



FEBIAD ion source development at ISOLDE: efficiency improvement for all the elements

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Ionization efficiency improvement at ISOLDE

FEBIAD Ion source	Ionization Efficiency					
	He	Ne	Ar	Kr	Xe	Rn*
Standard MK7 [1]	0.14	0.36	2.0	4.3	11	-
1 st proto (#380)	0.37		7.8	11	19	
2 nd proto (#317, #385)	1.4	6.7	26	38	47	62
Multiplying factor	10	18.6	13	8.8	4.3	-

#380 Nb (HRS)

Record yields for Krypton:

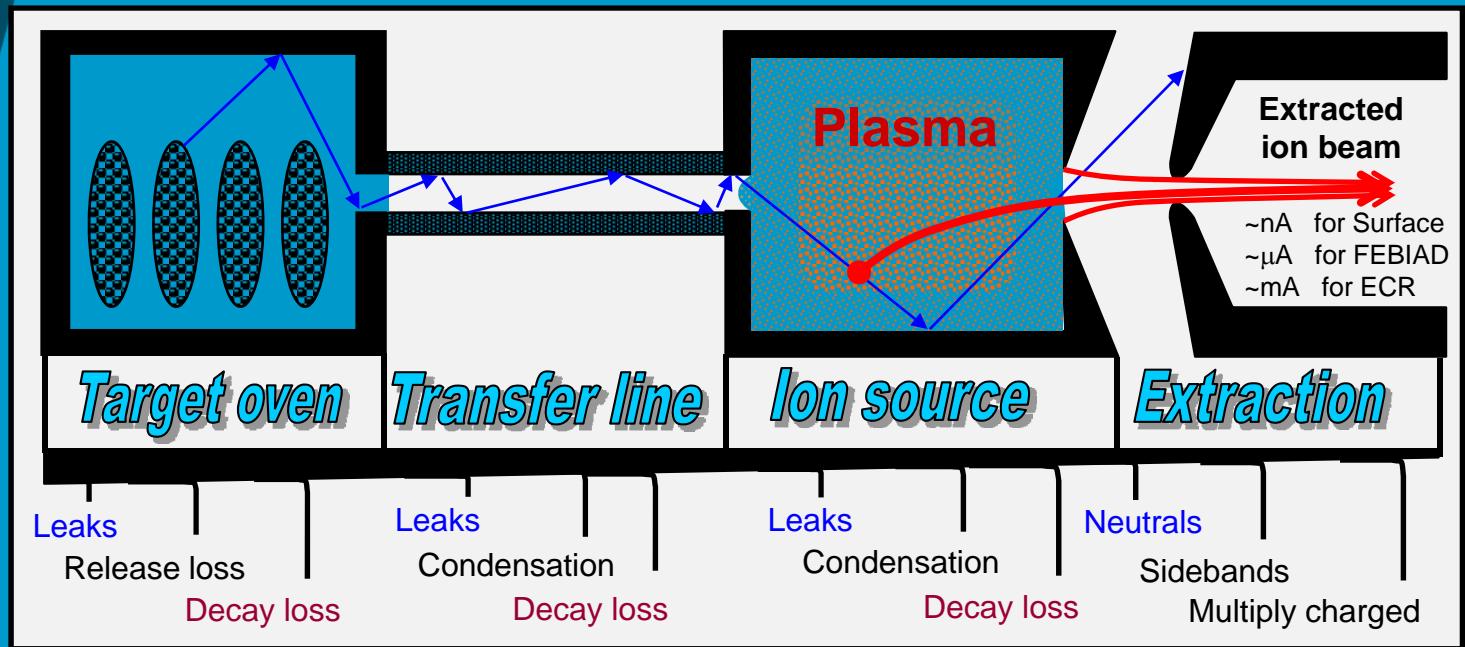
Yields	⁷² Kr	⁷³ Kr
Measured (at/ μ C)	1.1e4	1.2e6
Database (at/ μ C)	2.0e3	7.4e4

#385 UC_x (HRS)**Discovery of ²²⁹Rn.**

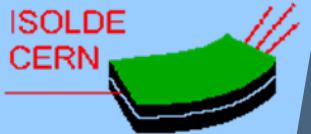
[1] U.C. Bergmann et al, NIM B204 (2003) 204



Efficiency of the ISOL process



- Nuclear reaction - cross section
- Diffusion
- Effusion
- Ionization
- Gas pumping
- Beam quality



1+ Ionization

- Ionization potential: ANY element
- Volatility: elements with $\Delta H_a < \sim 6\text{eV}$

Efficiency

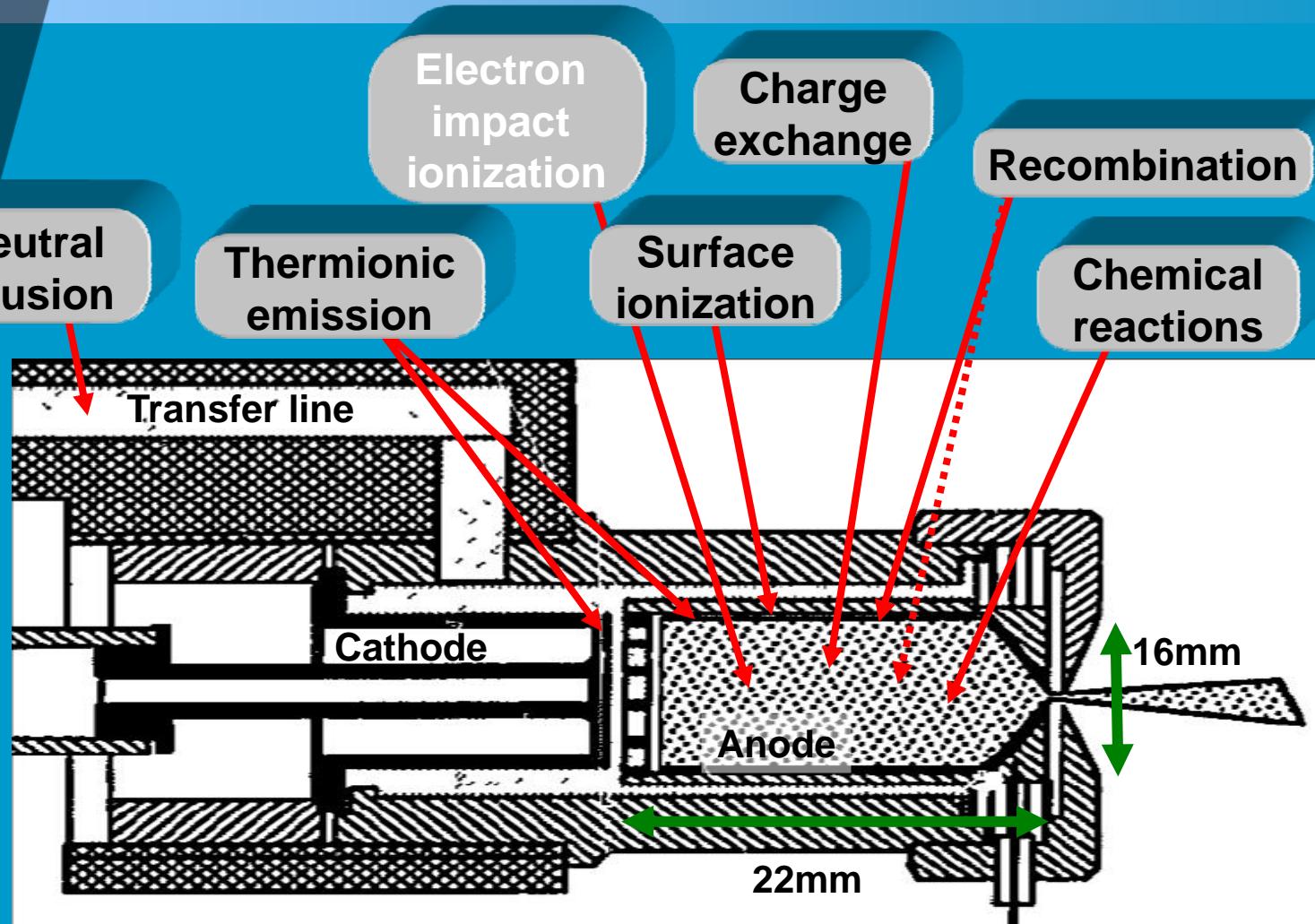
Dependent on:

- Mass
- Ionization potential
- Volatility
- ...

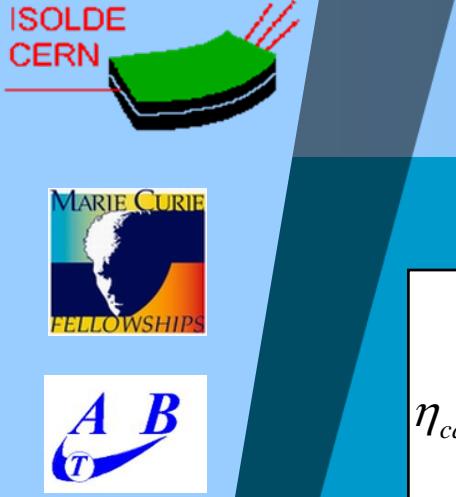
Elements produced at ISOLDE

Period	Ion source:																		2 He
1	1 H																		
2	3 Li	4 Be																	2 He
3	11 Na	12 Mg																	2 He
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg							
* Lanthanides		*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb			
** Actinides		**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No			

The arc discharge plasma



Theoretical models for FEBIAD ionization



→ Best approximation: empirical equation [2]

$$\eta_{calc} = \frac{4D_0 \cdot \frac{\langle l \rangle}{S_{out}} \cdot \sqrt{\frac{\pi \cdot M_i}{8kT_i}} \cdot l_e \exp\left[\frac{-I_p}{<kT_e>}\right]}{1 + 4D_0 \cdot \frac{\langle l \rangle}{S_{out}} \cdot \sqrt{\frac{\pi \cdot M_i}{8kT_i}} \cdot l_e \exp\left[\frac{-I_p}{<kT_e>}\right]}$$

Model parameters (FEBIAD):

$$\langle kT_e \rangle = 3.029 \text{ eV}; \\ T_i = 2273 \text{ K}; \\ 4\langle l \rangle D_0 / A_0 = 5.39 \cdot 10^5 \text{ cm/s}$$

Implications...

Fitted results: FEBIAD (Kirchner) and EBGP (Nitschke) sources

Where:

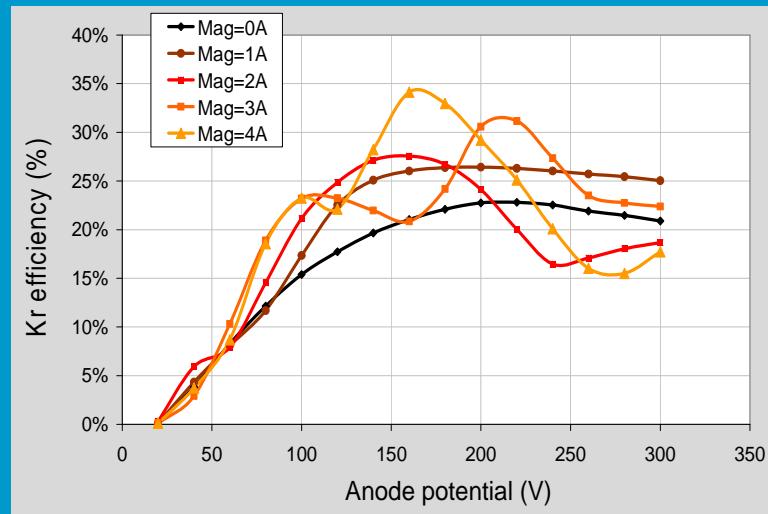
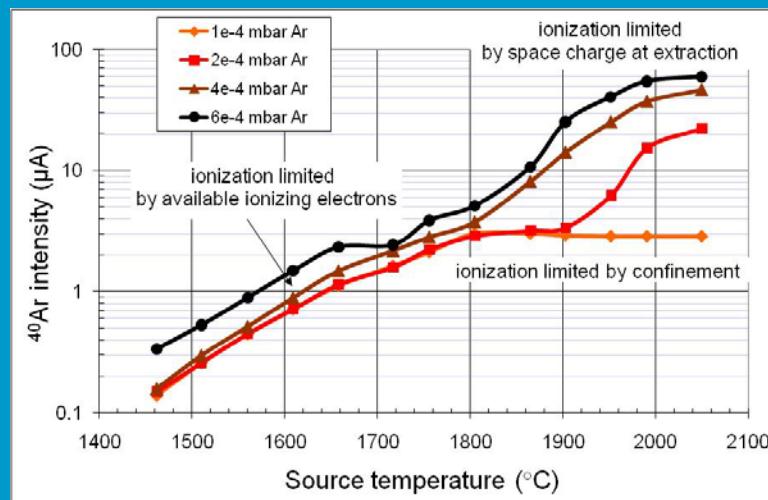
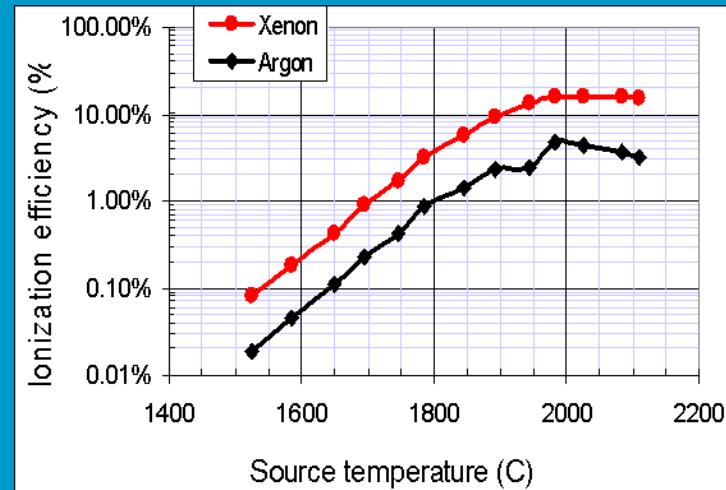
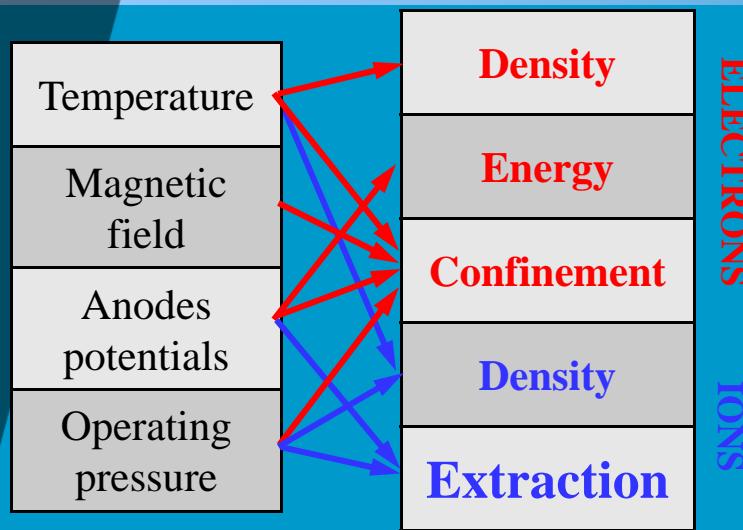
- $\langle l \rangle$ = average path length for a particle in the plasma;
- D_0 = constant (cm^2/s);
- S_{out} = emission area of the source;
- T_i = ion temperature;
- T_e = electron temperature;
- I_p = ionization potential;
- l_e = number of electrons in the valence shell of the atom with a given I_p ;
- M_i = mass of the species.

Not useful for:

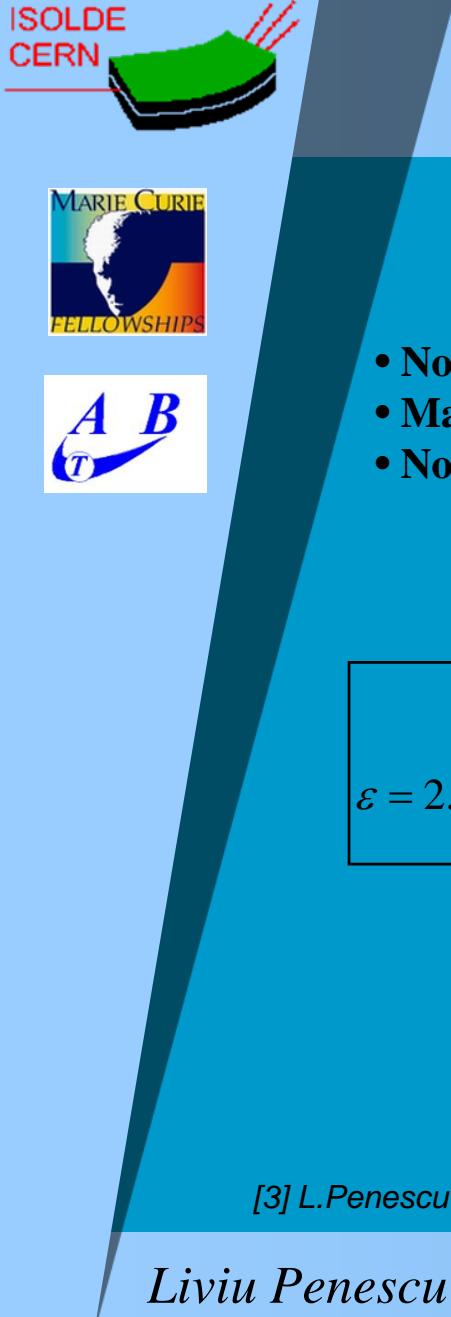
- Comprehension of IS internal parameters:
- Deducing:
- response time;
 - emittance;
 - collective behavior (=>selectivity)

[2] G.D.Alton, NIM A382 (1996) 207

FEBIAD – effect of operational parameters



FEBIAD - a parameter-oriented model



Model frame

- Inferred from **experimental study**;
- Introduced in [3].

- No plasma confinement;
- Mainly direct electron beam ionization;
- No ion heating.

$$\begin{aligned}T_e &\approx eV_{anode} \\T_i &\approx T_{gas} \approx T_{cathode} \\n_e &\approx n_{cathode}\end{aligned}$$

$$\mathcal{E} \sim \sigma_{ioniz} \cdot \sqrt{M} \cdot n_e \cdot f_{extr}$$

Equivalent with:

- Buffer gas not required for ionization;
- Emittance defined mainly by the extraction geometry;
- Fast ionization.

$$\mathcal{E} = 2.33 \cdot 10^4 \cdot f_{extr} \cdot f_{elec} \cdot V_{source} \cdot A \cdot \exp\left[\frac{-W}{kT}\right] \cdot l_e \cdot \frac{\ln\left(\frac{E_{elec}}{E_{ioniz}}\right)}{E_{elec} \cdot E_{ioniz}} \cdot \frac{\sqrt{M_i} \sqrt{T}}{S_{out}}$$

T = cathode temperature = gas & ion temperature;

A, W = cathode parameters (Richardson constant & work function);

E_{elec} = ionizing electrons energy;

E_{ioniz}, l_e, M_i = element parameters (ionization energy; available electrons; mass)

V_{source} = source volume;

S_{out} = emission area of the source.

[3] L.Penescu et al, NIM B **266**, 4415 (2008)

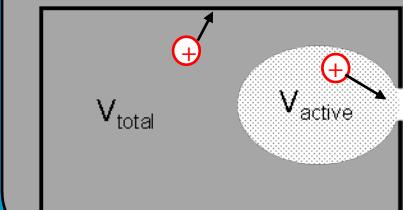
FEBIAD prototypes

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$$\mathcal{E} \sim \sigma_{ioniz} \cdot \sqrt{M} \cdot n_e \cdot f_{extr}$$

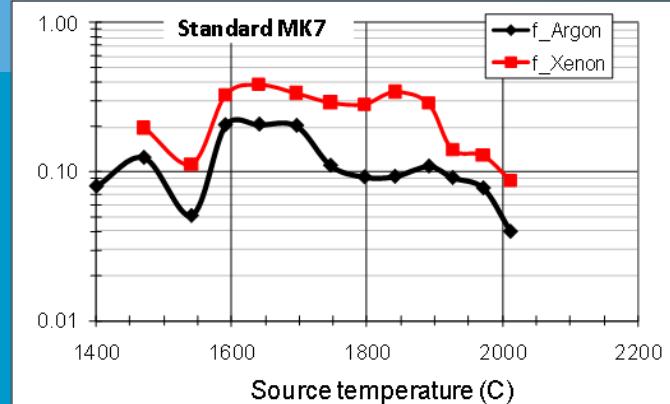
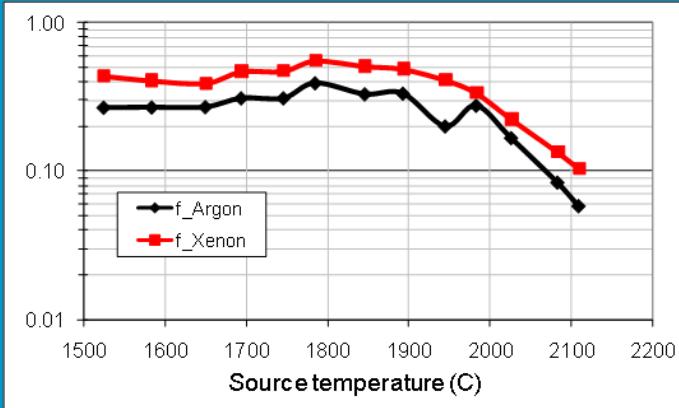
Improvement: Extraction factor,



$$f_{extr} \equiv \frac{V_{active}}{V_{total}}$$

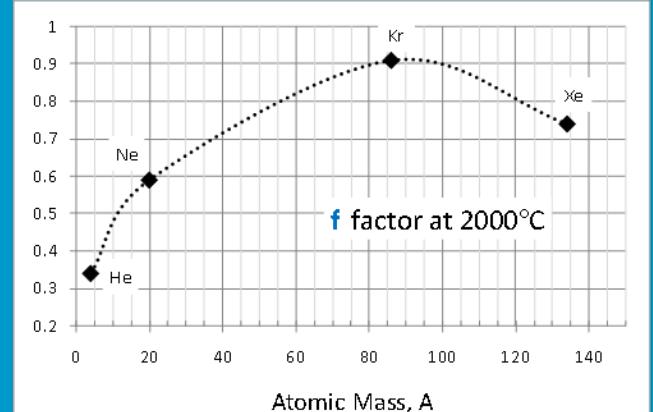
1st Prototype (#380 Nb):
optimization of extracting field

Only MK7 (“cold plasma”) => Only noble gases



2nd Prototype (#385 UC_x):
reduction of wall losses

MK7 and MK5
 (“cold” and “hot” plasma) => ALL elements



Expected element dependence

$$\mathcal{E} \sim \sigma_{ioniz} \cdot \sqrt{M} \cdot n_e \cdot f_{extr}$$



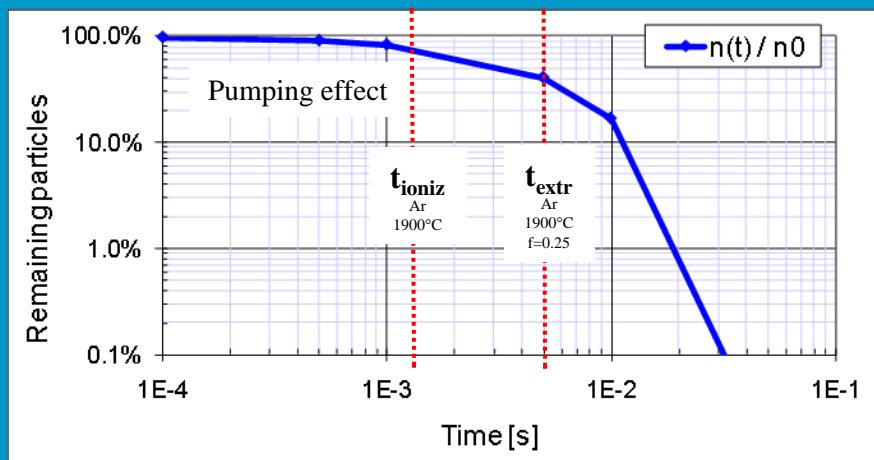
Valid for isotopes

VOLATILE
STABLE

Ion source response time:

ionization
extraction

pumping
sticking
decay



$$t_{extr} = t_{ioniz} \cdot N_{ioniz}$$

$$N_{ioniz} \approx \frac{1}{f_{extr}}$$

$$\Rightarrow t_{extr} \approx \frac{t_{ioniz}}{f_{extr}}$$

$$t_{ioniz} \sim \sigma_{ioniz} \cdot n_e \cdot v_{rel}$$

$$f_{extr} \uparrow \Rightarrow t_{extr} \downarrow$$

- Ion source **response time improved**
- Ion source response time < target + transfer line resp. time
- No isotope **lifetime** limitation from the ion source

Applicability

Improvement valid for:

- ALL types of transfer line (hot, cooled, quartz);
- ALL target materials;
- Atomic ionization AND molecular sidebands.

Effect on the **MK7** efficiencies (and RIB yields):

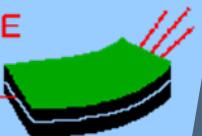
Element	He	Ne	Ar	Kr	Xe
Multiplying factor	10	18.6	13	8.8	4.3

Effect on the **MK5** efficiencies (and RIB yields):

Element	He	Ne	Ar	Kr	Xe
Multiplying factor	3.8	4.0	3.3	3.5	2.5

Expected to apply for ALL elements!

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*Thank you
for
your attention!*