SLEEVE:
Small **L**ead-Bismuth **E**utectic **EV**aporation **E**xperiment

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Outline

- Introduction
- Design of the experimental setup
- First results
- Conclusions
- Outlook

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Scope

MYRRHA project

- Liquid metal (lead/bismuth eutectic) spallation loop
  - Windowless spallation target
    - Target vacuum issues
      - Gasload at beam/target interface

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Windowless Spallation Target Vacuum Issues

Resolved

- **Compatibility** of hot LBE reservoir (~400°C) in contact with the beam line **vacuum** (10^{-6} bar)
- **Outgassing** of the LBE and the spallation target circuit

Unresolved

- **Evaporation rate** of species in the LBE melt
- **Sticking probability** of emanating species on the vacuum vessel walls
- **Composition** of emanating species

⇨ **investigated @ SLEEVE**

Methodology

- LBE evaporation rate ➔ **quartz microbalance**
  - Mass collected on microbalance $\propto$ evaporated mass
  - Detected quantity:
    - direct fraction: evaporates directly onto the detector
    - indirect fraction: reaches detector after n collisions
- Composition of volatiles ➔ **mass spectrometer**
  - complete mass scan 0.4 – 510 amu
  - time evolution for selected species
- Composition of condensables ➔ **Chemical analysis**

design

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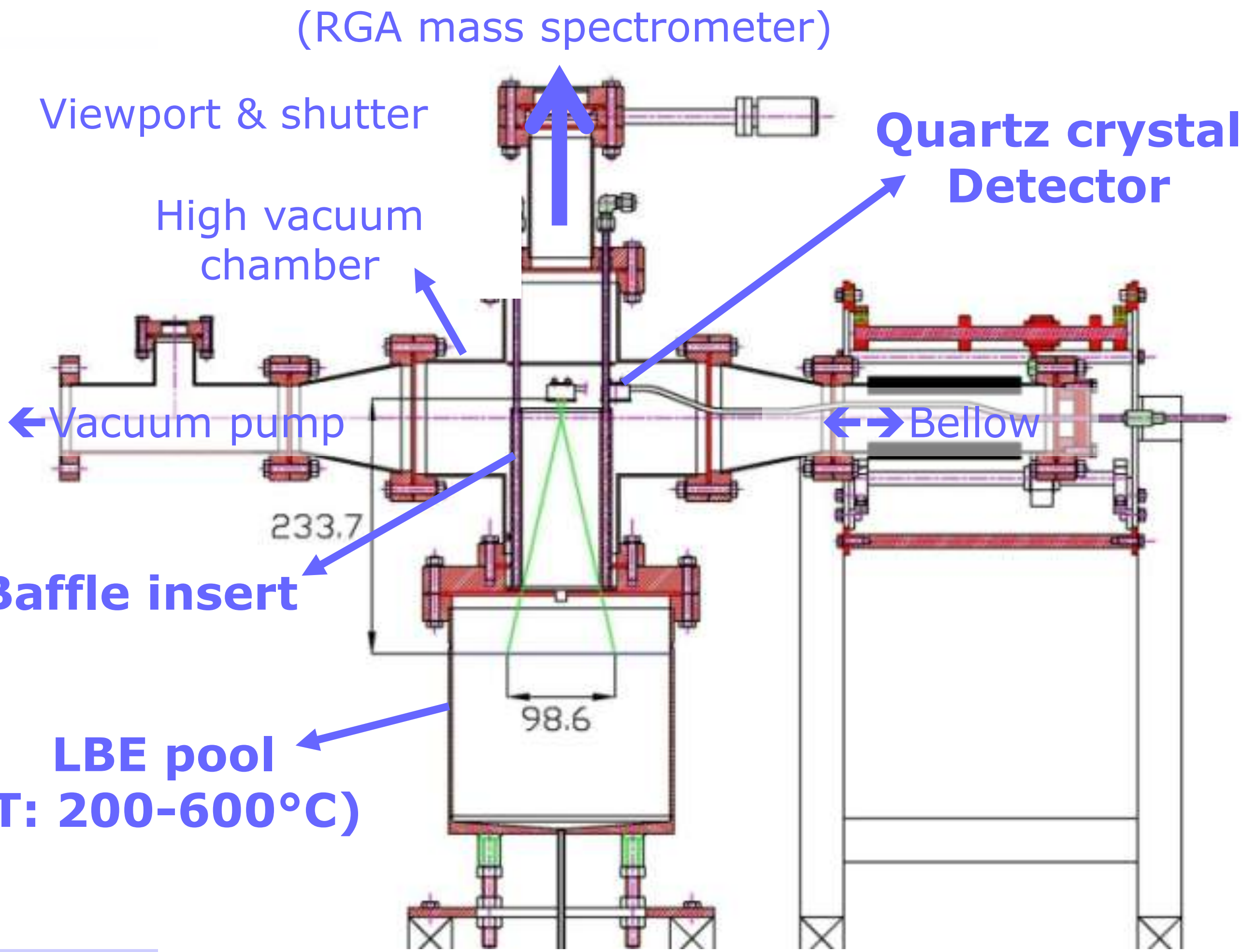
Experimental setup



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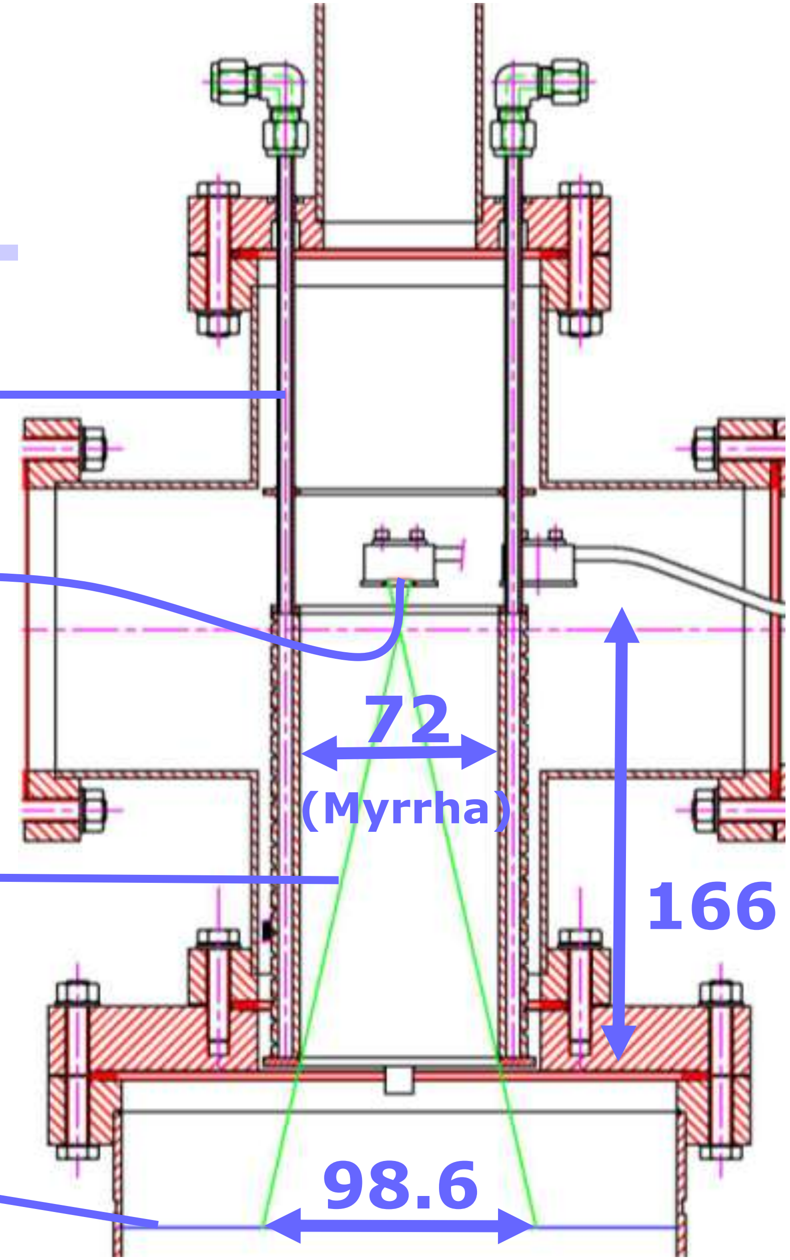
Baffle details

cooling channels

quartz crystal

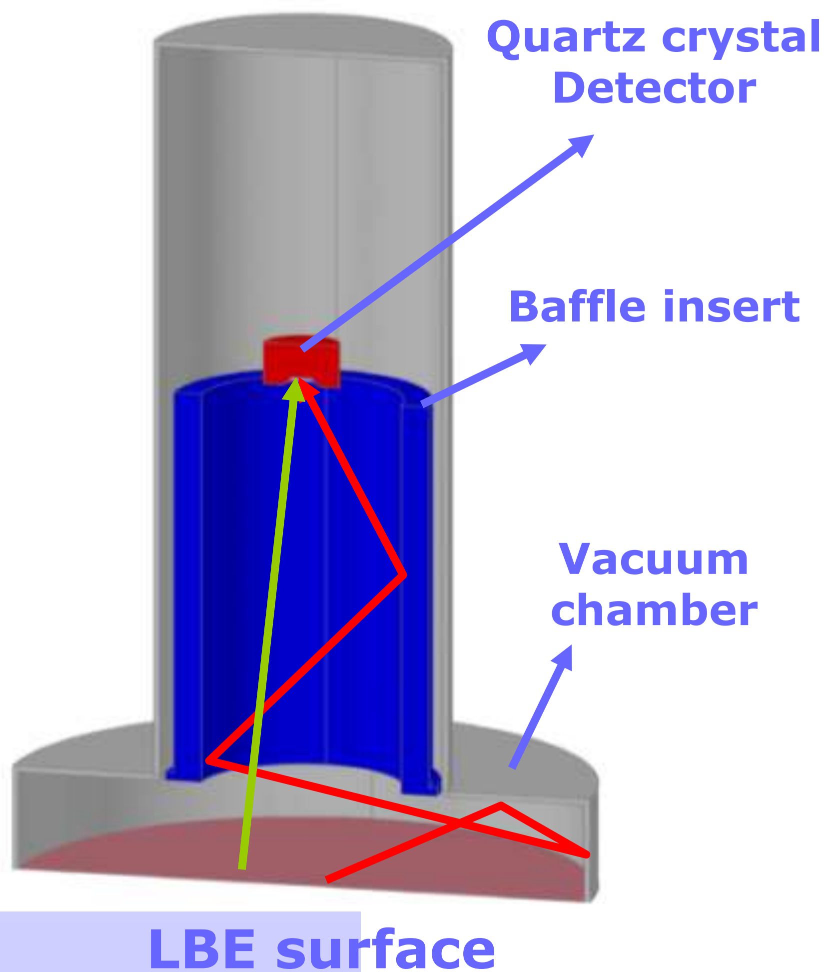
Opening angle for direct contribution

LBE level



design

Particle collection by the quartz crystal



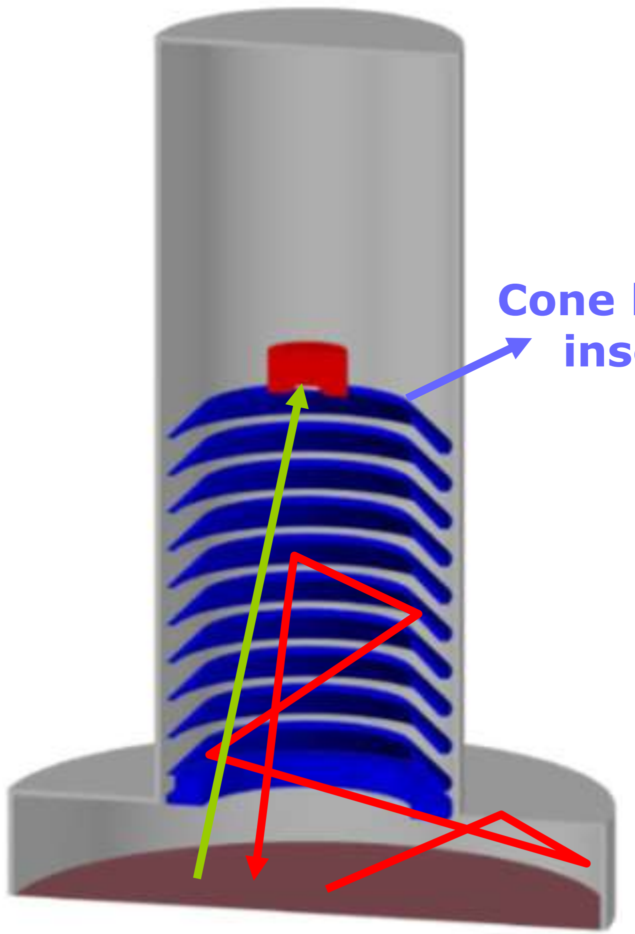
Direct fraction parameters :

- LBE evaporation rate ➔ LBE temperature (variable)
- LBE surface fraction seen by the quartz crystal ➔ dimensions/geometry (fixed)

Indirect fraction parameters:

- number of collisions ➔ baffle geometry (variable)
- sticking of particles on baffle ➔ baffle temperature (variable)

Determination of the LBE evaporation rate

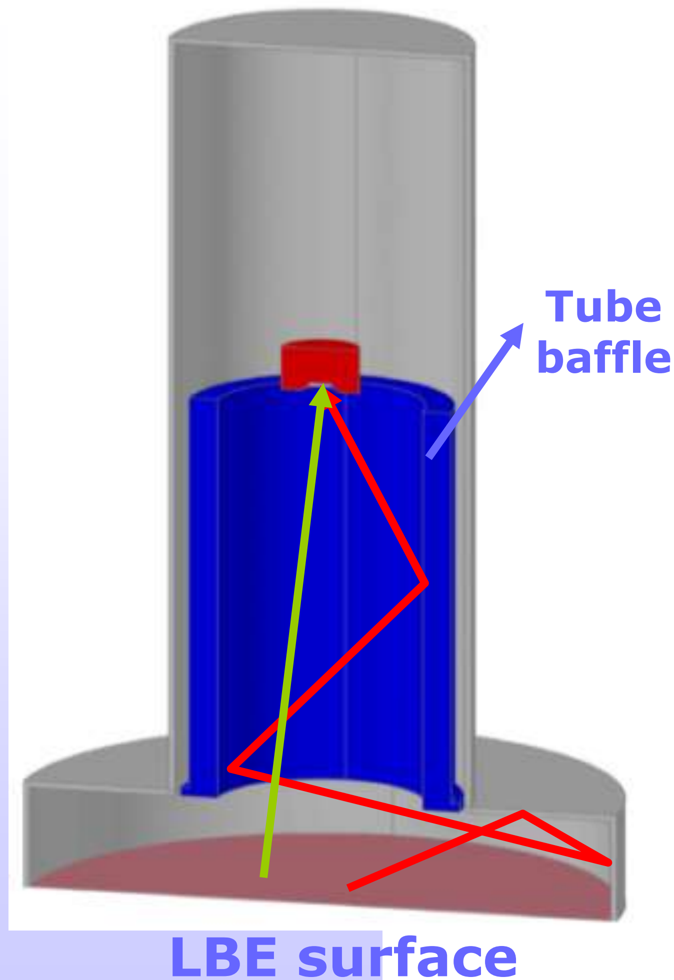


get rid of the indirect fraction

- Cone baffle ➔ maximize number of particle-baffle collisions
- Cool the baffle ➔ maximize sticking factor (~1)

➔ **We measure only the direct fraction ∝ LBE evaporation rate**

Determination of the sticking factor



Direct fraction

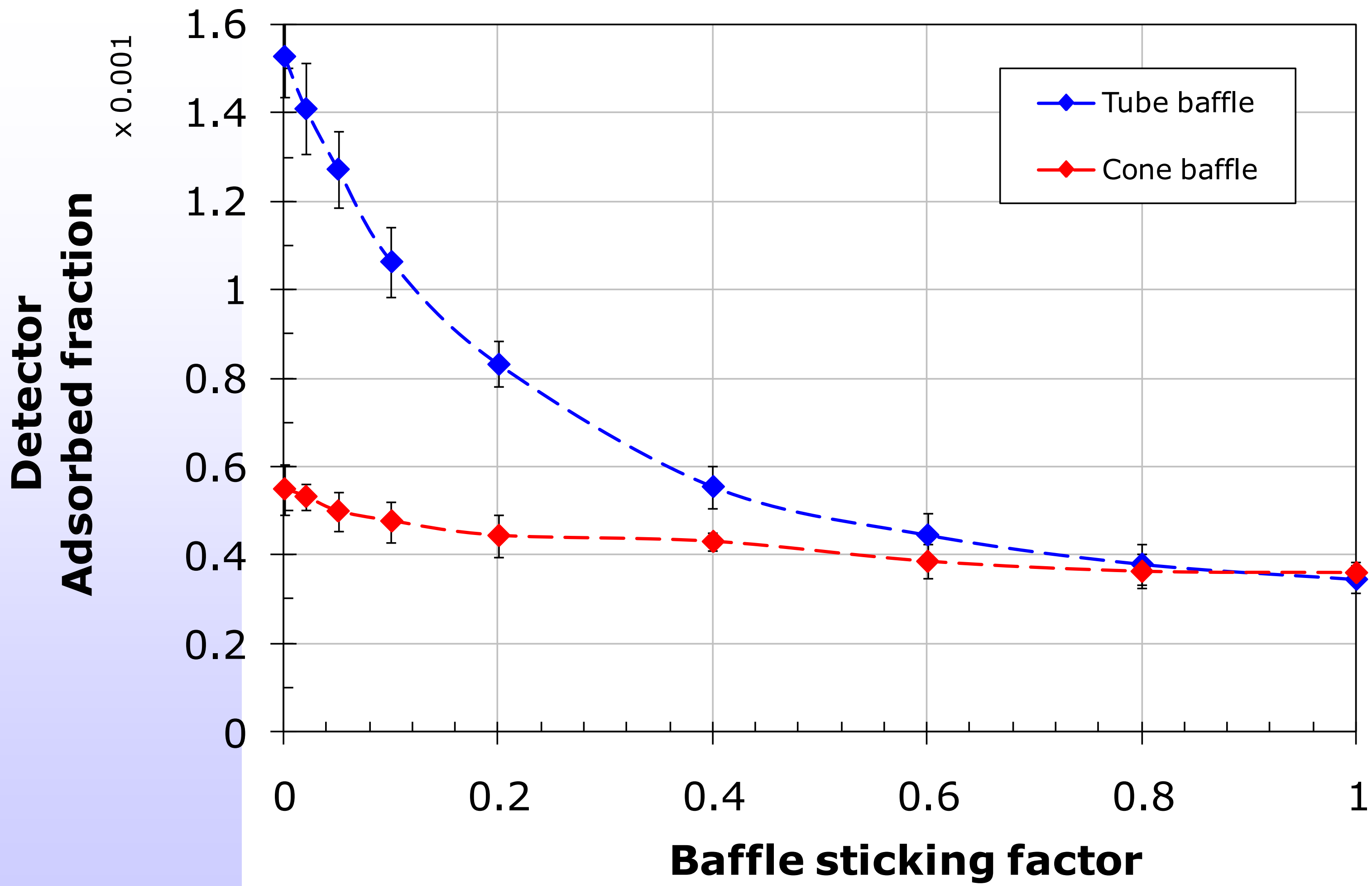
- known from measurements with the cone baffle

Indirect fraction

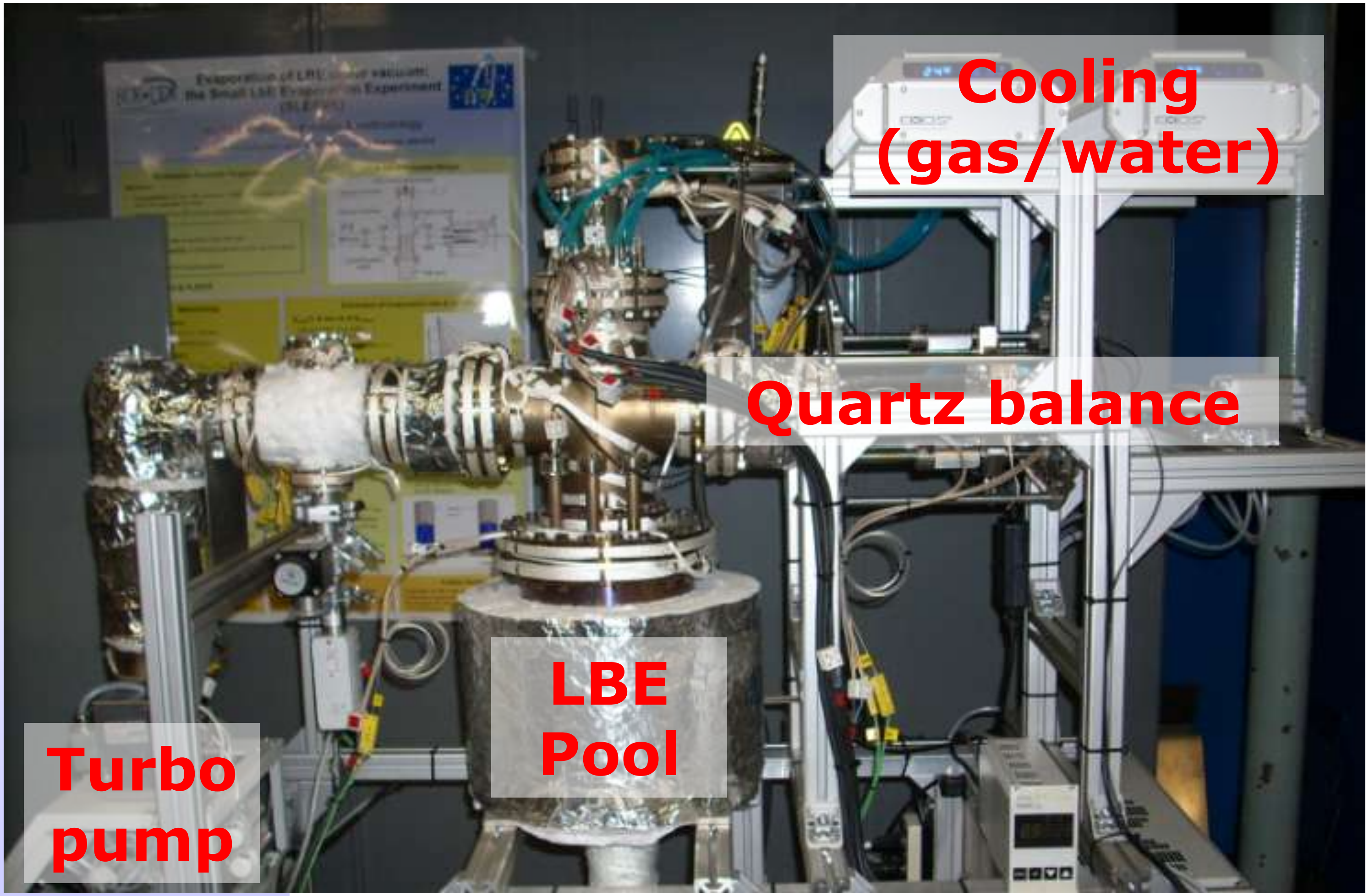
- = total – direct fraction
- Tube baffle ➔ minimise n° of collisons
- Baffle surface variable 30°C-600°C ➔ vary sticking factor
- Extract sticking factor from correlation of measurement with Monte Carlo simulations (MOLFLOW)

design

Calculated detector response (MOLFLOW)



Experimental setup



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First results

- Tube baffle
- Water cooling of baffle and QB → sticking factor ≈1
- Vacuum chamber passively cooled (convection) → sticking factor ≈1
- Conditioned LBE ([O] ~10^{-6}wt%)
- LBE temperature 350-500°C

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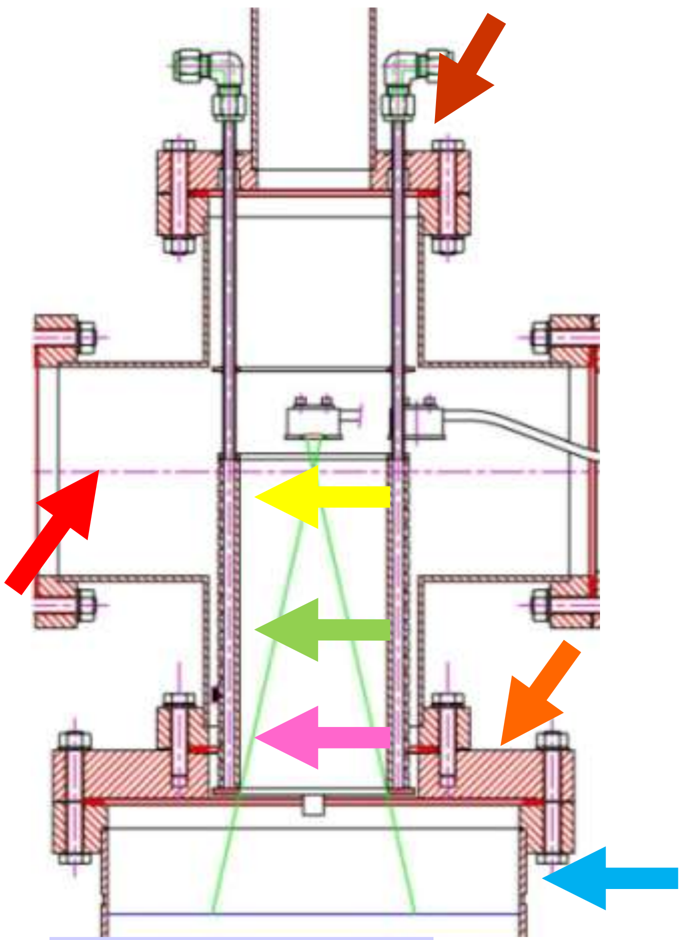
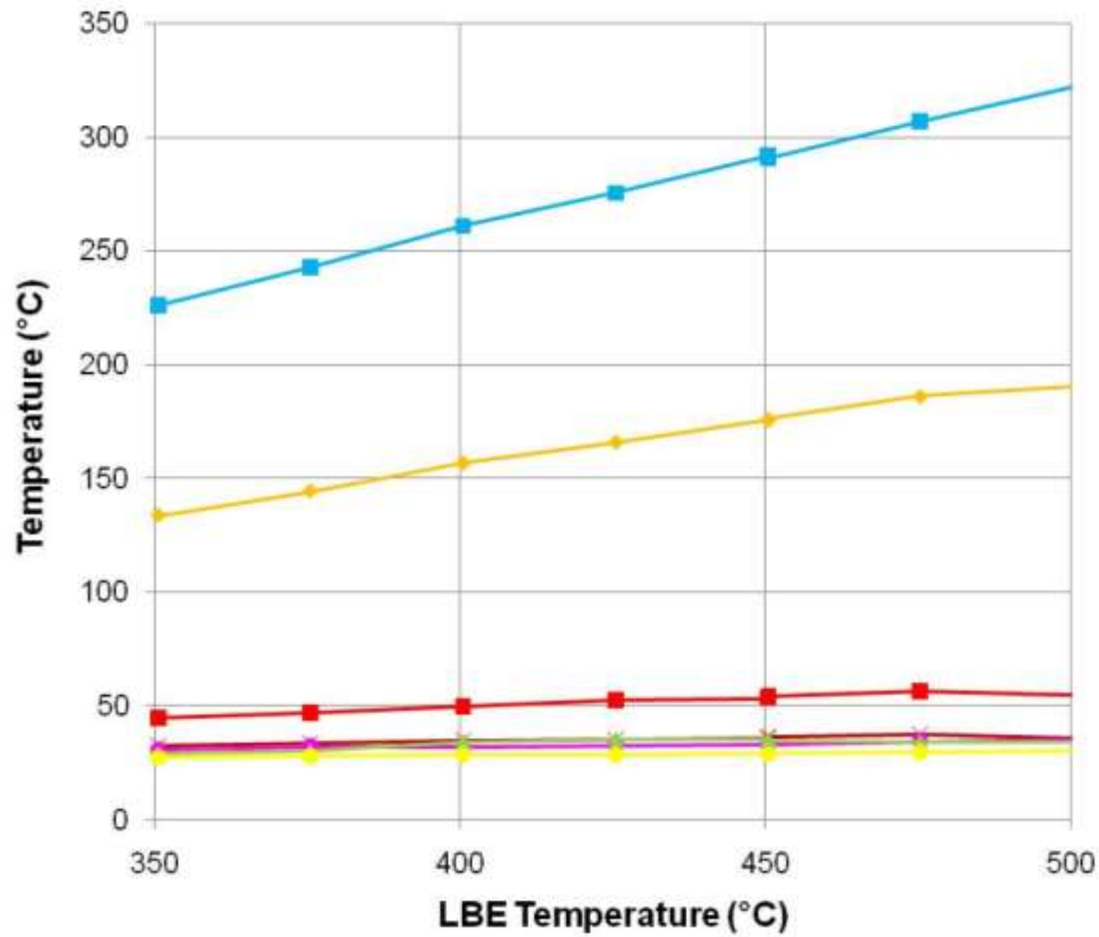
Temperature distribution, as ft of LBE pot temperature





Quartz Balance response

Sauerbrey equation*: $$\Delta f = -\frac{2 f_0^{\ 2}}{A\sqrt{\rho_q \mu_q}} \Delta m$$

$$\rightarrow \left| \frac{\Delta m}{\Delta f} \right| = 6.21 \mathrm{ng/Hz}$$

Sensor resolution: 0.06 Hz

f_0~6MHz, measuring range 500kHz

*G. Sauerbrey, Z. Phys., 1959, 155, pp. 206-222

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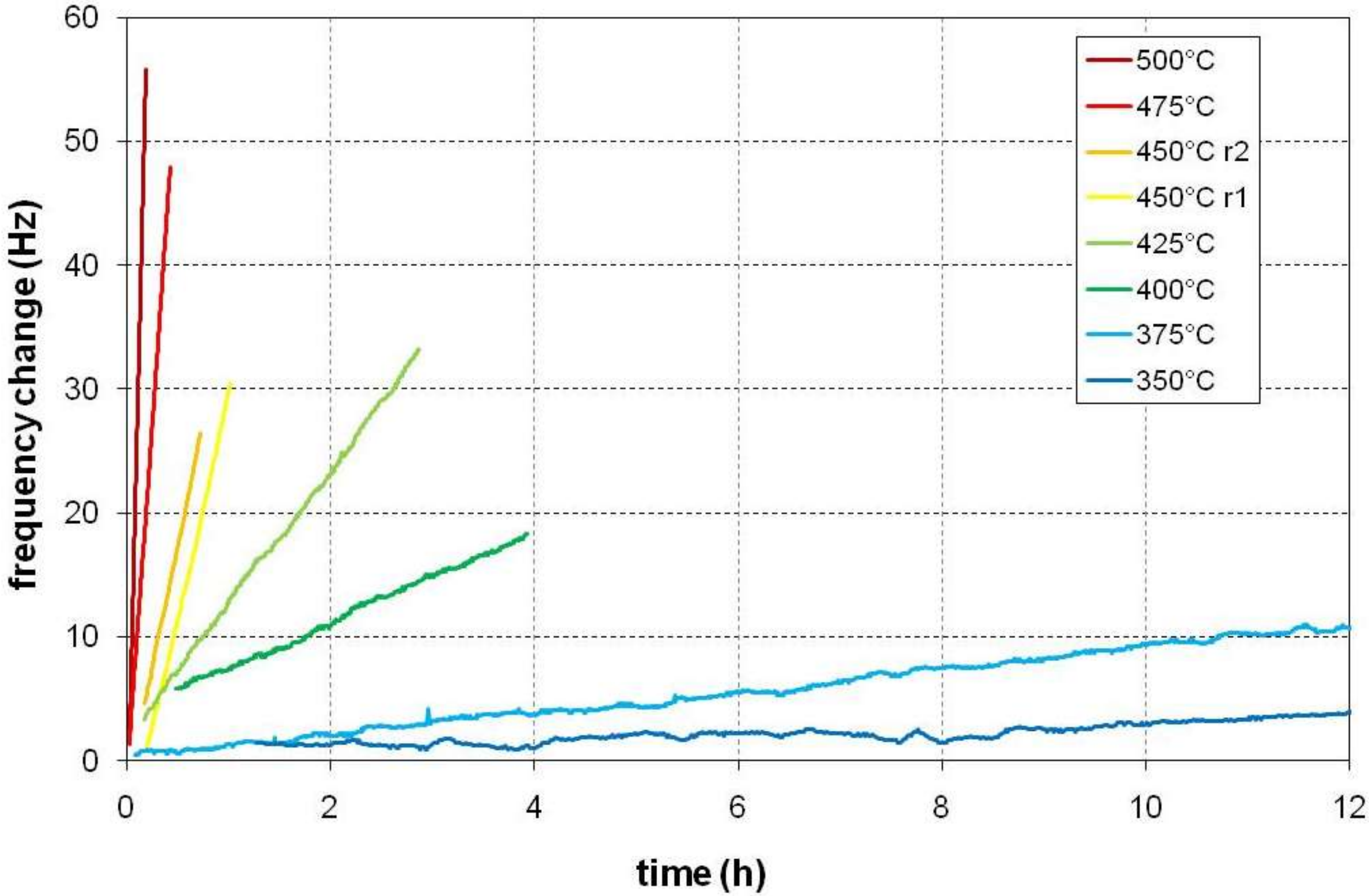
Frequency change



Evaporation rates (to be verified)

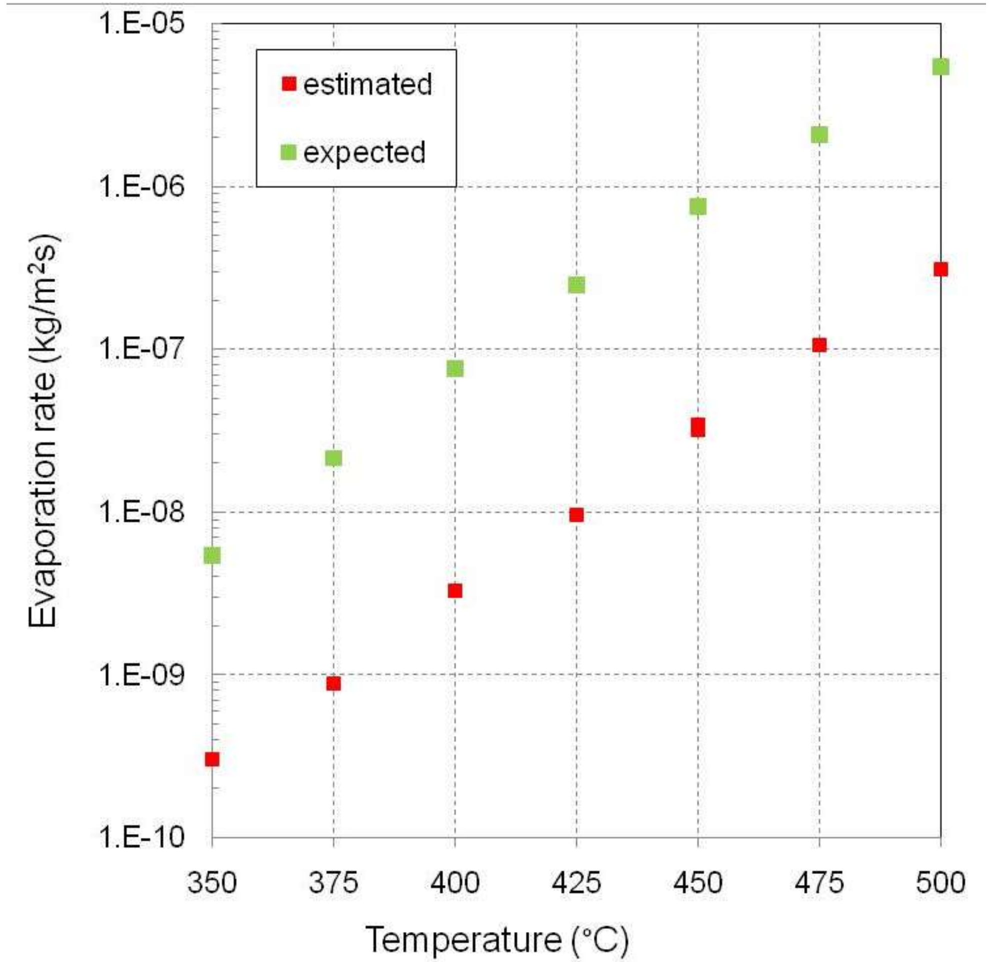
Assumptions

- All sticking factors = 1
- QB only sees direct contribution

Calculation

- QB captures fraction f_{QB} of total evaporated mass

$$f_{QB} = \frac{A_{direct}}{A_{total}} F_{QB,LBE} = 6.15 \cdot 10^{-5}$$



Conclusions

- First evaporation rate results obtained
- LBE stagnant, conditioned
- LBE evaporation rates are ~20x lower than expected from saturated vapour pressure data
- Increase x1000 350°C→ 500°C

(but what about pump effect?)

Outlook

Current measuring program

- *Direct evaporation, Clean LBE, sticking factor= 1*
- Effect of proton beam tube temperature → baffle temperature ~300-400 °C (sticking factor <1)
- Verify evaporation rates using cone baffle
- Measure volatile composition (Mass spectrometer)

SLEEVE 2.0:

- Add weir to eliminate surface contamination effects

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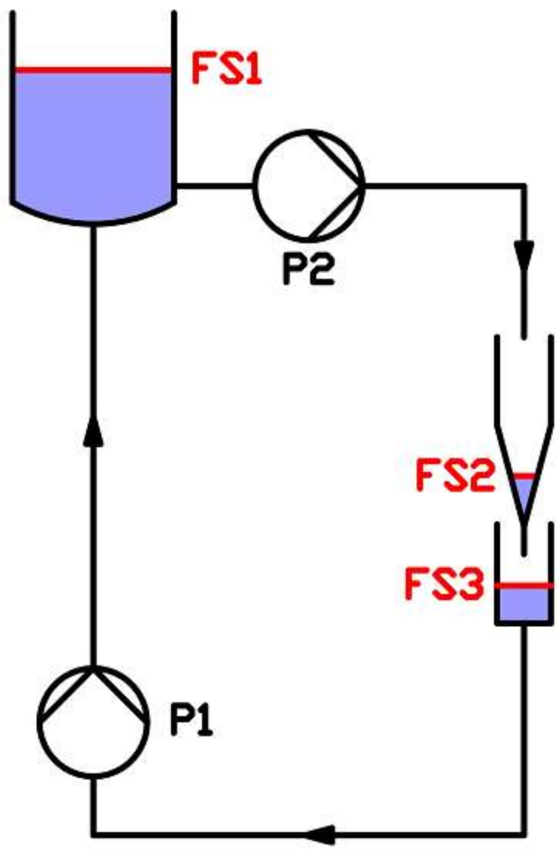
Thanks for your attention

Spallation loop



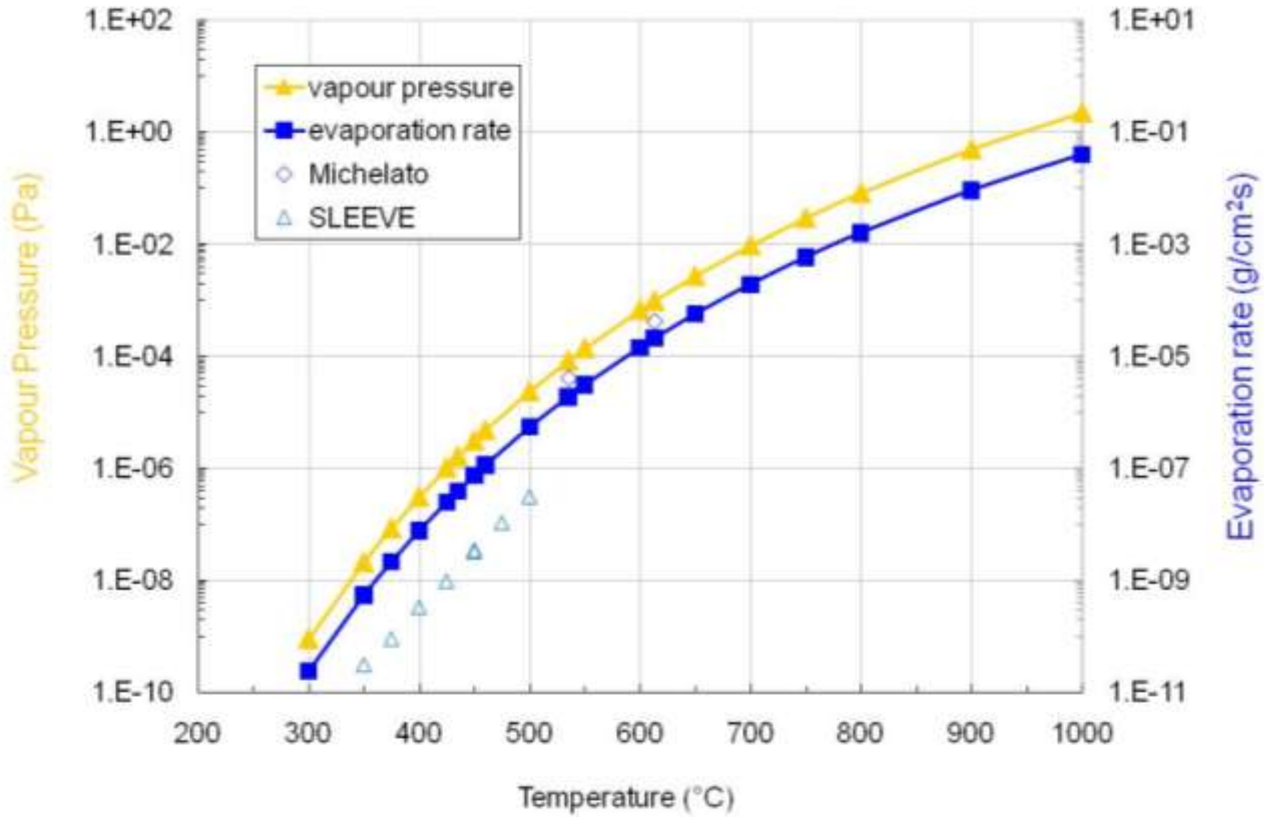
FS1

- LBE stagnant
- T ~300°C
- Surface oxidized?
- High/low vacuum ?

FS2

- LBE flowing (~2 m/s)
- High vacuum required
- T ~ 400°C
- Pump effect ?

LBE Vapour pressure/evaporation



$$m'_{LBE} = s_c p_{LBE} \sqrt{\frac{m}{2\pi kT}} = 63 \frac{s_c p_{LBE}}{\sqrt{T}} \frac{g}{m^2 s}$$