Supply and installation of a magnet for the construction of a mass separator coupled with laser ionization at the SUBATECH laboratory in Nantes.

Project technical note

Project definition

1. Purpose of the consultation

This consultation concerns the supply and installation of a dipole magnet for a mass separator at the SUBATECH laboratory. It covers: the definition of the design, the supply of the magnet, power supply, vacuum chamber, installation, commissioning and user training in the technology.
The cooling system, vacuum system, field and vacuum control instruments are offered as possible additional services, as well as a preventive and corrective maintenance proposal.
This magnet must be delivered by the end of 2027 due to constraints related to its financing from CPER and FEDER funds.

Place of delivery: SUBATECH Laboratory, 4 Rue Alfred Kastler, 44307 Nantes Cedex 3

2. Presentation of the SUBATECH laboratory and the PRISMA team

The SUBATECH laboratory is a joint research unit (UMR 6457) under the supervision of three organisations: the Institut Mines Télécom through its IMT Atlantique school, Nantes University, and the CNRS with the National Institute of Nuclear Physics and Particle Physics (IN2P3). The SUBATECH laboratory is based on the IMT Atlantique campus in Nantes. The laboratory's activities focus on nuclear physics, hadronic physics, particle and astroparticle physics, and radiochemistry. SUBATECH conducts also research related to energy, environment, and health. The current consultation concerns the PRISMA (Physics of Radiation InteractionS with Matter and Applications) team, which focuses its fundamental and applied research on the interaction of radiation and particles with matter. Three areas with a strong societal impact are being studied: the production of innovative radionuclides for diagnosis and therapy, elementary and non-destructive analysis of materials and structures, and dosimetric studies for radiobiology and unconventional radiotherapy. This research is being conducted in collaboration with the ARRONAX public interest group.

3. Presentation of the SMILES project led by the PRISMA team

The SMILES project is funded under the State-Region Plan Contract (CPER 2021-2027) and led by IMT Atlantique. Its objective is to develop mass separation devices using electrostatic or magnetic fields coupled with selective laser ionization within the PRISMA team at the SUBATECH laboratory. While the 'Time of Flight' system, dedicated to analysis, uses an electric field that allows temporal separation of ions produced by selective laser ionization, the provided magnet will spatially separate the ions. These facilities will meet the needs for isotopic analysis of trace elements in the environment - a major challenge in determining their origin, assessing their impact and monitoring their migration (copper, radium, etc.) - and isotopic analysis, as well as research into separation and purification for the production of innovative radioisotopes for nuclear medicine (Cu 67, Sc 44, Sc 47, etc.). Finally, they will also enable the purification and enrichment of rare isotopes. The new facilities will be located in a dedicated building within the SUBATECH laboratory on IMT Atlantique campus.

4. Facility building

The building includes a room known as the ‘Laser Room’ for the laser ionization facility and a room known as the ‘Magnet Room’ (Figure 1) where the magnet will be installed. The latter will also house the ion source and the beam line (Figure 2). A window allows the laser beam to pass from the ‘Laser’ room to the ‘Magnet’ room. The maximum power supplied for the equipment in this building is 60kVA. The plan of the ‘Magnet’ room (Figure 2) shows the dimensions of the room, the devices around the magnet and the average radius of curvature envisaged for the magnet based on initial simulations carried out in the laboratory.

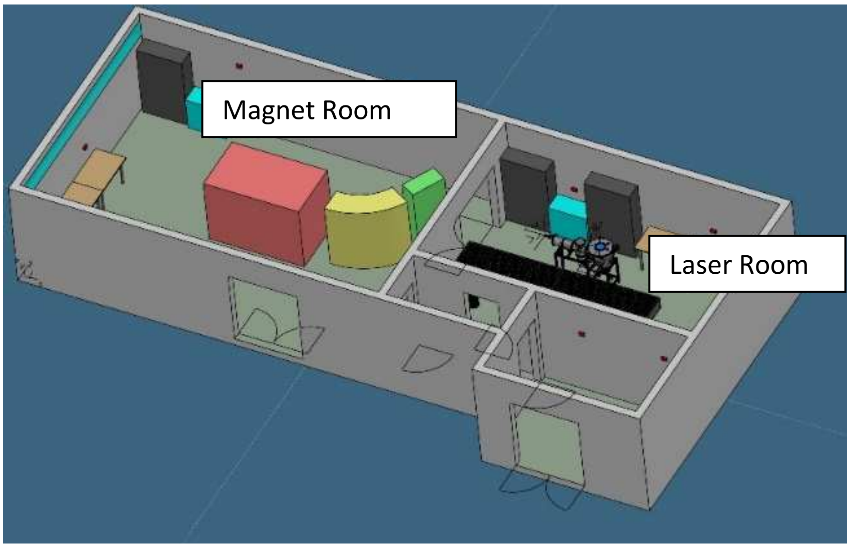

Figure 1: Buildings housing the facilities

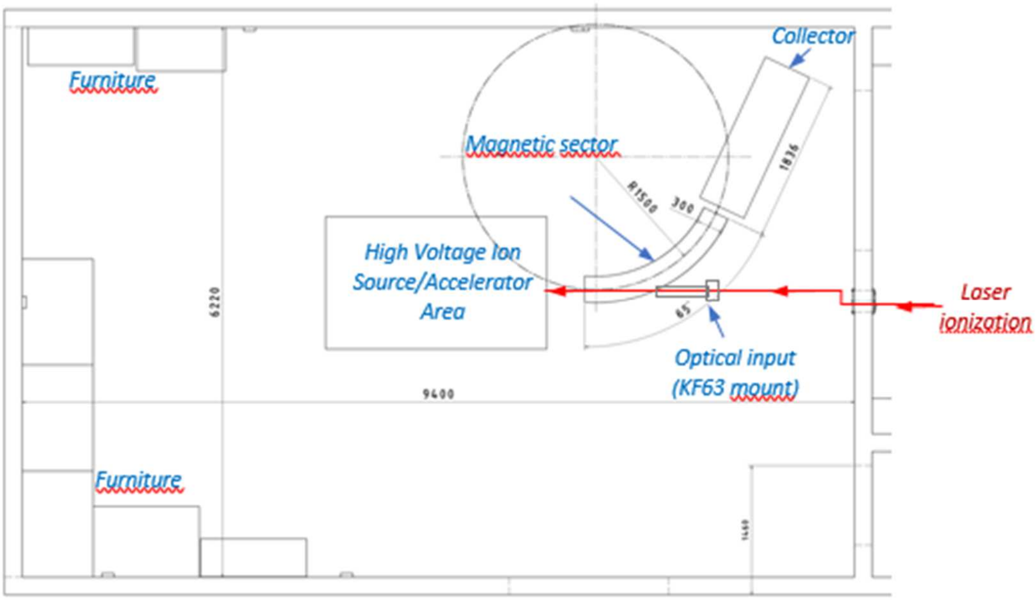

Figure 2: Dimensions in mm of the room housing the magnet with the different components

5. Magnet characteristics

The magnet will be used to spatially separate ions produced by selective laser ionization. An initial literature review and simulations using SIMION software were carried out to define the desired performance characteristics for the magnet. Similar devices, RISIKO in Mainz and ISOLDE and MEDICIS at CERN, served as models [1,2,3].

The pairs of ionic isotopes considered for establishing our models and performing these initial simulations are given in Table (1).

Isotopes	Masses [u]	m/Δm
Cuivre $^{63}Cu^{+}/^{65}Cu^{+}$	62.9295975 64.9277895	32
Radium $^{226}Ra^{+}/^{228}Ra^{+}$	226.025410 228.031070	113.2
Erbium $^{167}Er^{+}/^{168}Er^{+}$	166.932054 167.932376	167.4
Uranium $^{235}U^{+}/^{236}U^{+}$	235.043923 236.045568	235.2
Plutonium $^{241}Pu^{+}/^{242}Pu^{+}$	241.056852 242.058743	241.1

Table 1: Isotope pairs used for initial simulations to define the performance required for the magnet

The objective is to achieve 100% isotopic purity for each isotopes pair studied.

5.1 Magnetic sector geometry and notation

Various parameters used to describe and simulate a magnetic sector are listed below.

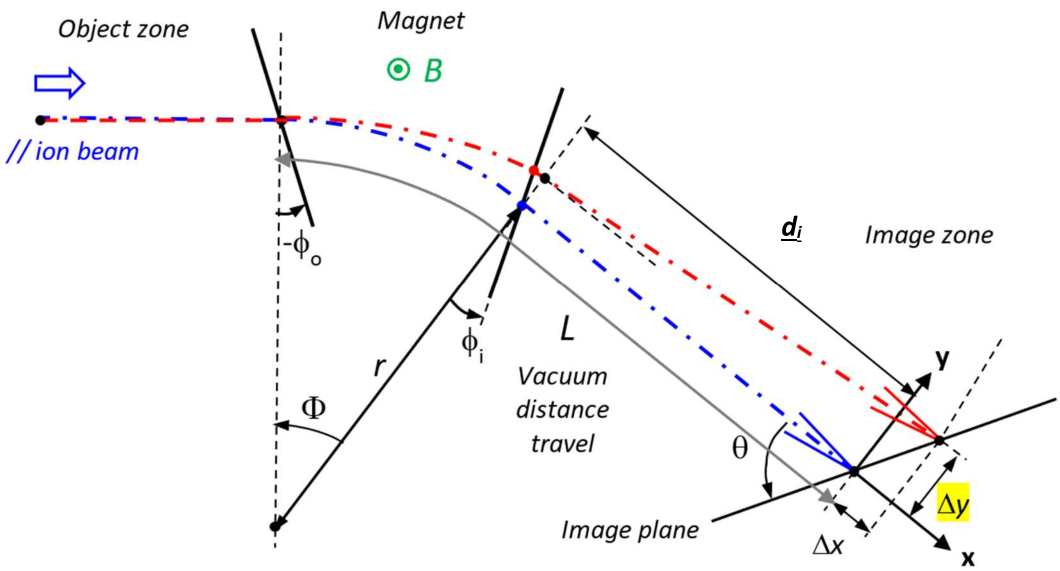

Figure 3: Magnet description parameters

B: magnetic field.
ϕ_o: entry angle (object area)
ϕ_i: exit angle (image area)
Φ: bending angle
r: bending radius
d_i : focal length at the image zone boundary: 'external focal length image zone'
L: ion path between the magnet entrance and the collection plane
θ: image plane angle
Δx: longitudinal separation
Δy: radial separation

5.2 Expression and desired value of radial separation

The radial separation between two isotopes (Figure 4) is written as **$\Delta y = D_m \frac{\Delta m}{m} \Delta y$**, where D_m is the radial dispersion coefficient expressed as:

$$D_m = \frac{1}{2}[(1-\cos(\Phi))r + (\sin(\Phi) + (1-\cos(\Phi))\tan(\phi_i))d_i] \cdot$$

Simulations were used to recalculate achieved values for existing infrastructure and define the required value for the desired magnet.

The chosen value for radial spatial separation must therefore be **Δy ≥ 6.2 mm**.

To achieve this value, the required mass dispersion coefficient Dm is such that **Dm ≥ 1500 mm**.

5.3 Average deflection radius and ion path length between the magnet inlet and the collection plane

According to the literature, Dm ≈ r.

Under these conditions, a suitable starting value for r is: r ≤ 1500 mm. However, any technical solution that reduces this value while maintaining the desired dispersion coefficient Dm ≥ 1500 mm would be acceptable.

5.4 Required magnetic field

The magnetic field values B, were calculated for an average deflection radius **r = 1500 mm**, setting the maximum ion energy at **60 keV** (energy supplied by the ion source accelerating electrode) for $^{242}PuO^{+}$ ions.

Thus, according to these calculations, the peak field value B is set at B = 0.4 T.

The good field zone is defined as the zone in which the field meets a homogeneity criterion relative to its nominal value, i.e.:

(By(x,y) - By(0,0)) / By(0,0) < 0.01% for dipoles whose field is along the vertical y-axis.

Taking into account simulated beam emissivity, it corresponds to a rectangular area with dimensions between:

ΔX = 50 mm (horizontal) et ΔY = 25 mm (vertical).

The stability required for the power supply is that which enables a stable magnetic field to be achieved with an accuracy of **one-tenth or even one-hundredth of a mT**.

For the ramp, the requirements can be up to 0.2 mT/s. These scans are performed during each experiment to scan the samples prior to collection or analysis and to determine the presence of impurities.

The intensity is generally controlled in order to adjust the field strength.

5.5 Mechanical environment

The mechanical aperture, the junction to the beam line will have to be specified (figure 4 and 5). The flanges should be as large as possible whilst remaining compatible with the dimensions of the vacuum chamber. KF-type (polymer) seals are suitable for the flanges. For information, the dimensions of the inlet opening, based on the MEDICIS installation [2], are:

[Xo = 200 mm * Yo = 55mm].

Finally, as regards the passage of the laser beam through the magnet, the flange must be compatible with the height of the vacuum chamber.

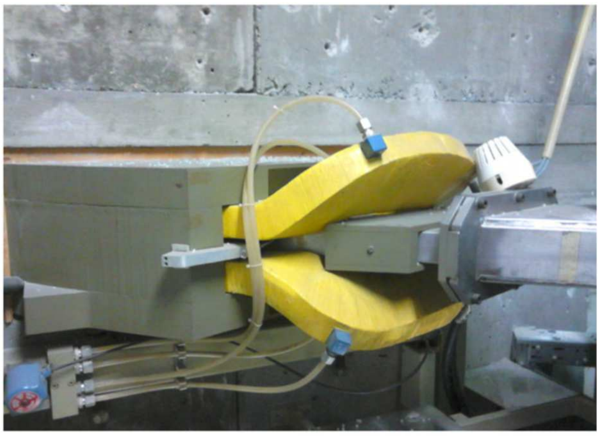

Figure 4: Medicis magnet aperture when it was in Leuven Laboratory [2]

Figure 5: Insertion of the magnet into the mass separator line (MEDICIS)

5.6 Summary of magnet characteristics

The mandatory specifications are:

1. Mass dispersion coefficient: D_m **≥ 1500 mm**
2. Bending radius: ***r* ≤ 1500 mm**
3. Magnetic field: ***B max* ≥ 0.40 T**
4. Good field zone along the y-axis defined by (By(x,y)-By(0,0))/By(0,0) < 0.01% at size:

   ΔX = 50 mm (horizontal) et ΔY = 25 mm (vertical)

5. A KF flange is required to allow the ionising laser beam (Figure 6) to enter along the axis of the accelerator. The flange must be compatible with the height of the vacuum chamber.

Figure 6: MEDICIS magnet with the window outlined in green

5.7 Results of simulations performed that correspond to the desired characteristics

Simulations performed in the laboratory yielded the following set of parameters that may meet the necessary characteristics for the magnet:

Paramètres	Valeurs Spécifiées	Unit	Explications
r	≤ 1.5	m	Bending radius
Dm	≥ 1.572	m	Mass dispersion coefficient
Δx	> 12.1	mm	Longitudinal separation $^{241-242}Pu^+$
Δy	> 6.5	mm	Radial separation $^{241-242}Pu^+$
Φ	65	°	Bending Angle
Φ_o	10.6	°	Object Tilt angle (entry angle)
Φ_i	30.1	°	Image Tilt angle (exit angle)
θ	28.3	°	Angle plan image
L	< 3.54	m	Image focale lenght **(to minimize)**
g	55	mm	Gap
p	200	mm	Pole width
ΔX	50	mm	Good field zone (horizontal)
ΔZ	25	mm	Zone verticale de bon champ
B homogeneity	> 10^{-5}	-	Within the good field area
Peak field	> 0.40	T	With precision at tenth to hundredth of mT
Field integral	0.70903	T·m	Field integral
Ramping speed	0.0002	T/s	
Vacuum requirement	10^{-7}	mbar	Vacuum requirement

Table 3: Required specifications for the magnet

6. Implementation schedule

The design must meet the above specifications. The schedule below is provided for information purposes. (Table 3)

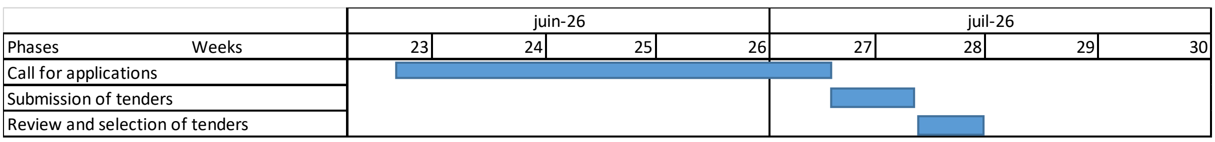

Table 3: Provisional schedule for call of tenders with the various stages

The magnet must be delivered by the end of 2027. Staff training could be carried out until the first quarter of 2028.

7. Offer evaluation

Offers will be evaluated using a points system.

Various weighted criteria will be considered: price (40%), delivery times (20%), technical content of proposals (30%), environmental criteria (10%).

For the price, the supply of the magnet and its equipment, including transport and commissioning, will be taken into account.

For delivery times, given that the magnet must be installed before the end of 2027, the delivery deadline is set at 30 November 2027. The offer with the shortest and most realistic delivery time will receive the maximum score for this criterion. The delivery deadline is fixed and must be respected by the supplier.

With regard to the technical solution, the following criteria will be evaluated:

- Magnetic design in compliance with characteristics set out in paragraphs 5.6 and 5.7;
- Mechanical design (overall geometric dimensions, fastening of the various parts) in compliance with the characteristics of paragraphs 5.6 and 5.7;
- Installation solution for the vacuum chamber when the magnet is positioned in the mass separator line;
- Power loss;
- Electrical connection and water connection;
- Manufacturing process.

Finally, the environmental criteria will take into account the device's electricity and water consumption, the construction materials, and the possible modes of transport envisaged that are the least costly from an environmental point of view.

[1] The CERN-MEDICIS Isotope Separator Beamline, Yisel Martinez Palenzuela et al, Frontiers in Medicine, *September 2021 | Volume 8 | Article 689281*
[2] Characterization and optimization of a versatile laser and electron-impact ion source for radioactive ion beam production at ISOLDE and MEDICIS*, Yisel Martinez Palenzuela et al, CERN-THESIS-2019-032*
[3] Implementierung der Laserionenquellenfalle LIST bei ISOLDE und Validierung der Spezifikationen Effizienz und Selektivitat, Sven Richter, Dissertation zur Erlangung des Grades Doktor der Naturwissenschaften, *Institut fûr Physik Johannes Gutenberg Universitat Maiz Deutchland, April 2015*