High intensity ISOL ion source for long-term irradiation

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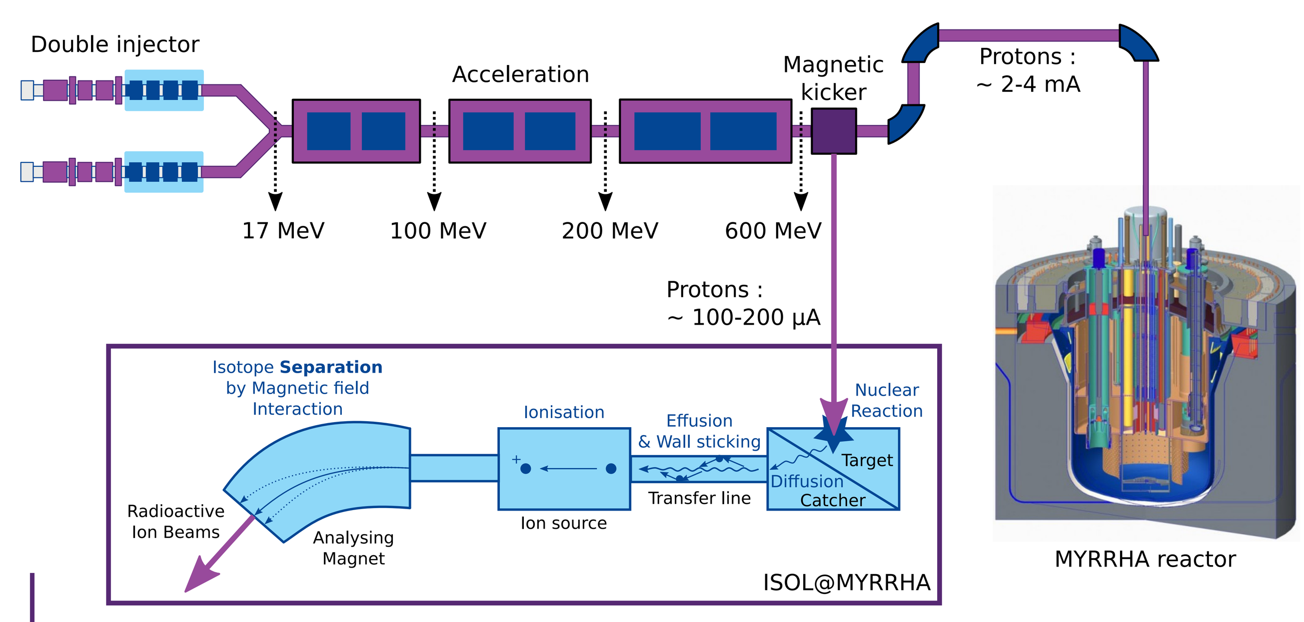
Introduction

Isotope Separation On-Line (ISOL) is an isotope production technique looking at short-lived isotopes, down to millisecond half-lives. This system couple the production, extraction, purification and transport of the desired radioisotope into a single installation. We want to apply this scientific tool to other scientific domains inside **ISOL@MYRRHA**.

The **MYRRHA** project (Multi-purpose hYbrid Research Reactor for High-tech Applications) is the first prototype of a subcritical lead-bismuth cooled reactors driven by a particle accelerator (∼ 100-600 MeV proton). In parallel to the reactor, **ISOL@MYRRHA** will extract part of the proton beam coming from the accelerator and use it to produce Radioactive Ion Beams (RIBs) for experiments which require **long beam times without interruption**, **high-precision measurements** or to perform experiments which **hunt very rare phenomena**. Those experiments have different needs as already existing ISOL: an **isotope production increase** by using **higher intensity beams** on a **longer period** of time **without losing the radioisotope beam quality**.
One part of this ISOL system, which will be affected by this higher input, will be the ion source, and we will need to **create an ion source adapted** to this new input before the start of the new accelerator at SCK-CEN.



Objectives

How can we build an ion source inside an ISOL system which can sustain a high intensity irradiation and high atom influx on long-term irradiation without losing secondary beam quality? And what requirements this ion source will need to have?:

Have higher total efficiency, if possible, or same efficiency as already existing ion sources at lower intensities

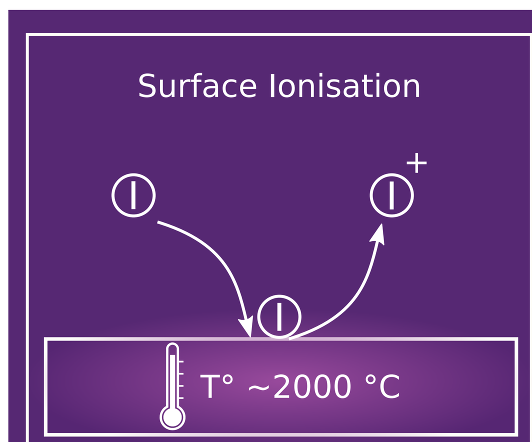
Sustain hard conditions: **High temperature** (around 2000°C) & **Thermal cycling** (Heating & Cooling period several times)

Sustain hard conditions: **High irradiation** and **High input atom influx** (Need to deal with saturation problems)

Keep a good beam quality output: **Good beam emittance**, **High intensity output beam**, **High purity**. If possible, ionise selectively the desired isotopes, or have a beam quality that allows easy separation.

Methods

There are multiple ways to ionise atoms, but for this application we will focus first our research on **Surface Ionisation** physical mechanism and the **Surface Ion Source [SIS]** related to it. We choose this source because it is **reliable** and usually of a **simple design**. Then, we will find ways to improve its performance.

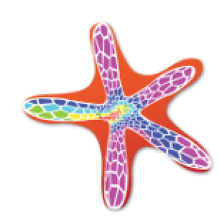


When an isotope interacts with a heated surface, it can lose or gain an electron before leaving the surface.

This interaction depends on the properties of the:
- **Ionise elements**:
  - Electronic structure, so its ionisation potential
- **Surface material**:
  - Temperature
  - Work function φ (= energy needed to remove an electron from a solid to a point in the vacuum)

To **identify the relevant parameters** which will affect our ion source at higher intensity, we need to understand through **theoretical studies** and **numerical simulation analysis** how those parameters affect the **output parameters**, like the total efficiency.

With **Thermal-Electric simulations**, we will estimate T° and electric ($\bar{E}$) conditions inside the cavity using **ANSYS** [1], an engineering software for structural mechanics, electrical & thermal modelling.



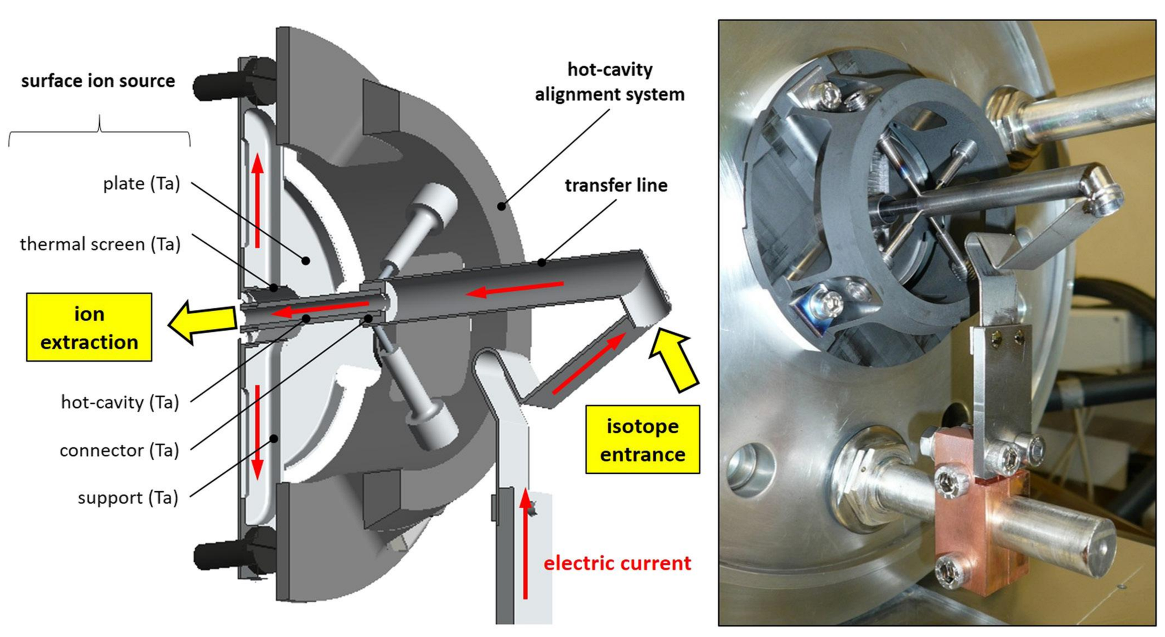
With **Plasma simulations**, and the cavity T° and electric ($\bar{E}$) conditions coming from ANSYS results, we will estimate plasma parameters inside the cavity: like ion n_i, electron n_e, and neutral n_0 densities, or plasma potential Φ.

Using **Starfish** [4], a 2D (Cartesian or axisymmetric) code which simulates a wide range of plasma, it implements an ElectroStatic Particle-in-Cell (ES-PIC) method: PIC is a technique used to solve a certain class of partial differential equations. We will **model the RIB-formation process inside the ion source**: interaction with neutral background, extraction and ionisation processes.

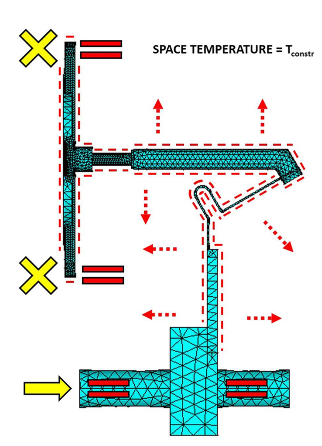
Results & Discussion

How can we improve this ion source? Improvement ideas:
- **Increase cavity volume** to avoid the space charge saturation or **Increase cavity surface** to increase ionisation
- **Change the cavities size** (length, diameter, thickness) or **Change cavities inner form** (circular, hexagonal, ...) for a better surface/volume ratio, or **Increase ion source exit surface orifice** for better ion extractions
- **Improve temperature homogeneity** to avoid cold spots and so neutral or ion accumulation, or **Increase cavity temperature** to increase the wall collision
- **Adding an Electric or a Magnetic field** inside the cavity to improve ion extraction and reduce space charge saturation

Those ideas will be assessed through simulation first, then through an experimental test. But, to start our simulation, we need first to validate our model and simulation condition with already existing experimental results. That why we tried, as a starting point, to **reproduce the results coming from the heating system** of an ion sources & its transfer-line from a study [3] from the Selective Production of Exotic Species (SPES) project at Legnaro National Laboratories (LNL).



The electrical clamp is copper, the rest of the heating system is **tantalum** which has good properties for surface ion source: High work function (φ=4.19 eV), High melting point (∼ 3000 °C).



Applied load and constraints:
- **Temperature** T_{constr} = 25°C,
- **Radiation emissivity** $\epsilon_{T\alpha}$(T°C) of tantalum depends on the temperature,
- **Voltage constraint** at 0 V,
- **Current load** at 380 A, 350 A, 300 A and 250 A.

Our model and SPES ANSYS results are close, except for the connection part between the ionizer and the transfer line. But, at this point, we have no experimental result, so we cannot say which one of the ANSYS models will be closer to the reality. For the other experimental points, our model agrees correctly to experimental results.

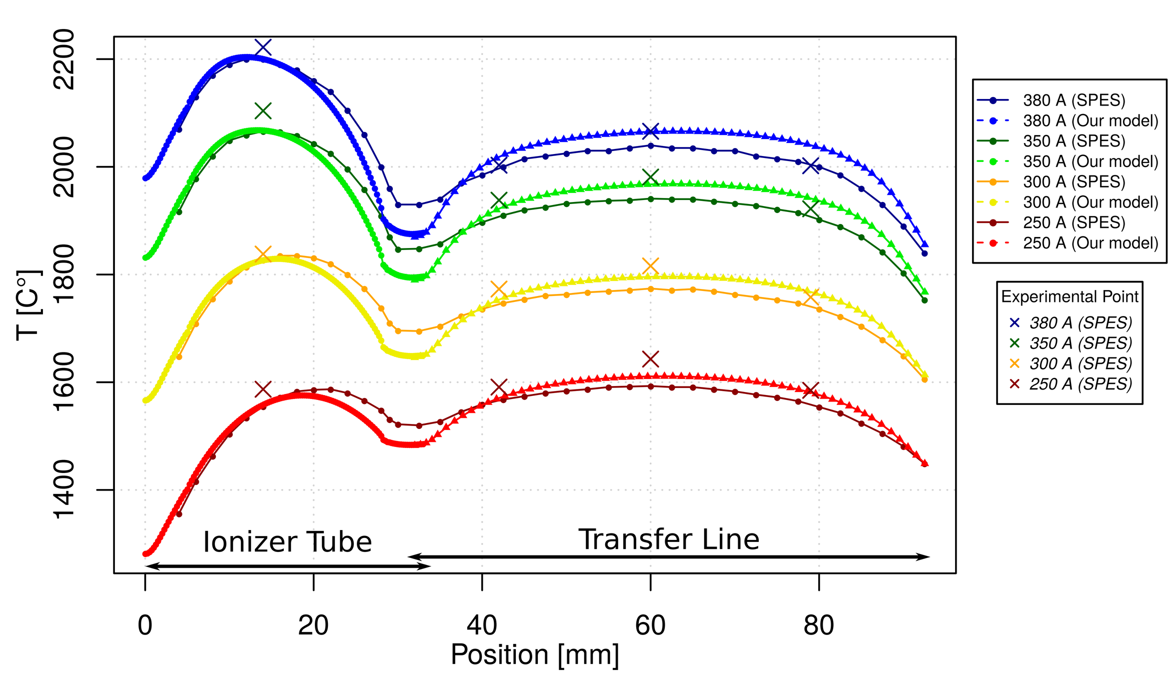
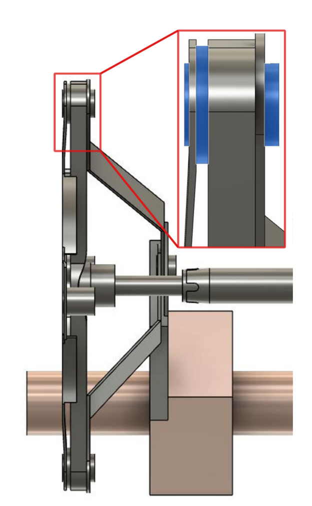


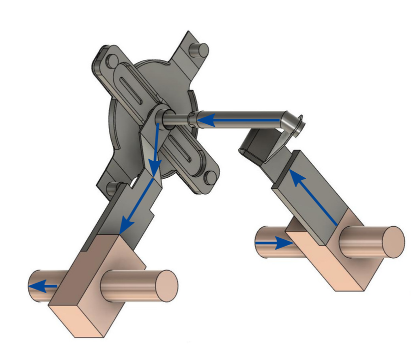
Figure 1: Temperature comparison between SPES and our model of ANSYS simulation results along the ionizer tube [0-33 mm] & the transfer line [30-95 mm]

With this simulation model, which was validated by experimental results, we can **start modifying our ion source** and see what the thermal-electric response:

Insulate electrically (& Thermally) the ion source & transfer line heating system and its support from its tank by putting insulating screw and washer between the support and the tank, the blue body in the figure.



Add a second feed through for the electrical current for the heating system of our ionizer and transfer line, like this, there will be one at the current input and one at the output.



With this second feed through or insulator, we will have a **better control of the electrical flow** going through our system. And with better control on this electrical flow, we will have a **better control on the heating of the ionizer tube** and especially on the exit part of the tube where we have on the SPES model a decrease of temperature which can lead to ion & neutral recombination or ions which get stuck on cold spot surfaces, all this will lead to a decrease of the ionisation total efficiency.

Those **new ion source heating systems need to be tested, improved and validated** with ANSYS thermal-electric simulations and then used to establish temperature profile of our cavity. Then with the Starfish plasma simulations, we will calculate the plasma parameters and estimate the output parameters of our ion source, like for example the ionisation efficiency as a function of the ion, neutral and electron densities.

Conclusion

To conclude, we are looking to solve the challenge of high intensity input in ISOL, for a surface ionisation source, for long-term irradiation. Only a few attempts to modify these sources have been made on materials and cavity sizes, by Kirchner [2] for example. But there are other parameters to explore. There is also a lack of research on the physical processes inside the ionisation cavity and their impact on the performance of the source. To understand those processes and their impact, we will need to perform simulations, first thermal-electric, then plasma simulations. Concerning the thermal-electric simulations, we already made good progress. Now the next step will be to test new designs of ion source in Starfish for the **creation of the best ion source for the day-1 operation at ISOL@MYRRHA**.

References

[1] *ANSYS*. <www.ansys.com>.
[2] R. Kirchner. "On the thermoionization in hot cavities". In: *Nuclear Instruments and Methods in Physics Research Section A 292* (July 1990). <doi.org/10.1016/0168-9002(90)90377-I>, pp. 203–208.
[3] M. Manzolaro et al. "The SPES surface ionization source". In: *Review of Scientific Instruments 88, 093302* (Sept. 2017). <doi.org/10.1063/1.4998246>.
[4] *Starfish*. <www.particleincell.com/starfish>.