ISOLDE Workshop and Users meeting 07/08

Selective contaminant adsorption for RIB purification at ISOLDE

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- What?
  - Delivering unprecedented pure beams of exotic n-rich Cd and Zn.
- How?
  - Trapping contaminant elements (produced alkalis such as Rb, Cs and also In and Ga) by the addition of a quartz insert in the transfer line.

Introduction

- RIB intensity equation:

$$I_{RIB} = (\sigma_{prod} \cdot N_{target} \cdot I_{prim-beam}) \cdot \varepsilon$$

Production cross section	Target thickness	Primary beam intensity	Efficiencies (**release**, ionisation, transport…)

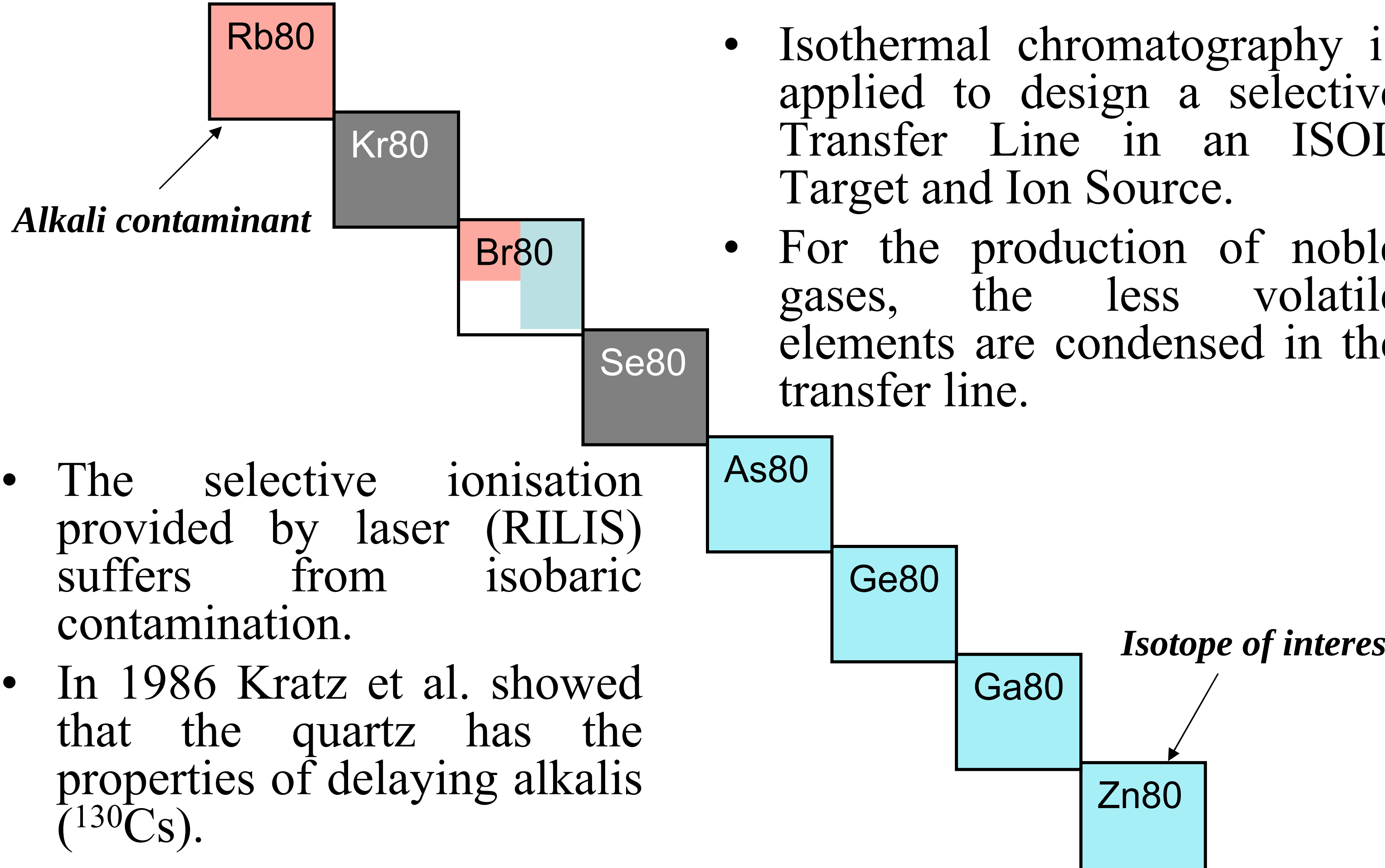
- Release efficiency depends on the bulk target diffusion and **effusion** characteristics
- Effusion consists of 3 important parameters:
  - Number of collisions (n_{coll}) with the surface of the materials
  - The mean sticking time (t_s) per collision (depending on temperature and **adsorption enthalpy**)
  - The mean flight time (t_{fly}) between collisions (depending on the geometry, the mass and temperature)

Beam Purity!

- The Beam Purity **BP** is the ratio of the desired isotope yield to all other, including molecular side bands and multiple charge states.
  - BP is a function of:
    - Cross sections and target thickness
    - Projectile nature and flux
    - Mass resolution of the separator
    - Ion-source efficiencies
    - Released fractions (diffusion effusion ad-de-sorption enthalpies)
    - Chemical nature of element, structural materials (ad-ab-de-sorption enthalpies) and surface purities

Beam Purity!

- Isothermal chromatography is applied to design a selective Transfer Line in an ISOL Target and Ion Source.
- For the production of noble gases, the less volatile elements are condensed in the transfer line.



- The selective ionisation provided by laser (RILIS) suffers from isobaric contamination.
- In 1986 Kratz et al. showed that the quartz has the properties of delaying alkalis (^{130}Cs).

Theory…

- Frenkel equation:

$$t_{eff} = t_{fly} + n_{coll} \cdot t_s$$

Sticking time

$$t_s = t_0 \cdot e^{(-\Delta H_{ad}/kT)}$$

- Exponential decay expression:

$$N(t) = N_0 \cdot e^{-\lambda \cdot t}$$

λ = ln2 / $t_{1/2}$ — *Half life of the nuclei*

N_0: *Number of radioactive nuclei at time = 0*

- Combination gives:

$$f_{th}(\lambda, T) = \frac{N_0}{N(\lambda, T)}$$

Estimation of suppression factor

$$f_{th}(\lambda, T) = e^{\lambda \cdot t_0 \cdot \int \frac{dn_{coll}}{dl} e^{(-\Delta H_{ad}/kT(l))} dl}$$

Design of the transfer line

- To efficiently trap alkalis, the transfer line must operate within a certain range of temperatures, then 3 prototypes have been designed with a controlled transfer line temperature:
  - From 700ºC to 1100ºC (Version 1.0)
  - From 300ºC to 800ºC (Version 2.0 and 3.0)
- RIBO code allowed the estimation of the quartz dimensions to be used according to the number of collisions: 50mm long tube, 6mm diameter
- An ISOLDE UC_2-C target/ion source unit operates at temperature above 2000ºC: estimation of the heat flow mandatory to avoid the quartz to melt

Design of the transfer line

- Heat transfer equations…

$$q_x(L) = k.A_1(L).\frac{dT}{dL} \qquad q_{rad}(L) = A_2(L).\varepsilon.\sigma.(T_s^4(L) - T_0^4)$$

q_x heat flow rate (W), A_1 section through which the heat is conducted (m2), dT/dL temperature gradient along the line (K/m) and k thermal conductivity (W/m.K)

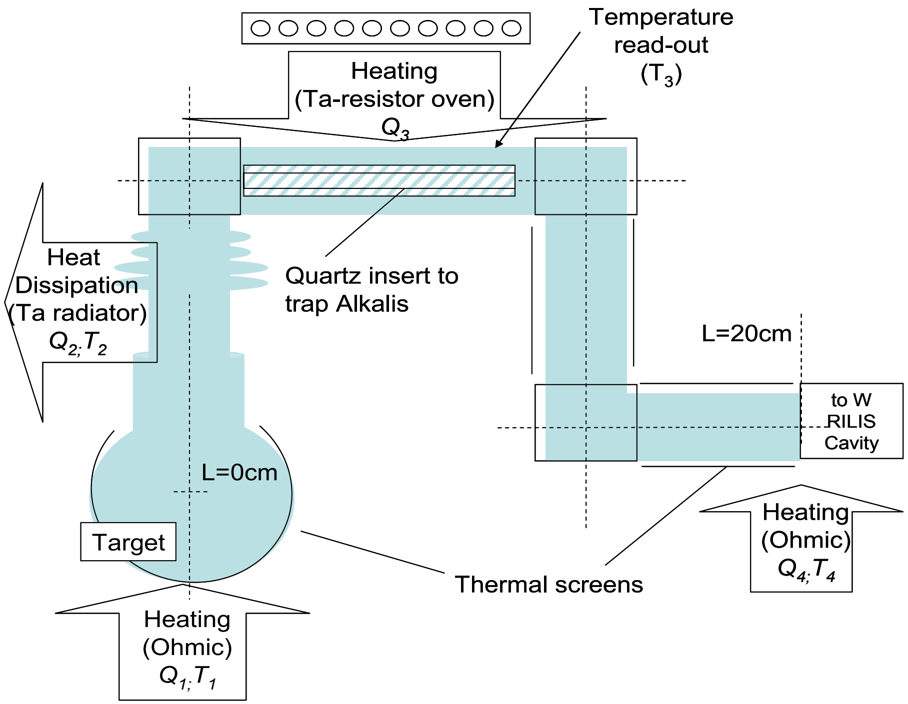
q_{rad} radiated heat flow (W). A_2 is the area (m^2), ε emissivity, σ Stefan-Boltzmann constant (σ = 5.67 X 10-8 $W/m^2.K^4$). T_s temperature of the surface, T_0 temperature of the surrounding surface.

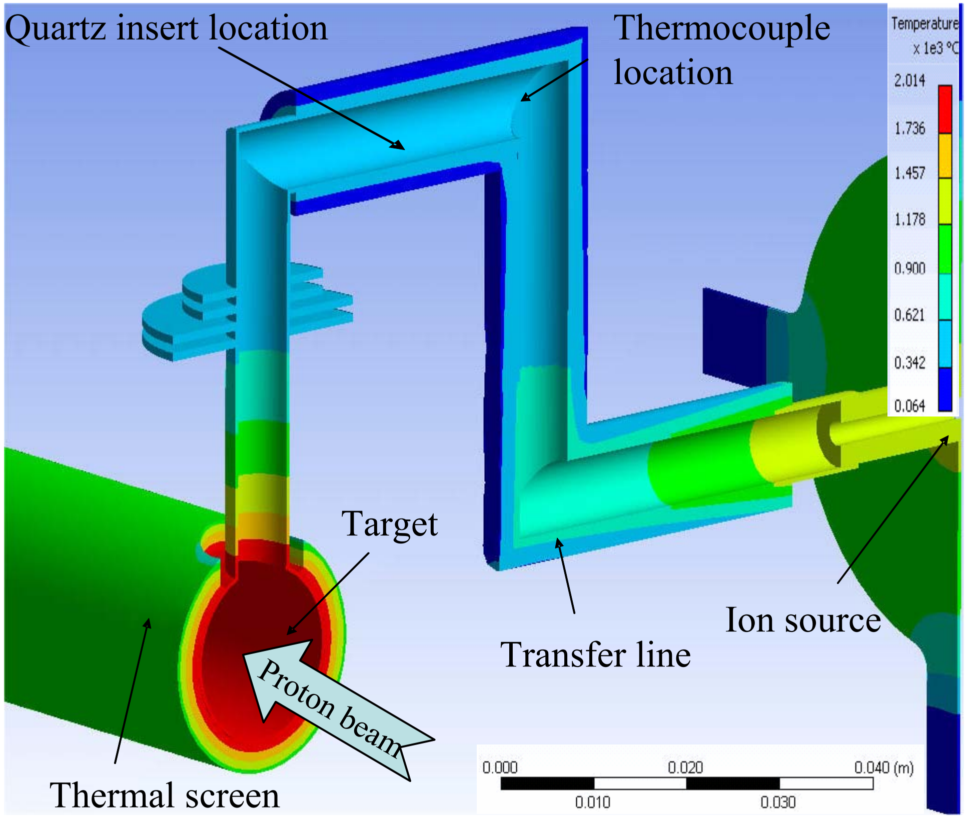
…and…

- Simulation software: ANSYS Workbench 11.0

…have been used to estimate the temperature along the transfer line.

Design of the transfer line

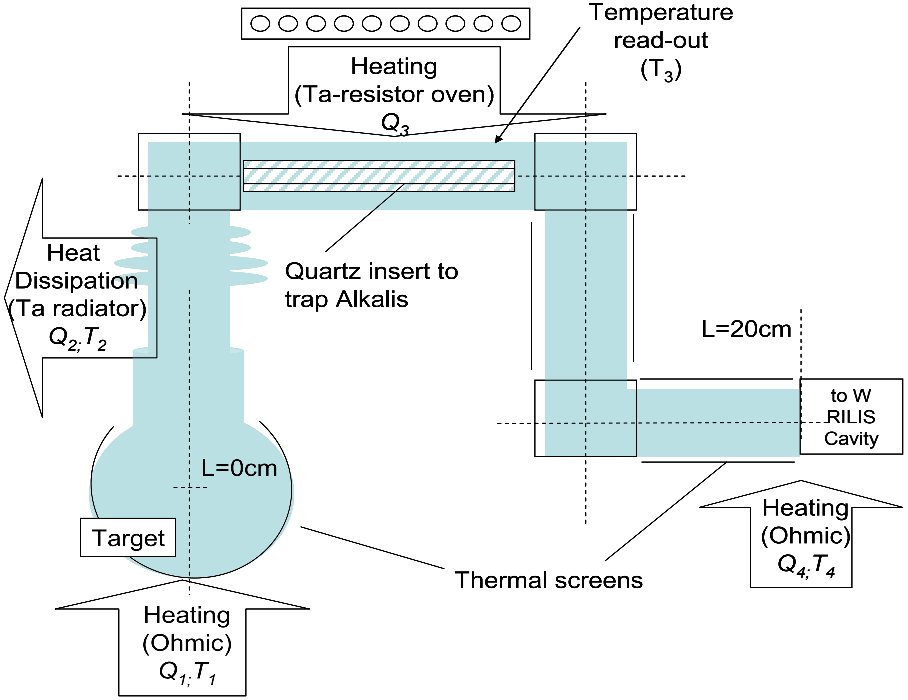


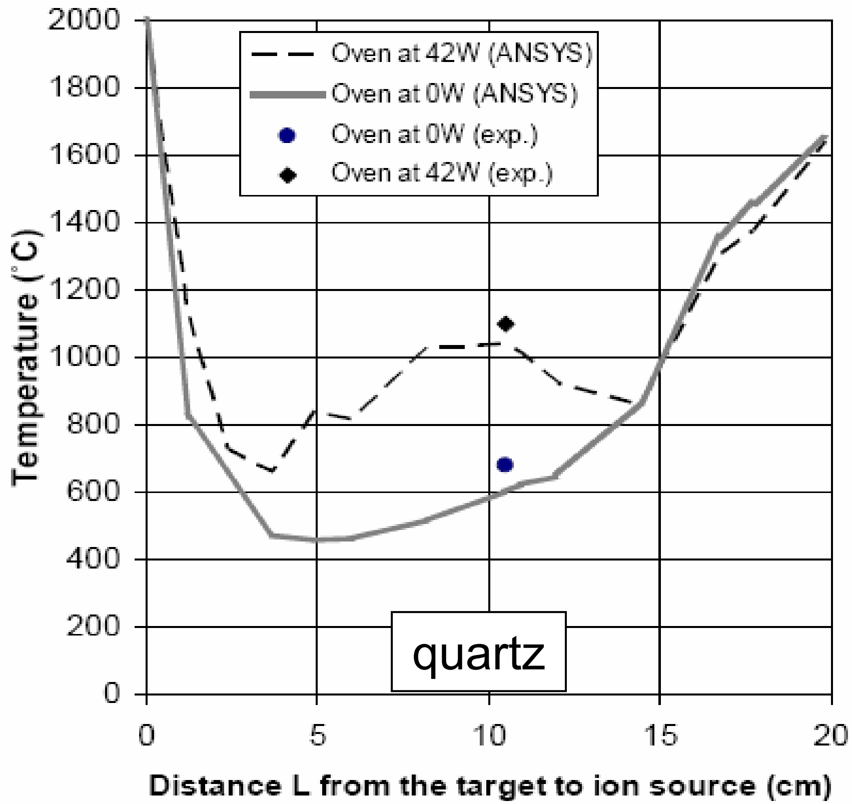


S.Marzari

Schematic layout and temperature profile within the quartz transfer line (v.1.0)

Design of the transfer line





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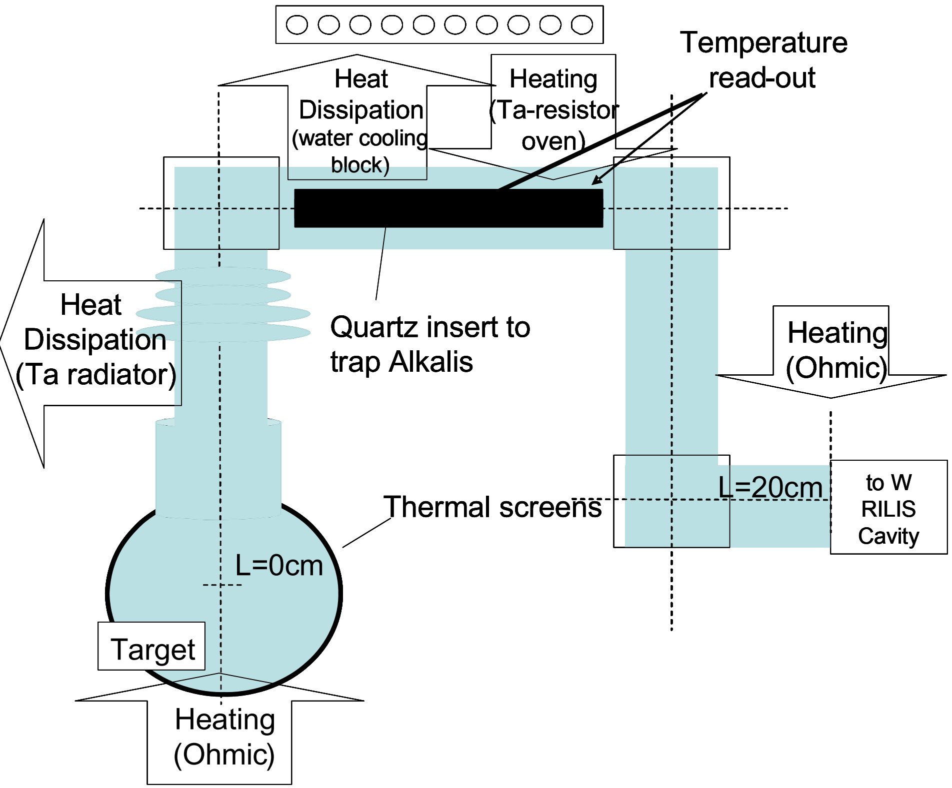
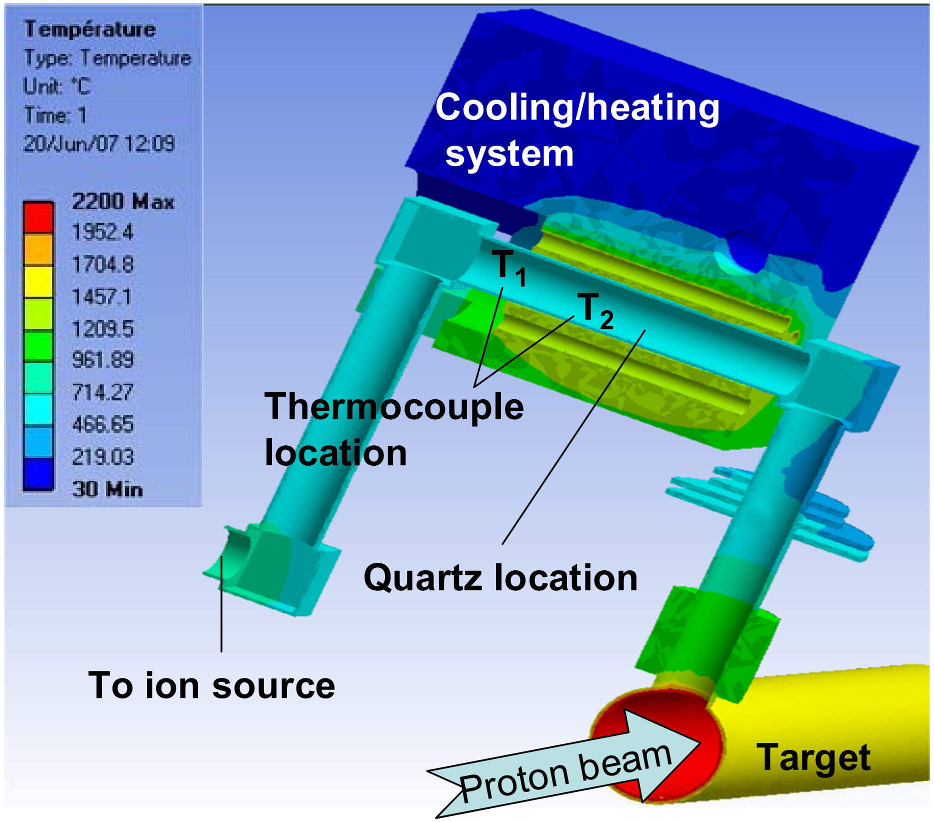
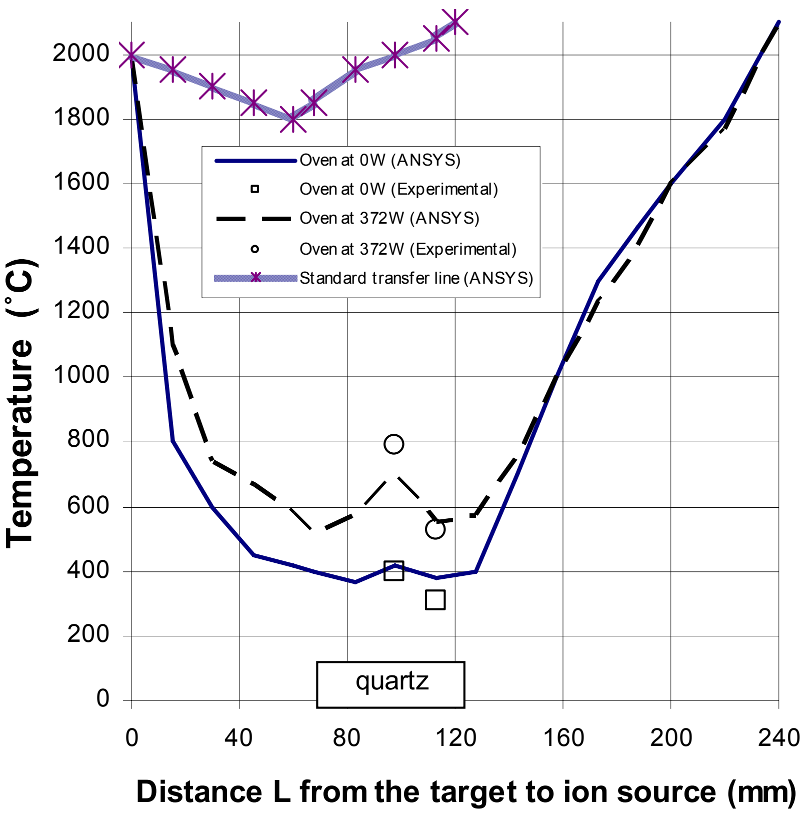
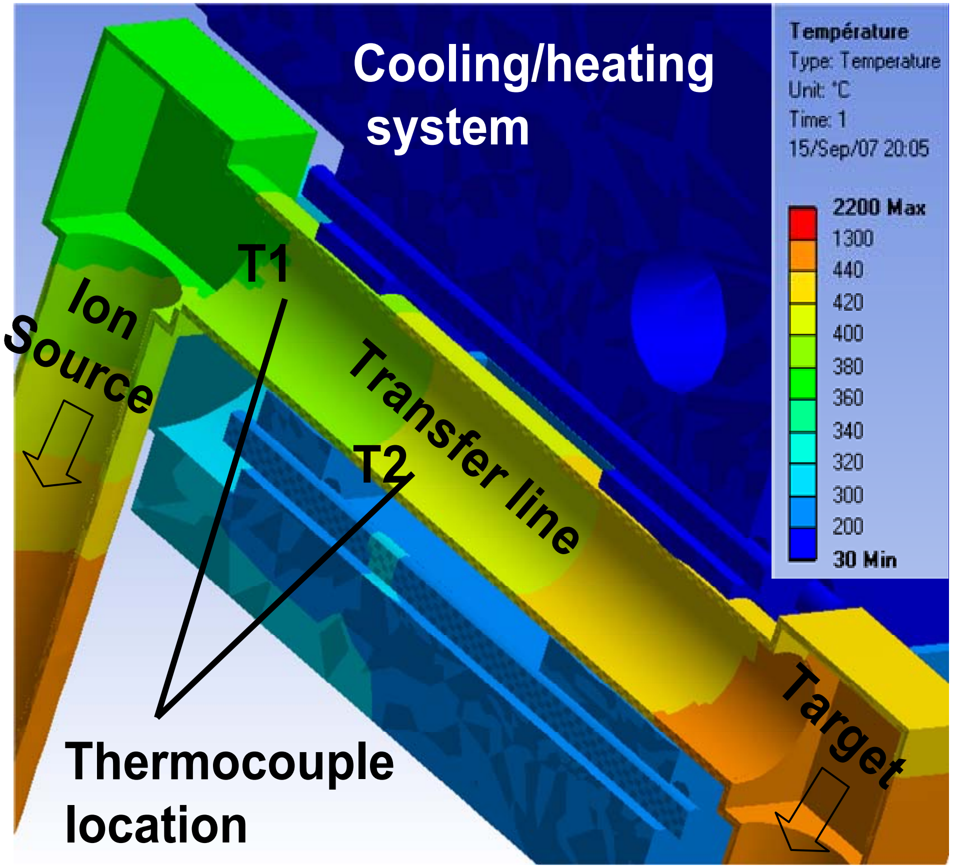




Schematic layout and temperature profile within the quartz transfer line (v.2.0)

Design of the transfer line





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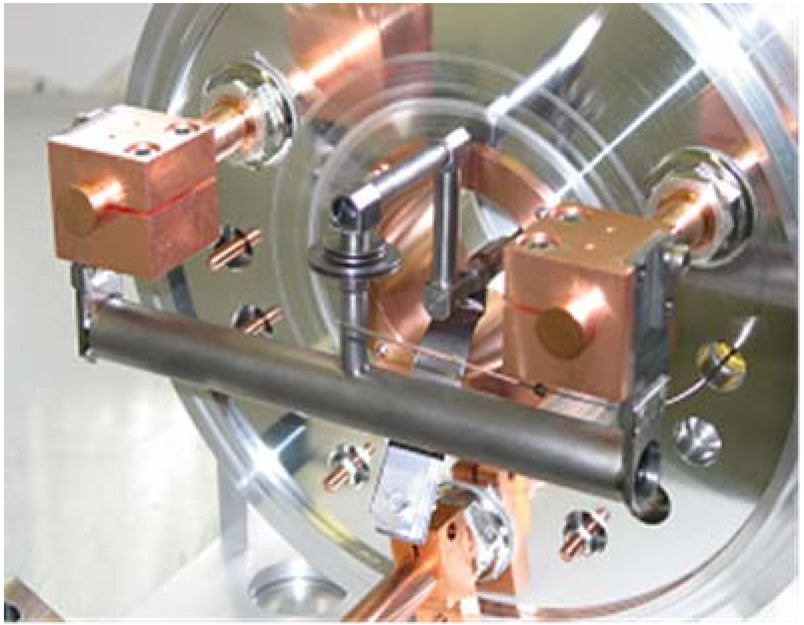
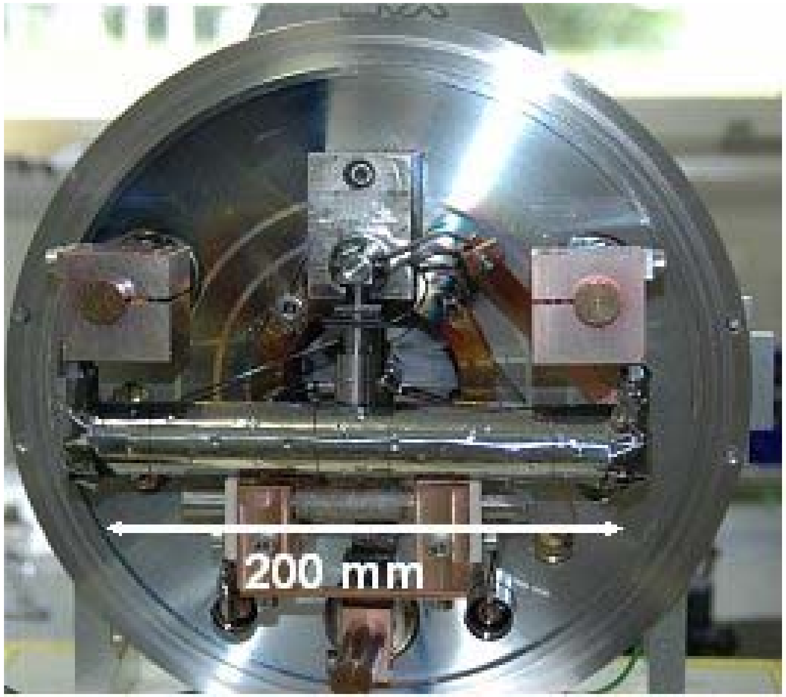
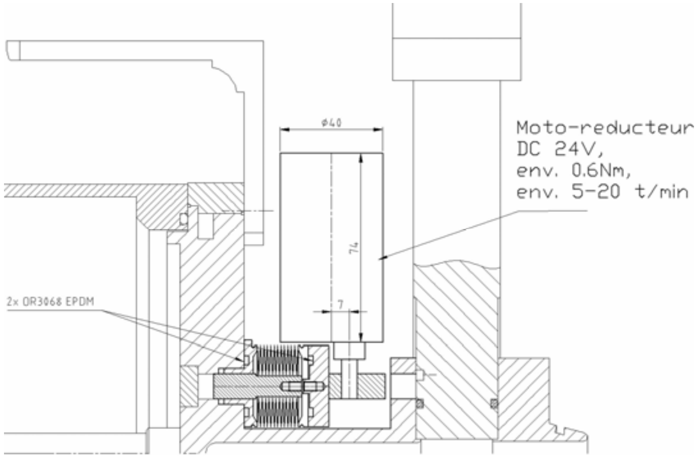


Quartz Transfer Line version 1.0
(before the final assembly)



Quartz Transfer Line version 2.0

Design of the transfer line



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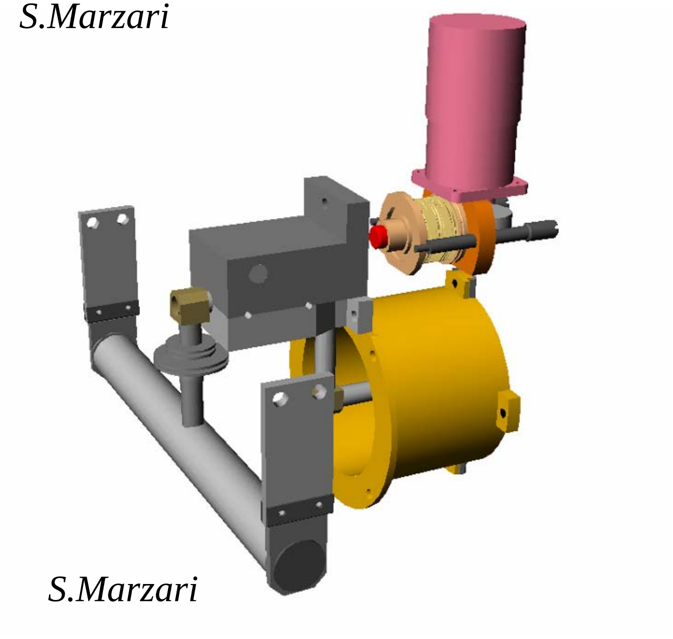

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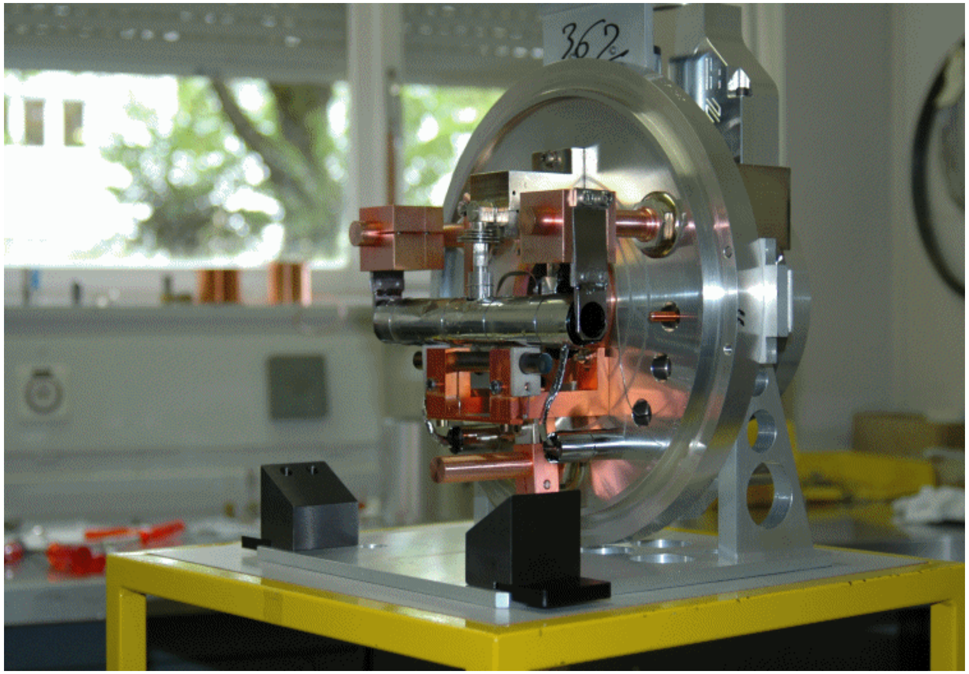


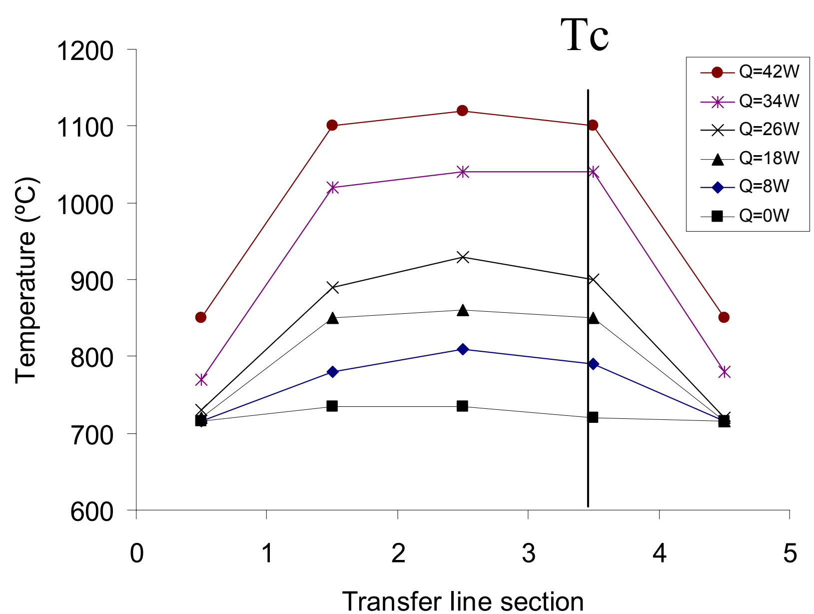
Schematic layout of the quartz transfer line version 3.0

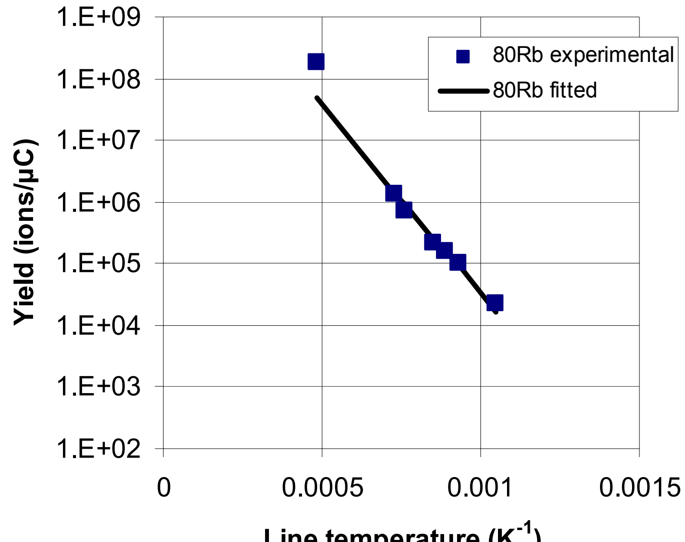
Online Results

Alkali Suppression

- ^{80}Rb ($t_{1/2}$=34s) suppressed by 4 orders of magnitude when compared to a standard UC_2-C unit:
  - 3.3×10^3 ions/µC (transfer line at 400ºC); 1.8×10^8 ions/µC (for standard unit)
- Significant quartz transfer line temperature effect on the ^{80}Rb yields

$$f_{th}(\lambda,T) = e^{\lambda \cdot t_0 \cdot \sum_{i=1}^{n} \left\langle (L_i - L_{i-1}) \cdot \frac{n_{coll}}{L} e^{(-\Delta H_{ad} / kT_i)} \right\rangle}$$





n_{coll} = 220 (from RIBO)
t_0 = 0.23 ps
k = 1.38×10^{23} J.K^{-1}
$-\Delta H_{ad}$ = 242 ± 20 kJ/mol

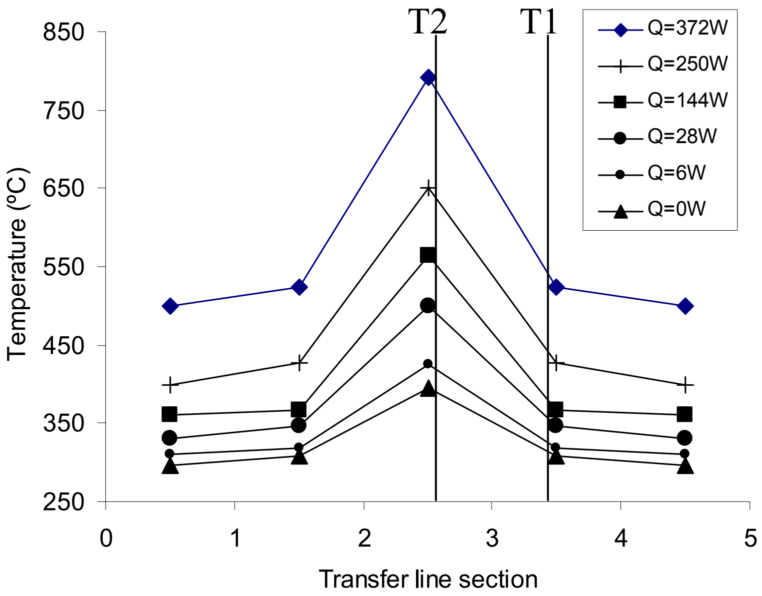
Measurement:
400 kJ/mol
U. Köster et al.

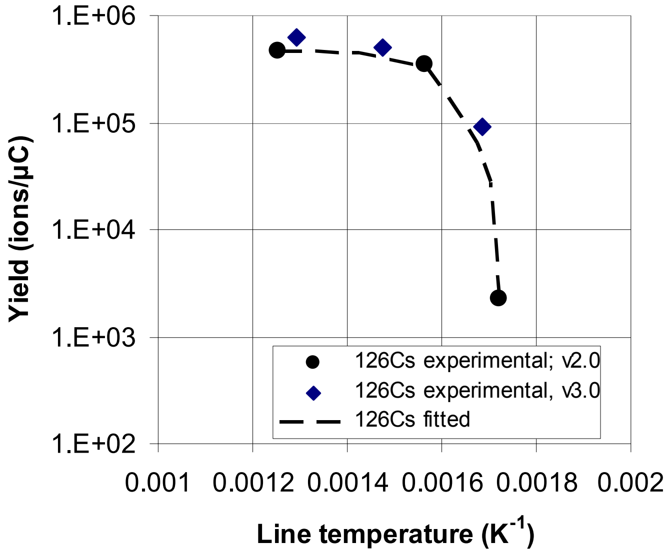
Online Results

Alkali Suppression

- ^{126}Cs ($t_{1/2}$=98.4s) suppressed by 2 orders of magnitude:
  - 2.3x10^3 ions/µC (transfer line at 308ºC); 4.6x10^5 ions/µC (transfer line at 550 ºC)
- Significant quartz transfer line temperature effect on the ^{126}Cs yields

$$f_{th}(\lambda,T) = e^{\lambda \cdot t_0 \cdot \sum_{i=1}^{n} \left\langle (L_i - L_{i-1}) \cdot \frac{n_{coll}}{L} e^{(-\Delta H_{ad} / kT_i)} \right\rangle}$$





n_{coll} = 220 (from RIBO)
t_0 = 0.23 ps
k = 1.38x10^{23} J.K^{-1}
$-\Delta H_{ad}$= 145 ± 15 kJ/mol

Measurement
230 kJ/mol
U. Köster et al.

Online Results

Alkali Suppression

^{207}Tl ($t_{1/2}$=4.77min) has been measured with the version 3.0 of the quartz line:

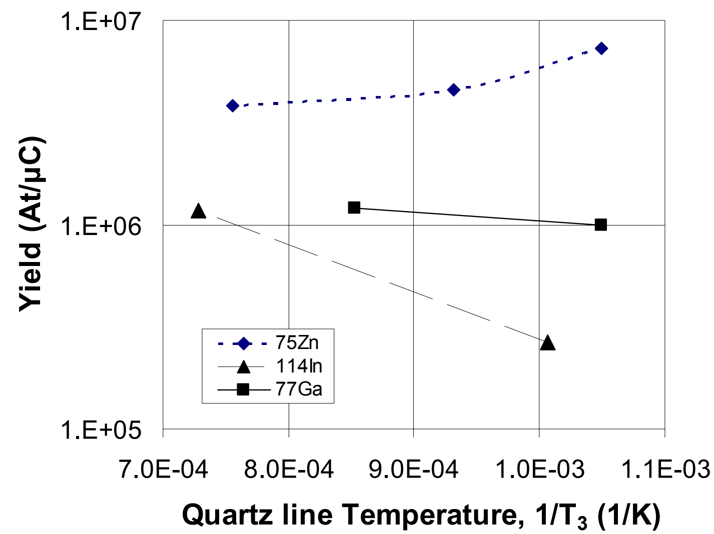
- Yield of 6.91x10^5 ions/µC (transfer line at 550 ºC)
- Suppression of ^{207}Fr contaminant

		Yield (atoms/µC)		
Isotope	Half Life (ms)	Quartz line T=300˚C	Standard ISOLDE Ucx T=1800˚C	Suppression factor
^{80}Rb	34000	3.3x10^3	1.8x10^8	54500
^{46}K	115200	6.5x10^5	5.4x10^7	80
^{8}Li	840.3	1.7x10^5	3.9x10^7	230
^{142}Cs	1780	2.5x10^5	1.5x10^8	600

Other alkali suppression factors

Production of In, Zn, Ga and Sr

Isotope	Half life (ms)	TL Temperature (ºC)	Yield (atoms/µC)
^{75}Zn	10200	700	7.3x10^6
^{77}Ga	13200	700	9.9x10^5
^{114}In	72000	700	2.7x10^5
^{77}Ga	13200	300	4.8x10^4
^{96}Sr	1070	300	1.5x10^4



Summary

- Chemical selectivity was achieved by specific interaction of the contaminant with a catching material inserted in the transfer line
- Clear dependence of the ^{80}Rb and ^{126}Cs suppression as a function of the quartz temperature was observed
- Enthalpy of adsorption has been estimated for the
  - Rb ($-\Delta H_{ad}$ = 242 kJ/mol)
  - Cs ($-\Delta H_{ad}$ = 145 kJ/mol) elements and are ~60% of values by isothermal chromatography
- ^{207}Tl has been measured (suppression of ^{207}Fr)

Future Investigations

- Test of a prototype operating with a broader range of temperature (from 200ºC to 1200 ºC)
- Further investigations on experimental data could lead to physical models to deduce the suppression factor for the different other isotopes
- The use of other materials to suppress different contaminants (collaboration C. Jost, ORNL)

References

- E. Bouquerel, R. Catherall, M. Eller, J. Lettry, S. Marzari, T. Stora and the ISOLDE Collaboration, " *Purification of a Zn Radioactive Ion Beam by alkali suppression in a quartz line target prototype*" (European Phys. Journal A.) *in press*.
- U. Köster, O. Arndt, E. Bouquerel,' *Progress in ISOL target-ion-source-systems*', Nuclear Instruments and Methods in Physics Research, Section B (NIMB). (*to be published*)
- S. Sundell, H. Ravn and the ISOLDE Collaboration, NIM B70 (1992) 160.
- V.N.Fedosseev et al,"*Development of the RILIS Research laboratory at ISOLDE*", CERN-INTX-2006-015, INTC-I-065, 20.01.2006
- K.L. Kratz et al., "The Beta-decay half-life of ${}^{130}_{48}Cd_{82}$ and its importance for astrophysical r-process scenarios", CERN-EP/86-189, 18 November 1986.
- M. Santana Leitner, *A Monte Carlo Code to Optimize the Production of Radioactive Ion Beams by the ISOL Technique*, PhD. Thesis, UPC-ETSEIB / CERN.
- M. Turrion Nieves, Private Communication – CERN.
- Fundamentals of Heat and Mass Transfer Fifth Edition, Frank P Incropera, David P DeWitt, John Wiley & Sons 2002, pp 53, pp 699.
- http://www.ansys.com/products/workbench.asp.
- ISOLDE target reference UC2020.

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Thank you for your attention!