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talk

Efficient Production of Intensive Beams of Rare Isotopes

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FLNR
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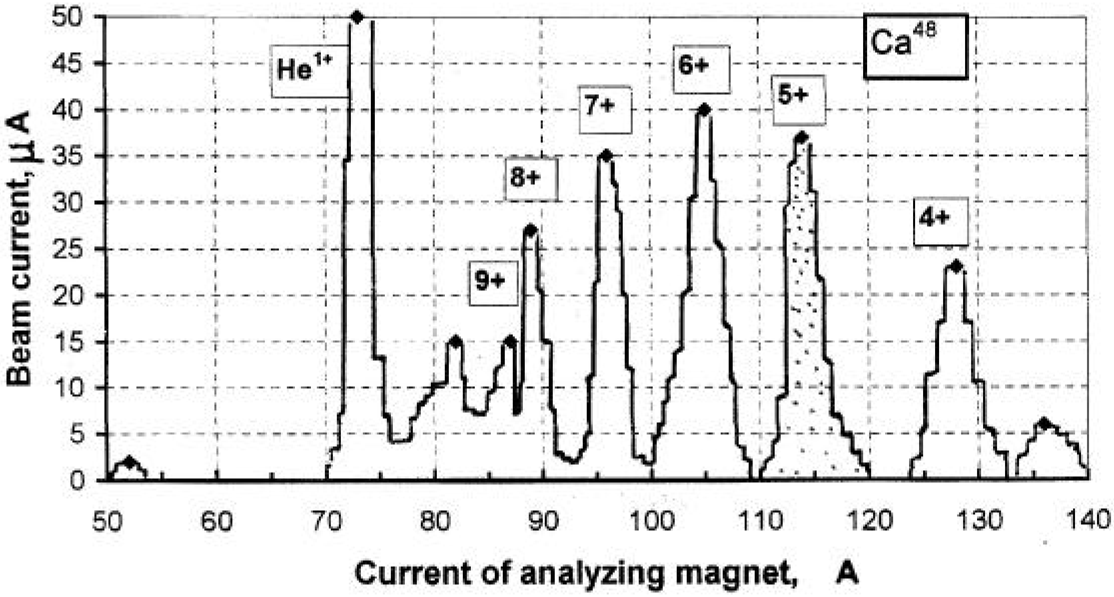
Production of solid ion beams with the ECR4M

A new method using a combination of a microoven with a hot tantalum sheet inside the discharge chamber was used at the ECR4M for the production of intense beams of metallic ions with a relatively low melting point such as Mg and Ca.

After the first experiments using CaO+Al as working substance, metallic calcium was used to provide intense ion beams of ^{48}Ca. To ensure optimal consumption of ^{48}Ca during long experiments the intensity of the $^{48}Ca^{5+}$ beam from the ECR4M was set at a level of 30-50 μAe.

Spectrum of ^{48}Ca from ECR4M optimized for $^{48}Ca^{5+}$.



- The oven and screen temperature of about 400°C was supplied.
- The efficiency of $^{48}Ca^{5+}$ production was about 4% of consumed substance.
- The average consumption of metallic calcium without collection and regeneration can be evaluated as 0.4 mg per hour.

U400

48Ca beam from ion source to target
(U_{inj} = 15 kv)

Beams	
From ion source	28 ρμa (48Ca 5+)
In cyclotron center	4 ρμa (14%)
Accelerated	3,2 ρμa (80%)
Extracted beam	1,34 ρμa (40% stripping)
On the target	1,14 ρμa (85%)

$$\boldsymbol{\varepsilon_{\Sigma} = 4\ \%}$$

48Ca beams from ECR4M (14,5 GHz) with hot chamber screen (FLNR U400)

Q	1^+	2^+	3^+	4^+	5^+	6^+	7^+	8^+	9^+	
$I_{p\mu a}$	5	20	26	27	27	17	9	5	1	$\Sigma 140$

$I_\Sigma = 8{,}2 \cdot 10^{14}$ pps

Matter consumption –0,8 $^{mg}/_{hour}$

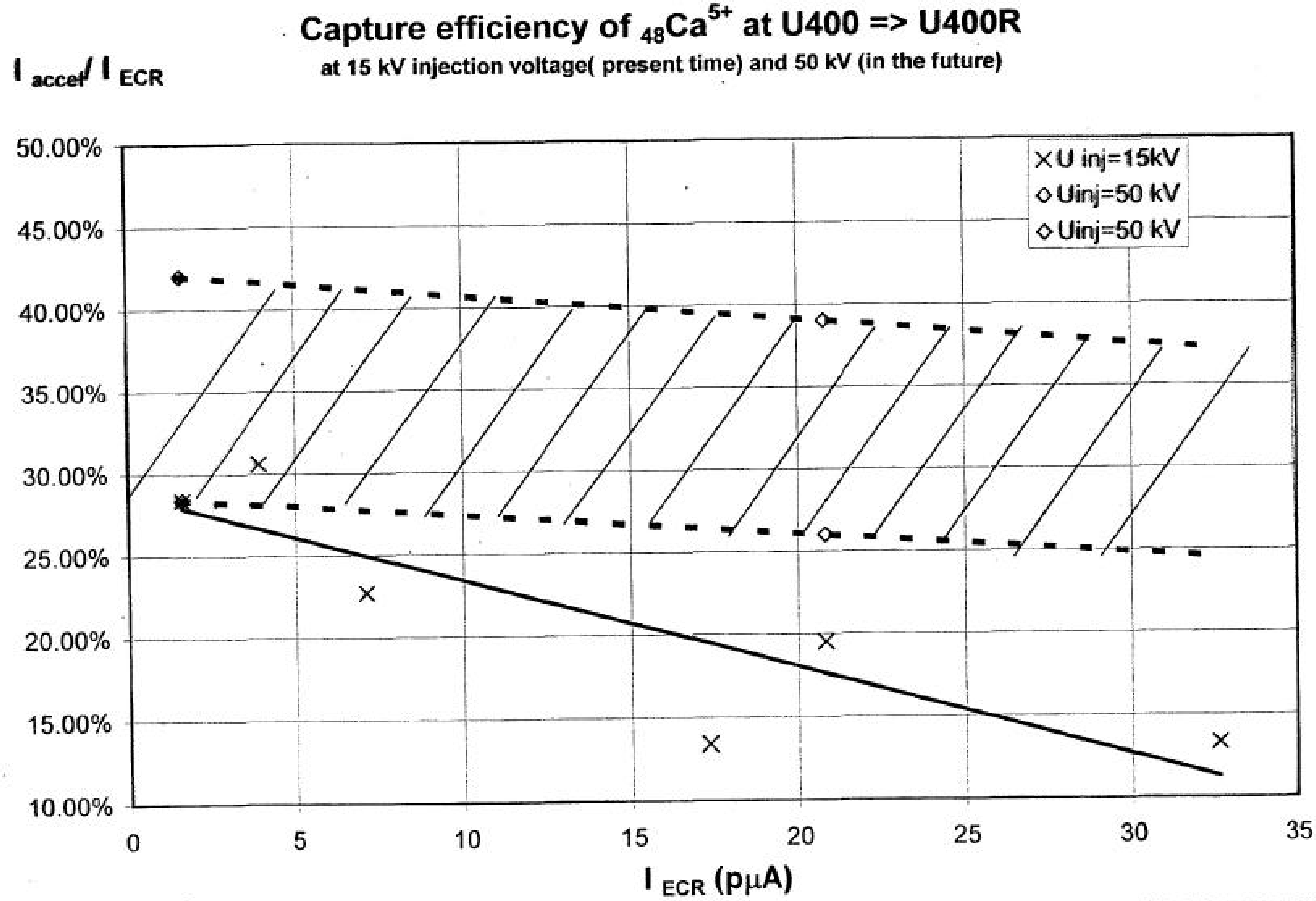
Utilization – 0,16 $^{mg}/_{hour}$ (20%)

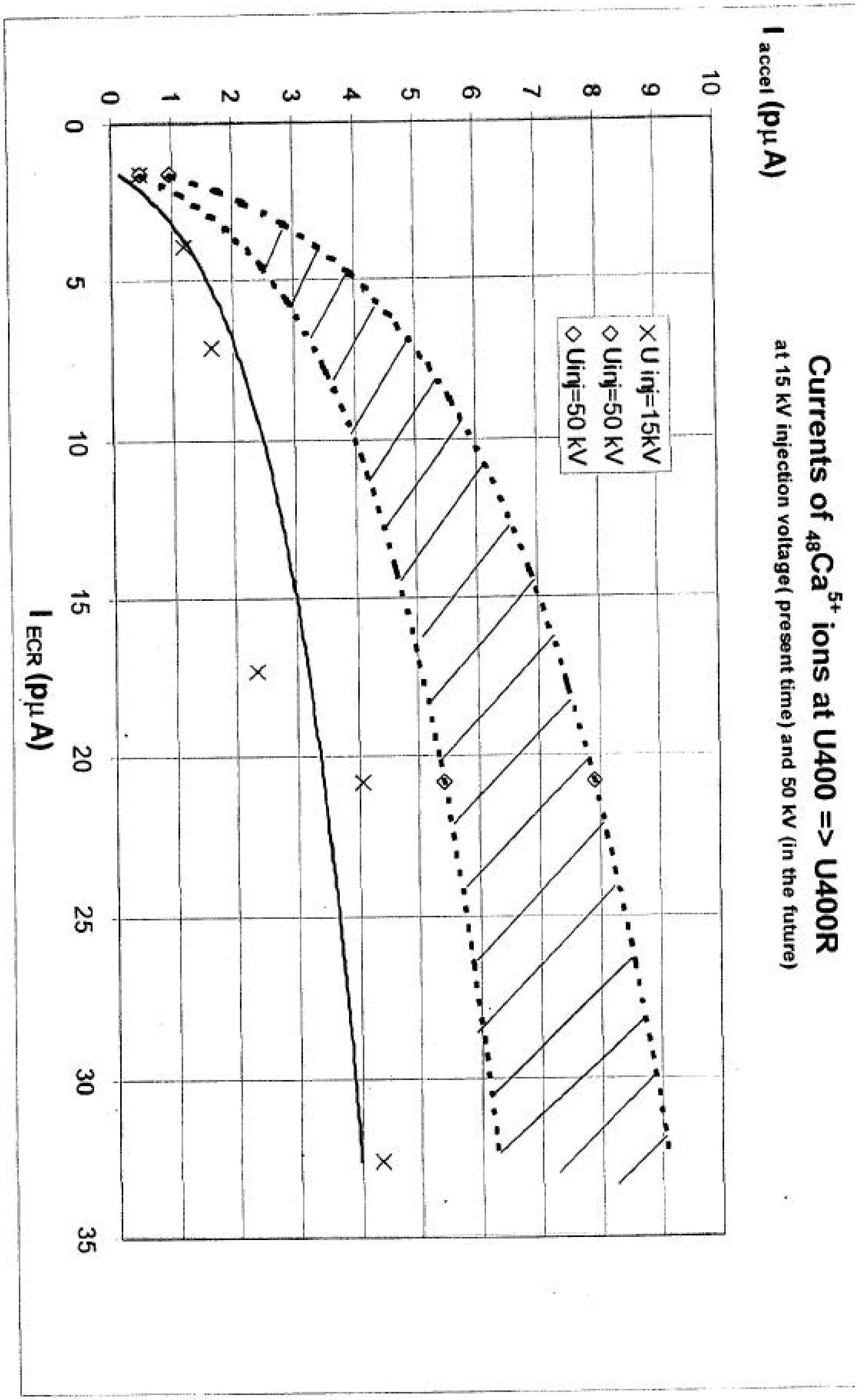
48Ca consumption (60% in matter)

$\frac{dN}{dt} \cdot (48Ca) = 12 \cdot 10^{14}$ pps (0,4 $^{mg}/_{hour}$)

Efficiency $\varepsilon_{0\text{-}n} \approx 65\%$

Efficiency $\varepsilon_{0\text{-}5+} = 10\%$


Capture efficiency of $_{48}Ca^{5+}$ at U400 => U400R
at 15 kV injection voltage(present time) and 50 kV (in the future)
I_{accel}/I_{ECR}
50.00%
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
0
5
10
15
20
25
30
35
I_{ECR} (pμA)
U inj=15kV
Uinj=50 kV
Uinj=50 kV



Currents of $_{48}Ca^{5+}$ ions at U400 => U400R
at 15 kV injection voltage(present time) and 50 kV (in the future)
U inj=15kV
Uinj=50 kV
Uinj=50 kV
I accel (pμA)
I ECR (pμA)
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30
35

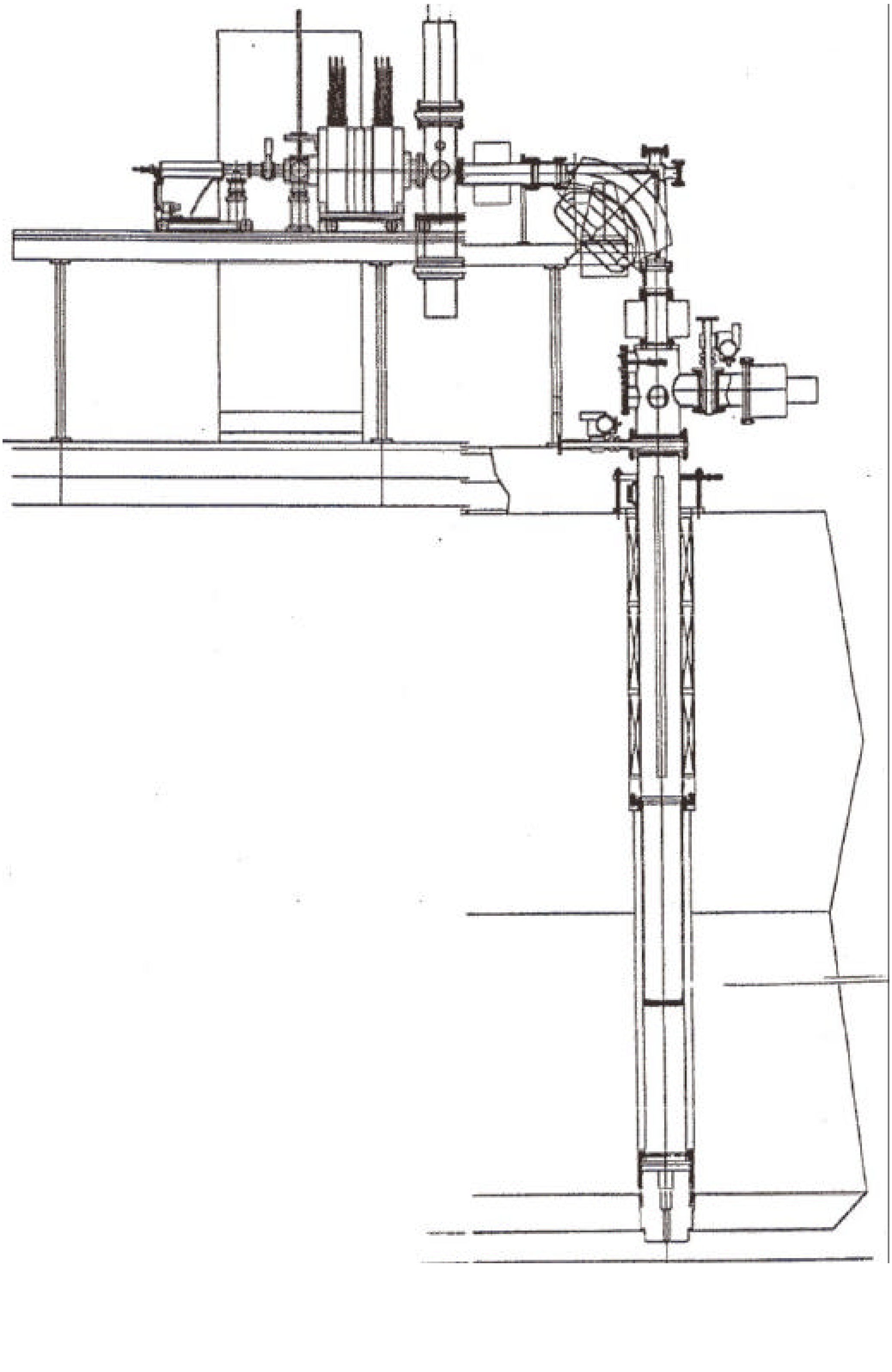
U400R

1. Increasing 48Ca beam intensity on the target up to 4 pμa.

2. Variation of the ion energy on the target with factor up to 5

3. Ion energy spread on the target $\frac{\Delta E}{E} \approx 10^{-3}$

4. Beam emittance on the target up to 10π mm · mrad.

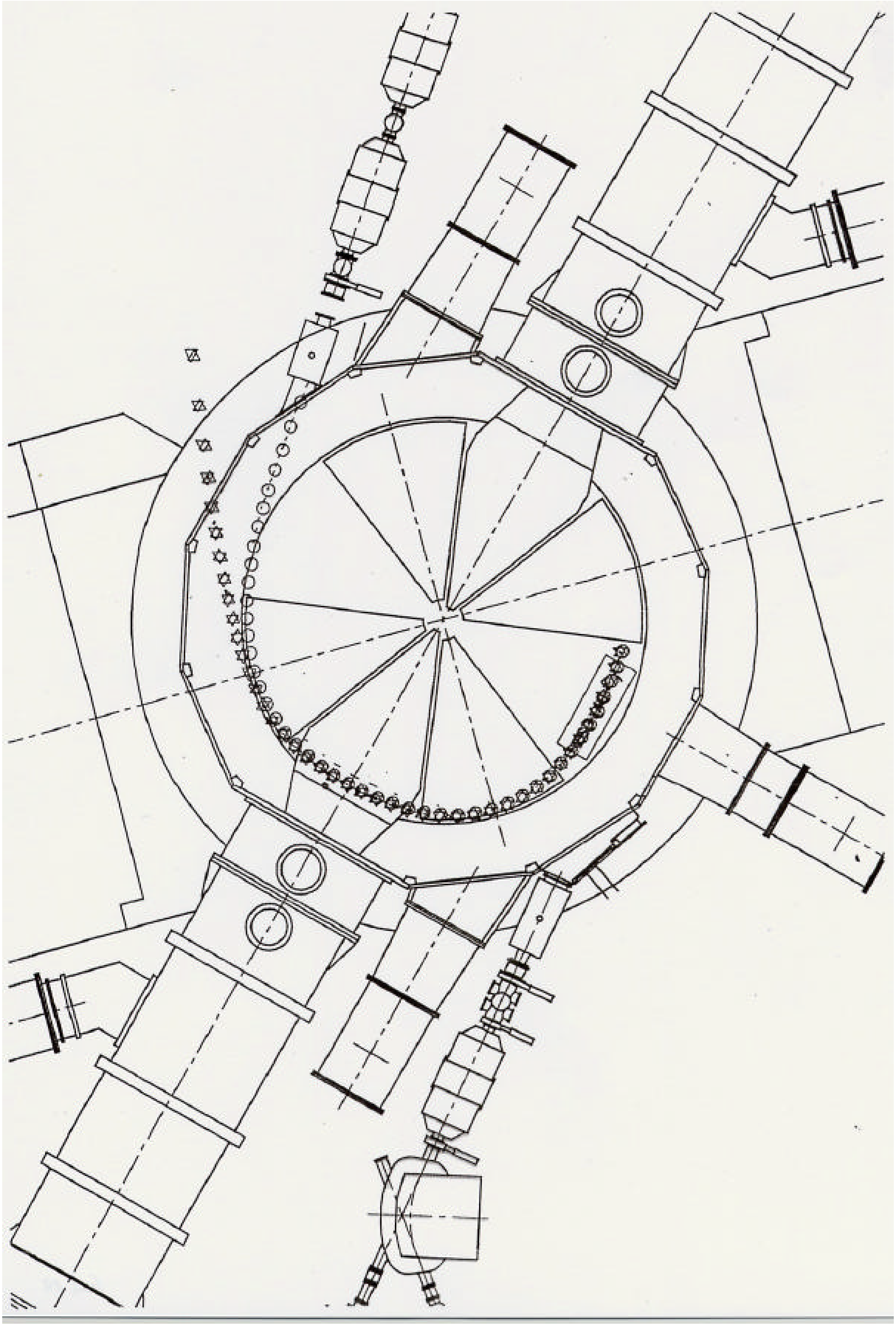


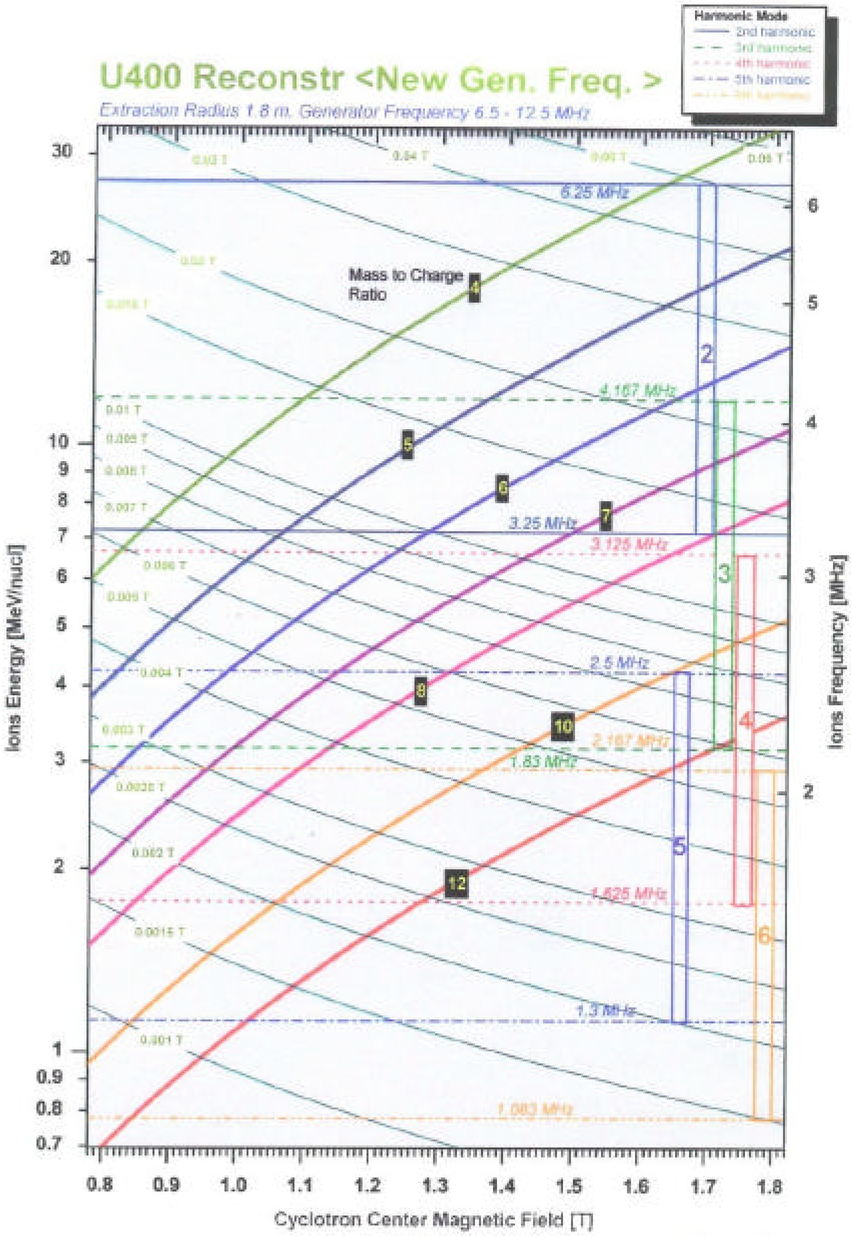
U400R

$^{48}Ca \cdot (5^+) \cdot (6^+) \cdot (7^+)$

E = 200 ÷ 300 mev

$I_{ECR\ p\mu a}$	4	8	12	16	20	24	28
$I_{Accel(15kv)p\mu a}$	1.0	2.0	2.8	3.2	3.4	3.8	3.9
$I_{Accel(50kv)p\mu a}$	1.5	3.0	4.5	6.0	7.5	8.5	9,6
$\frac{dm}{dt}$ mg/hour	0.07	0.14	0.21	0.28	0.35	0.43	0.5
$I_{TARGET\ p\mu a}$	0.63	1.3	2.0	2.5	3.0	3.5	4.0



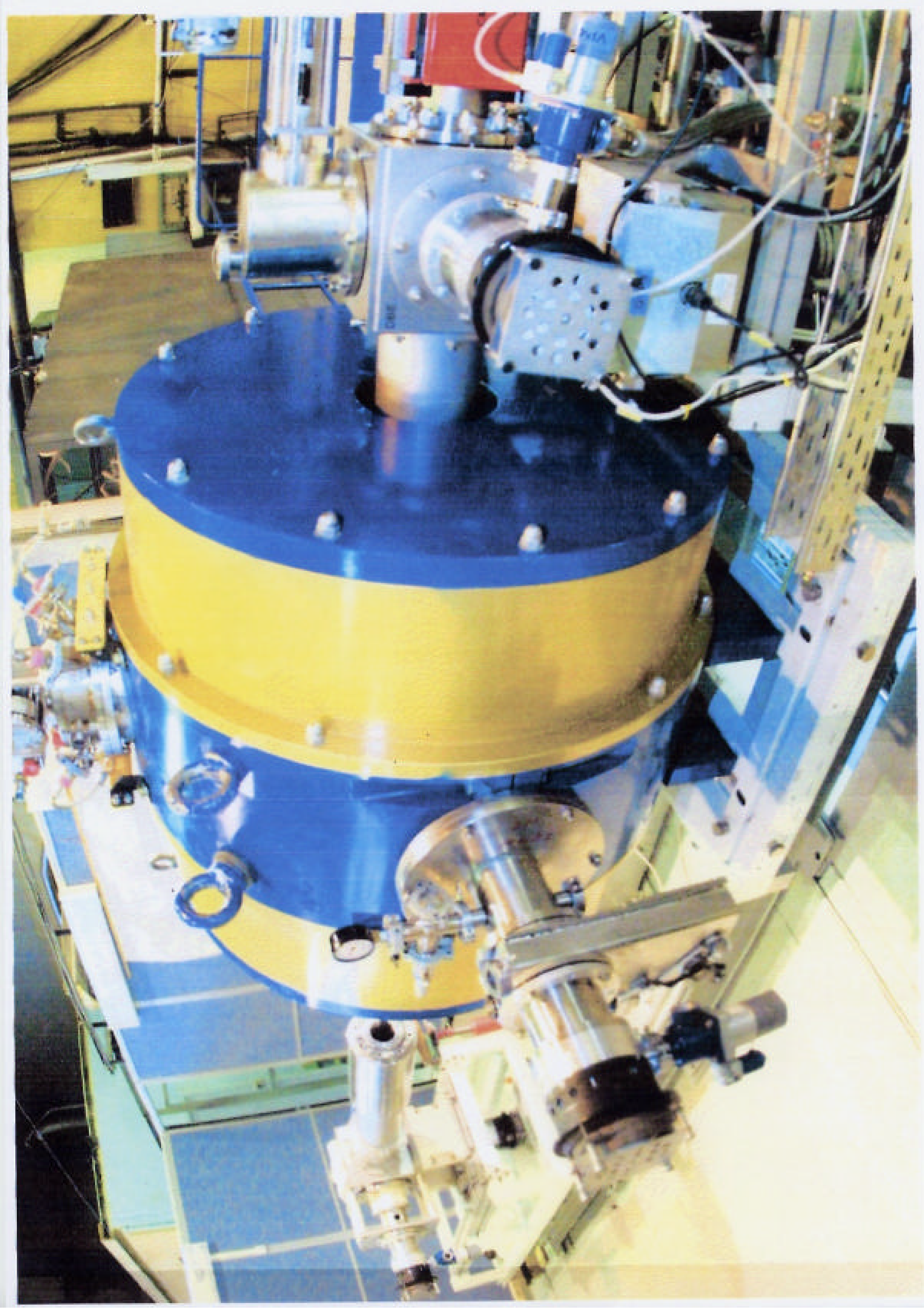


Harmonic Mode
2nd harmonic
3rd harmonic
4th harmonic
5th harmonic
U400 Reconstr <New Gen. Freq. >
Extraction Radius 1.8 m, Generator Frequency 6.5 - 12.5 MHz
Mass to Charge Ratio
6.25 MHz
4.167 MHz
3.25 MHz
3.125 MHz
2.5 MHz
2.167 MHz
1.83 MHz
1.625 MHz
1.3 MHz
1.083 MHz
Ions Energy [MeV/nucl]
Ions Frequency [MHz]
Cyclotron Center Magnetic Field [T]

Expected ion beam intensities from DECRIS-SC for the IC100 cyclotron (A/Z ≈ 5.5 ÷ 6)

Ион	A	Z	I_{ECR} (eμA)	I_{ECR} (pμA)
Li	6	1+	>200	>200
B	11	2+	>200	>100
C	12	2+	>200	>100
Ne	22	4+	>300	>75
Mg	24	4+	>300	>75
Si	28	5+	>300	>60
S	34	6+	>100	>15
Ar	40	7+	>300	>40
Ca	40	7+	>200	>30
Ti	48	8+	>100	>12
V	51	9+	100	11
Cr	52	9+	100	11
Mn	55	10+	100	10
Fe	56	10+	100	10
Co	59	10+	100	10
Ni	58	10+	80	8
Cu	63	11+	50	4.5
Zn	64	11+	100	9
Kr	84	14+	120	8.5
Kr	84	15+	100	6.5
Zr	90	16+	10	0.6
Mo	98	17+	10	0.5
Sn	118	20+	20	1
Xe	129	22+	110	5
Xe	129	23+	80	3.5
Xe	132	24+	60	2.5
Ta	181	31+	1	0.03
Hg	202	34+	5	0.15
Pb	208	35+	5	0.14
U	238	40+	>1	>0.025

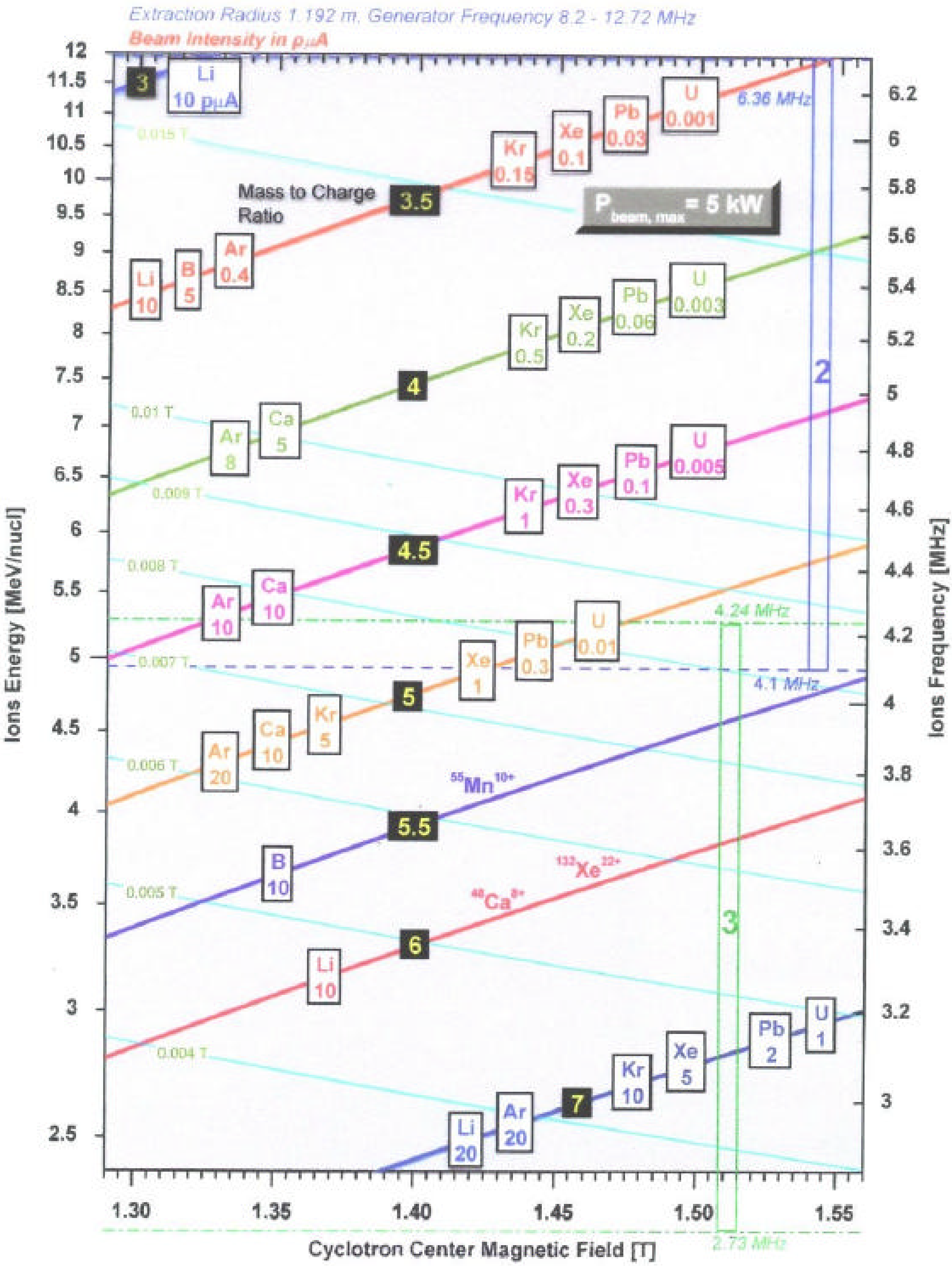
Using of the ordinary gas supply system
Existing micro oven
MIVOC
Design of the special techniques is required (micro oven up to 1900 °C, plasma sputtering, chemical compounds et al.)
(For all isotopes the enrichment about of 100% was assumed)



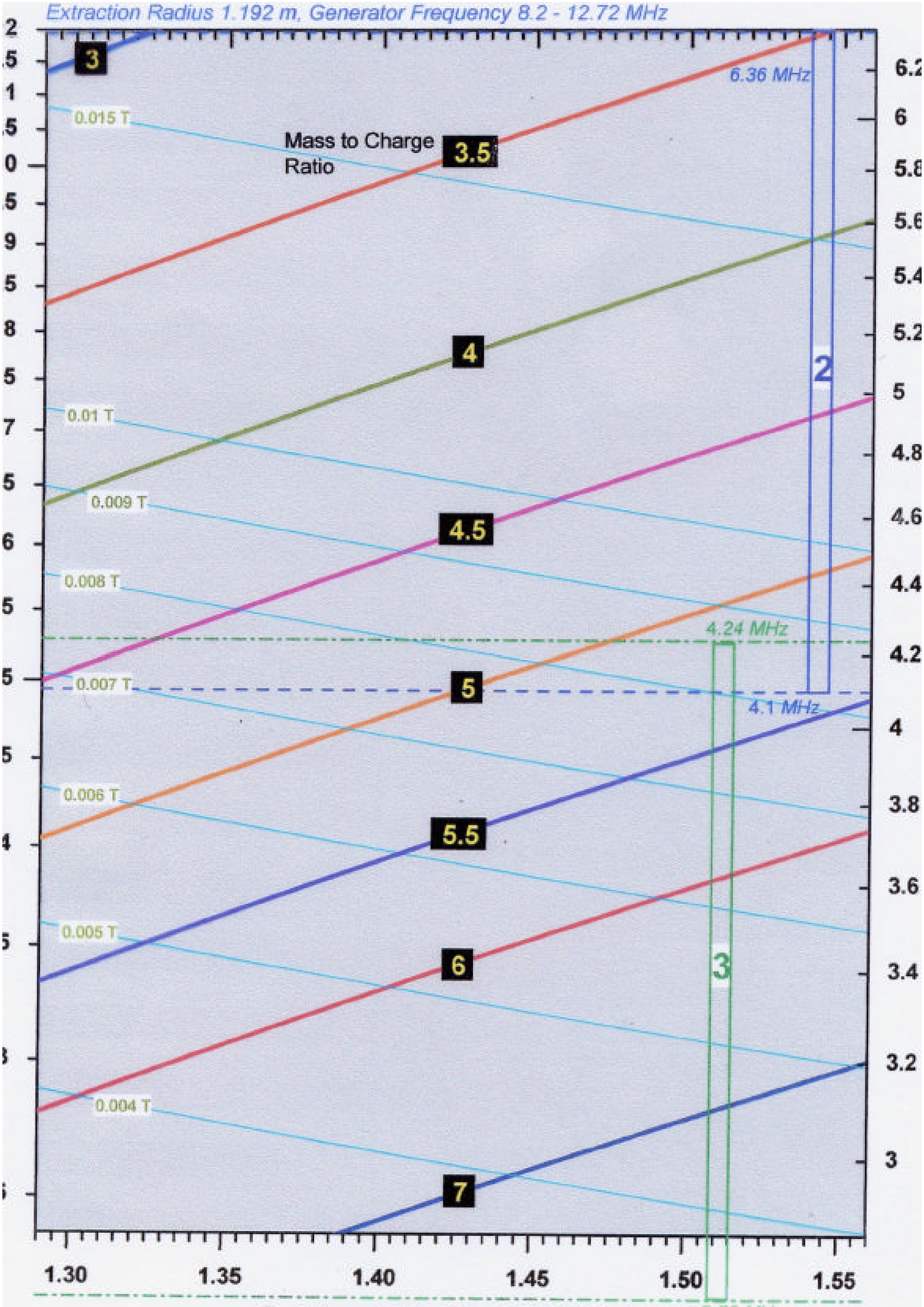
C160

Cost estimation

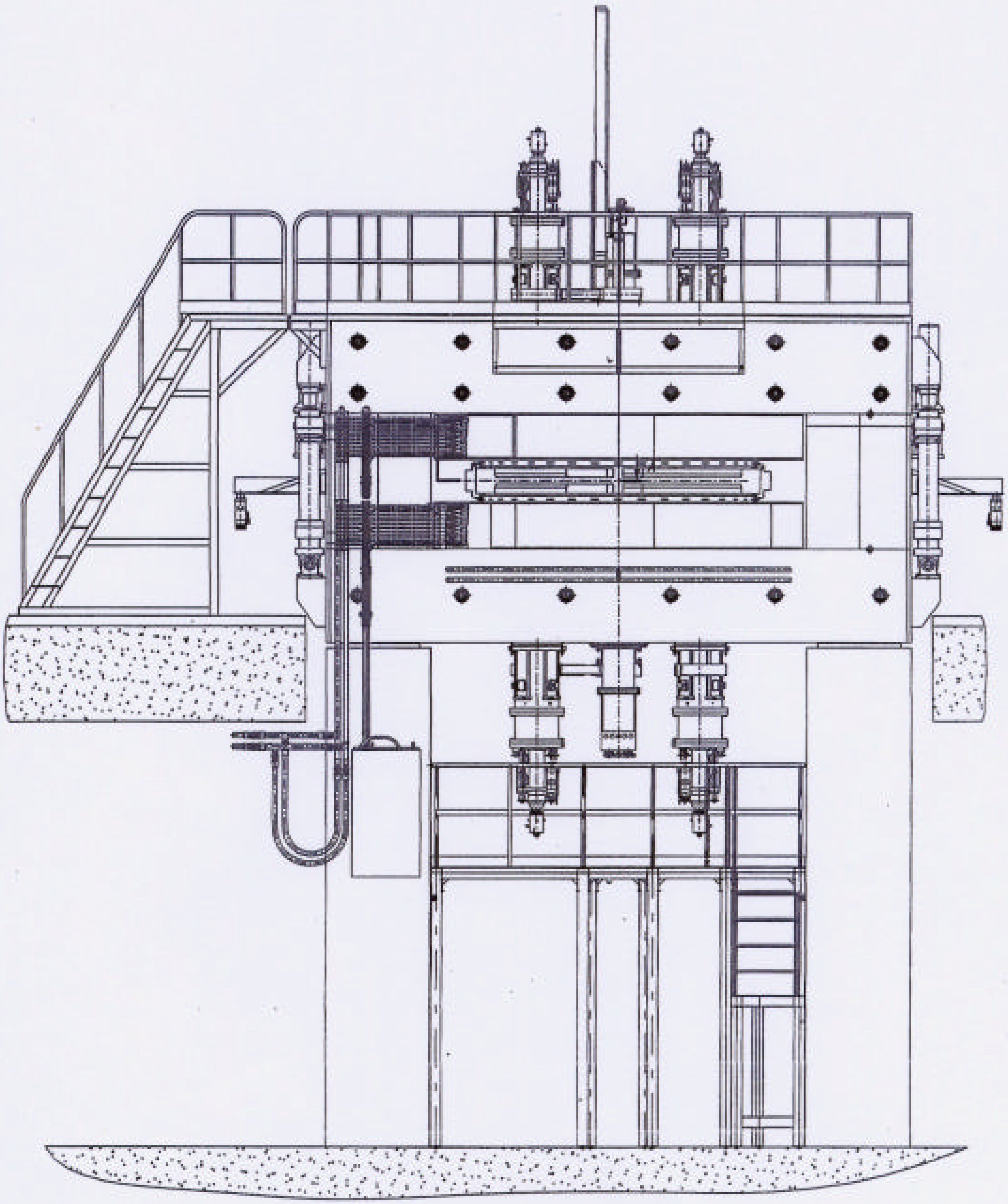
Main мagnet	1,2 M$
Vacuum chamber	0,2 M$
RF generator	0,3 M$
RF system	0,5 M$
Vacuum system	0,5 M$
Diagnostics	0,15 M$
Trim coils	0,25 M$
Axial injection	0,25 M$
Magnets power supply	0,15 M$
Control system	0,6 M$
Ion source	0,5 M$
Beam extraction system	0,05 M$
High voltage power supply	0,05 M$
Simulation design	0,5 M$
Installation	0,5 M$
Σ	**5,7 M$**



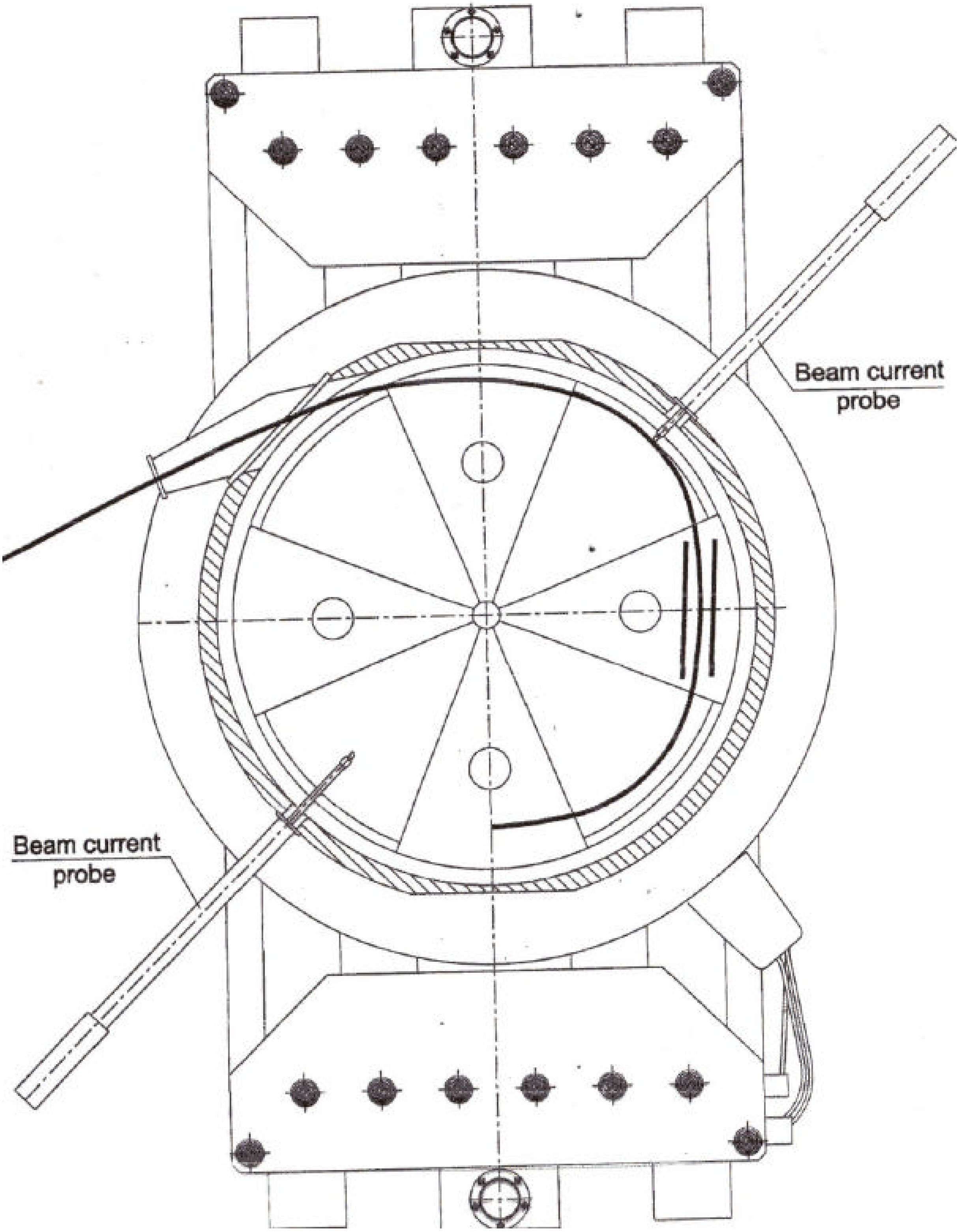
Extraction Radius 1.192 m, Generator Frequency 8.2 - 12.72 MHz
Beam Intensity in pμA
Mass to Charge Ratio
Pbeam, max = 5 kW
6.36 MHz
4.24 MHz
4.1 MHz
2.73 MHz
Ions Energy [MeV/nucl]
Ions Frequency [MHz]
Cyclotron Center Magnetic Field [T]
55Mn10+
132Xe22+
48Ca8+


Extraction Radius 1.192 m, Generator Frequency 8.2 - 12.72 MHz
Mass to Charge Ratio
3
3.5
4
4.5
5
5.5
6
7
0.015 T
0.01 T
0.009 T
0.008 T
0.007 T
0.006 T
0.005 T
0.004 T
6.36 MHz
4.24 MHz
4.1 MHz
2
3
1.30
1.35
1.40
1.45
1.50
1.55

C-160 cyclotron



C-160 cyclotron



Extraction

Type of extraction	By electrostatic deflector
Radial position	1180 мм
Length of deflector	880 мм
Gap of deflector	1 см
Maximum voltageon defector	100 $^{kv}/_{cm}$
Focusing in fringing field	By passive iron channel

Ion source + injector

Ion source	ECR 28 GHz
Injector length	5 м
Level of pressure	10^{-5} pa
Injection potential	>30 kv

Power consumption

Ion source + axial injection	0,2 Mw
Magnet + trim	0,08 Mw
RF	0,08 Mw
Vacuum	0,02 Mw
Σ	**0,38 Mw**

Cyclotron C160

Magnet

Agerage magnetic field	1,3 T – 1,55 T
Pole diameter	2,7 м
Number of sectors	4
Magnet weight	330 ton
Copper weight	8 ton
Power consumption	80 kw

R·F

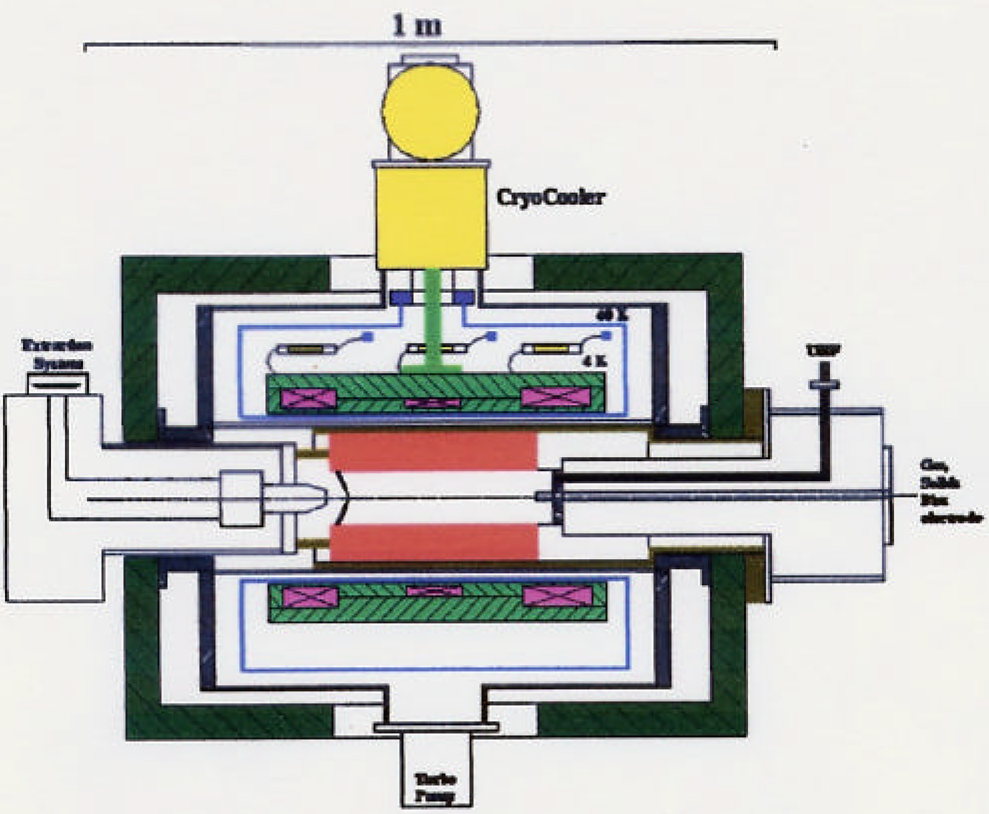
Frequency range	8,1 ÷ 12,4 MHz
Harmonic number	2,3
Number of dees	2
Angle of dee	40°
Dee voltage	60 kv
RF structure	2 x $\lambda/4$
RF power consumption	2 x 20 kw
Electricity power consumption	80 kw

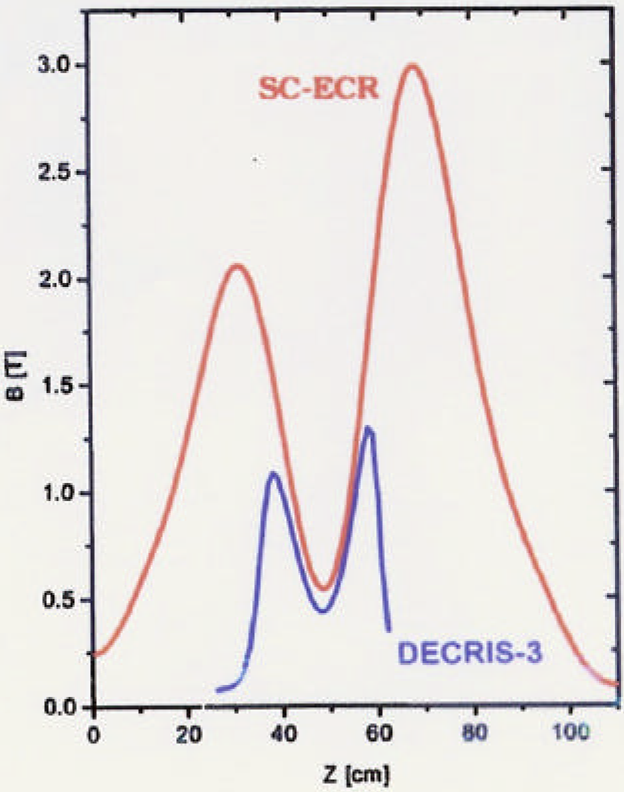
Vacuum system

Pressure	10^{-5} Pa

Main pumping x 2 x 5000 L/сек cryogenic pump

Support pumping x 2 x 500 L/сек TMP


1 m
CryoCooler
4 K


SC-ECR
DECRIS-3
B [T]
Z [cm]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100

Generation on U400M and acceleration on U400 6He t½=800 мсек

Process	Time, sec		Efficiency	
	Project	Test	Project	Test
Σ_1-diffussion from carbon catcher (1μ)	50×10^{-3}	50×10^{-3}	1	1
Σ_2-transport to ion source (1m x Ø 0,1m)	20×10^{-3}	20×10^{-3}	1	1
Σ_3-ionization 1+ and separation	1×10^{-3}	$(50 \div 130) \times 10^{-3}$	0,5	0,1
Σ_4-transport 6He 1+	2×10^{-4}	2×10^{-4}	0,8	0,23
Σ_5-acceleration capture	0	0	0,5	0,4
Σ_6-acceleration	50×10^{-6}	50×10^{-6}	1	0,8
Σ_Σ	70×10^{-3}	$(120 \div 200) \times 10^{-3}$	15×10^{-2}	$0{,}736 \times 10^{-}$

$$\frac{\sum \Sigma \ project}{\sum \Sigma \ test} = 20$$

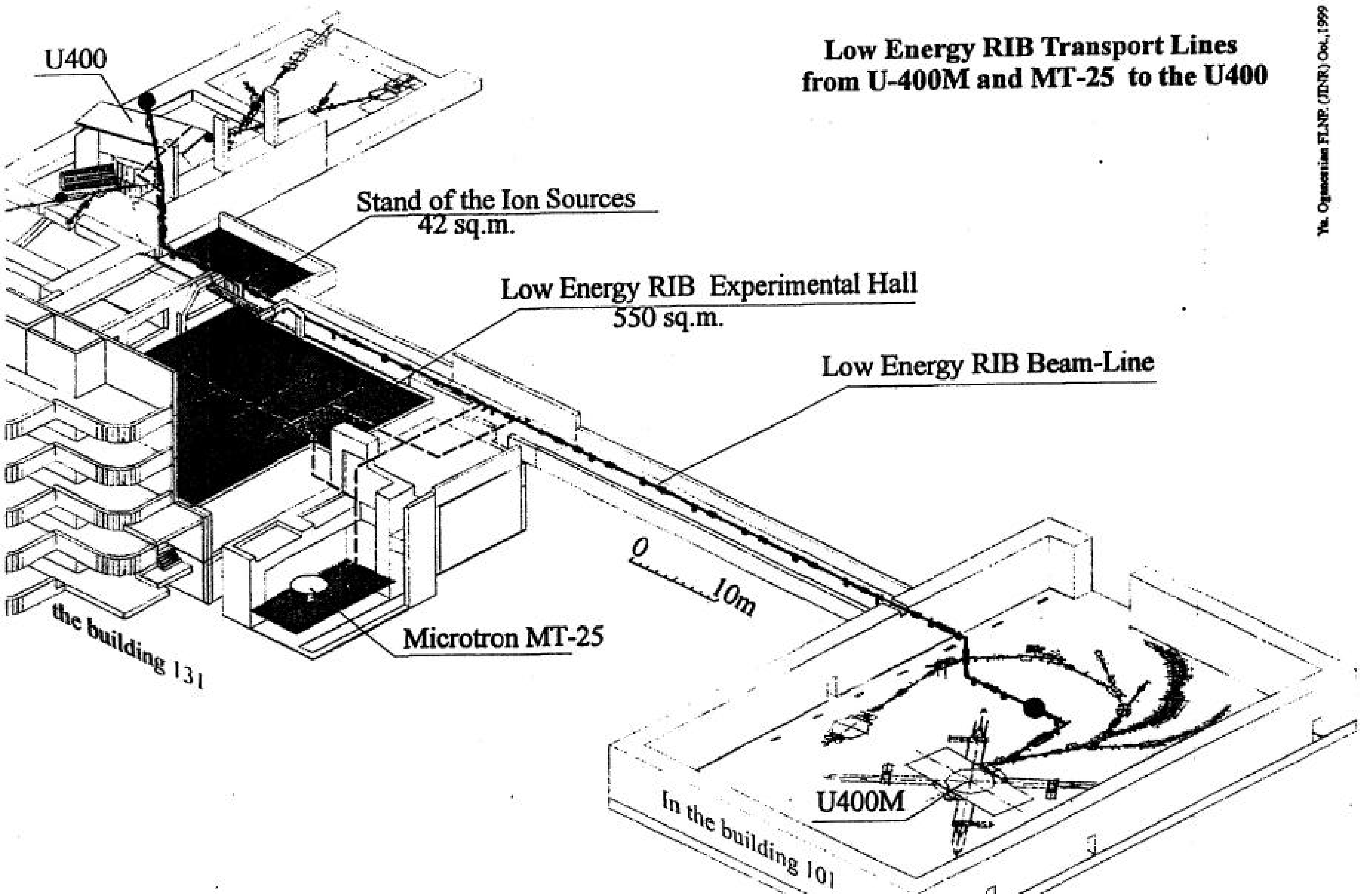
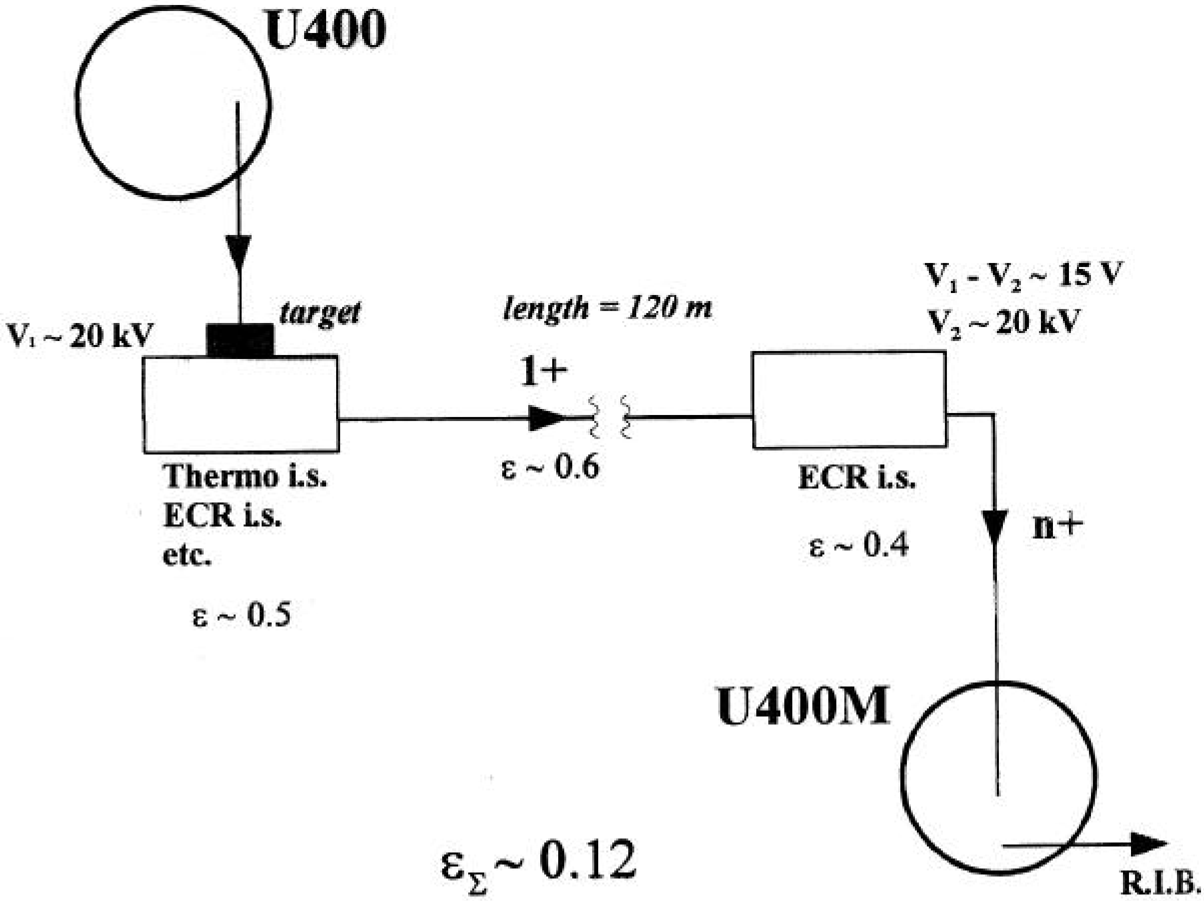
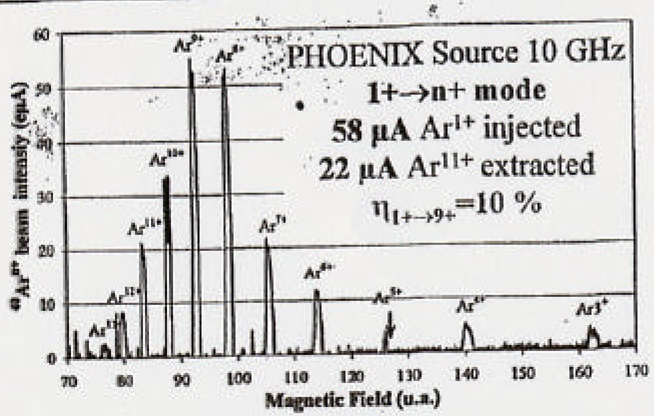

Low Energy RIB Transport Lines
from U-400M and MT-25 to the U400
Yu. Oganessian FLNR (JINR) Oct.,1999
U400
Stand of the Ion Sources
42 sq.m.
Low Energy RIB Experimental Hall
550 sq.m.
Low Energy RIB Beam-Line
0
10m
the building 131
Microtron MT-25
U400M
In the building 101

Table: Beams of the U-400M cyclotron.

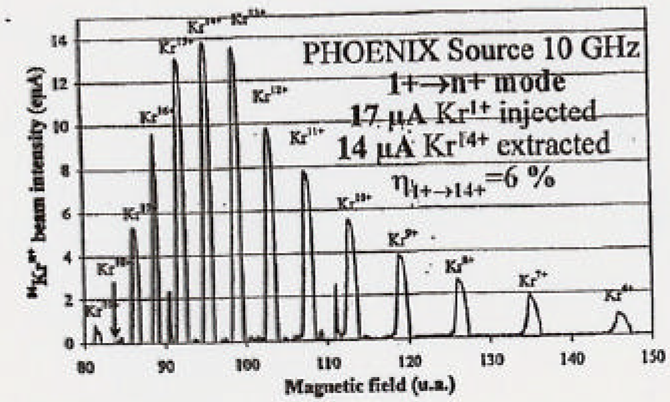
Ion	E, MeV/n	I, ECR	I, extracted	I, extracted
$^{7}Li^{2+}$	35	100μA	30μA	6*10^{13} pps
$^{11}B^{3+}$	32	90μA	30μA	4*10^{13} pps
$^{12}C^{4+}$	47	100μA	35μA	4*10^{13} pps
$^{14}N^{4+}$	35	100μA	35μA	3*10^{13} pps
$^{14}N^{5+}$	54	50μA	15μA	1.5*10^{13} pps
$^{18}O^{5+}$	33	100μA	30μA	2.5*10^{13} pps
$^{22}Ne^{6+}$	32	50μA	15μA	1*10^{13} pps
$^{22}Ne^{7+}$	43	50μA	15μA	1*10^{13} pps
$^{36}S^{10+}$	33	10μA	1.7μA	6*10^{11} pps
$^{40}Ar^{12+}$	40	12μA	2μA	7*10^{11} pps
$^{48}Ca^{10+}$	20	10μA	1.7μA	5*10^{11} pps


U400
target
$V_1 \sim 20$ kV
length = 120 m
1+
$V_1 - V_2 \sim 15$ V
$V_2 \sim 20$ kV
Thermo i.s.
ECR i.s.
etc.
$\varepsilon \sim 0.5$
$\varepsilon \sim 0.6$
ECR i.s.
$\varepsilon \sim 0.4$
n+
U400M
$\varepsilon_\Sigma \sim 0.12$
R.I.B.

$1^+ \rightarrow n^+$ results with PHOENIX Booster 10 Ghz



1.36×10[15] charges in the plasma



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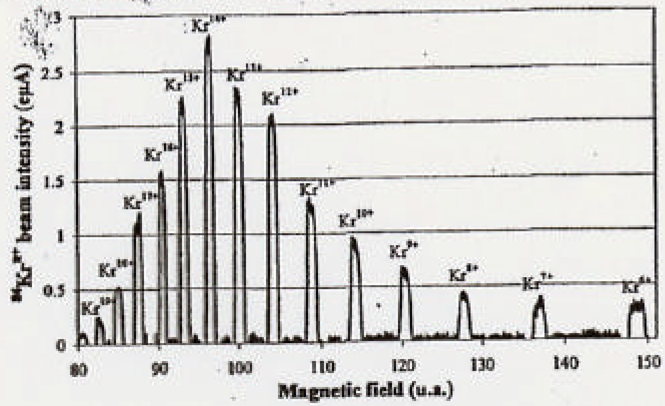
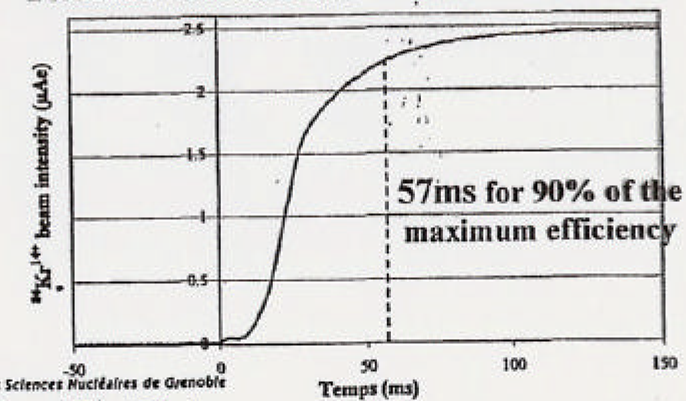
$1^+ \rightarrow n^+$ results with PHOENIX Booster 10 Ghz

PHOENIX BOOSTER 10 Ghz - 250 W - for $Kr^{1+} \rightarrow Kr^{n+}$ charge breeding with Kr^{1+} beam intensity injected : 1.93 µA



$$\eta_{Kr^{1+} \rightarrow Kr^{14+}} = 10.3\%, \quad \sum_i \eta_i \approx 65\%$$

Release time for $Kr^{1+} \rightarrow Kr^{14+} \approx$ **60 ms**



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U-400M

$T - beams$

1. $5(TD)^+ \to 3T^+ + 2D^+$

$$\frac{(B\rho)_1}{(B\rho)_2} = 1.66$$

$Z/A = 0.2$; $E_T \cong 54$ MeV

2. $4(TH)^+ \to 3T^+ + 1H^+$

$$\frac{(B\rho)_1}{(B\rho)_2} = 1.33$$ (degrading in stripping foil)

$Z/A = 0.25$; $E_T \cong 80$ MeV

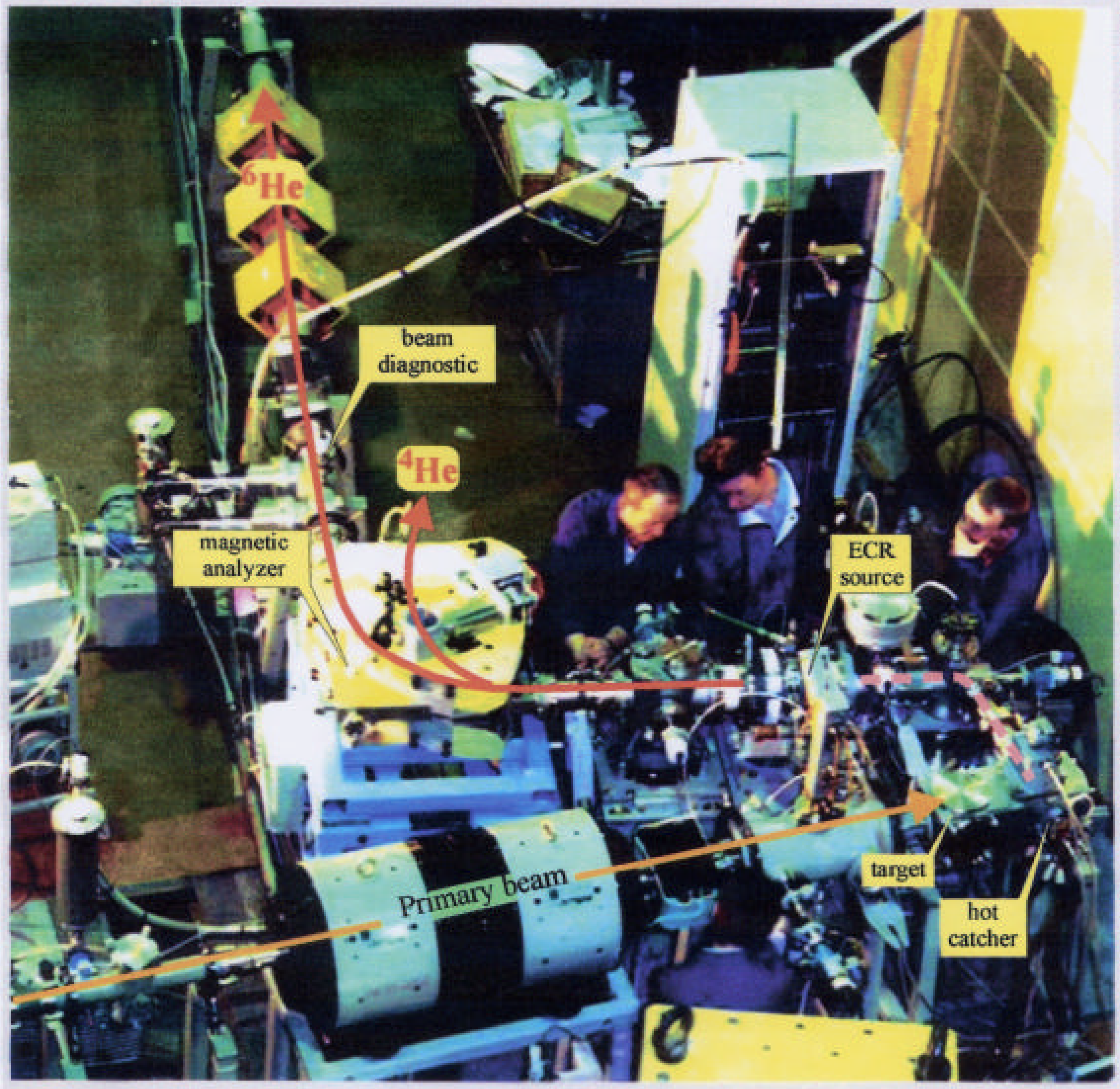
3. $3T^- \to 3T^+$

$$\frac{(B\rho)_1}{(B\rho)_2} = -1$$ (Lorentz force ?)

$Z/A = 0.33$; $E_T \cong 150$ MeV

DRIBs - Project

Transformation of the primary beam into a low energy radioactive ion beam



FLNR (JINR) Feb.2001