# Post-irradiation analysis of the tantalum container of an ISOLDE LBE target

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*We acknowledge the financial support of the European Community under the FP6 "Research Infrastructure Action – Structuring the European Research Area" EURISOL DS Project Contract no. 515768 RIDS. The EC is not liable for any use that can be made on the information contained herein.

10th International Workshop on Spallation Materials Technology

Beijing, 18-22nd October 2010

# Outline

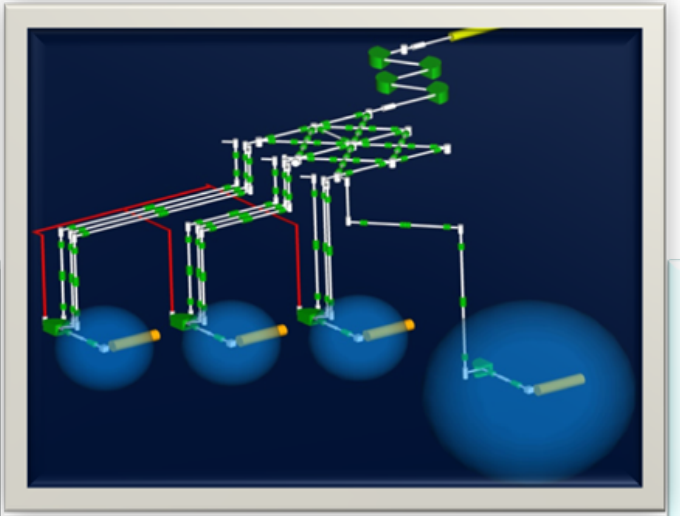
- The EURISOL Design Study
- Target geometry
- Irradiation conditions
- Post-irradiation analysis
- Summary

# The EURISOL Design Study

## 100 kW direct targets

RIB production:
- Spallation-evaporation
  - Main: P-rich (10 to 15 elements below target material)
  - Residues: N-rich (A few elements below target material)

Target materials:
- Oxides
- Carbides
- Metal foils
- Liquid metals



**Participants:**
**~20 institutions**

**Duration:**
**2005-2009**

**Contributors:**
**~20 institutions**

**12 Tasks**

**EU suport (~30%):**
**~9.2 MEuros**

## mMW fission target

RIB production:
- Fission
  - N-rich
  - Wide range Z = 10 to Z = 60

Target material:
- U (baseline)
- Th

Converter:
- Hg

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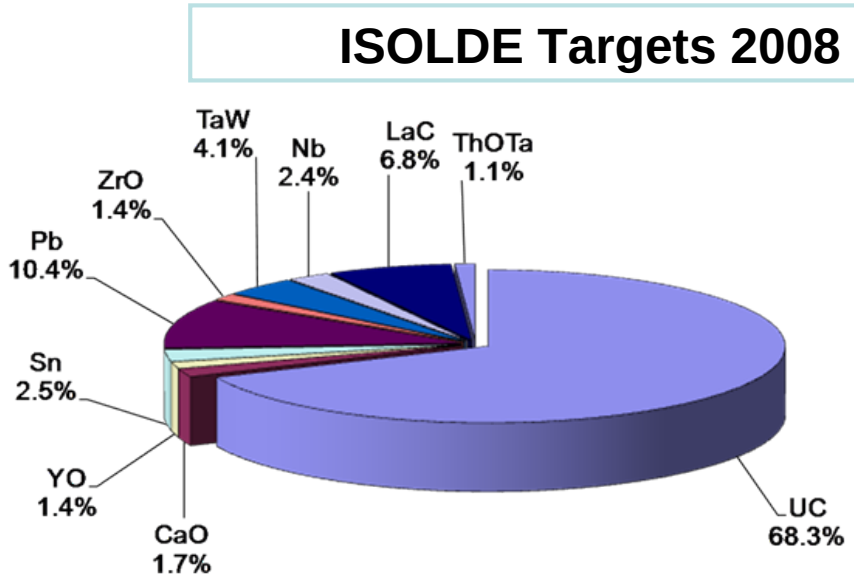
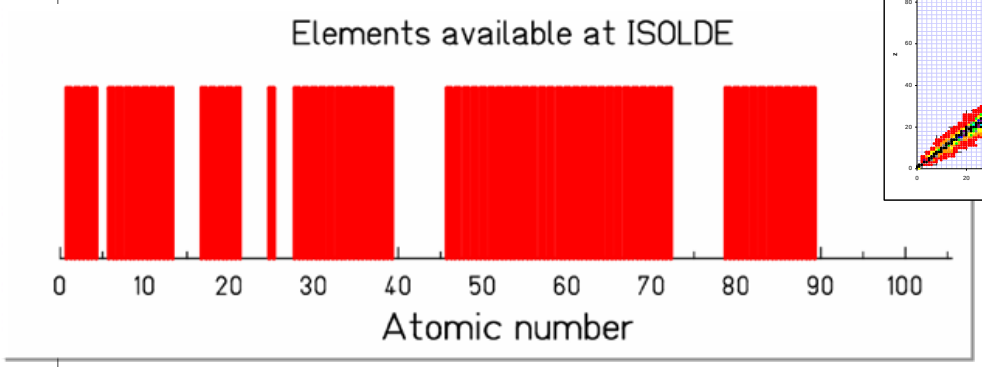
# ISOLDE Targets and RIBs

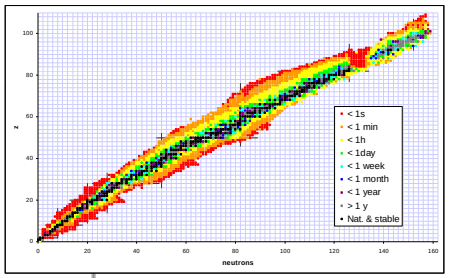
## Target elements

- UCx, ThCx
- CaO, MgO, $Al_2O_3$, ZrO
- Ta, Nb
- Sn, Pb, La
- SiC, $LaC_2$




## RIBs

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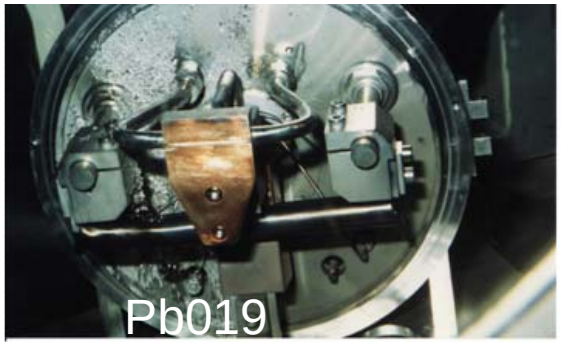
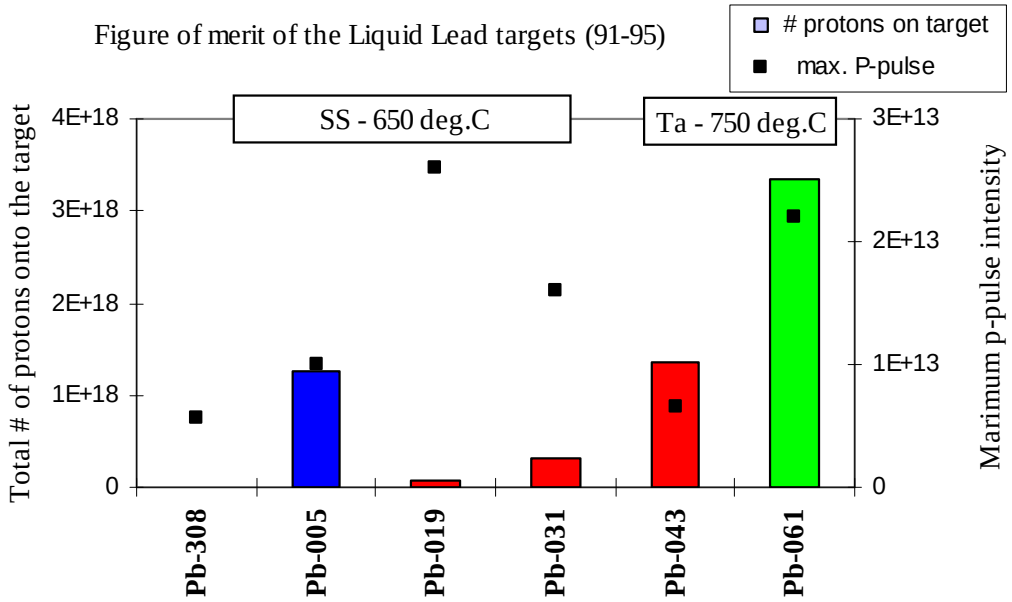
# Pb target history


Condensed Pb found on condensation helix introduced in chimney.


Broken container welds and splashing of Pb onto target enclosure.



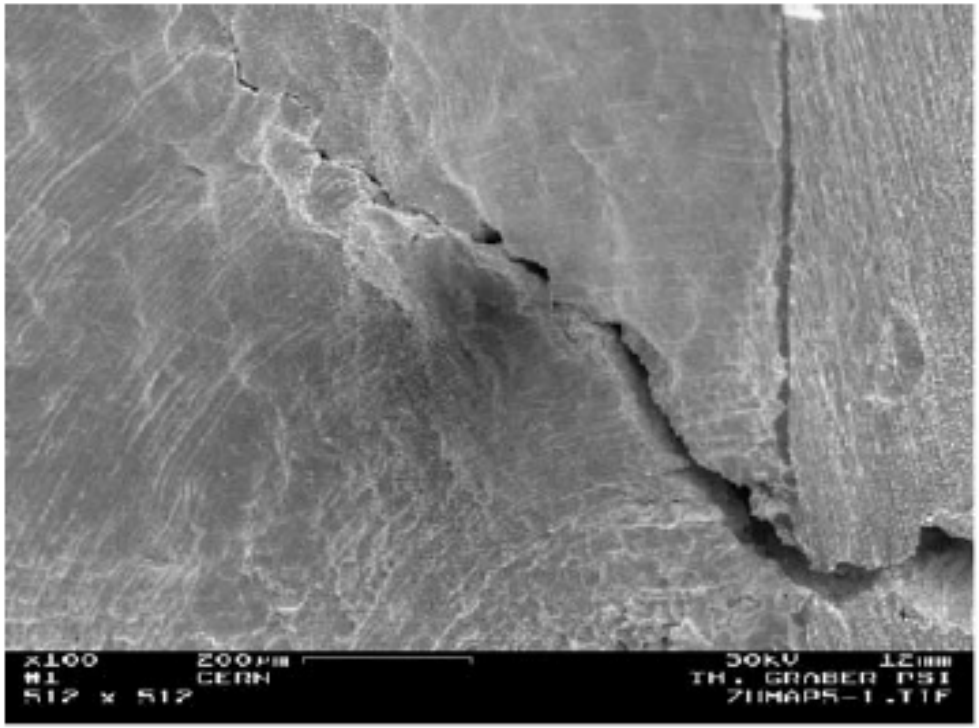

Some early target units were destroyed after just a few pulses from the PSB (e.g. Pb019, Pb031)

Data and photos from J. Lettry
Photos taken by CERN photos

# Target container damage

Ta-window of the ISOLDE molten lead target Pb-043

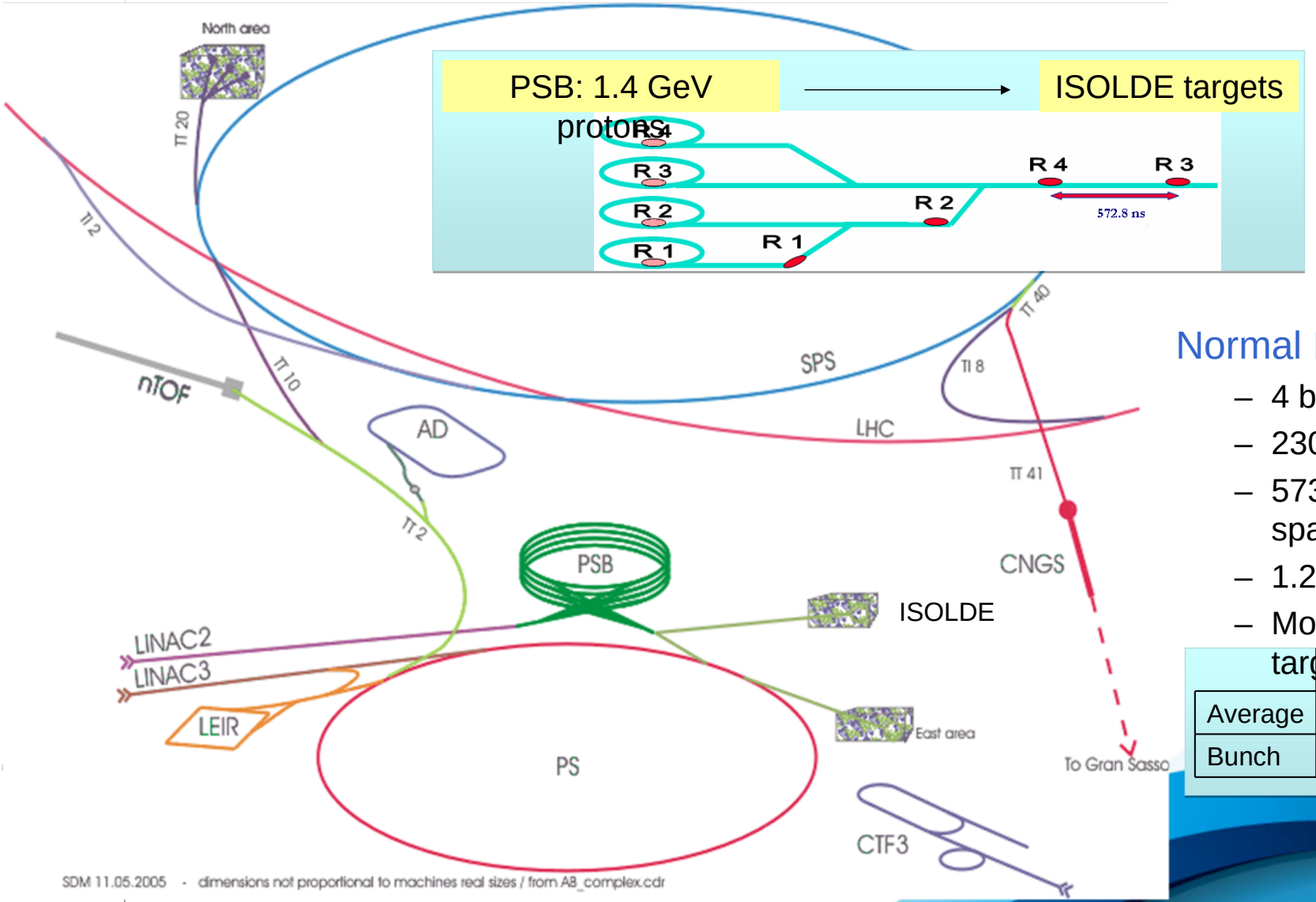
thermal stress induced crackcorrosion pattern of cavitation





*J. Lettry et al. / Nucl. Instr. and Meth. in Phys. Res. B 204 (2003) 251–256*

# Origin: pulsed nature of proton beam







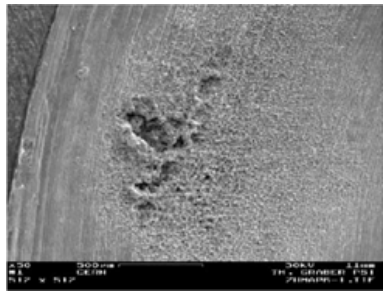
## Normal PSB beam

- 4 bunches.
- 230 ns bunch width.
- 573 ns bunch spacing.
- 1.2 s repetition rate.
- Most ISOLDE targets

| | Current | Power |
|---|---|---|
| Average | 1.92 μA | 2.7 kW |
| Bunch | 8.36 A | 11.7 GW |

# Beam current density

| | Averaged over 1s | Within pulse |
|---|---|---|
| SNS | 12.5 μA/cm$^2$ | 2.4 × 10$^6$ μA/cm$^2$ |
| | | 2.1 × 10$^5$ μA/cm$^2$ |
| Isolde 1990s | ♭ 5.7 μA/cm$^2$ | |
| Isolde 2010 | ♯ 1.7 μA/cm$^2$ | 5.3 × 10$^4$ μA/cm$^2$ |

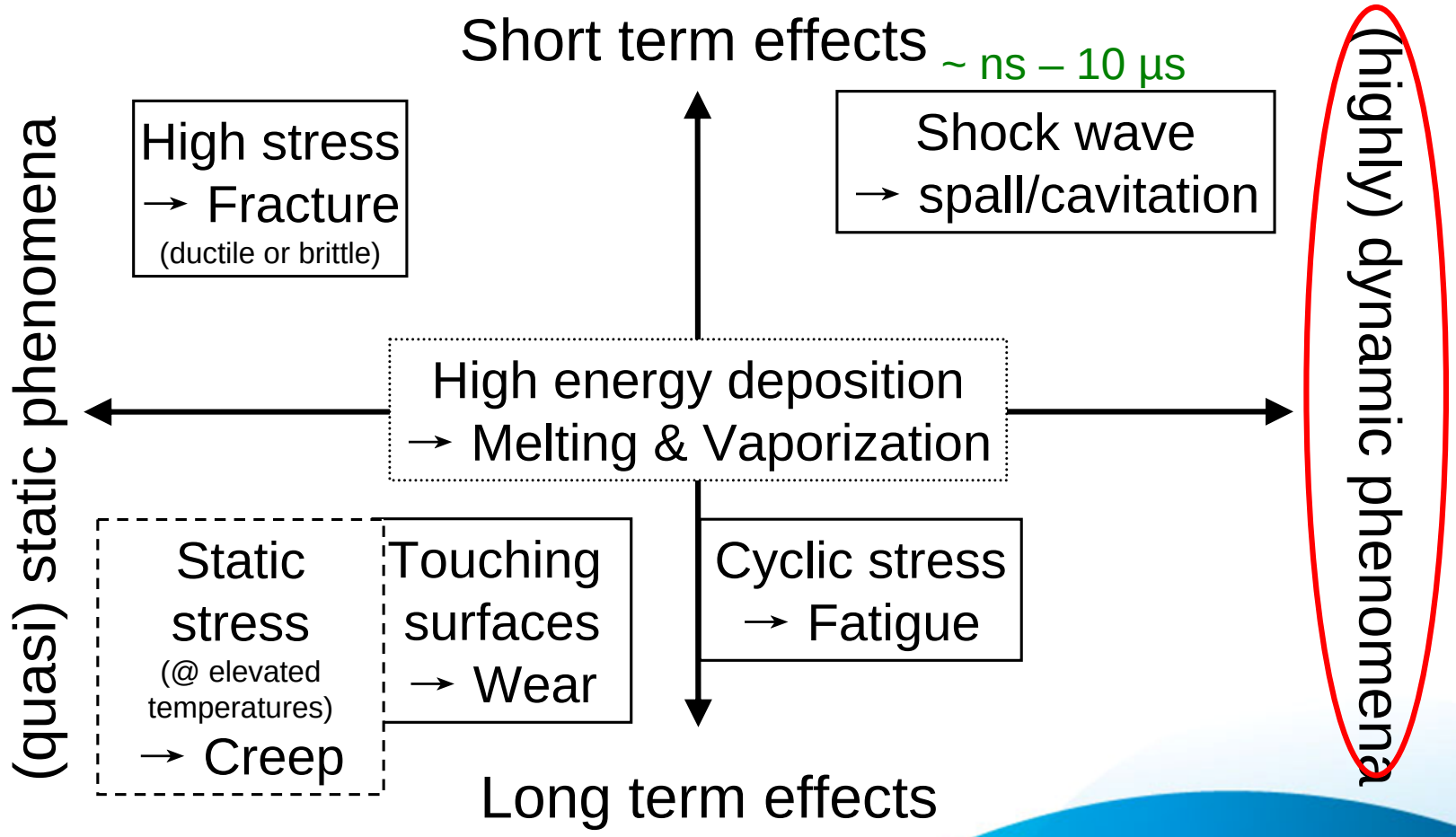



♭ 6.5 × 10$^{12}$ protons per pulse

♯ 1.0 × 10$^{13}$ protons per pulse

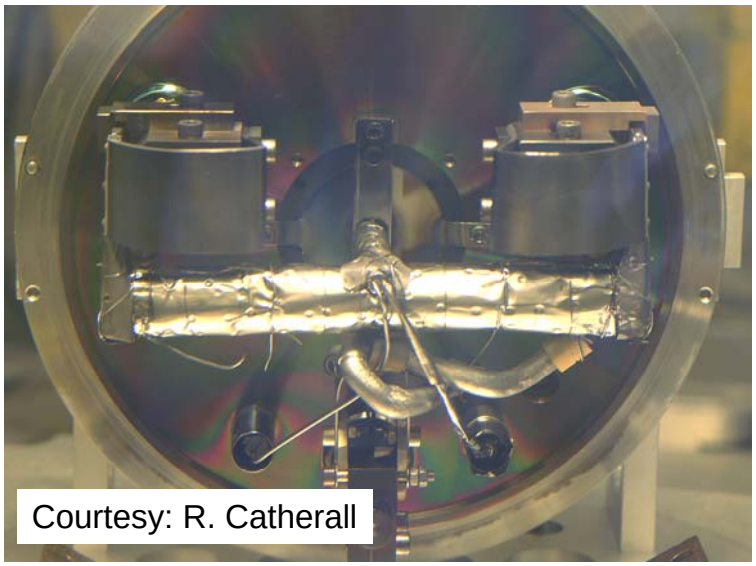
# Causes of material failure

*(schematic)*




H. richter

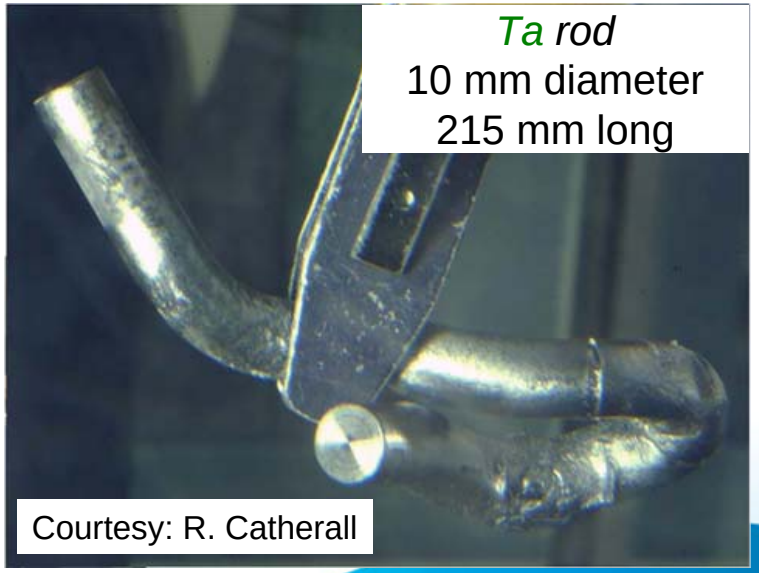
# Some examples...



Courtesy: R. Catherall

Target #183 $UC_2$-C

- W Surface Ion Source
- 5.5E+18 protons
- (50% on converter)



*Ta rod*
10 mm diameter
215 mm long

Courtesy: R. Catherall

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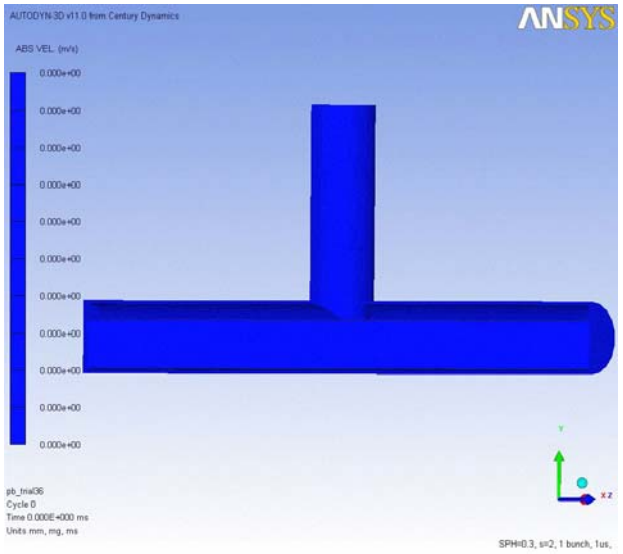
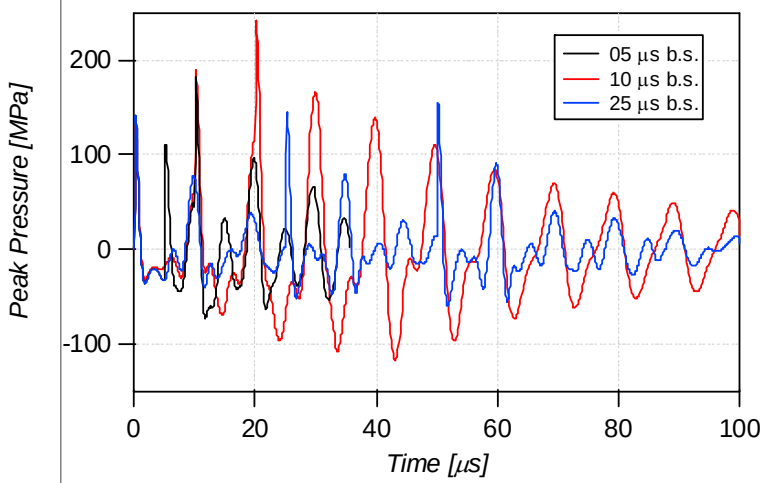
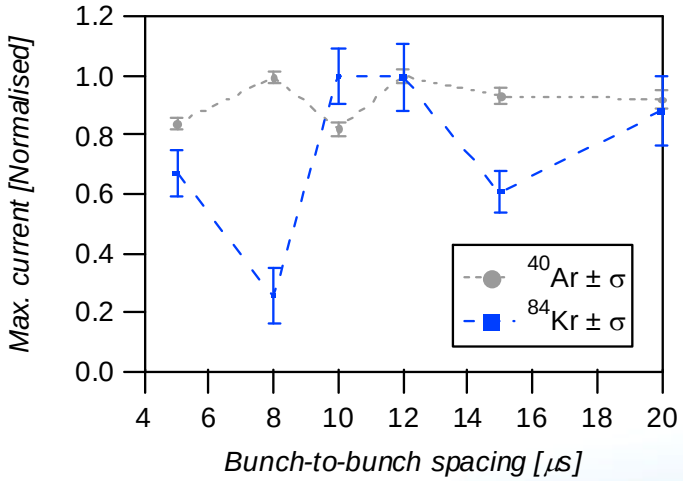
# Changing proton bunch spacing




*E. Noah et al., NIM B 266 (2008) 4304-4307*

- Pb target #305:
  - August 2007.
  - MK3 ion source.
  - ISOLDE GPS separator.
  - $10^{13}$ protons.
  - 1.4 GeV.
  - Time-staggered beam.

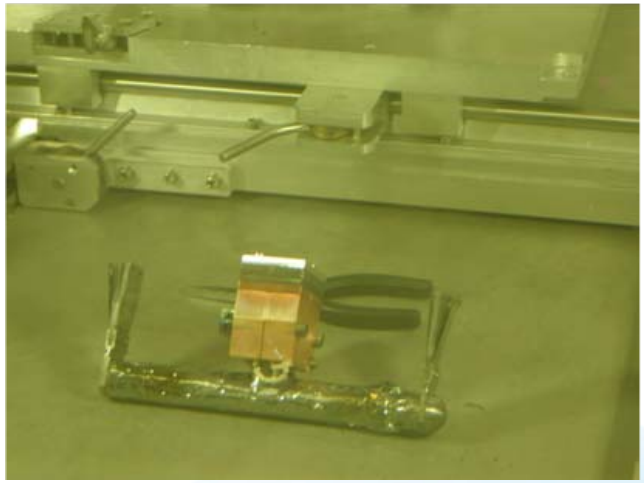



2009: change bunch spacing from 10 μs to 16 μs

# Motivation for further investigations

- Changes to operation environment at ISOLDE:
  - - Target geometry
  - - Change in beam profile: “STAGISO” beam with change in bunch-to-bunch separation.
- Post-irradiation analysis of an ISOLDE LBE target within the framework of the MEGAPIE project: Interest in determining whether noble gases were completely released from target during online operation at ISOLDE.
- Opportunity to study structural components of LBE target.

LBE target #264:
-1.3 $\times$ $10^{17}$ protons in 2004
-1.0 $\times$ $10^{18}$ protons in 2005



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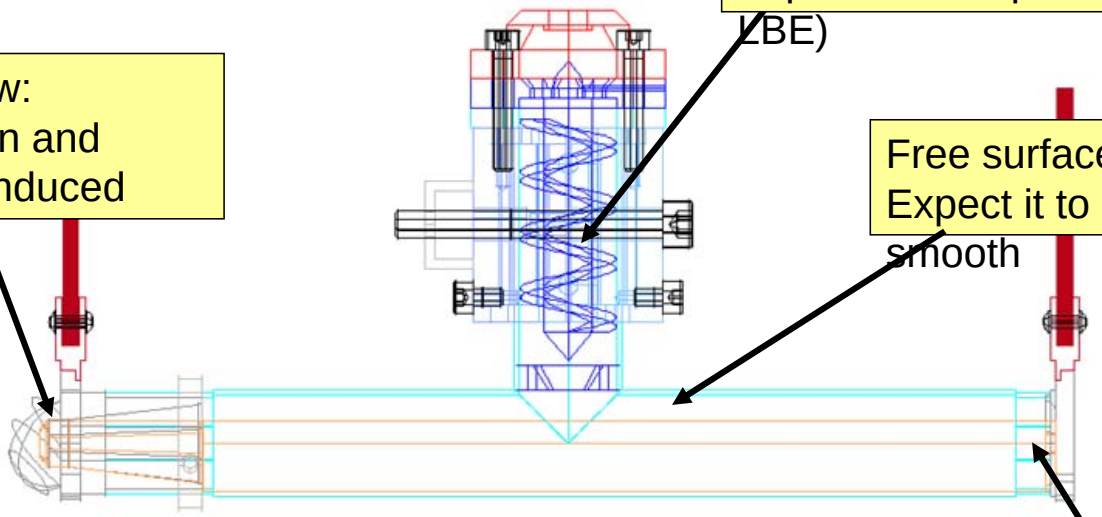
# Tantalum container investigations



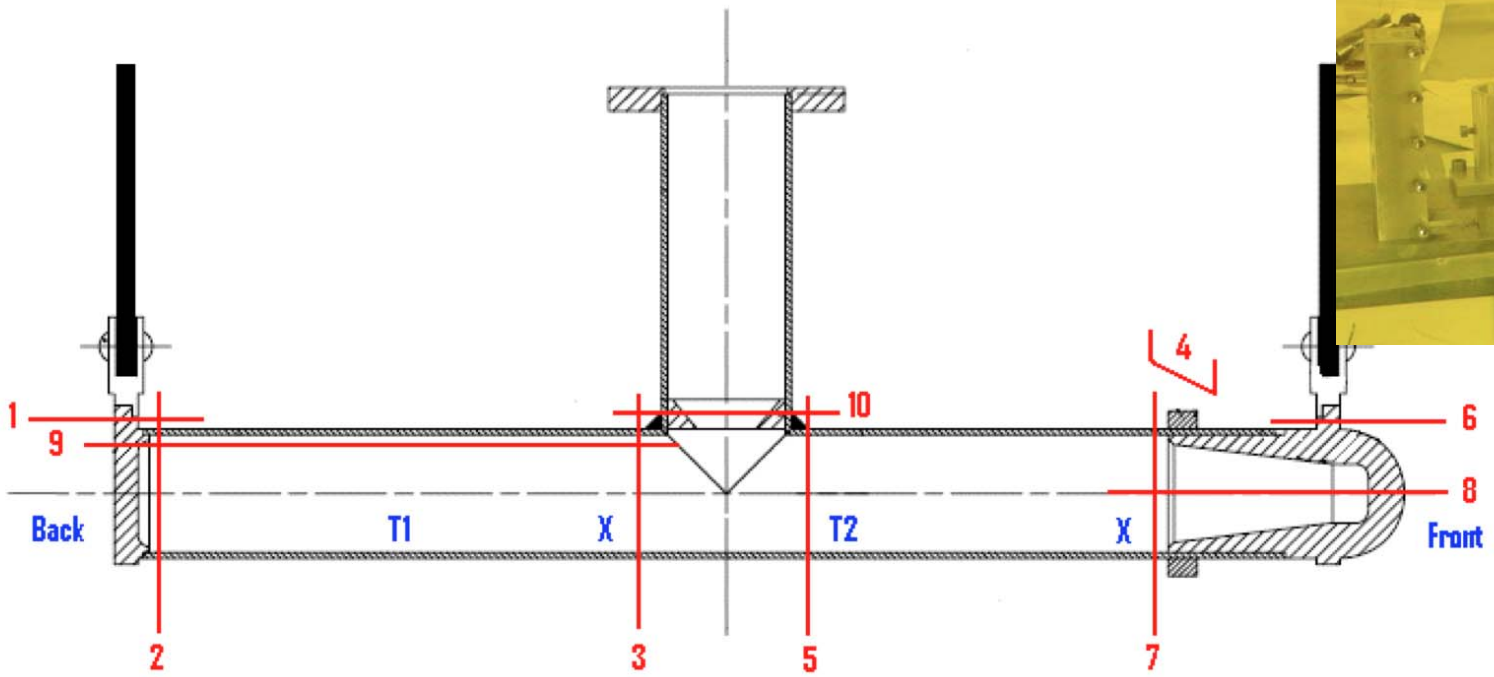
Ta chimney and helix:
Expect LBE deposits (splashing of LBE)

Ta beam window:
Expect cavitation and thermal stress-induced cracks

Free surface of LBE:
Expect it to be smooth

Ta back of target (stub end):
Compare with beam window

# Target cutting



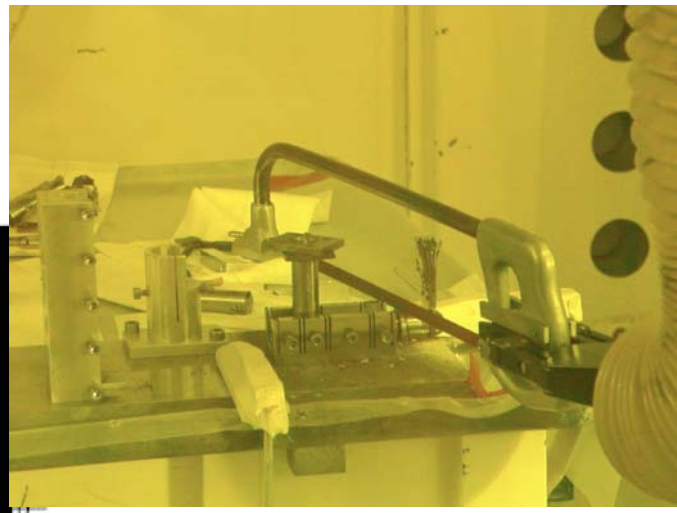
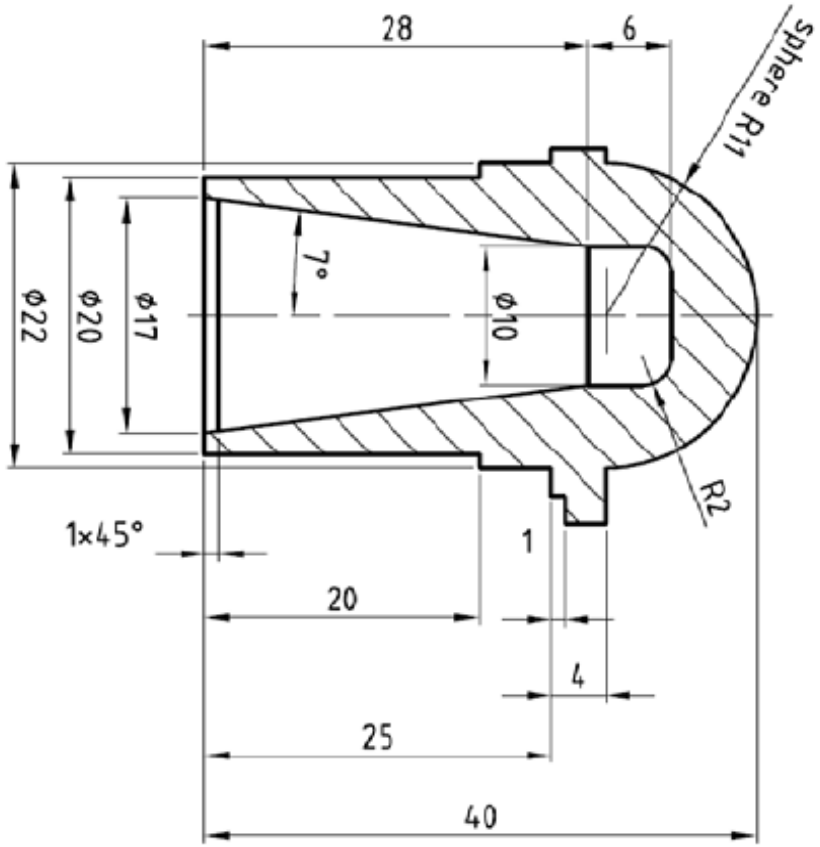
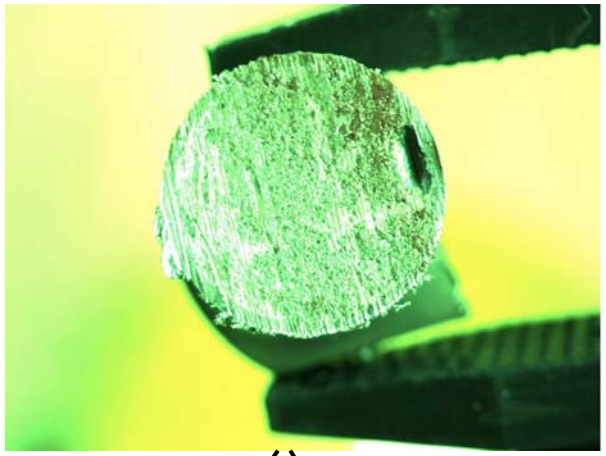



Photo by V. Boutellier

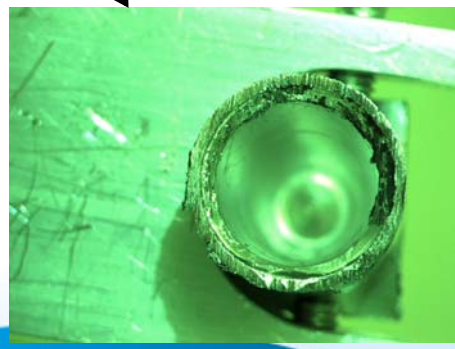
- Beam window: cuts 4,6,7,8.
- Stub end: cuts 1,2.
- Chimney: cuts 3,5,10.
- LBE free surface: cut 9.

# LBE Removal: beam entrance window



Heat



Photos by V. Boutellier, PSI

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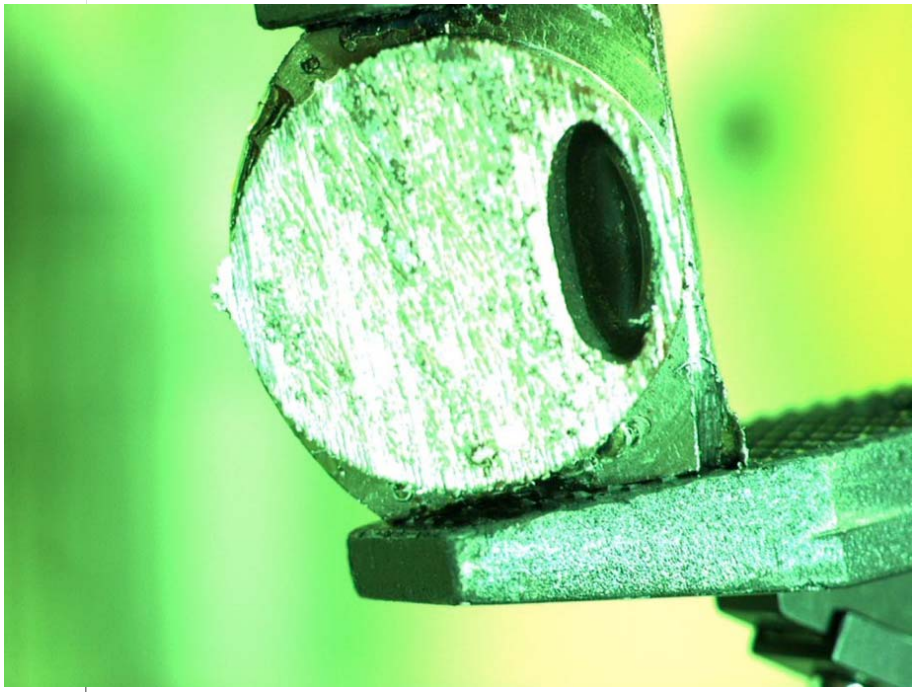
# LBE removal: back of target



Photos by V. Boutellier, PSI

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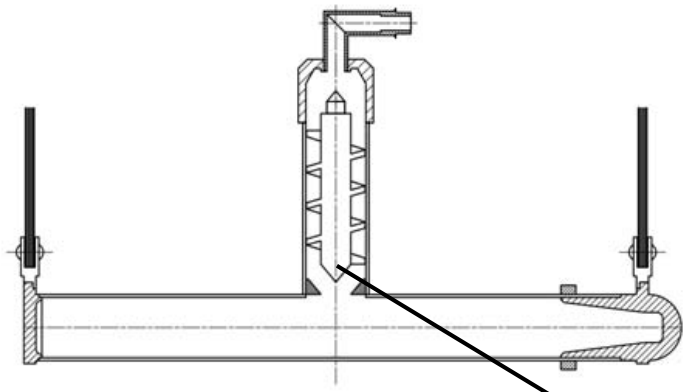
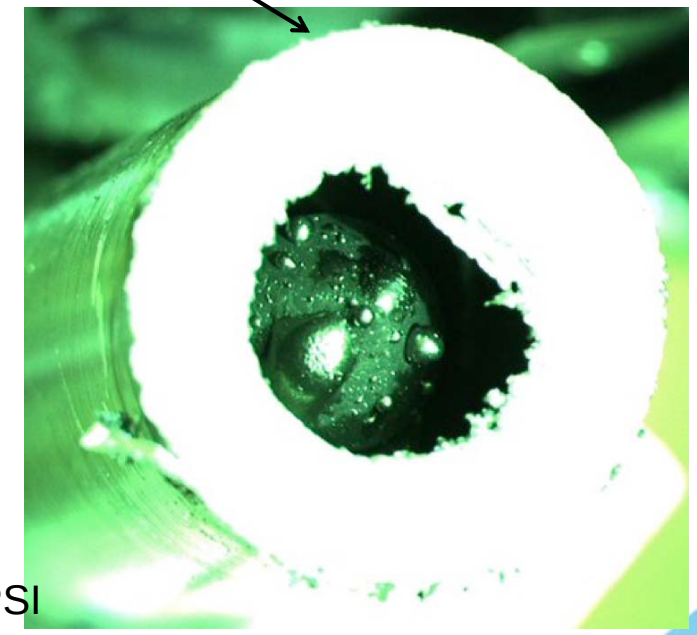
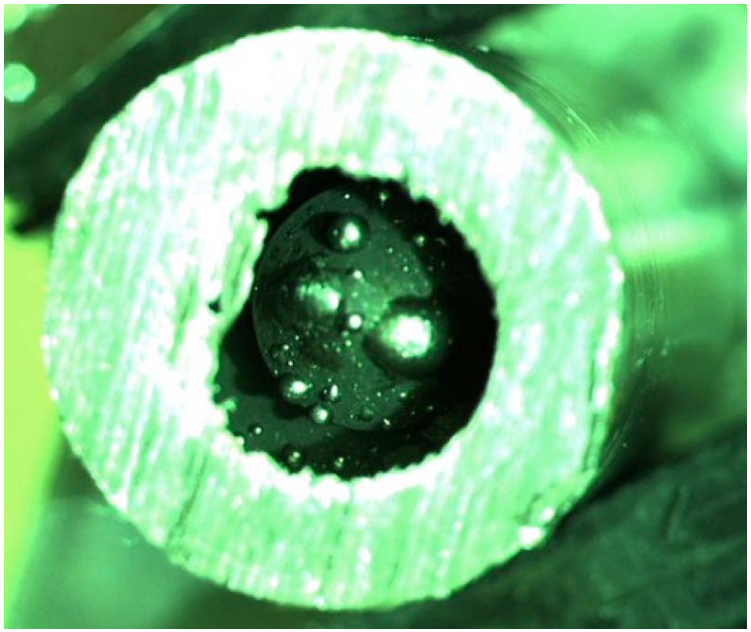
# Chimney

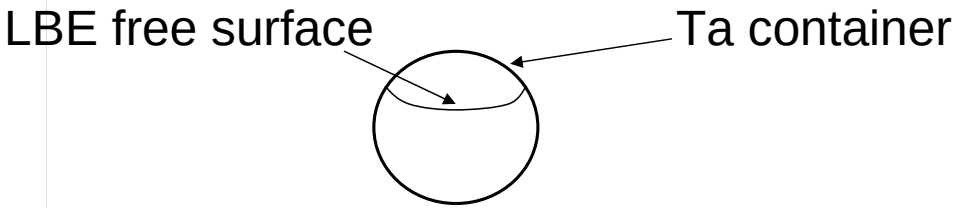


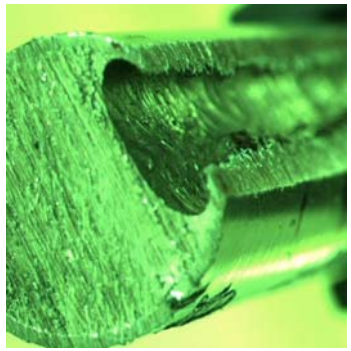


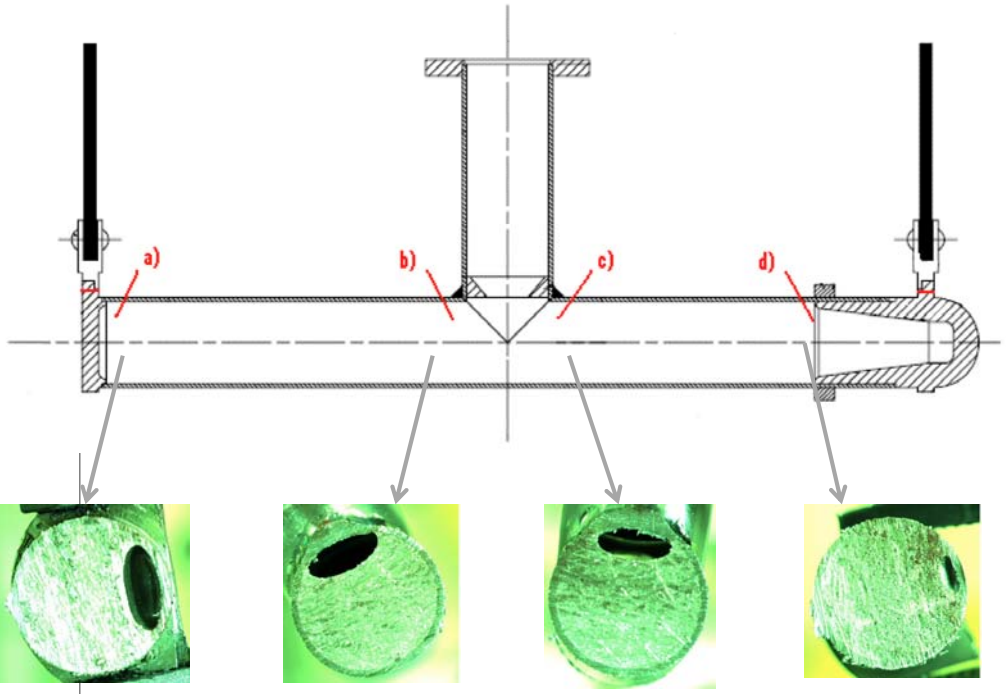


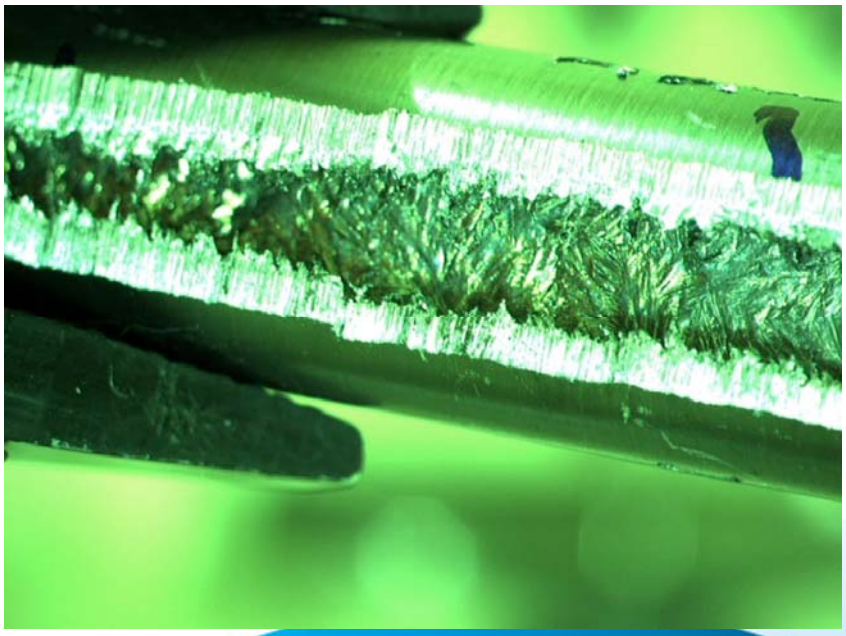
Photos by V. Boutellier, PSI

# LBE free surface



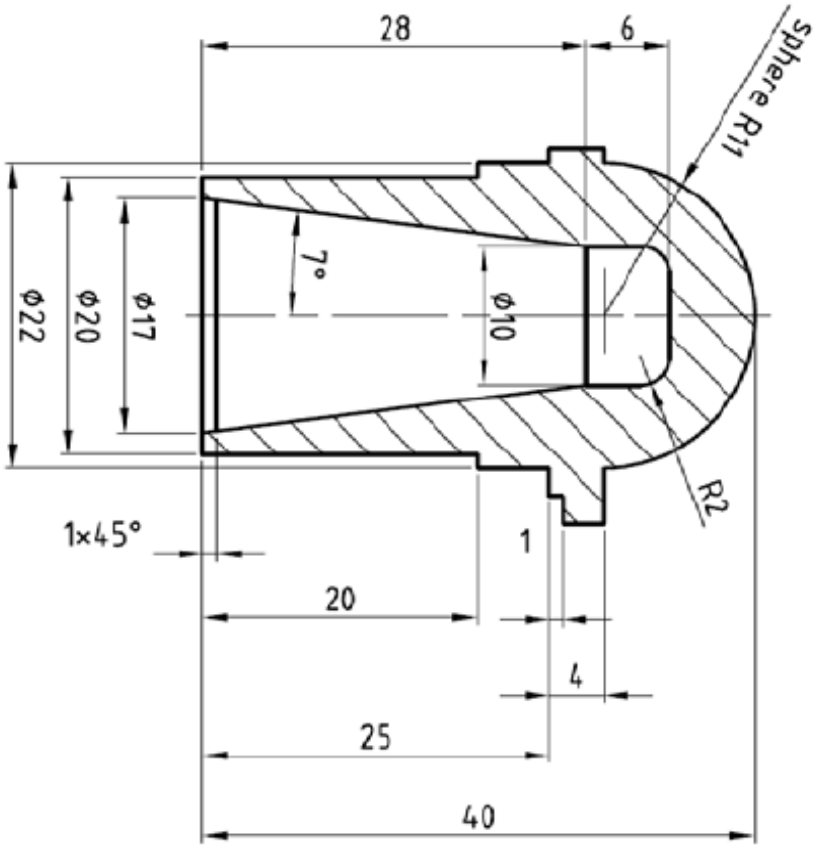



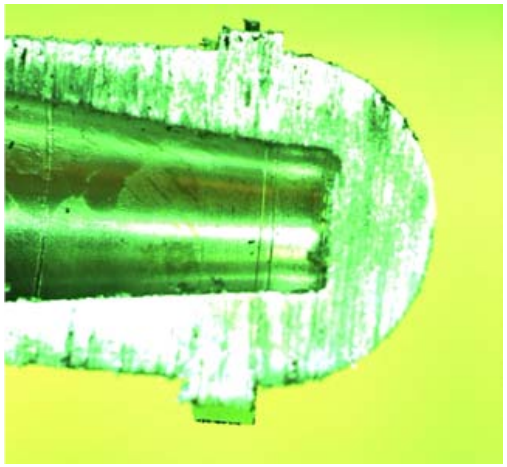


Photos by V. Boutellier, PSI

# Beam Entrance Window



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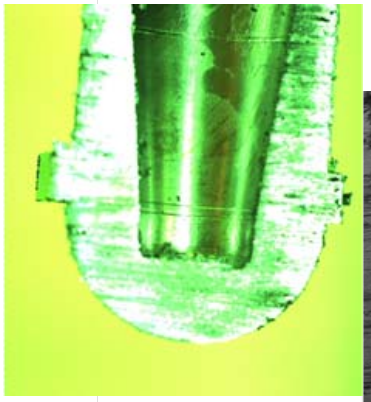
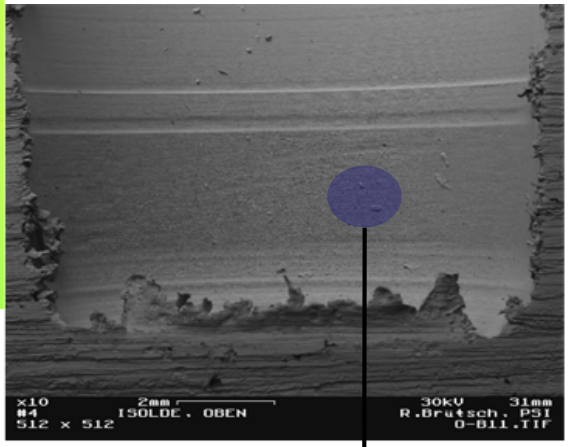
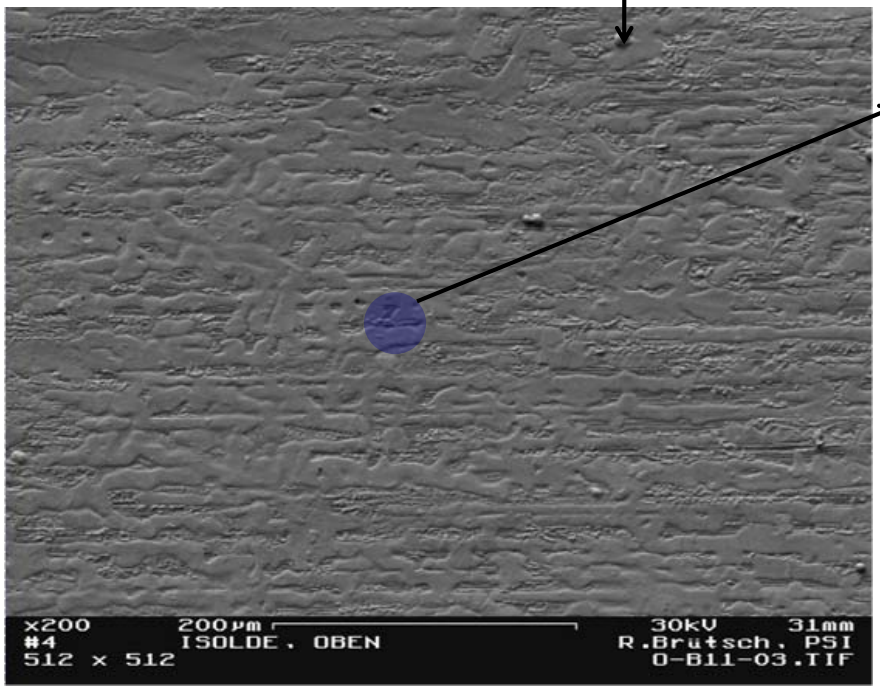
# Beam Entrance Window: SEM







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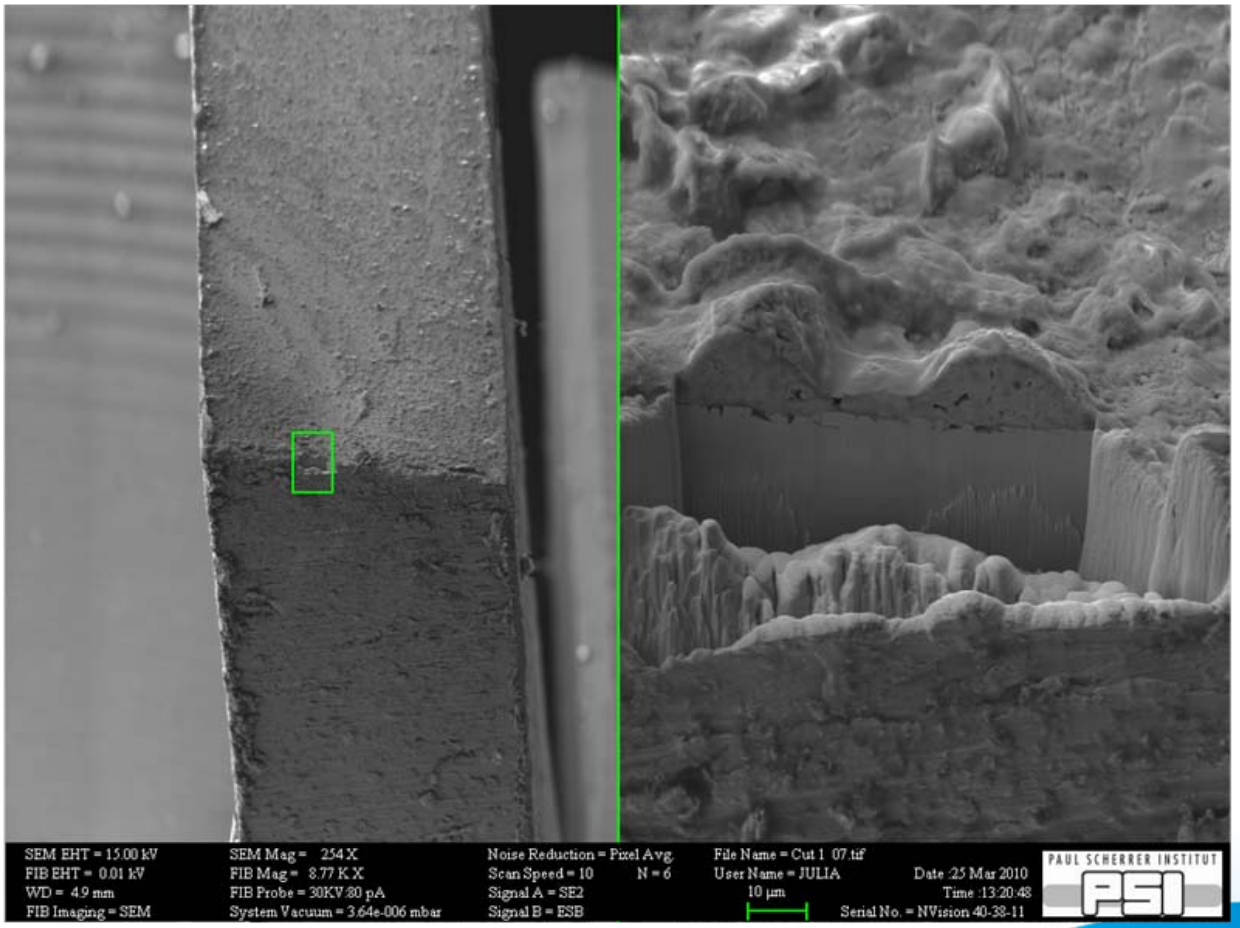
# Beam Entrance Window: FIB

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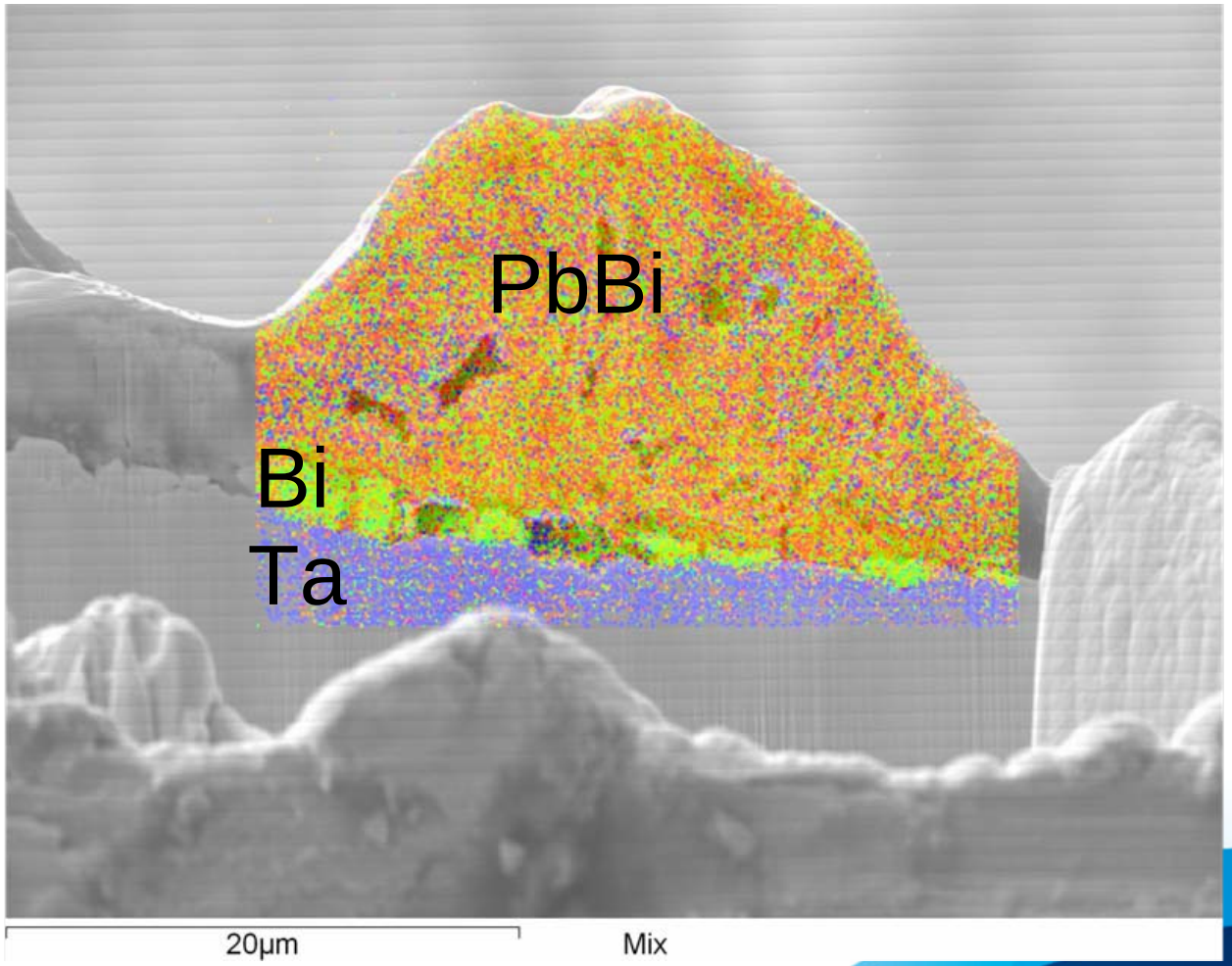
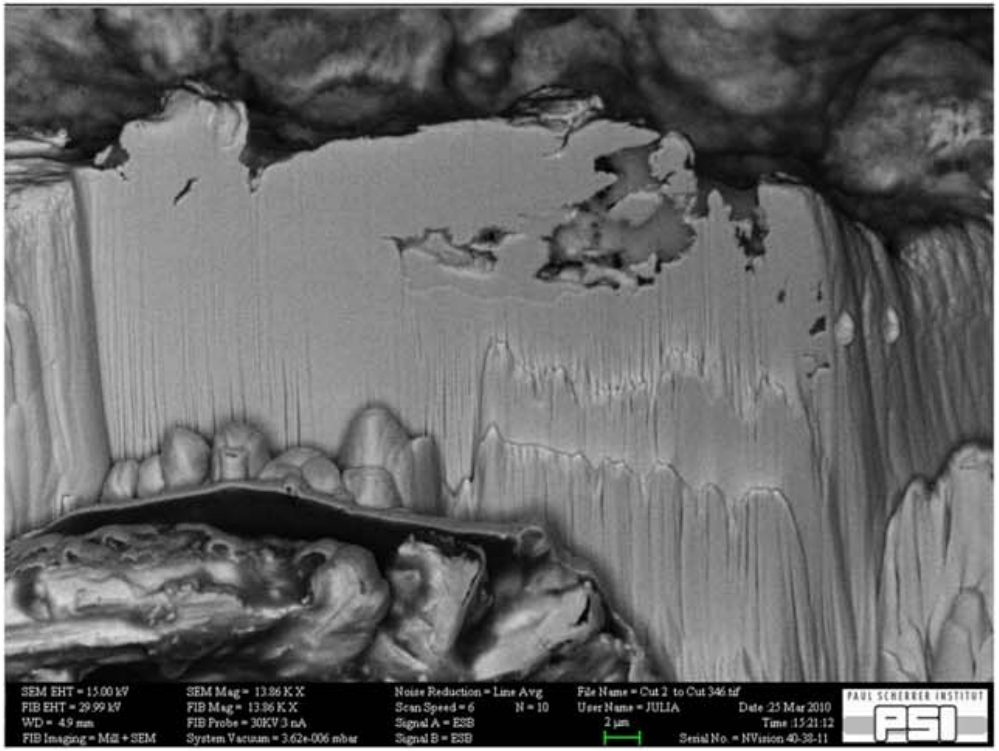
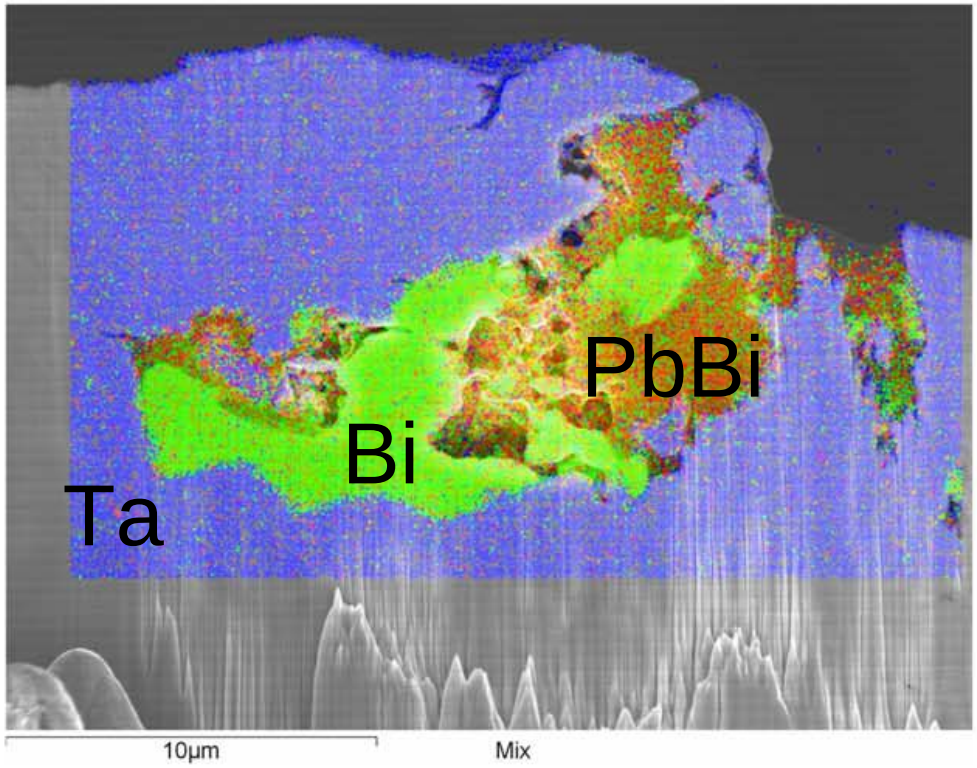
# BEW: Ta/Bi/PbBi Surface Layer



# BEW: PbBi-filled Micron-sized Crack

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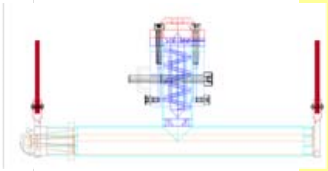
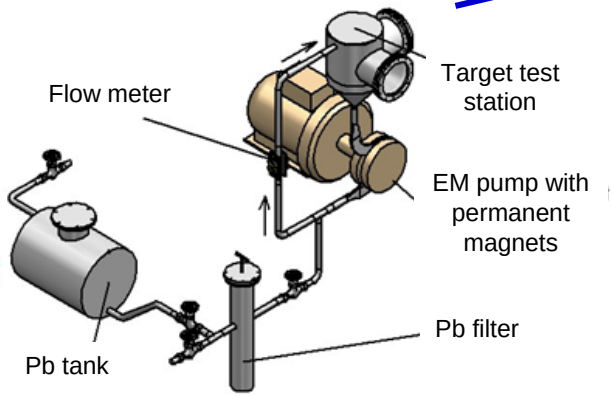
# Outlook: LM Target for RIBs

## Static



- Today's state of the art [ISOLDE]:
  - Release fraction < 2% for short-lived Hg
  - Diffusion $\tau$ >> 10s
  - Max. power deposition 1 kW !!!

## Loop: for heat removal



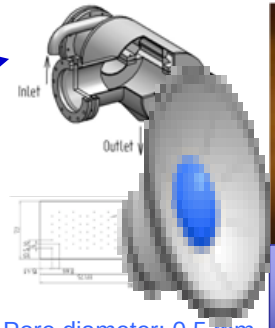

## 100 kW loop

- Loop=Target material: Pb, LBE
  - Operating temperature: 1100 K
  - ΔT: 100 K
  - Flow rate: 0.2 l/s
- Beam: 1 GeV $H^+$
  - 100 μA, $\sigma_x/\sigma_y$=0.3/0.7 cm
  - 30 kW deposited in target

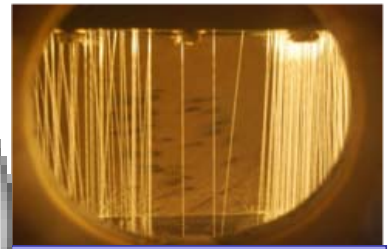
Diffusion chamber prototype:

- Improve diffusion of radioisotopes out of Pb
- Reduce decay losses

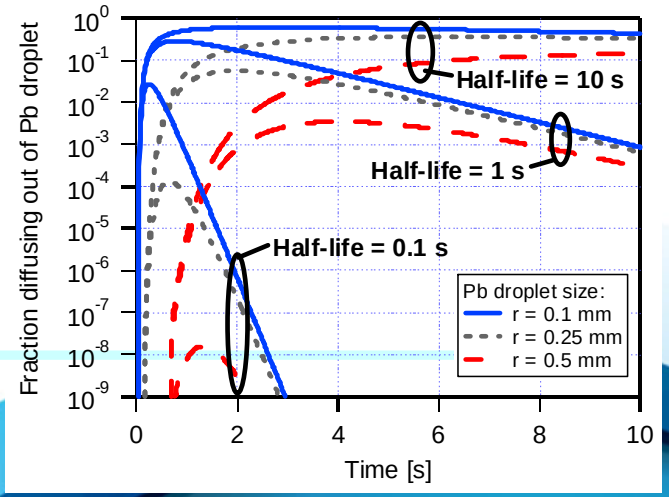
→ **Create Pb droplets**




Pore diameter: 0.5 mm
Number of pores: 160



IPUL PbBi proto loop
600 °C
EM pump, ΔP = 0.7 bar

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# Summary

- Investigations of tantalum container of an LBE target post irradiation:
  - Large droplets (dia = 3 mm) observed on chimney located 10 mm above melt.
  - Free surface rough with recrystallisation of Pb/Bi.
  - SEM of BEW shows 5-15 μm layer of PbBi.
  - FIB + SEM show 1-2 μm Bi layer between Ta and PbBi.
  - Crack 10 μm deep with 1 μm entrance hole filled with PbBi.
- LM target developments for RIB applications ongoing:
  - Recently changed bunch-to-bunch spacing (2009, 10 – 16 μm).
  - New ion source in 2010.
  - Plans for irradiation online of a Pb loop at ISOLDE: test diffusion chamber.