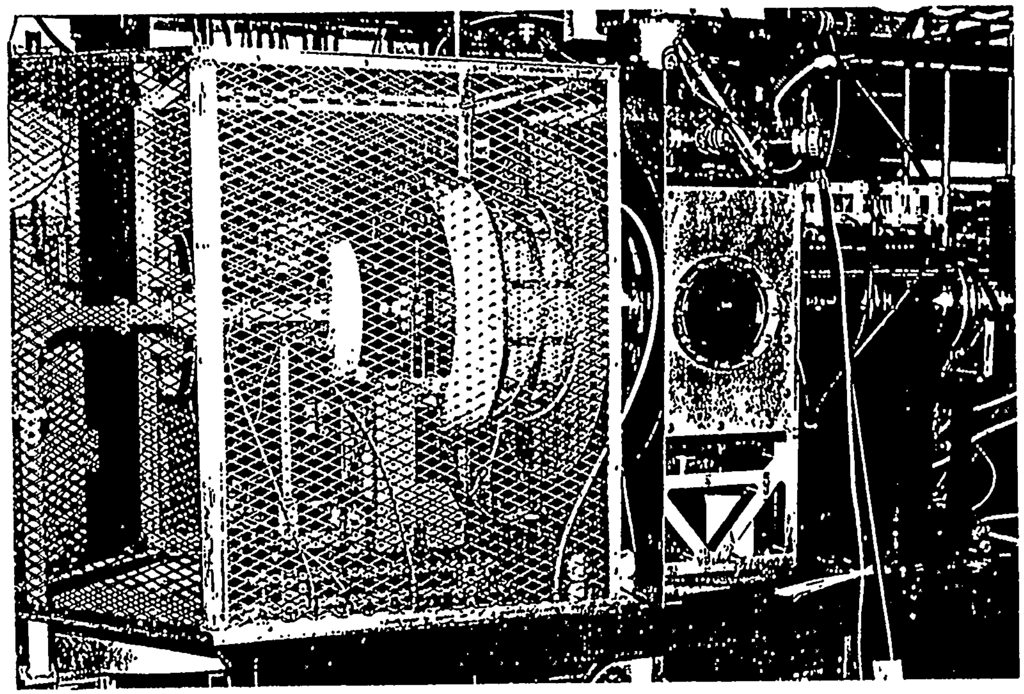
Los Alamos

Schematic Diagram of the APDF Injector



Los Alamos

APDF Injector



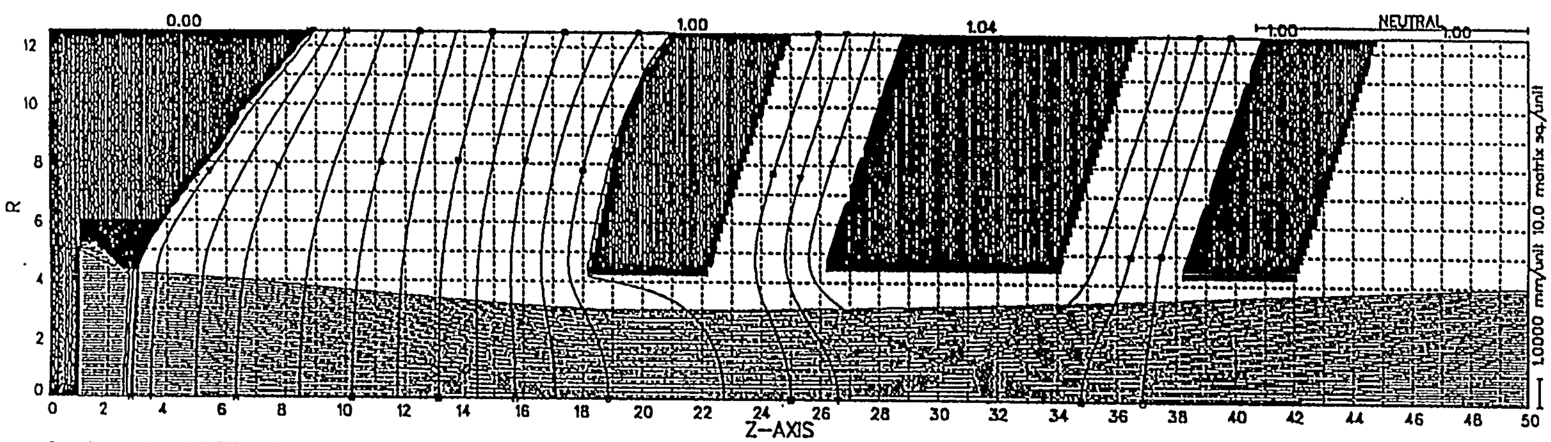
Los Alamos

SNOW Calculation for 75 kV Extractor

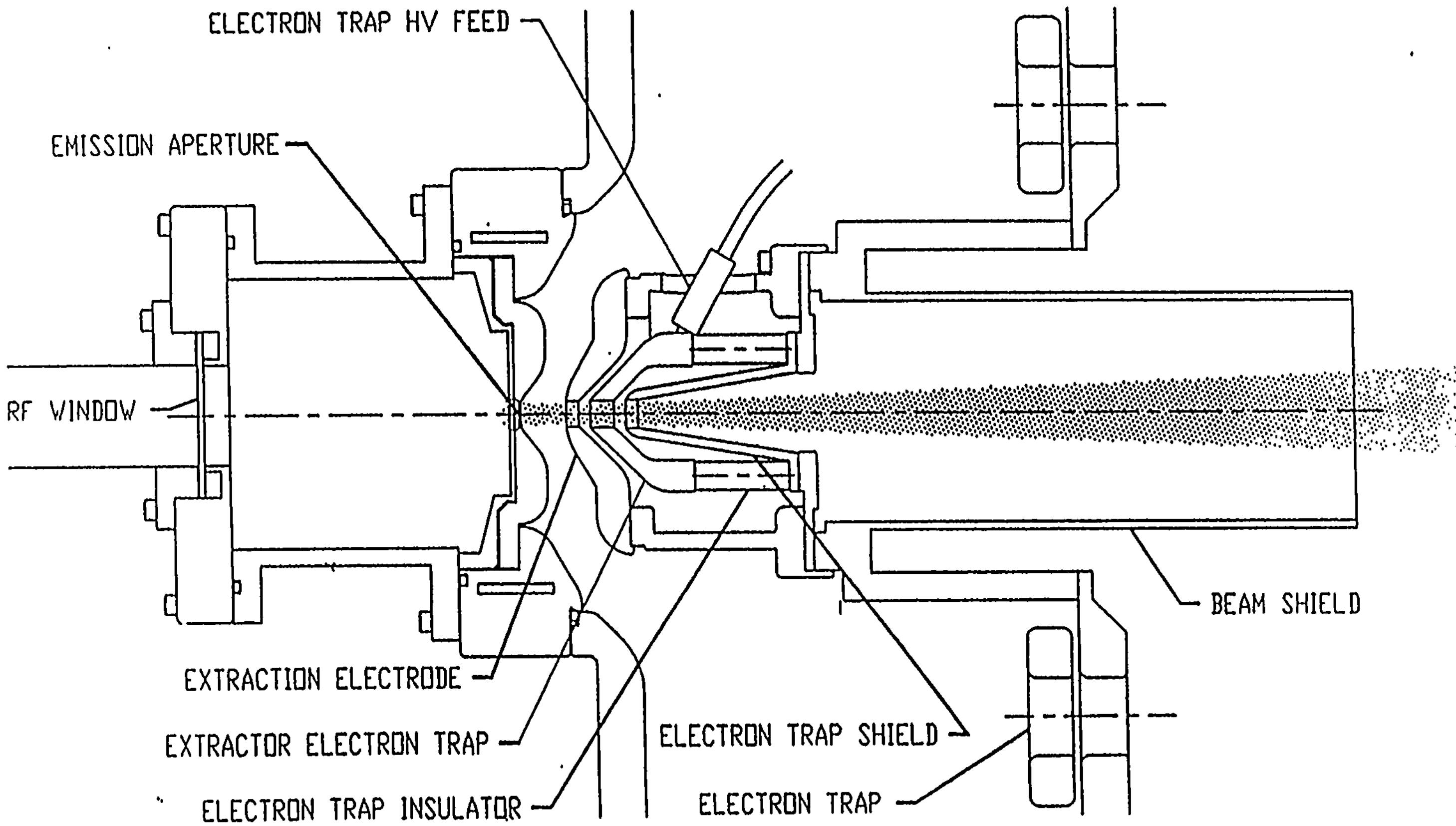
Beam fractions: 85% H^+, 7.5% H_2^+ and H_3^+.

Extraction system designed for optimal emittance at 75 keV, 110 mA H^+.

TRAJECTORIES AND EQUIPOTENTIALS

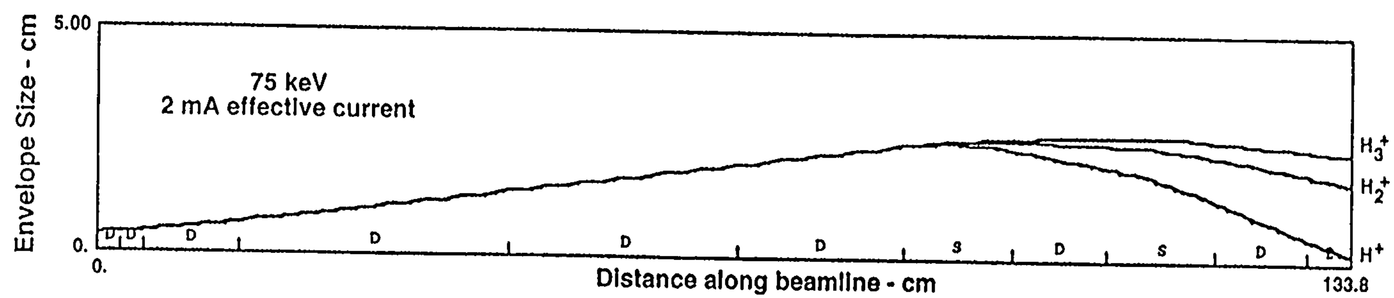


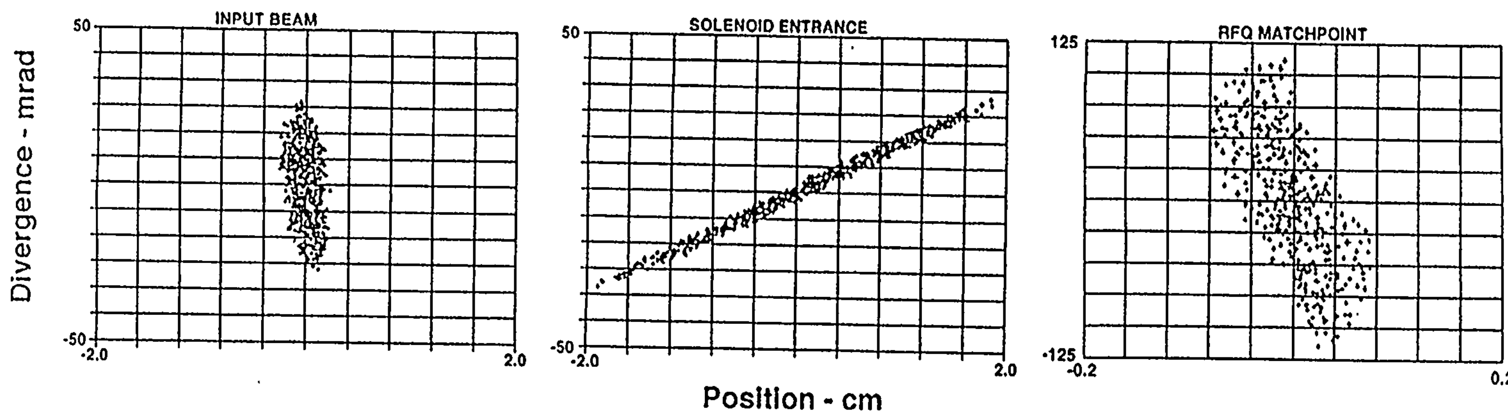
Extractor System for the APDF Injector



Los Alamos

Beam Simulations for the APDF Injector





Los Alamos

Summary

- The Linac-Only mode for LANSCE II will be used to provide pulsed high current proton beams to a neutron spallation target.

- The initial 1MW option can be provided with the existing ion source and injector at LAMPF and no further ion source development is required.

- The 5MW upgrade will require higher beam currents than now being produced and, depending on the final beam energy, either the present source will be upgraded or a new source such as the CRL microwave source will be employed.

- The details of the new injectors needed will be addressed after the architecture of the upgraded facility is defined. The initial 1MW operation will be provided with the present injectors.

Los Alamos

CRL Microwave Ion Source Test

R. Stevens

Los Alamos National Laboratory

CRL Microwave Ion Source Test

Ralph R. Stevens, Jr.
Los Alamos National Laboratory

The Chalk River microwave ion source is being studied at LANL for use in a cw neutron spallation source application. This source is now being operated at 48 keV with 60 mA total ion current for an extended lifetime test. Over 120 hours of continuous operation has already been logged. The initial results are:

(1) The gas flow controller was unstable and additional air cooling was needed.

(2) The microwave (2.456 Hz) power to the source was also unstable and means were taken to stabilize this system.

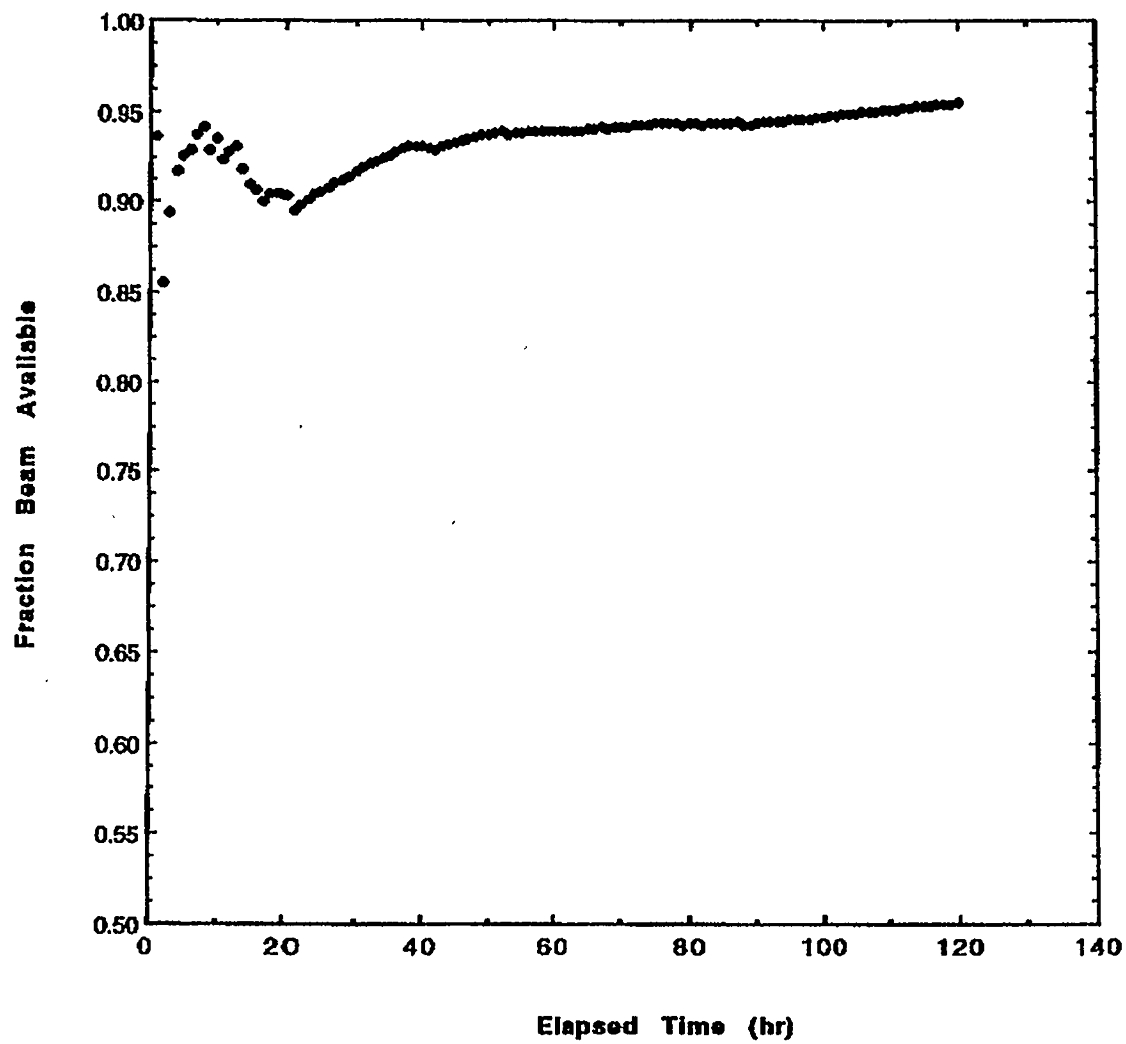
(3) The HV sparking rate was initially 16 faults per eight-hour shift, but after 120 hours this rate had decreased to 2-3 faults per shift.

(4) Beam availability (beam with > 60 mA at 47 kV) was initially less than 90% but after 120 hours exceeds 95%.

Graphs showing the time dependence of several of the important ion source parameters are presented below. Although this ion source is now being operated in a cw mode, we believe that it can be run in a pulsed mode by appropriate modulation of the 2.45 GHz RF driver.

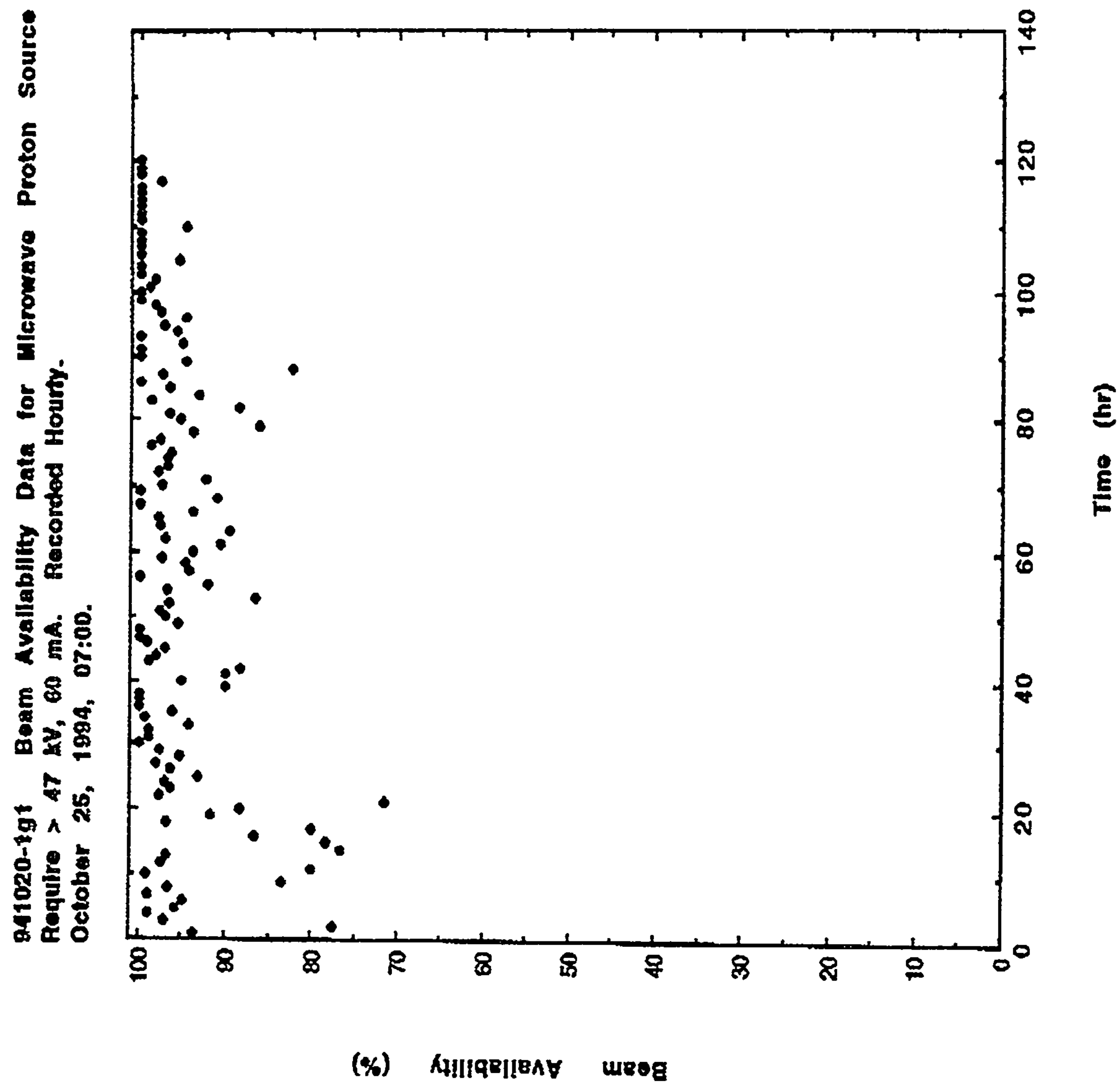
We anticipate running for 176 hours before terminating this test.

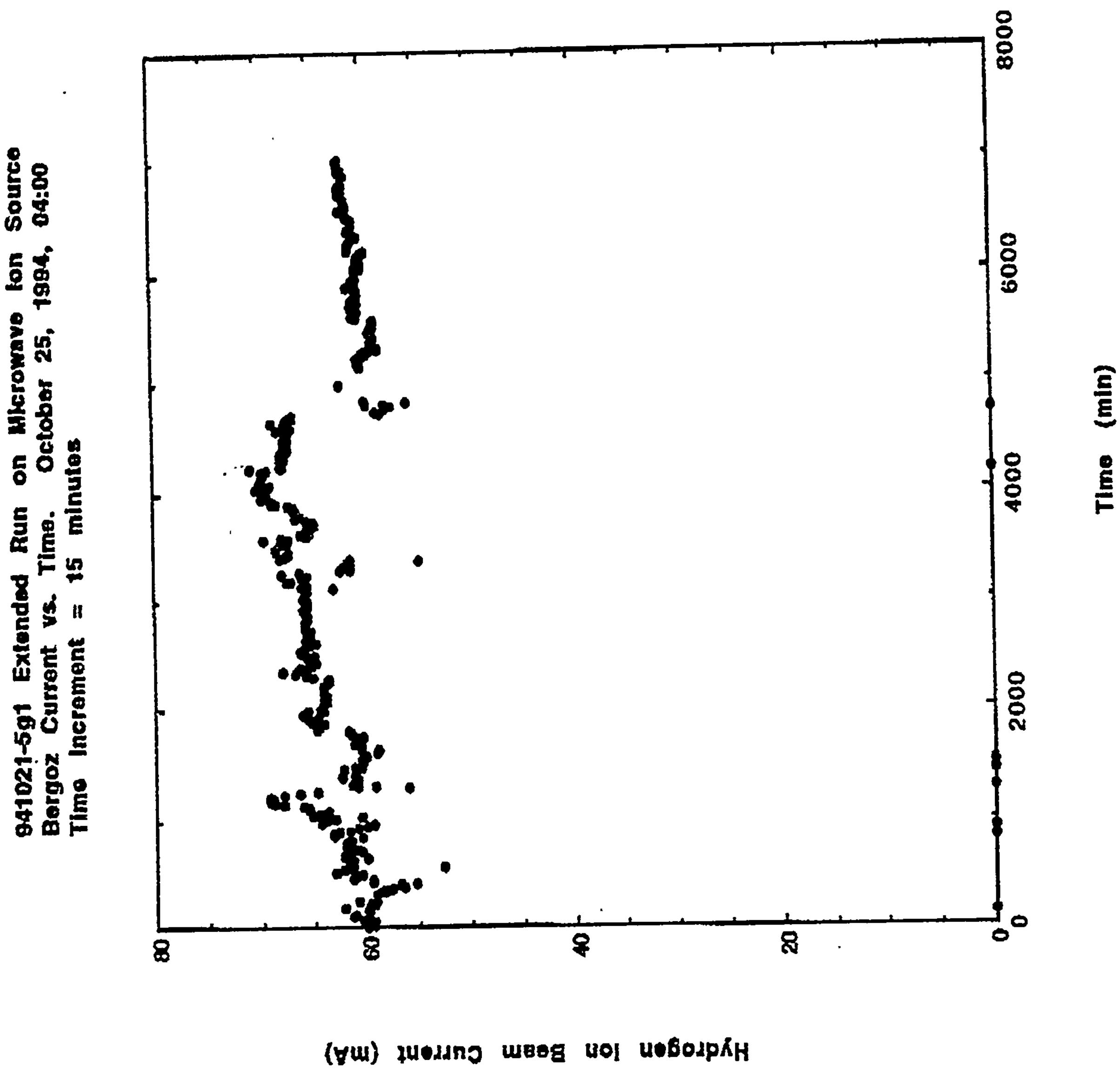
941020-1g2 Fraction Beam Available vs. Time
Extended Microwave Ion Source Run. Recorded Hourly
October 25, 1994, 07:00

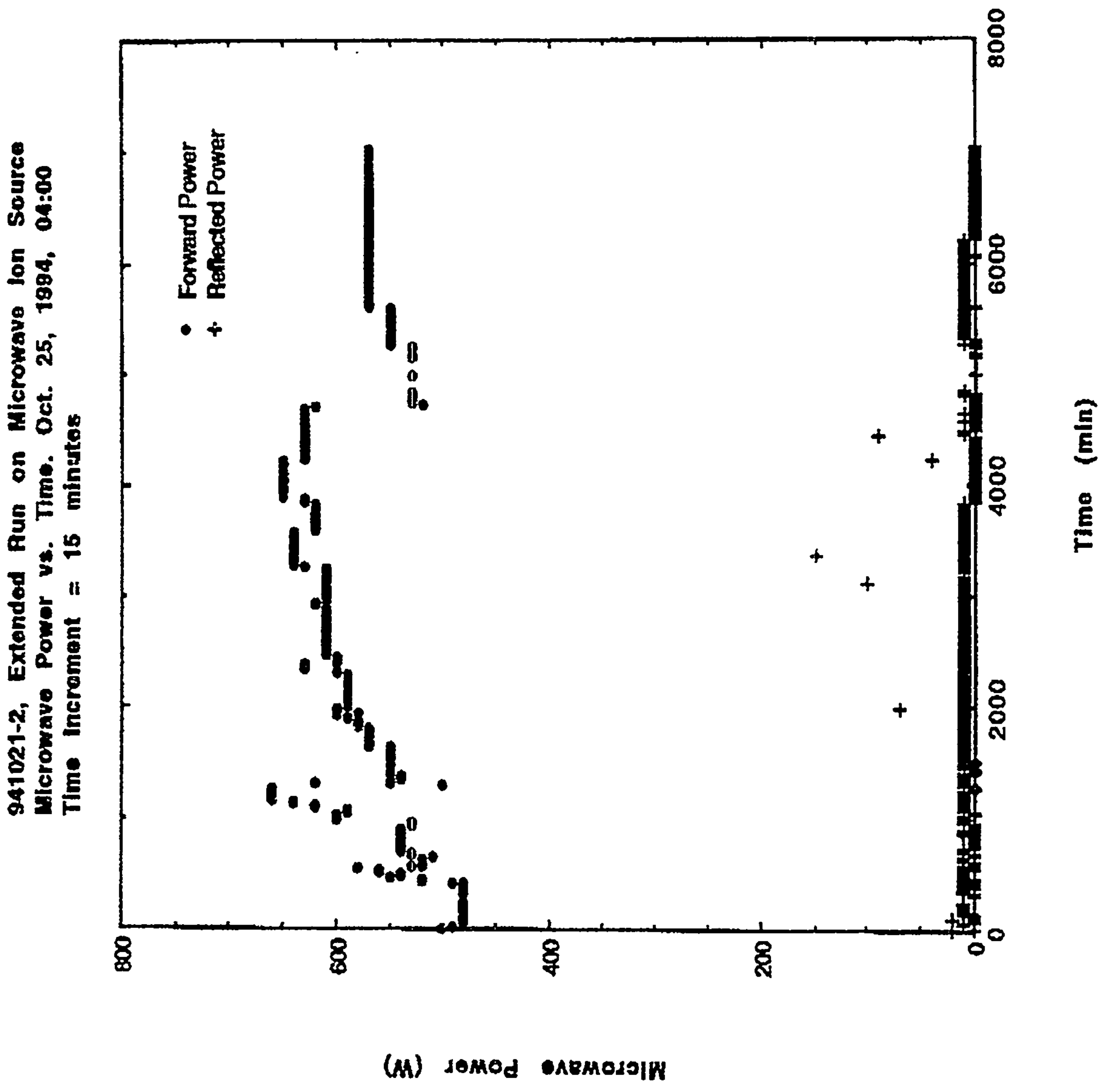


Fraction Beam Available is a running sum of beam-on-time divided by total elapsed time.

Beam Availability is beam-on-time averaged over a one hour period.




941021-5g1 Extended Run on Microwave Ion Source
Bergoz Current vs. Time. October 25, 1994, 04:00
Time Increment = 15 minutes
0
2000
4000
6000
8000
Time (min)
0
20
40
60
80
Hydrogen Ion Beam Current (mA)


941021-2, Extended Run on Microwave Ion Source
Microwave Power vs. Time. Oct. 25, 1994, 04:00
Time Increment = 15 minutes
Forward Power
Reflected Power
Microwave Power (W)
Time (min)
0
200
400
600
800
0
2000
4000
6000
8000

Fast Beam Chopping at BNL

J. Alessi

Brookhaven National Laboratory

Fast Beam Chopping at BNL

J. Alessi

To improve injection efficiency into the AGS Booster.

Very useful for machine studies.

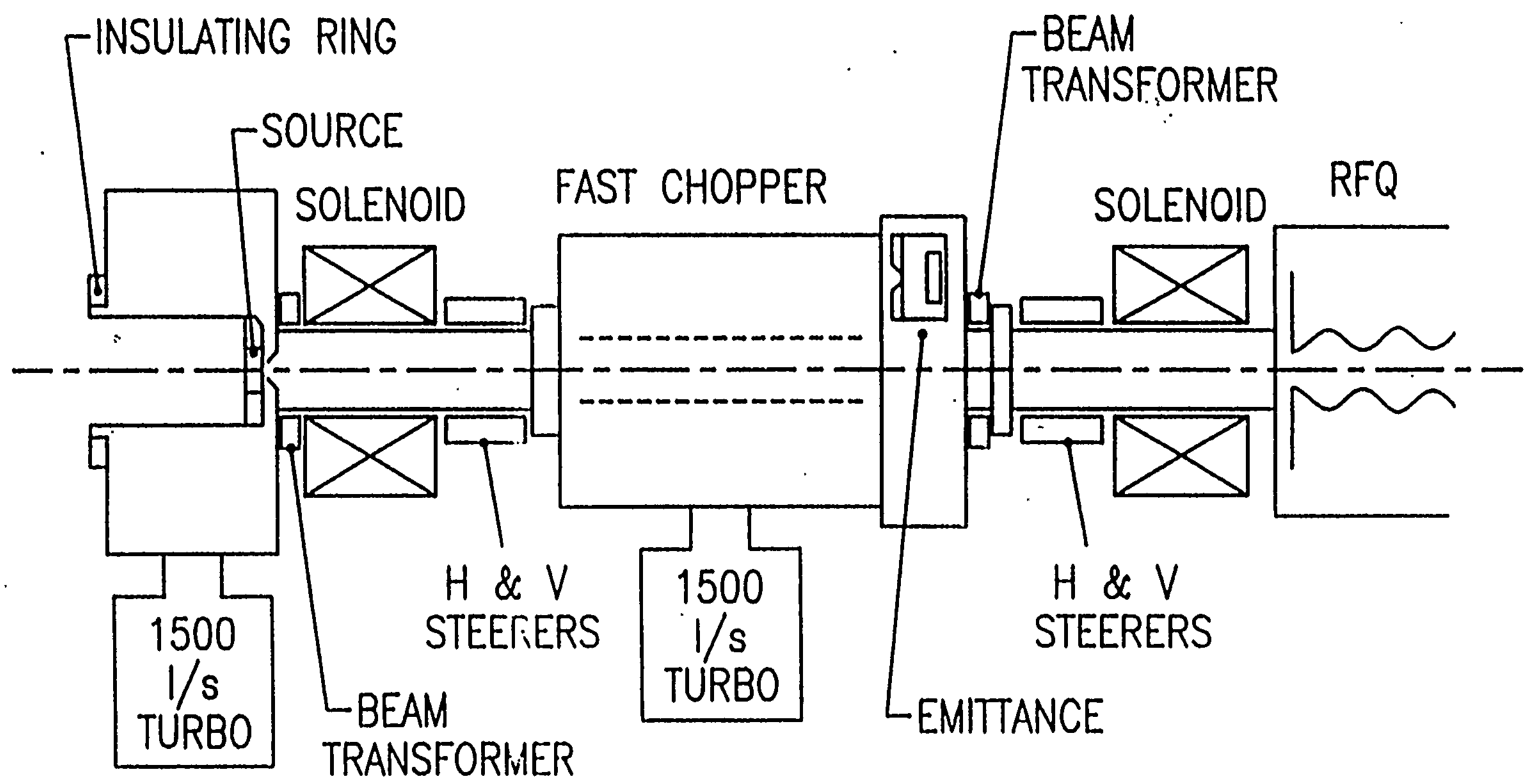
35 keV chopper — installed with RFQ (~'89)

750 keV chopper — switched to this ~3 years ago.

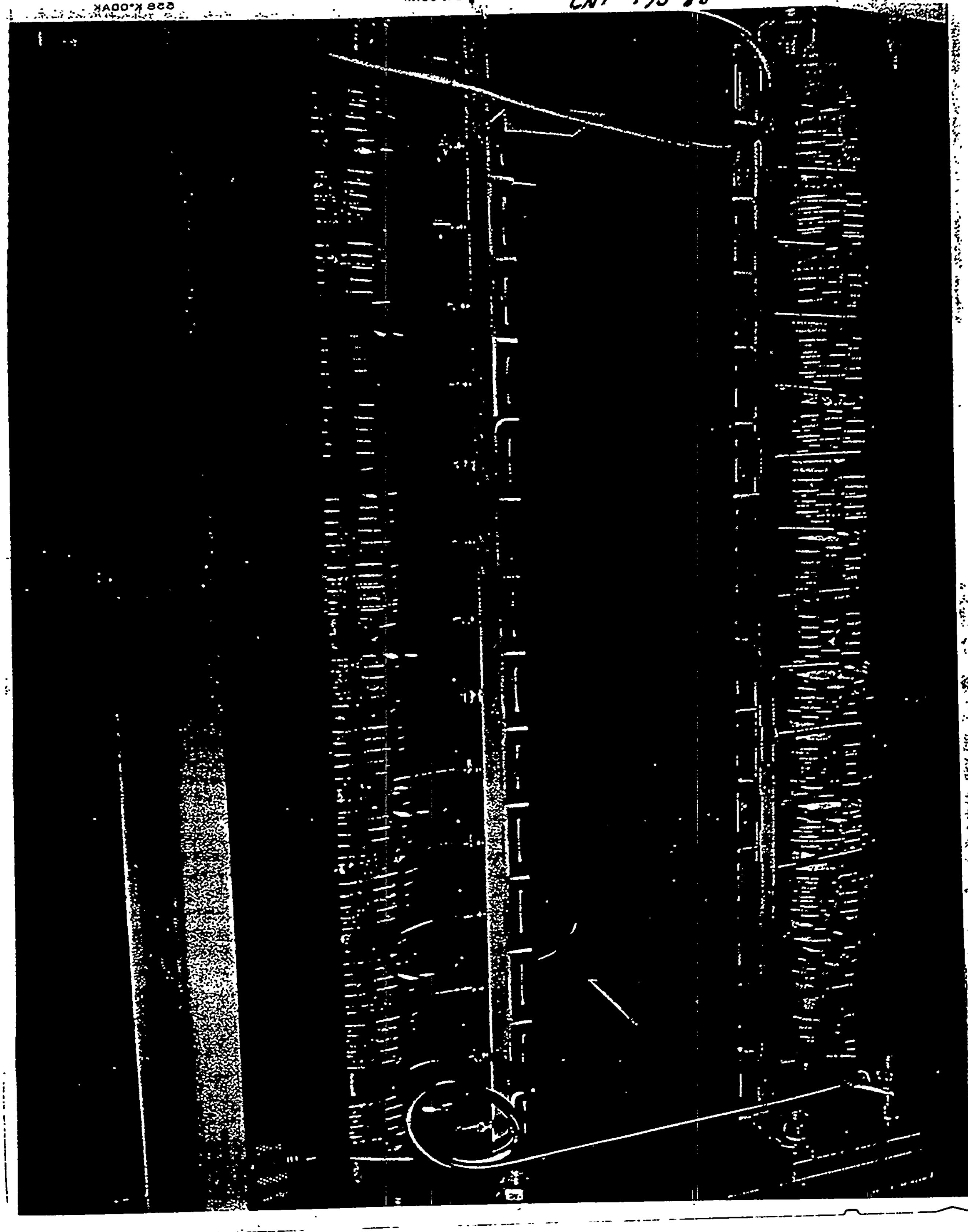
h=3; chopped at 2.5 MHz

Now, h=2, chop at 1.67 MHz
(chop ~ 200 ns out of 600 ns)

35 keV Beam Transport



CN1- 135-88



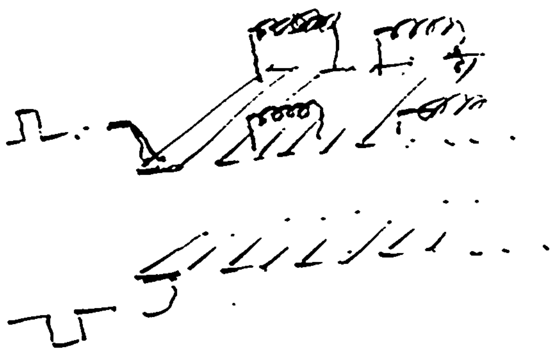
35 keV Chopper

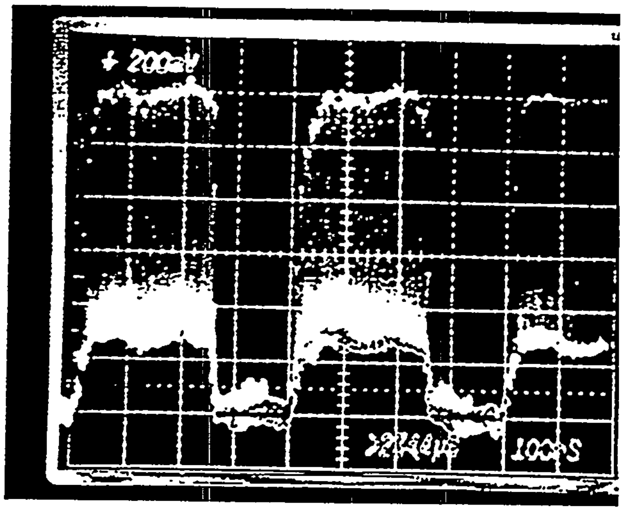
Traveling wave, 15 plates,

38 cm total length, 8 cm gap.

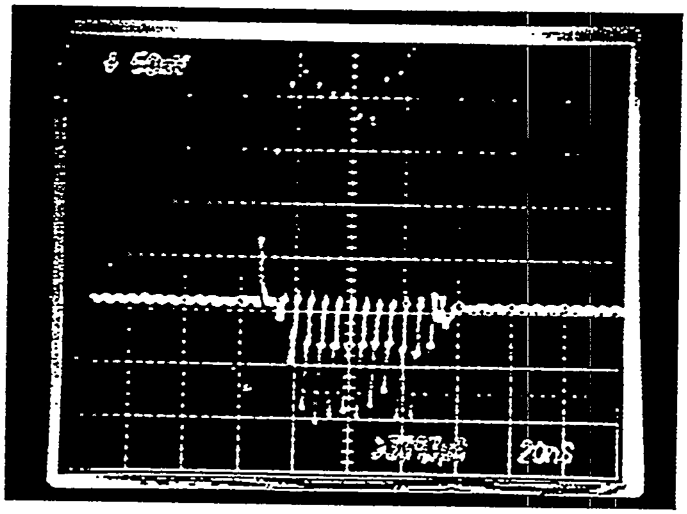
~ ± 800 volts → 110 mrad kick

Beam rejected at entrance to RFQ.

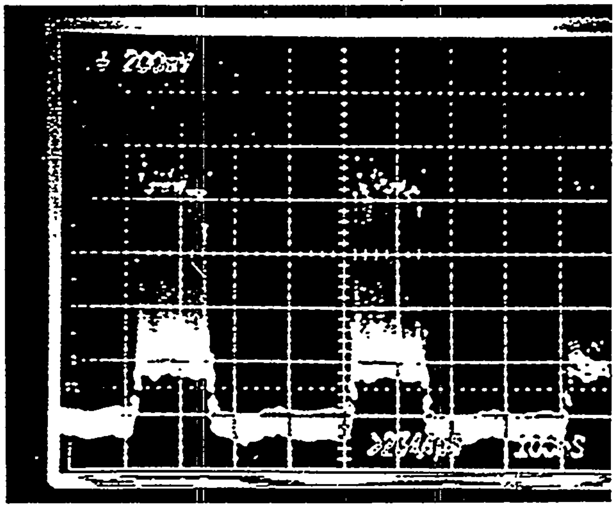




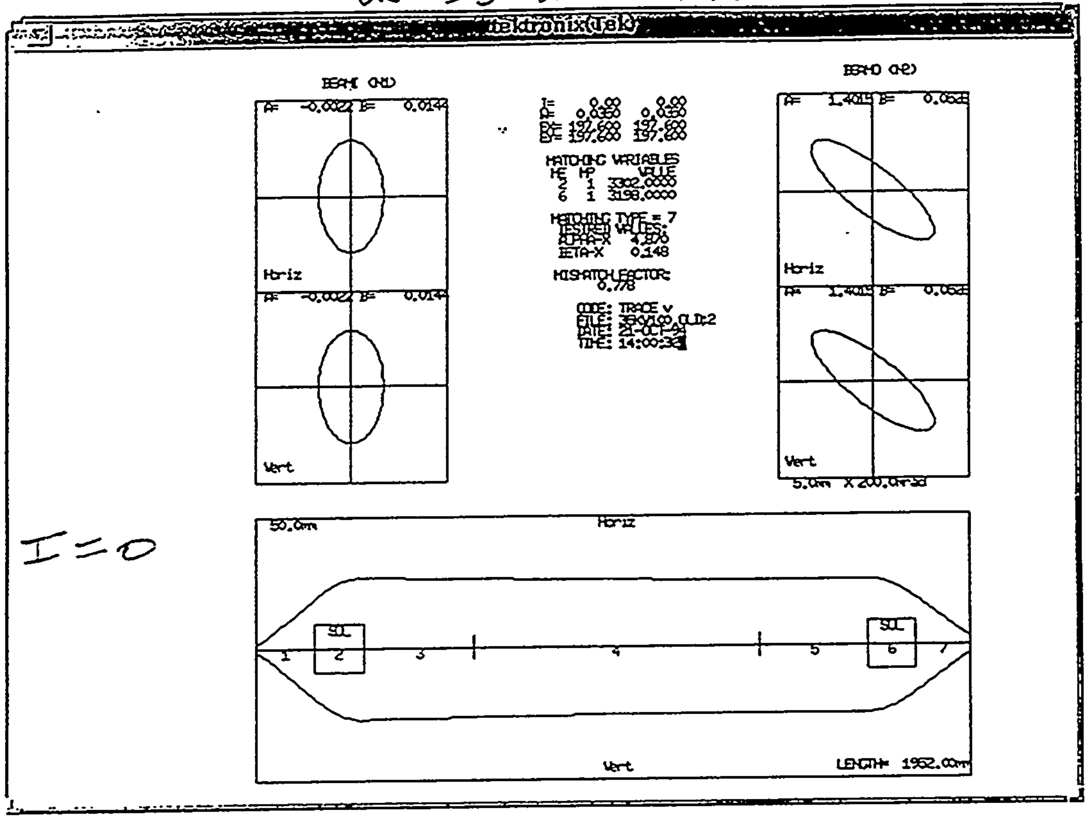
5/16/89 - FFC

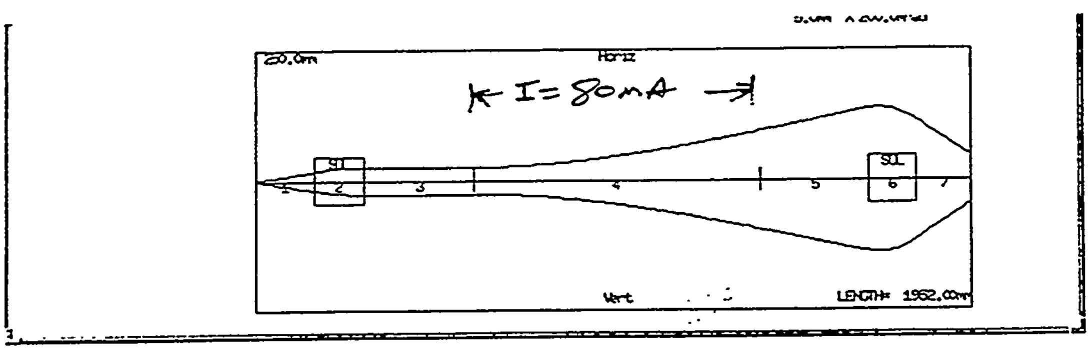


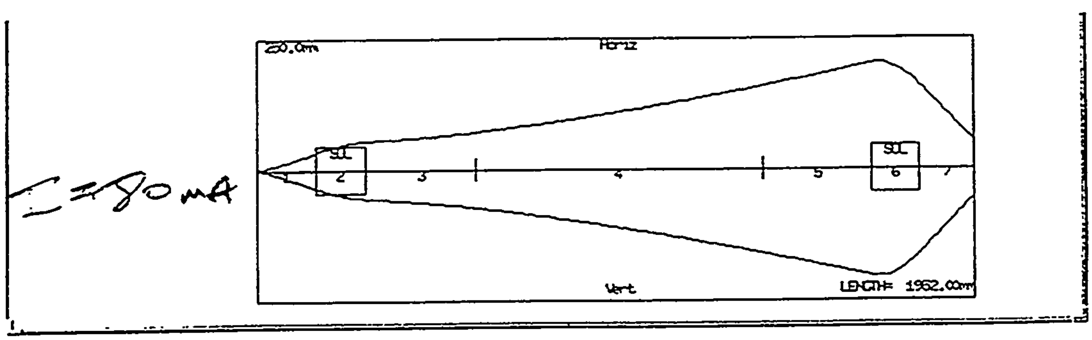
B = 10037 ns
A = 10052 ns

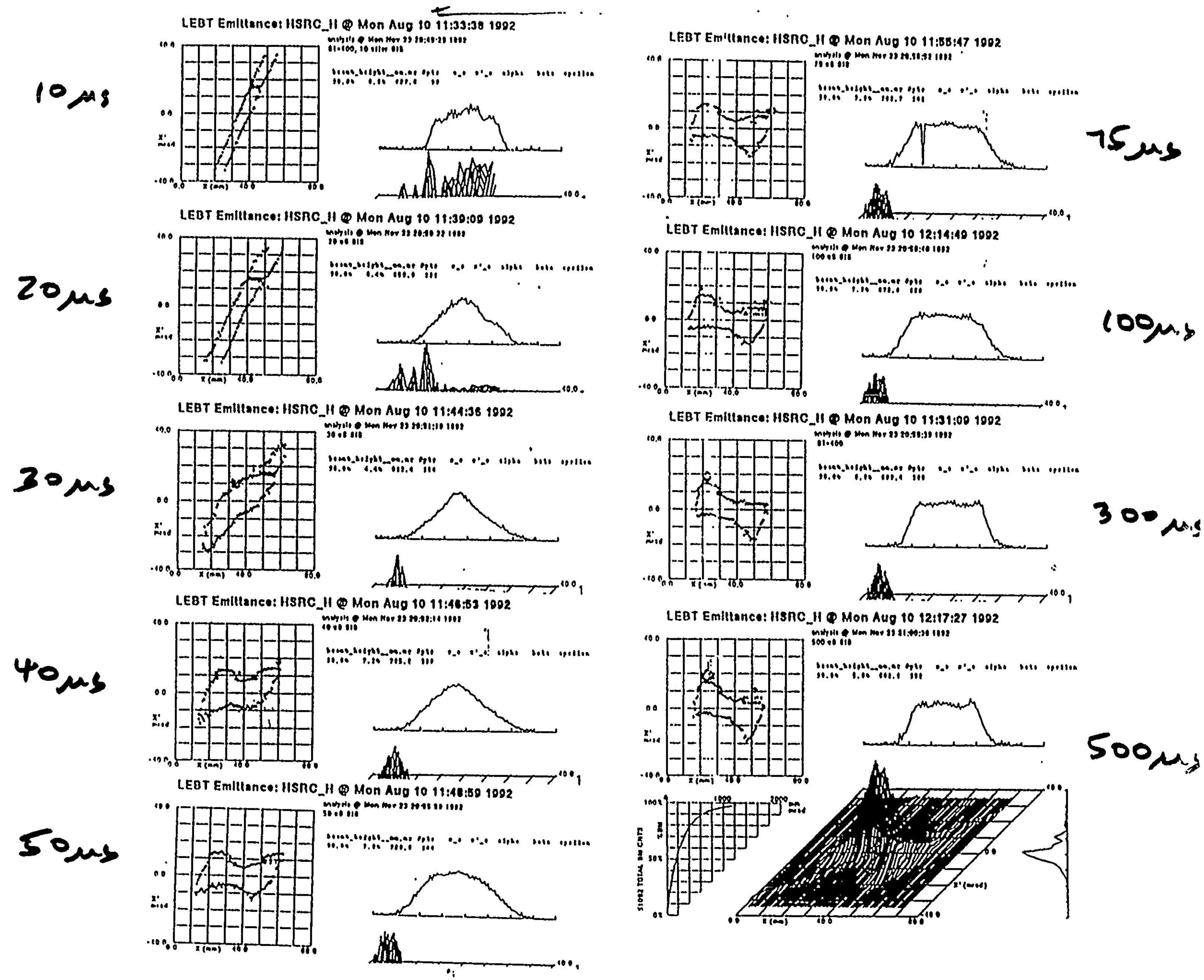


Space charge neutralization very important in 35 keV line..



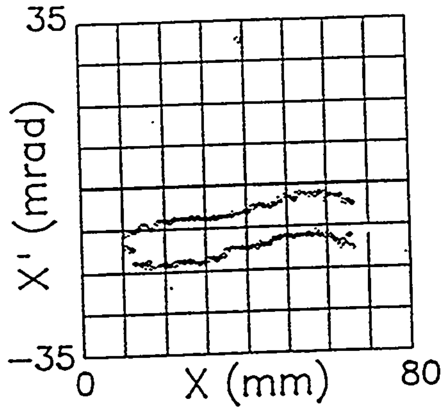




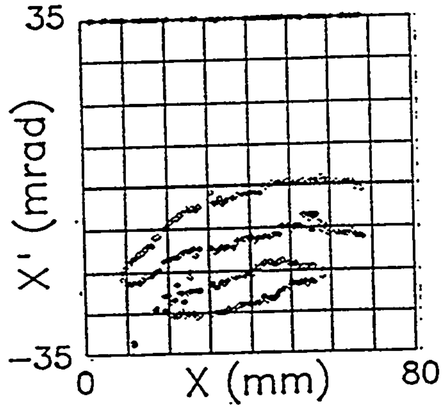

10μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:33:38 1992
20μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:39:09 1992
30μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:44:36 1992
40μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:46:53 1992
50μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:48:59 1992
75μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:55:47 1992
100μs
LEBT Emittance: HSRC_II @ Mon Aug 10 12:14:49 1992
300μs
LEBT Emittance: HSRC_II @ Mon Aug 10 11:31:09 1992
500μs
LEBT Emittance: HSRC_II @ Mon Aug 10 12:17:27 1992

35 KeV

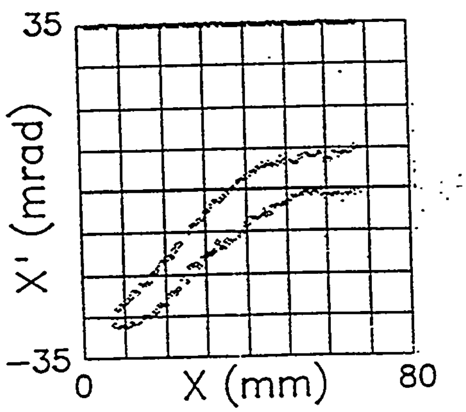
chopper off

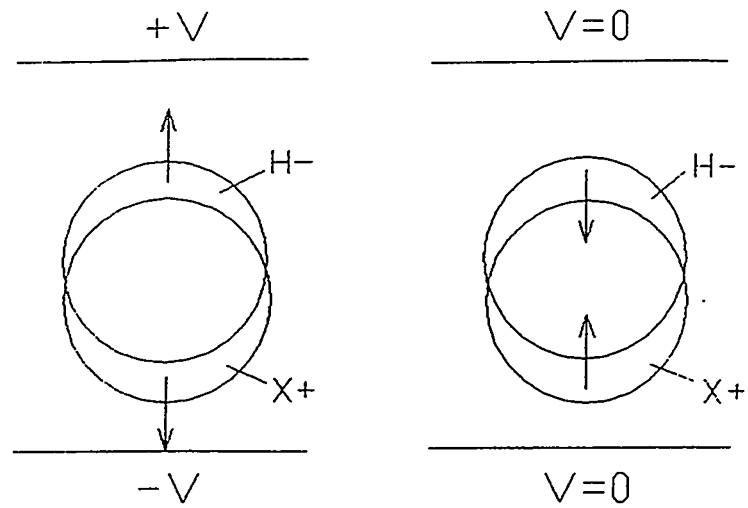


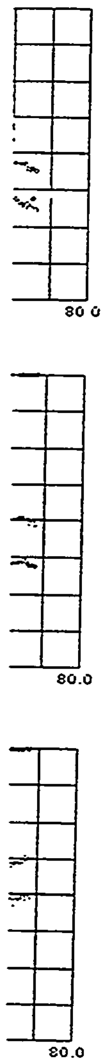
± 250 v.



± 700 v.







The 200 ns voltage on-time is not long enough to sweep away the neutralizing ions, but merely displaces them. When the voltage goes off, there is a restoring force between the H- beam and these displaced ions, causing a kick on the H- beam in a direction opposite to the direction that the chopper deflects the beam. In addition, due to the displacement of the neutralizing ions, a portion of the H- beam is unneutralized, and therefore becomes divergent. This distortion of the emittance decreases/increases as the voltage-on time decreases/increases at the 2.5 MHz frequency. When operating with the chopper, the 35 keV line is retuned to partially compensate for this distortion, but the full intensity out of the RFQ cannot be recovered. The net effect can be a loss of 25-50% of the beam current out of the RFQ. This may force us to switch in the future to a beam chopper at 750 keV.

35 kev Chopping

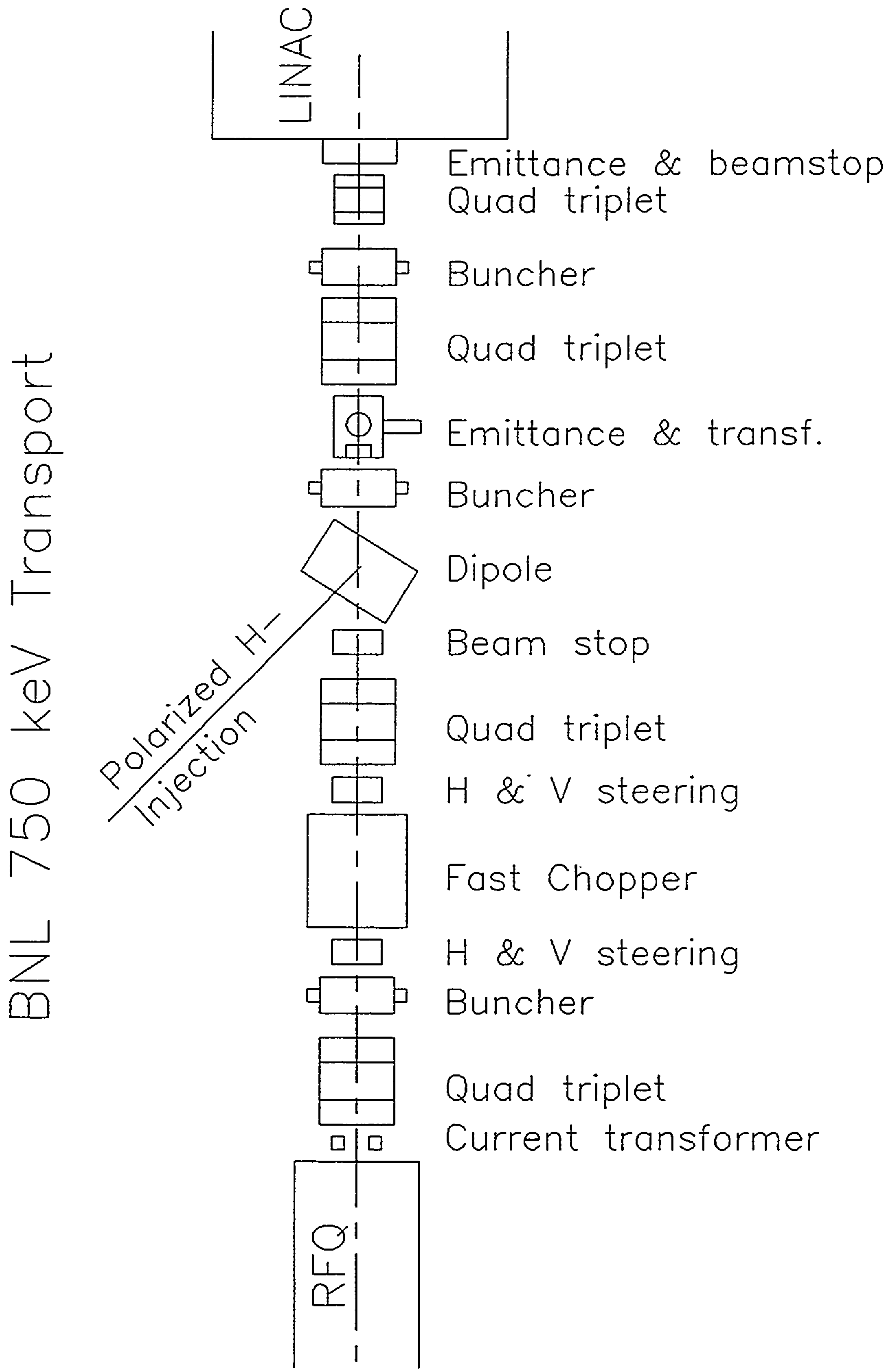
10 ns rise + fall times

Space charge effects:

Need much higher voltage than expected to get good rejection.

(Beam spot at RFQ entrance becomes large?)

Chopper V off - lose ~1/3 of beam current due to E distortion from background ions.


BNL 750 keV Transport
LINAC
Emittance & beamstop
Quad triplet
Buncher
Quad triplet
Emittance & transf.
Buncher
Dipole
Polarized H-
Injection
Beam stop
Quad triplet
H & V steering
Fast Chopper
H & V steering
Buncher
Quad triplet
Current transformer
RFQ

750 keV Chopper

~1 m long

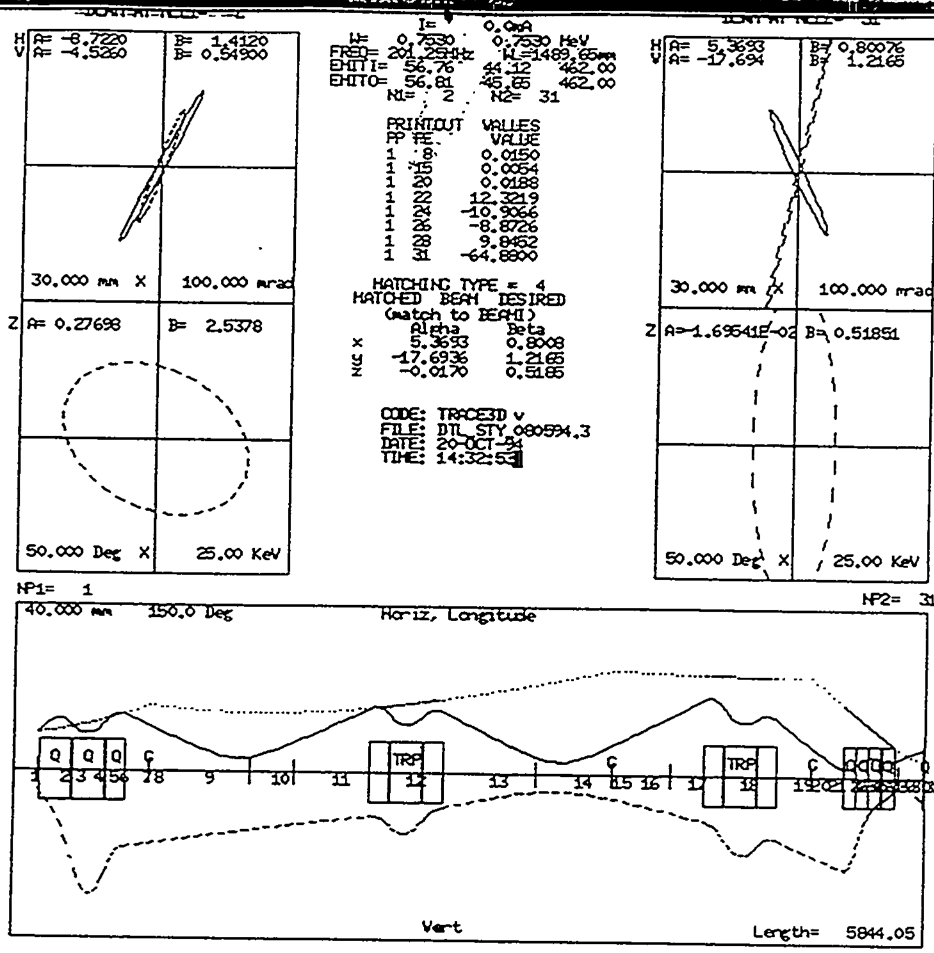
15 plates, traveling wave

4 cm plate separation

± 1000 v. → ~34 mrad kick

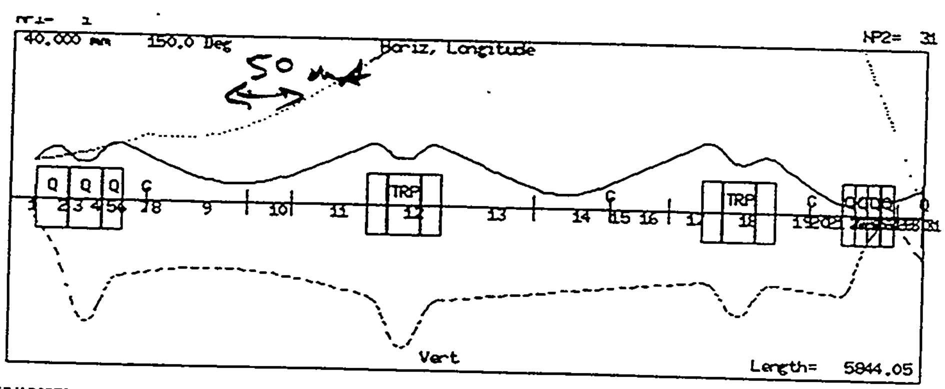
Beam deflected onto slits ~3 m downstream

- Smaller beam size (plates closer) and longer "lever arm" → can use same voltage as 35 keV chopper.

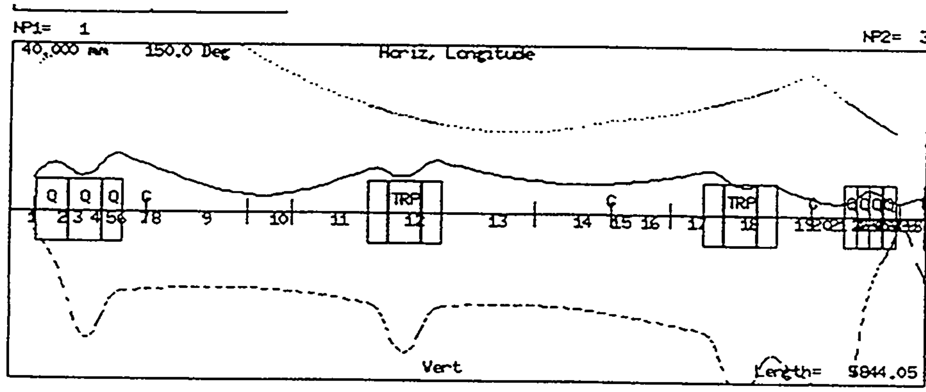


H A= -8.7220 B= 1.4120
V A= -4.5260 B= 0.54900
30.000 mm X 100.000 mrad
Z A= 0.27698 B= 2.5378
50.000 Deg X 25.00 KeV
I= 0.0mA
W= 0.7530 0.7530 MeV
FREQ= 201.25MHz WL=1489.65mm
EMITI= 56.76 44.12 462.00
EMITO= 56.81 45.65 462.00
N1= 2 N2= 31
PRINTOUT VALUES
PP FE VALUE
1 8 0.0150
1 15 0.0054
1 20 0.0188
1 22 12.3219
1 24 -10.9066
1 26 -8.8726
1 28 9.8452
1 31 -64.8800
MATCHING TYPE = 4
MATCHED BEAM DESIRED
(match to BEAMI)
Alpha Beta
x 5.3693 0.8008
y -17.6936 1.2165
z -0.0170 0.5185
CODE: TRACE3D v
FILE: DTL_STY_080594.3
DATE: 20-OCT-94
TIME: 14:32:53
H A= 5.3693 B= 0.80076
V A= -17.694 B= 1.2165
30.000 mm X 100.000 mrad
Z A=-1.69541E-02 B= 0.51851
50.000 Deg X 25.00 KeV
NP1= 1
NP2= 31
40.000 mm 150.0 Deg
Horiz, Longitude
Vert
Length= 5844.05

I = 0



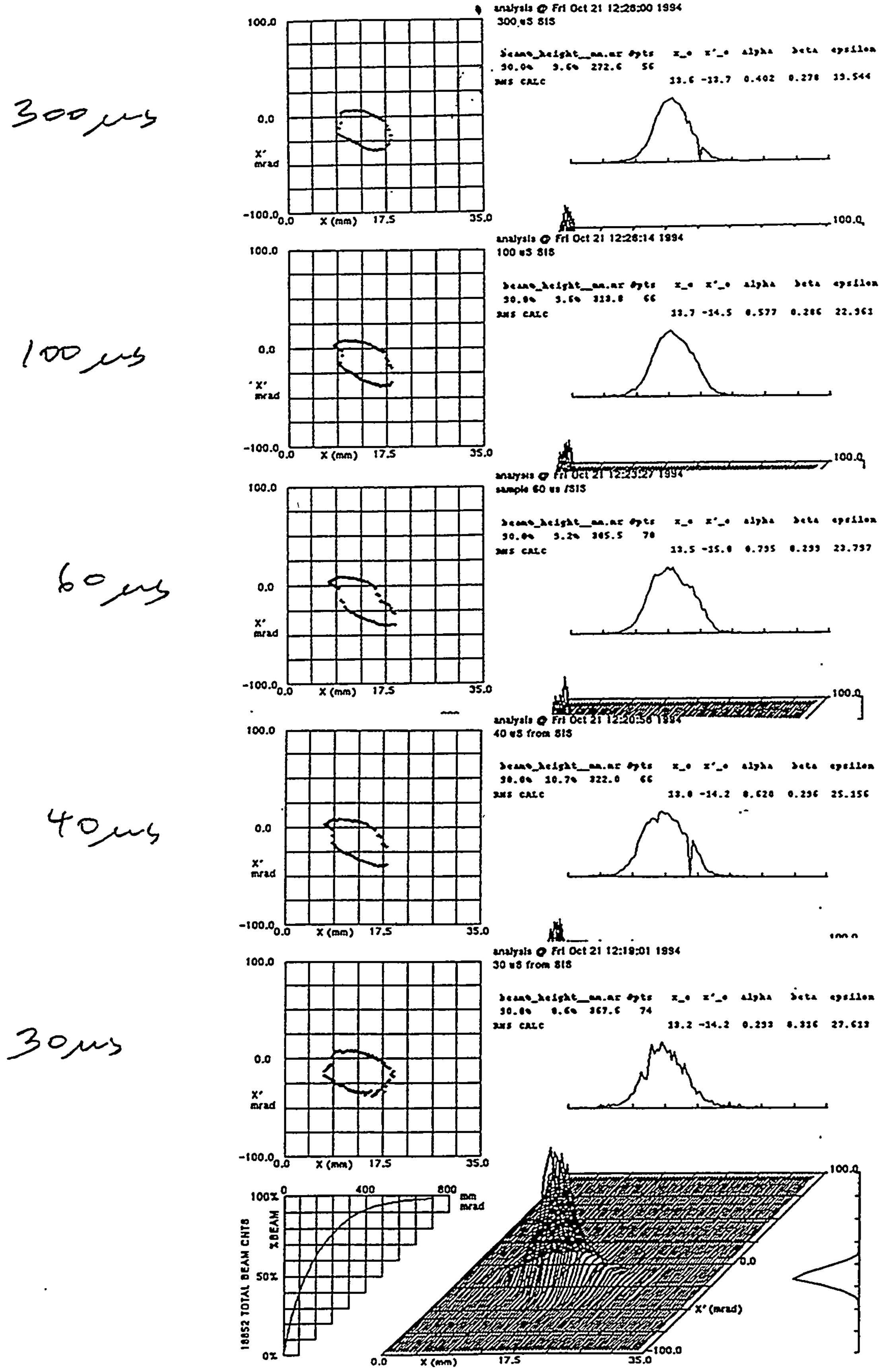
NP1= 1
NP2= 31
40.000 mm 150.0 Deg
Horiz, Longitude
50 mA
Vert
Length= 5844.05

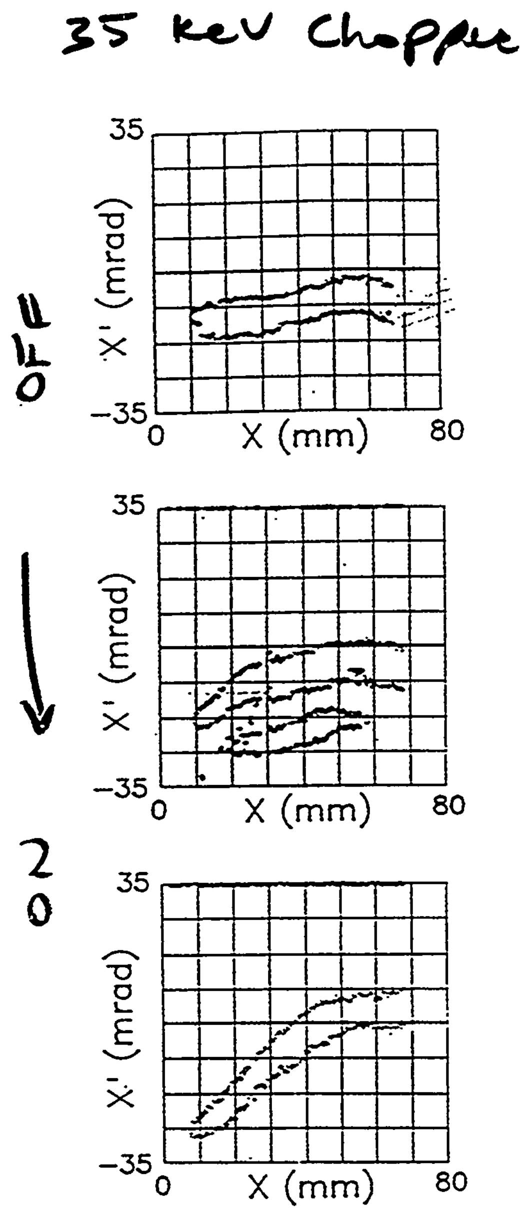


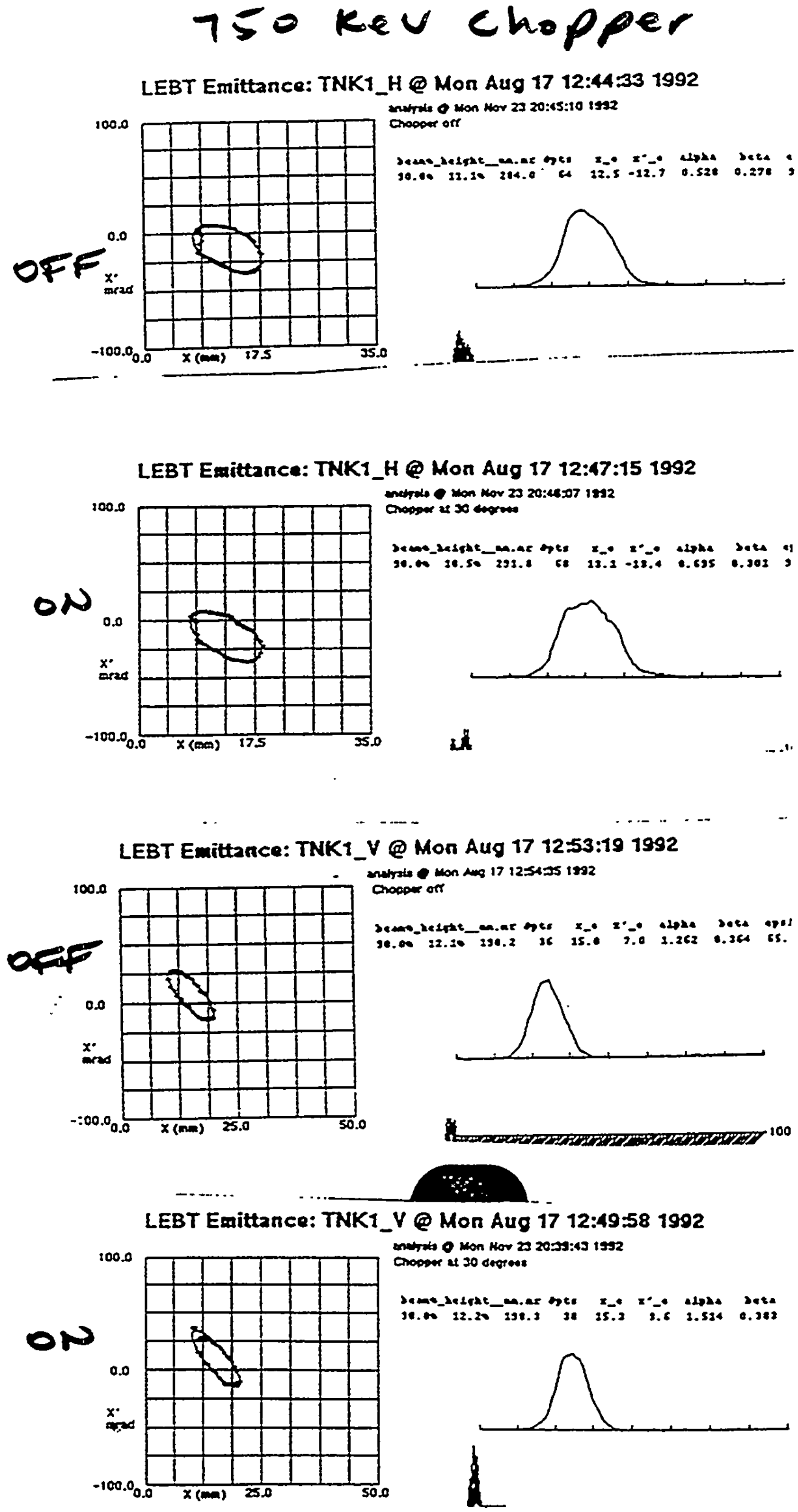
NP1= 1
NP2= 31
40.000 mm 150.0 Deg
Horiz, Longitude
Vert
Length= 5844.05

I = 50 mA

LEBT Emittance: TNK1_H @ Sat Aug 8 16:12:01 1992




35 keV Chopper
OFF
ON
20
35
X' (mrad)
−35
0
X (mm)
80


750 keV Chopper
LEBT Emittance: TNK1_H @ Mon Aug 17 12:44:33 1992
Chopper off
OFF
LEBT Emittance: TNK1_H @ Mon Aug 17 12:47:15 1992
Chopper at 30 degrees
ON
LEBT Emittance: TNK1_V @ Mon Aug 17 12:53:19 1992
Chopper off
OFF
LEBT Emittance: TNK1_V @ Mon Aug 17 12:49:58 1992
Chopper at 30 degrees
ON
100.0
0.0
-100.0
X' mrad
X (mm)
17.5
35.0
25.0
50.0

Conclusions

Chopping options:

1.) Chop with electrostatic deflection only where space charge effects are small (e.g. 750 keV vs. 35 keV)

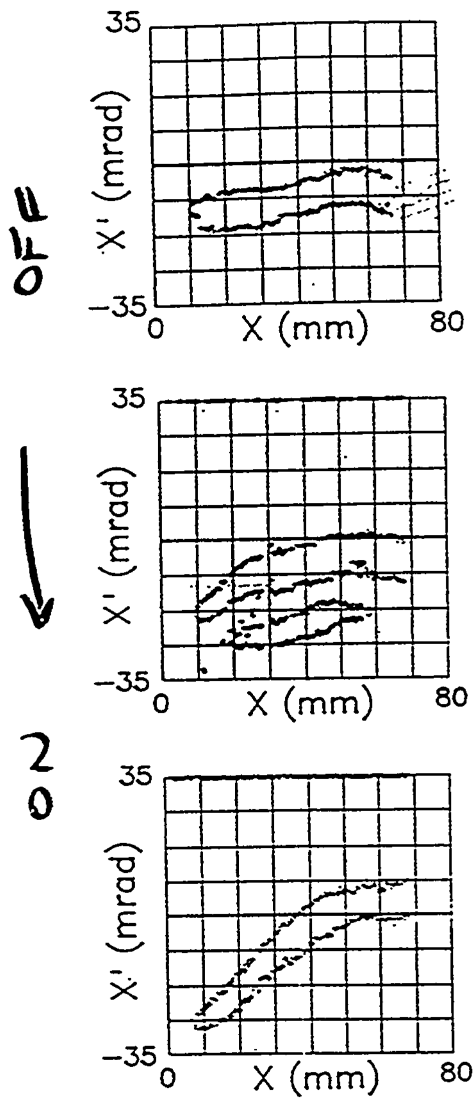
2.) Chop in an unneutralized beam transport (BNL - ESR/chop)

3.) Use other methods of beam shutoff -

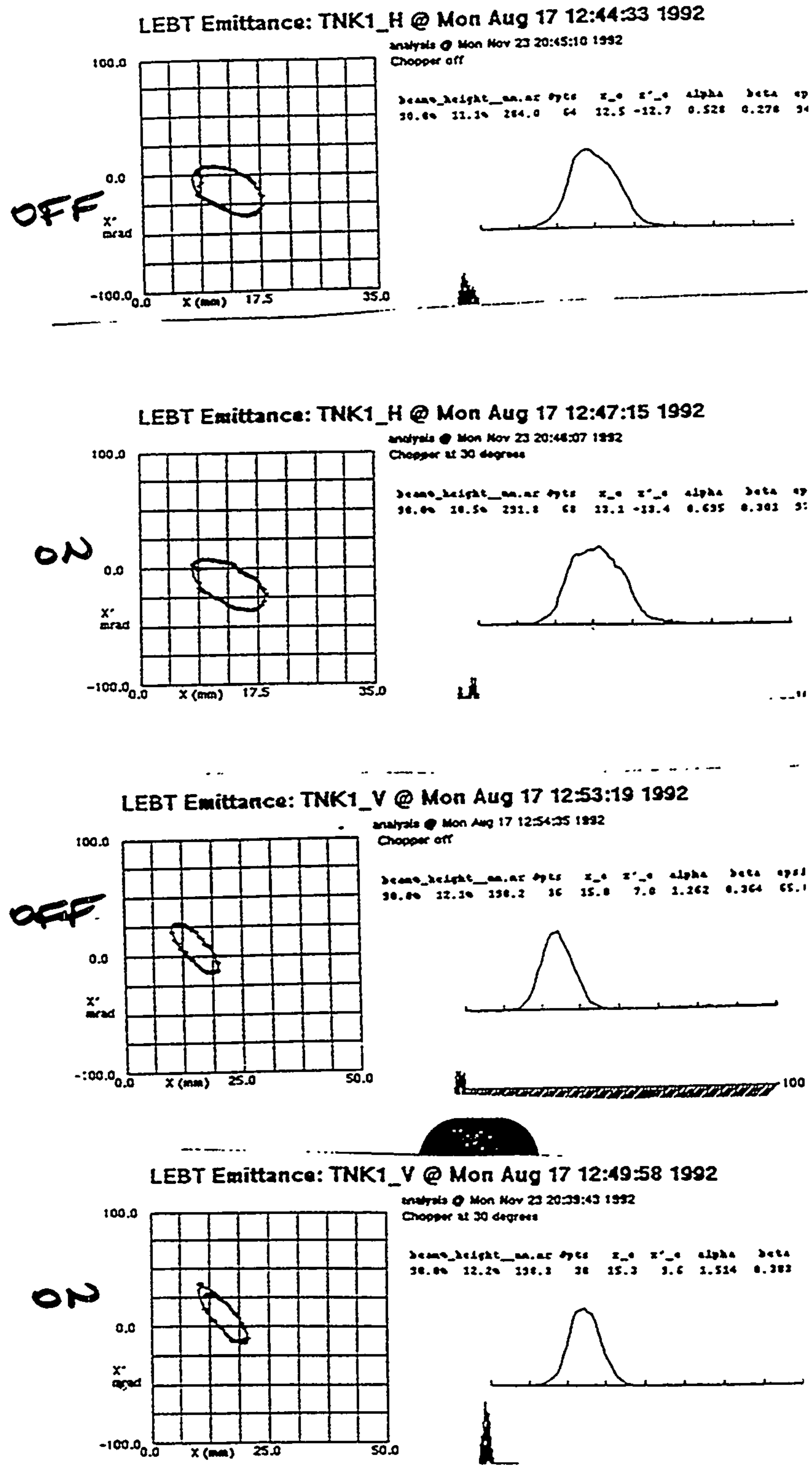
shutoff at source (LANL)

Modulate beam energy before the RFQ input ?

35 keV Chopper



750 keV Chopper



Travelling Wave Choppers for LANSCE II

R. Stevens

Los Alamos National Laboratory

Traveling Wave Choppers for LANSCE II

Ralph R. Stevens, Jr.

- Chopping Considerations
- Beam Requirements for LANSCE II
- Details of Present Traveling Wave Choppers
- LEBT vs RFQ Choppers
- Conclusions

Beam Chopping Considerations

- The compressor ring requires 235 ns "holes" every 671 ns in order to permit clean ejection of the stored beam from the ring.
- Electrostatic traveling wave choppers are a proven technology with linacs and are capable of providing the required beam chopping.
- Chopping before the RFQ was initially proposed, but there are space charge neutralization issues that must be addressed.
- Operation of the RFQ with high injection energy would solve this problem, but results in large longitudinal emittance growth in the RFQ.
- Chopping after the RFQ is now being considered with a system employing two traveling wave structures that will chop and restore the partially deflected bunches.
- Chopping in the ion source itself is also being considered and can possibly by used as a prechopper to a beam line choppper.

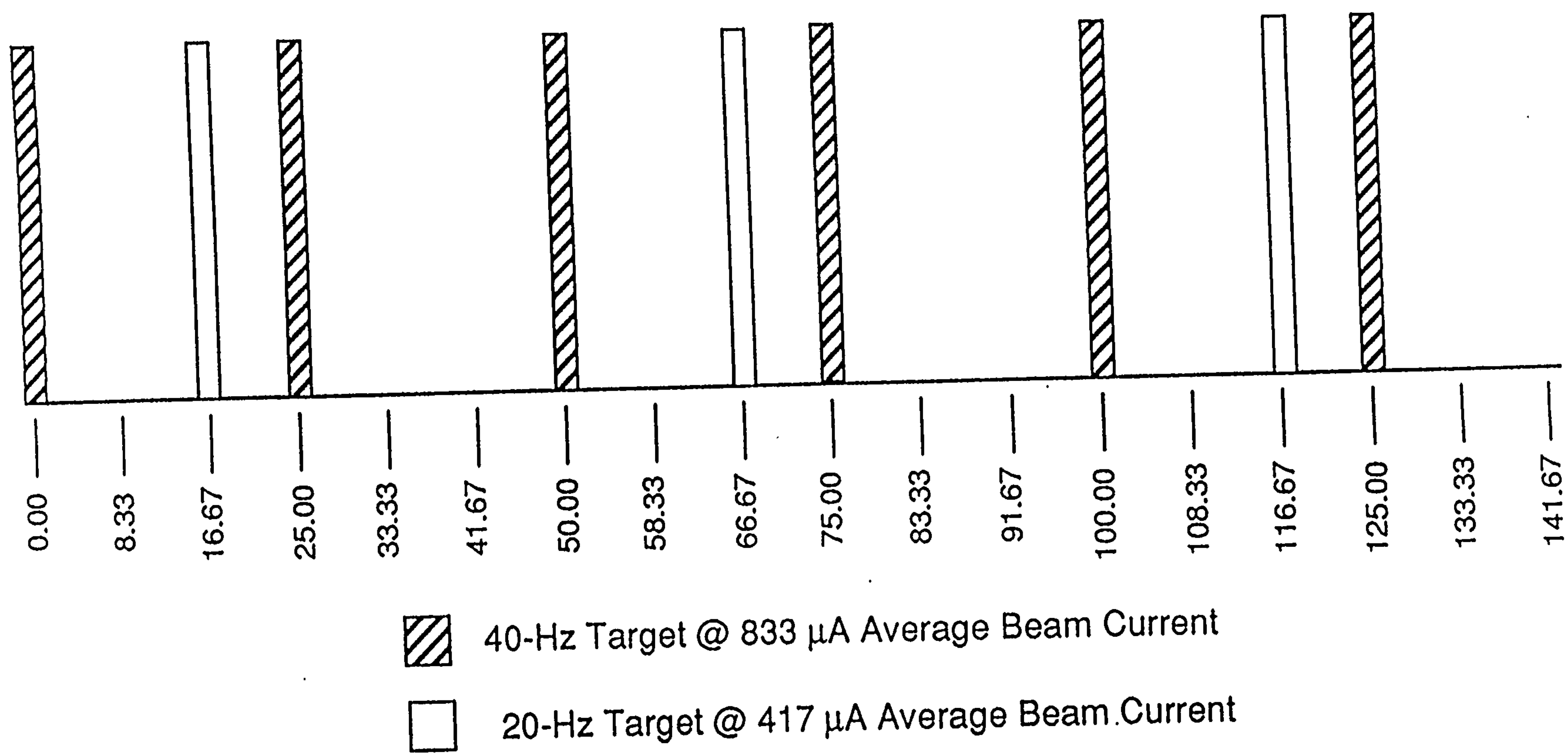
Los Alamos

Injector Requirements

- Beam Current - 33 mA at the RFQ match point (40 mA from the ion source)
- Beam Energy - 100 keV
- Pulse Length - 1.2 ms
- Beam Emittance - 0.020 πcm-mrad rms, normalized at the RFQ entrance
- Pulse Repetition Rate - 60 pps with 40 Hz and 20 Hz interleaved pulse trains at a 120 Hz basic repetition rate
- RFQ Match Parameters - $\alpha = 0.97$ with $\beta = 0.0034$ cm/mrad
- Chopping - 235 ns beam off / 436 ns beam on for the entire 1.2 ms pulse.
  Rise and fall times of beam pulses < 20ns.
  Rejection of chopped beam better than 99.99%
- Beam Turn-on Time - 30 μs with pulsed-time ramp after the initial 200 μs of each pulse is rejected
- Beam Duty Factor - 8.6% (1.43 ms at 60 pps)

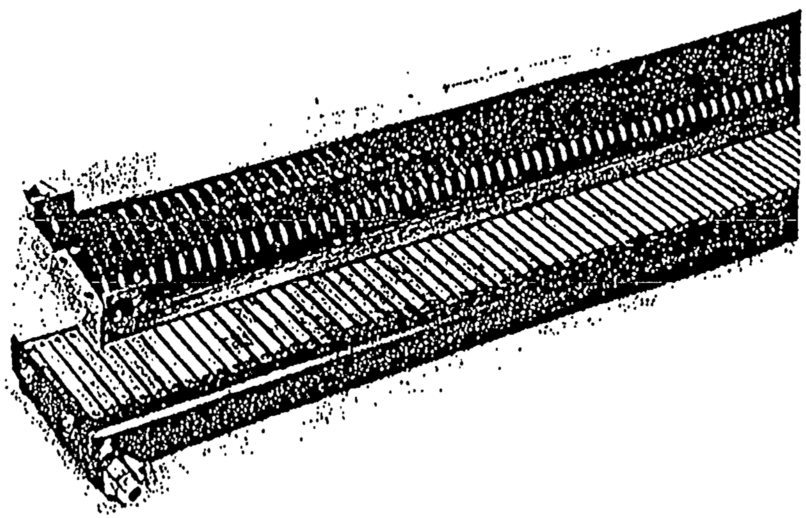
Los Alamos

LANSCE II Interlaced Macropulse Pattern

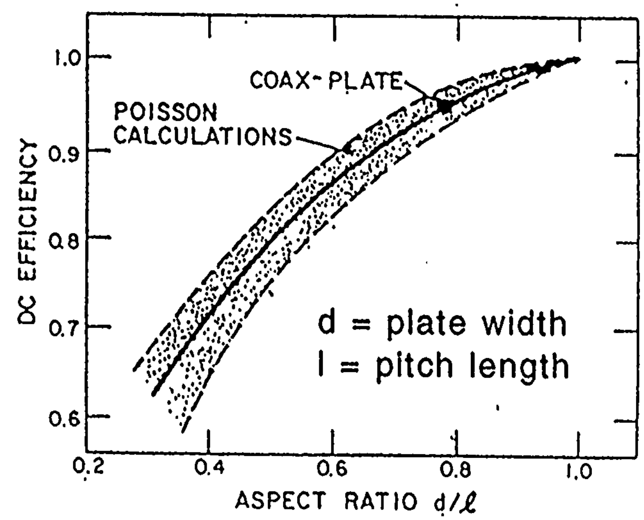


Los Alamos

LANL Coax-plate Traveling Wave Chopper



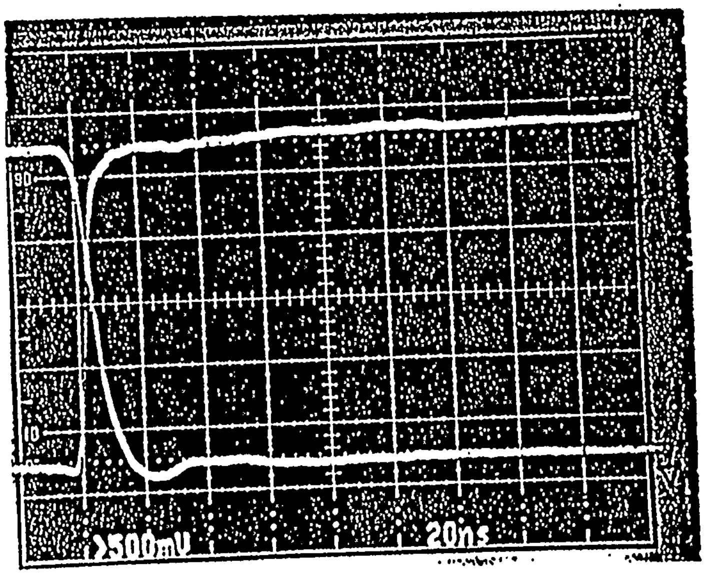
Coax-plate chopper structure



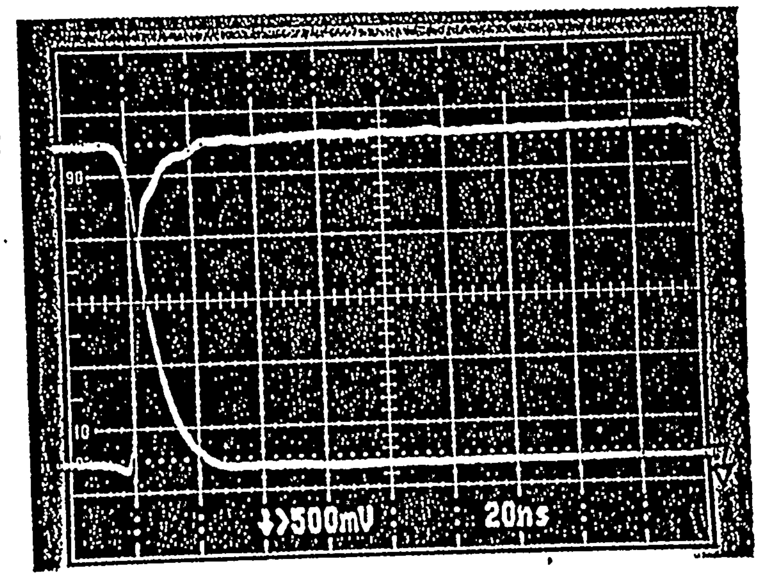
Chopper efficiency curve

Los Alamos

Traveling Wave Chopper Operating Waveforms



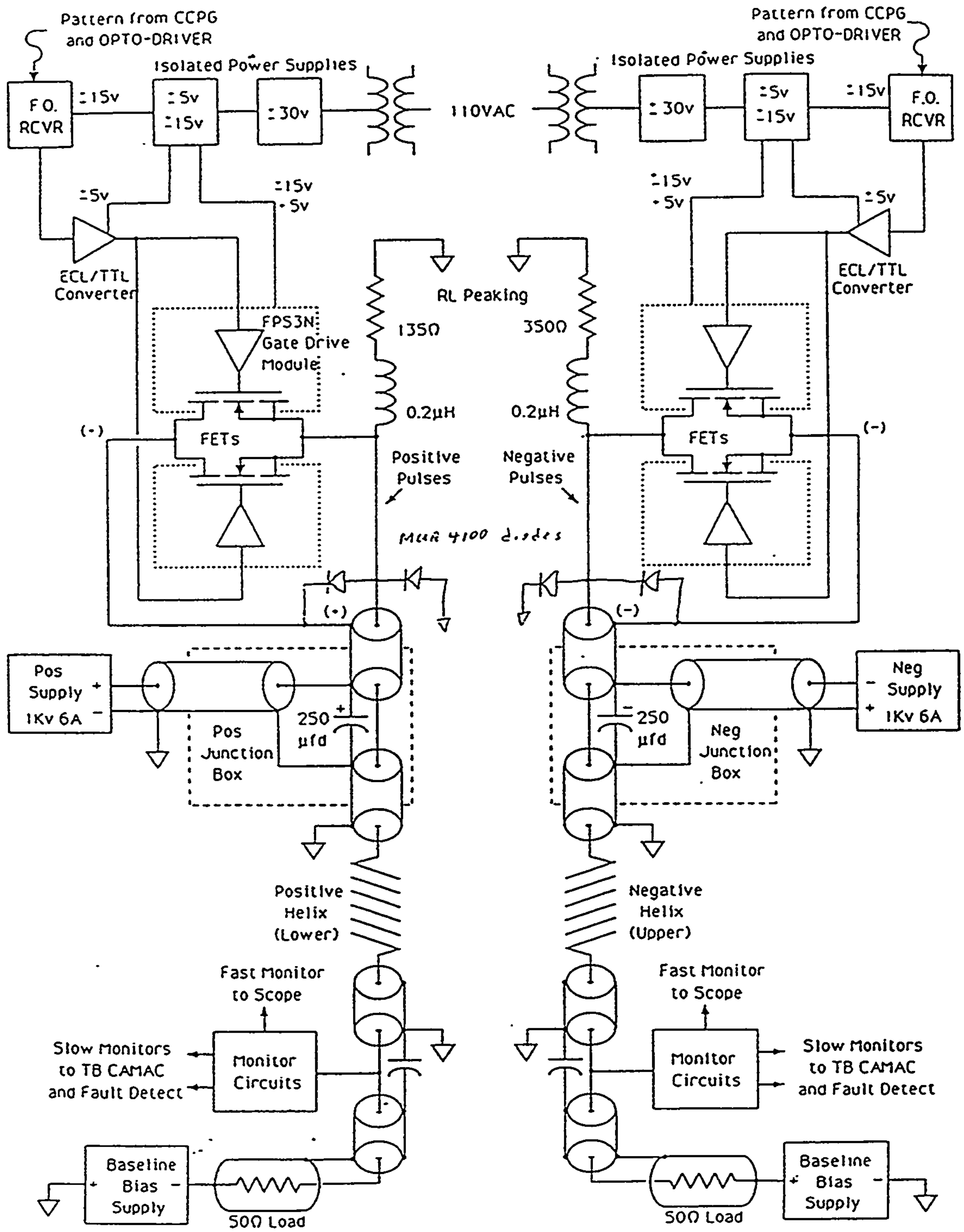
Positive Amplifier
Rise and Fall
+700 V Pulse



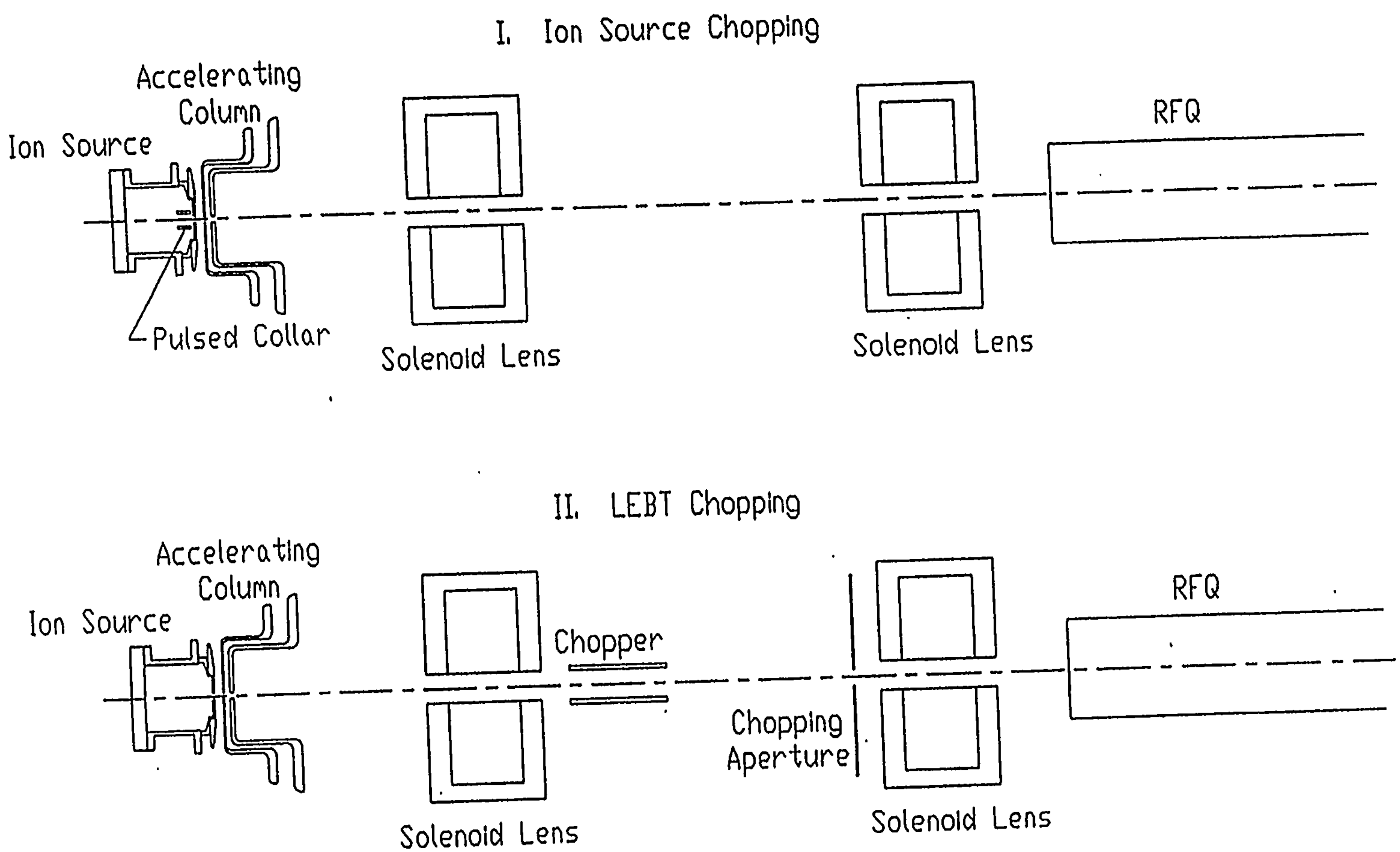
Negative Amplifier
Rise and Fall
-700 V Pulse

Los Alamos

TRAVELING WAVE CHOPPER DRIVERS
BLOCK DIAGRAM



Injector Chopping Options for LANSCE II



Los Alamos

LEBT Neutralization Model

- At the exit of the accelerating column, the H- beam will be completely neutralized by the background gas in the LEBT.
- In the chopper, the electric fields will be large compared to the beam space charge fields and the operating pressure will be low so that the beam will be essentially unneutralized in the chopper - thus precluding any phase space distortions from partially neutralized beams.
- In the region from the chopper to the chopping aperture, the background gas pressure will be reestablished and again neutralize the beam. The presence of cold electrons should damp the ion-hose instability.
- The beam will be only partially neutralized in the final region of the LEBT after the chopping aperture because of the dynamics of the decay of the positive ion column.

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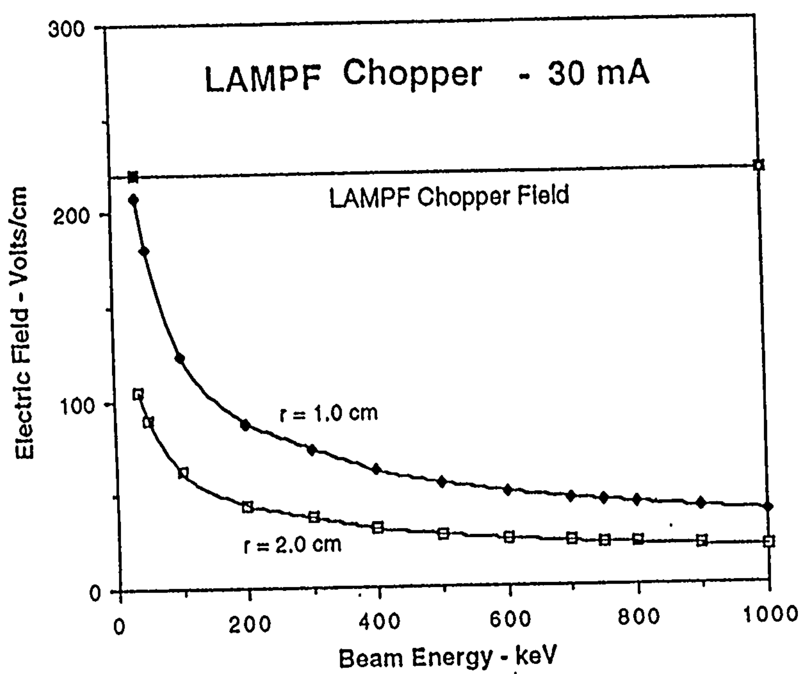
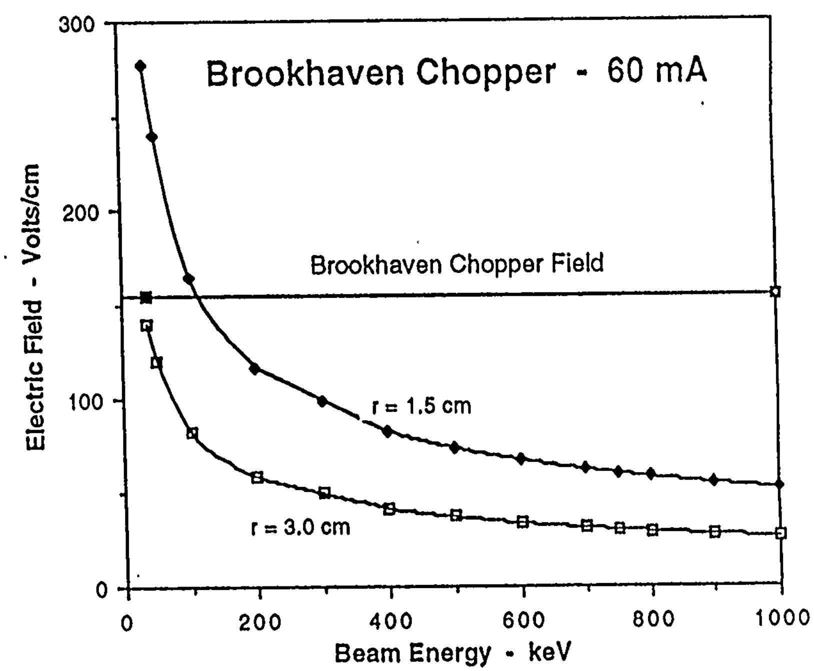
Chopper Space Charge Fields

$$E(r) = 1/2\pi\varepsilon_o [\ I/rv_b]$$

I = Ion beam current
v_b= Ion velocity
r = beam radius





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Neutralization of the Chopped Beam

- The degree of space charge neutralization in a chopped beam will be determined by a balance between the production and the loss of the plasma ions from the neutralization channel.
- Production of plasma ions occurs primarily during the 400 ns on time (T) and is given by:

$$\Delta n_i = [n_b n_g \sigma_i v_b] T$$

- Loss of the positive ion neutralization channel occurs during the 200 ns beam-off time. The maximum loss can be estimated by assuming that all the ions that expand spatially out of the neutralization channel due to space charge repulsion in this time interval will be lost.
- Equating the slow ion production to the estimated loss in the channel, we find that for a 1-cm radius beam propagating in 2 x 10-5 torr pressure of background gas, that the predicted beam neutralization is <2% for hydrogen gas, >60% for argon gas, and >100% (overcompensated) for xenon gas.
- Higher neutralization for this chopped beam can be achieved by using higher gas pressures, heavier gases, or larger beam channels.

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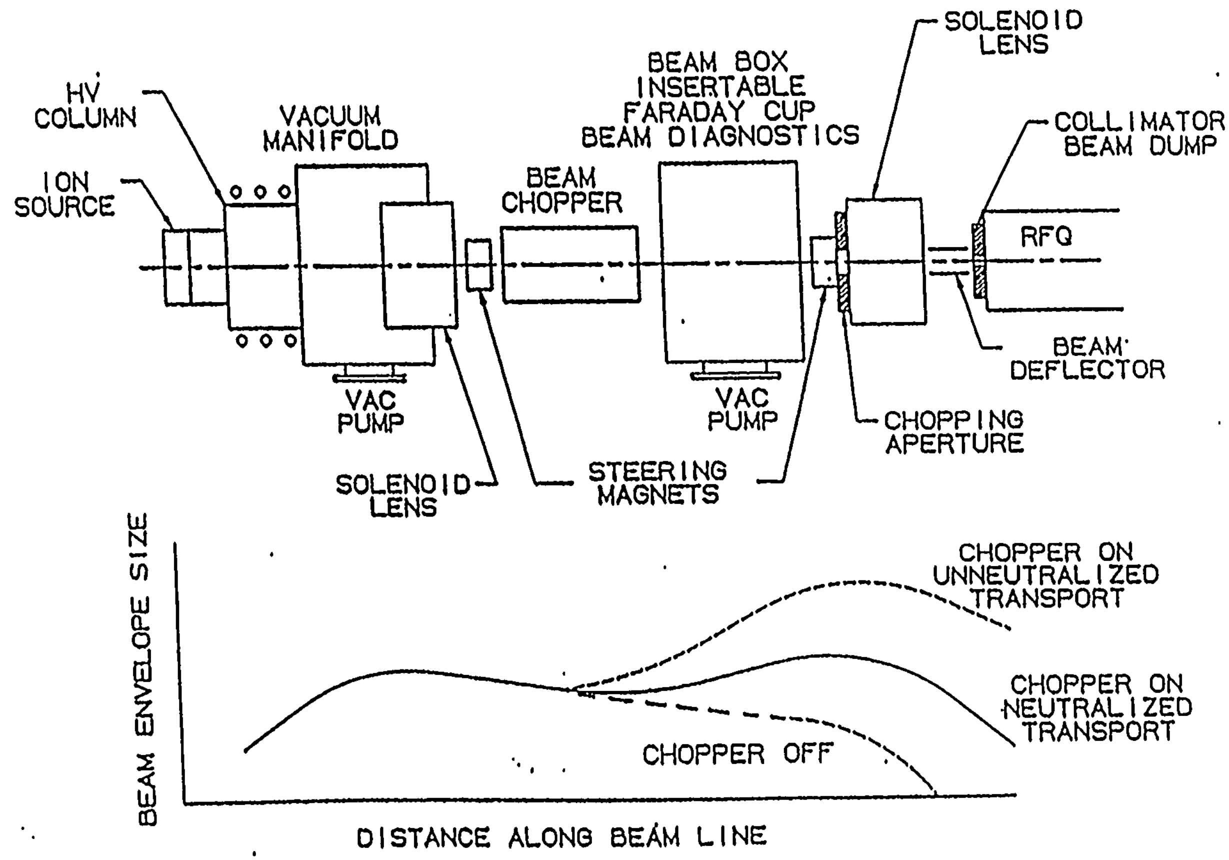
Layout of Proposed LEBT



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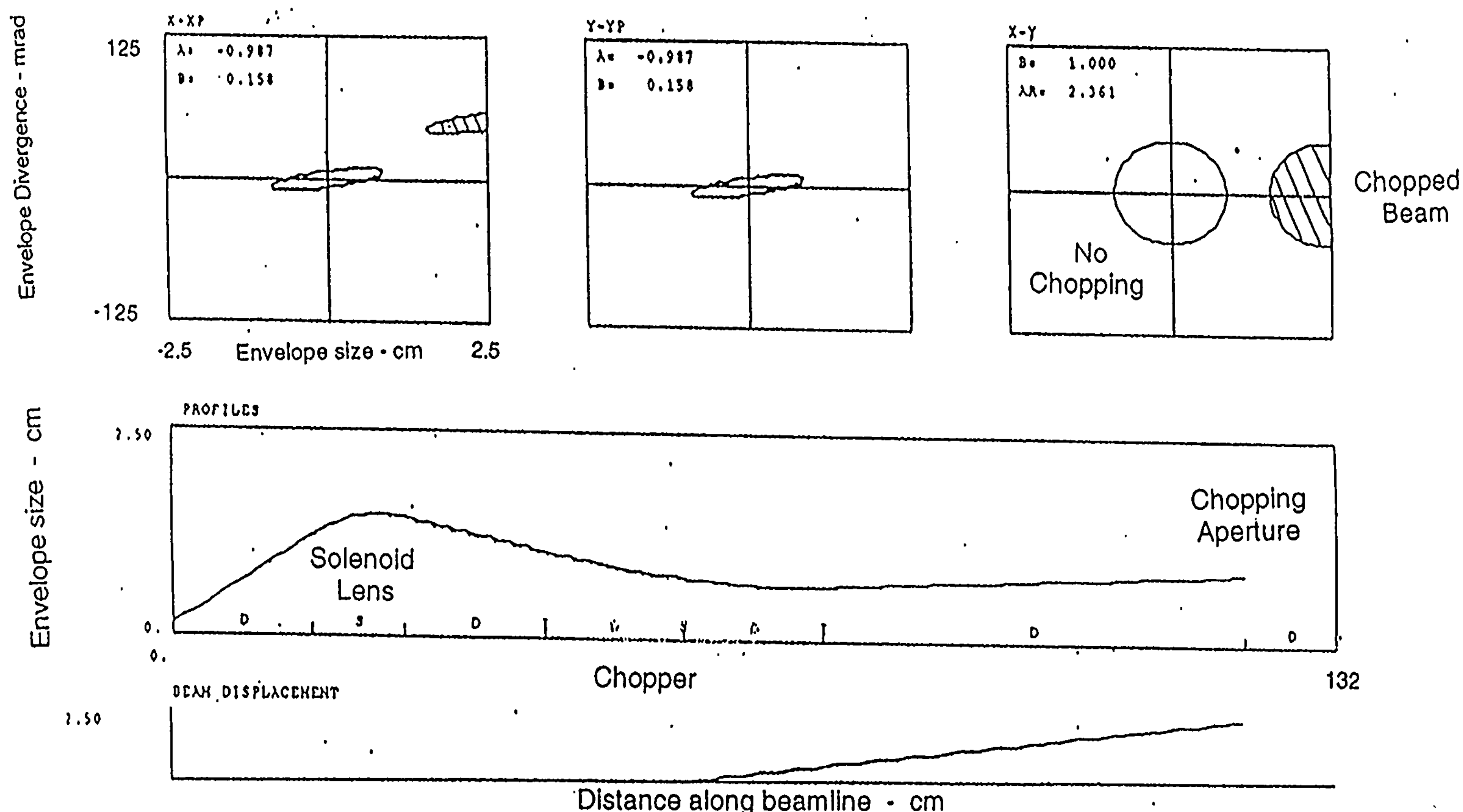
Chopping at the Aperture Plate
100 keV - 30 mrad



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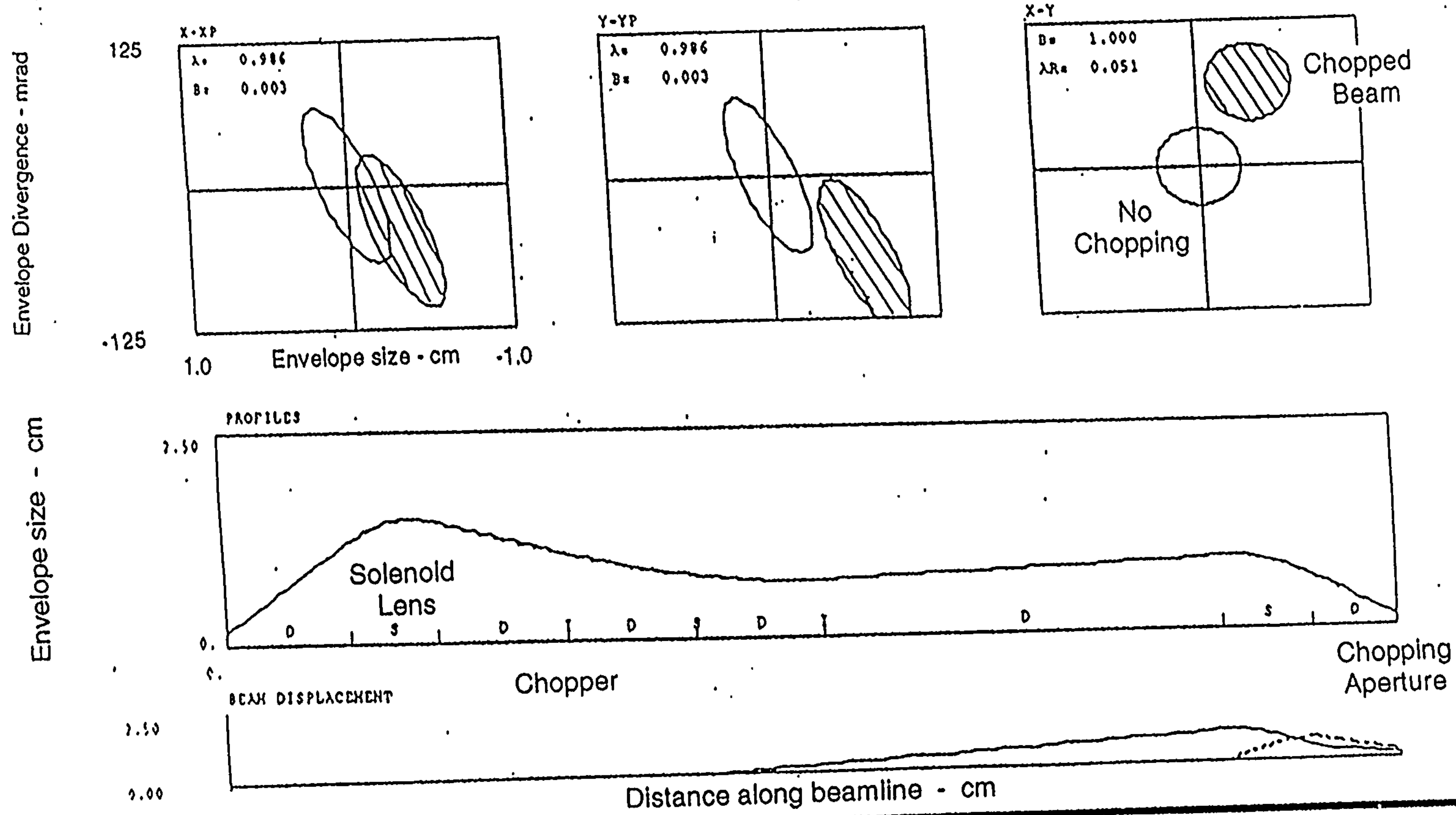
Chopping at the RFQ Entrance
100 keV - 15 mrad



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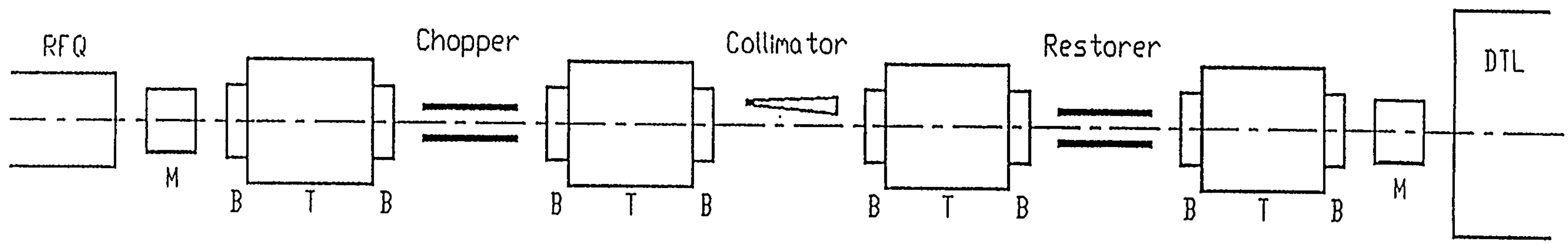
Post-RFQ Chopping Option for LANSCE II



B. - Buncher
T - Quad Triplet
M - Matching Quads

- Beam is tightly focused longitudinally and transversely.
- Parmila simulations show low emittance growth.
- System is capable of restoring partially deflected pulses.
- Power loading on collimator is estimated to be 50W/cm*2.

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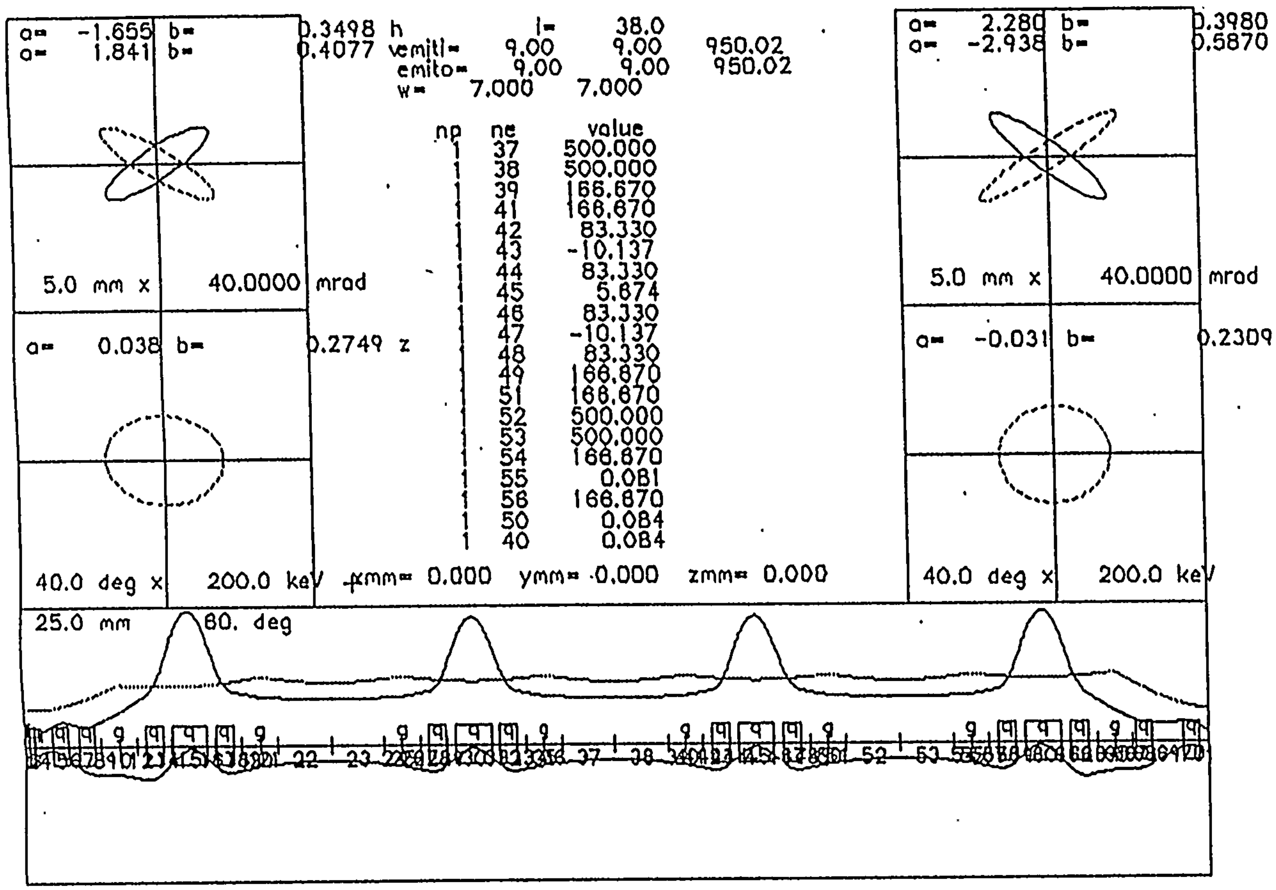
Beam Profiles for the RFQ Chopper



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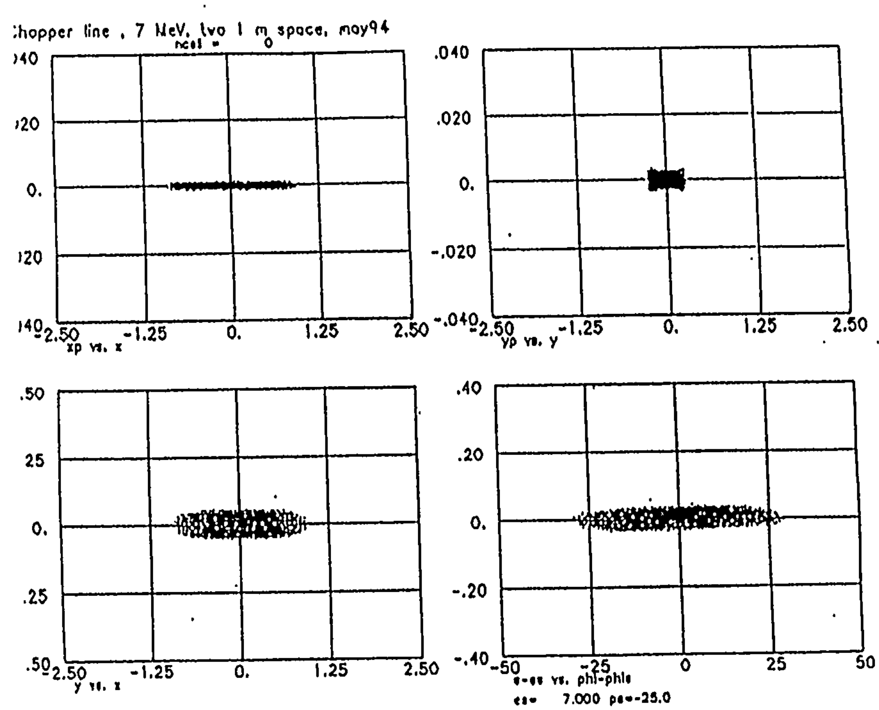
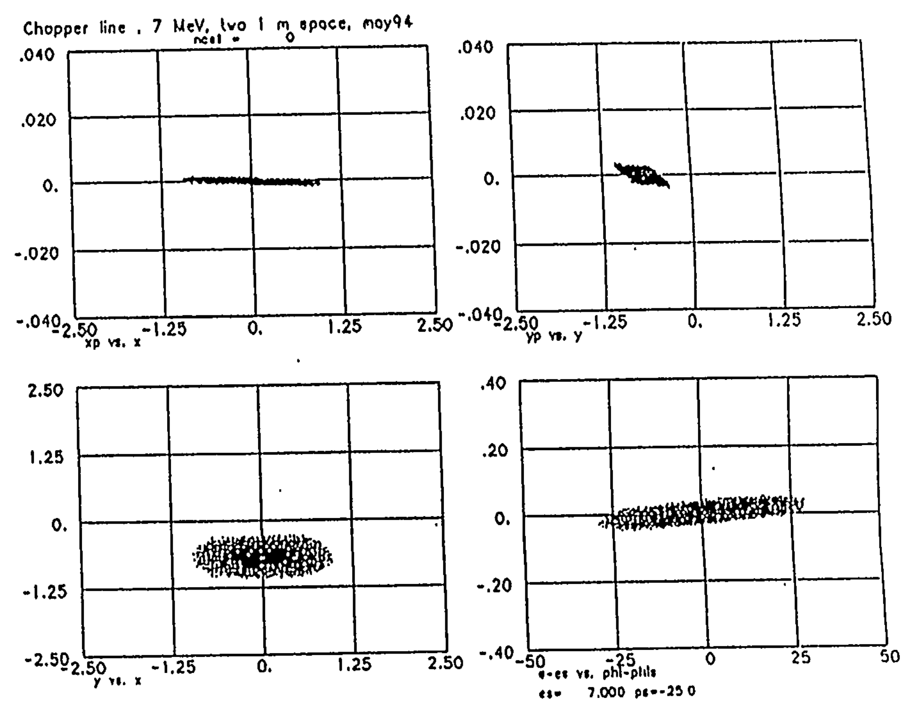
Phase Space Distributions for the RFQ Chopper



Undeflected Beam



Deflected Beam

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Comparison of Chopping Options

- At low energies (35 keV), the space charge field of the unneutralized beam leads to plasma buildup and subsequent phase space distortions in the chopped beam.
- At intermediate energies (750 keV), space charge effects are no longer important and traveling-wave choppers have been used sucessfully.
- At high energies (several MeV) , the questions of handling the rejected beam become more important. The beam transport is complicated by the need to provide proper matching and tune, but the system should result in cleaner chopping and low emittance growth.
- Ion source chopping provides an alternative approach but the technology has not yet been developed to meet the present requirements. However, it may be useful for prechopping.

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Conclusions

- Traveling Wave Choppers are proven systems and capable of providing the required time modulation for LANSEC II applications.

- Chopping in front of the RFQ is a simpler option but is complicated by space charge neutralization effects in the low energy beam line.

- Chopping after the RFQ is a cleaner but a technically more challenging option.

- Ion source chopping used to prechop the beam before the traveling wave chopper may facilitate the chopping problem.

H^- Beam Chopping in The Ion Source - Preliminary Experiments

V. Smith

Los Alamos National Laboratory

H^- Beam Chopping in the Ion Source - Preliminary Experiments

Vernon Smith

Accelerator Operations and Technology Division
Los Alamos National Laboratory

Presented to the

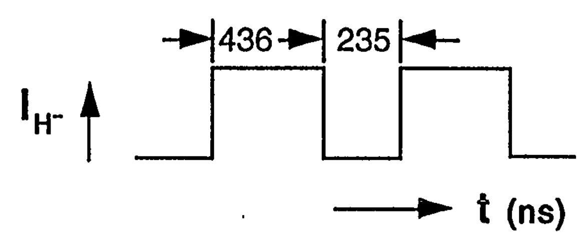
Workshop on Ion Source Issues
Relevant to a Pulsed Spallation Neutron Source

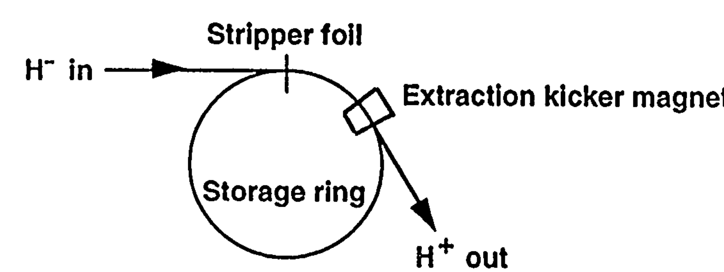
Berkeley, CA

Talk Outline

- LANSCE II beam-chopping requirements
- LANSCE II beam-chopping options
- Ion source beam-chopping experiments
  - York's experiment on a LBL cusped-field source
  - Smith's experiment on a Penning SPS
  - Mori's experiment on a BLAKE source
- Space-charge-induced time spreading of the chopped beam
- Summary

LANSCE II Beam-Chopping Requirements



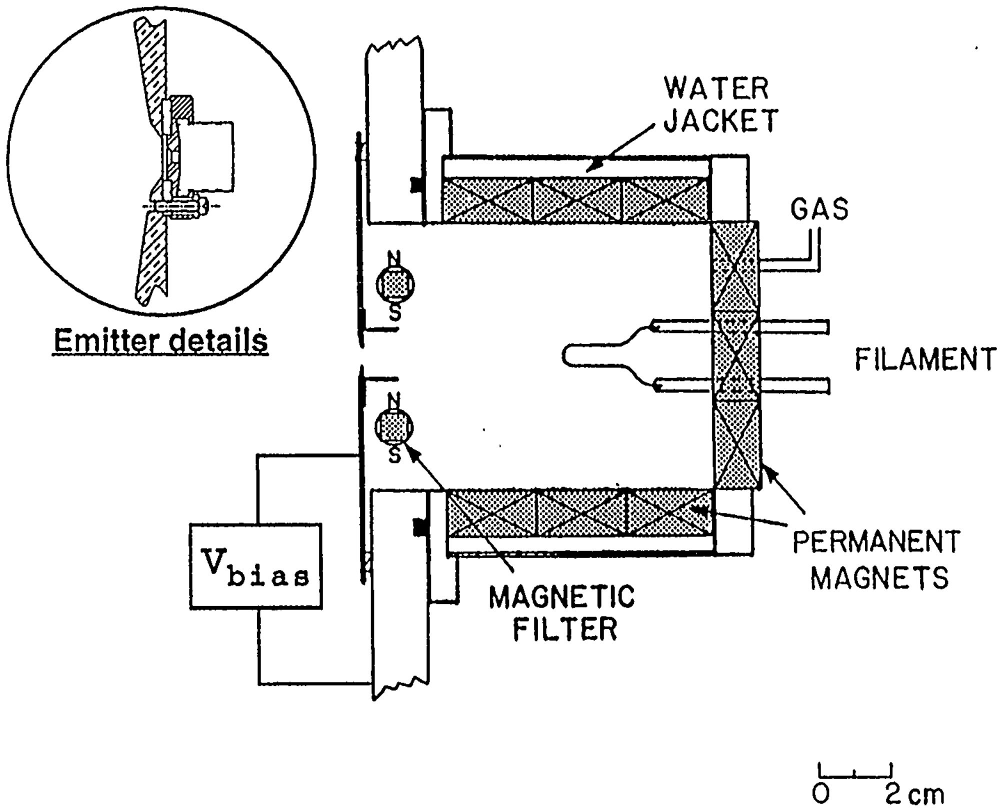


- The linac requires 235-ns-long "holes" in the H^- macropulse for charge-exchange injection into the storage ring
- The H^- beam modulation must be ≥99.99%
- The fall and rise time of the H^- current pulse must be ≤20 ns

LANSCE II Beam-Chopping Options

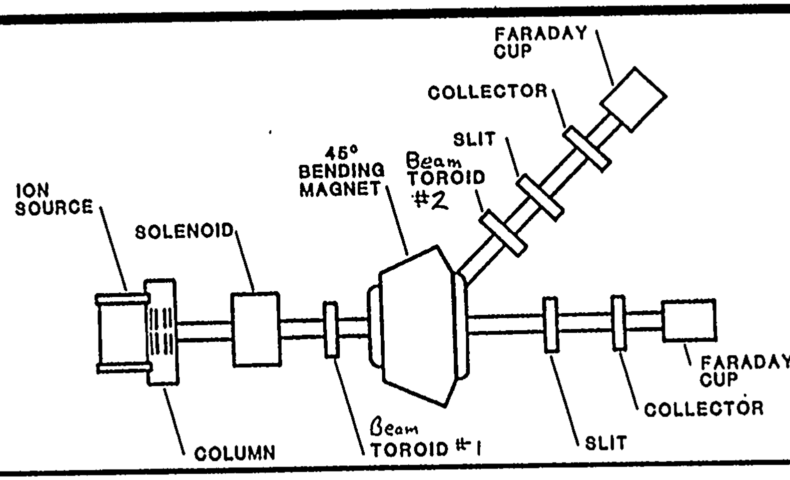
- Chop in H^- source
- Use conventional slow-travelling-wave chopper
  - at 100 keV (before the RFQ)
  - at a few MeV (between two RFQs)
  - at several MeV (in tightly-focused channel between RFQ and DTL)
- Laser photoneutralization
- Combination of any two of the three above methods
- Chop after the 800 MeV linac

York's Beam-Chopping Experiment

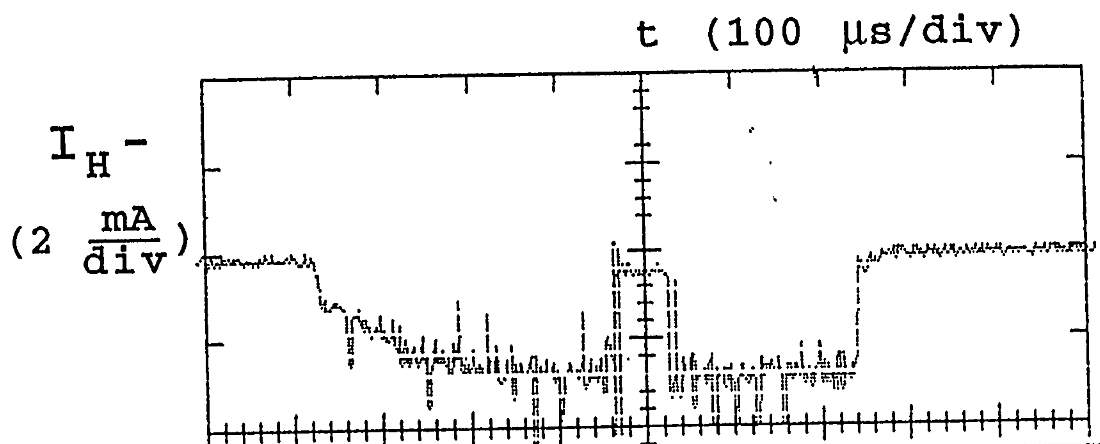


- Applied bias voltage to the plasma electrode and to the plasma electrode-collar structure in an LBL cusped-field volume source
- The source discharge was run in the hydrogen-only mode (no cesium)
- The emitter aspect ratio (L/R) was 2/1

York's Experiment . . . Continued

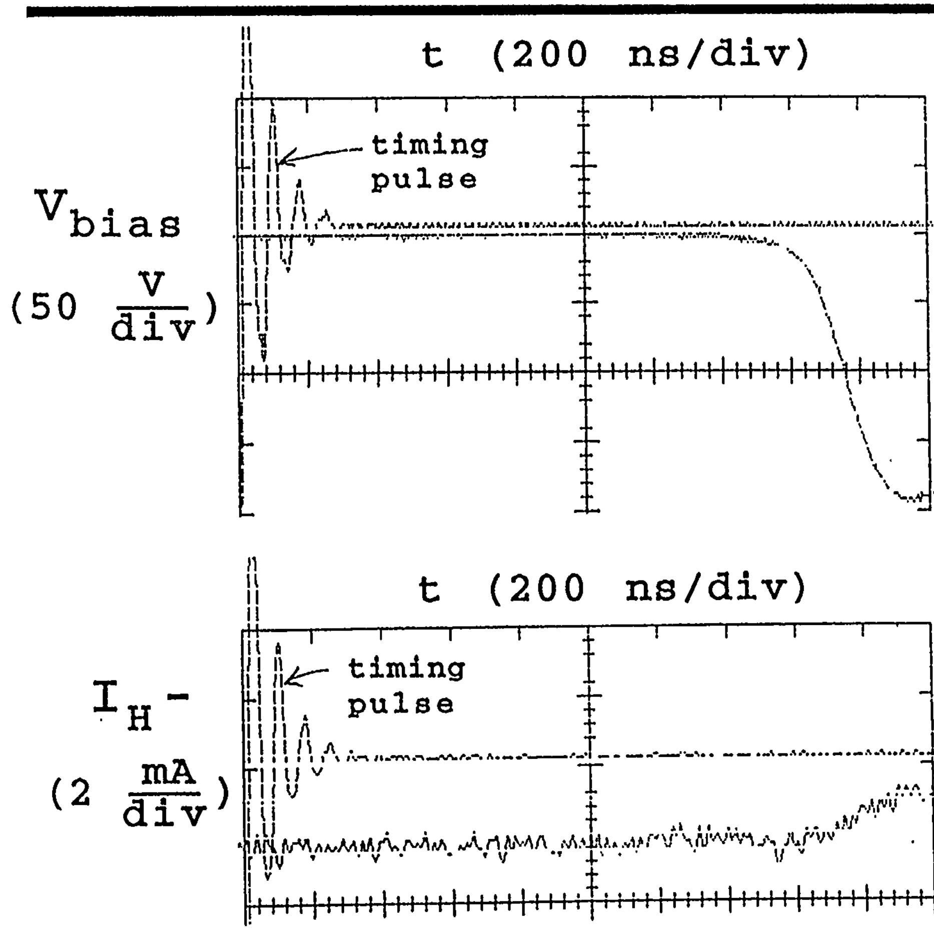


- The H^- beam is extracted from the source and transported to beam toroid #2 on the ISTS



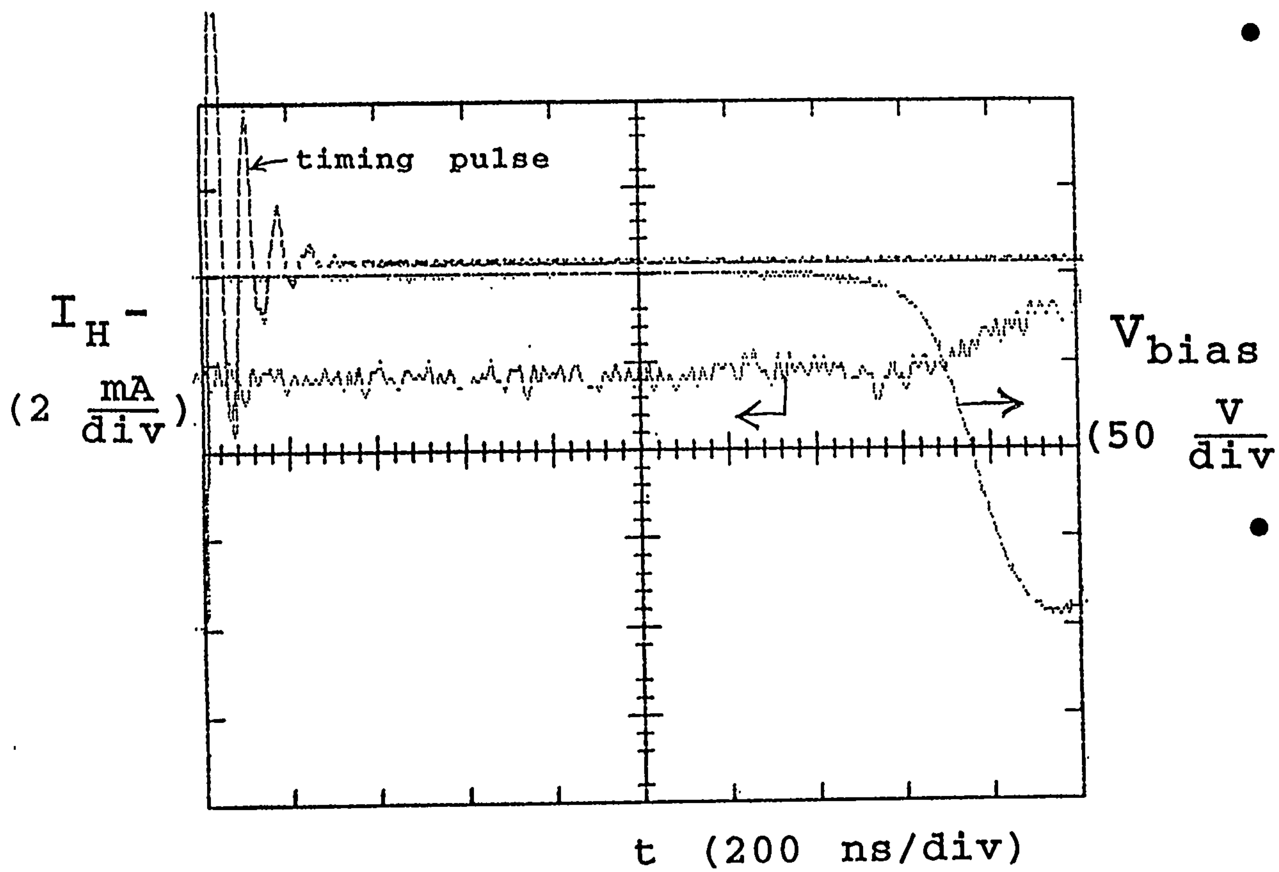
- The H^- beam pulse recorded with beam toroid #2

York's Experiment . . . Continued



- Problem - how to measure the relative timing of the bias voltage and the H^- beam current
  - the source and voltage pulser are at 80 kV
  - the toroid is at 0 V
- Solution - send a common timing signal to both, and align the time scale using this signal

York's Experiment . . . Continued

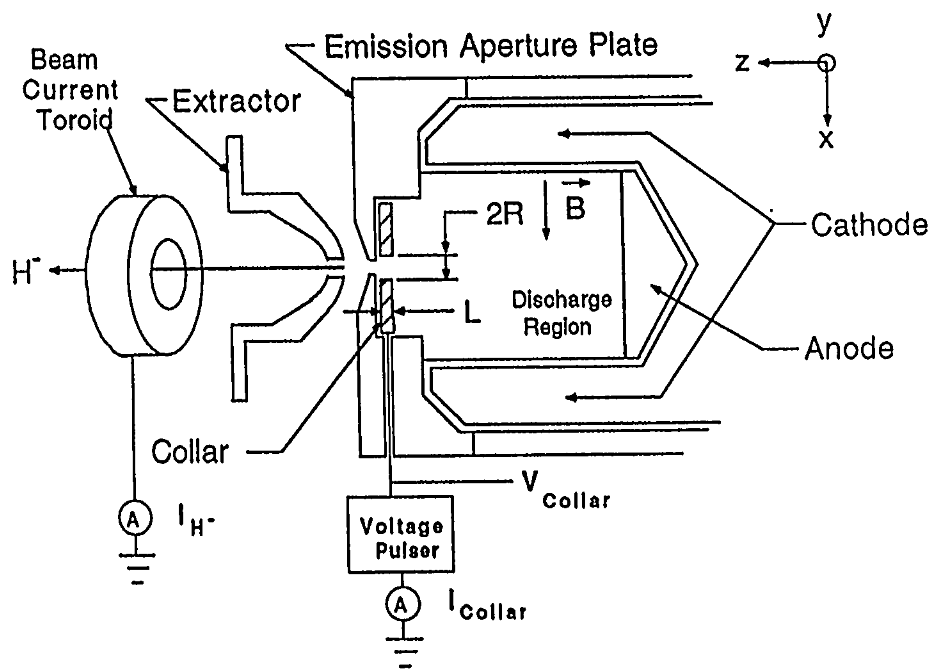


- Using the timing signal gives the absolute position of the H^- current and bias voltage waveforms
- For a 300-ns-rise- time voltage pulse the H^- beam current fall time is 300 ns

York's Experiment — Conclusions

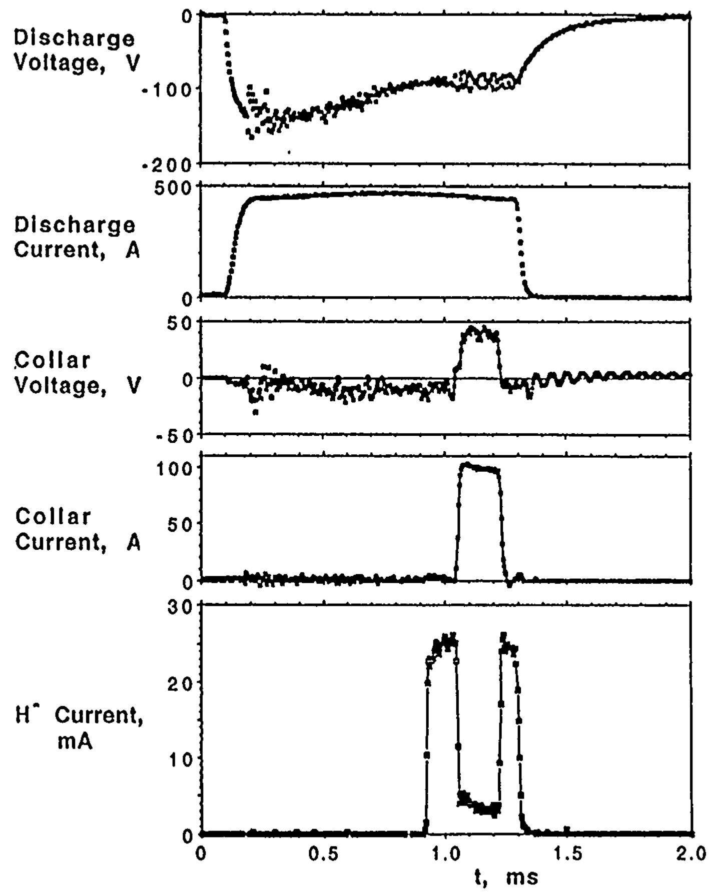
- 90% of the extracted H^- beam current is suppressed if the plasma electrode is biased at -150 V or at +40 V
- The plasma electrode can be pulsed to -150 V in 100 ns.
  - The time response of the H^- current exactly corresponds to that of the applied voltage.
  - The plasma electrode discharge time is also 100 ns
  - The H^- beam turn-on time is 100 ns
- The results are the same if the collar and the plasma electrode are biased together

Smith's Beam-Chopping Experiment



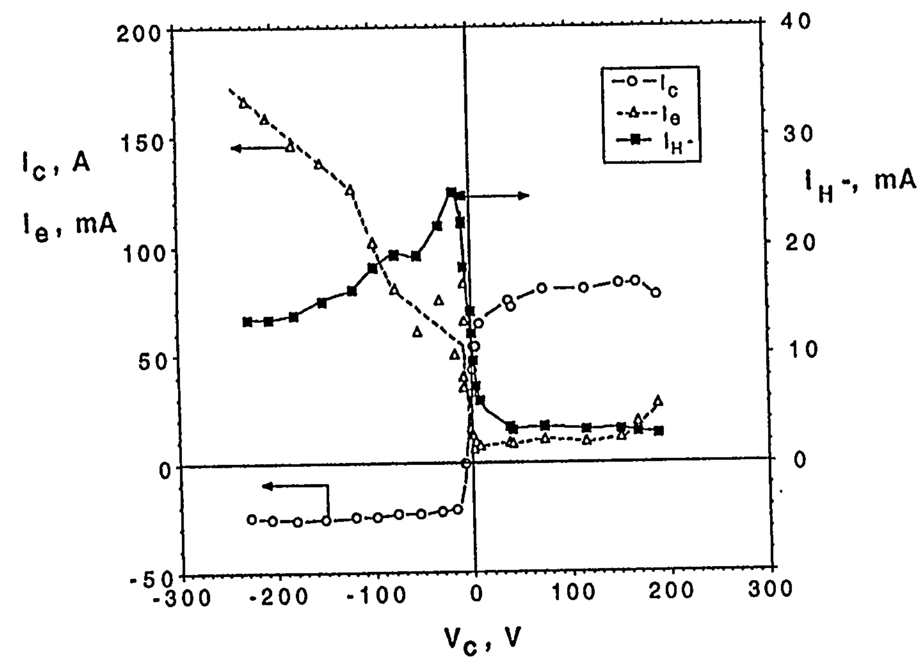
- Applied bias voltage pulse to the collar electrode in a Penning surface-plasma source
- Ran the source discharge in the hydrogen-cesium mode
- Measured the H^- current with a toroid and a Faraday cup (not shown) that are 4 and 8 cm from the emission aperture, respectively

Smith's Proof-of-Principle Results



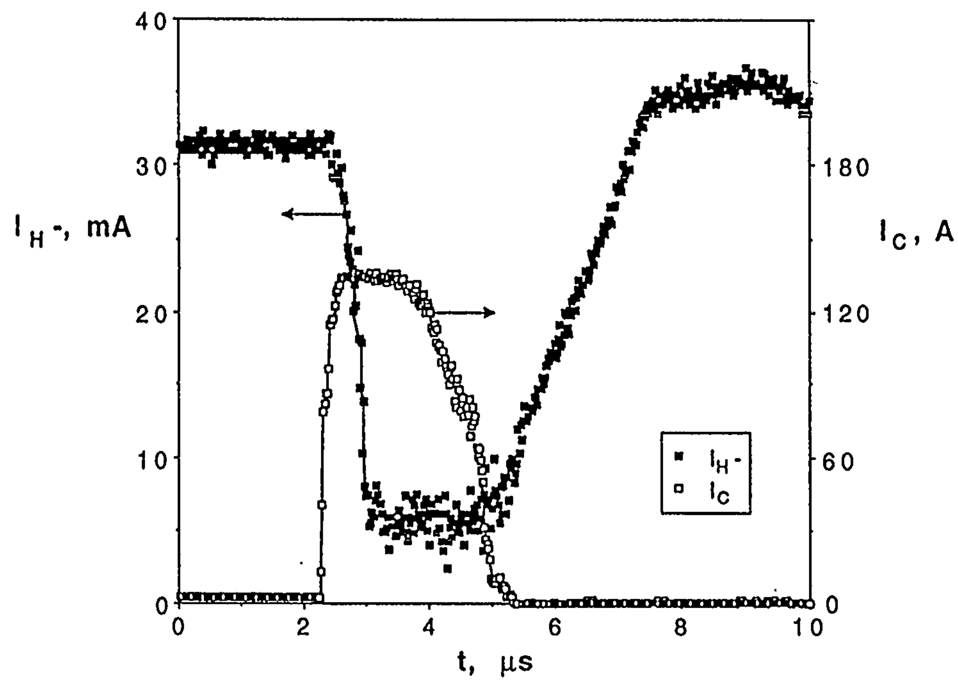
- A 38-V, 100-A collar pulse modulates a 25-mA H^- beam to 2.5 mA
- 90% modulation is useful if the beam fall and rise times are fast

Smith's Experiment - Collar Bias Variations



- Measured I_c, I_{H^-}, and I_e as a function of V_c
- If the collar pulser is off, the collar floats at -9 V
- Collar bias ≥40 V lowers I_H- to 3 mA and lowers I_e to 10 mA
- - 230 V collar bias lowers I_H- to only 13 mA, but raises I_e to 170 mA
- Positive collar bias is preferred for chopping the Penning SPS beam

Smith's Experiment - Fall and Rise Times

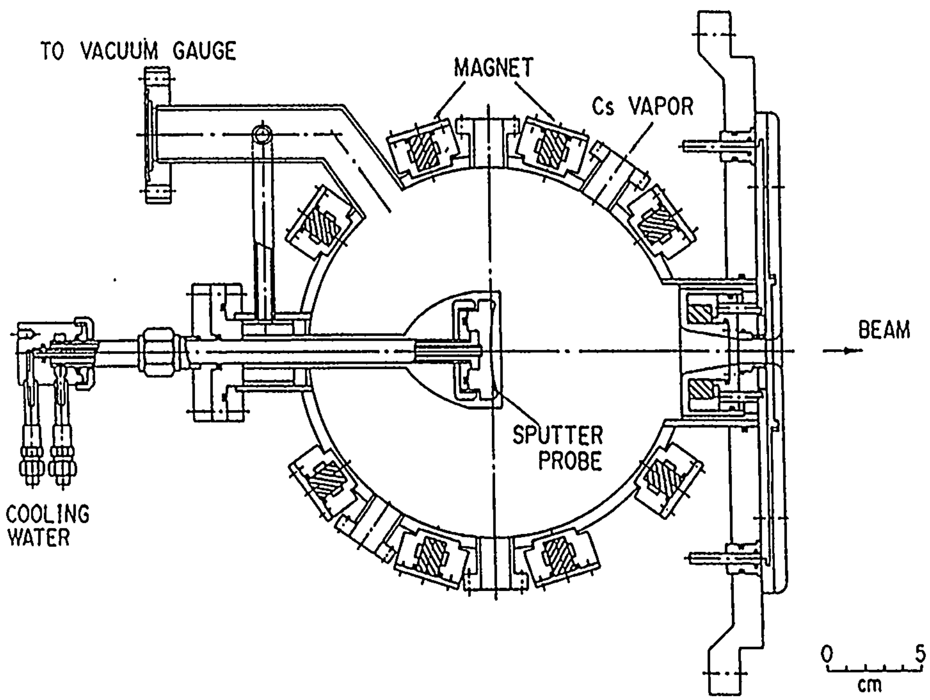


- Voltage/current pulser has 300-ns-rise and 500-ns-fall times
- Collar has L = 1.2 mm, R = 1.5 mm
- The H^- beam fall time is 450 ns
- The H^- beam rise time is 2.6 μs (collar floating)

Smith's Experiment - Conclusions

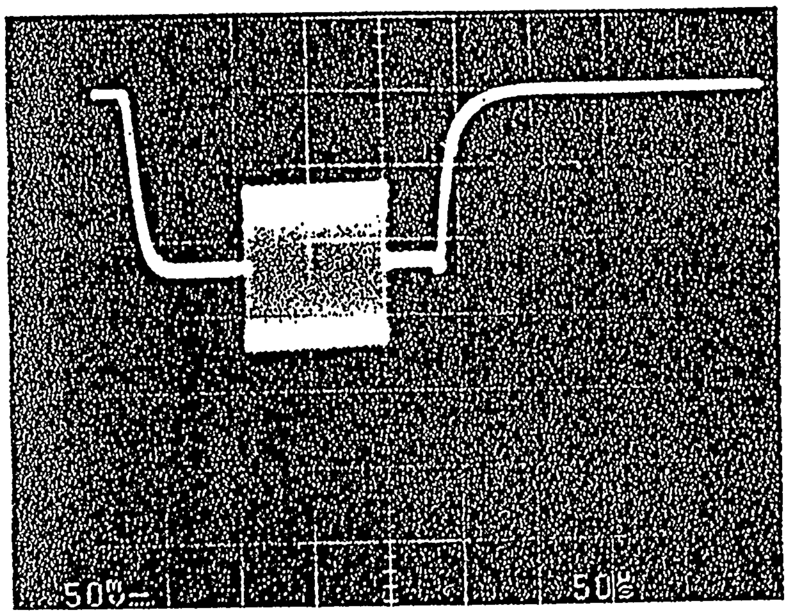
- The maximum achieved H^- beam modulation is 90%
- The minimum achieved H^- beam fall time is 400 ns (300 ns pulser rise time)
- The minimum achieved H^- beam rise time is 2 μs (500 ns pulser fall time)
- Further development is needed to decrease the beam fall and rise times and to increase the beam modulation

Mori's Beam-Chopping Experiment



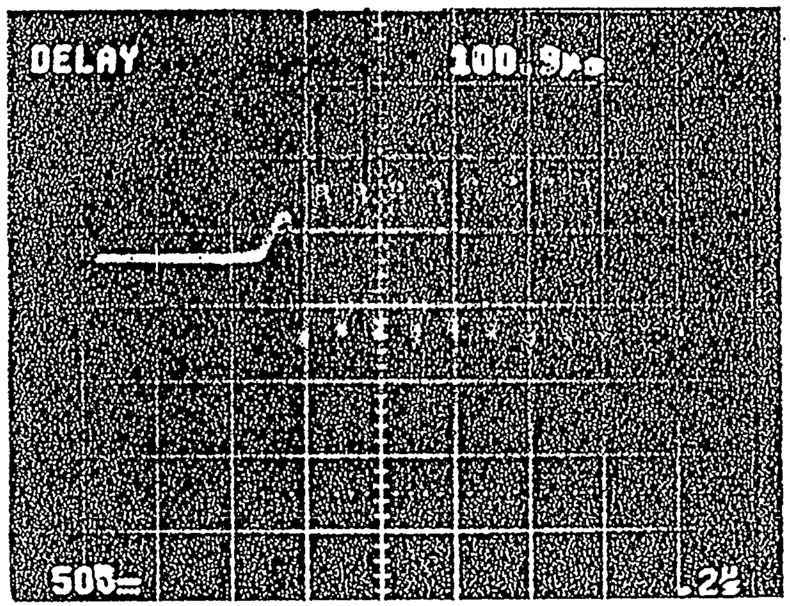
- Modulated the H^- beam from a BLAKE-II source by superimposing a rf voltage on the dc convertor voltage
- Ran the source on a hydrogen-cesium discharge
- Extracted the beam at 30 kV
- Measured the H^- current with a Faraday cup 1.5 m downstream (after the magnetic analyzer)

Mori's Experiment - Results



- A beam macropulse is shown at the left
- The rf-modulated H^- current is superimposed on top of the 2.4 mA pulse
- Mori estimates >15 mA extracted from the source
- The rf frequency is 10 MHz
- The vertical scale is 1 mA/div
- The horizontal scale is 50 μs/div

Mori's Experiment - Results

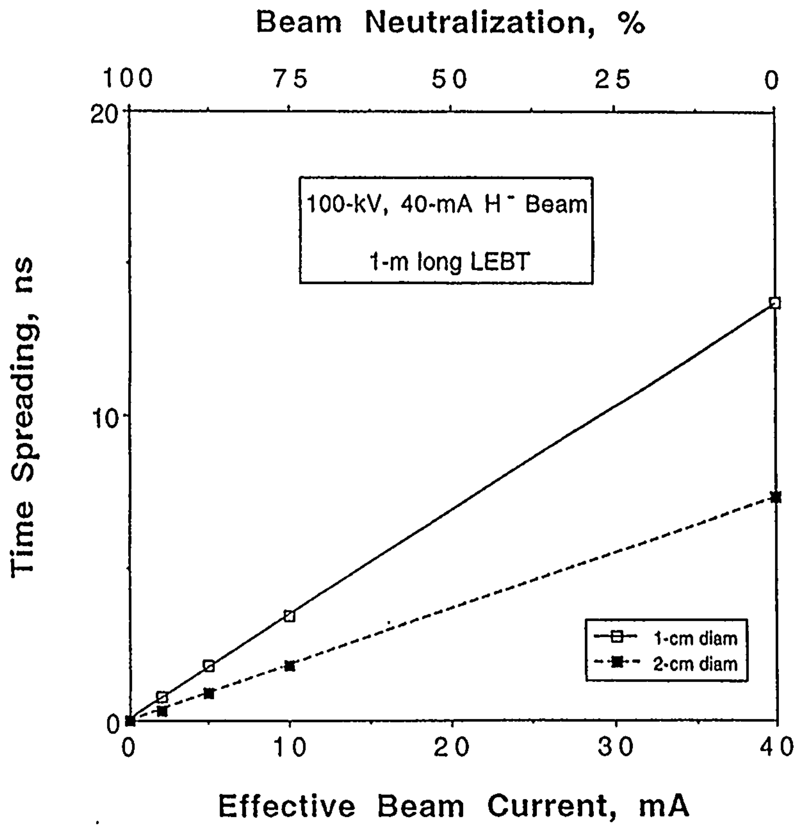


- A delayed sweep of the rf-modulated H^- current
- The vertical scale is 1 mA/div
- The horizontal scale is 200 ns/div
- The 10-MHz rf voltage modulates the 2.4-mA H^- current between 1.4 and 3.4 mA

Mori's Experiment - Conclusions

- H^- beam modulations of -58 % and +42 % have been achieved
- The time response of the H^- current is very fast — comparable to the 10 MHz rf-drive voltage (<100 ns)
- A further test using a rectangular fast pulser is in progress

Space-Charge-Induced Time Spreading of Chopped Beam



- Calculated the time spreading using the transport code SCHAR
- Assumed 40-mA, 100-keV, 1- and 2-cm diam beams in a 1-m long LEBT
- If H^- beam neutralization is ≥95 % the time spread is ≤0.4 ns for a 2-cm-diam beam
- If ≤20 ns fall and rise times are produced by ion-source chopping, they probably will be preserved in the LEBT transport

Comparison of Ion-Source-Chopping Results With LANSCE-II Design

Source	Beam Current	Modulation	Beam Fall Time	Beam Rise Time
LANSCE-II Design	40 mA	≤-99.99%	≤20 ns	≤20 ns
Cusped-Field Volume	2 mA	-90%	100 ns	100 ns
Penning SPS	25 mA	-90%	400 ns	2 μs
BLAKE-II	2.4 mA*	-58%, +42%	<100 ns	<100 ns

* >15 mA from source

Summary

- For each source, the beam-chopping results are mixed
  - The LBL volume source has demonstrated fast response time, but low modulation and low H^- beam current
  - The Penning SPS has demonstrated high beam current, but low modulation and slow response time
  - The BLAKE source has demonstrated fast response time, but low modulation and moderate H^- beam current
- The physics of the modulation process is poorly understood
- Work on this technique is recent, so rapid progress is likely
- We are closer to meeting the required beam fall and rise times than we are to meeting the required beam modulation
- 90% H^- beam modulation is useful with 2^{nd} chopping method
- Further development is warranted

LEBT: Ion Source to RFQ, Advantages and Problems of Space Charge Compensation

J. Pozimski

Frankfurt

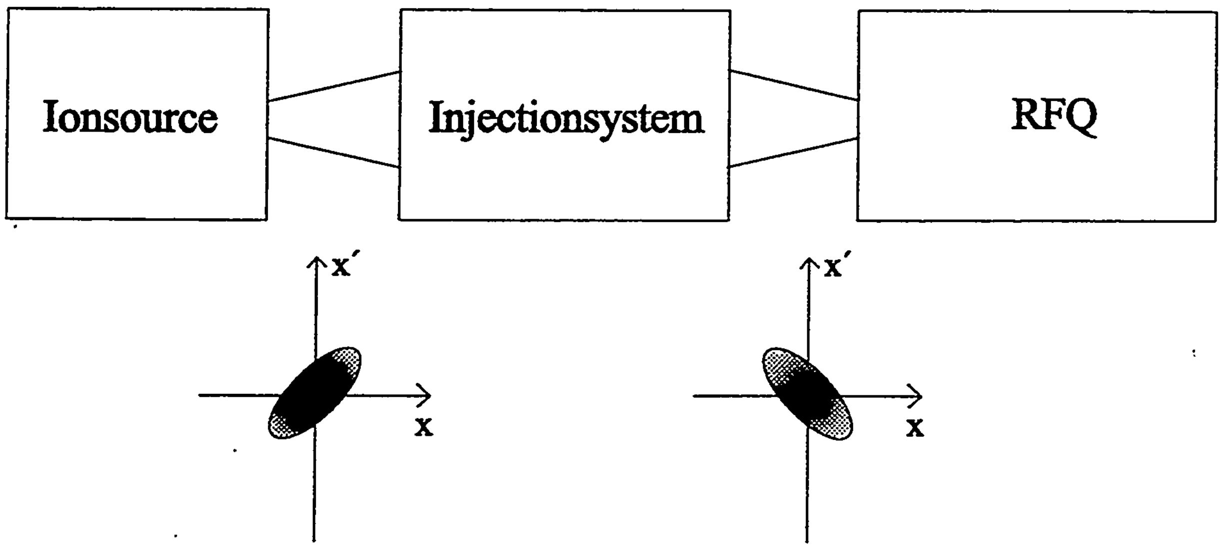
"Workshop on Ion Source Issues
relevant to a
Pulsed Spallation Neutron Source"
Berkeley
October 24th- 26th 1994

The Low Energy Beam Transport from Ion Source to RFQ, Advantages and Problems of Space Charge Compensation

J. Pozimski
P. Groß
R. Dölling
A. Jakob
K. Reidelbach

IAP -Frankfurt

The problem of beam injection into an RFQ - accelerator



Matching a maximized fraction of the beam current from the ion source into e.g. an RFQ requires:

- sufficient focusing strength

- control of emitance growth due to :
  * aberations of the focusing elements
  * non linear space charge forces
  * plasma instabilities

- high transmission
  * minimize charge exchange, stripping losses
  * losses due to rise time of space charge compensation

decompensated LEBT

(Einzellenses, ESQ,HESQ...)

⇒ small size, short length

⇒ has to be vacuum-transparent

⇒ significant emittance growth due to lens aberrations

⇒ minimized beam loss due to charge exchange/stripping

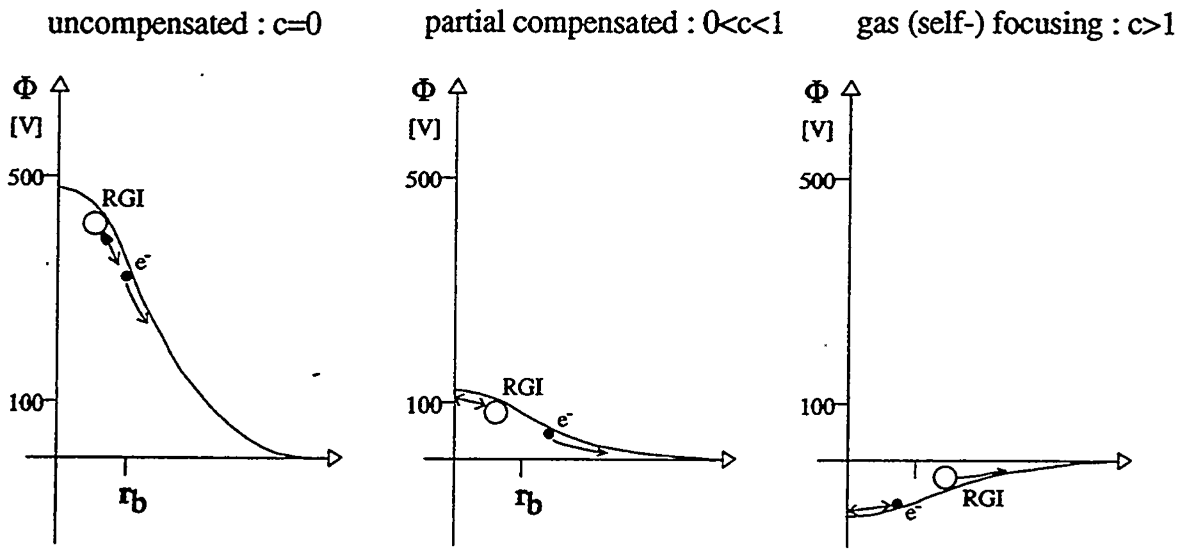
⇒ beam dynamics can be numerically simulated (in prinziple)

⇒ no space for beam diagnostics

⇒ little space for steerer

⇒ Alignment?

The compensation process - different stages



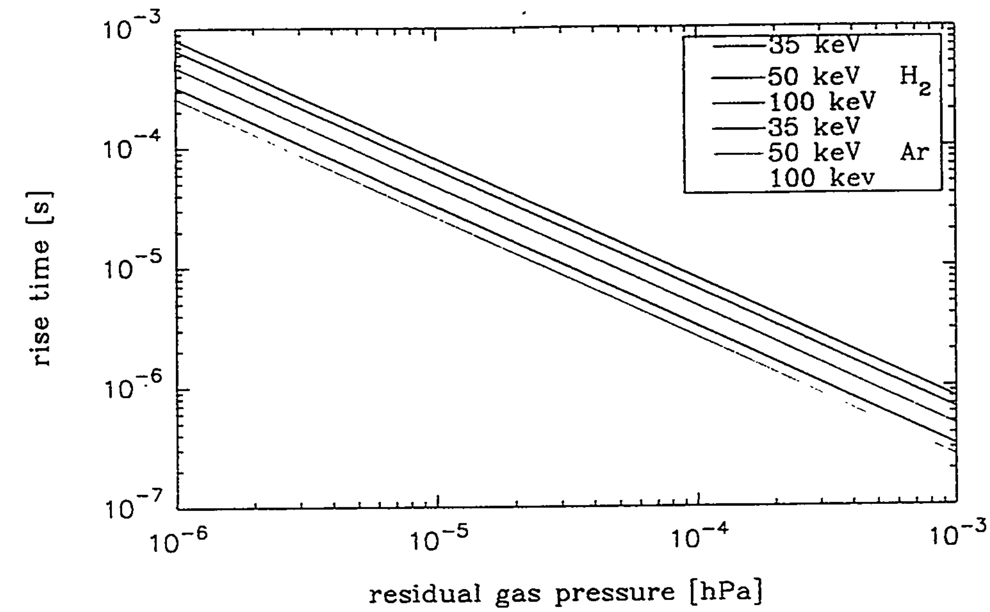
The lower pressure limit for overcompensation (c>1) can be estimated by:

$$p_{limit} = k_b \, T_{RGA} \frac{v_{RGI}}{r_b \, \sigma_{RGI} \, v_{BI}}$$

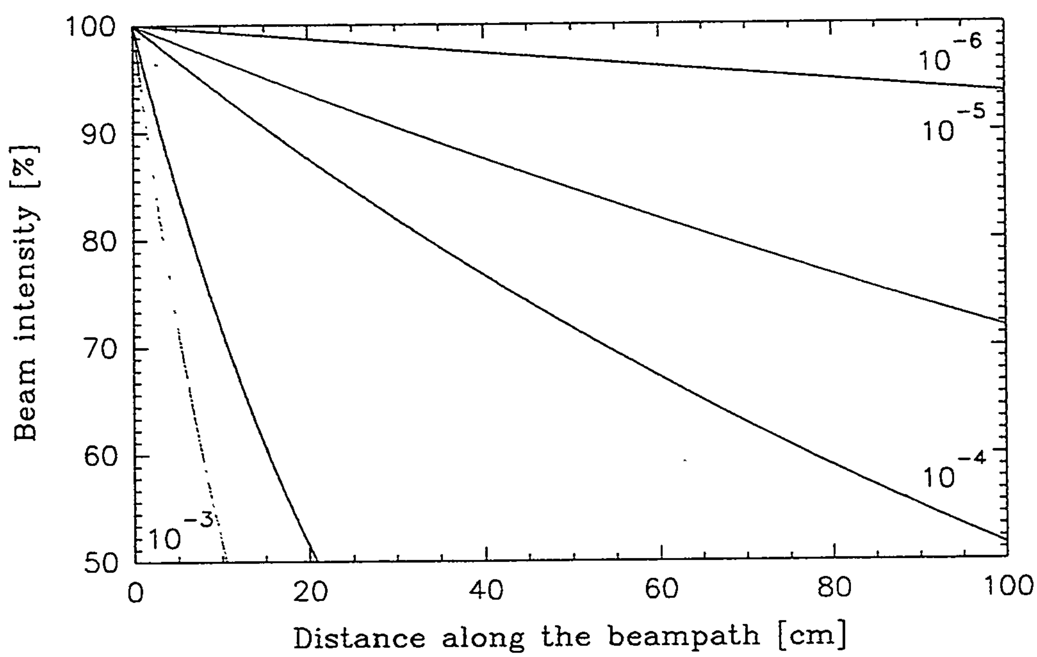
For ESS :

$$p_{limit} < 10^{-5} hPa$$

Minimum Rise Time of Space Charge Compensation



Rise time of compensation as a function of the residual gas pressure for different gases and ion energies. For the lower pressure limit the rise time will be appr. 50 µs.



Beamintensity losses along the beampath due to stripping for different residual gas pressures.For the lower pressure limit (overcompensation) and 80 cm of LEBT the transmission will be appr. 95 %.

Using cylindrical symmetry the radial potential distribution is given by

$$\Phi(r) = -\frac{1}{\varepsilon_0} \int_0^r \frac{1}{r'} \int_0^{r'} \rho_{res}(r'')\, r''\, dr''\, dr'$$

where ρ_{res} (r) is the resulting charge density distribution given by

Halo by peak of electric field

$$\rho_{res}(r) = \rho_{BI}(r) + \rho_{RGI}(r) + \rho_{CE}(r)$$

if

$$\tau_{coll.} << \tau_{trap}$$

the electrons are assumed to be thermalized. There density distribution is given by the Boltzmann equation.

$$\rho_{CE}(r) = \rho_{CE}(r{=}0)\ \exp - \left[\frac{-e\,\Phi(r)}{k\,T_{CE}}\right]$$

The "production" of RGI charge density is given by

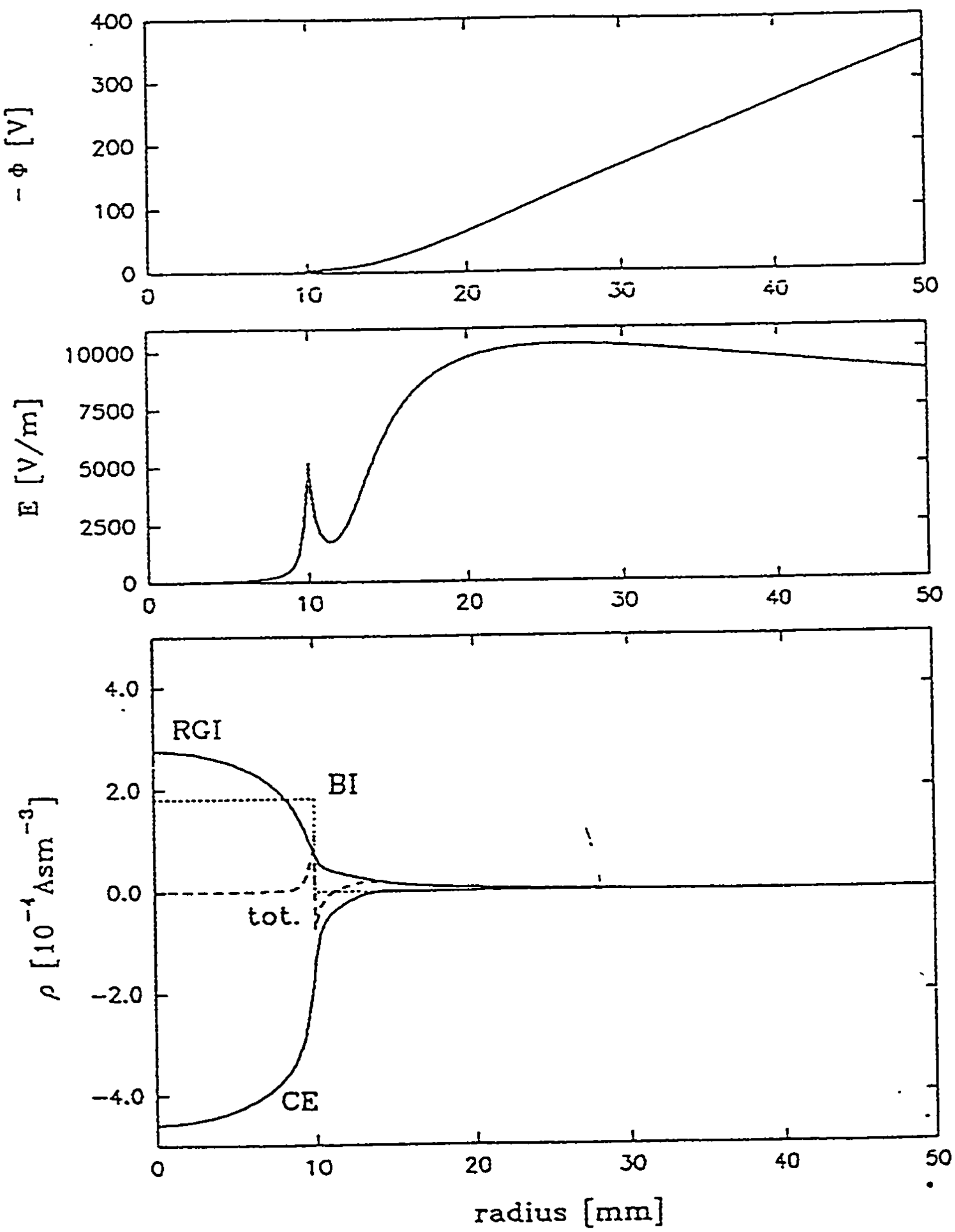
$$\dot{\rho}_{RGI} = \rho_{BI}\, v_{BI}\, n_{RGA}\, \sigma_{RGI}$$

and their velocity at radius r (if "produced" in r*) is given by

$$v_{RGI} = \sqrt{\frac{2\, q_{RGI}\, [\Phi(r^*) - \Phi(r)]}{m_{RGI}}}$$

the radial charge density for the RGI is then

$$\rho_{RGI}(r) = \frac{1}{r} \int_0^r \frac{\dot{\rho}_{RGI}(r*)\, r'}{v_{RGI}(r', r*)}\, dr'$$



Selfconsistent state for homogeneous distributed BI. T_{CE}=2.5 eV, $\rho_e(r=0) / \rho_{BI}(r=0) = 2.5$, $n_{RGA}\, \sigma_{RGI} = 0.15\ m^{-1}$.

RMS emittance growth due to charge redistribution

$$\frac{d}{dz}\varepsilon_{rms}^2 = -\frac{K}{2} <x^2> \frac{d}{dz}\Delta U$$

with the generalized perveance

$$K = \frac{I\, e\, \zeta}{2\,\pi\,\varepsilon_o\,\beta^3 c^3 \gamma^3 m\, A}$$

and the non linear field energy

$$\Delta U = U - U_{KV} = f\, u_o$$

with the electric field energy

$$U = \pi\,\varepsilon_o \left(\int_0^a E_i^2\, r\, dr + \int_a^R E_o^2\, r\, dr \right)$$

with a the beam radius and R the tube radius.

$$u_o = \frac{I^2}{4\,\pi\,\varepsilon_o\, c^2 \beta^2} = 10^{-7}\,\frac{I^2}{\beta^2}\ [joules/meter]$$

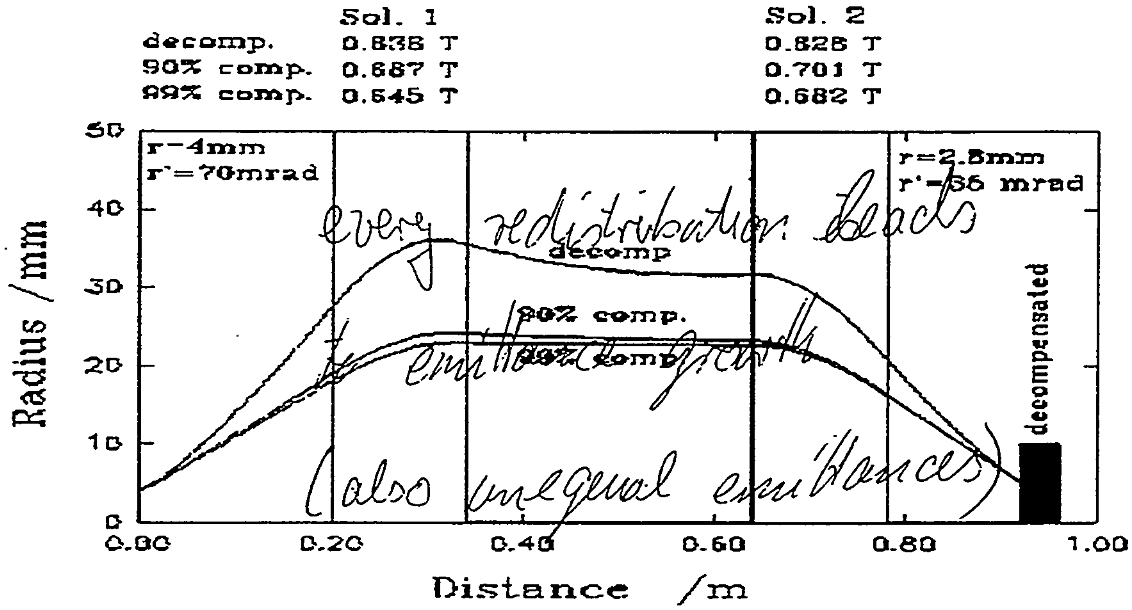
and the f-Factors

Waterbag	Parabolic	Conical	Gaussian
0.00560	0.01176	0.01408	0.03861

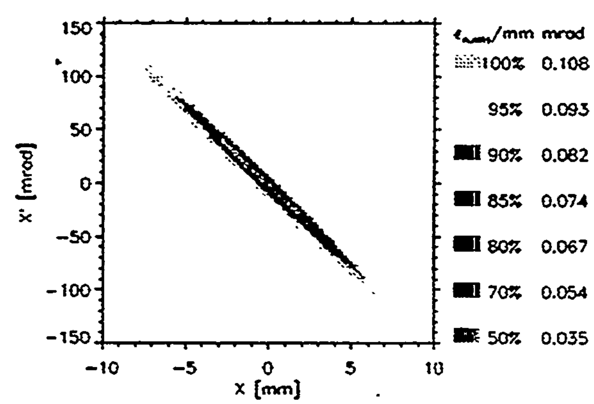
assuming a 70 mA, 50 keV, H^- beam of const. radius 10 mm ($2\sqrt{<x^2>}$) and an initial emittance of 0.1 πmmmrad and changing from gaussian to homogeneous shape

$$\frac{\varepsilon_f}{\varepsilon_i} = \sqrt{1 + \frac{K <x^2>\, 0.0386}{2\,\varepsilon_i^2}} = 4.5$$

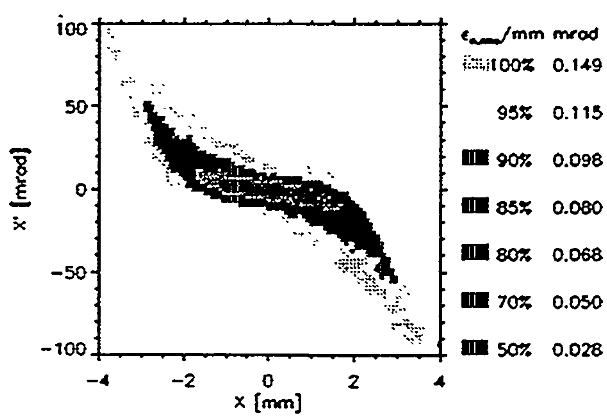
Influence of the Decompensation by the RFQ on the Beam emittance



Calculation of the beam enveloppe in a magnetic LEBT line for different degrees of compensation.

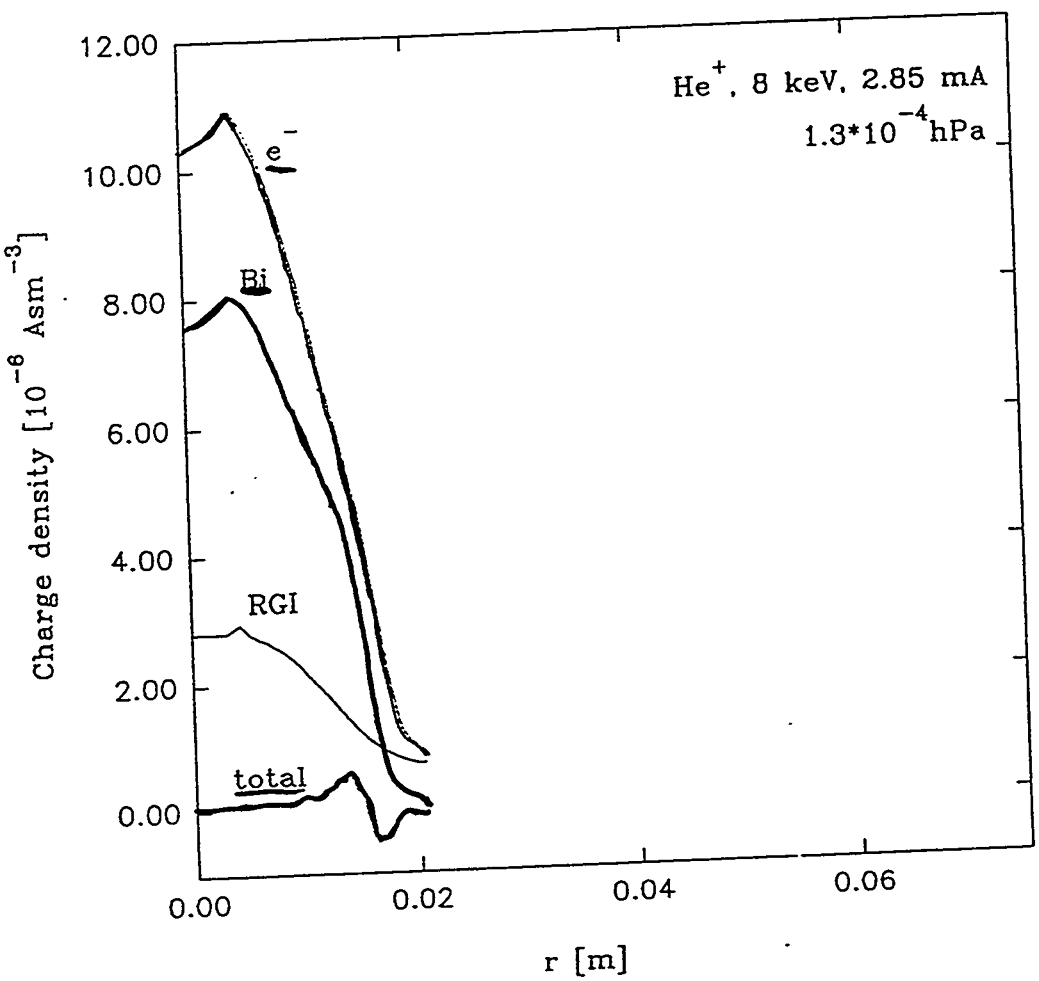


Initial emittance 4 cm in front of the RFQ. The radial density distribution is gaussian.

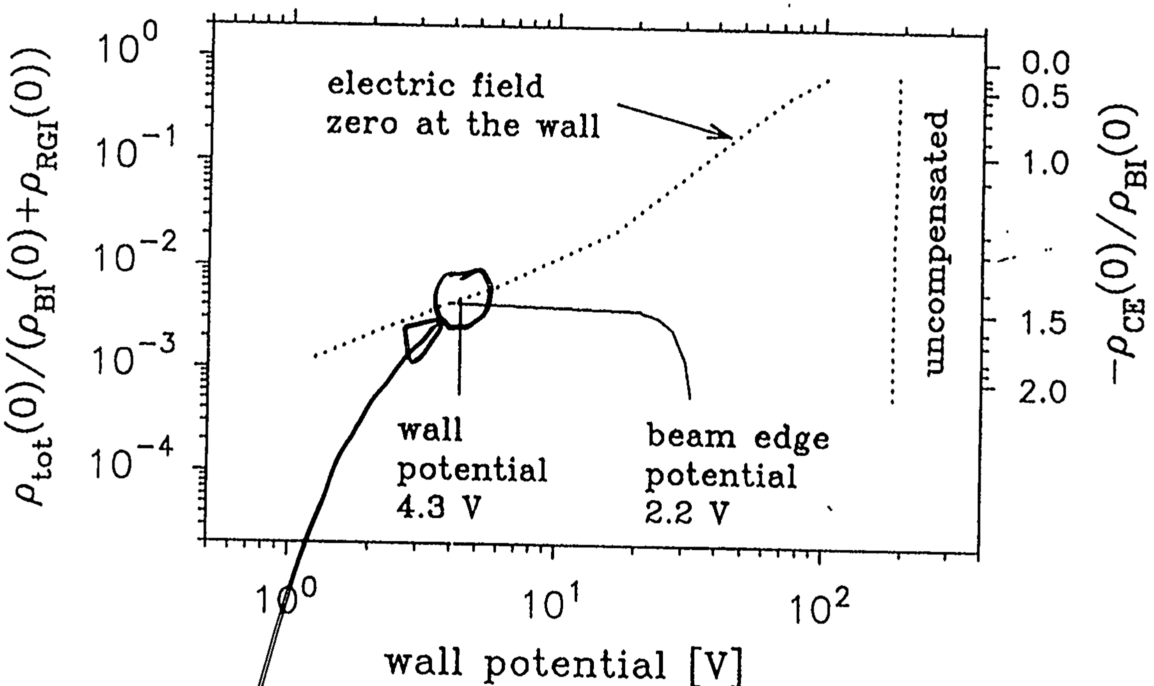


Emittance at the RFA entrance after redistrbution by space charge forces. Emittance growth appr. 20 %.

- Bi density distr. by Abel inversion of wire meas.
- RGI spectrum det. $e^{(-)}(r)$, RGI(r), tot(r)



measured

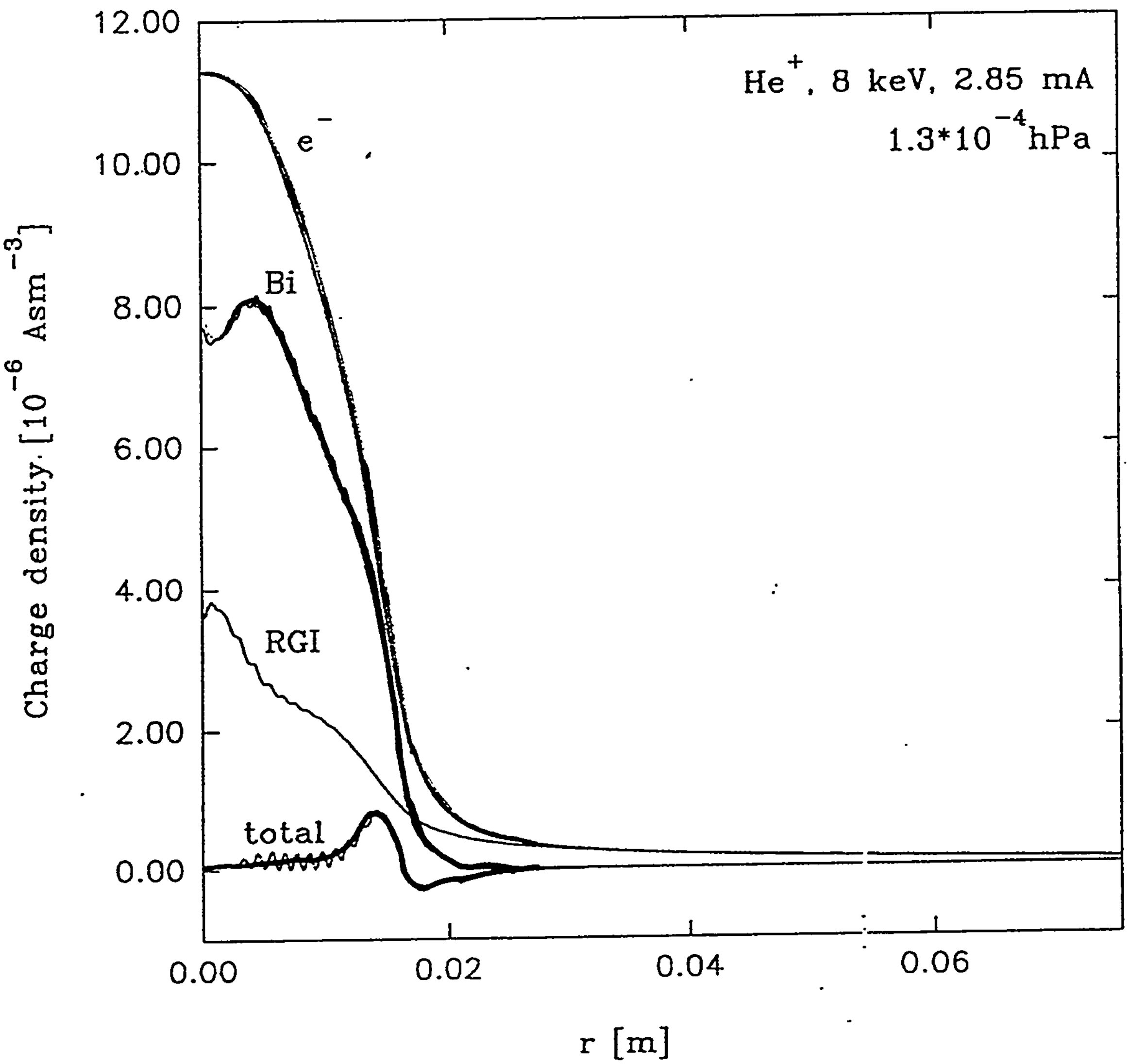


He^+, 8 keV, 2.85mA
$1.3 \cdot 10^{-4}$ hPA

self consistent state

$T_e = 0{,}9\,eV$

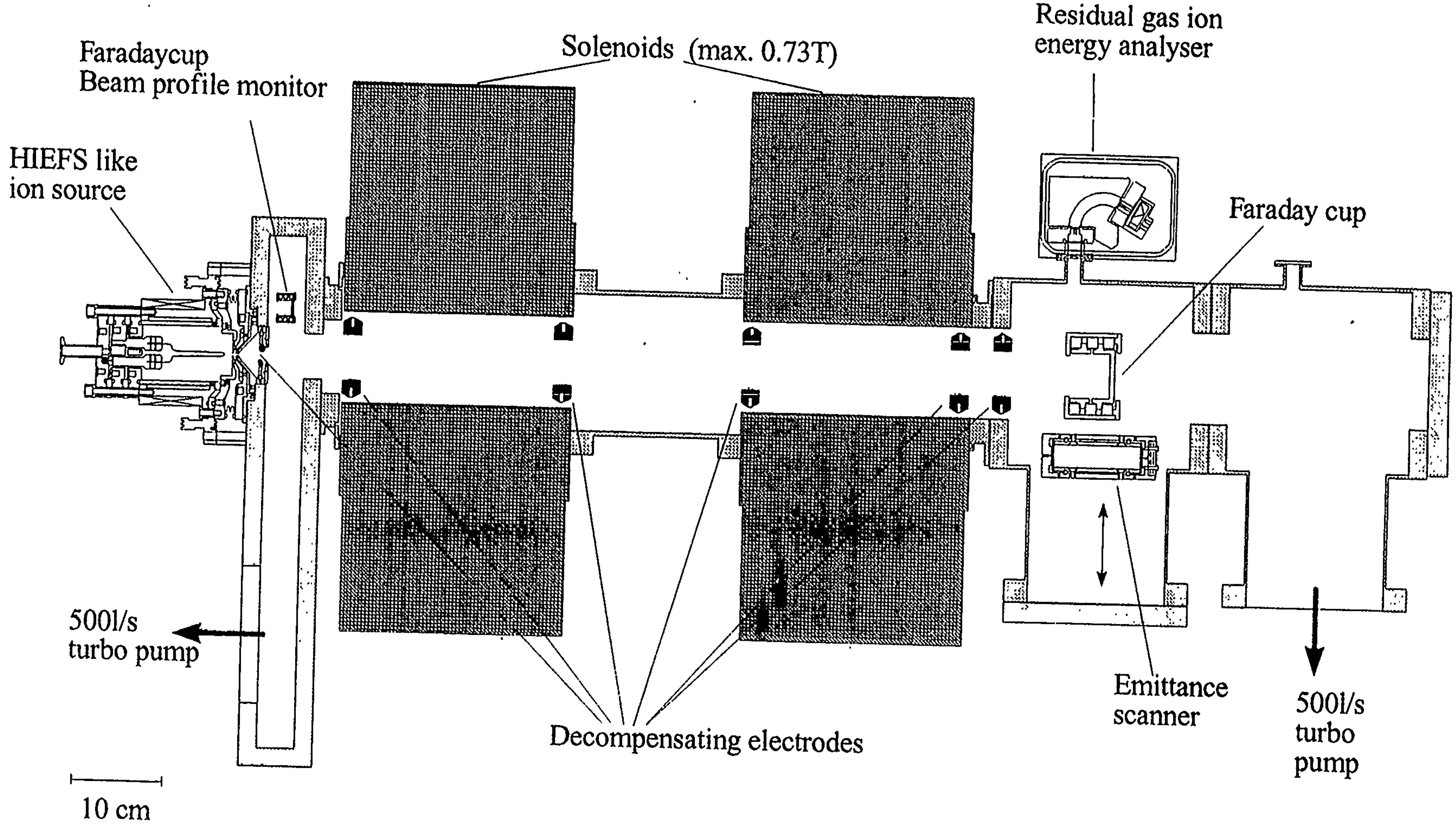
$\frac{\rho_e}{\rho_{BI}} = 1.46$ (on axis)

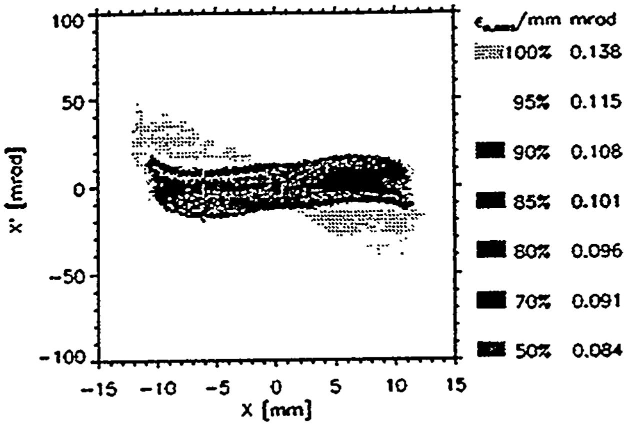


He+, 8 keV, 2.85 mA
1.3*10-4 hPa
e-
Bi
RGI
total
Charge density [10-6 Asm-3]
r [m]
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
0.02
0.04
0.06

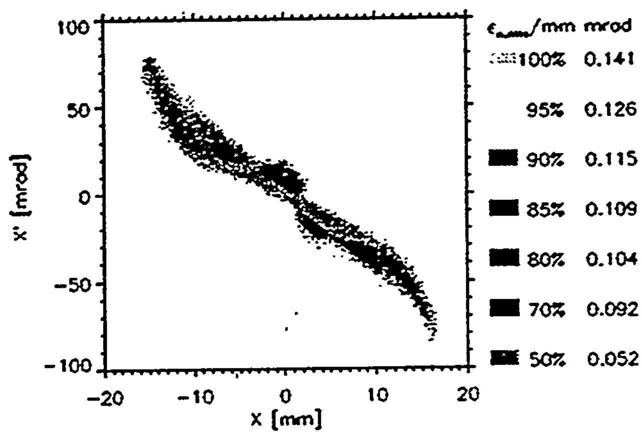
Theory

Schematic drawing of the Frankfurt LEBT

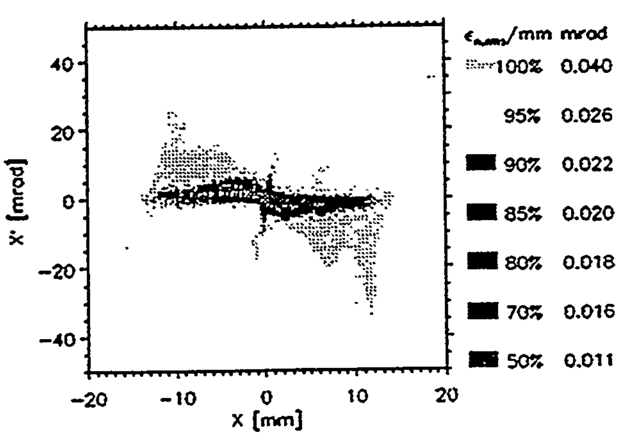




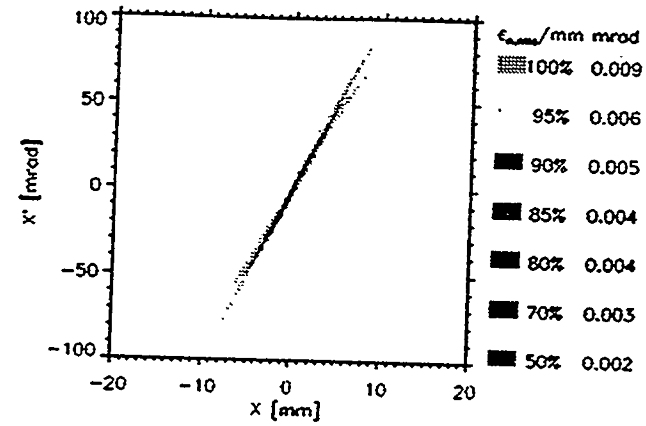
Emittance measured after the first Solenoid 446 mm from the extraction system. Both decompensating electrodes in the solenoid on -220 V. Instabilities occured.



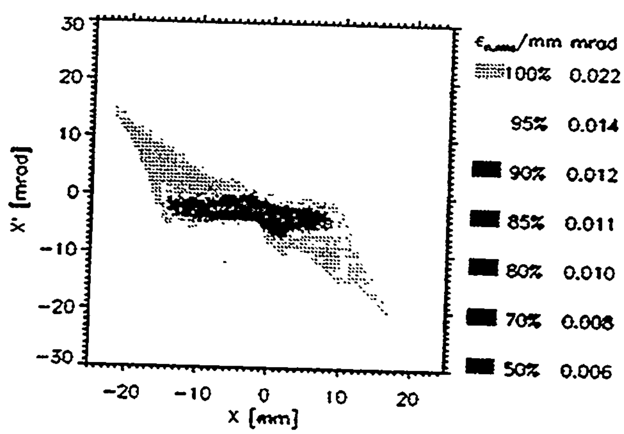
Emittance at the same position as above but all electrodes on +200 V (except first on +100 V).



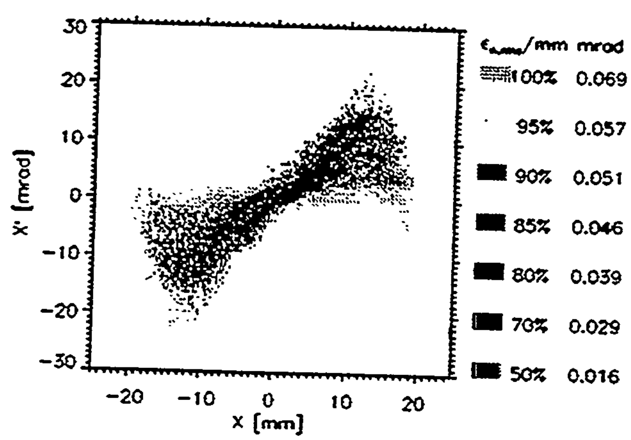
Emittance at the end of the LEBT line after the second solenoid 883 mm downstream All electrodes on ground potential



Initial emittance of a 2.5 mA,He $^{+}$, 10 keV beam after a drift of 112 mm.



Emittance measured afte the first Solenoid 446 mn downstream the extractio system. All decompensati electrodes on ground potential.



Emittance measured at the same position as above bu first electrode on +40 V. Instabilities occured.

ε - growth in a magnetic LEBT line

He^+

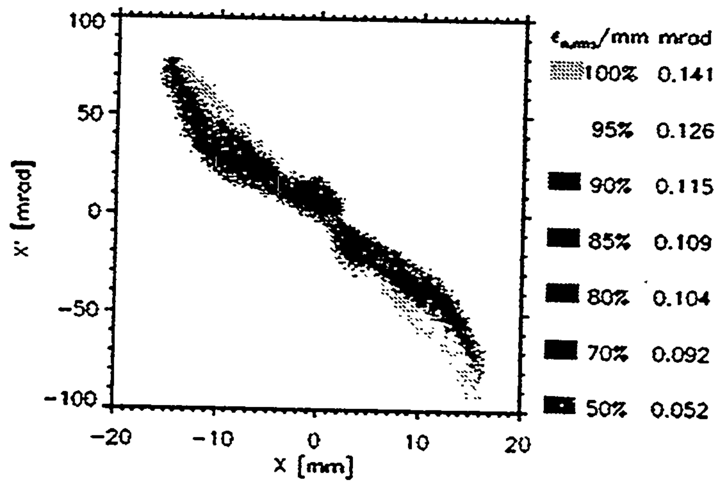
10 keV

2,5 mA

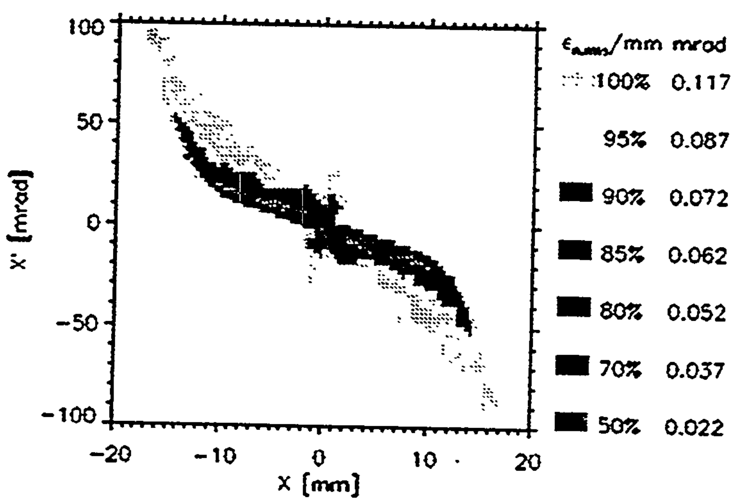
ε_{in} : $5*10^{-3}$

	axial position	$\varepsilon_{n,90\%,rms}$ $*10^{-3}$ [π mm mrad]
Drift **comp.**	112	5
Drift - Solenoid - Drift **comp.**	446	12
Drift - Solenoid - Drift U_{deko}=+40 V	446	51
Drift - Solenoid - Drift U_{deko}=-200 V	446	108
Drift - Solenoid - **Drift U_{deko}=+100 V /+200 V**	446	115
Drif -Sol-Drift-Sol.-Drift **comp.**	883	22

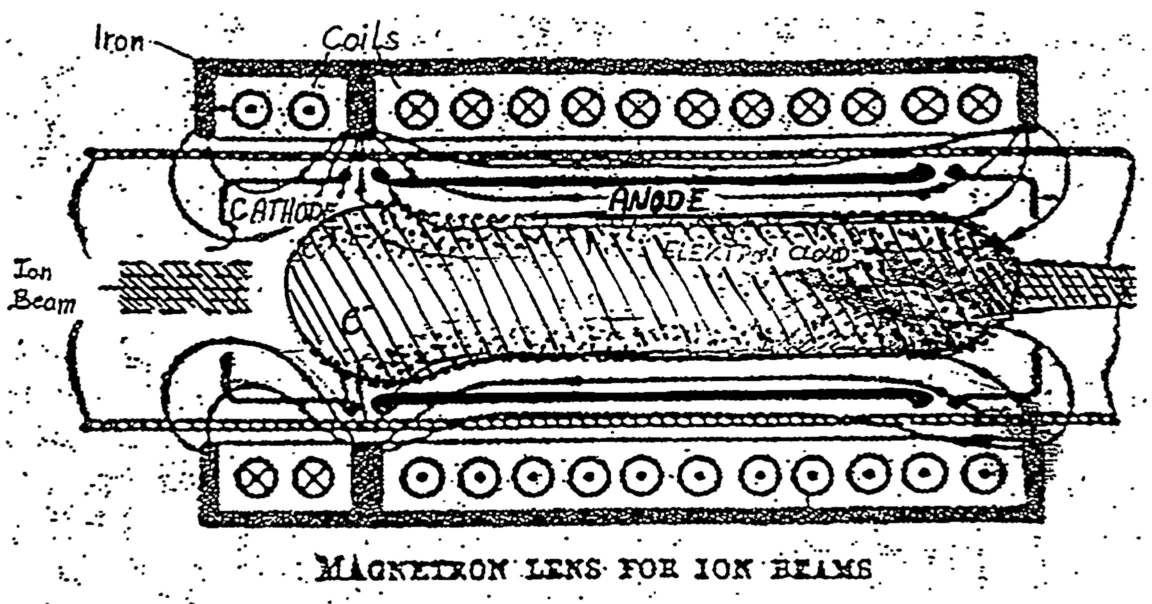
First comparison between measurement and simulation for partly compensated transport



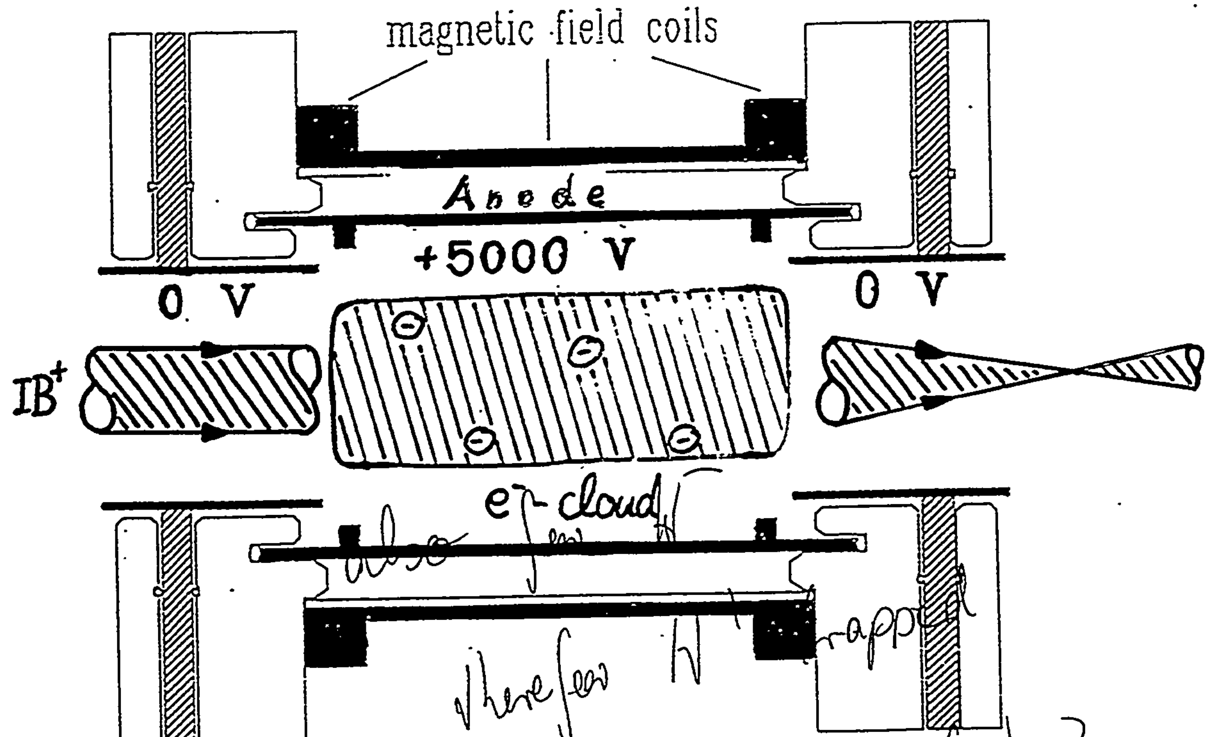
Measured emittance after the first solenoid with decompensating electrodes on +200 V.



Result of a simulation asuming compensating electrons only in a thin cylinder on the beam axis.

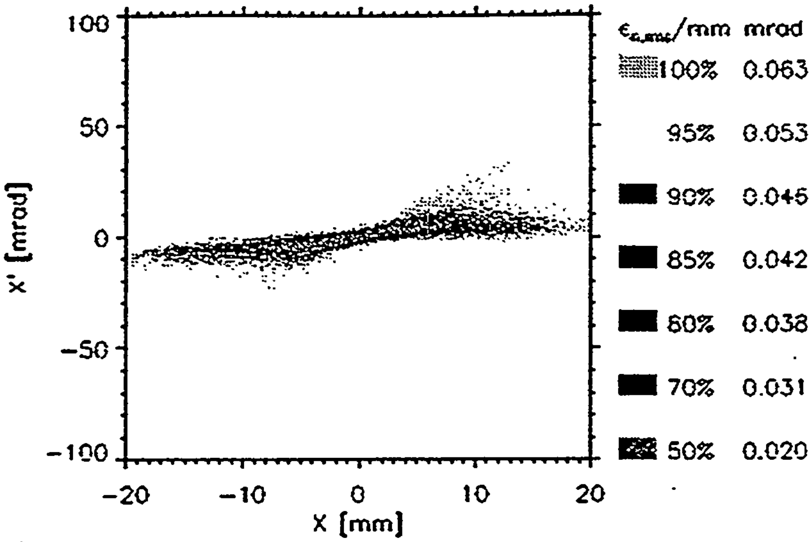


Original suggestion for a plasma lens by D. Gabor (1947). It combines strong axisymmetric electrostatic focussing with preservation of space charge.

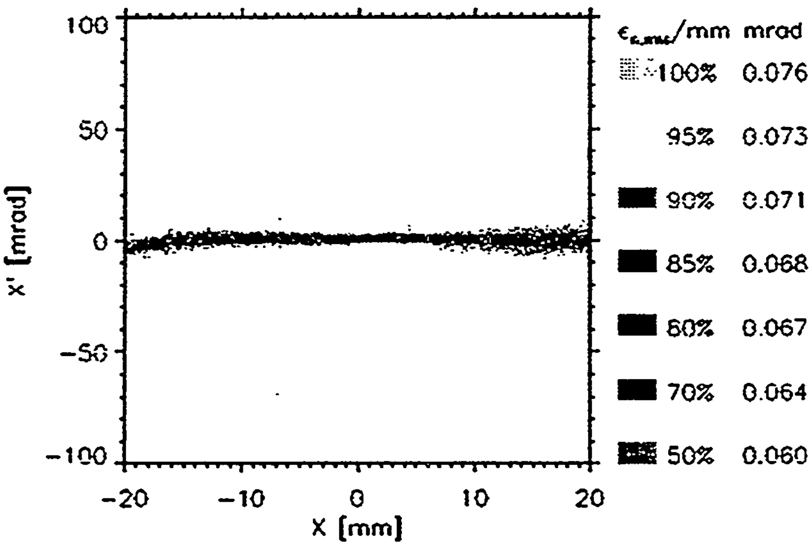


Setup of a Gabor plasma lens in Frankfurt. The focal length was between .4 and 2 m for an 10 keV He^+ beam of 1 mA. Anode voltage was up to 5000 V, the magnetic field between 60 and 280 Gauss. The electrondensity was in the range between $3*10^{-13}$ and $3*10^{-14}$ $1/m^{-3}$.

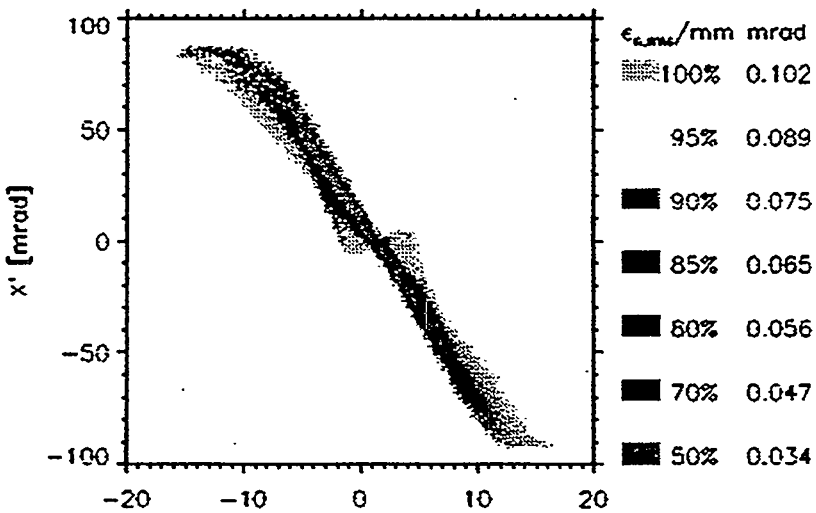
but inverse abberations



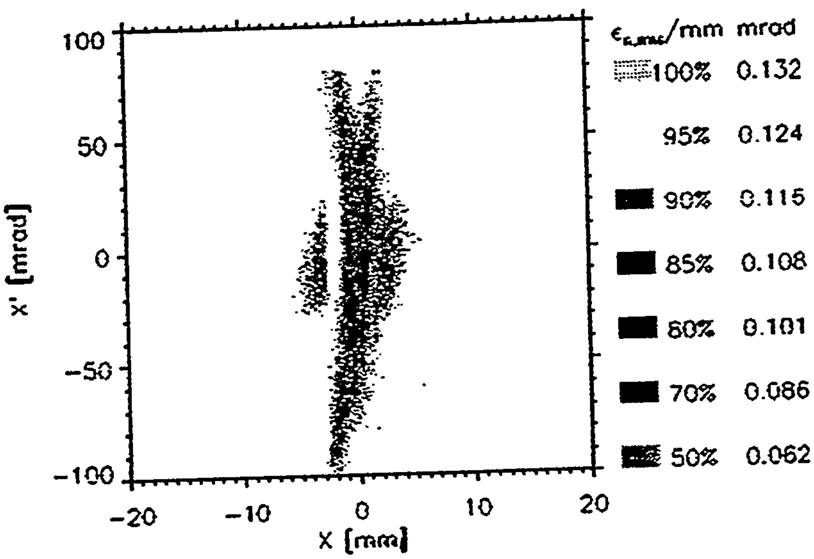
He^+
10 keV
4.5 mA
0 kV / 0 T



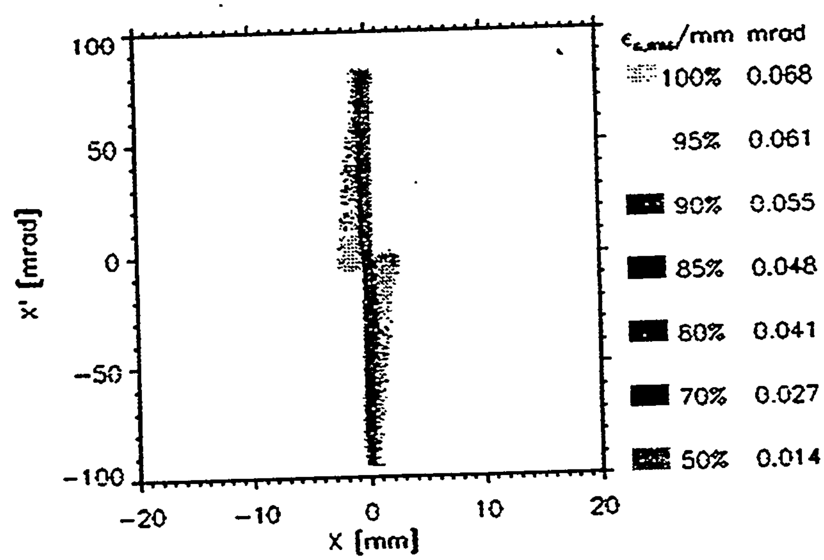
3 kV / 0.006 T



3 kV / 0.007

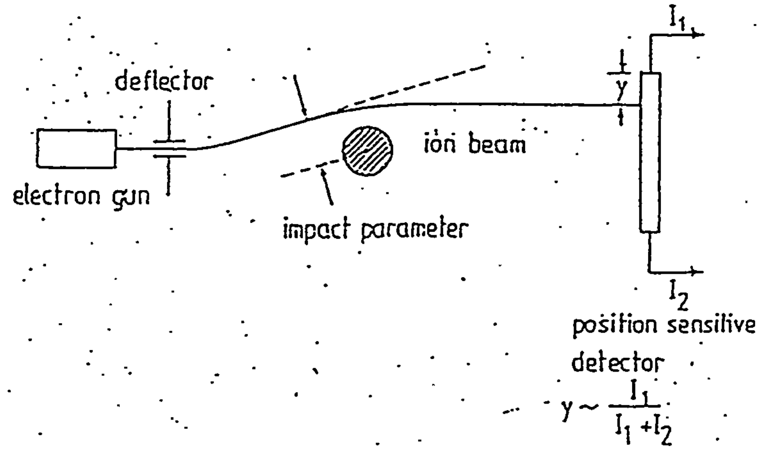


3 kV / 0.008 T

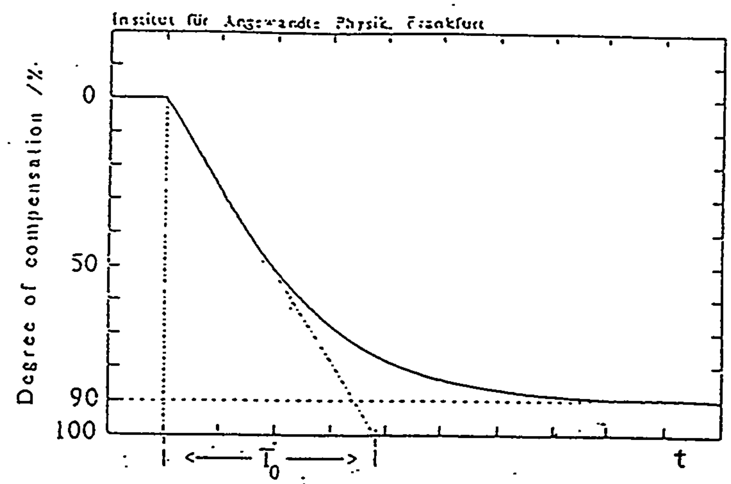


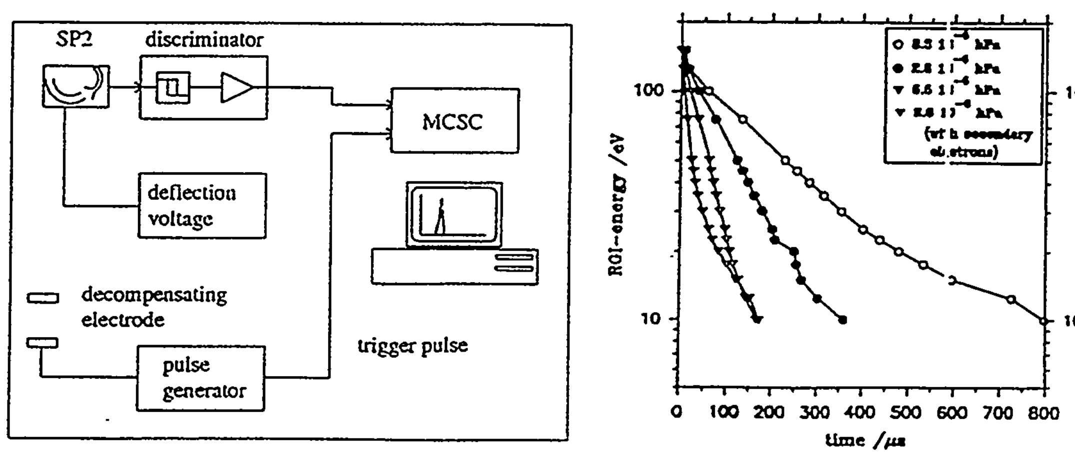
3 kV / 0.0084 T

Time Resolved Measurements of the Compensation Process



Electron beam probe.





Schematic set up of time resolved RGI energy measurements.

Space charge compensated LEBT

+ small beamradius in long LEBT
  => space for steerers, diagnostics, ...

+ convenient operation (no sparking, ...)

- beam loss due to stripping
- beam loss due to rise time of compensation

+/- emittance growth due to charge redistribution
- emittance growth due to plasma instabilities

* no closed theory of space charge compensation

* influence of chopping between solenoids on space charge compensation
  + slow compensating RGI
  - "external" RGI - heating by the beam
  ? influence of the electric field on the RGI and e^-
  - charge redistribution by chopping might occur (e-growth)

* more experiments needed.

A Compact Double Einzel Lens LEBT with Steering for H^+ Beams

C. Chan

Lawrence Berkeley Laboratory

A Compact Double Einzel Lens LEBT with Steering for H^+ Beams*

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1 Cyclotron Road, Berkeley, Calif 94720

Abstract

We have designed a six-electrode double-einzel lens low-energy beam transport (LEBT) system with several unique features. It will extract and transport a 30–50 mA, 40 keV proton beam from an rf-driven ion source to an RFQ accelerator and is only 11 cm long. Special features include: 1) Independent adjustment of beam radius and convergence angle (Twiss parameters) at the entrance of the RFQ by using two einzel lenses; 2) Beam steering to correct misalignment by using four-way split electrodes; 3) The all-electrostatic design avoids the problem of beam neutralization entirely; 4) Diagnostic instruments and a gate valve can be inserted into the beam line. Results of computer simulations with 2D and 3D codes will be presented, along with an engineering design. A slight variation of this design can be used for H^- beams.

Introduction

The transport and matching of a proton or H^- ion beam from an ion source to an RFQ is simplified if the proton beam can be kept unneutralized by using an all-electrostatic LEBT. Keeping the distance between einzel lenses short decreases the beam size in the lenses, decreasing the spherical aberration. Short LEBTs offer the advantage of keeping emittance blowup under control but the introduction of beam steering and diagnostic devices is difficult.

The LEBT presented here partially addresses some of these issues. Two einzel lenses allow some range of adjustment in α-β (Twiss parameter) space. Splitting the einzel lenses into four quadrants allows some degree of steering without introducing too much aberration, and a short space left immediately in front of the RFQ entrance allows the introduction of a gate valve and simple beam diagnostic.

Advantage of an Electrostatic LEBT

Injection into an RFQ usually requires a large convergence angle with the beam focused to a small spot beyond the beginning of the RFQ vanes. Reducing the distance between the last lens and the RFQ vane will reduce the beam size in the lens, which reduces the emittance growth introduced.

Electrostatic LEBTs are mechanically relatively simple and easy to fabricate, and avoid plasma build-up and instabilities. Three-dimensional computational tools to model the ion optics design of an electrostatic LEBT with segmented elements are now becoming available, so one can confidently predict the performance of relatively complex, three-dimensional configurations.

*This work was supported by the Director of Energy Research, Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U.S. Department of Energy under contract number DE-AC03-76SF00098

Specific Design Example

The design example shown here matches an rf-driven bucket H^+ source [1] to a 400 MHz, 800 keV RFQ [2]. The ion source parameters are:

Ion	H^+	
Extr aperture radius	0.21	cm
Current density	0.217	amp/cm^2
H^+ fraction	>90	%
Thermal energy kT_i	1.0	eV

The RFQ parameters are:

Ion	H^+	
Frequency	410	MHz
Input Energy	40	keV
Output Energy	800	keV
Length	1.0	meter
Foc Parameter B	4.77	
Avg radius r_0	0.304	cm
Initial α (Twiss)	2.25	
Initial β (Twiss)	6.29	cm
ε_{4rms} acceptance	0.05	π cm-mrad, norm
Beam spot radius	0.185	cm
Convergence angle	72	mrad
Peak current	40	mA

The LEBT is optimized to provide a match to the default Twiss match parameters given in the table, with sufficient range to accommodate variations due to changes in ion source parameters, beam current and RFQ characteristics.

Ion Beam Optics Computations

We use the axisymmetric 2D code WOLF [3] to compute the charged particle trajectories without steering and without the electron beam deflection magnet used in the H^- source. In order to compute the rms projected emittance in each phase plane properly, it is necessary to use the version of WOLF with skew beam dynamics [4]. Here, each beamlet is launched with axial, radial and azimuthal velocities, the last two quantities representing the thermal temperature of the ion from the source.

For the 3D beam optics computation including the effects of the split einzel lenses used to steer the beam, we use the ARGUS code developed by SAIC [5].

The result of the 2D beam optics computation is shown in Figure 1. After the match point coordinates of the beam are calculated from the raytrace code by the usual equations:

$$\varepsilon_{4rms} = 4\beta_0\gamma_0\left[(x^2_{rms})\ (x'_{rms})^2 - (xx')^2\right]^{1/2}$$

and

$$\alpha = -4\frac{\beta_0\gamma_0\langle xx'\rangle}{\varepsilon_{4rms}}, \qquad \beta = 4\frac{\beta_0\gamma_0\langle x_{rms}\rangle^2}{\varepsilon_{4rms}}$$

where $\beta_0\gamma_0$ is the usual relativistic factor.

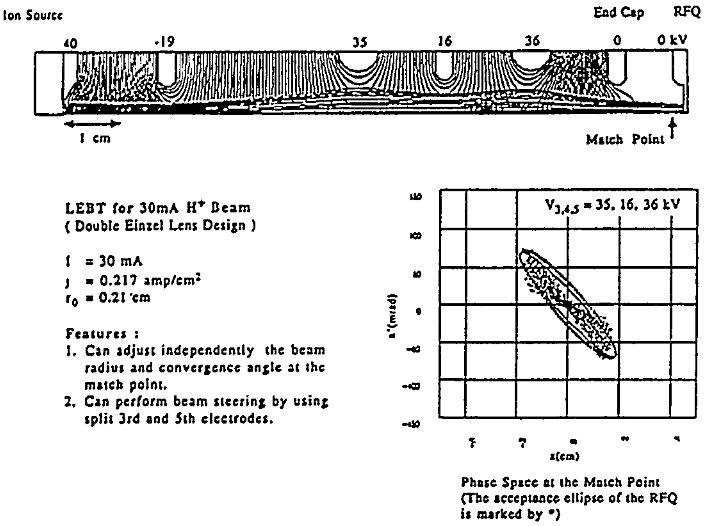


Figure 1. 2D Beam Optics for 30 mA Beam

The computed parameters corresponding to the figure are $\varepsilon_{4rms} = 0.038\ \pi$ cm-mrad, $\alpha = 3.12$ and $\beta = 8.89$ cm for a 30 mA beam. (We have assumed that the initial beam thermal energy $kT_i = 1.0$ eV, thus the initial intrinsic emittance is $\varepsilon_{4rms} = 0.014\ \pi$ cm-mrad.) The ion source current density is 0.217 amp/cm^2 with an aperture radius of 0.21 cm. The small extraction aperture insures a high fraction of over 90% of H^+ [6].

Variation of the Twiss parameters α and β is achieved by varying the potential of the two einzel electrodes (35 and 36 kV in Figure 1). The double einzel system allows the beam radius and convergence angle to be varied somewhat independently, as shown in the four examples in Figure 2.

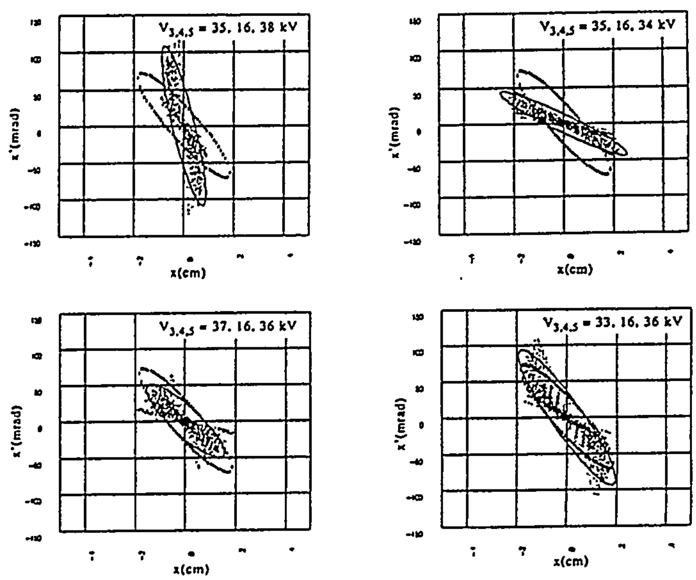


Figure 2. Exit Beam Variation vs. Einzel Potentials

The match for variations in beam current from 30 to 50 mA can be accommodated by varying the extraction electrode potential from -19 to -44 kV to restore the Child-Langmuir relation. The beam envelope for 50 mA is shown in Figure 3.

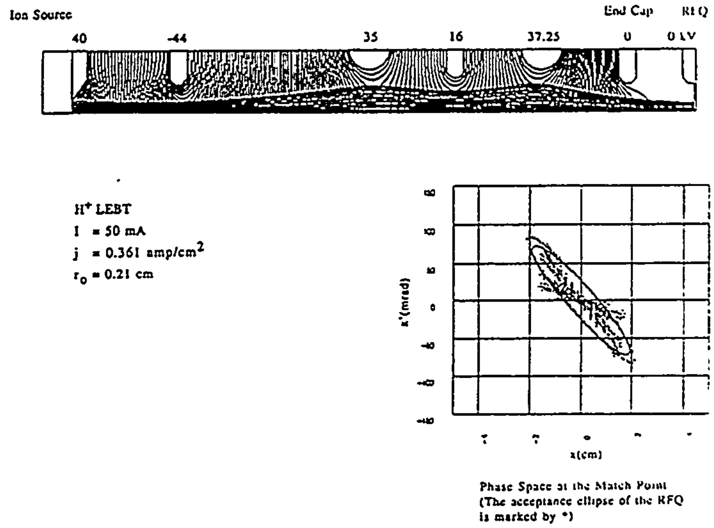


Figure 3. 2D Beam Optics for 50 mA Beam

Beam Steering with Split Electrodes

Two steering stations can be accommodated by splitting each of the two einzel lenses into four quadrants, split vertically and horizontally, allowing the presence of a transverse electrostatic field with additional power supplies. Figure 4 shows an ARGUS mesh for the electrodes, with one quadrant removed for clarity.

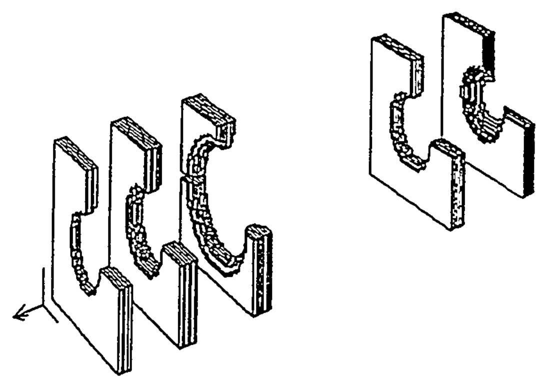


Figure 4. ARGUS Mesh of Split Electrodes

A balanced potential offset is applied to the split electrodes, each for the two transverse planes, producing a x- or y-steering of the beam. Two sets of split electrodes, i.e. each of the two einzel lenses, allows some correction of both position and angle over small limits at the entrance of the RFQ.

An example is shown correcting the deflection of the extraction of an H^- beam by the electron sweep magnet in the ion source extraction electrode using one split einzel lens [7]. Figure 5 shows the effect of a 0.5 kV potential difference across a split first einzel lens in the y-z plane, Figure 6 show plot in the x-z plane. The offset angle due to the sweep magnet is corrected, with a small residual offset in the y-direction.

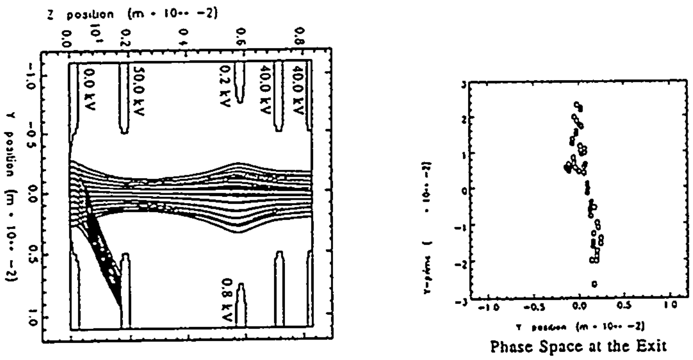


Figure 5. Steering Beam to Correct Sweeping Magnet Deflection in the y-z Plane

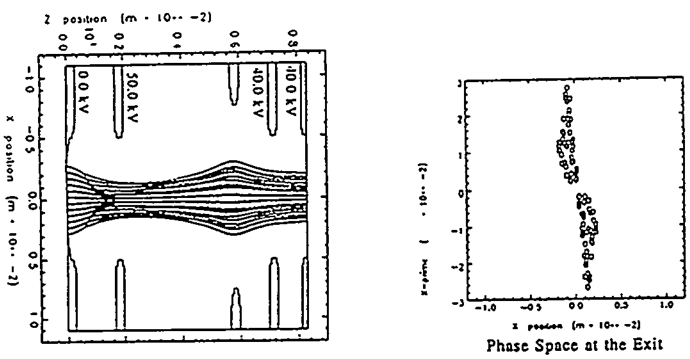


Figure 6. x-z Trajectory Plot and the Phase Space x-x'

Gate Valve and Diagnostic Instruments

By designing the second einzel lens (the one immediately in front of the endcap of the RFQ) so it can be taken down to ground potential, a gate valve or diagnostic instrument can be placed in the 1-cm space between the lens and the RFQ entrance endcap. Figure 7 shows the ion source and LEBT placed in front of the one-meter-long RFQ.

The gate valve swings in from the side on a pivoted arm and rests against the valve face machined into the end of the RFQ. This valve will hold with gas pressure on the ion source/LEBT side only. This allows the ion source to be brought to air for servicing while keeping the RFQ under vacuum.

A small five-segmented Faraday cup can also be swung into the beamline at this position with the last einzel lens operated at ground potential. The beam optics at the last einzel lens will be altered but can be calculated, and a segmented cup gives rough measurement of the zero, first and second moments of the beam.

Summary

This double-einzel split-electrode all-electrostatic LEBT is undergoing engineering development at present and will be tested on an existing ion source and RFQ. It offers beam unneutralized transport with steering and some range of adjustment in α–β Twiss space. A gate valve and beam diagnostic are all accommodated in a 11 cm axial length.

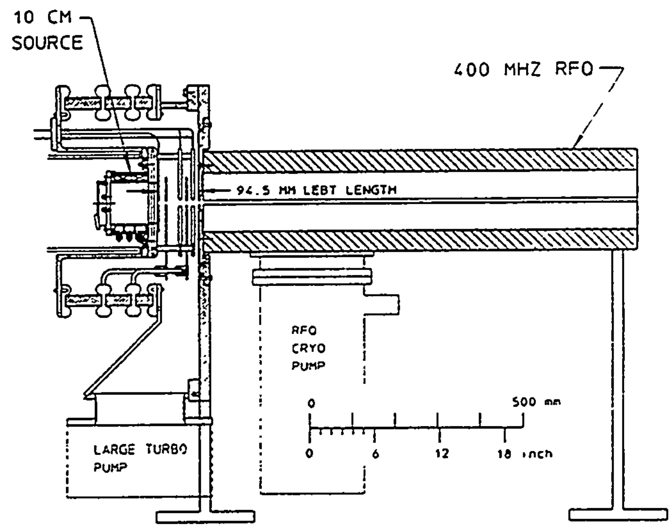


Figure 7. Ion Source, LEBT and RFQ

The authors acknowledge the contributions of Matt Hoff for the mechanical design, and Rick Gough and Ka-Ngo Leung for support.

References

[1] K.N. Leung et al, in Proceedings of the Conference on High Energy Accelerators 1992, Hamburg, Germany, Int J. Mod. Phys. A (Proc Suppl.) 2 (1993), p. 200; J. Rossbach, ed.

[2] S. Abbott, R. Caylor, R. Gough, D. Howard, R. MacGill and J. Staples, Design of an Integrally Formed RFQ, 1989 PAC, Chicago, 1989, p. 953

[3] W.S. Cooper, K. Halbach and S.B. Magyary, Proc. 2nd, Symp on Ion Sources and Formation of Ion Beams, Berkeley, LBL-3399, 1974.

[4] C.F. Chan et al, Nucl. Instr. Met. Phys. Res. A306, (1991), p 112

[5] Science Applications International Corporation, 1710 Goodridge Drive, McLean Va 22101

[6] K. Leung, private communication.

[7] C.F. Chan and K.N. Leung, Particle Accelerators, Vol 43(3), 1004, p. 145-158.

A Frankfurt Electrostatic Injection System

M. Sarstedt

Lawrence Berkeley Laboratory

A Frankfurt Electrostatic Injection System

Margit Sarstedt

IAP-Frankfurt, LBL-Berkeley

preceeding talk (J. Poziwski):

electrostatic LEBT =>

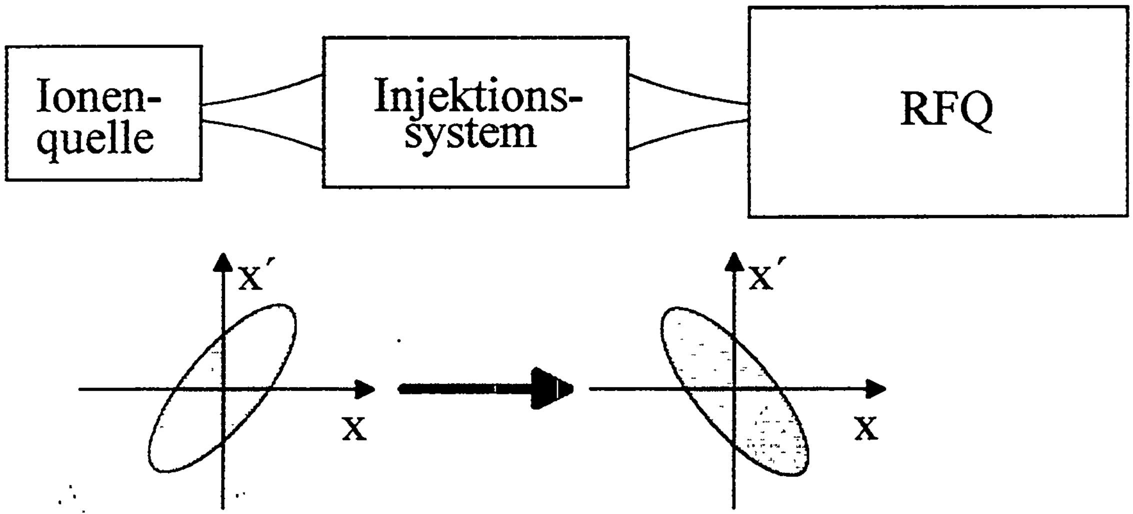
- easier to calculate

- no assumptions on degree of space charge compensation

- no mismatch in pulsed mode

- no decompensation in front of RFQ

Zum Problem der Strahlinjektion in einen RFQ-Beschleuniger

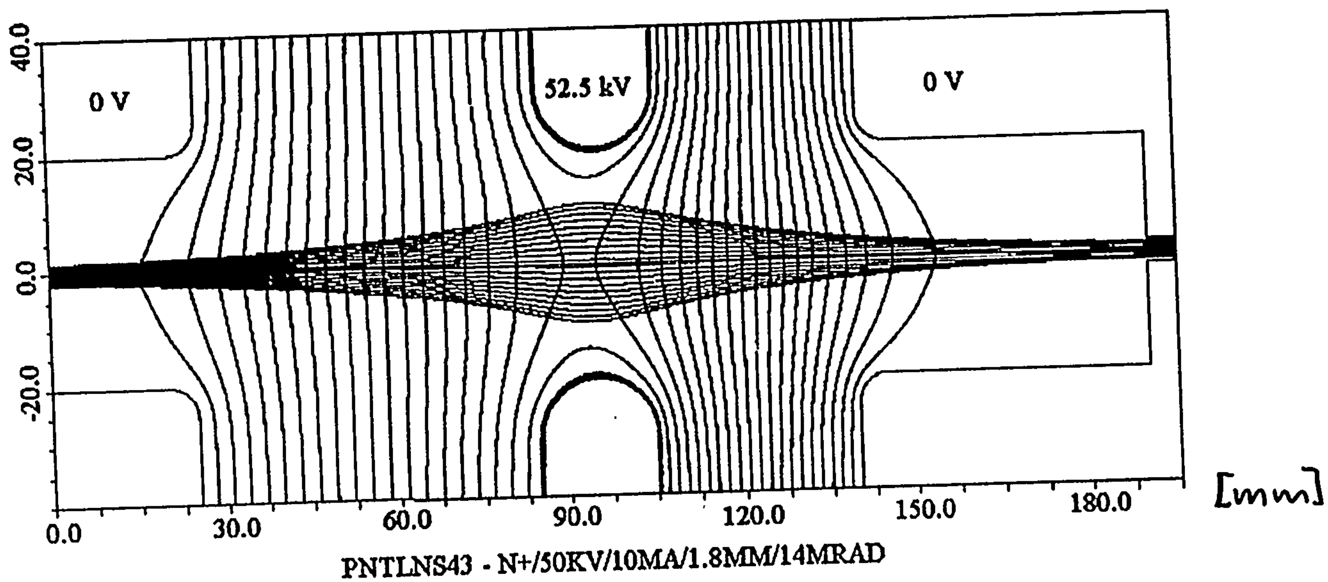


Strahlenergie: 3.57 keV / u (β_{rel} = 0.27 %)

Ionensorte: 50 keV N^+, 57 keV O^+

Akzeptanz:
$\varepsilon_{n,rms} = 0.75\ \pi$ mm mrad (I = 0 mA)
$\varepsilon_{n,rms} = 0.2\ \pi$ mm mrad (I = 10 mA)
$\alpha = 0.9$
$\beta = 0.056$ mm / mrad

Strahlenveloppe:
$\varepsilon = 75\ \pi$ mm mrad
r = 2 mm
r′ = -33 mrad (-1.9 °)

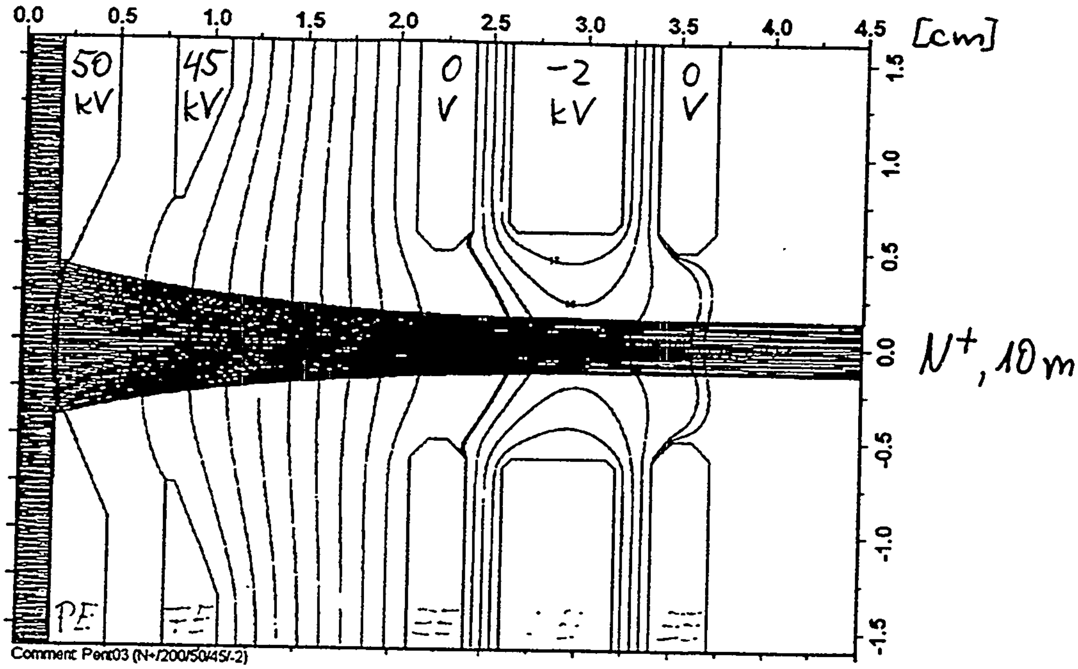


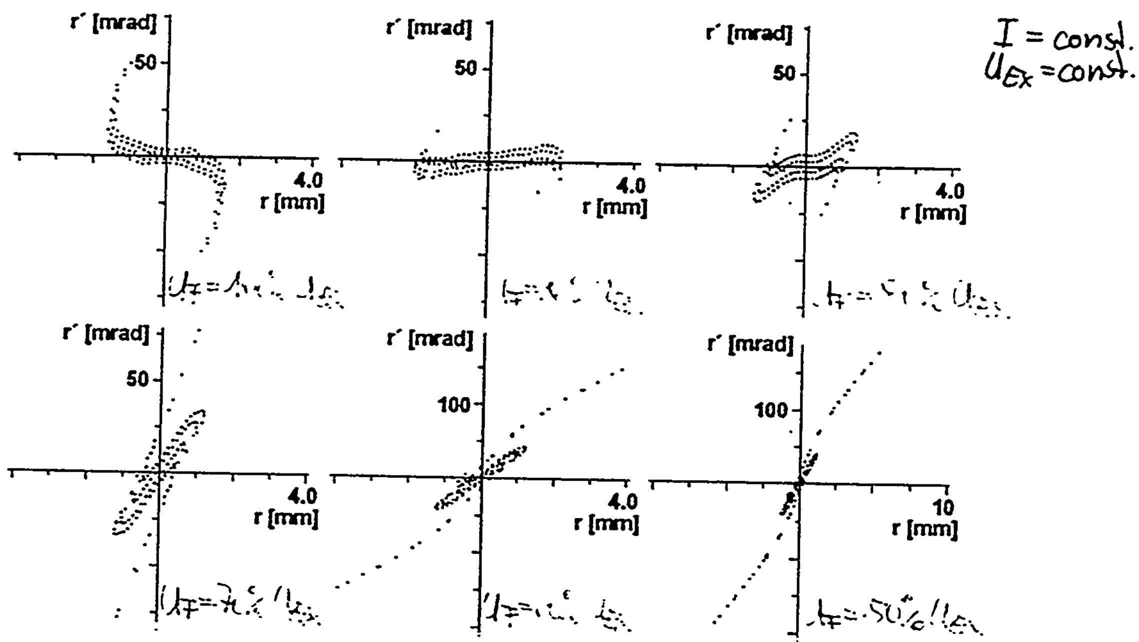
Fokussierung mit <u>elektrostatischen Einzellinsen:</u>

gut möglich für möglichst kleine Linsensysteme,

hier jedoch nur ein Freiheitsgrad

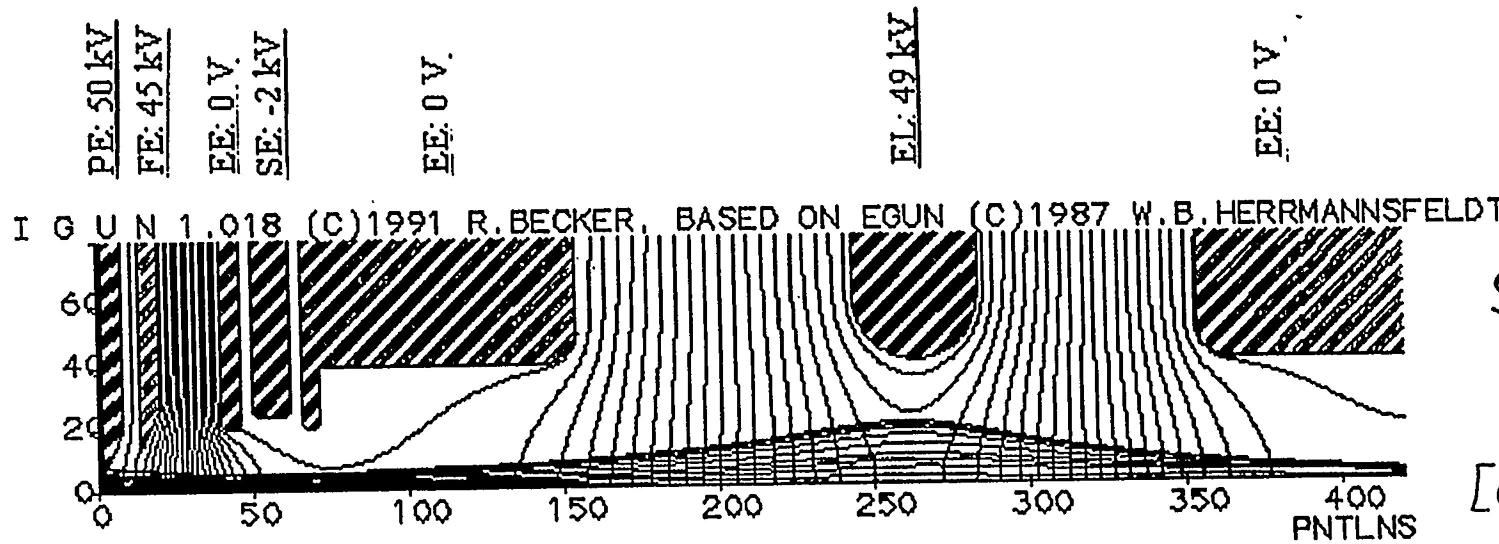
Pentoden-Extraktionssystem





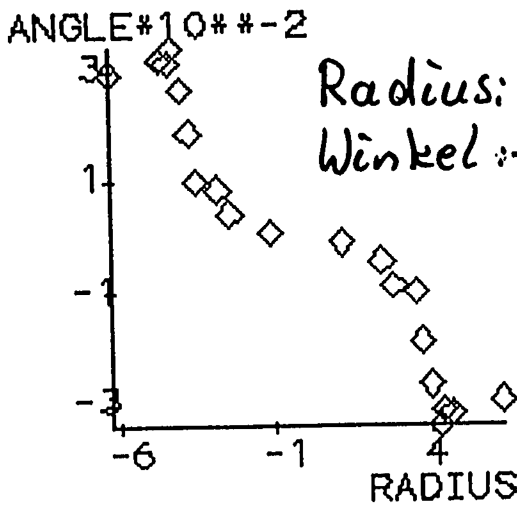
Änderung der rr'-Emittanz durch Variation des Potentials auf der Formierungselektrode

11



Stickstoff
50 keV

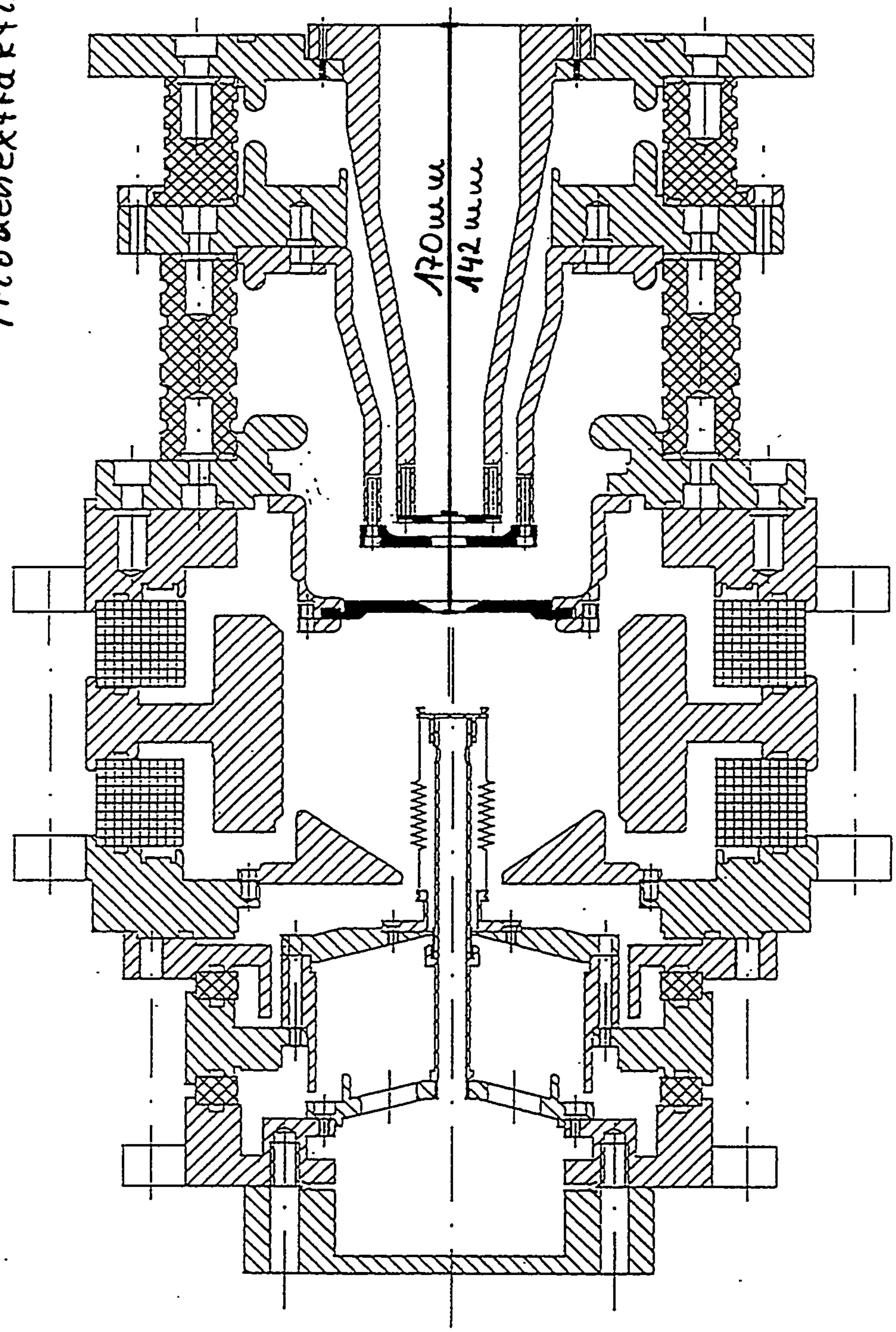
[0.5 mm]



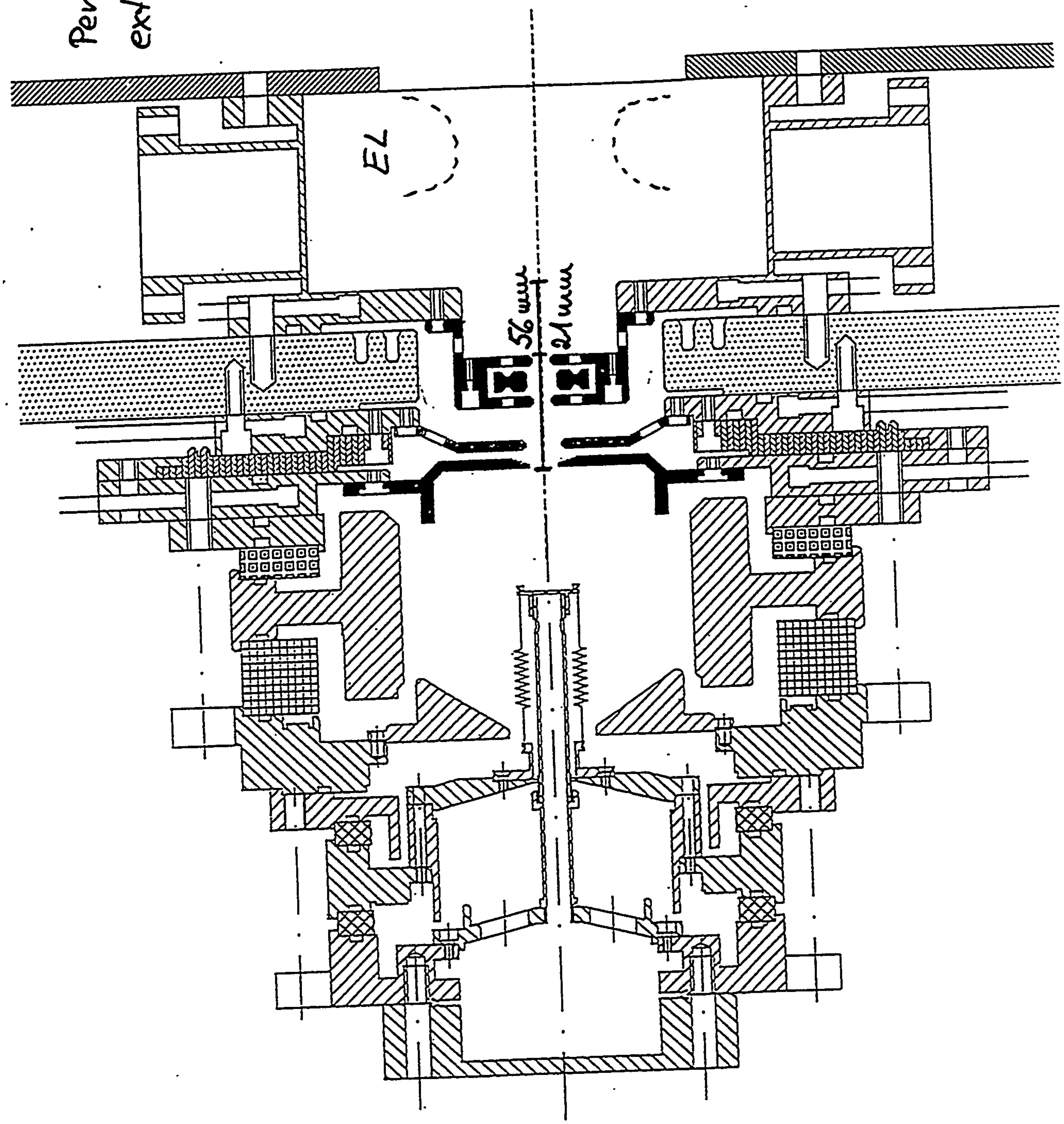
Radius: 2mm
Winkel: -30mrad

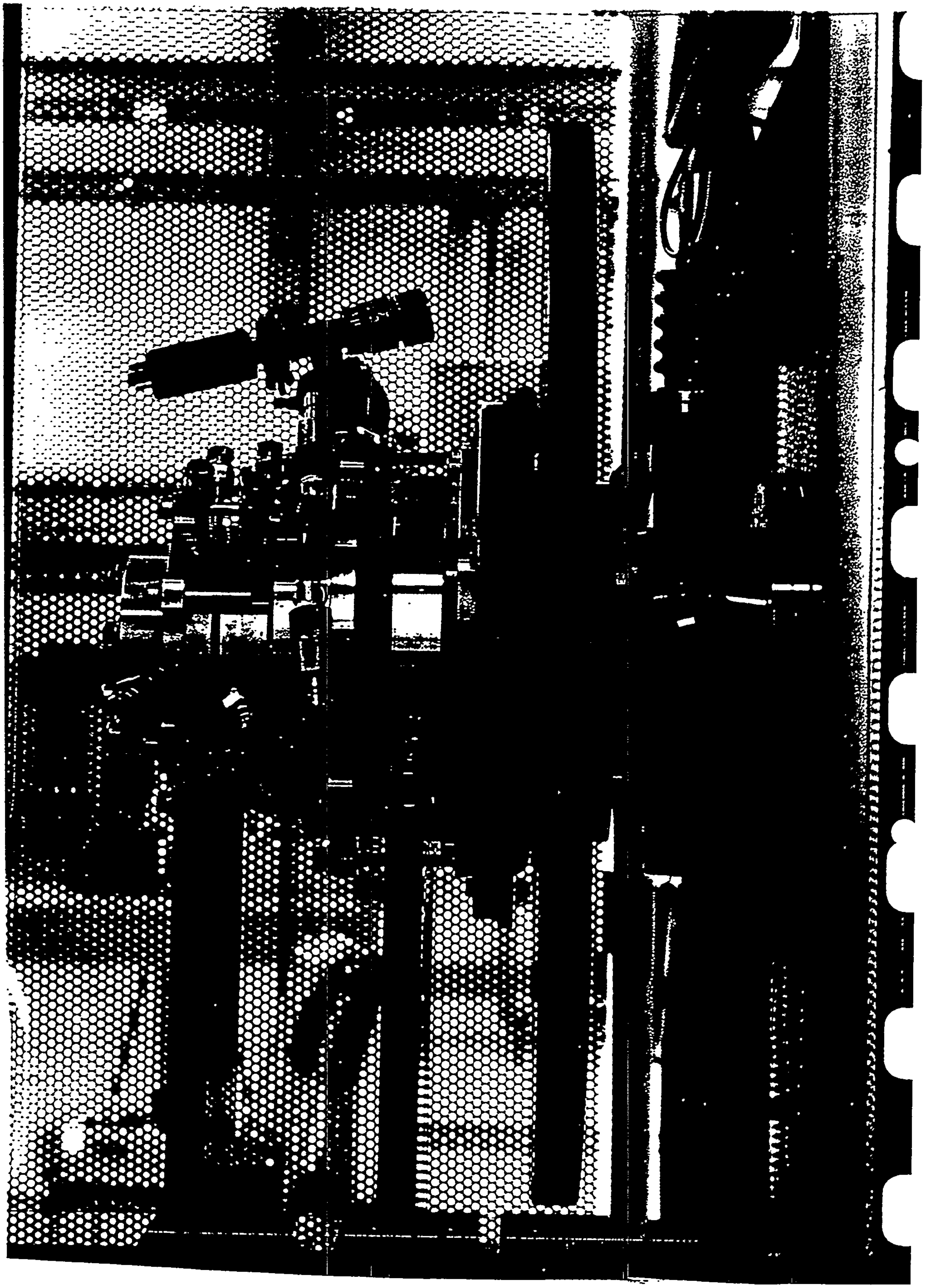
Mit dem Programm IGUN numerisch berechneter Strahlverlauf im Pentoden-Linsen-System und rr'-Emittanz am Ende des Systems.

Triodenextraktion



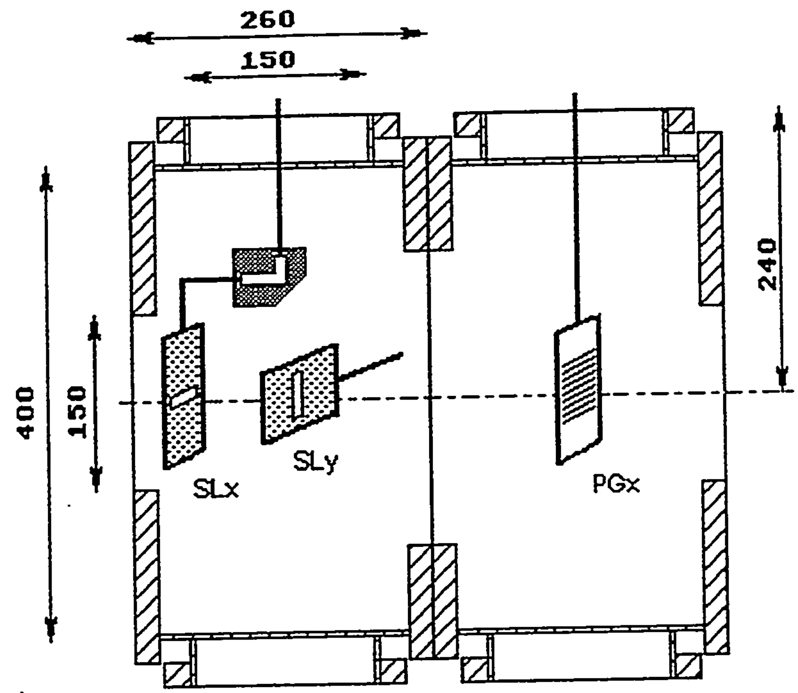
Pentoden-
extraktion

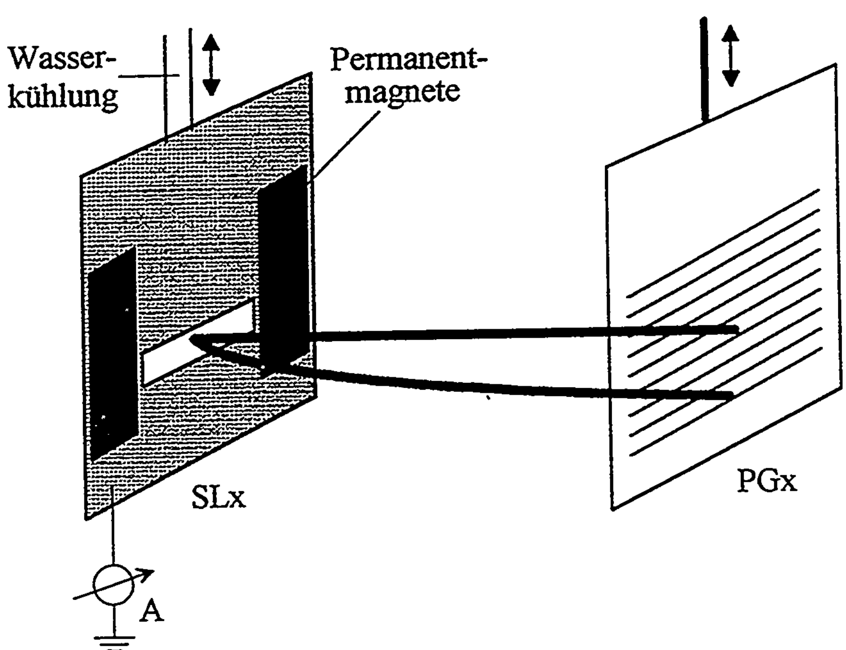




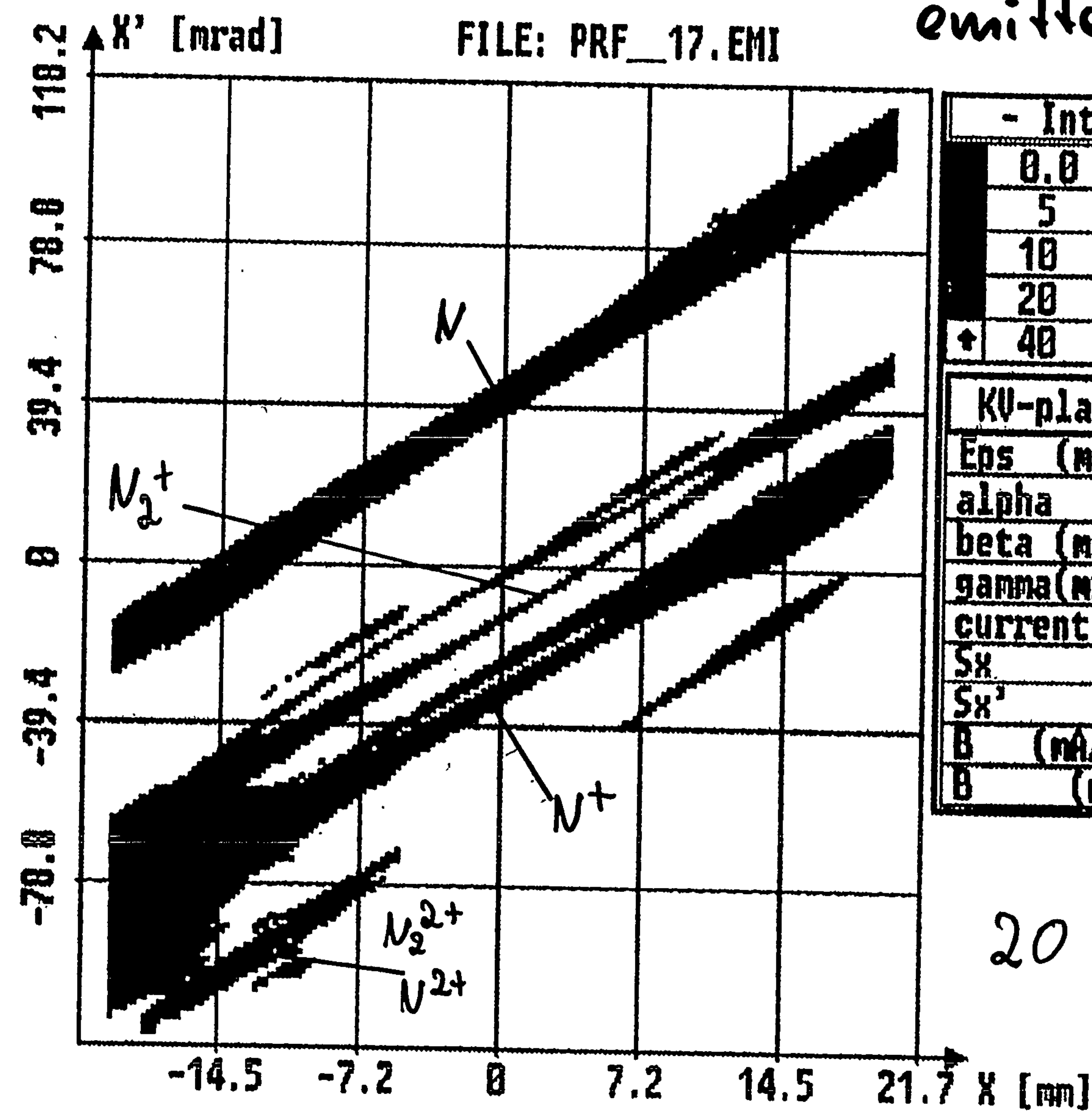
Aufbau der Emittanzmeßanlage

SL = Schlitz
PG = Profilgitter





ohne titel - **mass-separated emittance measurement**



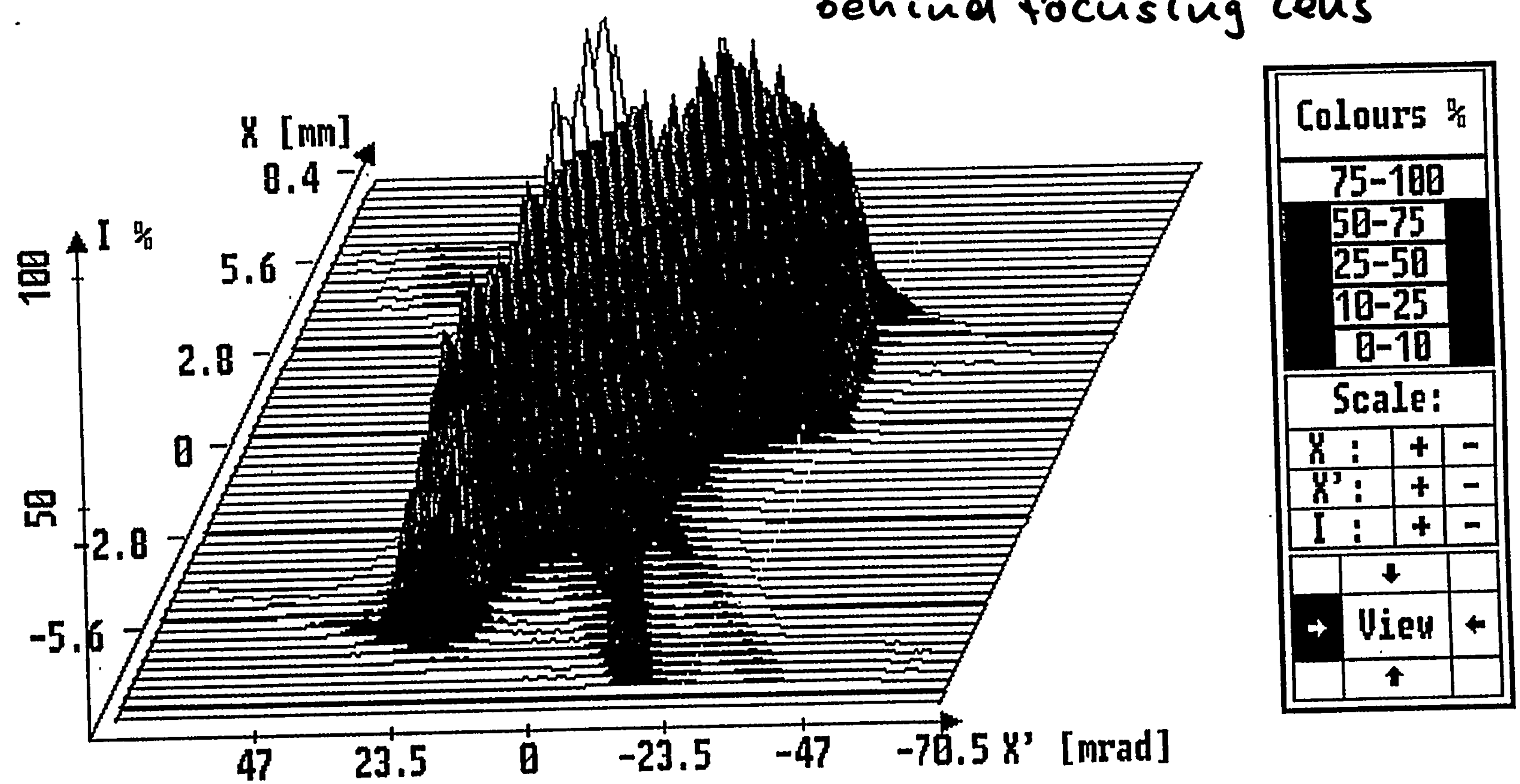
- Int	I %	E (mm mrad)
0.0	100.0	620.70
5	95.0	227.55
10	90.0	162.38
20	80.0	105.16
40	60.0	49.17

KV-plane:	10.0
Eps (mm mrad)	370.67
alpha	-0.92
beta (mm/mrad)	0.33
gamma (mrad/mm)	5.68
current (uA)	2832.113
Sx (mm)	-0.75
Sx' (mrad)	-8.49
B (mA/Eps ²)	2.09e-006
B (mA/E ²)	1.09e-005

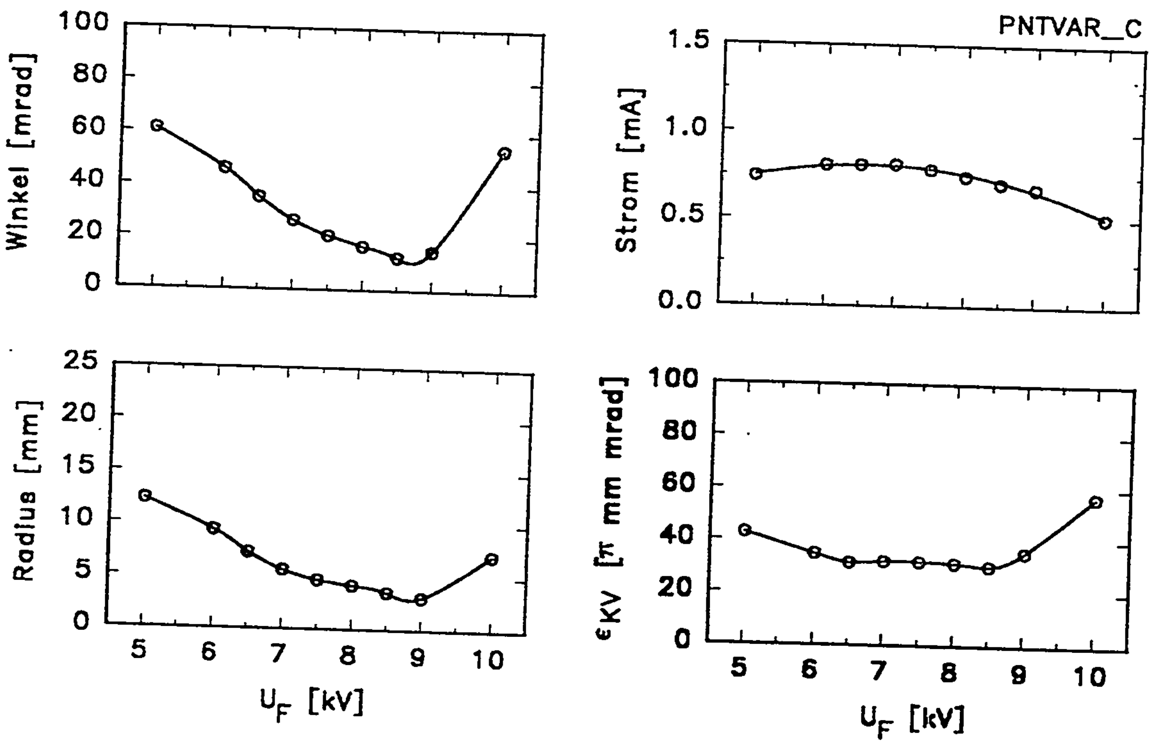
20 keV Stickstoff

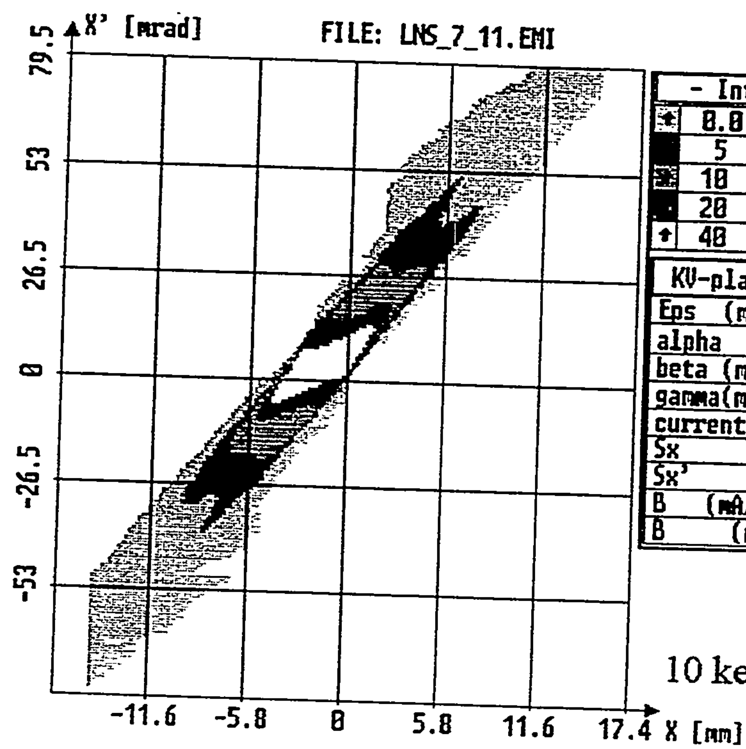
$N_2^+ / N^+ = 3.3$

emittance - intensity graph
for 10 keV N^+ ion beam
behind focusing lens



Messungen am Pentoden-Extraktionssystem



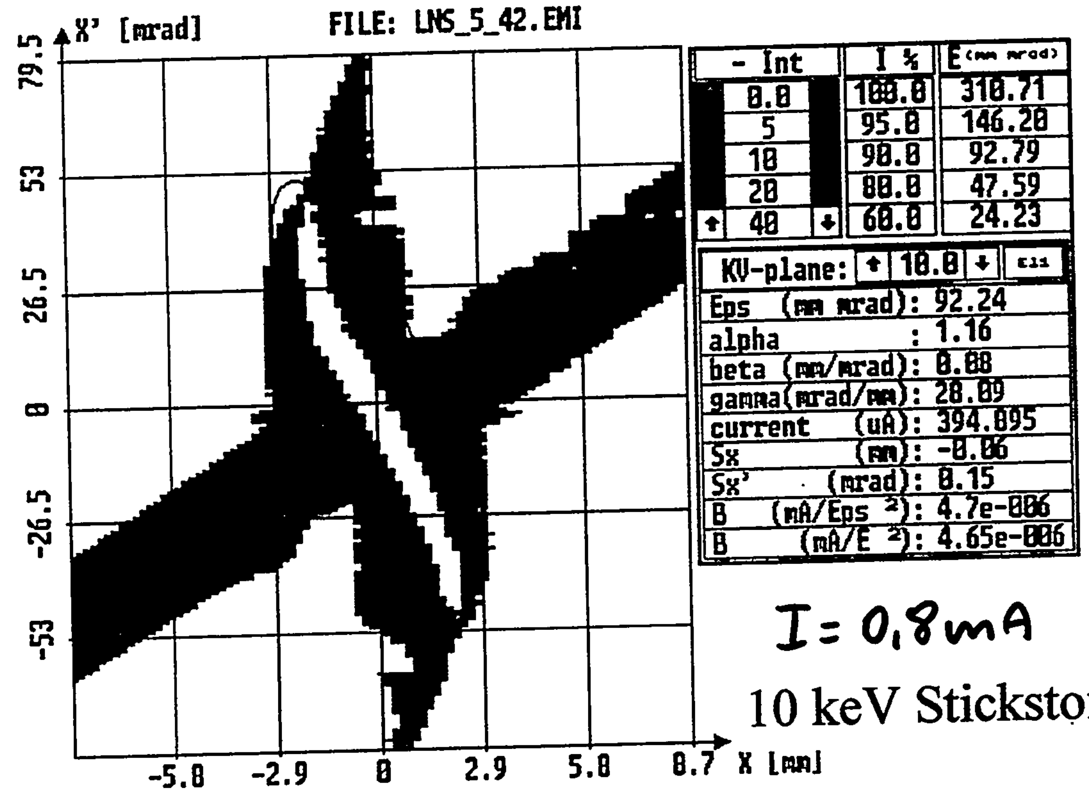


- Int	I %	E (mm mrad)
0.0	100.0	318.67
5	95.0	97.69
10	90.0	57.85
20	80.0	30.58
40	60.1	14.74

KV-plane:	10.0
Eps (mm mrad)	30.41
alpha	-1.49
beta (mm/mrad)	0.42
gamma(mrad/mm)	7.64
current (uA)	352.591
Sx (mm)	-1.44
Sx' (mrad)	4.47
B (mA/Eps ²)	3.06e-005
B (mA/E ²)	1.07e-005

10 keV Stickstoff

Beispiel für die xx′-Emittanz hinter dem Pentoden-Linsen-System



$I = 0{,}8\,\mathrm{mA}$

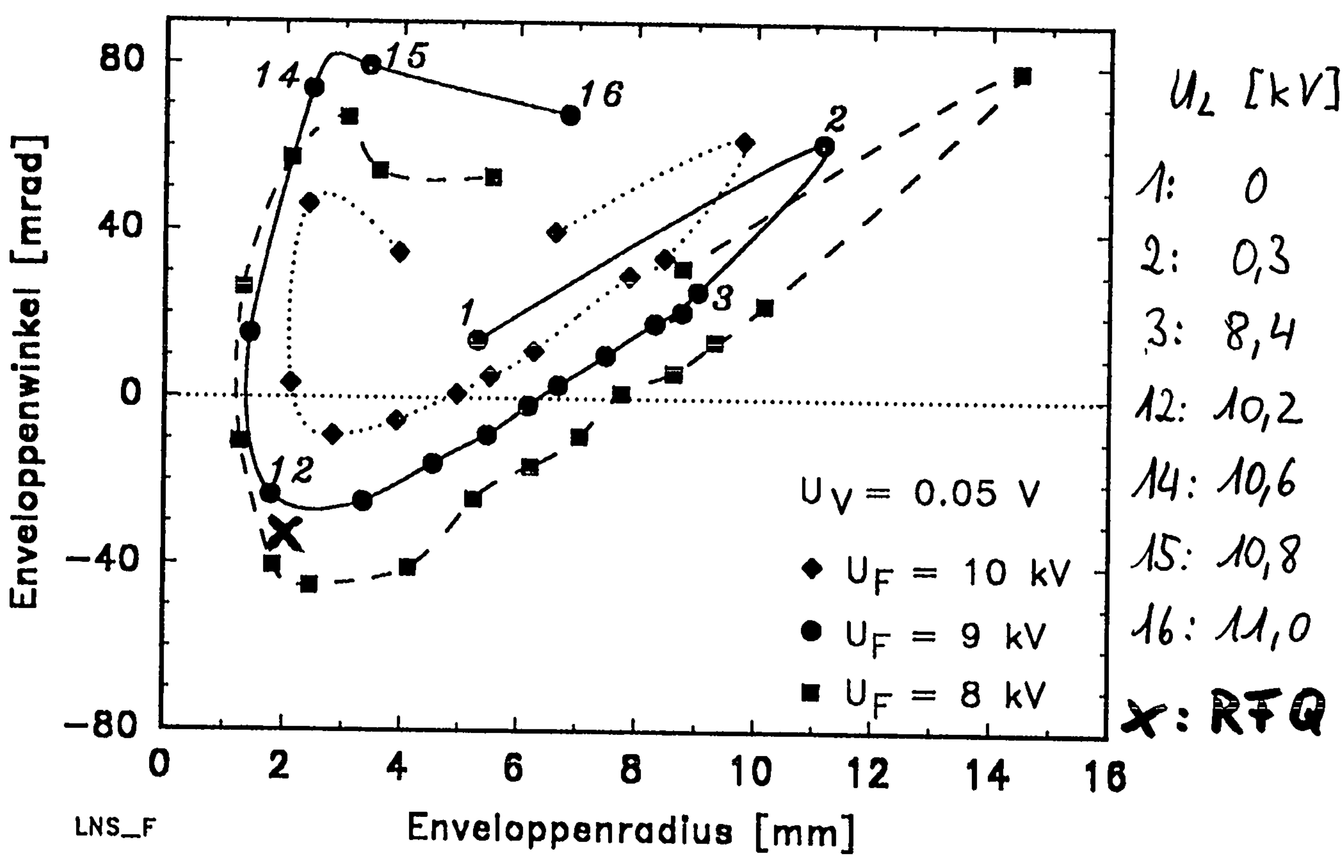
10 keV Stickstoff

$\varepsilon_{4rms} = 45\,\pi$ mm mrad
$\varepsilon_{n,4rms} = 0{,}05\,\pi$ mm mrad } emittance growth 50%

scaling: 20% N^+, 80% N_2^+ } $\bar{m} = 25.2$ u

$\Rightarrow$ $I(N^+, 10\,\mathrm{keV}) = 1.07\,\mathrm{mA}$
$I(N^+, 50\,\mathrm{keV}) = 12\,\mathrm{mA}$
$I(H^+, 50\,\mathrm{keV}) = 45\,\mathrm{mA}$

$I \sim \frac{U^{3/2}}{\sqrt{m}}$


80
40
0
−40
−80
0
2
4
6
8
10
12
14
16
Enveloppenwinkel [mrad]
Enveloppenradius [mm]
LNS_F
1
2
3
12
14
15
16
U_V = 0.05 V
U_F = 10 kV
U_F = 9 kV
U_F = 8 kV
U_L [kV]
1: 0
2: 0,3
3: 8,4
12: 10,2
14: 10,6
15: 10,8
16: 11,0
x: RFQ

Beam formation and focusing