Elemental Researches on Liquid Wall of KOYO-F -Aerosols, Beam port, and Cascade flow -

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Outline

- Introduction of KOYO-F
- Stability of cascade flow
- Protection of beam ports by a magnetic field
- Experimental simulation of ablation process by alpha particles using punch-out dot target

KOYO-F is a commercial or very “close to” commercial power plant.

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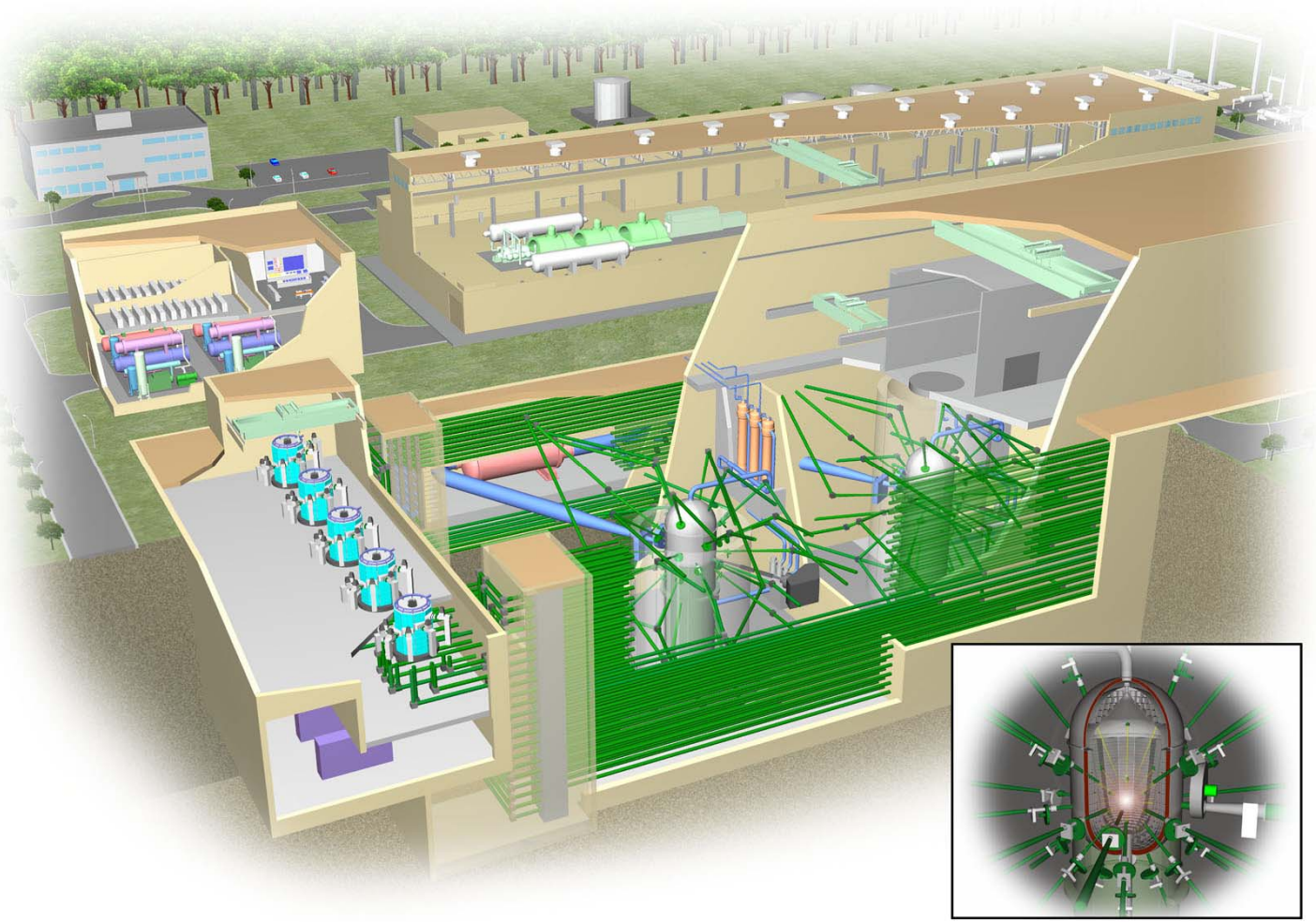


System specification

Thermal out put	3664 MW
Electric power	1280 MW
System efficiency	33 %

Laser

Cooled Yb:YAG Ceramic
1.2MJ/16Hz
(1.1MJ+100kJ)

Efficiency 13.1% for Main
5.4% for heating
11.8% in total

Plasma

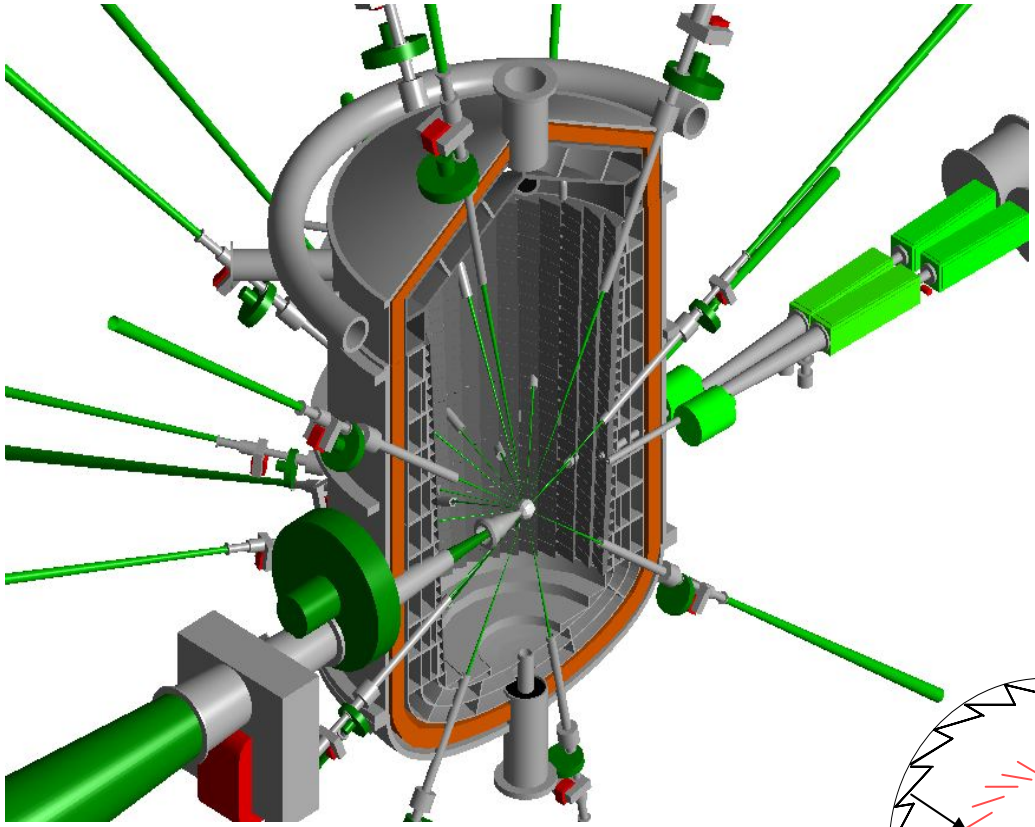
Gain	160
Fusion Yield	200MJ

Reactor

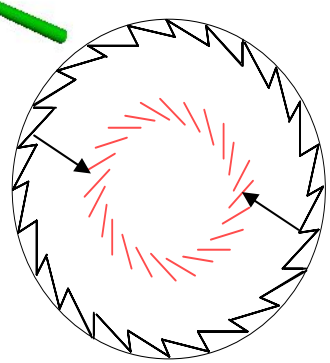
4 modular reactors

First wall Liquid LiPb
Cascade flow

KOYO-F with 32 beams for compression and one heating beam



Parameter of KOYO-F	
Number of beams	32 (compression) 1 (heating)
Inner size of chamber	3 m in radius 12 m in height
Thermal load on the first wall	1.8 MJ/m^2



Tilted first panels to make no stagnation point of ablated vapor

After activity of Reactor Design Committee, elemental, collaborative researches are continued to increase the reliability of KOYO-F.

- Ablation and formation of aerosols
  - **Ablation process of liquid flow from first wall and RT instabilities**
  - Aerosols from planar source;
  - Simulation;
- Stability of cascade flow;
- Protection of beam port;
- Injection and tracking;

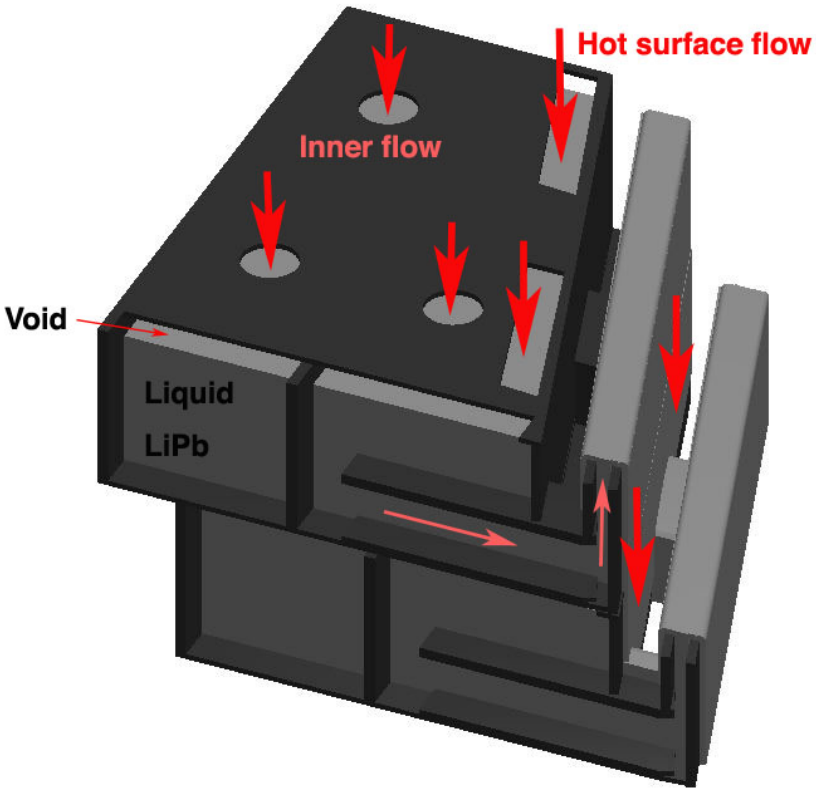
- Tritium recovery;
- Chamber Activation;
- Swelling;

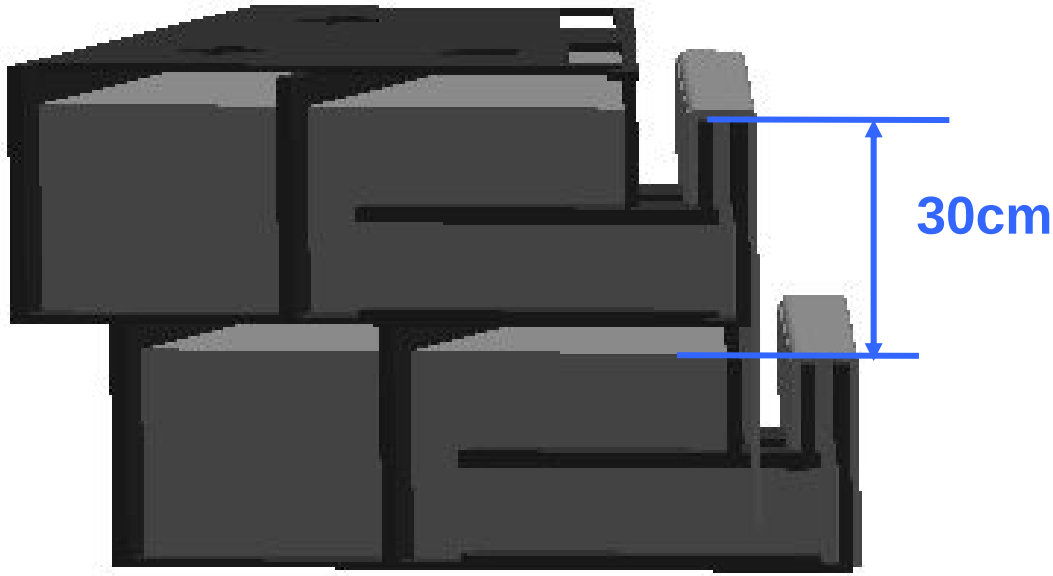
Outline

- Introduction of KOYO-F
- Stability of cascade flow
  - （Collaborative work with Dr Kunugi of Kyoto University)
- Protection of beam ports by a magnetic field
- Experimental simulation of ablation process by alpha particles using punch-out dot target

Cascade flow of KOYO-F

1) The height of cascade is 30 cm that comes from free fall distance in 0.25 sec (4Hz).
2) There is a void at the top of each step to obtain a stable flow.





Design base of mockup

- **Water was used instead of liquid LiPb for visibility.**
- **The mockup was designed to obtain the same Weber number.**

Reynolds number: $$\mathrm{Re} = \frac{u\delta}{\nu}$$

Weber number: $$We = \frac{\rho u^2 \delta}{\sigma}$$

$$\frac{We_{water}}{We_{LiPb}} = \frac{\sigma_{LiPb}}{\sigma_{water}} \frac{\rho_{water}}{\rho_{LiPb}} \left(\frac{u_{water}}{u_{LiPb}} \right)^2 = 1$$

$$\therefore \frac{u_{water}}{u_{LiPb}} = 1.21$$

The height of the front panel is the same as actual reactor but the width is ¼ of KOYO-F

15cm

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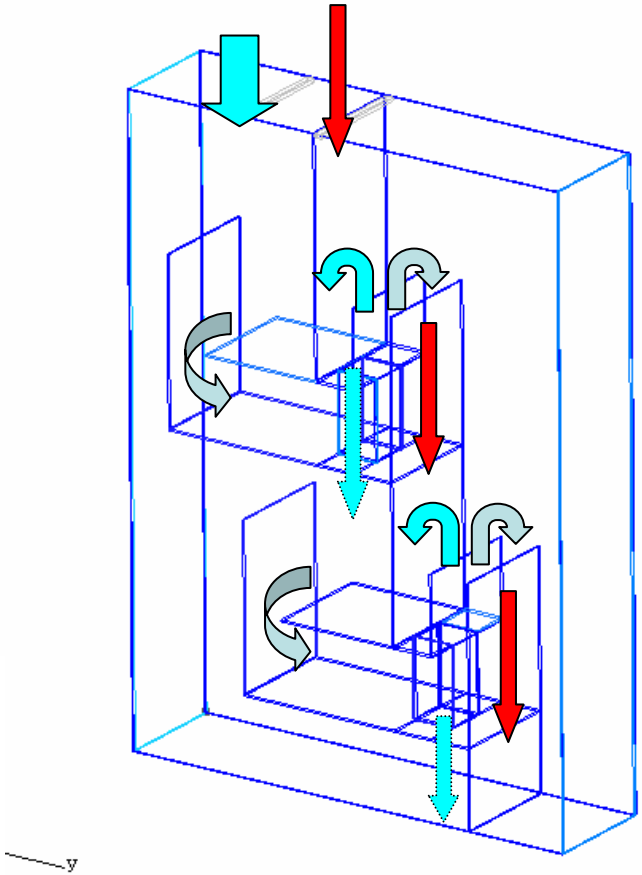

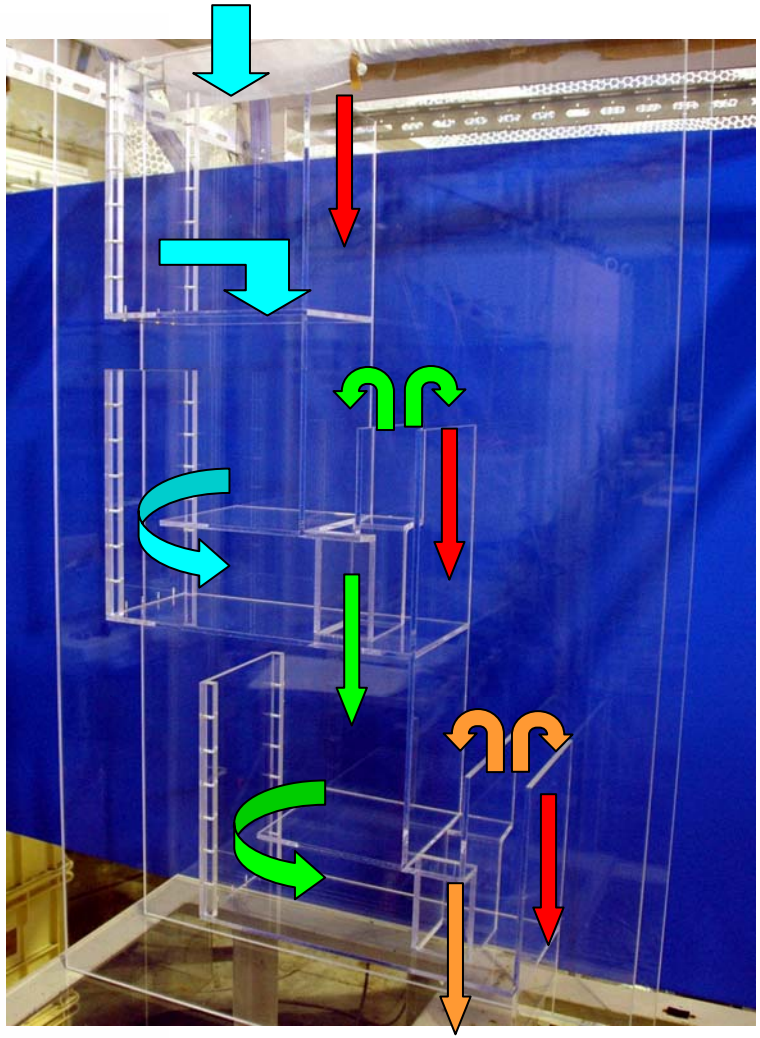

Flow loop of mockup

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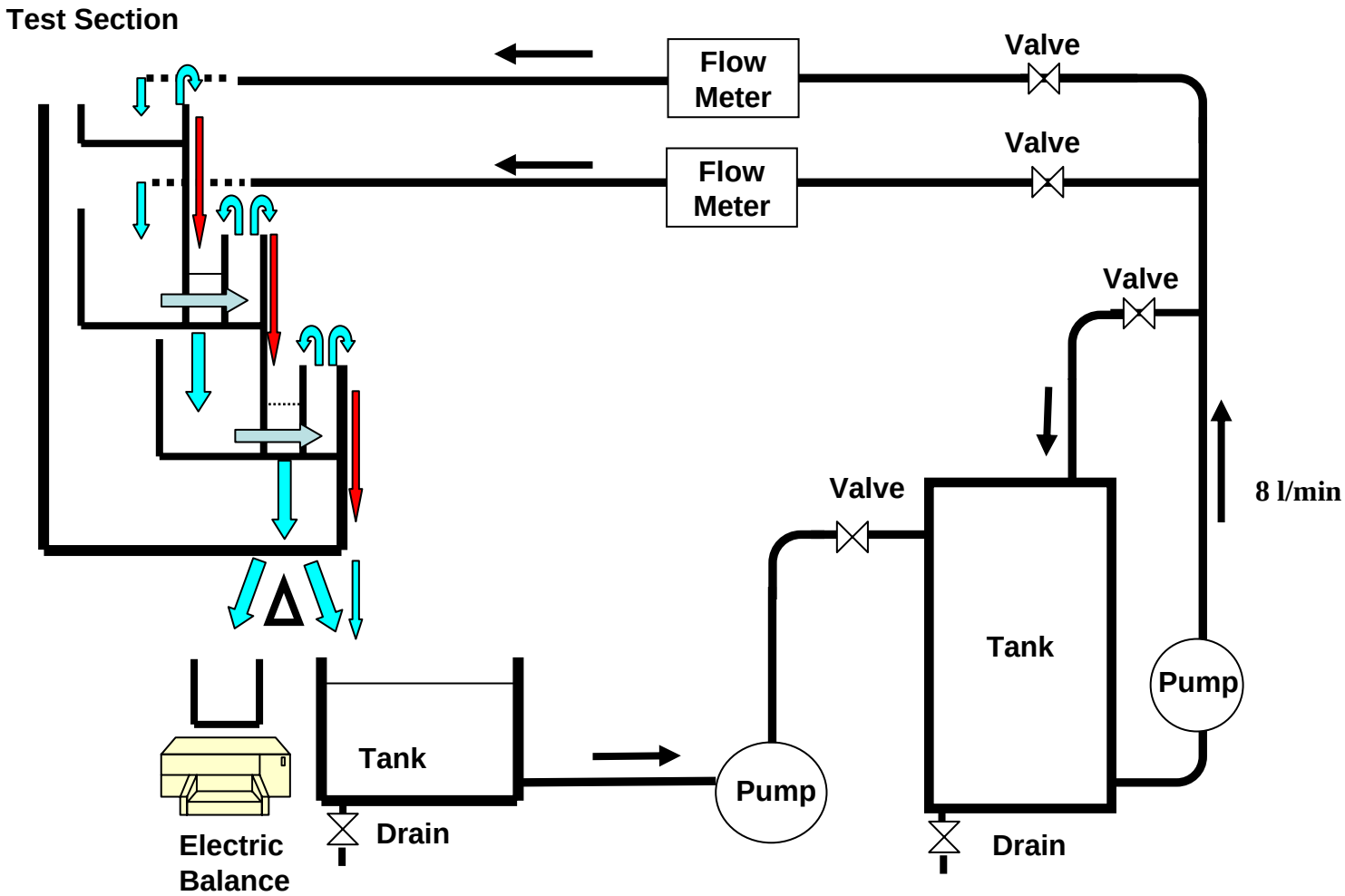
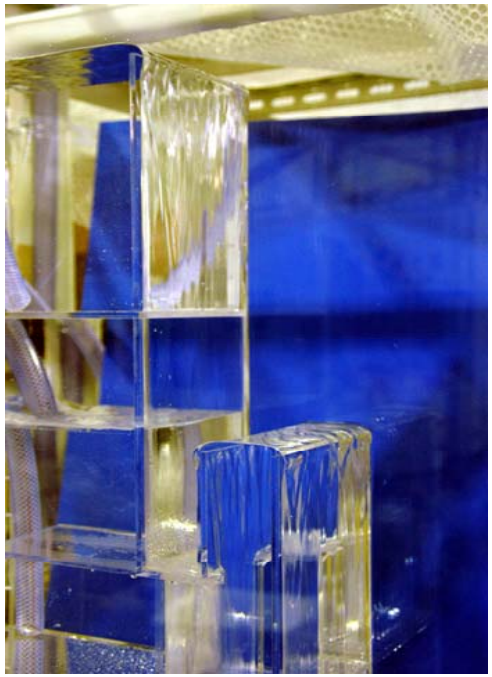
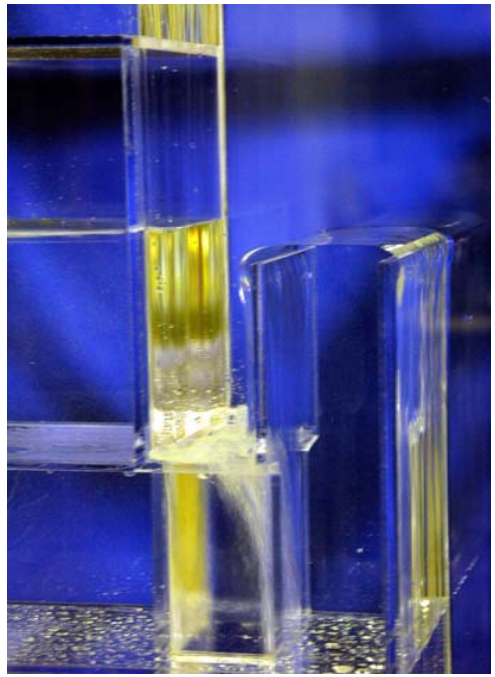


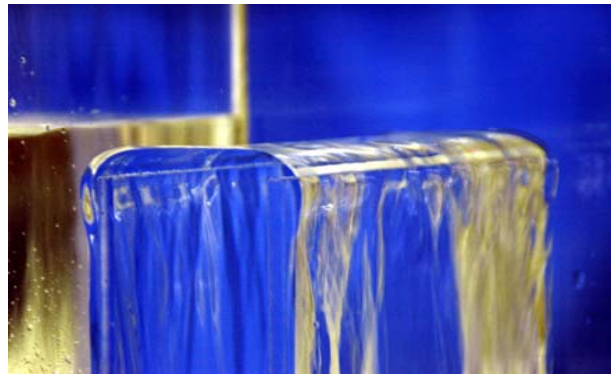
A continuous flow was obtained if the thickness is > 3mm.

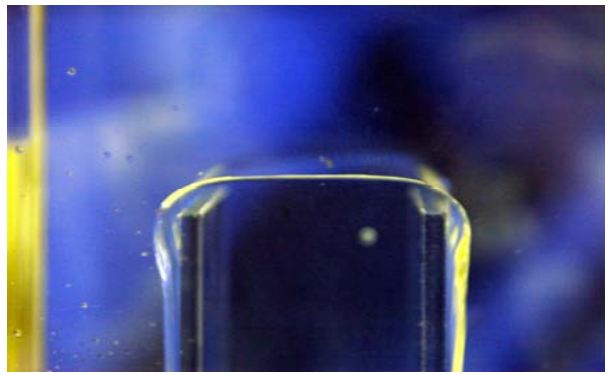


1st and 2nd steps

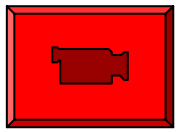


2nd 3rd steps





3rd step

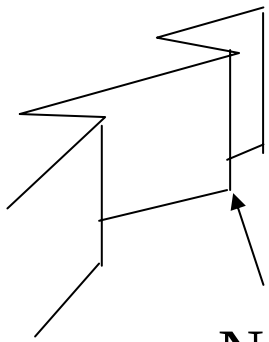


The flow rate was 1.5 time larger than KOYO-F

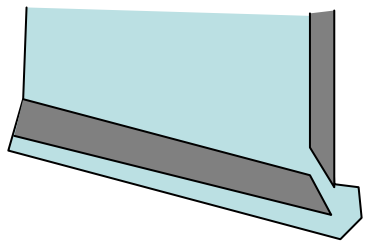
Summary of this section

- A continuous stable flow was formed if the thickness of flow was > 3mm.

- Remaining issue: demonstration of free edge
- A slit would be the solution (Proposed by Kozaki)



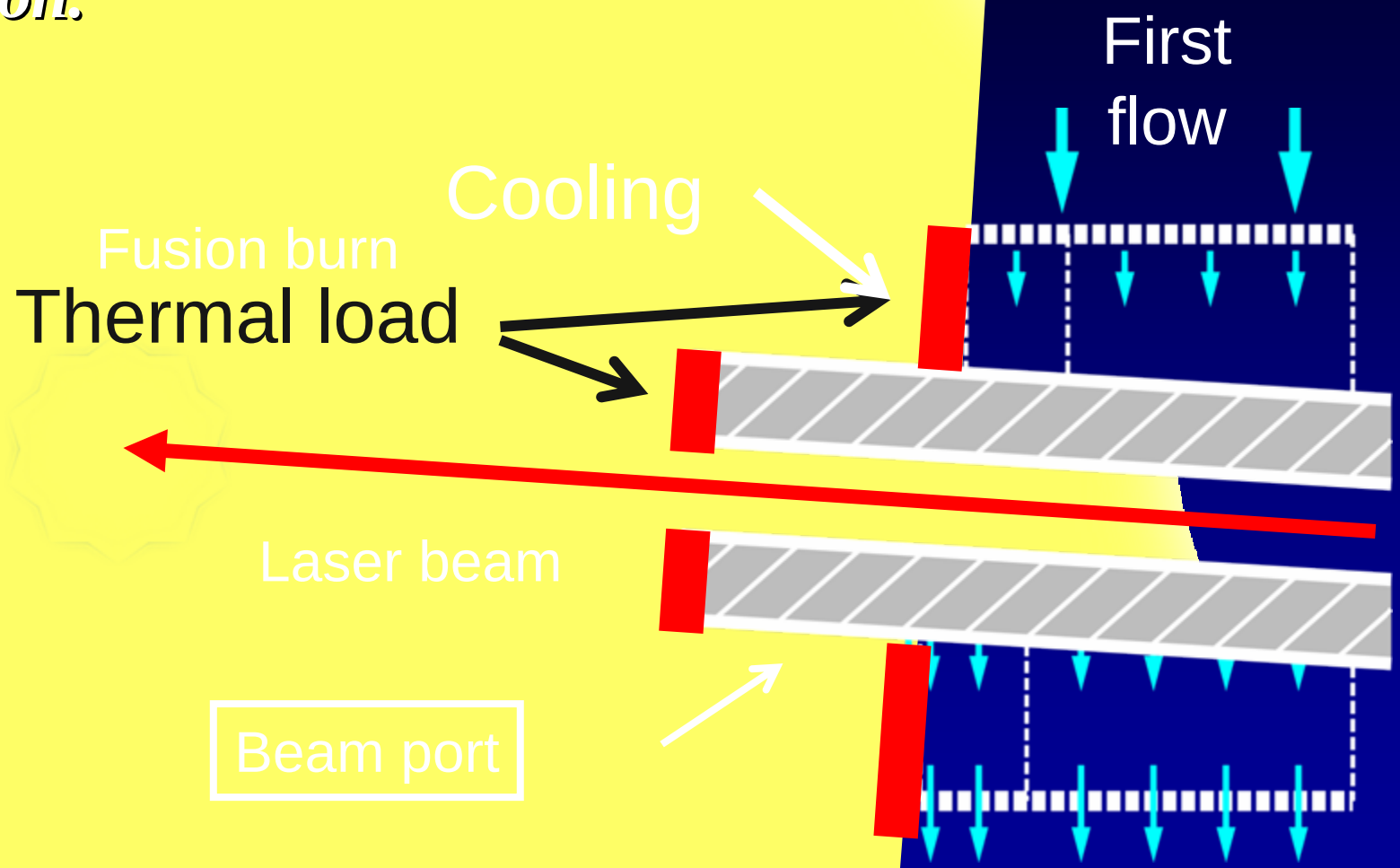
No support on this edge



Outline

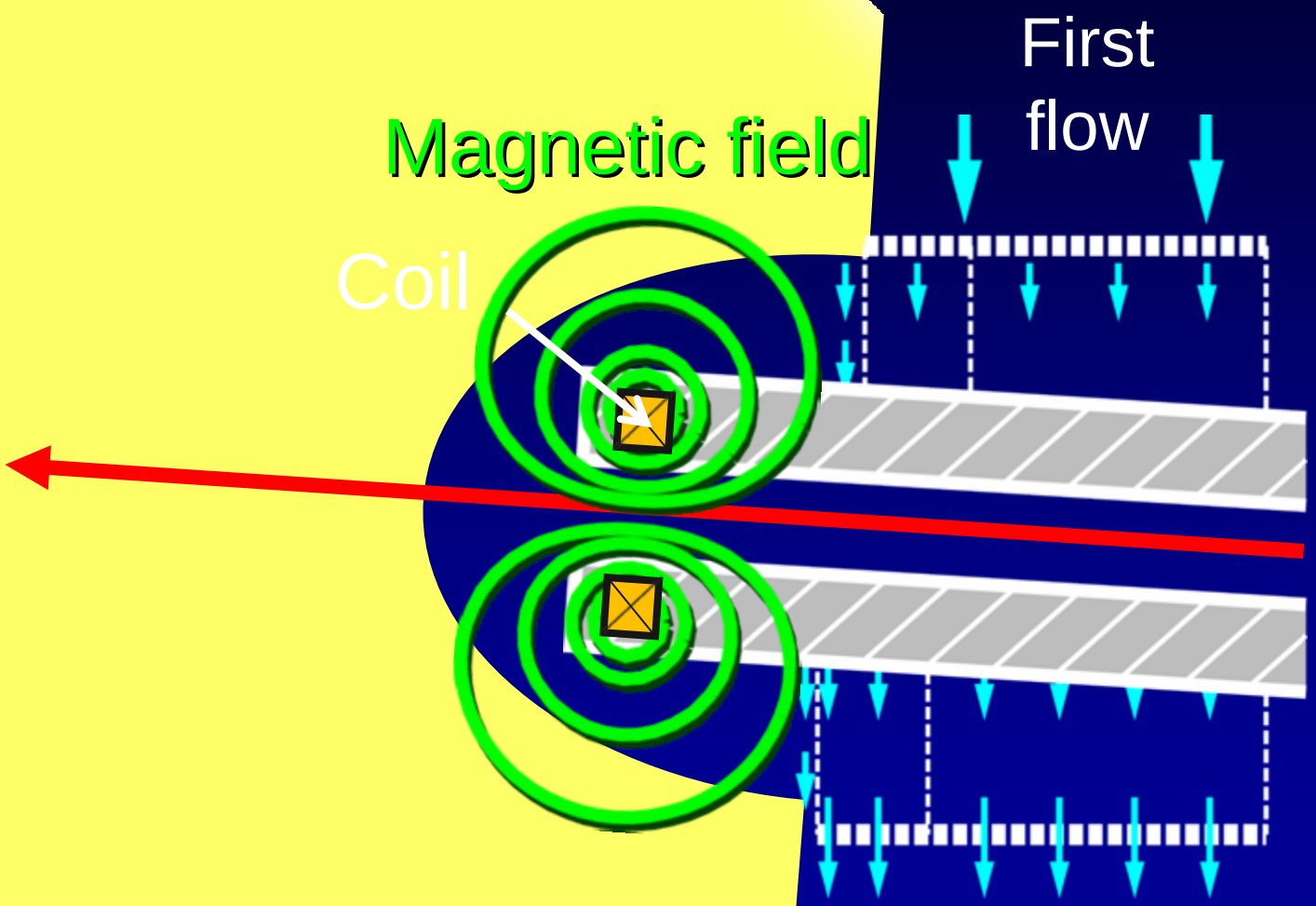
- **Introduction of KOYO-F**
- **Stability of cascade flow**
- **Protection of beam ports by a magnetic field**
  - **(Collaborative work with Dr. Nakashima and Kajimura of Kyushu University)**
- **Experimental simulation of ablation process by alpha particles using punch-out dot target**

After laser shot, the tip of beam port would be coated with a membrane of liquid LiPb due to condensation of evaporated LiPb but some protection scheme is necessary for long term operation.



Our primary goal is to reduce the load to 1/10 of original design.

Protection scenario



Three dimensional hybrid code was used.

Ions were treated as particles and electrons were treated as a fluid.

Equation of motion of ions

$$m_i \frac{d\mathbf{v}_i}{dt} = Ze(\mathbf{E} + \mathbf{v}_i \times \mathbf{B}), \quad \frac{d\mathbf{x}_i}{dt} = \mathbf{v}_i$$

Hydrodynamic equation of electrons

$$n_e m_e \frac{d\mathbf{v}_e}{dt} = -en_e(\mathbf{E} + v_e \times \mathbf{B}) - \nabla P_e$$

Faraday's law

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

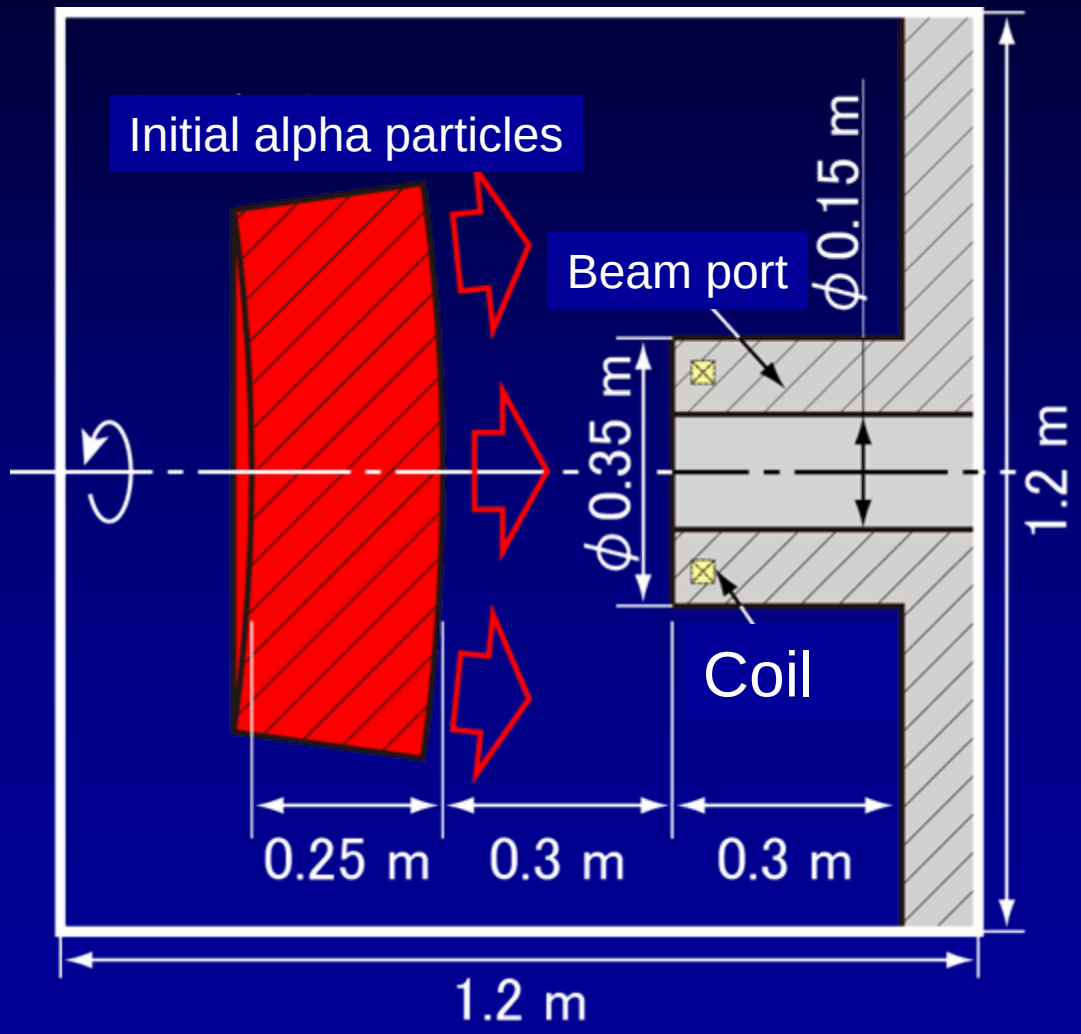
Ampere's law

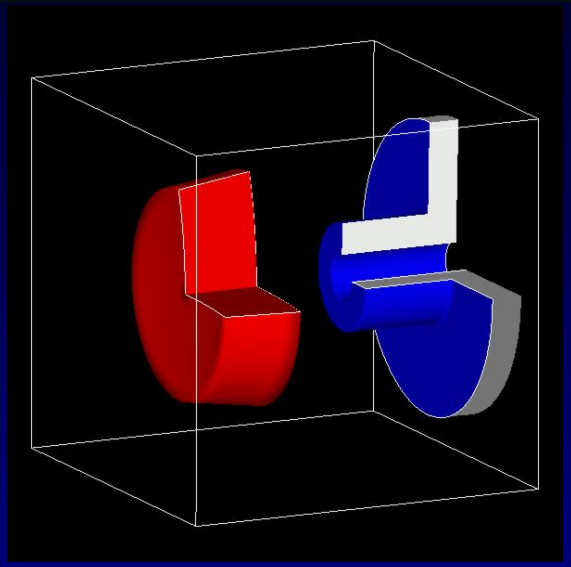
$$\nabla \times \mathbf{B}_p = \mu_0(\mathbf{J}_e + \mathbf{J}_i)$$

$$\mathbf{J}_e = -en_e\mathbf{v}_e, \ \mathbf{J}_i = en_i\mathbf{v}_i$$

•The electric field in plasma was calculated from motion of electrons and that in neutral region was calculated from Laplace equation.

Calculation model

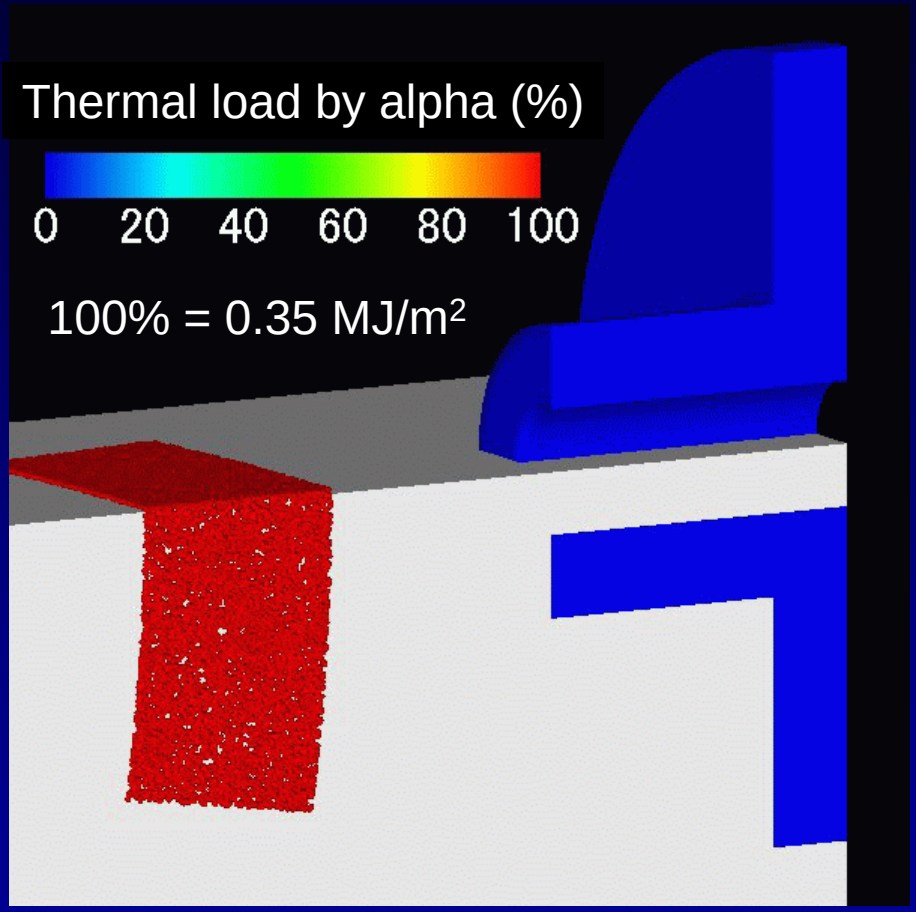




$N\alpha = 2.5 \times 10^{18}\ /m^3$

$V = 1.4 \times 10^{6}$ m/s

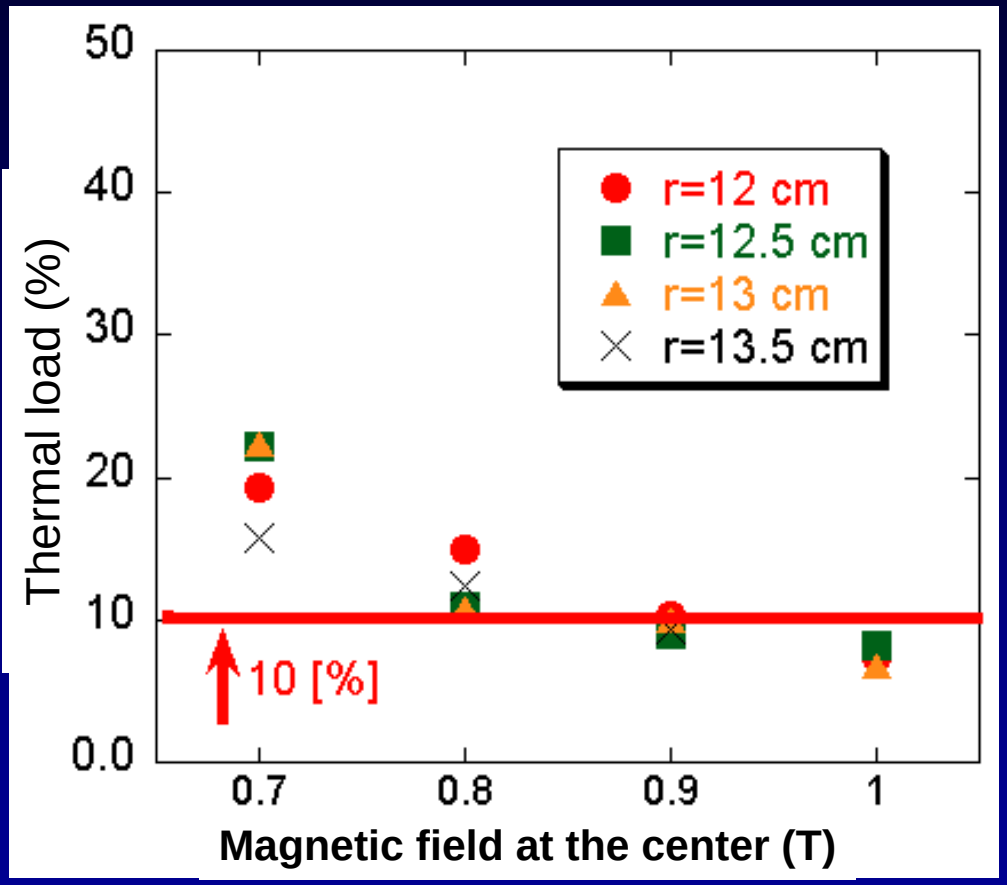
Magnetic field is effective to reduce the alpha load on the tip of beam port.

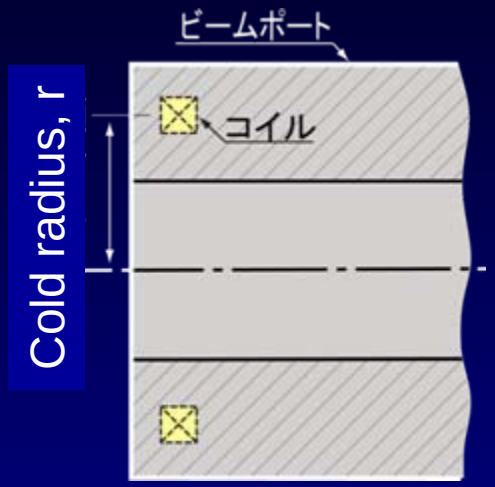


Coil radius r =13 cm
B =0.9 T

- No influence on side wall of beam port
- Thermal load around the beam port was increased to 150 % but this is acceptable.

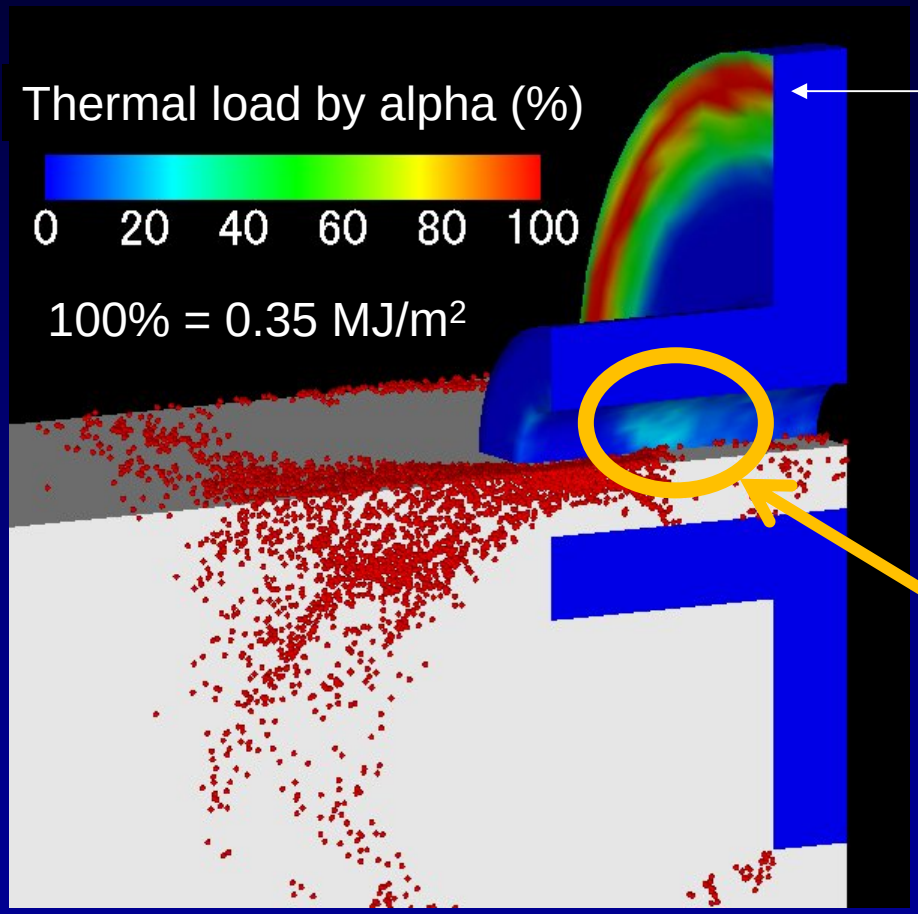
Optimization of the coil radius





- A magnetic field of >0.9 T is necessary to reduce the thermal load below 0.1 I_0.

New issue

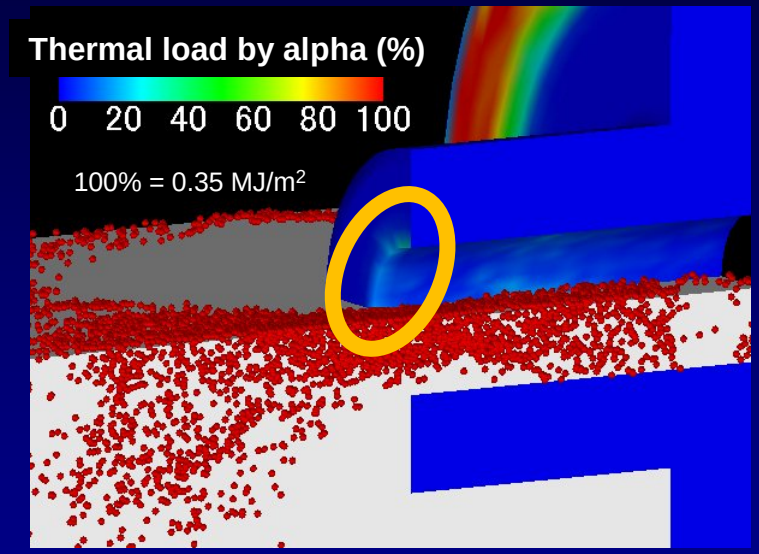


コイル半径r =13 cm
コイル中心磁場強度B =0.9 T

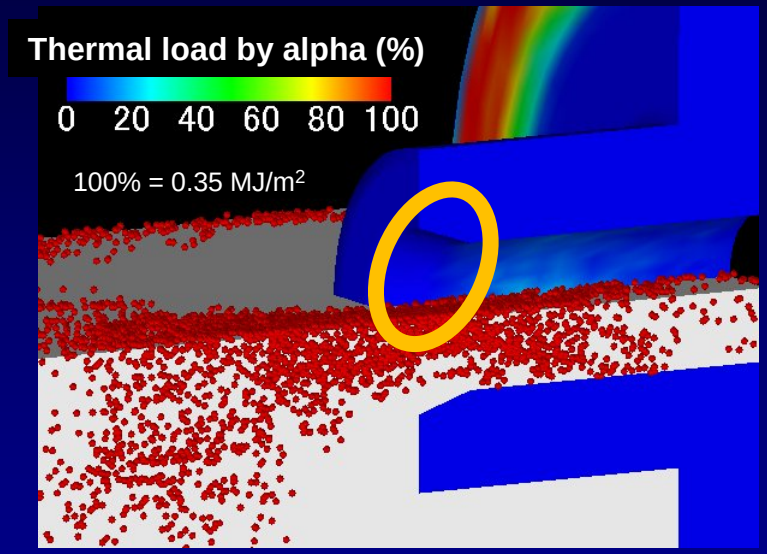
- Thermal load around the beam port was increased to 150 % but this is acceptable.

Thermal load on the inner wall of the beam port was increased to 0.15 I_0.

To reduce the load on corner



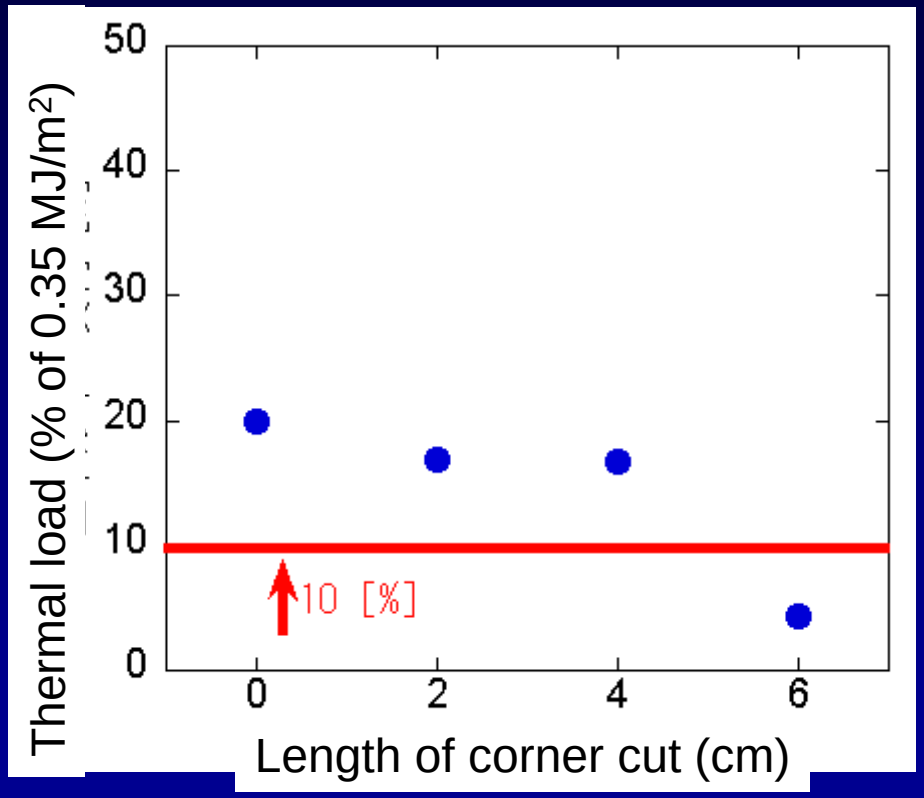
Original design



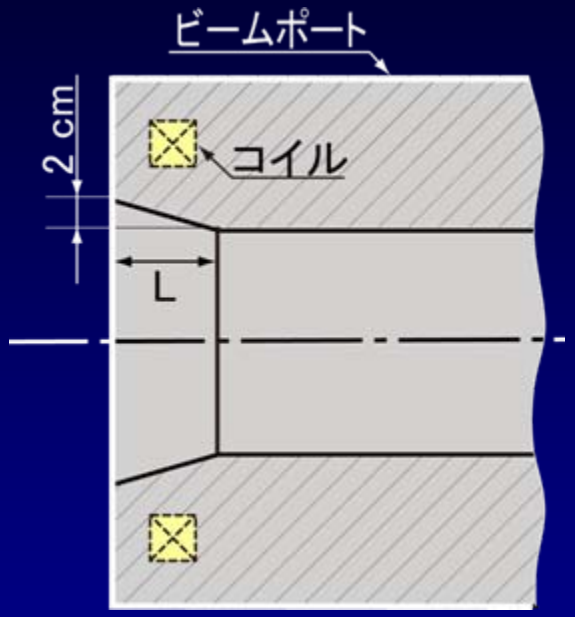
With corner cut L =6 cm

r =13 cm, B =0.7 T

Corner cut reduced the necessary magnetic field to 0.7 T.



The dependence of corner cut on the thermal load at B=0.7 T.



The magnetic field at the center was reduced to 0.7T with corner cut.

Summary of this section

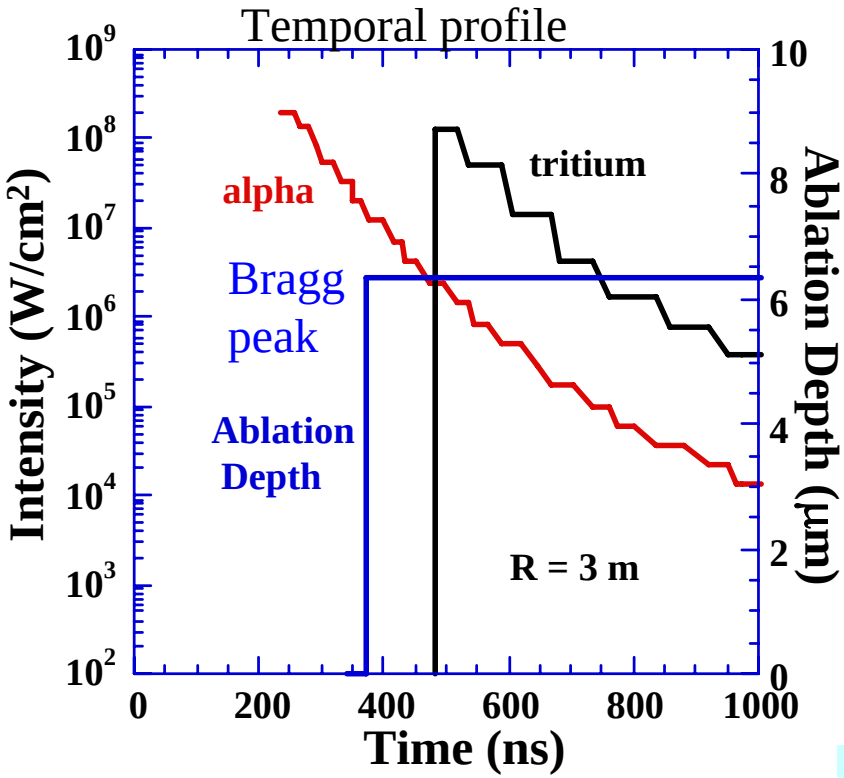
- We successfully reduced the thermal load on the beam port to acceptable level using a 0.7 T magnetic field.

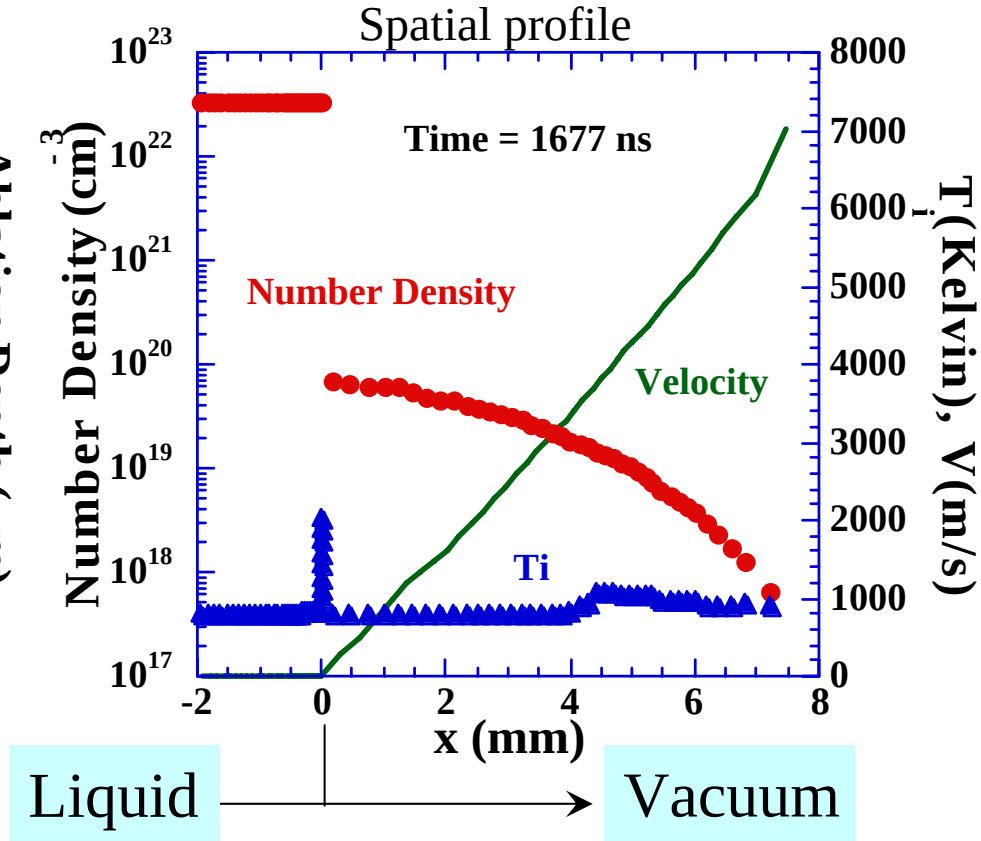
- Remaining issue;
  - Thermal load of 0.04 MJ/m^2
    - SiC would be the solution
  - How to make the 0.7 T field
    - Pulse operation, 50kA, 100 μs, 4Hz
    - Cooling of coil, the conductor would be liquid LiPb

Outline

- Introduce Design of KOYO-F
- Stability of cascade flow
- Protection of beam ports by a magnetic field
- Experimental simulation of ablation process by alpha particles using punch-out dot target

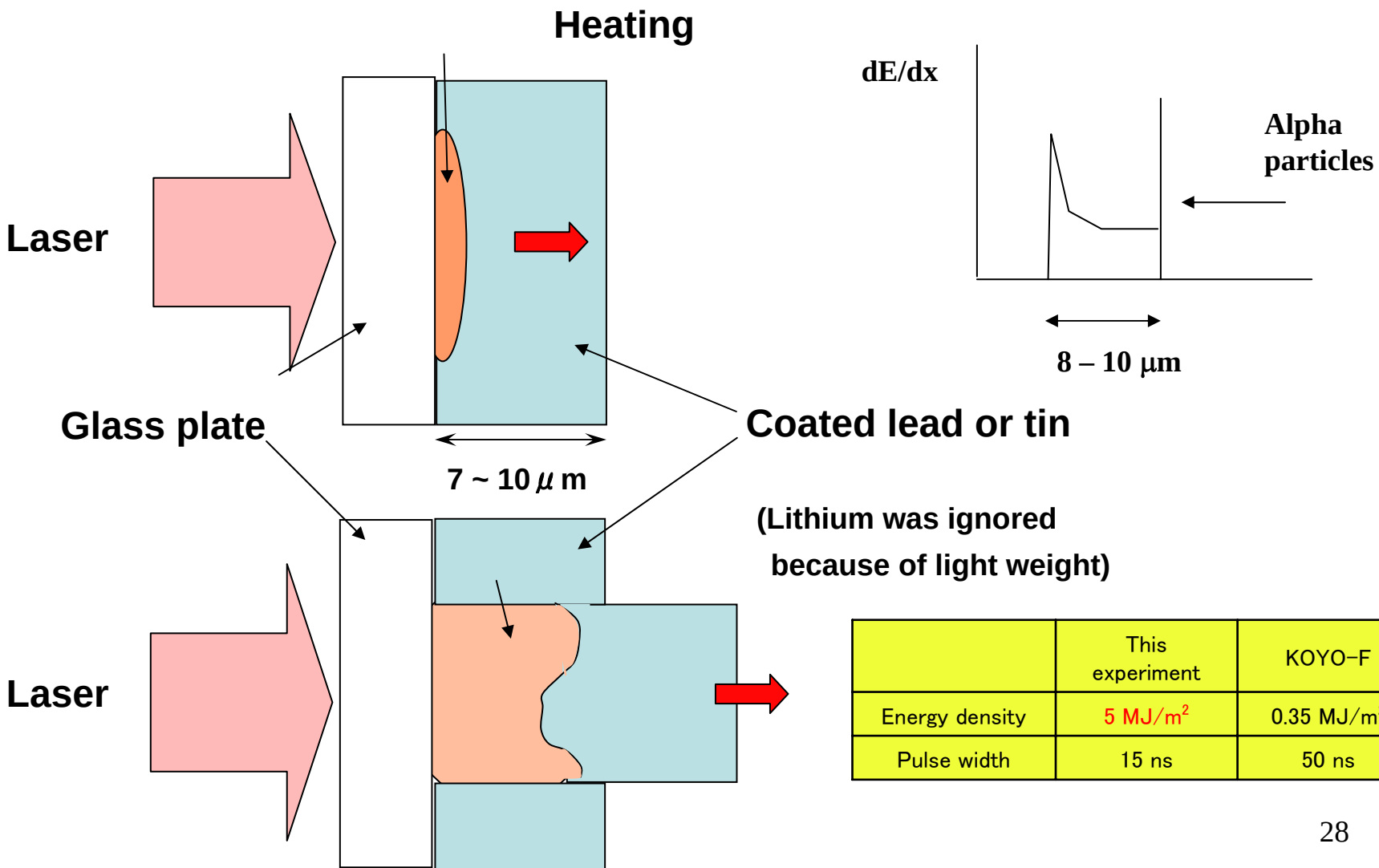
Ablation depth and profiles of ablated plume obtained by simulation





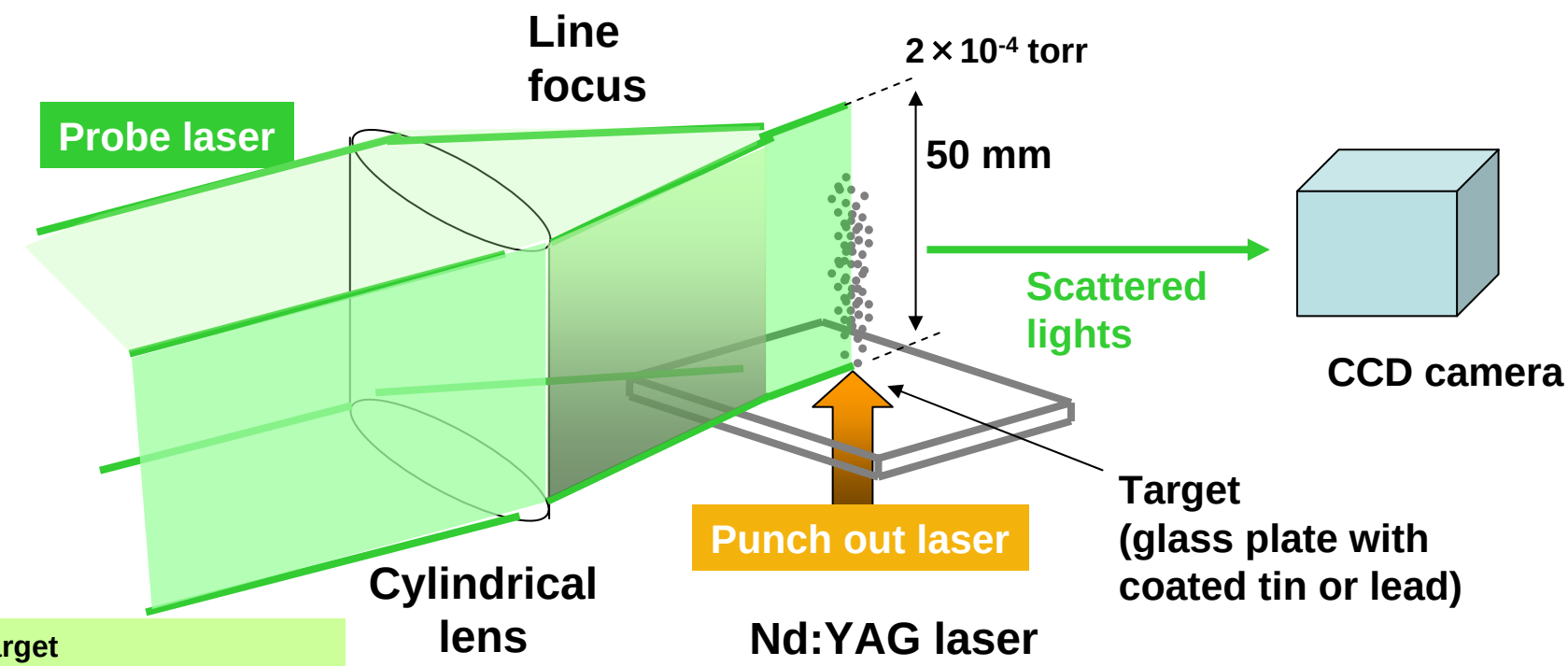
Pressure : few kbars at Bragg peak

Laser irradiation simulates for α-particles heating from backside of metal layer

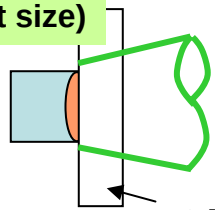


	This experiment	KOYO-F
Energy density	5 MJ/m^2	0.35 MJ/m^2
Pulse width	15 ns	50 ns

Experimental setup. Laser-scattering measurement was used to observe flying situation of metal



Dot target
Diameter : ϕ500 μm
(smaller than laser spot size)



Intensity: 0.5 – 1 GW/cm^2
Spot size : 700 - 800 μm$^{\phi}$
Pulse duration : 15 ns

Dot target propelled toward without large divergence angle

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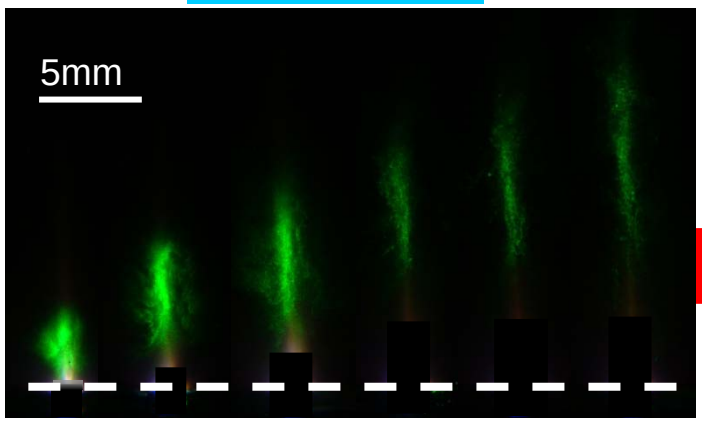
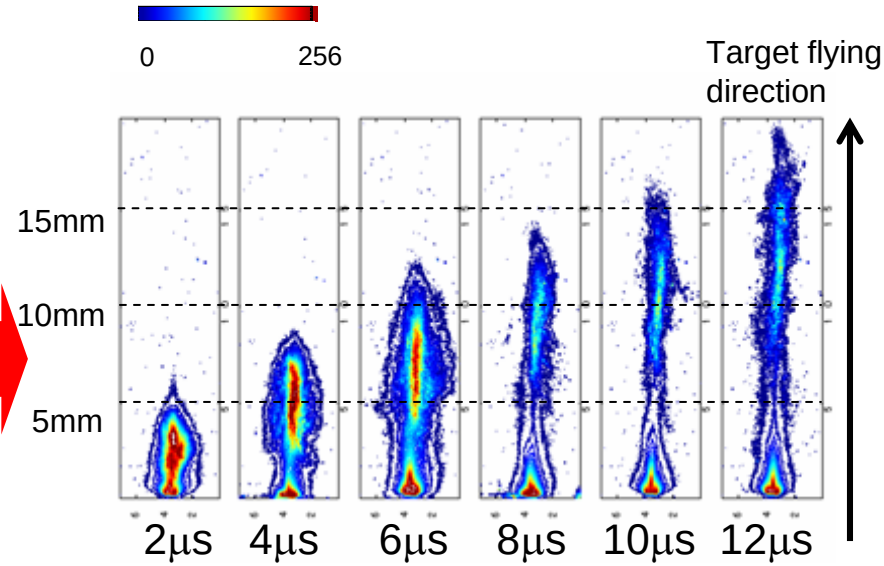
Dot tin 9μm



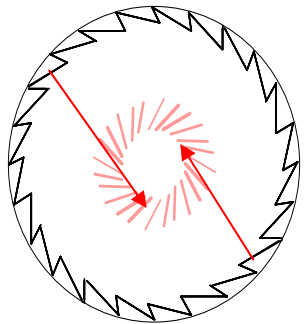
2μs 4μs 6μs 8μs 10μs 12μs



Time resolution : 7.5 ns

Targets were propelled forward without large divergence angle

This result indicates the tilted-front-panel concept works well.



Velocities of mass center of tin particles were 1.0 ~ 1.5 km/s

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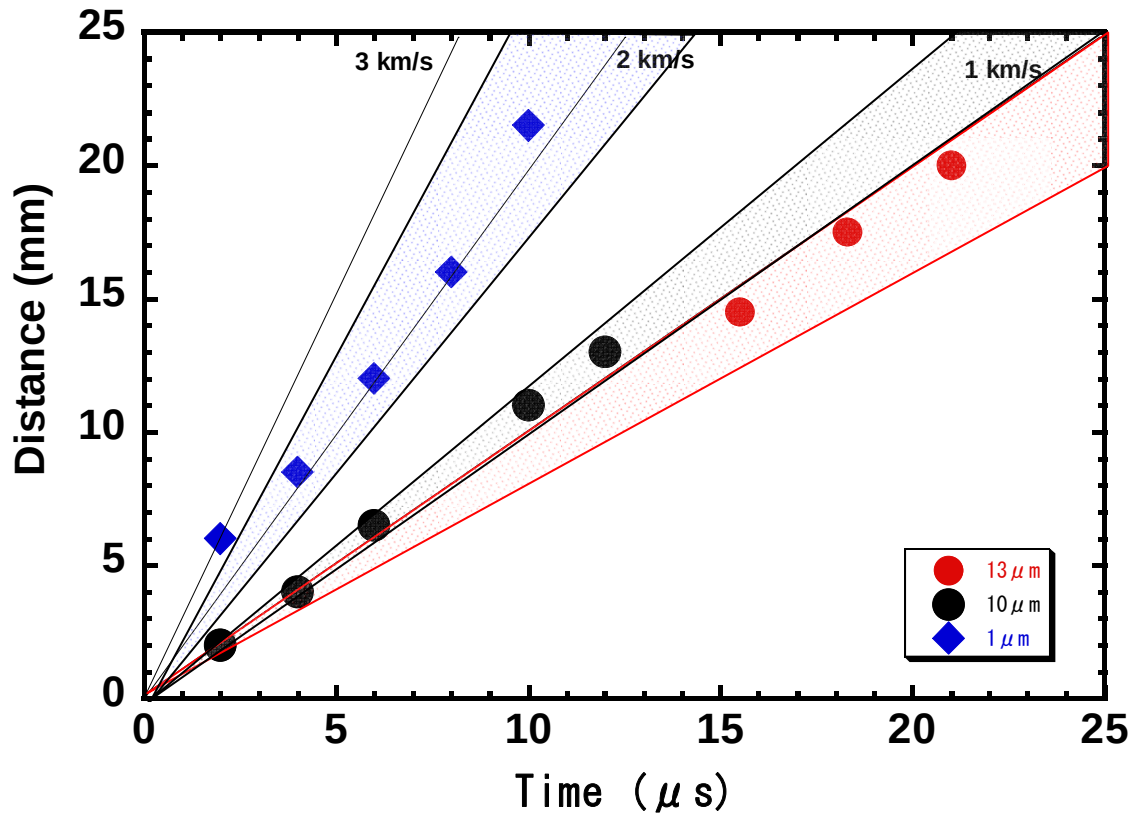

$$\frac{dP}{dt} = m\frac{dv}{dt}$$

p ~ 0.8 kbar

@ 1km/s

(Similar to simulation)

1.0 ~ 1.5 km/s @ 10 μm thickness

5MJ/m^2

250 ~400 m/s @ KOYO-F

0.35 MJ/m^2

Spouted gas and small particles, and large particles were detected at 10-mm away from glass plate

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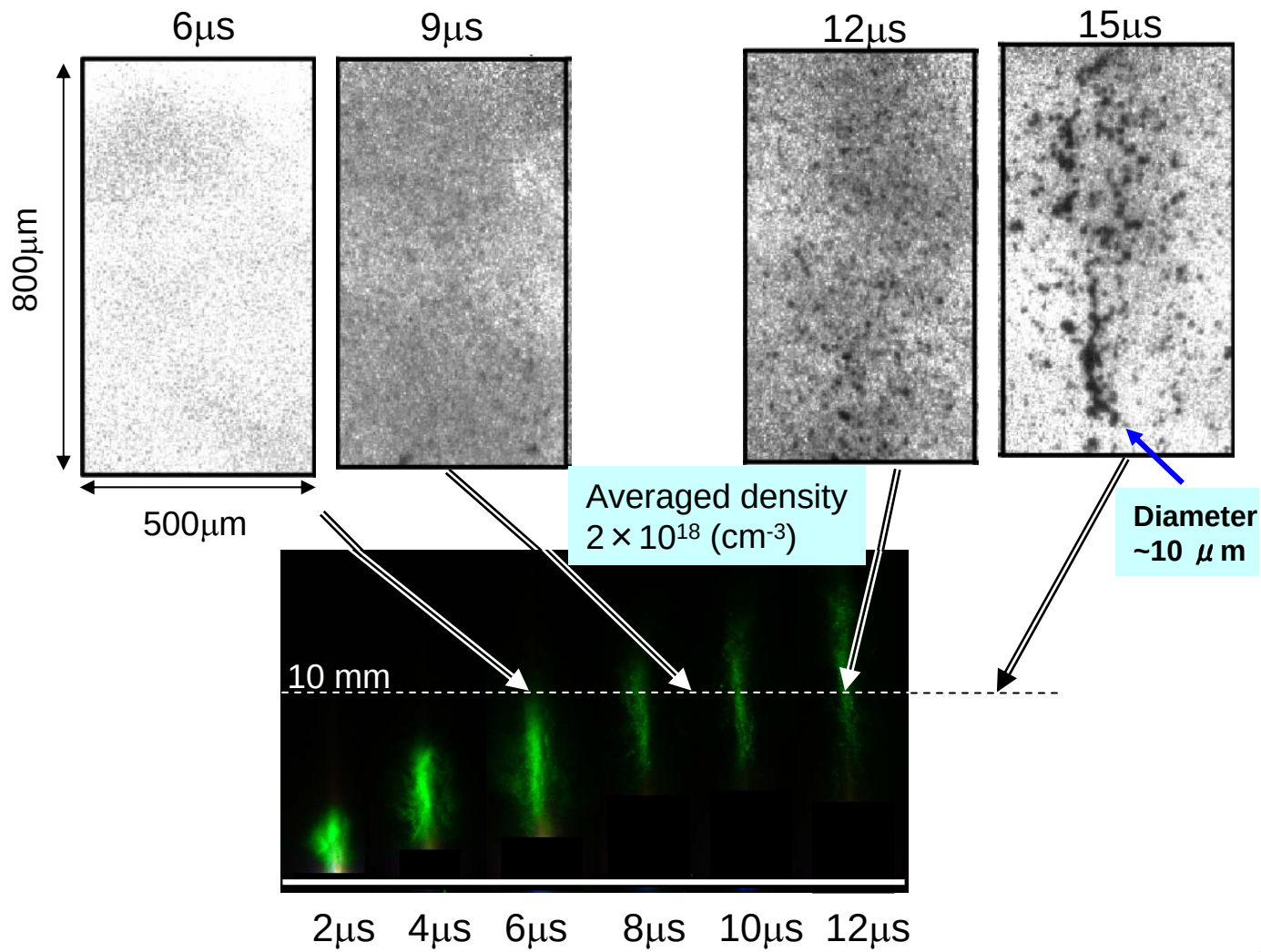
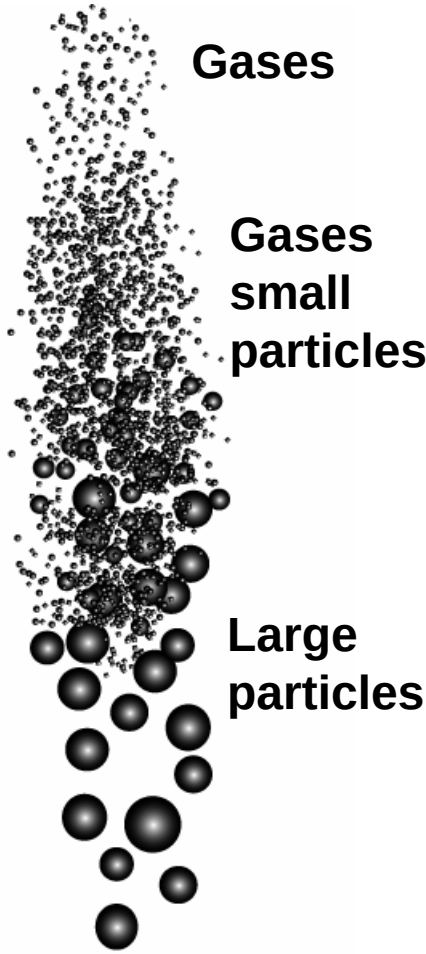
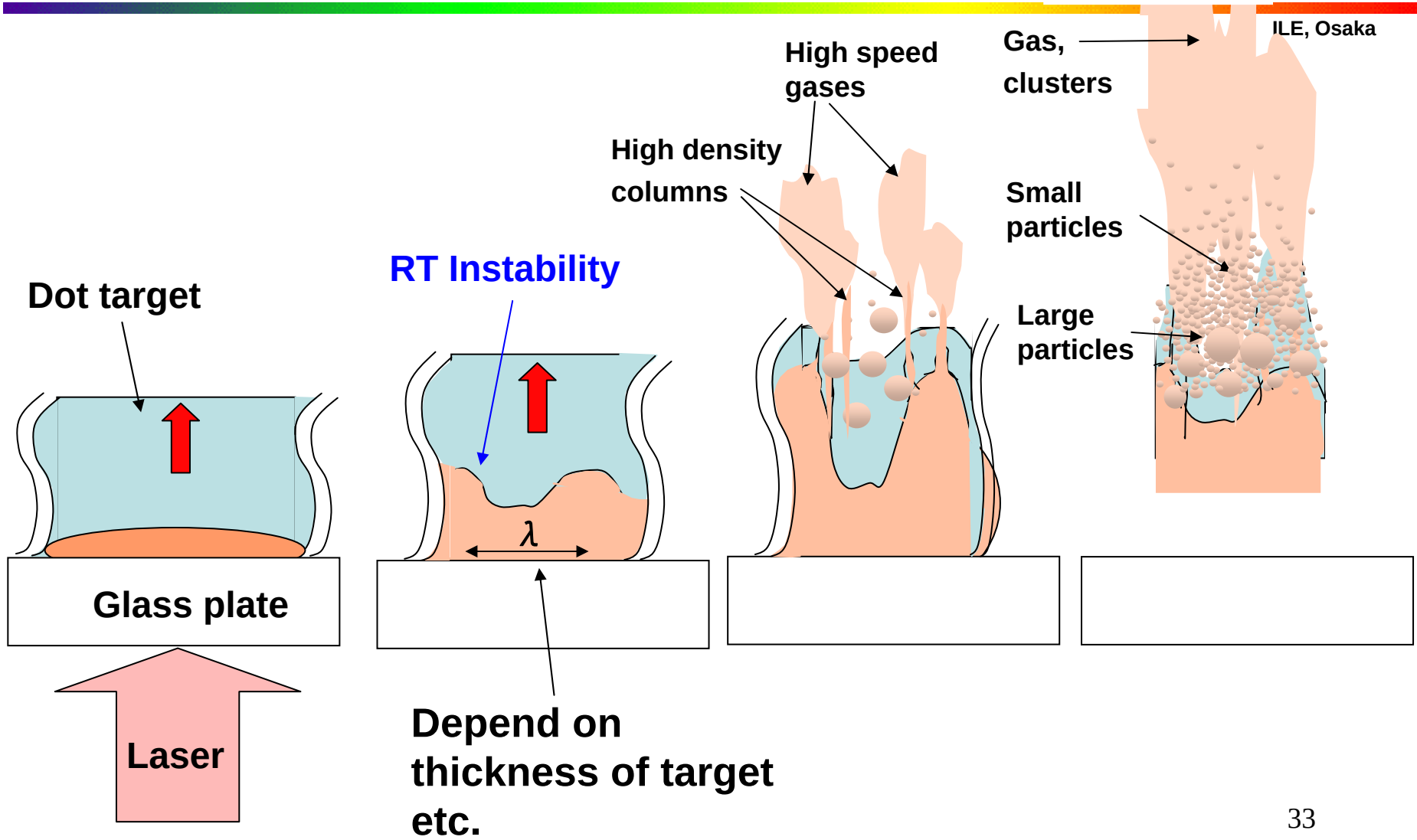




Laser irradiation induces RT instability and break up solid thin surface, generates gas clusters and large particles

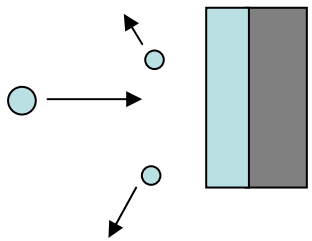


Summary of this section

- When we discuss chamber clearance, we must consider hydrodynamic process of ablation.

- Large diameter (10 μm) particles would be formed.

- Remaining issue
- Discussion on the secondary particles are necessary.



Summary

- **Stability of cascade flow**
- **When the thickness of the flow is > 3 mm, a continuous stable flow was obtained on a hydrophobic panel.**
- **Protection of beam port**
- **Thermal load of alpha particles was reduced to 1/10 of the original design. No ablation takes place.**
  - **Remaining issue: protection of inner wall**
  - **SiC would be the solution.**
- **Aerosols(100 nm diameter) and particles (10 μm)**
- **Hydrodynamic process must be considered to discuss formation of aerosols and particles.**
  - **Remaining issue: Secondary particles**