

Concept and preliminary experiment on protection of final optics in wet-wall laser fusion reactor



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Introduction



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- In a laser fusion reactor with a wet wall, the critical issue is protection of the final optics, especially from neutral metal vapor.
- Following each laser shot, more than 20 kg of liquid metal evaporates in a reactor of 5 m radius.
- We are going to use a set of rotating shutters having different rotational speeds to block the major portion of the blast wave from the opposite inner surface.
- However, some neutral vapor (9mg/shot) will enter the beam duct, possibly contaminating the final optics and promoting erosion of the surface by laser-induced plasma.

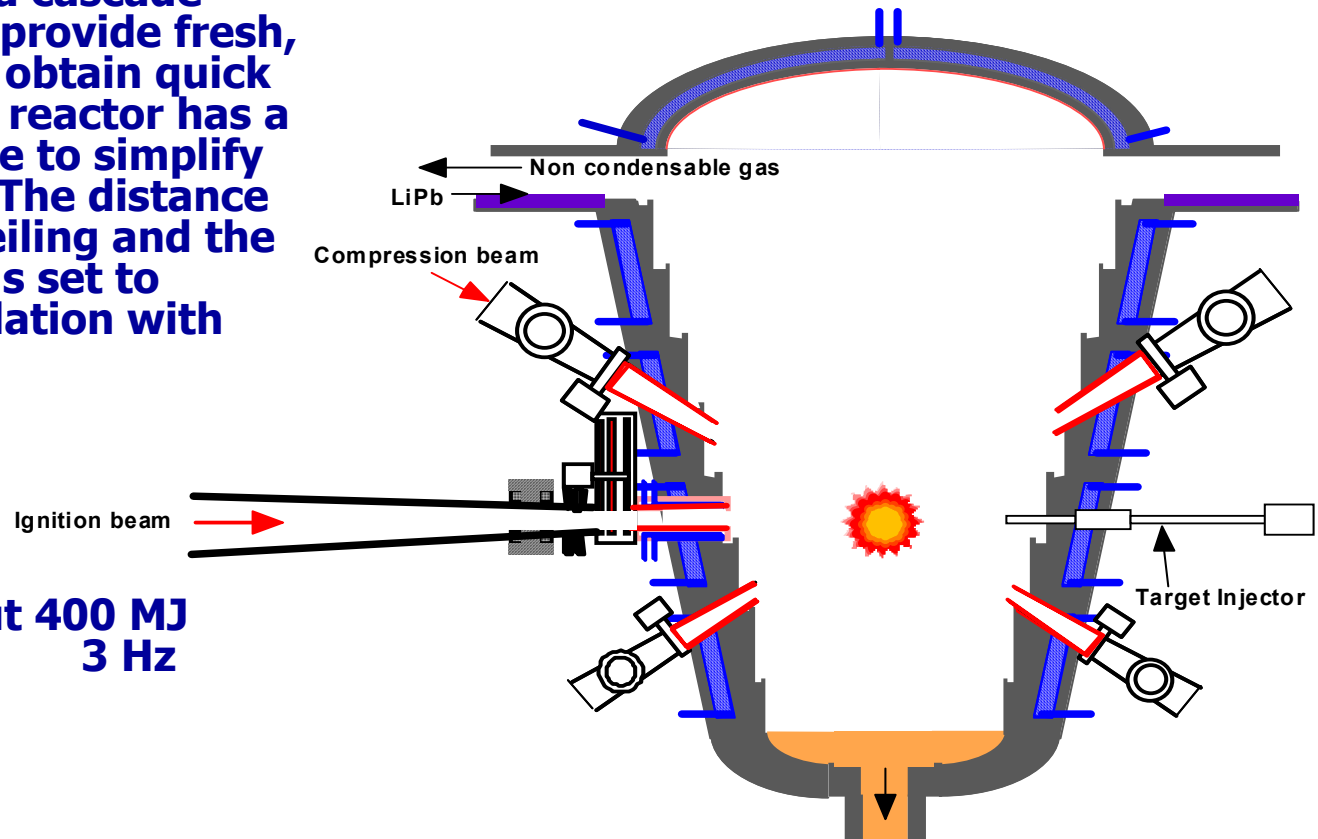
Cascade reactor for fast ignition scheme



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- New Koyo has a cascade flow of LiPb to provide fresh, cold surface to obtain quick pumping. The reactor has a hybrid structure to simplify the LiPb flow. The distance between the ceiling and the firing position is set to balance the ablation with condensation.

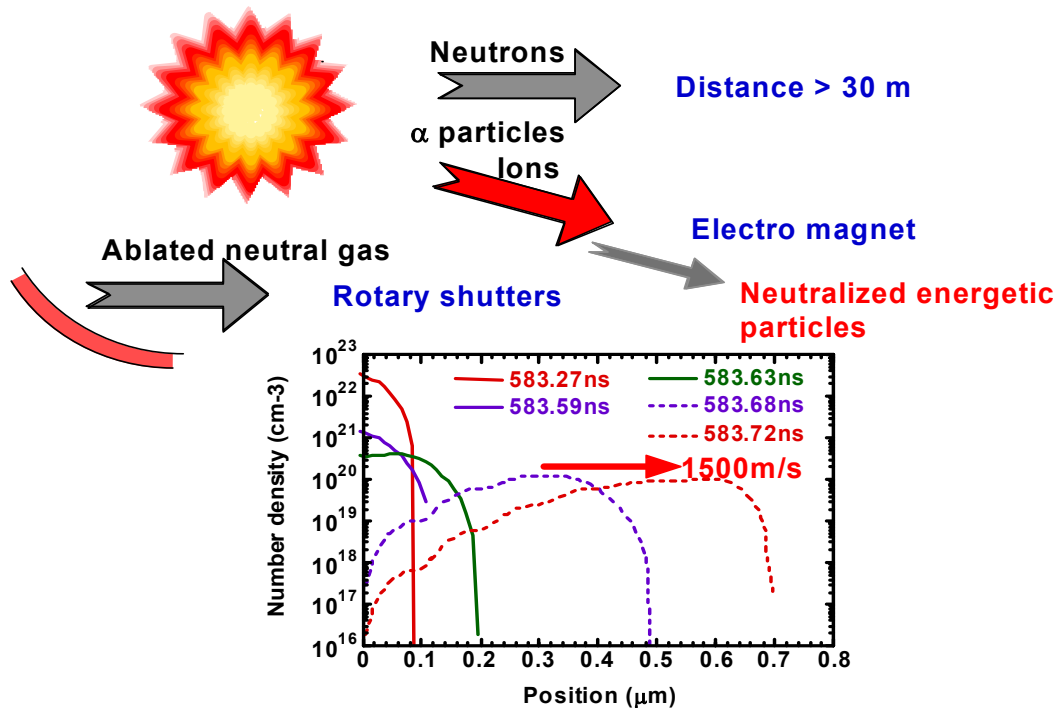
Thermal out put 400 MJ
Rep-rate 3 Hz



In wet-wall reactor, protection of final optics from neutralized particles seems most critical.



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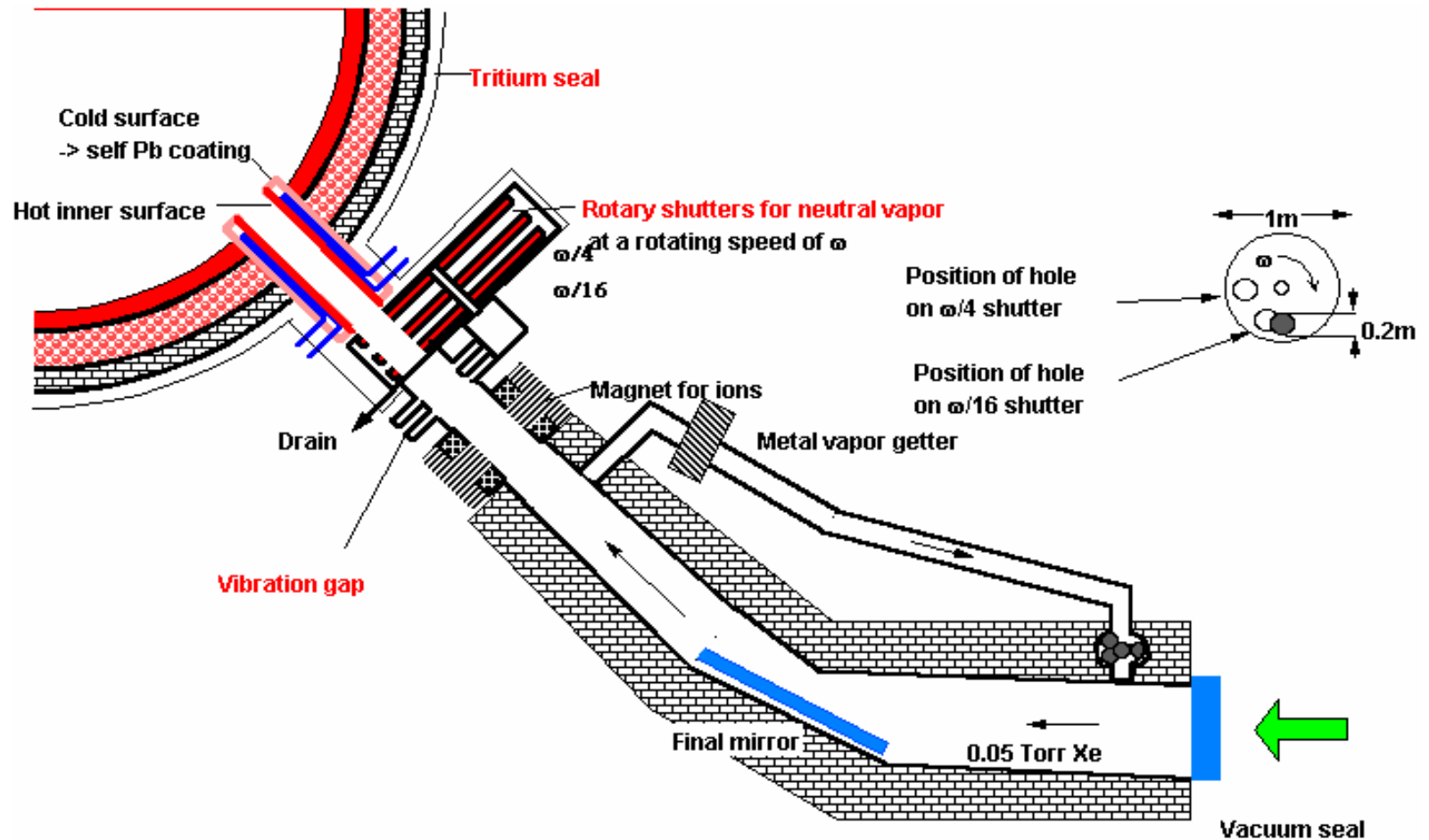
The speed of blast wave is estimated to be 1500 m/s.

- Neutron damage can be reduced by locating the optics 30 m apart.
- Alpha particles and ions can be removed by a Magnetic field.
- Ablated metal from inner surface can be shielded by rotary shutters.

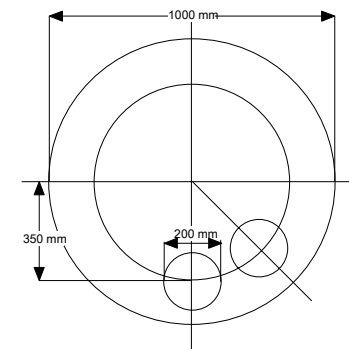
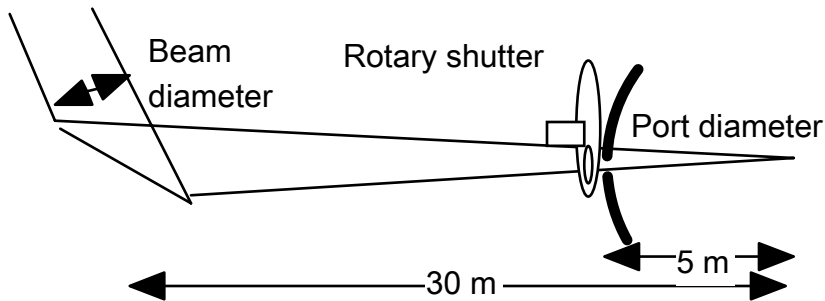
Protection scheme of final optics by rotary shutters



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The dimension and the rotational speed of the first shutter seem acceptable.



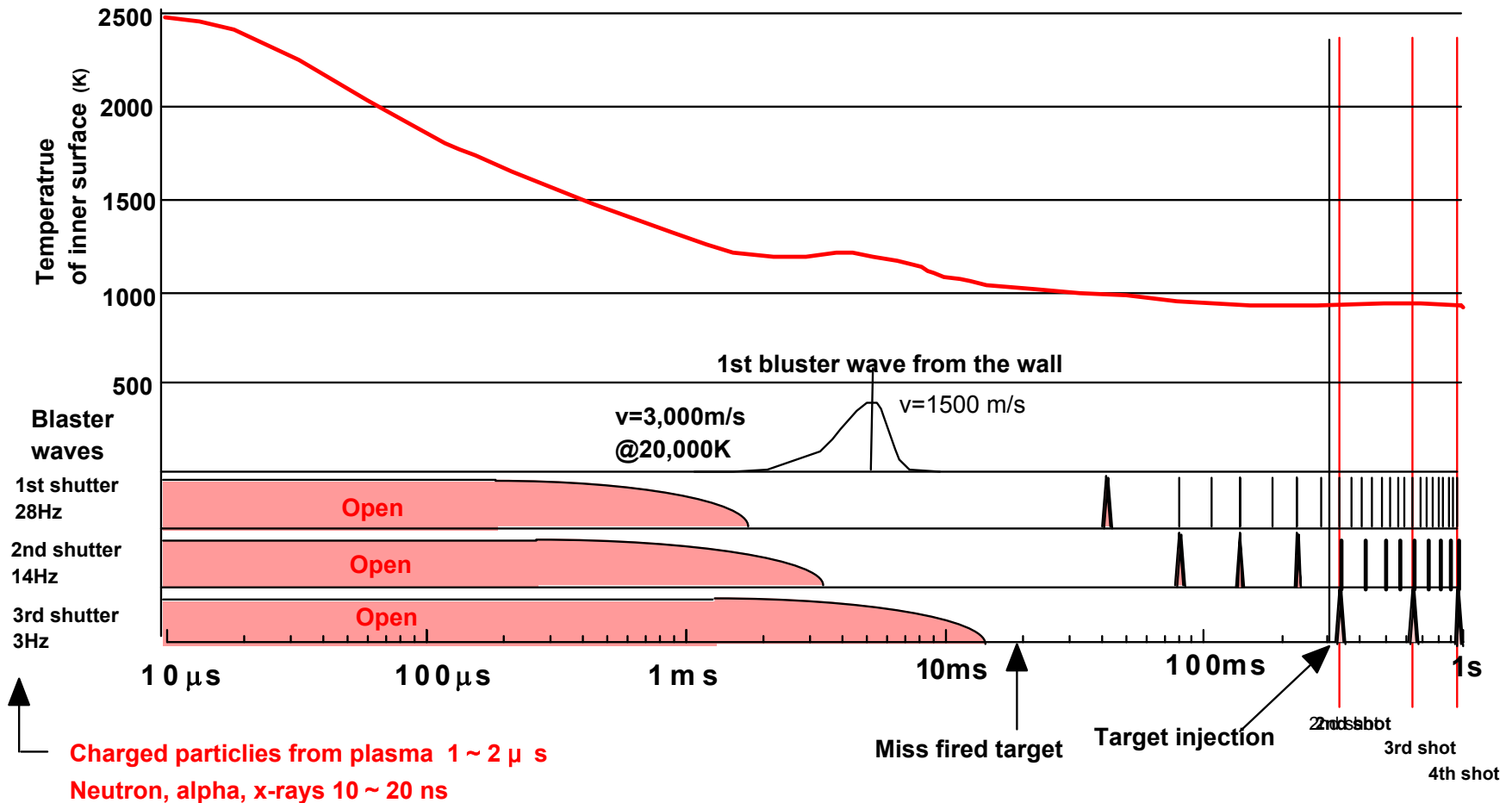
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Mode	Beam Number	Laser Energy kJ/ beam	Beam diameter (m)	Port diameter (cm)	Diameter of shutter (m)	Rotarional speed of first shutter (rps)
Central ignition	32	125	1	17	1	21.65
Fast ignition	Compression	25	0.5	10	0.5	25.47
	Heating 1	70	4	60	2	38.21

Timing chart for blast wave and rotary shutters



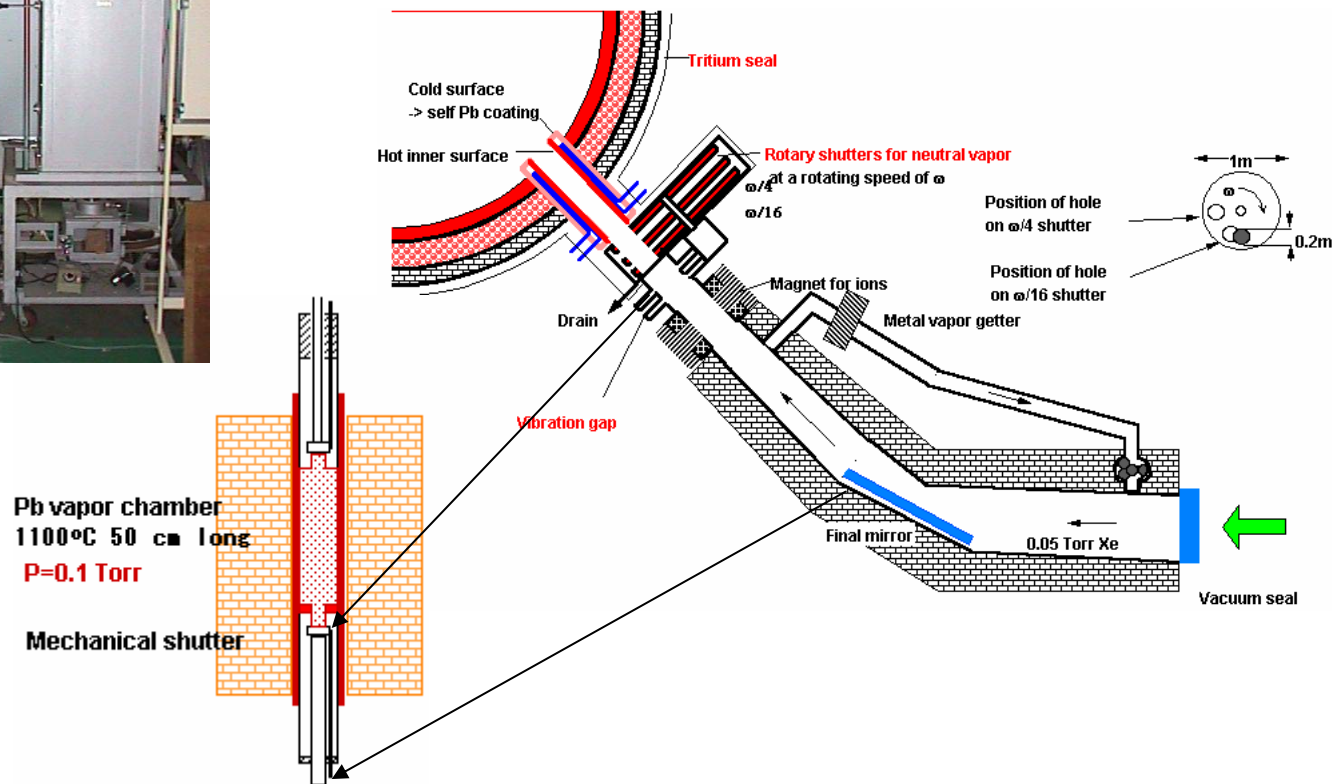
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To experimentally simulate Pb vapor diffusion in a beam duct, an electro furnace to make glass shells was employed.



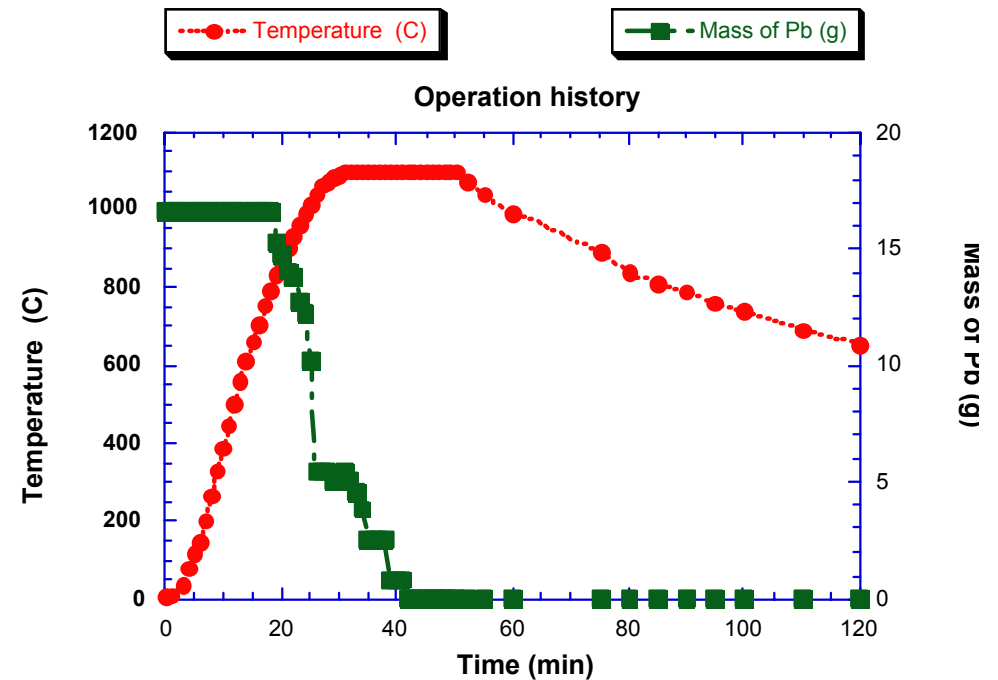
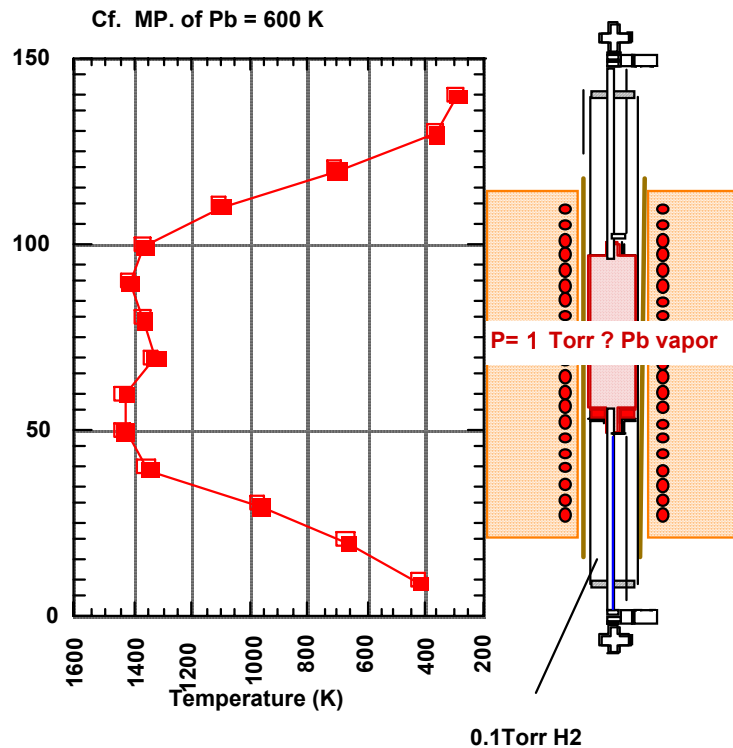
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Basic characteristics of furnace



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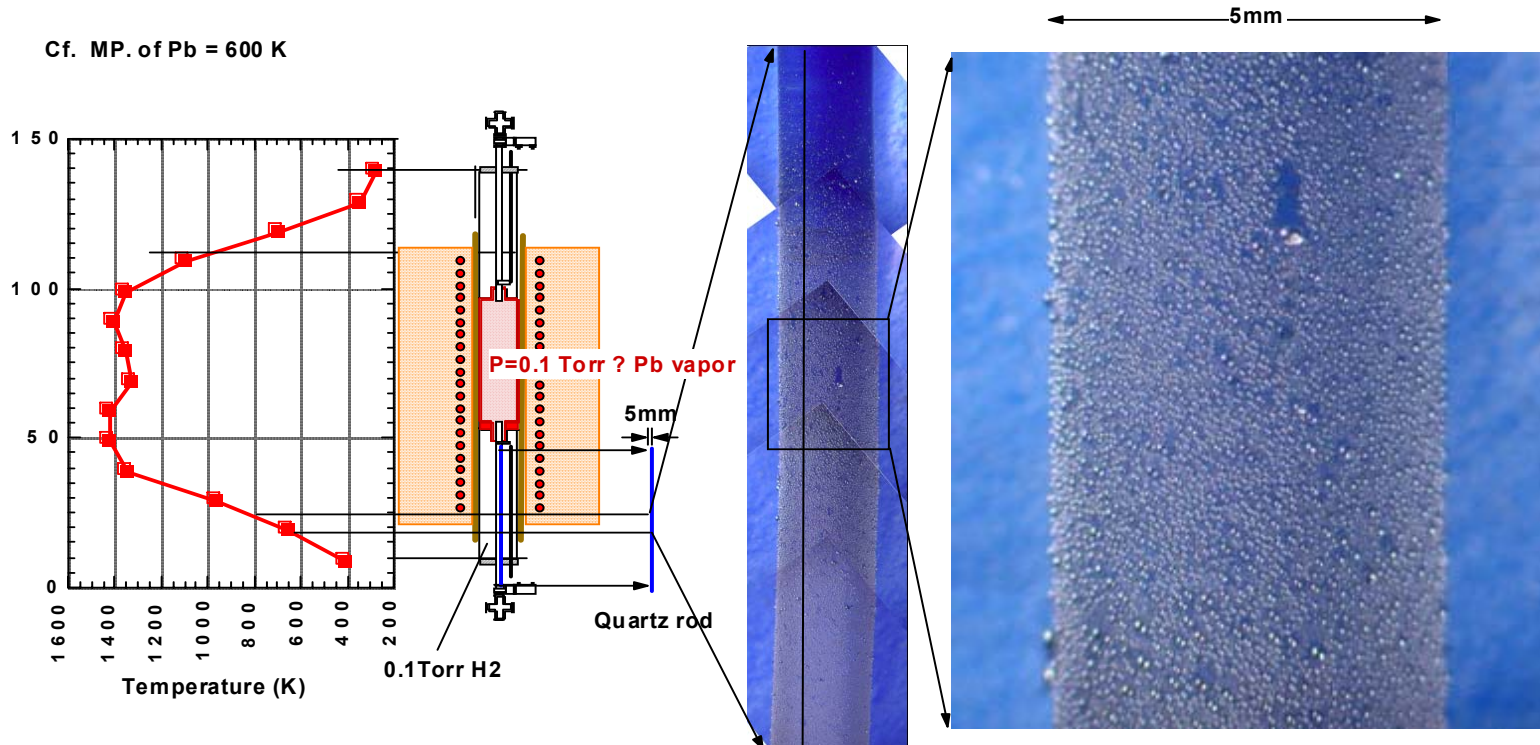


A lot of Pb particles, drops of dew, was observed on the surface of a quartz rod during a **H₂ 10 Torr, 1400K, 1hr** operation.

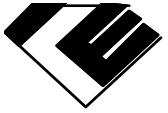


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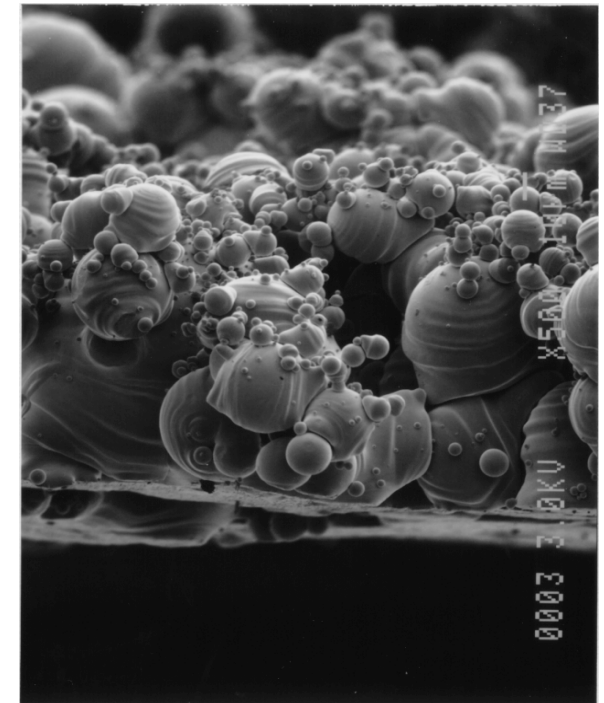
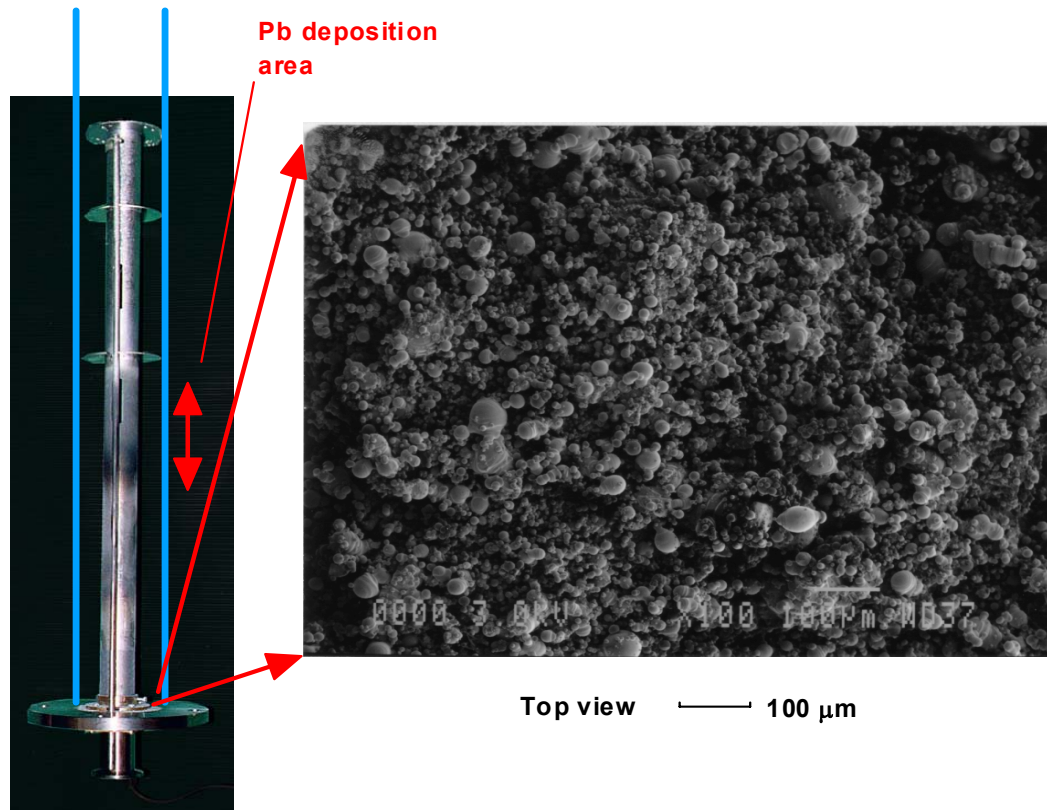
- To simulate diffusion of Pb vapor from wet-wall-reactor to the final optics, 25 g Pb was evaporated.
- No deposition of Pb at areas of $T > 800\text{K}$ and $T < 600\text{K}$.
- A lot of Pb particles ranging $< 300\text{ nm}$ at the area of $650\text{K} < T < 750\text{K}$.



Many Pb particles ranging 0.1 to 30 μm were deposited on the bottom of furnace filled with **10 Torr H_2** .



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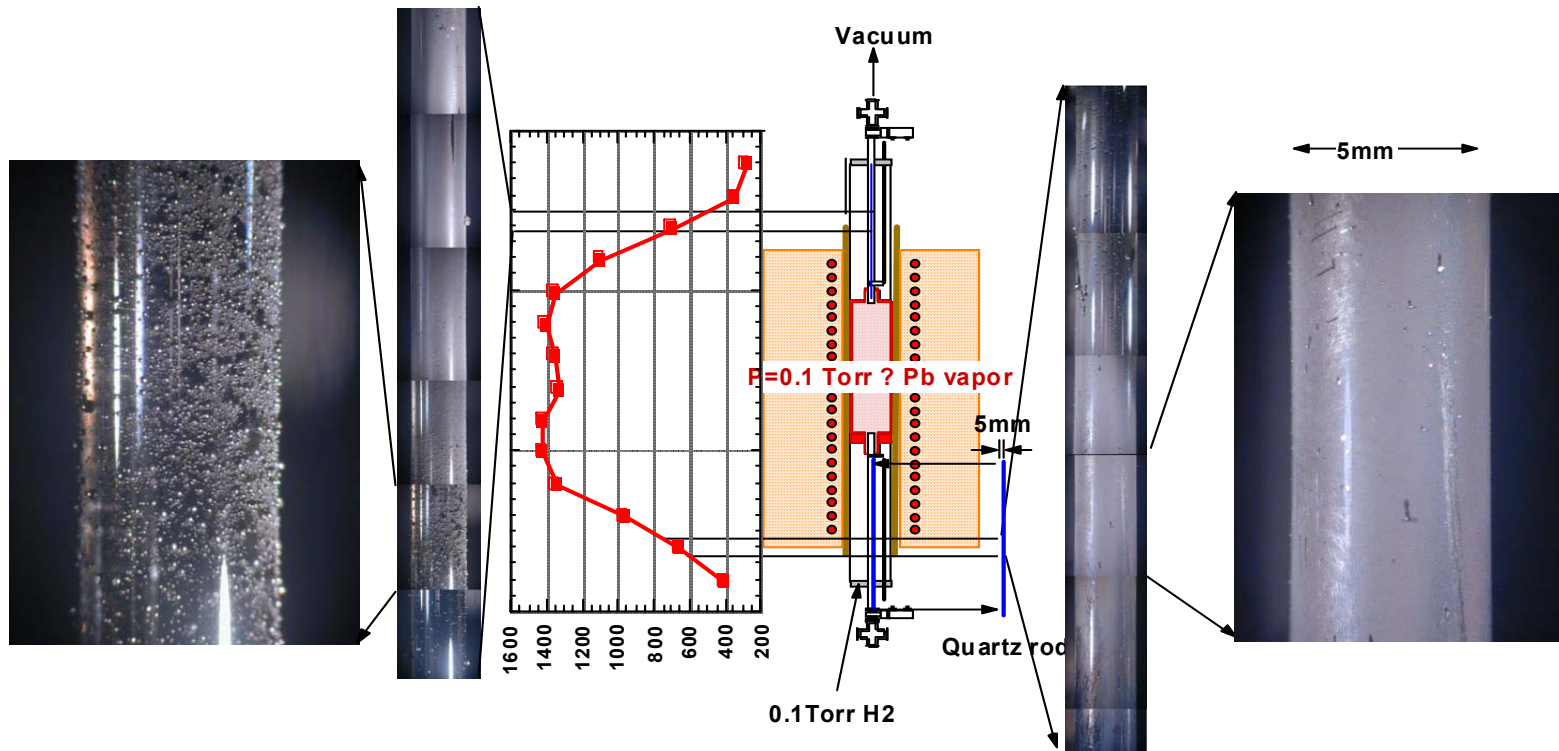


Lead deposited on the 500K to 800K surface during a **H₂ 0.1 Torr, 1400K**, 1hr run. No dew on the bottom rod.



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- To simulate diffusion of Pb vapor from wet-wall-reactor to the final optics, 14 g Pb was evaporated.
- No deposition of Pb at bottom area of $T > 800\text{K}$ and $T < 600\text{K}$ and at top area of $T > 750\text{K}$ and $T < 500\text{K}$. Hydrogen gas flow from bottom to top carried the Pb vapor toward colder region.

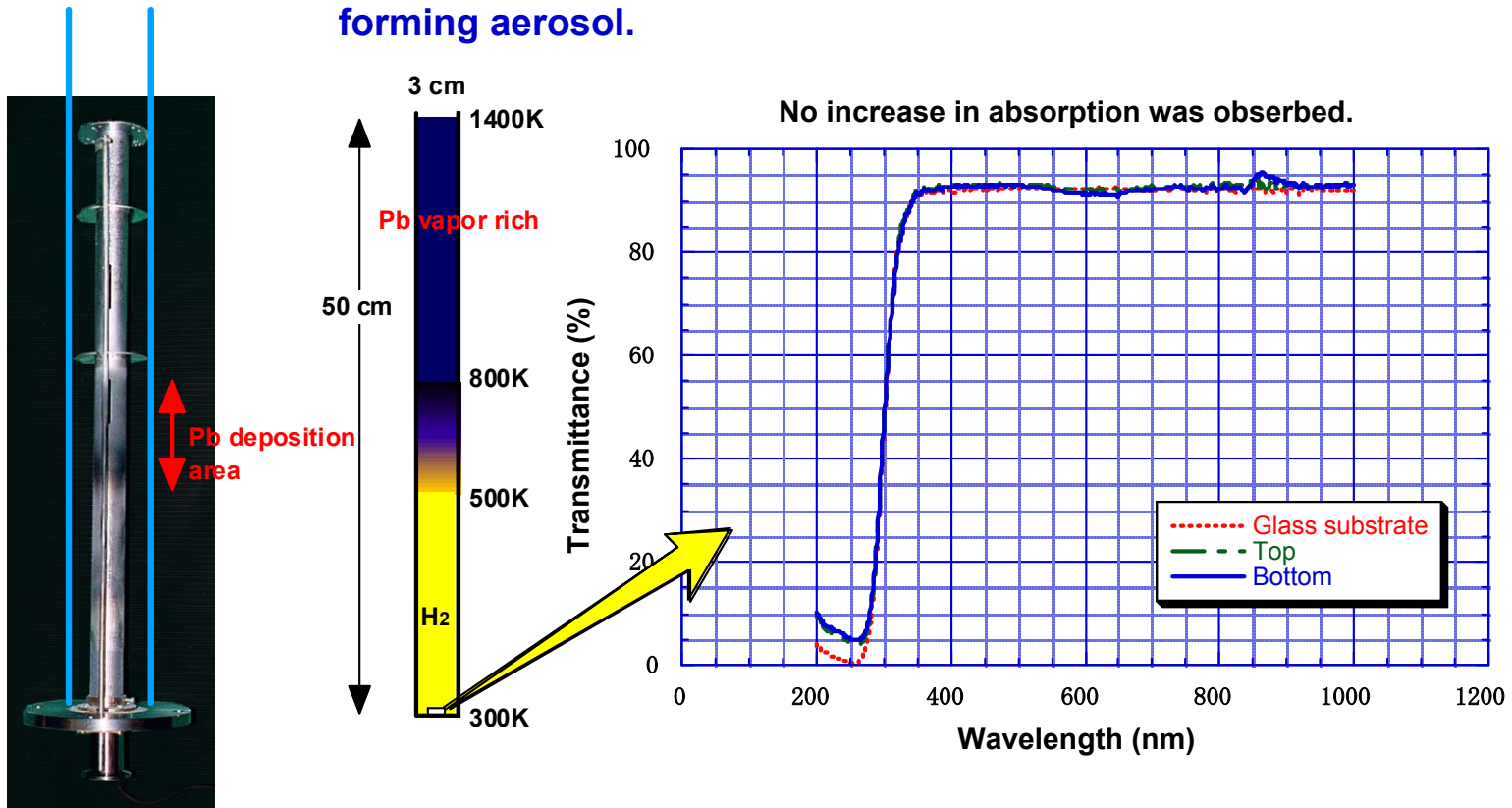


No deposition of Pb was observed on witness plate in **0.1 Torr H_2** .



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It seems that Pb vapor condenses on cold surface before forming aerosol.

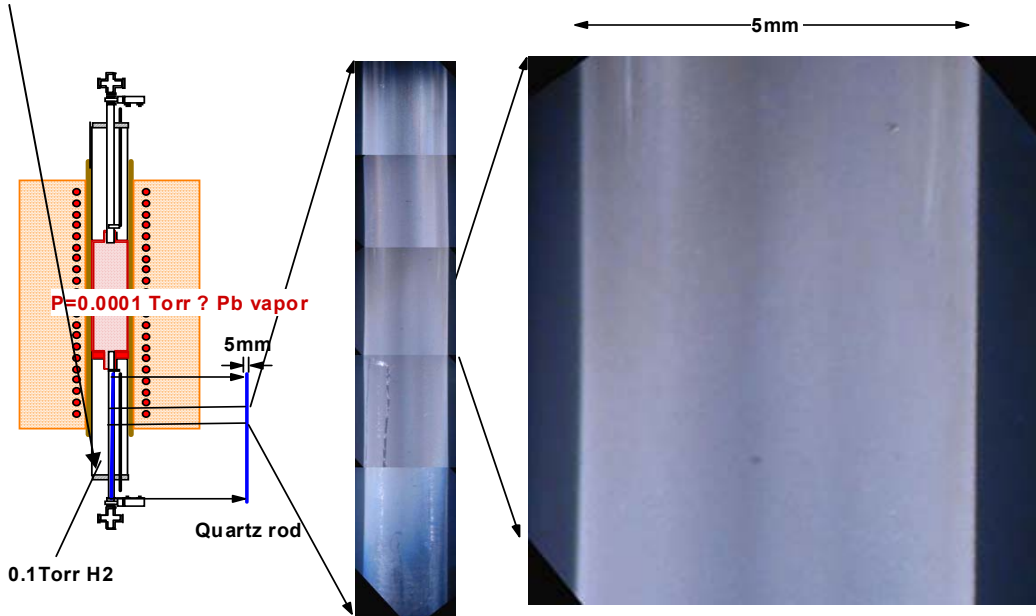


Deposition area moved inward during a **H₂ 0.1 Torr, 780K, 1hr run. But no deposition on witness plate**



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No deposition on witness plates



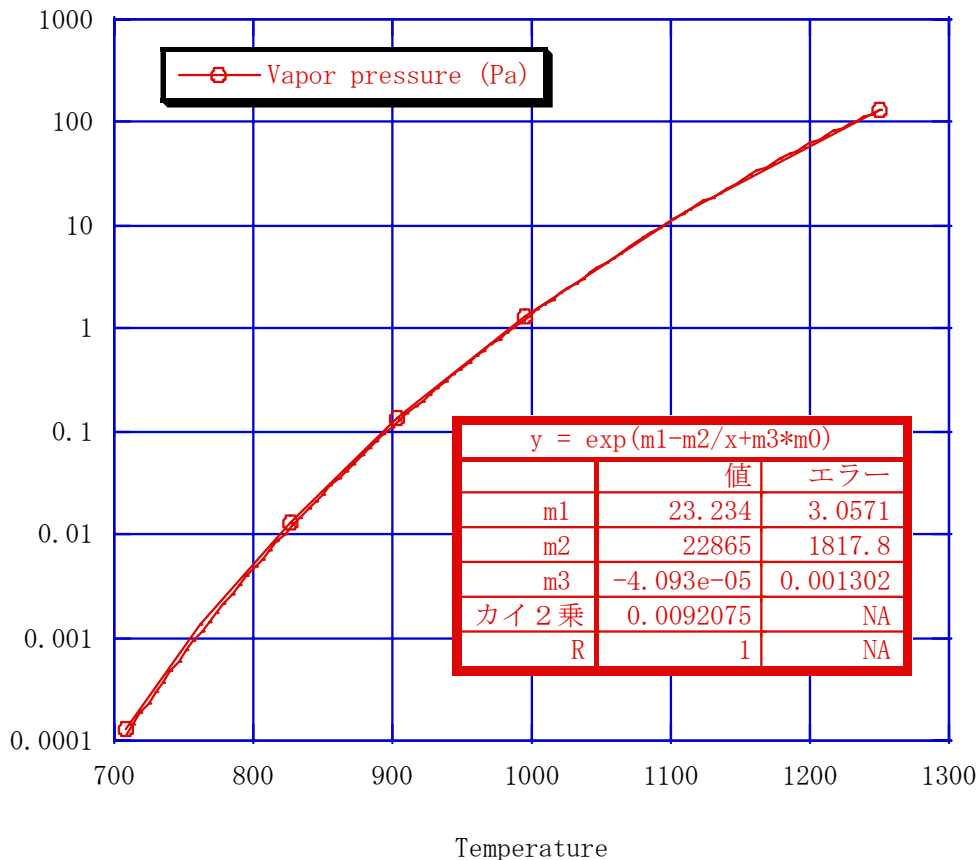
- 9.5 g of Pb (1/3 of previous case) was evaporated during 1hr run.
- Deposition area moved inward.
- No drop of dew was observed.
- **No deposition on bottom**
- **This result indicates that contamination of final optics can be avoided if the first bluster wave is blocked.**

For simplification, theoretical value of Diffusion constant for Pb was used instead of LiPb.



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Vapor pressure of Pb

$$P(T) = \text{EXP}\left(23.23 - \frac{22865}{T} - 4.09 \times 10^{-5} T\right)$$

Theoretical diffusion constant

$$D = \frac{\sqrt{2}}{6n\pi\delta^2} \left(\frac{8kT}{\pi m} \right)^{1/2}$$

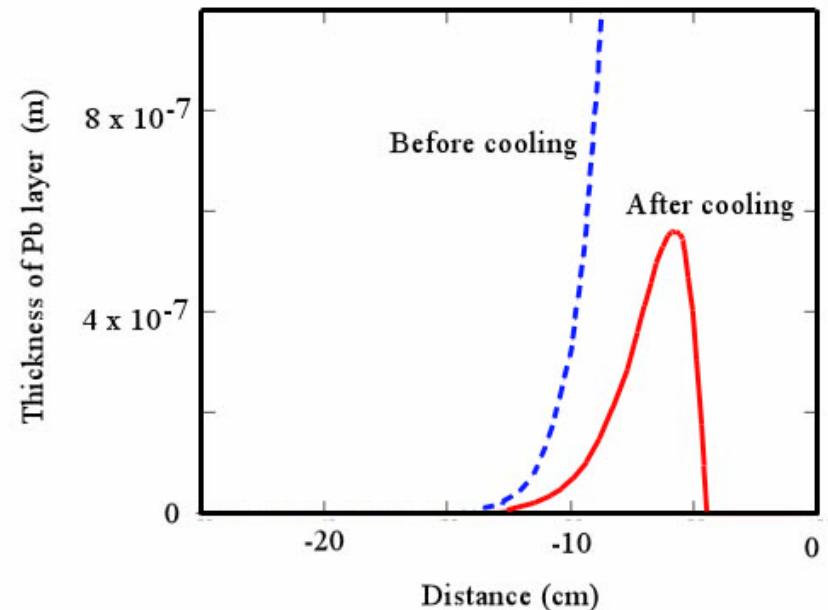
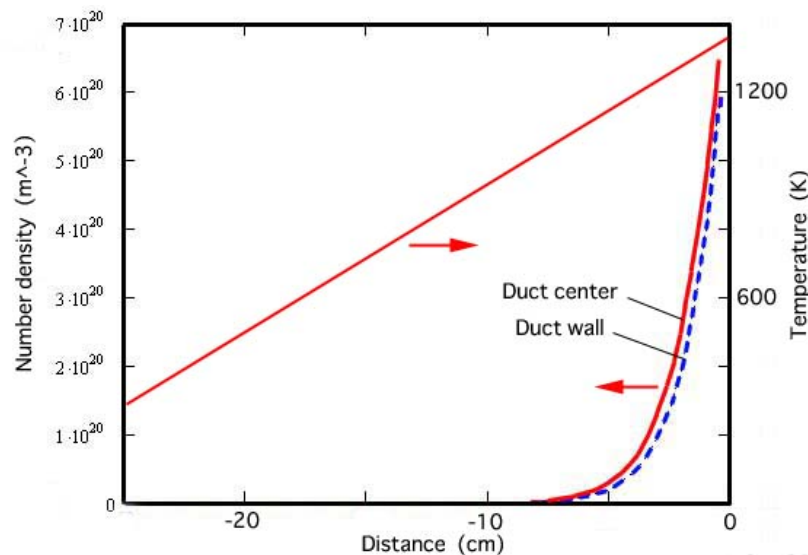
Saturated evaporation rate

$$v = \frac{P}{\sqrt{2\pi mkT}}$$

No deposition on $>800\text{K}$ area can be explained by re-evaporation.



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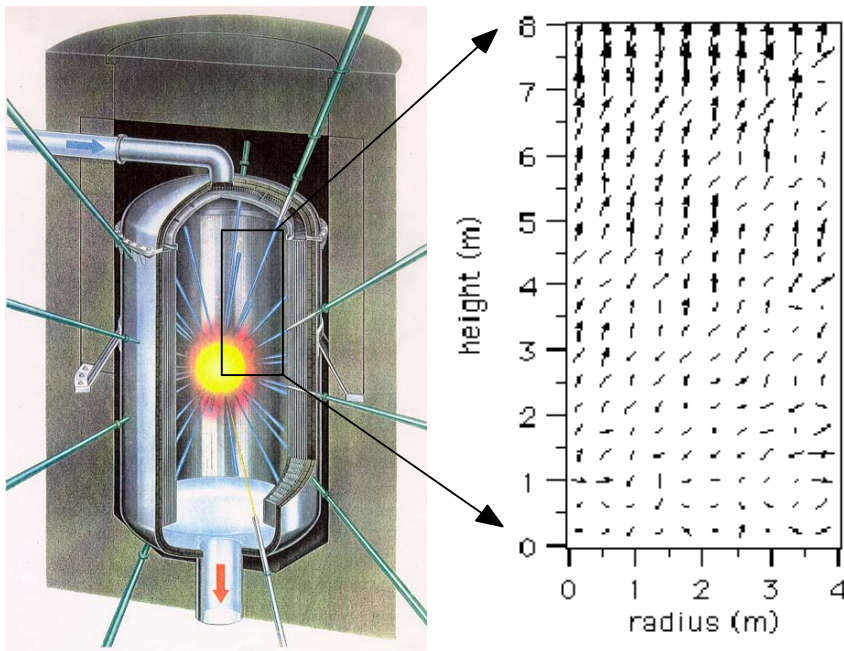


- **Distribution of Pb vapor in the duct is dominated by wall temperature. (Left) No deposition at $>800\text{K}$ can be explained by re-evaporation. (Right)**

The speed of vapor at beam inlet is estimated to be 100 m/s.



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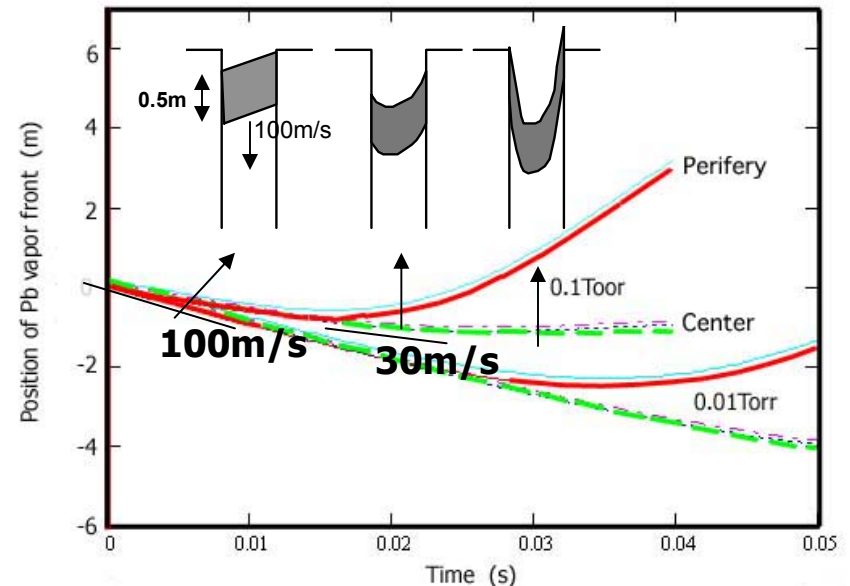
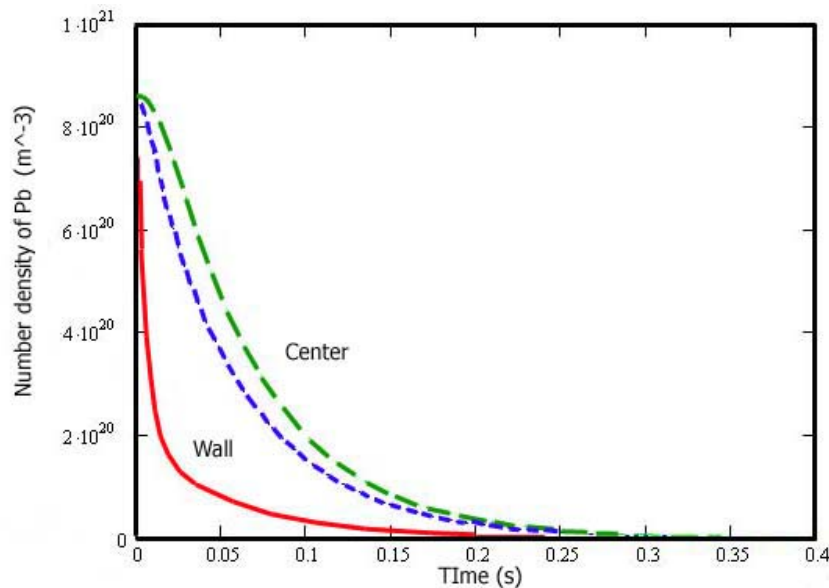
→ = 1.718e+02
case3 (60msec)

- When the shutter opens, a radial gas flow still develops due to cryogenic effect of the camber wall.
- The LiPb vapor pressure is estimated to be <0.05 Torr.
- In the next calculation, 0.1 Torr, 100 m/s were used for safety.

Pb vapor whose initial speed of 100 m/s can not reach final optics in 0.1 Torr buffer gas.



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- The velocity of Pb vapor decreases to 30 m/s before the amplitude of deformation exceeds the thickness of Pb vapor. The vapor enters into the duct by 6m.

Summary



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- **In a future laser fusion reactor, final optics at the end of 30m-long beam duct can be protected from metal vapor using a rotary shutter and 0.1 Torr hydrogen gas.**

The vapor ($v=100\text{m/s}$) will stop within 6m.

- **When the hydrogen gas in the duct is sufficiently low, (0.5 Torr for 3 cm diameter duct, 0.05Torr for 30cm duct), formation of Pb aerosol seems to be not very serious.**



Remaining issue

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- **Synchronization of target injection with rotary shutter.**

Since it is quite difficult to change rotating speed of the shutter disk, target injection must synchronize with the open timing of the shutter.

For example, $v=200 \pm 1$ m/s

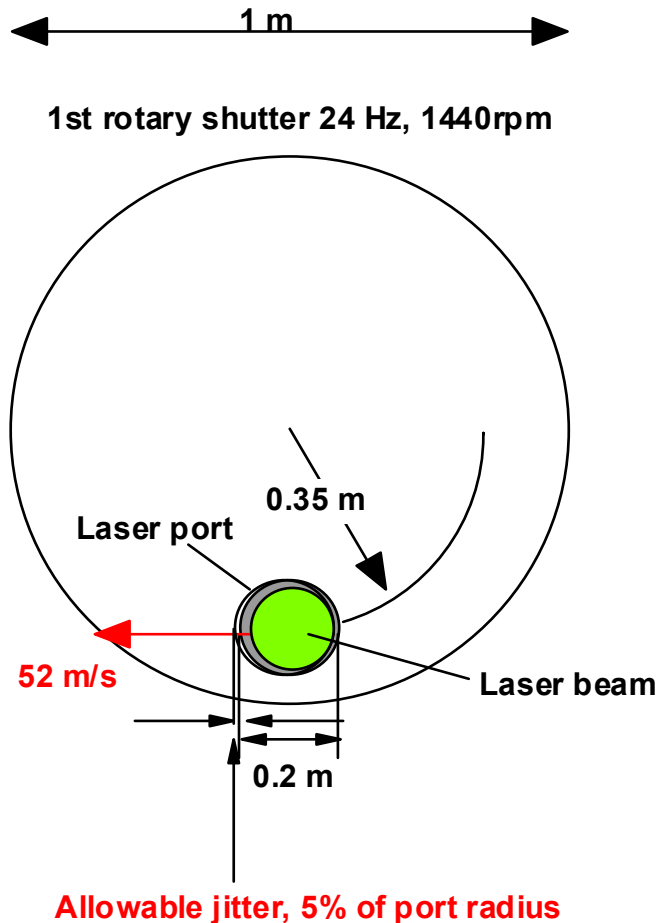
- **Chamber clearance**

Because of thermal radiation transfer, blast wave becomes cold before it reach the chamber center resulting rot of particles when it collides at the chamber center.

Rotary shutters impose severe accuracy for the injection velocity.



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- Fire timing of the target and open time of the rotary shutters must be synchronized with accuracy of 0.2 ms.
- This requires the injection velocity of **200 +/- 2 m/s**.