Marie Curie Initial Training Network

Cryogenics, Accelerators and Targets at ISOLDE

# Target conceptual design WP6, ESR9

**Serena Cimmino – Stefano Marzari**
**(CERN EN-STI-RBS)**

**CATHI Final Review Meeting Barcelona 22-26 September 2014**

# Outline:

1. Thermal measurements
2. Container optimization
3. Water cooling alternatives
4. Other contributions
5. Conclusions

# Introduction :

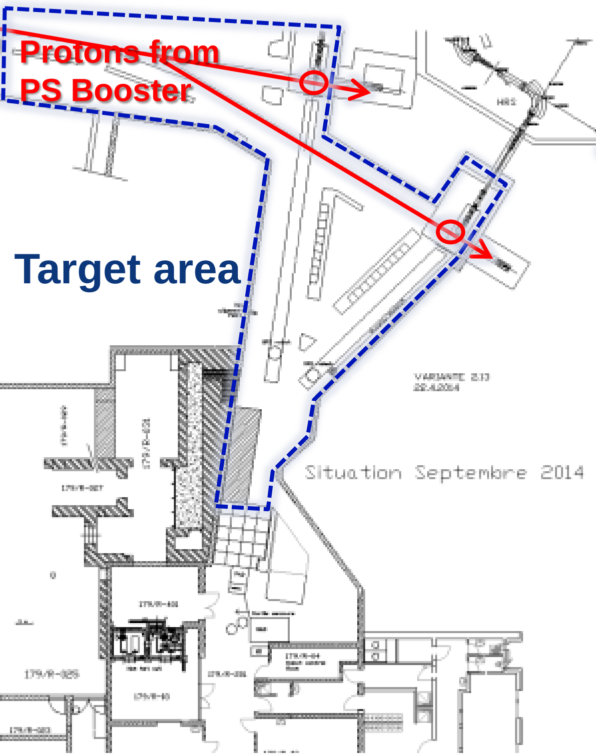
- The “Target conceptual design” is part of WP6 (Studies for ISOL Target & Front-End upgrades) ESR9 (Target conceptual design)

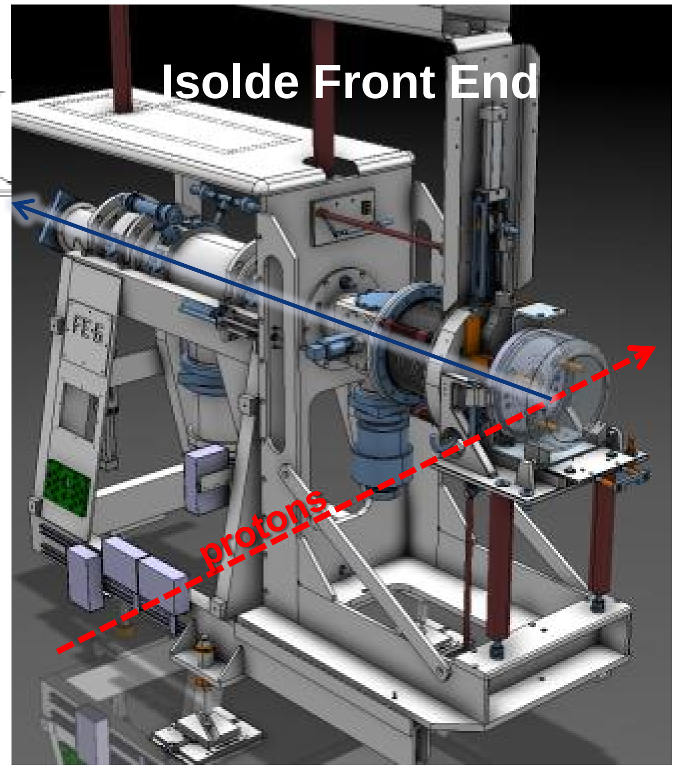
- This WP was held by CATHI fellow *Serena Cimmino* (from February 2012 up to June 2014)

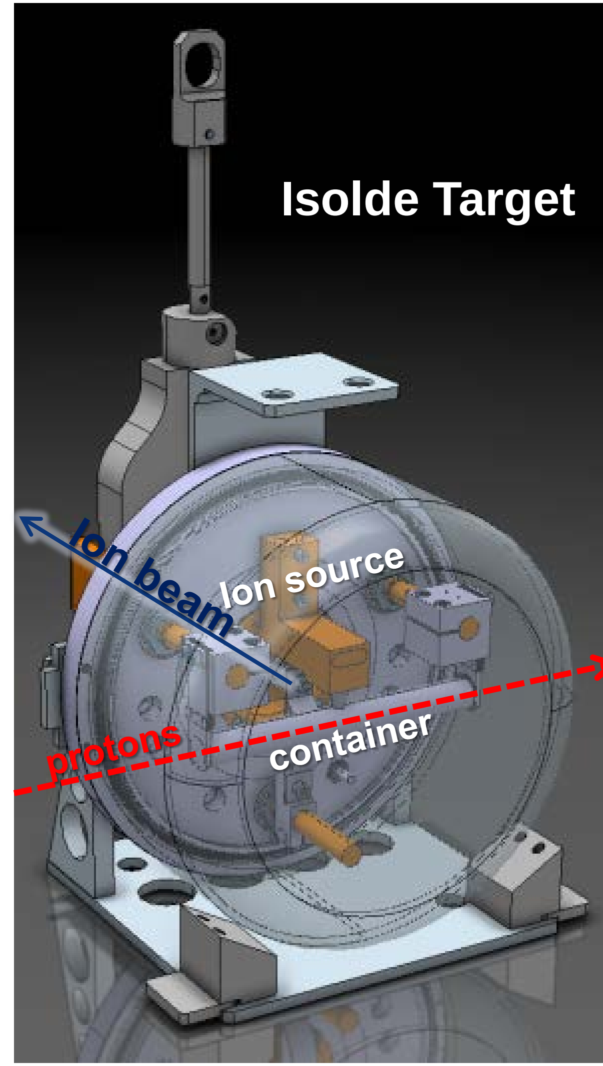
- Supervisor: Stefano Marzari (EN-STI-RBS)

# Introduction :

- Isolde Target…




Heat generated by proton energy deposition ~500W
Heat generated by ohmic heating ~2500W
Water cooled 90%

# Introduction :

- Main areas of improvement:

1. Thermal measurements and calibrations
2. Target Container (new concept)
3. Water cooling & Safety
4. Nuclearisation (rad hardness and recycling)

# 1. Thermal measurements :

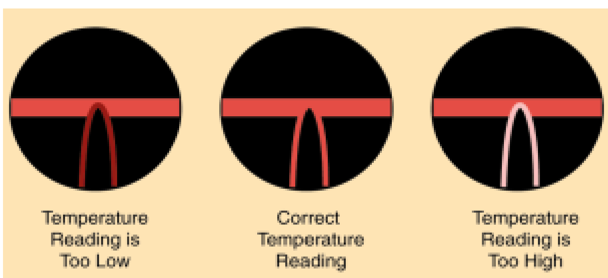
- Pyrometer calibration
- Improve our knowledge in thermocouple and pyrometer utilisation
  - Organisation of a specific training at LNE (Laboratoire National d'Essais) in Paris
  - Collaboration protocol with LNE for future developpements
- Measurement on the pump stand
- Comparison with ANSYS model
- Creation of a reference folder

# *Our pyrometers calibration @ LNE*

Le progrès, une passion à partager

Optical pyrometers

IR pyrometer dichromatic

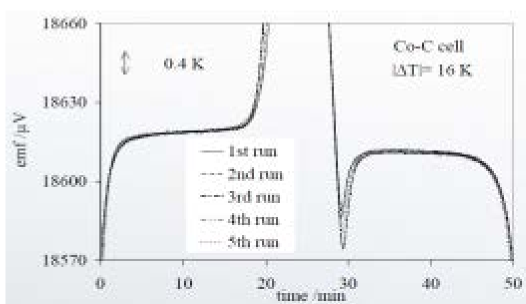



| Température * Bande spectrale centré sur 650 nm | Pyromètre | | Correction sur l'Indicateur | Incertitudes d'étalonnage ( k=2 ) |
|---|---|---|---|---|
| | Echelle | Indication | | |
| °C | / | °C | °C | °C |
| 922,3 | 700-1500 | 747,3 | 175,0 | ± 12 |
| 1002,2 | 700-1500 | 854,7 | 147,5 | ± 11 |
| 1352,1 | 700-1500 | 1289,3 | 62,7 | ± 15 |
| 1502,0 | 700-1500 | 1444,0 | 57,9 | ± 15 |
| 1502,0 | 1200-2000 | 1380,0 | 122,0 | ± 17 |
| 1702,0 | 1200-2000 | 1622.0 | 80,0 | ± 16 |
| 1951,9 | 1200-2000 | 1884,3 | 67,6 | ± 16 |

# *LNE training and future collaboration*

Thermocouples
& Pyrometers
calibration Lab

Calibration cell development for thermocouple correction on-line :




⇒ Melting point reference of a specific metal
⇒ Has to be miniaturized
⇒ Collaboration protocol under approval

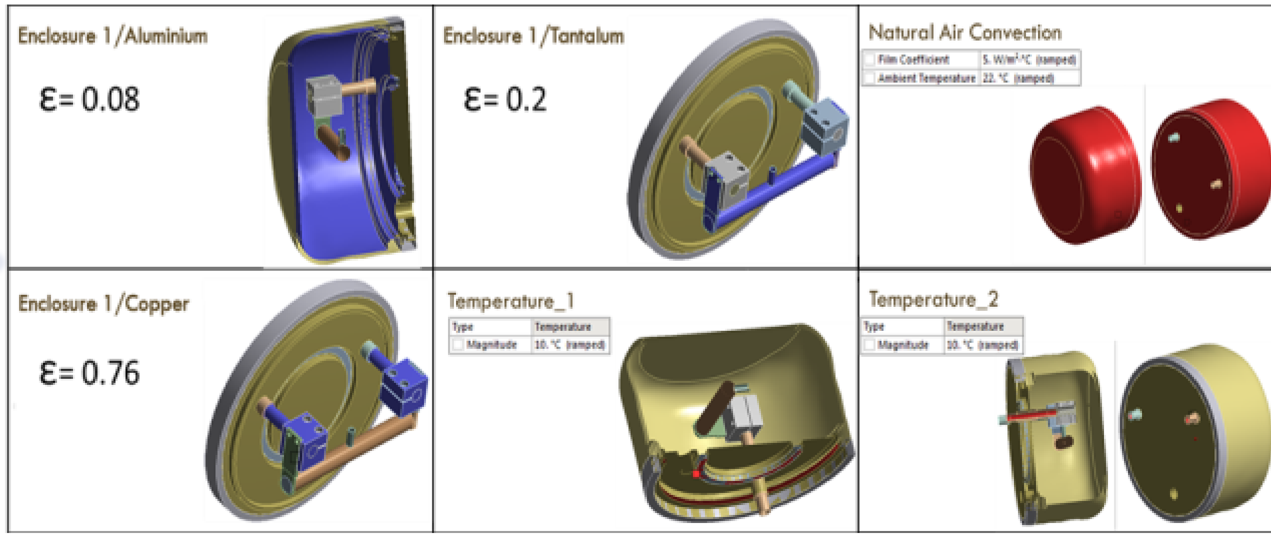
# *Measurements and simulations*

- Start with a simplified case (bare container without heat screens)
- Heating Tests on the Pump Stand (measurements with thermocouples and pyrometers)
- Simulation with ANSYS Workbench and comparison
- Iterations …
- Model validation

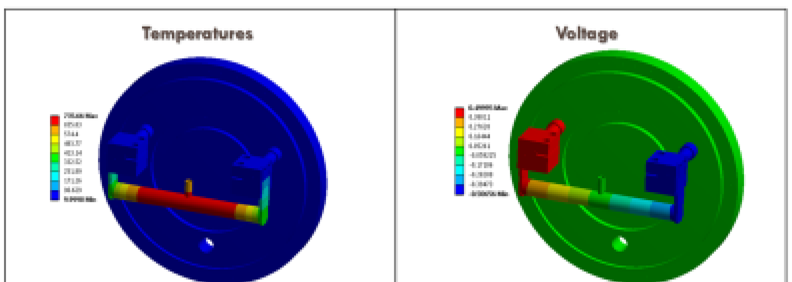

# *Measurements and simulations*

- Thermo-electrical analysis (and model validation)


**Geometry simplification**




**Results**




$T_{measured\_thermocouple} = 730[°C]$

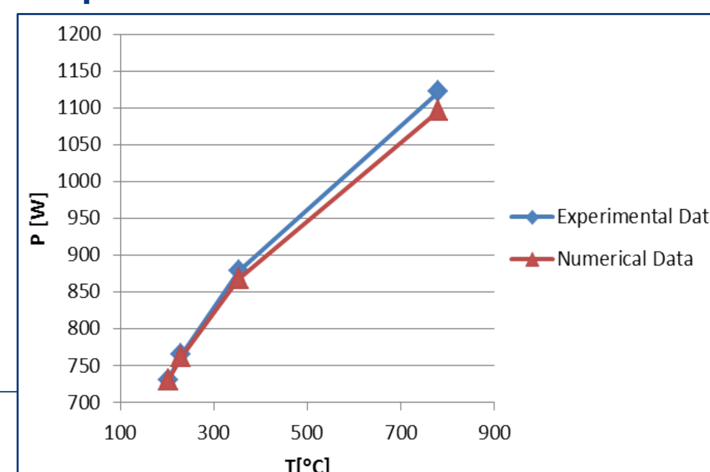
$Error\% = \frac{730-735.66}{730}\% = -0.77\%$

$\Delta V_{numerical} = 0.49995 + 0.50656 = 1.00651[V]$

$\Delta V_{exp} = 1.0096[V]$

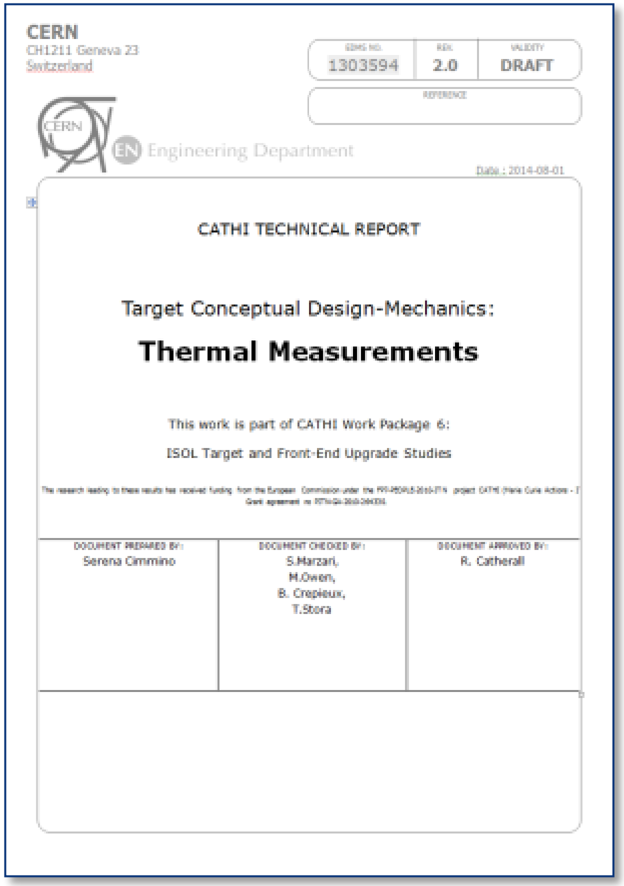
$Error\% = \frac{1.0096-1.00651}{1.0096}\% = 0.3\%$

**Comparison with real measurements**



# *Creation of a reference folder*

- Folder available for Technicians, Users and students…
  - Paper form and in EDMS database
  - Summary of measurement theory
  - Measurement and off-line user guide
  - Material Emissivity data base



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CH1211 Geneva 23
Switzerland

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| 1303594 | 2.0 | DRAFT |

REFERENCE

Engineering Department

Date : 2014-08-01

CATHI TECHNICAL REPORT

Target Conceptual Design-Mechanics:

**Thermal Measurements**

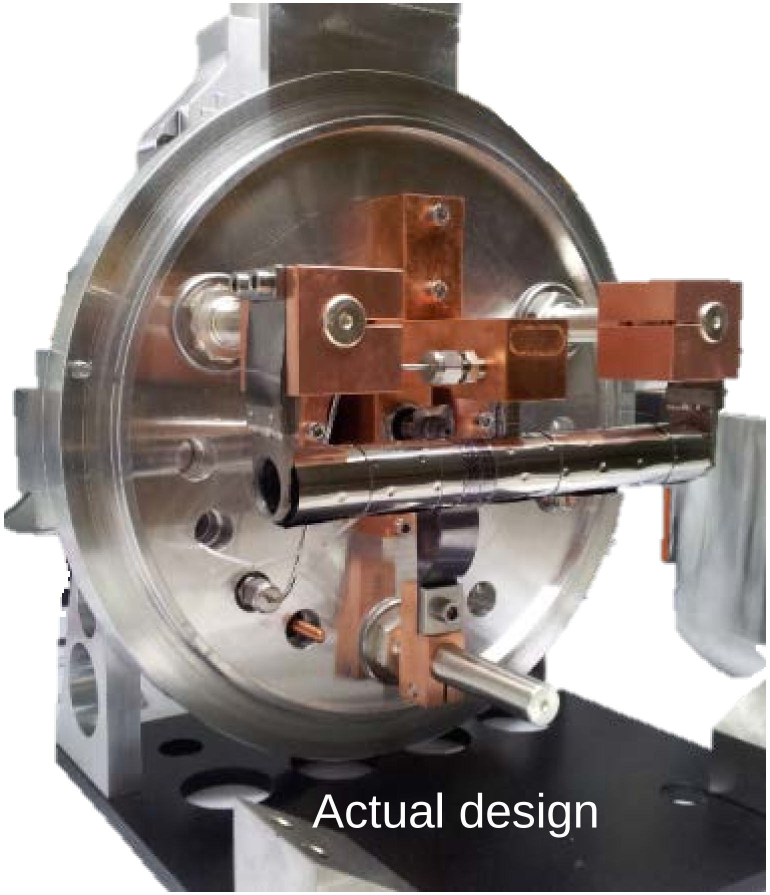
This work is part of CATHI Work Package 6:

ISOL Target and Front-End Upgrade Studies

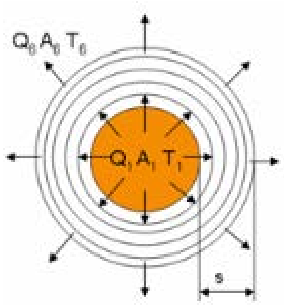
| DOCUMENT PREPARED BY: | DOCUMENT CHECKED BY: | DOCUMENT APPROVED BY: |
|---|---|---|
| Serena Cimmino | S.Marzari, M.Owen, B. Crepieux, T.Stora | R. Catherall |

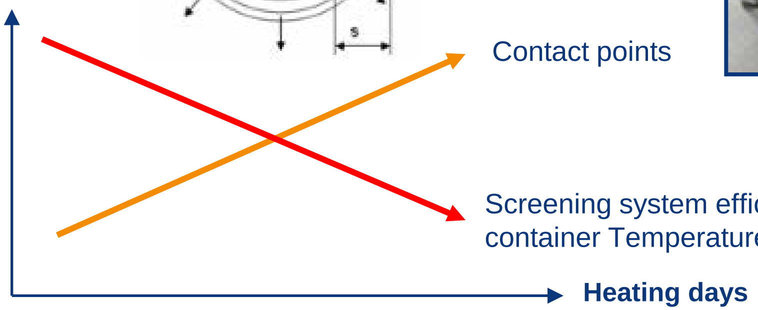
# 2. Container optimization:

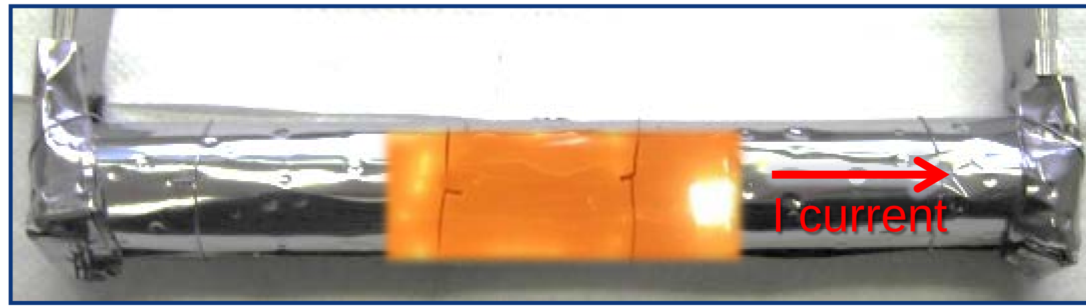
- Un-couple container and heating function
- Uniformise the profile of temperature
- Reduce the aging factors
- Reduce weight of waste
- Improve the temperature control



# *Actual Isolde design*




Tantalum container with 5 layers of thermal insulation

- Thermal insulation efficiency changes
- Container material changes characteristics (recrystallization)
- Target material changes structure

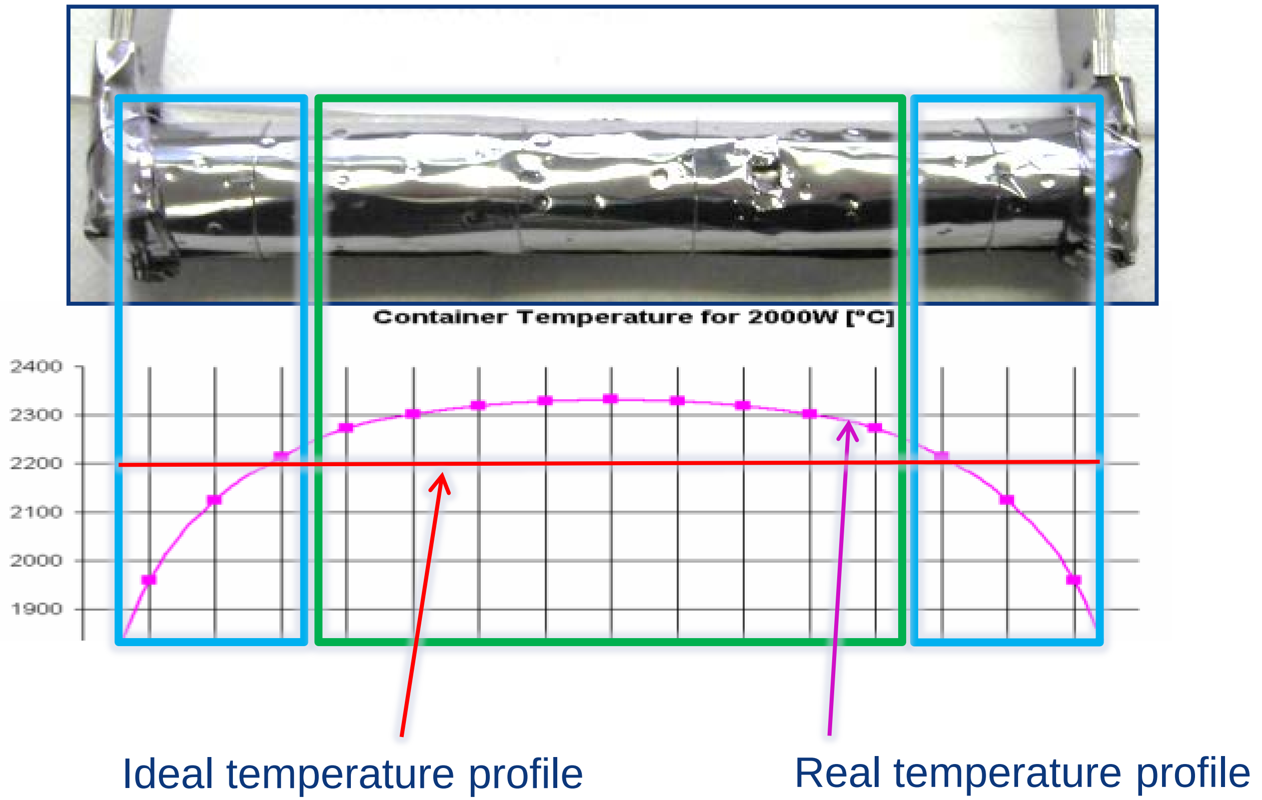
⇒ **The electrical resistance of the containers changes during operation**

⇒ **The calibration chart T= f(I) is no more reliable !**

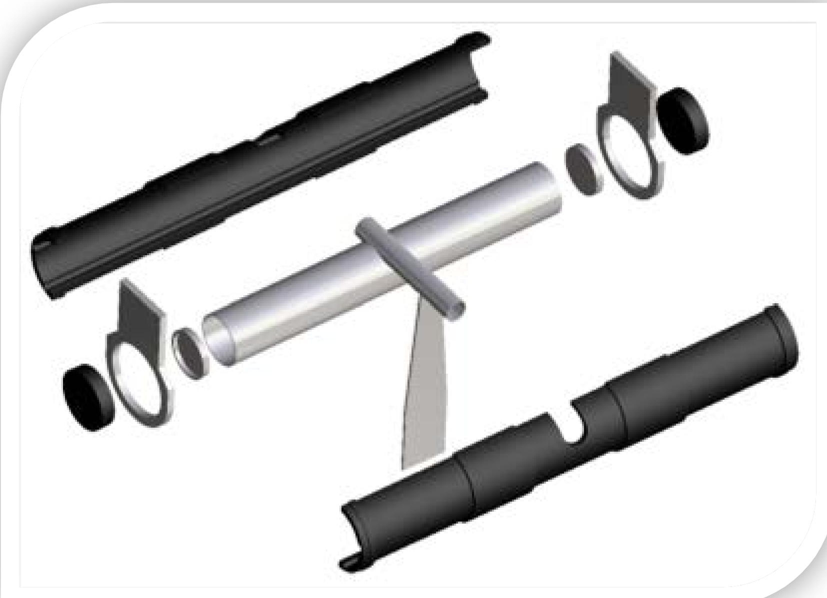
| $I_{cont}$ [A] | $V_{cont}$ [A] | $I_{source}$ [A] | $T_{cont}$ [°C] | $T_{source}$ [°C] |
|---|---|---|---|---|
| 450 | 3.01 | 270 | 1717 | 1294 |
| 500 | 3.38 | 270 | 1740 | 1294 |
| 550 | 3.68 | 270 | 1850 | 1294 |

# *Thermal profile on the target container*

- Reduction of the production efficiency due to the “cold areas” each side of the container

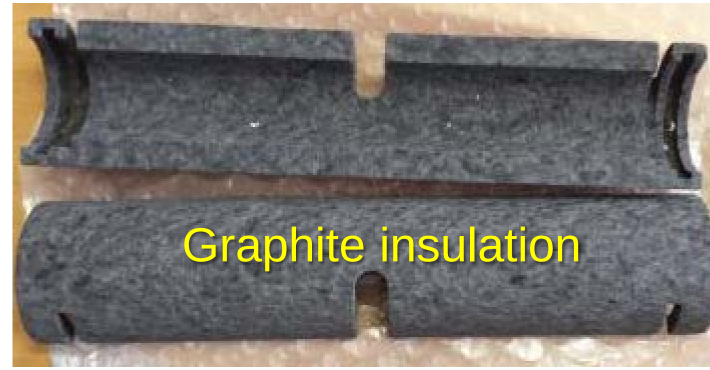


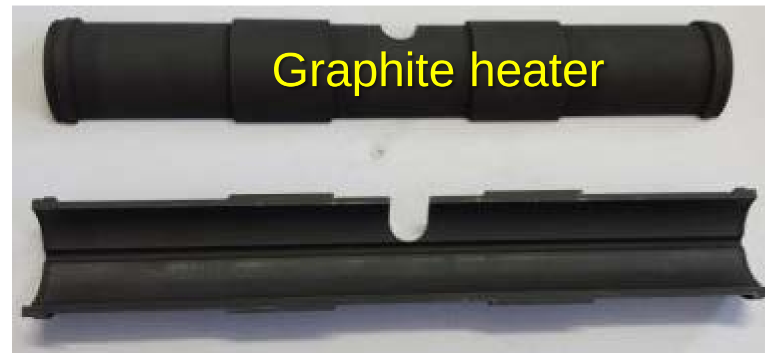
# *Un-couple container and heating functions*

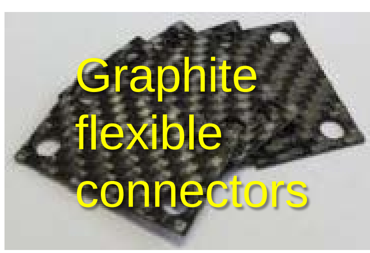


- Utilization of graphite pieces
- Reduction of Tantalum weight 50%

**=> nuclear wastes reduction**

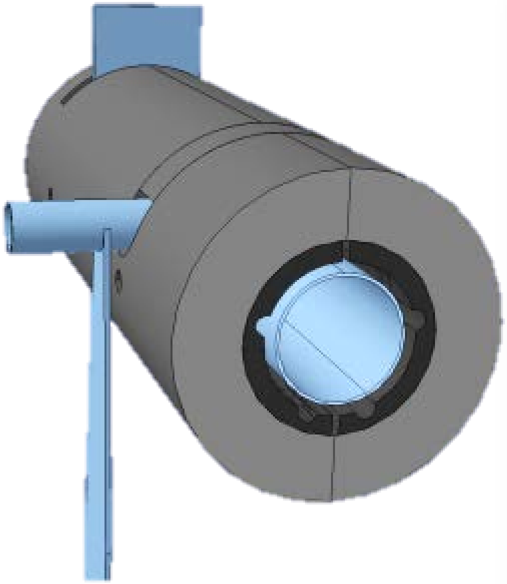




# *Prototype*

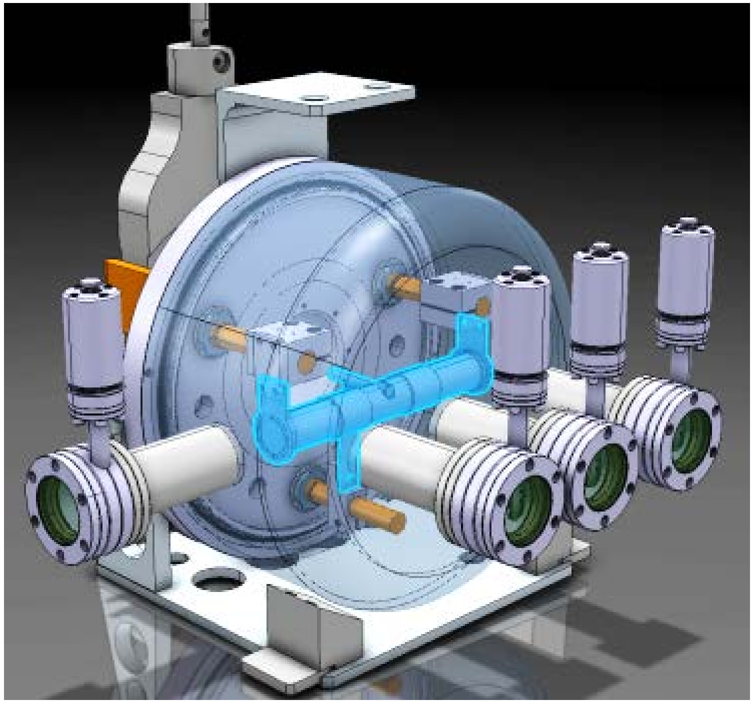


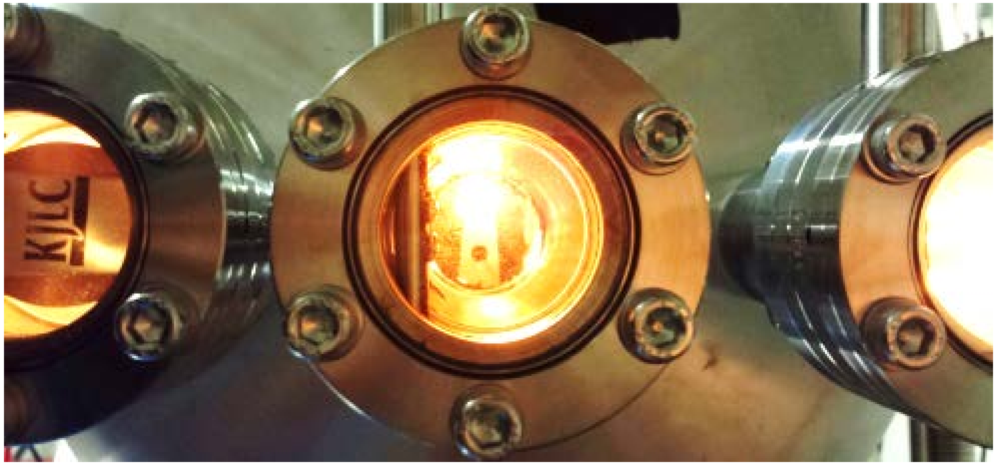

- Insertion of a thermocouple between the heater and the container

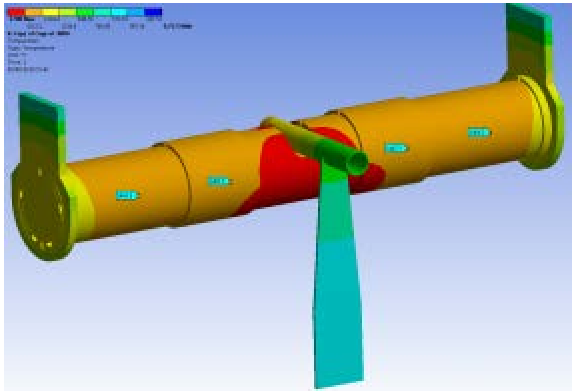
**=> Direct Temperature measurement (without calibration)**

# *The tests are promising…*

- Better temperature profile was measured (but could be improved)
- Good mechanical stability (strength, dilatations)
- No increase of the outgassing verified (due to the porous graphite insulation)







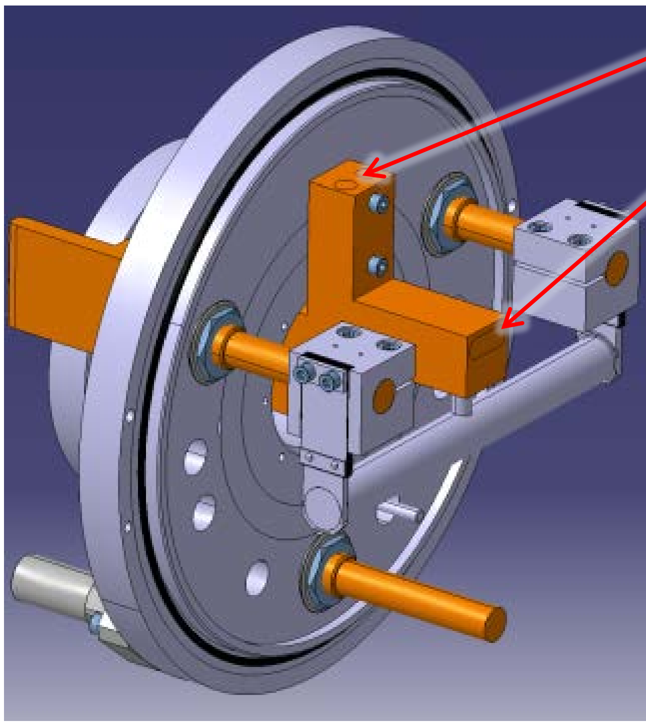
**=> Next steps: container profile optimization and on-line tests….**

# 3. Water cooling alternatives :

- Water leaks risks on inside the target volume (for cooled transfer lines)

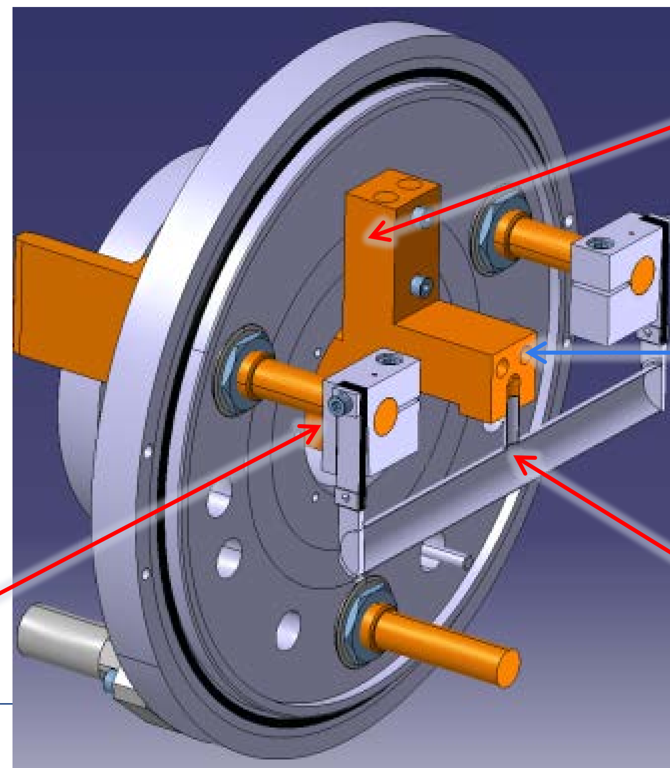


Weldings



Elastomers
EPDM O-rings

Water circuit



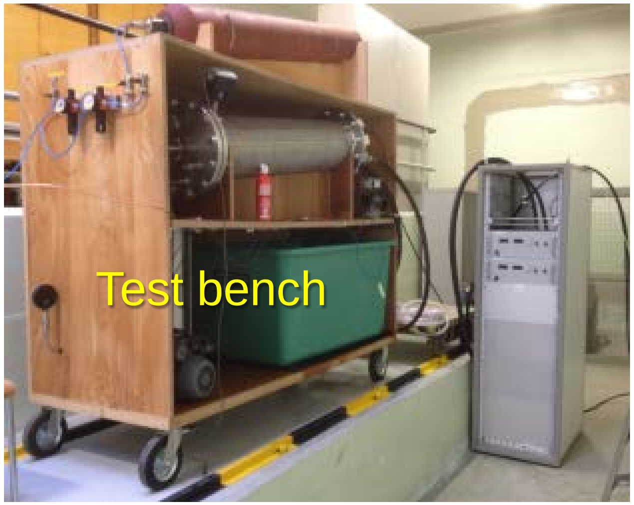
>2000°C ion source

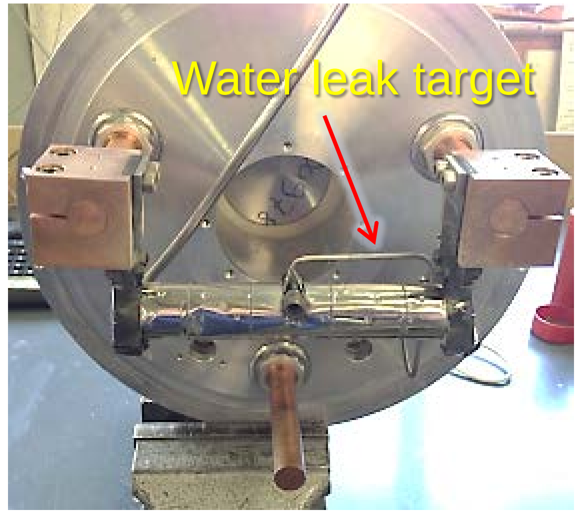
>2000°C target container

# *Risk analysis and tests…*

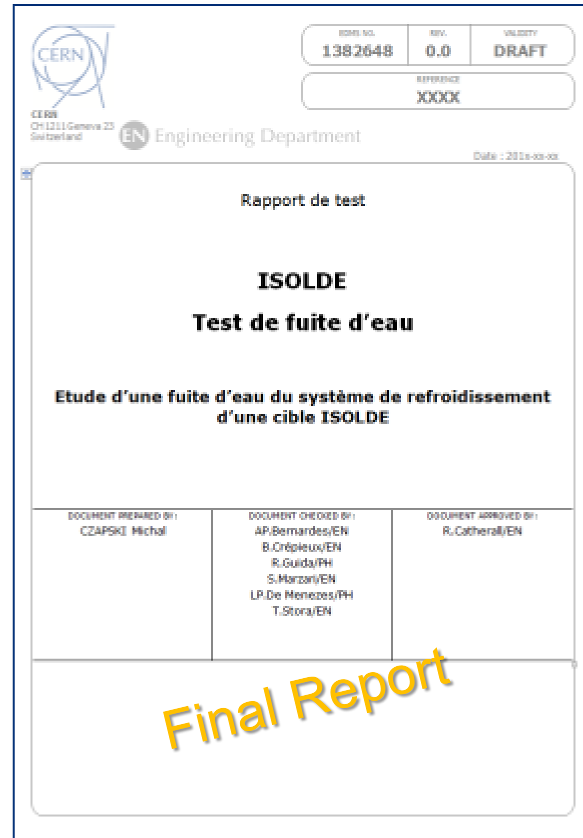
- A test was done simulating a direct water leak on the Tantalum container
- Hydrogen production by Tantalum oxidation was measured

$\Rightarrow$ **explosion risk confirmed**




Hydrogen production measurement device



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REFERENCE XXXX

CERN CH 1211 Geneva 23 Switzerland

EN Engineering Department

Date : 201x-xx-xx

Rapport de test

**ISOLDE**

**Test de fuite d'eau**

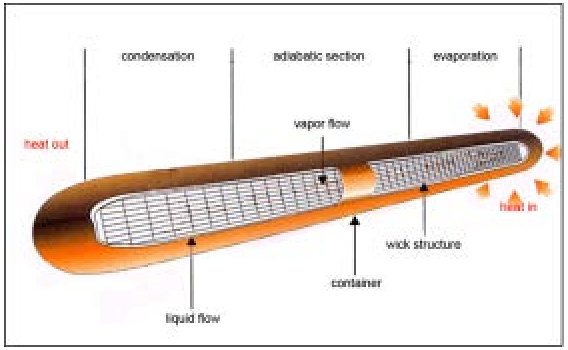
**Etude d'une fuite d'eau du système de refroidissement d'une cible ISOLDE**

| DOCUMENT PREPARED BY: | DOCUMENT CHECKED BY: | DOCUMENT APPROVED BY: |
| --- | --- | --- |
| CZAPSKI Michal | AP.Bernardes/EN<br>B.Crépieux/EN<br>R.Guida/PH<br>S.Marzari/EN<br>LP.De Menezes/PH<br>T.Stora/EN | R.Catherall/EN |

# *Proposed solutions*

- Some solutions were studied and discharged :

  - Utilization of heat pipes (impossible to integrate into a so small volume)



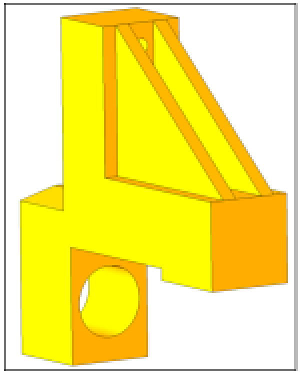

(a)

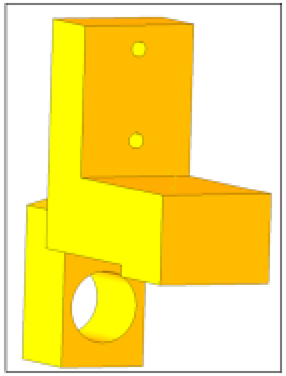
(b)

Heat pipe diam.8mm, l=100mm ~60W heat removal capacity

=> We need to remove ~750W !

  - Modification of the transfer line geometry to optimize the heat flux



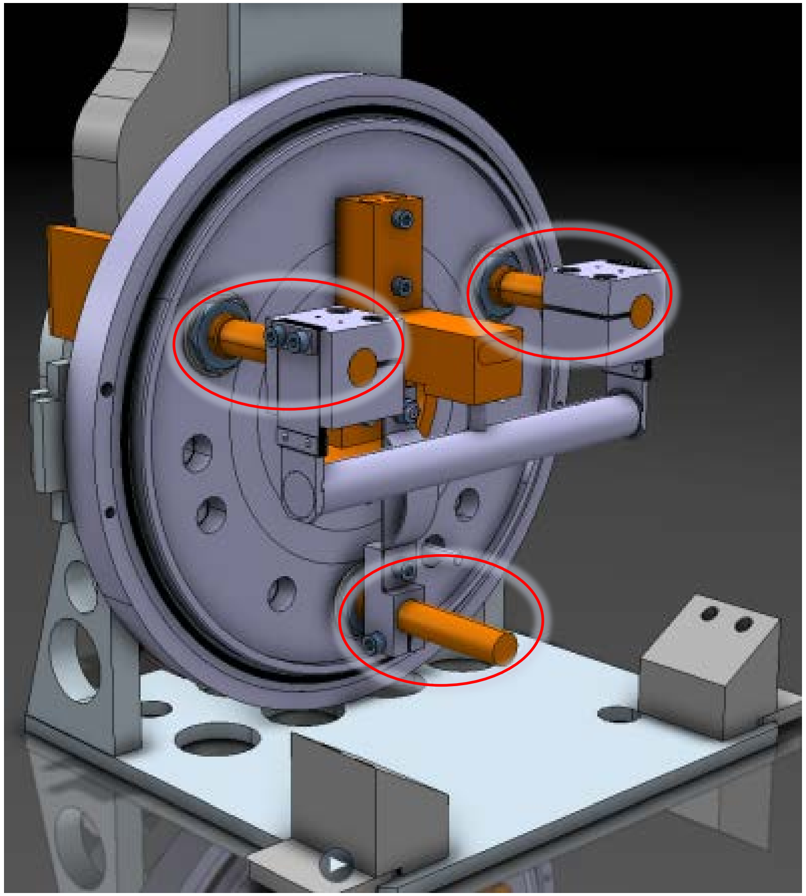


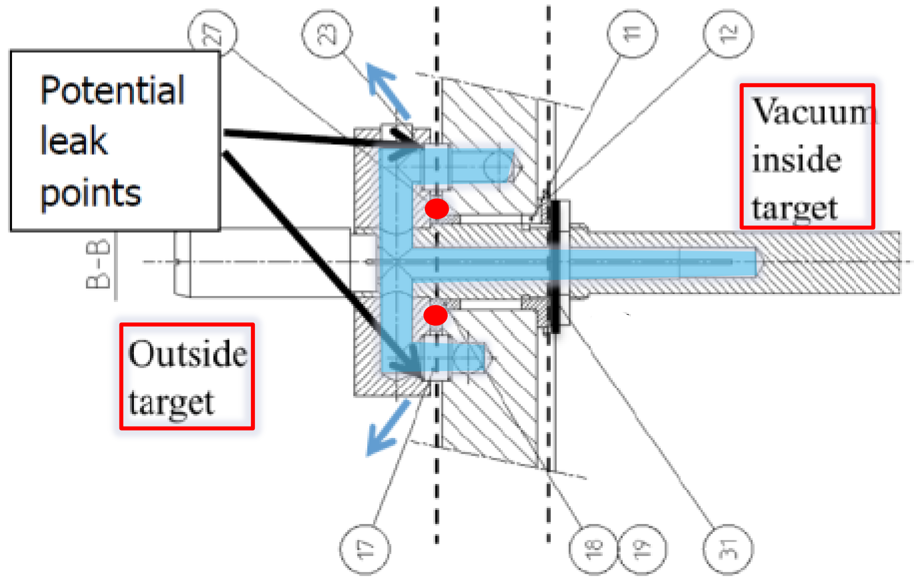
Examples of geometry trials

=> Not enough heat transfer capacity

# *Best solution…*

- Use the same water cooling principle as the 3 power conductors :



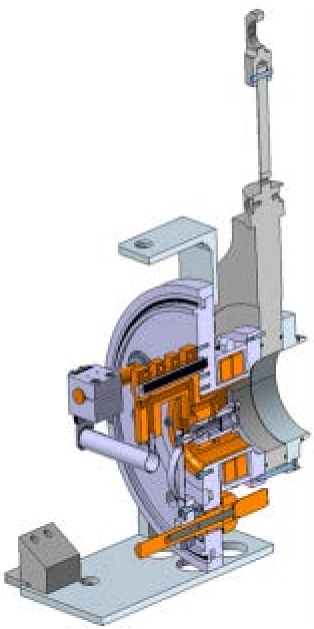


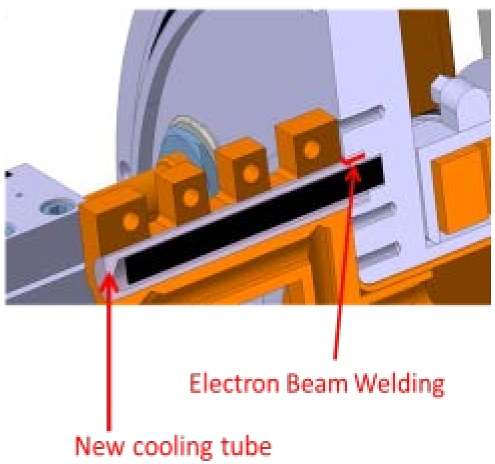

No more O-rings or welding inside the vacuum !

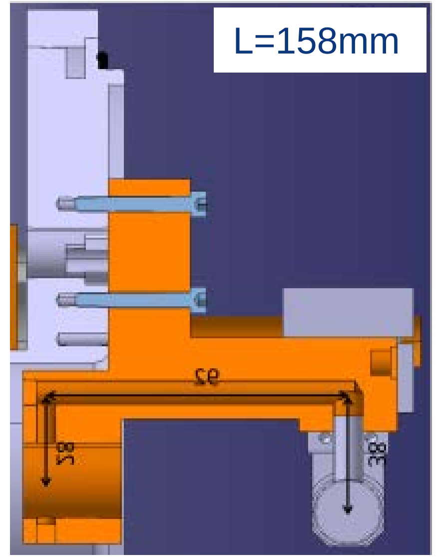
**=> In case of leaks no direct contact between water and hot pieces**

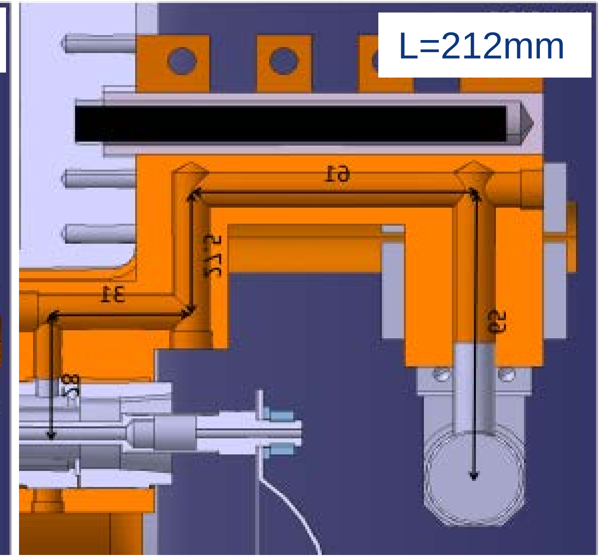
# *Study…*

- Additional 4th cooled finger assembled by EB welding
- Cooled line screwed on it
- Thermal contact by pressure



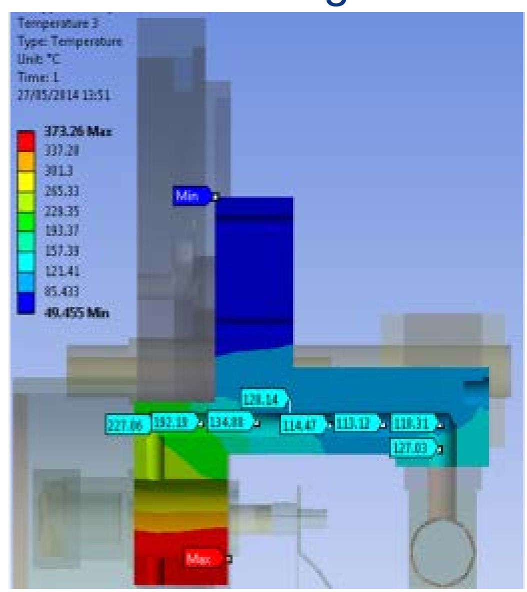


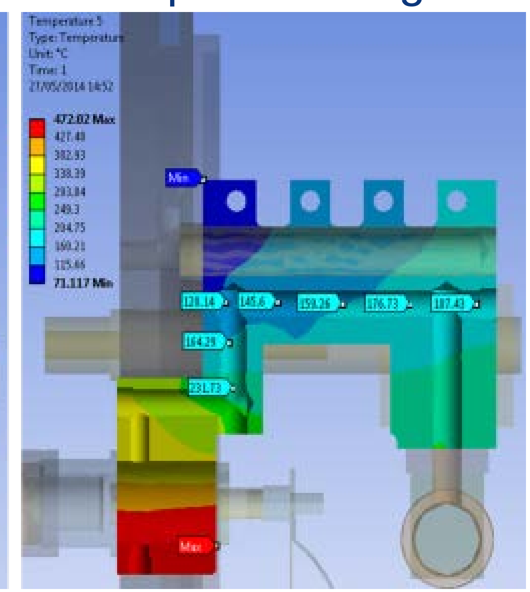




Actual design

Proposed design



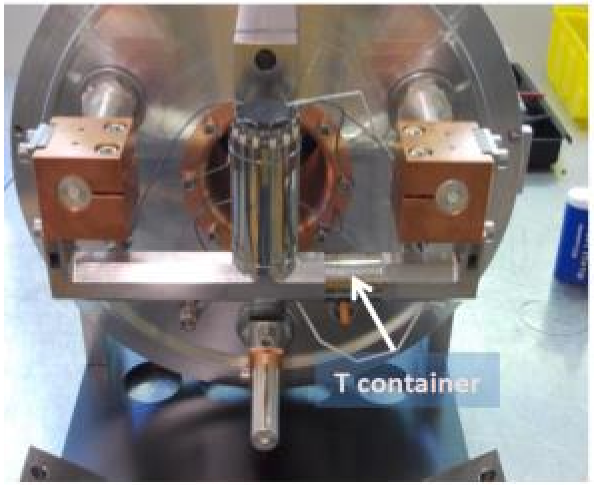

**=> This solution has still to be tested and validated by a prototype**

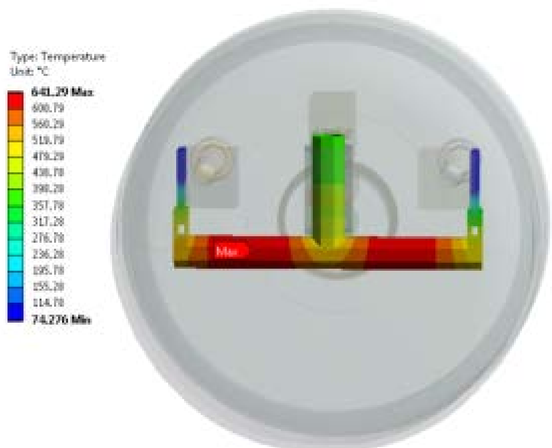
# 4. Other Serena's contributions :

- Molten salt target (supervised by T.Mendonca)
- Donut neutron converter (supervised by T.Stora)
- Target Nuclearisation (leak of time…)

# Molten salt target

- Thermal issues analysis
- Author of a Publication in 2013

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## Validation of electro-thermal simulation with experimental data to prepare online operation of a molten salt target at ISOLDE for the Beta Beams

S. Cimmino [a,*,1], T.M. Mendonca [b], S. Marzari [a], T. Stora [a]

[a] CERN, European Organization for Nuclear Research, CH-1211, Geneva 23, Switzerland
[b] IFIMUP and IN, Institute of Nanosciences and Nanotechnologies, University of Porto, Portugal

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ABSTRACT

The main objective of the Beta Beams is to study oscillation property of pure electrons neutrinos. It produces high energy beams of pure electron neutrinos and anti-neutrinos for oscillation experiments by beta decay of $^{6}He$ and $^{18}Ne$ radioactive ion beams, stored in a decay ring at $\gamma = 100$. The production of $^{6}He$ beam has already been accomplished using a thick beryllium oxide target. However, the production of the needed rate of $^{18}Ne$ has proven to be more challenging. In order to achieve the requested yield for $^{18}Ne$ a new high power target design based on a circulating molten salt loop has been proposed. To verify some elements of the design, a static molten salt target prototype has been developed at ISOLDE and operated successfully. This paper describes the electro-thermal study of the molten salt target taking into account the heat produced by Joule effect, radiative heat exchange, active water cooling due to forced convection and air passive cooling due to natural convection. The numerical results were compared with the available experimental data in order to validate the model. This approach allows one to improve the reliability of the model, which will help to predict the thermo-mechanical impact of the required targets for future facilities such as HIE-ISOLDE and the Beta-Beams.



### 1. Introduction

The Beta Beams aim is to produce (anti-) neutrino beams from the decay of beta active ions circulating in a storage ring [1].

Within the *EURISOL – DS* project [2] the feasibility of the beta emitter ion pair $^{6}He$/ $^{18}Ne$ production has been investigated. These isotopes, also known as baseline isotopes, can be produced in large quantities and do not have any long-lived daughter products.

The study showed, via a top-down approach, the need for production of about $6 \times 10^{13}$ $^{6}He$ and $1 \times 10^{13}$ $^{18}Ne$ ions per second injected in the ion source for 2 and 8 years of operation, respectively. The production of $^{6}He$ has been verified using the isotope separation on-line (ISOL) method with 1.4 GeV proton beam onto a tungsten neutron converter located close to a thick BeO target [3]. On the other hand, the production of the required $1 \times 10^{13}$ $^{18}Ne/s$ was found to be more challenging. The first approaches using spallation reactions of 1 GeV protons onto magnesium and aluminium oxide targets resulted in a production shortfall by one order of magnitude.

Therefore, alternatives had to be explored [4]. In this context, a proposal where $^{18}Ne$ is produced via a high power molten salt loop was presented [5]. It profits of existing facilities at CERN: as one can see in Fig. 1, PS and SPS are used to accelerate radioactive ions allowing the production of neutrino beams from their $\beta$ decay in a dedicated ring. Rates of $1 \times 10^{13}$ ions/s are expected using 160 MeV, 1 MW proton beam from an upgraded Linac 4. Molten fluoride salt would present several advantages as target material for the production of $^{18}Ne$. For instance, the presence of Na, F or Mg would be favourable following the reaction cross-sections for $^{18}Ne$. Moreover, these compounds have been extensively studied and their chemical and physical properties are well known. In addition, due to the high density of the molten state, high in-target production rates can be obtained by using molten targets. However, their long diffusion times limit their use on the production and extraction of short lived species. In order to overcome these limitations, a circulating loop is preferable allowing to decrease diffusion times and accommodate high beam powers.

* Corresponding author.
*E-mail address:* serena.cimmino@cern.ch (S. Cimmino).

1 This paper summarizes the work of several teams: The ISOLDE collaboration, the HIE-ISOLDE project team, and numerous groups at CERN within the accelerator and technology sector. We acknowledge funding from the Big Science program G.0706.08 of the FWO-Vlaanderen (Belgium) and the research council K.U. Leuven. We would like to acknowledge as well the receipt of fellowships from the CATHI Marie Curie Initial Training Network: EU-FP7-PEOPLE-2010-ITN project number 264330. Support from the Spanish Programme Industry for Science from CDTI is also acknowledged.

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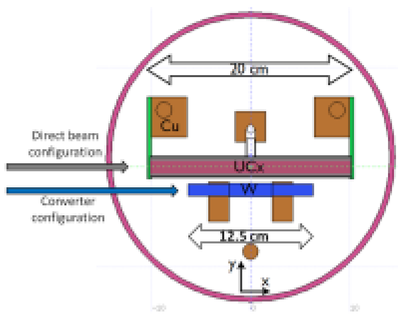
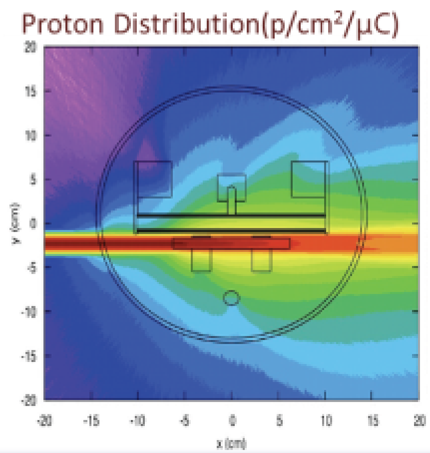
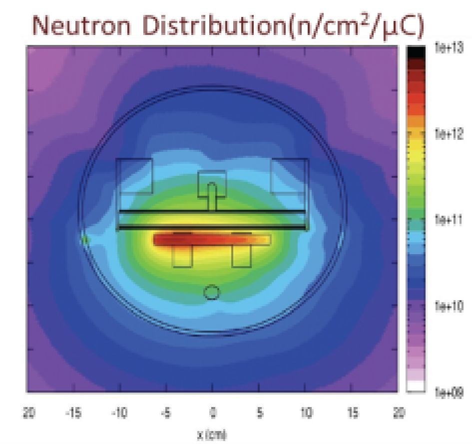
# “Donut” neutron converter

- Collaboration with Triumf (CA) TRIUMF
- Geometry optimization
- Production analysis with Fluka an thermal analysis with Ansys

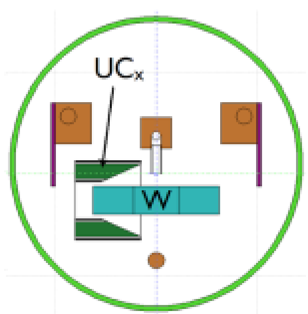
Isolde traditional converter

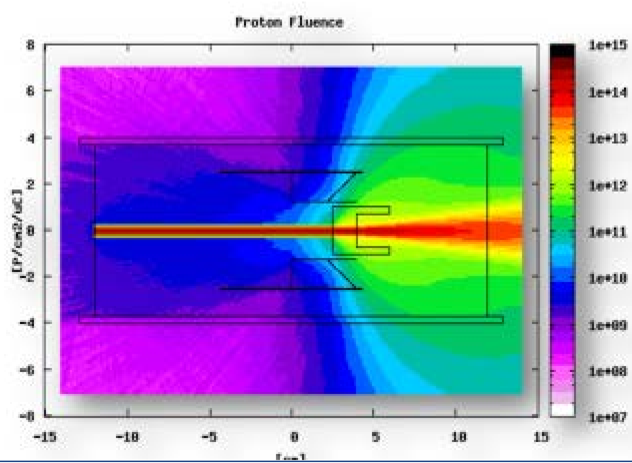


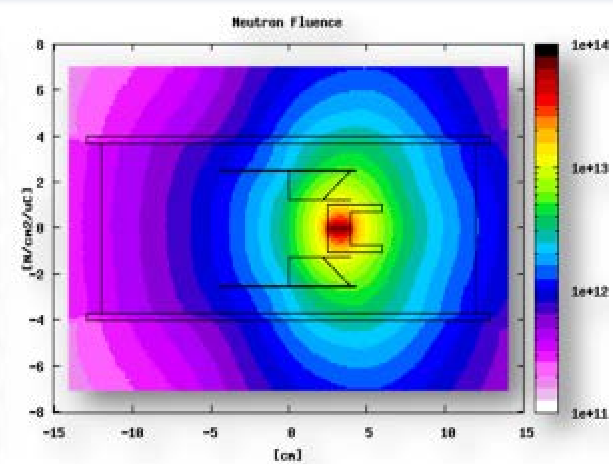




New “Donut” converter

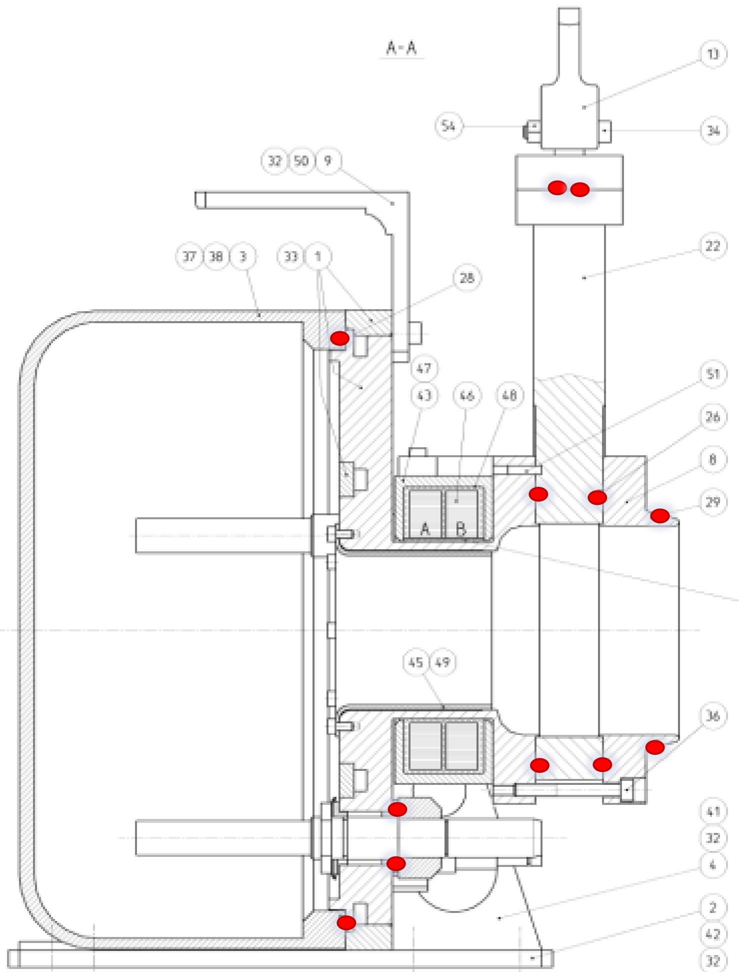


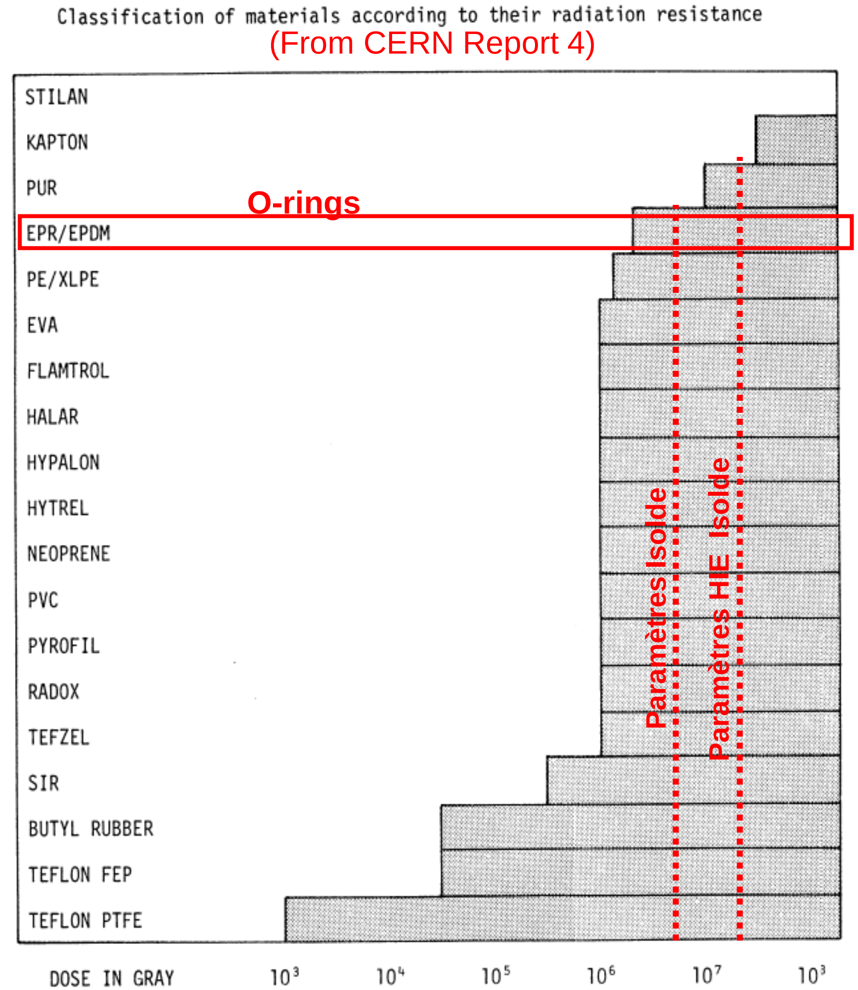



# Target nuclearisation

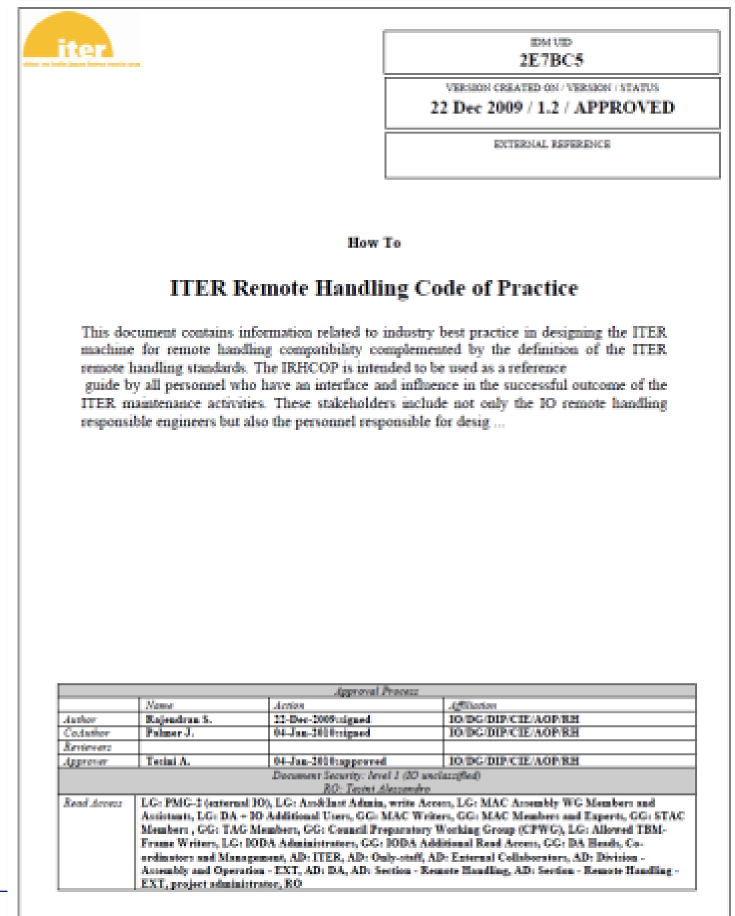
- Development of a Rad-Hard design (O-ring water and vacuum tightness)



# *Target nuclearisation*

- Improve the dismountability with remote handling devices (like tele manipulators into the ISOLDE hot cell)
- If possible, remove to small screws and fittings
- If possible, integrate the "**ITER Remote Handling Code of Practice"** (license agreement with CERN)



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22 Dec 2009 / 1.2 / APPROVED

EXTERNAL REFERENCE

**How To**

**ITER Remote Handling Code of Practice**

This document contains information related to industry best practice in designing the ITER machine for remote handling compatibility complemented by the definition of the ITER remote handling standards. The IRHCOP is intended to be used as a reference guide by all personnel who have an interface and influence in the successful outcome of the ITER maintenance activities. These stakeholders include not only the IO remote handling responsible engineers but also the personnel responsible for desig ...

| *Approval Process* | | | |
|---|---|---|---|
| | *Name* | *Action* | *Affiliation* |
| *Author* | **Rajendran S.** | **22-Dec-2009:signed** | **IO/DG/DIP/CIE/AOP/RH** |
| *Co-Author* | **Palmer J.** | **04-Jan-2010:signed** | **IO/DG/DIP/CIE/AOP/RH** |
| *Reviewers* | | | |
| *Approver* | **Tesini A.** | **04-Jan-2010:approved** | **IO/DG/DIP/CIE/AOP/RH** |
| *Document Security: level 1 (IO unclassified)* *RO: Tesini Alessandro* | | | |
| *Read Access* | **LG: PMG-2 (external IO), LG: Asst&Inst Admin, write Access, LG: MAC Assembly WG Members and Assistants, LG: DA + IO Additional Users, GG: MAC Writers, GG: MAC Members and Experts, GG: STAC Members , GG: TAG Members, GG: Council Preparatory Working Group (CPWG), LG: Allowed TBM-Frame Writers, LG: IODA Administrators, GG: IODA Additional Read Access, GG: DA Heads, Co-ordinators and Management, AD: ITER, AD: Only-staff, AD: External Collaborators, AD: Division - Assembly and Operation - EXT, AD: DA, AD: Section - Remote Handling, AD: Section - Remote Handling - EXT, project administrator, RO** | | |

# 5. Conclusions :

- Acknowledgments to Serena for her great and useful work during these 2 years and 4 month fellowship
- Some studies are not finished and have to be tested and optimized (like the graphite container, the water cooling and the “donut” converter)

Thanks for your attention !!