Nier-Bernas ion sources program at IJCLab: ISOL beams

Workshop on R&D for new ISOL beams (SPIRAL 1 and ALTO)

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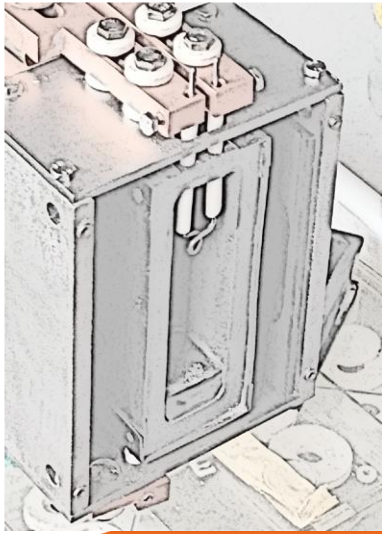
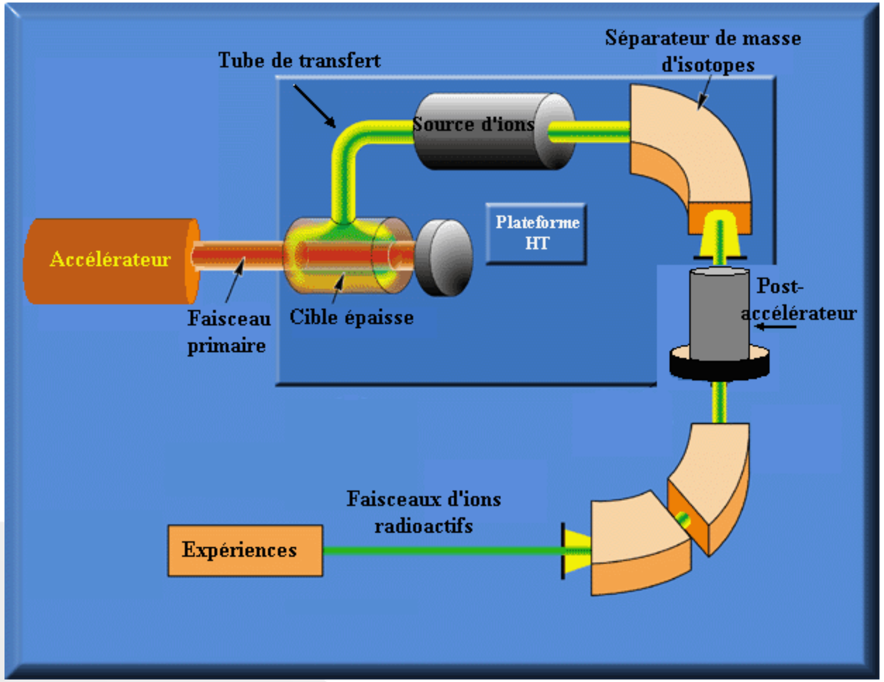


ISOL Technique

- ISOL method is an approved technique since ~70 years
- Allows to use thick targets
- Primary beam does not need to hit the ISOL target directly
- Nobel gases are very suitable for ISOL method

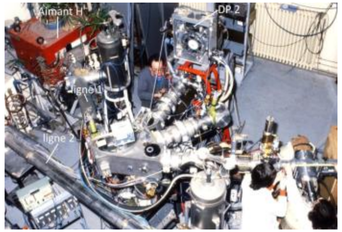
$$I = \Phi.\sigma.N.\varepsilon_{target}.\varepsilon_{source}.\varepsilon_{separ}.\varepsilon_{\det}$$



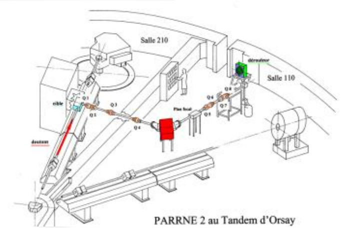
ISOL constraints: Selectivity + Rapidity

ISOL ion sources at Orsay (Legacy from the past and present)

1973



1998



2001

2020

ISOCELE 1&2 → **PARRNe 1&2** → **ISOL ALTO**

- Nielsen type ion source
- Nier-bernas ion source

1st Spectrometer closed to synchro-cyclotron
+
1st RIB experiement with online ISOL method in march 1974

- Nier-bernas ion source
- FEBIAD MK5 ion source at Orsay
- Surface ionization ion source

Pioneering *photofission experiment at CERN with the LEP injector*

- FEBIAD MK5 ion source
- Surface ionization ion source
- Laser ion source

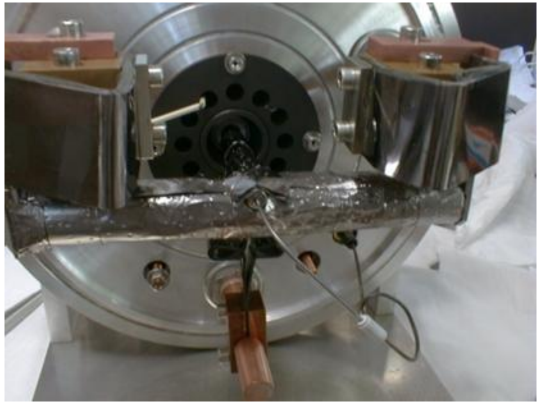
No universal ion source !

Common RIB ISOL ion sources

<u>Hot plasma source :</u>

(Isolde MK5 type)

Up to 30% for gaseous & condensable elements



<u>Surface ionization Source :</u>

(Isolde MK1 type)

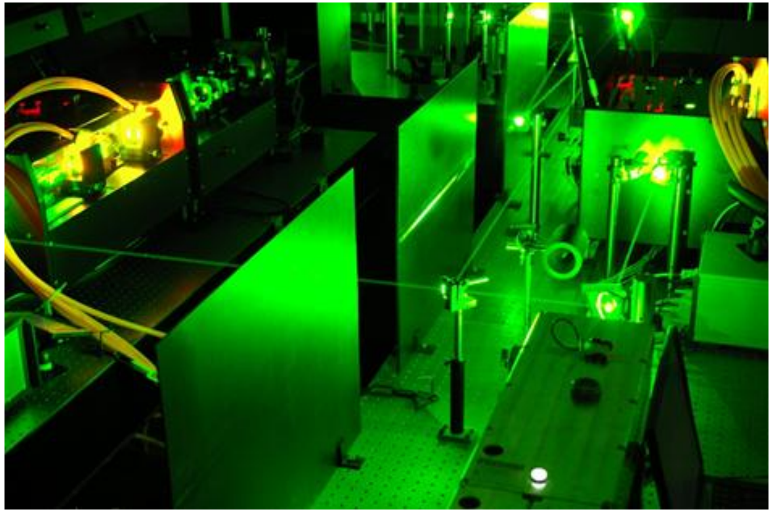
Suitable for $E_i \leq$ 6eV

<u>Laser Ion source:</u>

Maximum selectivity

Good efficiency if

F ≥10 kHz (~10%)



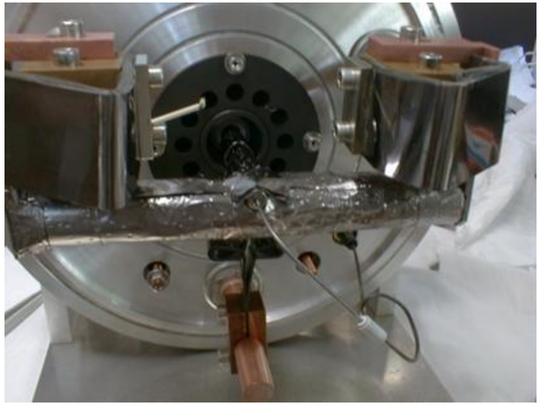
Surface ionization Source :

$<1\ \mu A/mm^2$

(10 – 20 π mm mrad)

(< 2 eV)

FEBIAD ion source:



$< 20\ \mu A/mm^2$

(< 20 π mm mrad)

(few eV)

Nier-Bernas ion source:

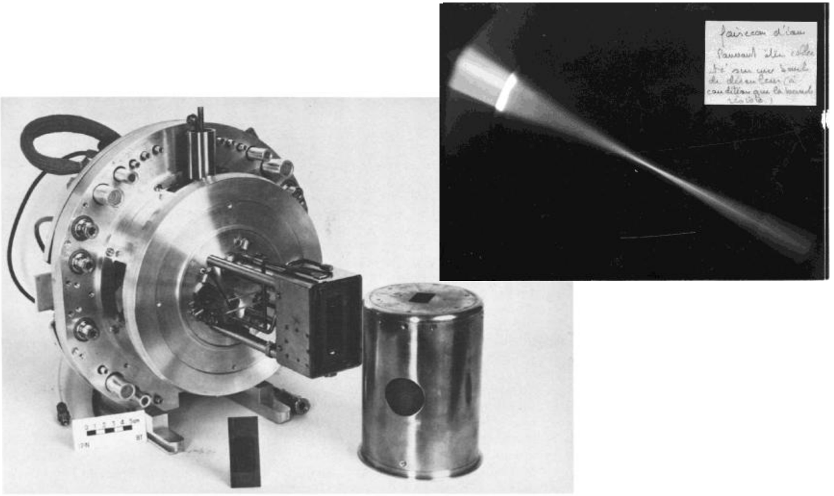


Fig 2 ISOCELE 2 ion-source

$< 5\ mA/mm^2$

(< 20 π mm mrad)

(few eV)

Focus on FEBIAD and Electron Impact Ion Sources

- Efficiency : (20-70% for the elements above Ne)

Nier-Bernas (~mA range)

- Threshold pressure of 10^{-3} to 10^{-2} mbar
- Efficient ionization of gaseous and condensable elements
- Need of High intensity mass separator that handle space charge problems

Suitable

- When running molten targets or target materials with much intrinsic impurities at very high temperatures
- When using a molecular separation technique : Target consumption up to 1 g/hr + a high gas load from the target.

FEBIAD (~µA range)

- Threshhold Pressure 5.10^{-4} to 3.10^{-5} mbar
- Very efficient for elements heavier than Ar
- ionization efficiencies for these sources are high and widely pressure-independent
- Simple and economic low-intensity mass separator needed
- Not able to cope with high gas load → ionization efficiency is quenched

FEBIAD and Nier-Bernas problem with Light elements

1. Lower ionisation cross section

2. Shorter transit times through the ionising volume → ionization efficiency ↘

Particularly troublesome elements : C, N, O → their volatile molecular compounds CO, CO2, N2, O2 are very reactive in hot enclosures → cold-enclosure ECR sources

Negative ions with Nier-Bernas ion sources

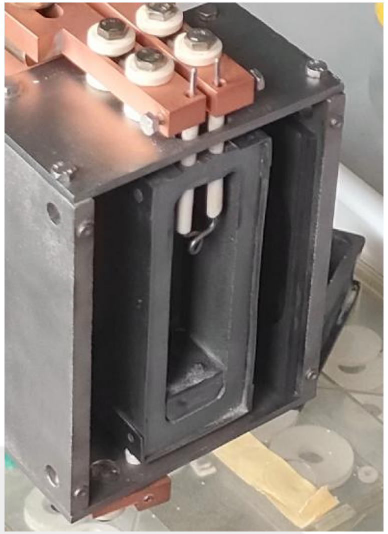
Successful proof of a concept : injection of suitable gases close to the exit slit.

TABLE 1

Observed intensities of negative ion beams obtained from a Bernas–Nier type source. Because of the limitations noted in the text, these currents are probably not the maximum obtainable.

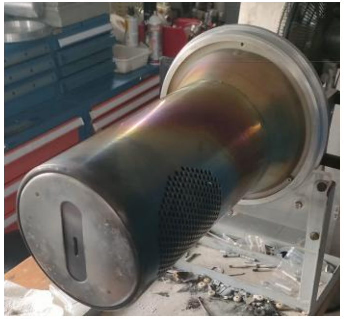
Ion	Gas	Current (μA)
C^-	CO	0.03
O^-	CO	1.05
N^{-a}	N_2	0.3
NH^-	N_2	0.007
$^{35}Cl^-$	CCl_4	12
$^{37}Cl^-$	CCl_4	4

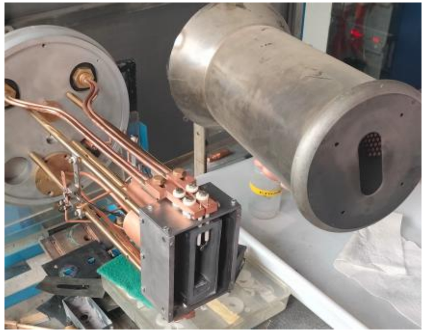
[a] Attributed to the ^1D state[2,3]).



J. Denimal *and al.* (NIM B. 109 (1973) 409.

Actual uses and developments





- ❑ Nier-Bernas ion source is already used at IJClab for ion implanter at the MOSAIC facility.

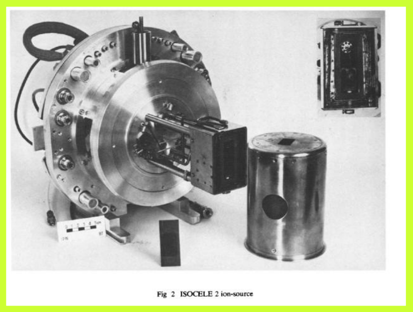
- ❑ Widely used in the fied of ion implanters and the semiconductor doping

→ Many ion source developments are achieved last years in these field[1]

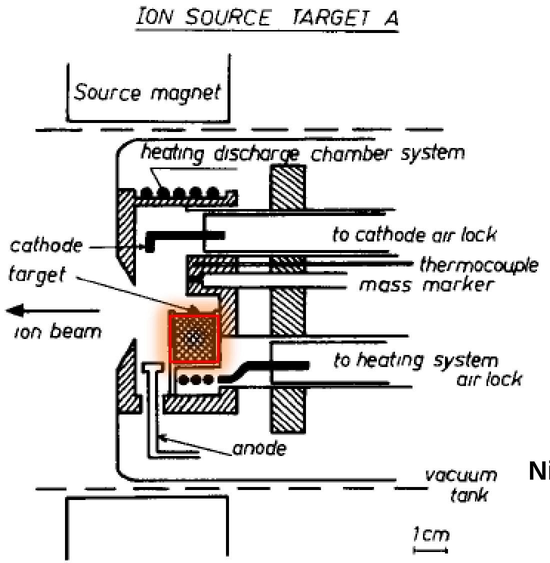
1 http://www.gursung.com/global/en/cont/2/2.php#n

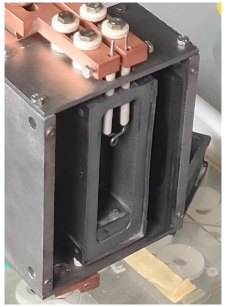
Nier-Bernas Ion Source at Orsay : ISOCELE schemes

ISOCELE concept:



Nier-Bernas ion source @ ISOCELE





Nier-Bernas arc chamber

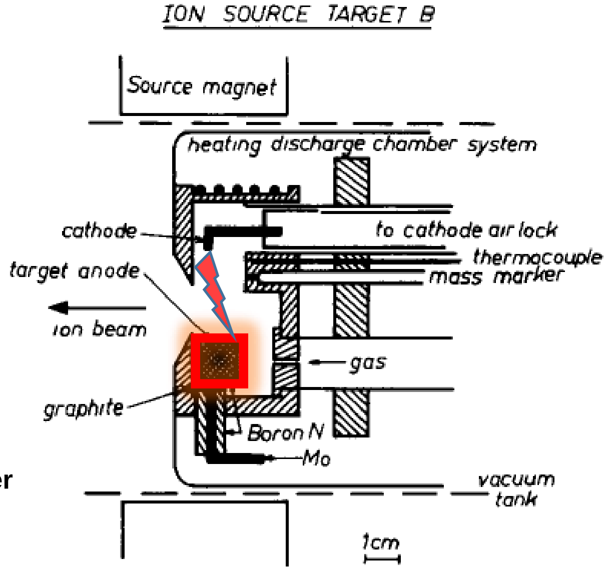


Fig 1 Schematic view of target–ion-source systems A – target behind the arc, B – target under the arc

Main technical features:

Target
- 2 target positions (behind / under the arc)
- High température volume for the target
- Most of release issues from conventional ISOL targets will be ruled out

Ion source
- Versatile plasma ion source
- High intensity ion source (~mA)
- Low beam emittance

Nier-Bernas Ion Source at Orsay : more exotic schemes

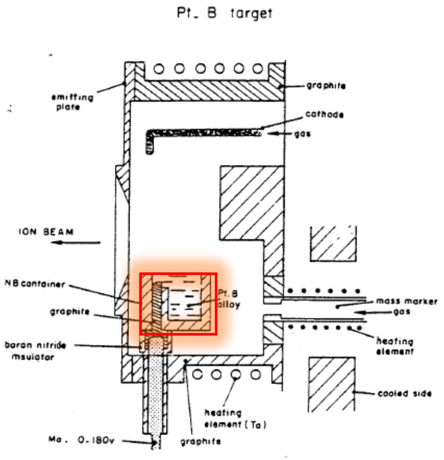


Fig. 5. Pt-B target ion-source arrangement.

- Target heated with arc discharge power (~100 v – ~2 A)
- Beam intensities :~ 1 – 2 mA

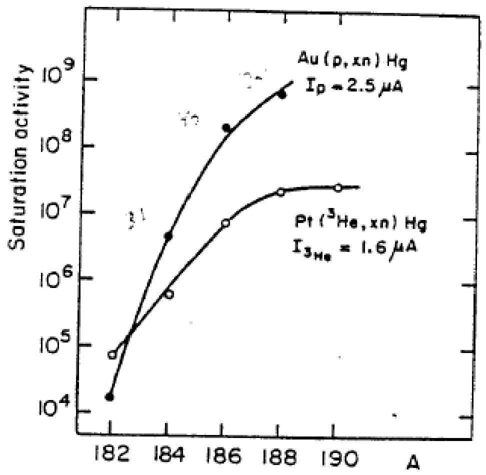


Fig. 4. Yields of Hg from Au and Pt-B targets.

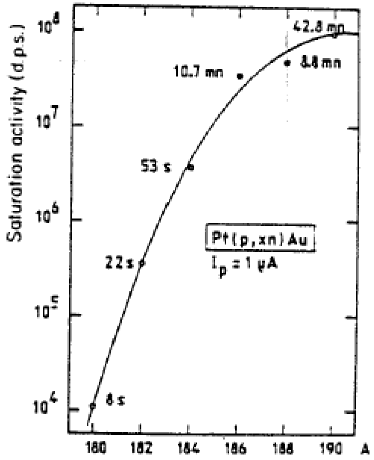
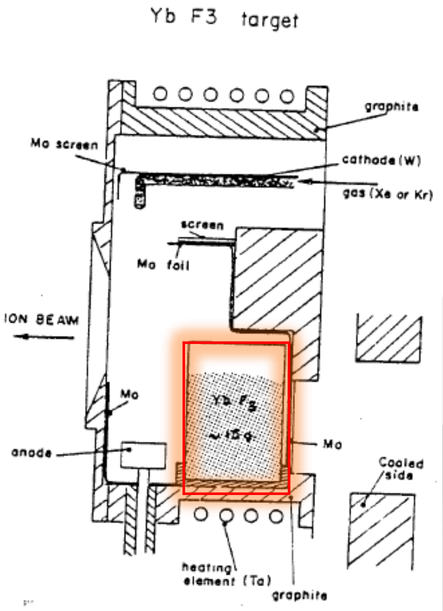


Fig. 6. Yields of Au from a Pt-B target.

^{3}He+Pt → Hg

P + Pt → Au

Nier-Bernas Ion Source at Orsay : more exotic schemes



$^3He + Yb \rightarrow Hf$

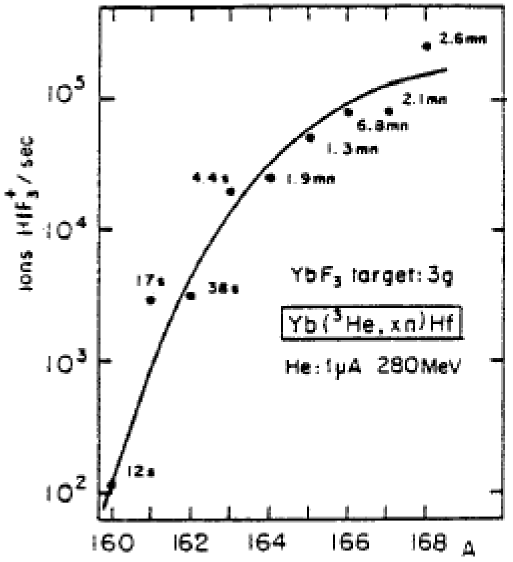
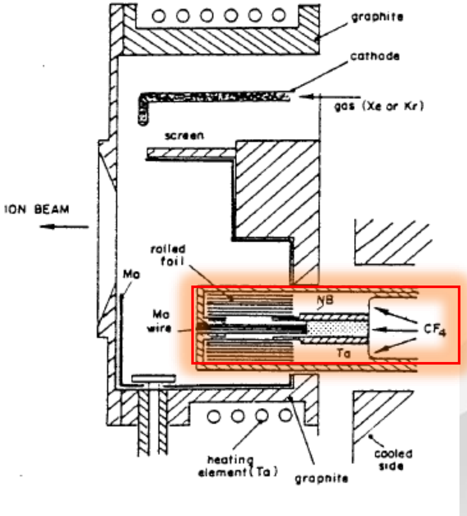


Fig. 12. Yields of Hf (HfF_3^+) from the YbF_3 target.

- Target slightly set back from the direction of the arc
- Solid way fluorination

Nier-Bernas Ion Source at Orsay : more exotic schemes



P / $^{3}He + Mo \rightarrow 33<Z<44$

- Mo target
- Target slightly set back from the direction of the arc
- Rolled sheets target
- gaseous way fluorination

Table II. Boiling points of elements (36 < Z < 42) and of their most volatile fluoride.

Element	Kr	Rb	Sr	Y	Zr	Nb	Mo
Oxidation number		1	2	3	4	5,3	6-2
Boiling point °C	-152	688	1384	3338	4377	4742	4612
Fluoride the most volatile		RbF	SrF_2	YF_3	ZrF_4	NbF_5	MoF_6
Boiling point °C		1410	2489	1387	~600*	236	35

*Sublimation point.

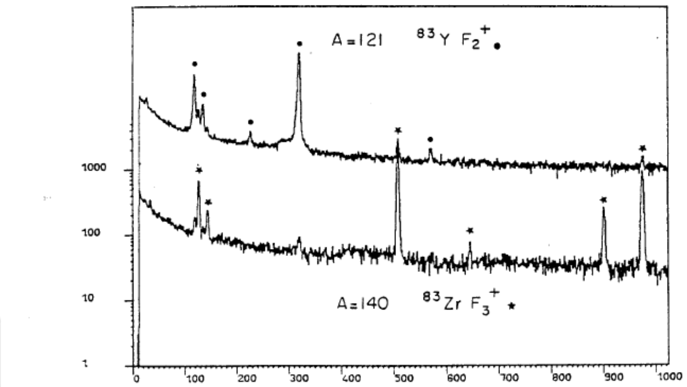


Fig. 10. Comparison of γ spectra for ZrF_3^+ (A = 140) and YF_2^+ (A = 121), separation of the isobars Zr and Y of the chain 83 can be seen.

Nier-Bernas Ion Source at Orsay : more exotic schemes

Xe production with an outsided taregt (NaI or CsI)

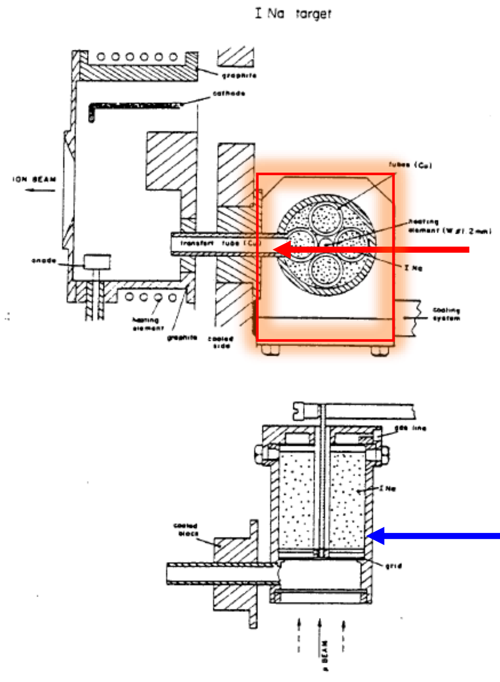


Fig. 7. NaI (or CsI) target ion-source arrangement.

Carrier gas used to accelerate the transfer of Xe to the ionization chamber

Outsided and cooled target

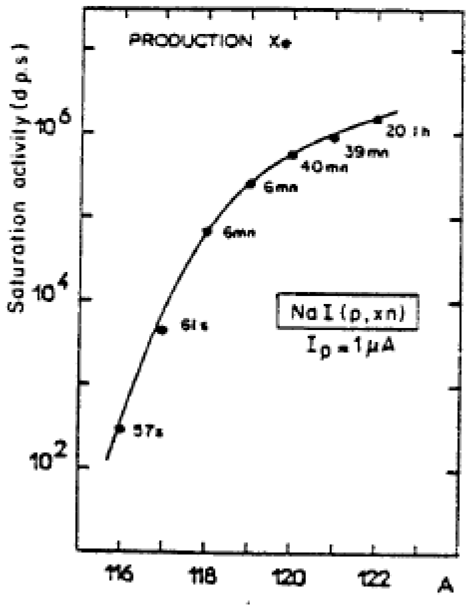


Fig. 8. Yields of Xe from a NaI target.

P + I→ Xe

Nier-Bernas Ion Source → ISOCELE achived beams

Achieved targets/beams

Not less than 31 combinations tested with ISOCELE Nier-Bernas Ion source!

Target	SC beam	Extracted elements		
Ni	^3He	Cu, Zn		
Ge	^3He	Zn, Ga		
Ag	^3He	In, Cd		
Sn	α,p,^3He	Te, Sb, In, Cd		
Pr	p	Nd		
Nd	^3He	Sm		
Gd-Cu	^3He	Dy, Eu, Sm, Pm		
Tb	p,^3He	Ho, Dy, Eu, Sm		
Er-Cu	p	Tm, Ho, Dy		
Pt-B	p,^3He	Au, Hg		
Au	p,^3He	Hg, Tl		
La	p,^3He	La, Ba, Cs		isobar separation using CF_4
Ce	p,^3He	La, Ba, Cs		isobar separation using CF_4
YbF	^3He	Hf	powder	isobar separation using CF_4
SrF_2	^3He	Zr, Y, Rb	powder	isobar separation using CF_4
YF_3	^3He	Zr, Sr, Rb	powder	isobar separation using CF_4
Y	^3He	Y, Sr, Rb		isobar separation using CF_4
LuF_3	^3He	Ta, Hf	powder	isobar separation using CF_4
Mo	^3He	Nb, Zr, Y, Sr, Rb	rolled foil	isobar separation using CF_4
W	^3He	Ta, W, Hf	rolled foil	isobar separation using CF_4
TeO_2	^3He	Xe	powder	
NaI	p	Xe	powder	
CsI	p	Xe	powder	
Bi	p	Po		

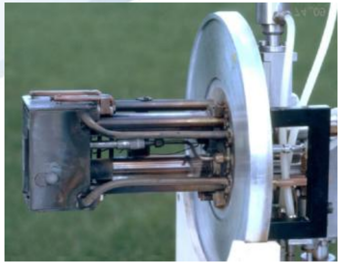
Nier-Bernas Ion Source for ISOL beams at IJCLab

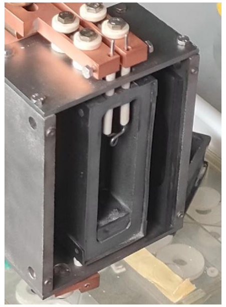
Main advantages :

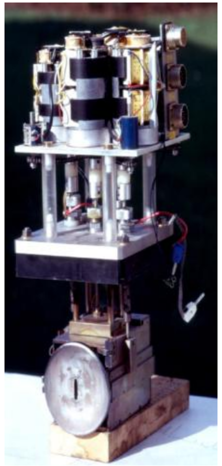
- High current intensity
- High pressure operating regime
- Good capability of handling molecular beams
- Target in the ionization volume…

- Nier-Bernas Develpopements At IJCLab
  - TIS for ISOL RIB
    - Radioisotopes (CERN-MEDICIS)
    - ISOL facilities
  - TIS for MNT reactions
    - NEWGAIN

Nier-Bernas Ion Source for ISOL beams at IJCLab

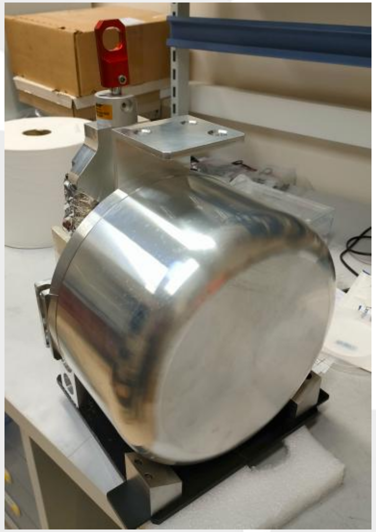




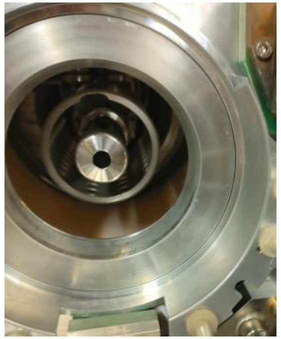


Extraction : slit shape + 4 directions

TIS for ISOL RIB

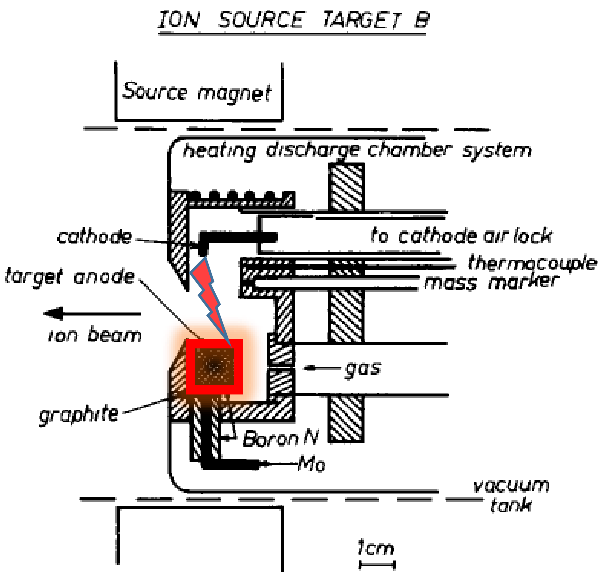


ISOLDE target vacuum chamber



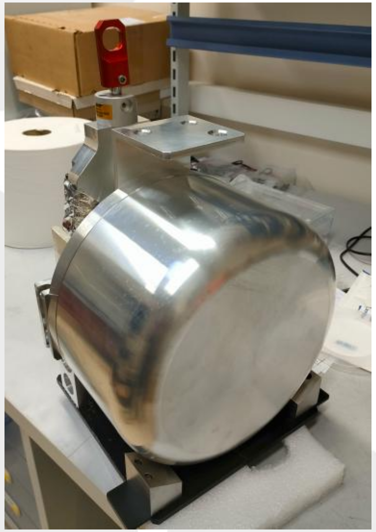
Extraction : hole shape + 1 directions

Nier-Bernas Ion Source for ISOL beams at IJCLab



A – target behind the arc, B – target under the arc

TIS for MNT reactions



ISOLDE target vacuum chamber

Or other design...

New ISOL ion sources test bench @ IJCLab

Gray room: assembly of prototypes

Thermal test bench: thermal measurments (16 sensors + pyrometer) and filament developments.

→ Commissioning in progress