Activity of WP2 Isotope

Ezio Previtali
(INFN Milano Bicocca)

Summary of the WP2 activities

WP2: Isotope production and purification

Objectives in terms of isotope procurements, pre-screening and purification are:

1. Identification of the possible producers
2. Study of the enrichments techniques
3. Preparation of small samples
4. Characterization of enriched samples (level of enrichment, chemical impurities)
5. Development of procedures for the purification of enriched samples and source production

Isotope Separation

Enrichment in double beta decay experiments will produce a net increase in sensitivity:

$$S\left(\tau^{0\nu}_{1/2}\right) \propto \epsilon \cdot \frac{a.i.}{A} \sqrt{\frac{M\, t_{meas}}{\Delta E \cdot bkg}}$$

- **detector efficiency** (ϵ)
- **isotopic abundance** ($a.i.$), atomic number (A)
- **detector mass** [kg] (M)
- **measuring time** [y] (t_{meas})
- **energy resolution** [keV] (ΔE)
- **background** [c/keV/y/kg] (bkg)

Te120	Te121	Te122	Te123	Te124	Te125	Te126	Te127	Te128	Te129	Te130
	16.78 d		1E+13 y				9.35 h	2.2E24 y	69.6 m	7.9E20 y
0+	1/2+	0+	1/2+	0+	1/2+	0+	3/2+	0+	3/2+	0+
	*		*		*		*		*	
	EC		EC				β-	β-β-	β-	β-
0.096		2.603	0.908	4.816	7.139	18.95		31.69		33.80

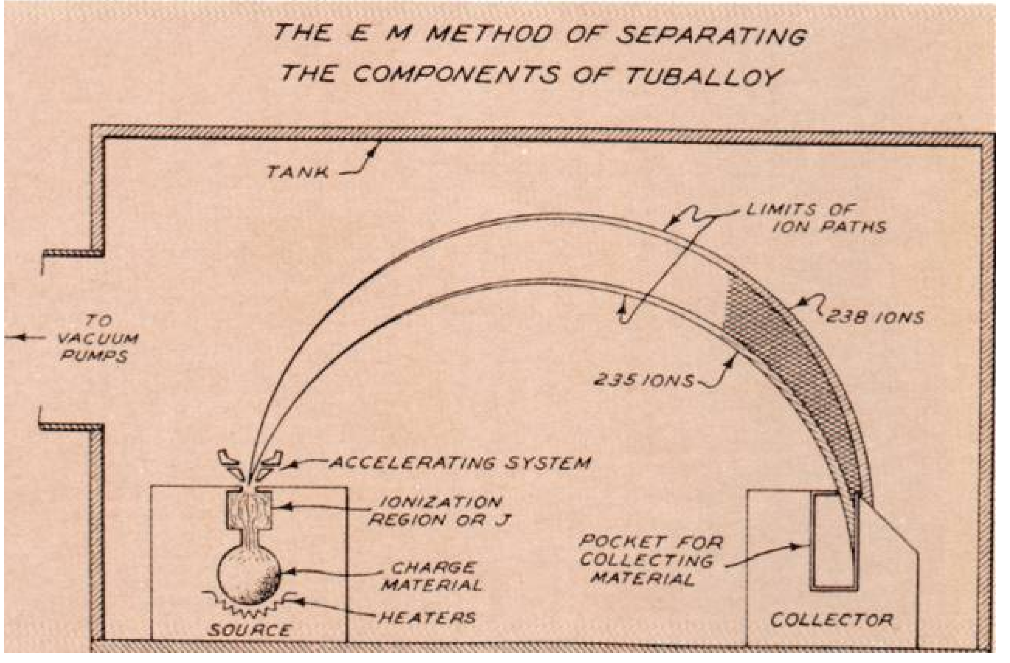
Non attivi doppio beta (Te120, Te122, Te123, Te124, Te125, Te126)

Doppio beta attivi (Te128, Te130)

Isotopical enrichment techniques (1)

Electromagnetic Separation: Calutron

Fundamentally is a mass spectrometer but:
- high current, up to 100 mA
- high separation capabilities
- very flexible
- low production efficiency
- high production cost



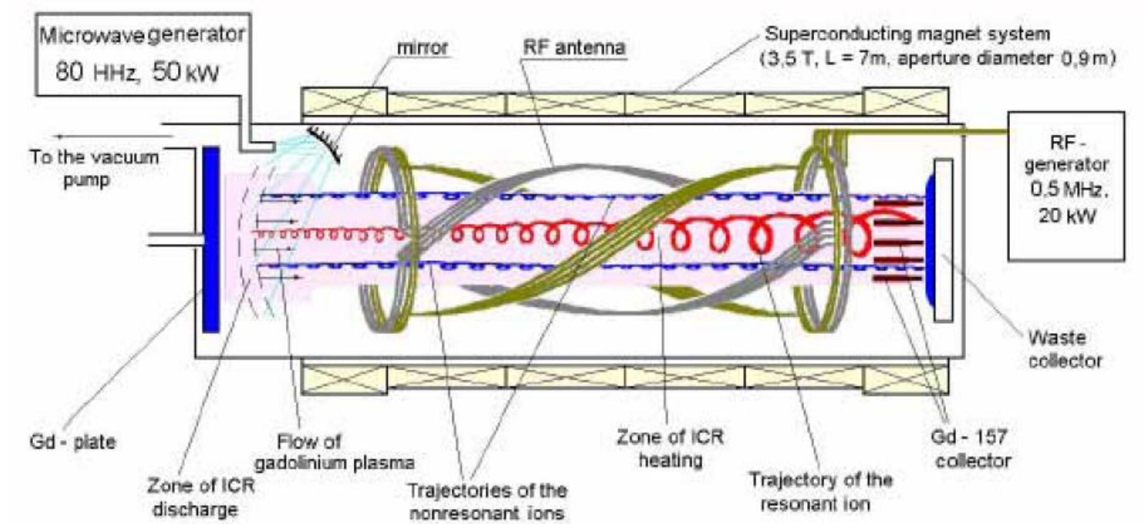
Schematic drawing E.O. Lawrence

Isotopical enrichment techniques (2)

Electromagnetic Separation: Plasma Ion-Cyclotron Resonance (ICR)

Ciclotron Resonance shows:
- very high current, up to 100 A
- very good separation factor
- suitable for many isotopes
- very large production

MCIRI isotope separation system



$Q \approx 10$ kg/day

$I_{eq} \leq 100A$

Zone of homogeneous field

$B = 3{,}5$ T, $\frac{\Delta B}{B} \leq 3 \cdot 10^{-4}$

$l = 5$ m, diameter 0,5 m.

^{157}Gd (80%)	250 g/day
^{102}Pd (40%)	10 g/day
^{150}Nd (80%)	200 g/day
^{48}Ca (20%)	10 g/day

Isotopical enrichment techniques (3)

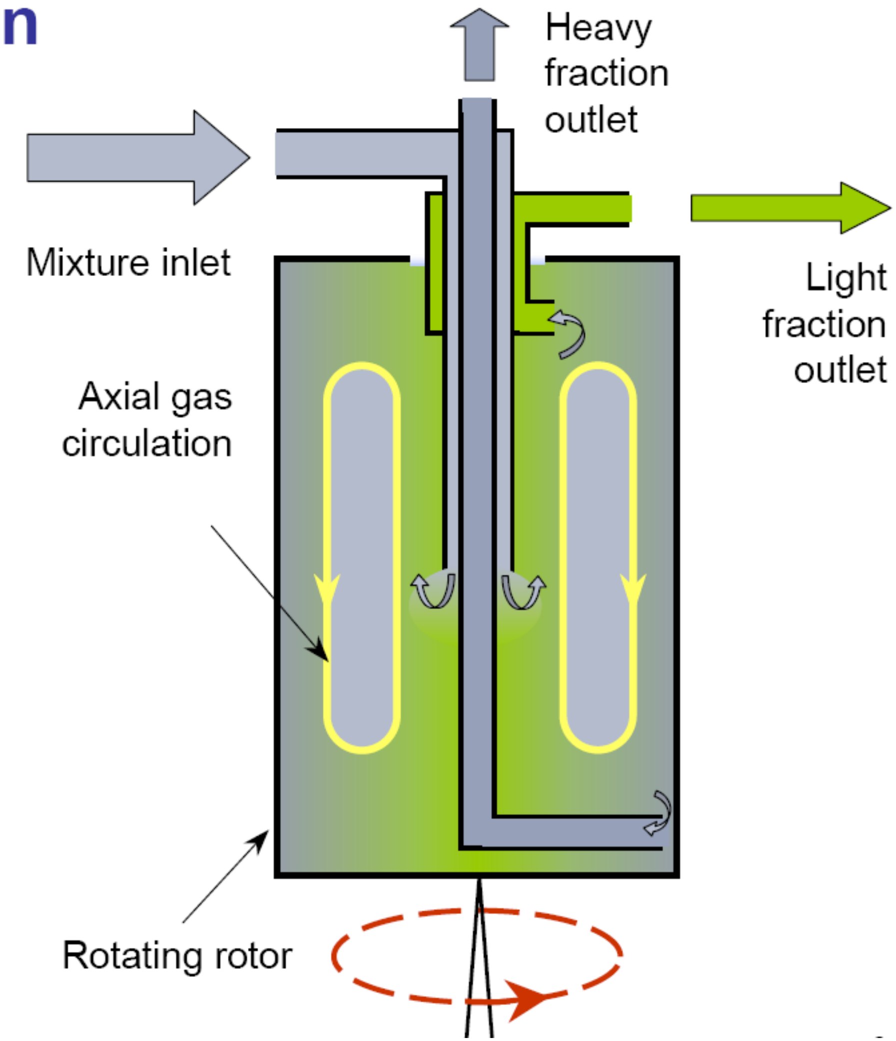
Principle of gas-centrifuge isotope separation

Centrifuge acceleration is up to **500 000 g.**
The gas is enriched with the heavy fraction ($^{238}UF_6$) on the periphery of the rotor cavity, and with the light fraction ($^{235}UF_6$) closer to the axis.
The separation factor, α_0, and the separation capacity limit of a counter-current centrifuge, δU,
(K. Cohen's formula, 1951) :

$$\alpha_0 = \exp\left(\frac{\sqrt{2\Delta M v^2}}{2RT}\frac{Z}{d}\right),$$

$$\delta U = D\rho\left(\frac{\Delta M}{2RT}\right)^2 v^4 Z$$

Z, d are the rotor length and diameter, accordingly
D is the gas diffusion factor,
ρ is the gas density



Isotopical enrichment techniques (4)

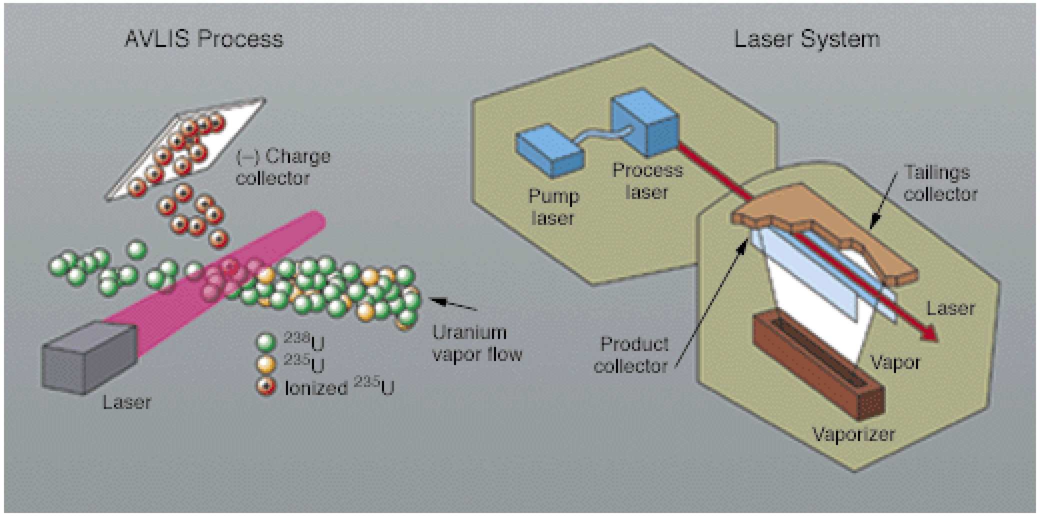
Isotope separation with lasers:

AVLIS – Atomic Vapor Laser Isotope Separation

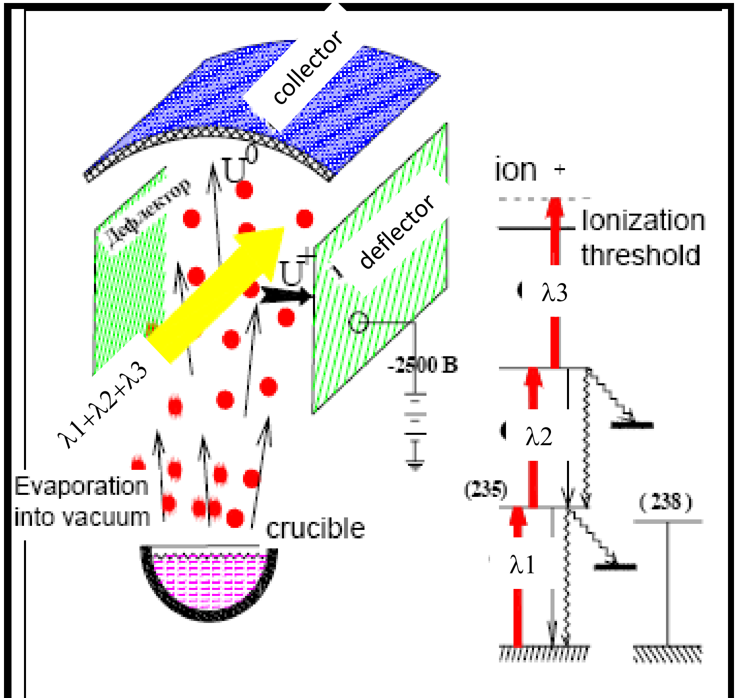
MLIS – Molecular Laser Isotope Separation

Isotopes of the same element show different electron binding energy (optical shift)

Lasers tuned with corrected wavelength can ionize only the specific isotope



In the laser system used for the LIS uranium enrichment process (right), electrons from the ^{235}U atoms are separated (left), leaving positively charged ^{235}U ions that can be easily collected for use.



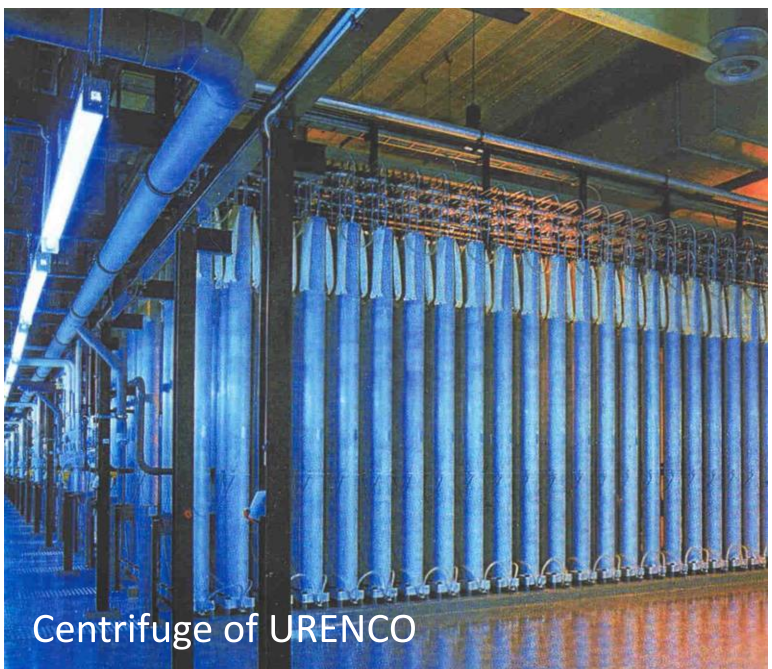
Flow-chart of selective multiphoton atom ionization

Comparison of enrichment methods

Method of selection	*Energy, eV/atom*	*Status*	*Productivity scale or capacity of prototype*	*Scale of price (approximately)*	*Special requirements*
Electromagnetic (mass-spectrometric)	$10^{6 \div 7}$	Commercial	~100 g per year	high	—
Gas diffusion	$3{\cdot}10^{6}$	Industrial	> tons per year	Medium	Gas compound
Gas nozzle	10^{6}	Industrial	> tons per year	Medium	Gas compound
Gas centrifuge	$3{\cdot}10^{5}$	Industrial	> tons per year	Low	Gas compound
Rectification	10^{3}	Industrial	> tons per year	Low	Light elements
Isotope exchange	10^{2}	Industrial	> tons per year	Low	Light elements
ICR	10^{3}	R&D	~100 kg per year	Medium	—
AVLIS/SILVA, laser efficiency ≈10%	10^{2}	R&D	>100 kg per year	Medium	—
MLIS, laser efficiency ≈10%	10^{2}	R&D	>100 kg per year	Medium	—

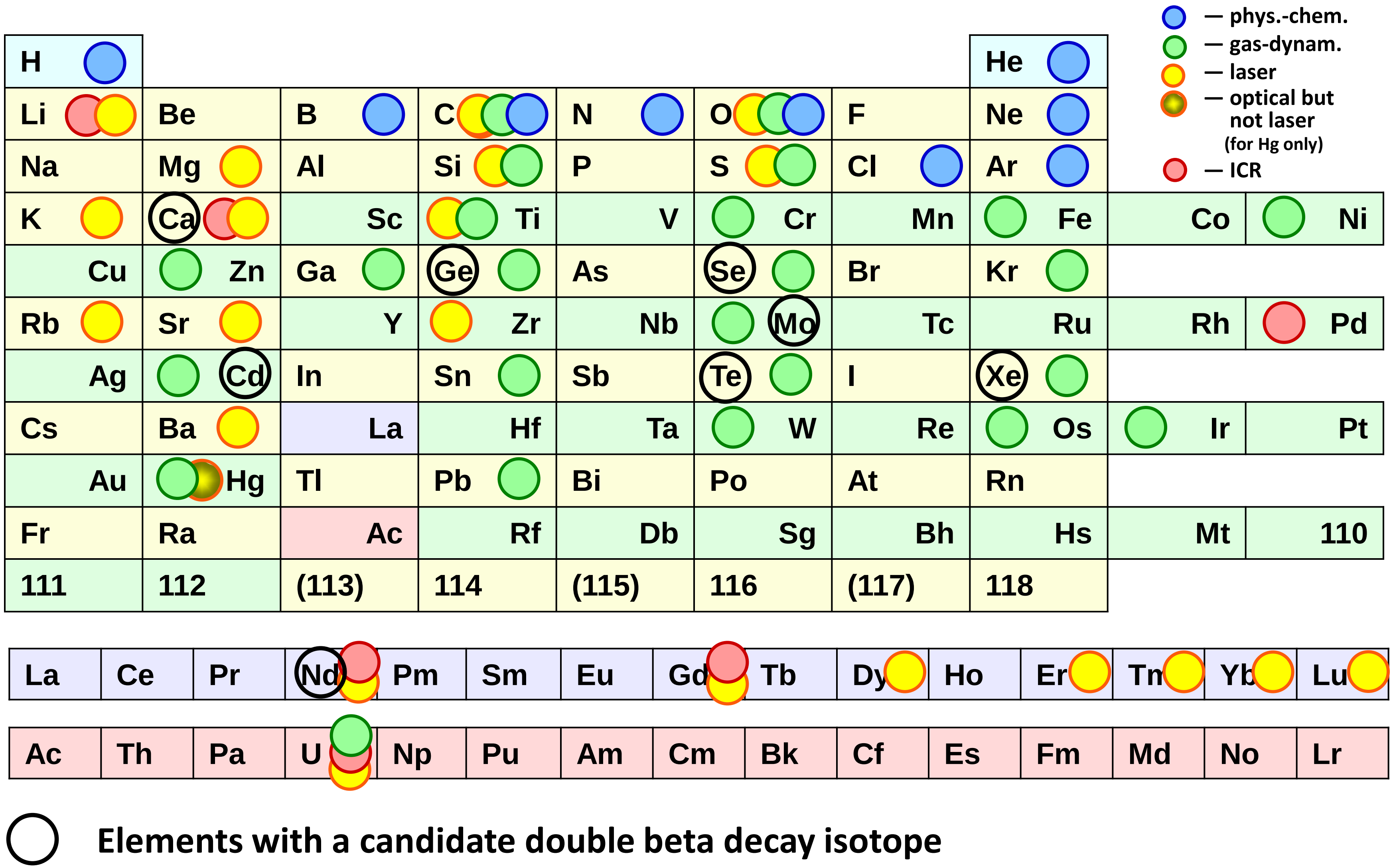

Centrifuges of USA


Ural Electrochemical Integrated Plant


Centrifuge of URENCO


Japanese centrifuges

Separation methods for various elements



Possible producers

USA: Calutron production was stopped in 2004
Medium size ICR machine founded by DOE is installed at Theragenics
production is oriented to medicine application
New program for AVLIS founded at Livermore (very expensive)
it is unclear if this program will be completed
Ultracentrifuges at Oak Ridge are in operation???

Russia: Few labs are able to produce isotopes with Ultracentrifuges
Only elements that have gas compounds can be produced
Production capabilities are relatively high
Prices of enriched isotopes are growing

Europe: URENCO co. have some Ultracentrifuge lines dedicated to stable isotopes
Production capabilities are few kg per year
Cost of productions are in the scale of 100 $/g
There are possibilities to restart some production plants

Korea: Kaery group is able to produce enriched isotopes
for ultracentrifuges the situation is similar to Europe
some R&D was made for AVLIS and ICR implementations

Production quality

Background will be very critical:
    "old" experiments had background in the range of 0.1 counts/(keV kg y)
    future experiments are going to the range of 0.001 counts/(keV kg y)

For some detectors also chemical purity is mandatory:
    impurities will prevent crystallization
    chemical contamination reduces light emission

After the separation processes with ultra centrifuges we normally have fluorides
To obtain metals or other molecules chemical processes are necessary
For some aspects this is the most critical point

Purification will be of primary importance and needs precisely evaluations
    technically and economically

WP2 possible strategy

1. **Identification of the possible producers**
    - Russian factories
    - URENCO
    - Kaery
2. **Study of the enrichments techniques**
    - Actually ultracentrifuges are the only reliable approach
      This imply that only elements with gaseous compound can be enriched
    - Great care must be dedicated at the chemical treatments after enrichment
3. **Preparation of small samples**
    - In case of small sample productions the costs are not negligible
    - We can use as test actual and past productions, with some problem on history
4. **Characterization of enriched samples (level of enrichment, chemical impurities)**
    - Measurements with ICP MS techniques can give us
        Level of enrichment
        Chemical contaminations
5. **Development of procedures for the purification of enriched samples and source production**
    - On small samples it is not straightforward the purification
    - Chemical and physical treatments have normally small efficiency with small samples

WP2 possible strategy

Quotation for the acquisition of small samples of ^{100}Mo

Isotope	Enrichment (%)	Form	Quantity	Unit	Price/Unit	Delivery	Total Price
Mo-100	97%+	metal powder	2000	mg	$1.20	3-4 weeks	$2,400.00
Mo-100	97%+	metal powder	5000	mg	$1.15	3-4 weeks	$5,750.00
Mo-100	97%+	metal powder	10000	mg	$1.00	3-4 weeks	$10,000.00
Mo-100	97%+	metal powder	20000	mg	$0.85	3-4 weeks	$17,000.00

With the actual budget it is very hard to buy 10 g of enriched materials
In any case we can have samples that are in stock, without a production characterization
With small masses we can perform the chemical and isotopical characterizations
It is very difficult to imagine a purification treatments on few grams of material
but we can use natural samples to simulate the purification

We can plan to extract information on such parameters on ongoing production
Information can be collected from previous enriched materials