High intensity ISOL ion source for long-term irradiation

by Sophie Hurier[1,2]

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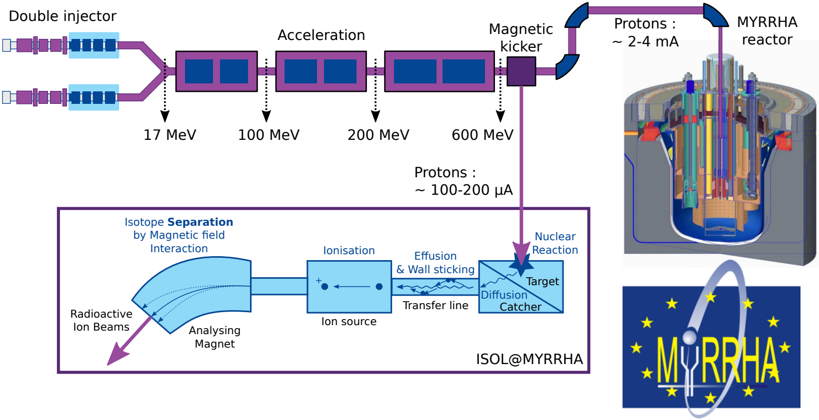
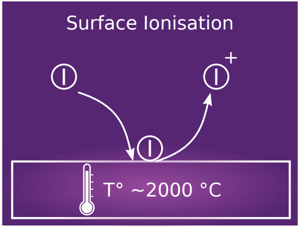

Double injector
Acceleration
Magnetic kicker
Protons : ~ 2-4 mA
MYRRHA reactor
17 MeV
100 MeV
200 MeV
600 MeV
Protons : ~ 100-200 µA
Isotope **Separation** by Magnetic field Interaction
Ionisation
Effusion & Wall sticking
Nuclear Reaction
Target
Diffusion
Catcher
Transfer line
Ion source
Radioactive Ion Beams
Analysing Magnet
ISOL@MYRRHA
MYRRHA

How can we build an adapted ISOL ion source to ISOL@MYRRHA condition?

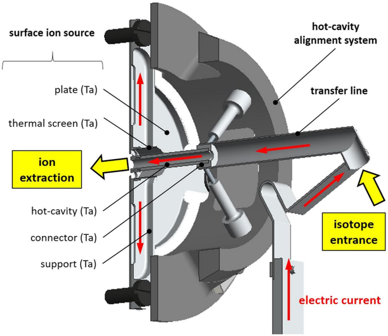
- **Have higher total efficiency**, if possible
- **High temperature** (around 2000°C) & **Thermal cycling** (Heating & Cooling period several times)
- **High irradiation** & **High input atom influx** (Saturation problems)
- Keep a good beam quality output: **Good beam emittance**, **High intensity output beam**, **High purity**.

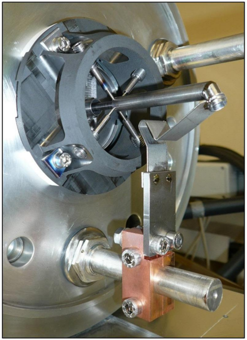


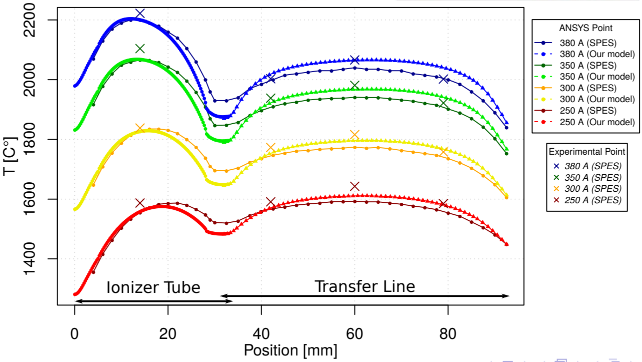
Surface Ion Source [SIS], because it's **reliable** and usually of a **simple design**.

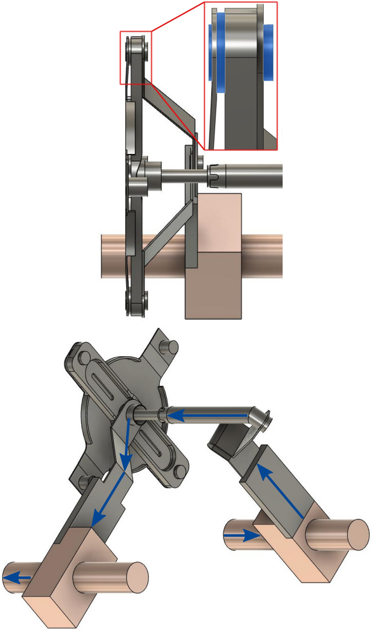
Thermal-Electric simulations

Plasma simulations: **Starfish**


surface ion source
plate (Ta)
thermal screen (Ta)
ion extraction
hot-cavity (Ta)
connector (Ta)
support (Ta)
hot-cavity alignment system
transfer line
isotope entrance
electric current




T [C°]
1400
1600
1800
2000
2200
0
20
40
60
80
Position [mm]
Ionizer Tube
Transfer Line
ANSYS Point
380 A (SPES)
380 A (Our model)
350 A (SPES)
350 A (Our model)
300 A (SPES)
300 A (Our model)
250 A (SPES)
250 A (Our model)
Experimental Point
380 A (SPES)
350 A (SPES)
300 A (SPES)
250 A (SPES)



Modifying the ion source :

Insulate electrically (& Thermally) the heating system from its vacuum vessel.

Add a second feedthrough for electrical current: one input & one output.

⇒ **Better electric flow control**, so **Better heating control**.

High intensity ISOL ion source for long-term irradiation

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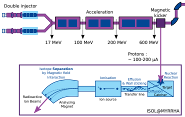
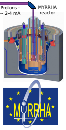
Introduction

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, **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** or **high-precision measurements**.





Objectives

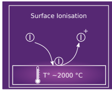
New experiments with different needs : an **isotope production increase** by using **higher intensity beams** on a **longer period** of time **without losing the radioisotope beam quality**. Inside ISOL system, the ion source will be affected by this higher intensity. So, before the start of the new accelerator at SCK-CEN, we will need to **create an ion source adapted** to this new input.

How can we build an adapted ISOL ion source to ISOL@MYRRHA condition?

- **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.

Starting from a **Surface Ion Source [SIS]**, because it's **reliable** and usually of a **simple design**. Then, we will find ways to improve its performance.

Methods



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

Interaction properties parameter :

- **Element to Ionise**:
  - Electronic structure, so Ionisation potential
- **Surface material**:
  - Temperature & Work function φ (= minimum energy needed to remove an electron from the surface of a material)

To **identify the relevant parameters** that affect our ion source, we need to understand how parameters affect the **performance**, like the total efficiency.

Thermal-Electric simulations, to estimate T° and electric ($\vec{E}$) conditions using **ANSYS** [1], an engineering software for structural mechanics, electrical & thermal modelling. ⇒

Plasma simulations, using **Starfish** [3], an ElectroStatic Particle-in-Cell (ES-PIC) 2D code, to **estimate plasma parameters & model the RIB-formation process**: like plasma potential Φ.

Results & Discussion

How can we improve surface ion source?

- **Increase cavity volume** to avoid 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 & ion accumulation
- **Adding an Electric or a Magnetic field** inside the cavity to improve ion extraction and reduce space charge saturation

Model & simulation condition validate with existing experimental results : we **reproduce simulation results coming from the heating system** from a study [2] from the Selective Production of Exotic Species (SPES) project at Legnaro National Laboratories (LNL).

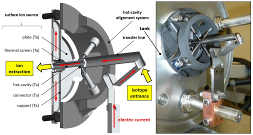


Figure 1: SPES ionizer & transfer line heating system setup [2]

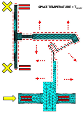
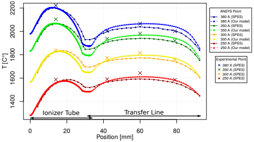
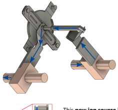


Figure 2: ANSYS simulation applied load and constraints [2]

- **Temperature** T_{constr} = 25°C,
- **Radiation emissivity** ϵ_{Ta}(T°C) of tantalum depends on the temperature,
- **Voltage constraint** at 0 V,
- **Current load** at 380, 350, 300 & 250 A,
- **Ta Material** High work function (φ=4.19 eV), High melting point (~ 3000 °C).

Our model and SPES ANSYS results are close, except for the **ionizer & transfer line connection** for which the article has **no experimental result**, so we cannot say which ANSYS models is closer to the reality.

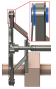




With this validated simulation model from SPES, we can **start modifying our ion source** :

- **Insulate electrically (& Thermally)** the ion source heating system from its vacuum vessel by putting an insulating screw & washer (the blue body).
- **Add a second feedthrough** for electrical current of the heating system: one input & one output.

⇒ **Better electric flow control**, so **Better heating control**, especially on the tube exit part where a T° decrease can lead to a bad ion confinement, decreased of ionisation chance and sticking to the wall.



This **new ion source heating systems needs to be validated and possible further adapted** with:

ANSYS thermal-electric simulations → cavity temperature profile

Starfish plasma simulations → calculate plasma parameters → estimate ion source output parameters

Conclusion

To solve the challenge of high intensity input in ISOL, for SIS, only a few attempts to modify the materials or cavity sizes were made. But other parameters can be explored. To understand the physical processes inside the ionisation cavity and their impact, we perform simulations, first thermal-electric, already started, then plasma simulations. Next step is to test new designs of ion source for the **creation of the best ion source for the day-1 operation at ISOL@MYRRHA**.

References

[1] *ANSYS*. <www.ansys.com>.

[2] M. Manzolaro et al. "The SPES surface ionization source". In: *Review of Scientific Instruments 88, 093302* (Sept. 2017). <doi.org/10.1063/1.4998246>.

[3] *Starfish*. <www.particleincell.com/starfish>.

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