Critical issues of laser fusion reactor KOYO-F

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Outline

ILE, Osaka

- Introduction
  - Conceptual design reactor KOYO-F
- Issues on liquid wall
- Tritium control
- Issues on neutron damage

Reactor Design Committee was organized to clarify the feasibility of Laser Fusion Plant based on Fast Ignition by IFE Forum and ILE, Osaka University

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- Chair; A. Tomabechi
- Co-chair; Y. Kozaki (IFE, Forum)
  T. Norimatsu (ILE, Osaka)

Core plasma Working Group

H. Azechi (ILE),
Y. Nakao (Kyushu Univ.),
H. Sakagami (Hyogo Unv.),
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R. Kodama (ILE),
H., Nagatomo(ILE),
T. Johzaki (ILE)

Laser Working Group

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K. Ueda (Univ. Elector-Com.),
N. Tuchiya (Nishin Co.)
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Y. Fujimoto (ILE),
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H. Furukawa (ILT)

Target Working Group

T. Norimatsu (ILE),
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Plant system Working Group

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Y. Soman (Mitsubishi Heavy Ind.),
K. Okano (CRIEPI),
Y. Furukawa (ILT),
Y. Sakawa (Nagoya Univ.),
A. Sagara (NIFS),
T. Norimatsu (ILE)

Purpose

1) to make a reliable scenario for the fast ignition power plant basing on the latest knowledge of elemental technologies,
2) to identify the research goal of the elements
3) to make the critical path clear.

KOYO-F

KOYO-F is a fast-ignition, laser-fusion power plant with 4 modular reactors powered by 1.2 MJ, 16Hz, cooled-, Yb:YAG ceramic laser.

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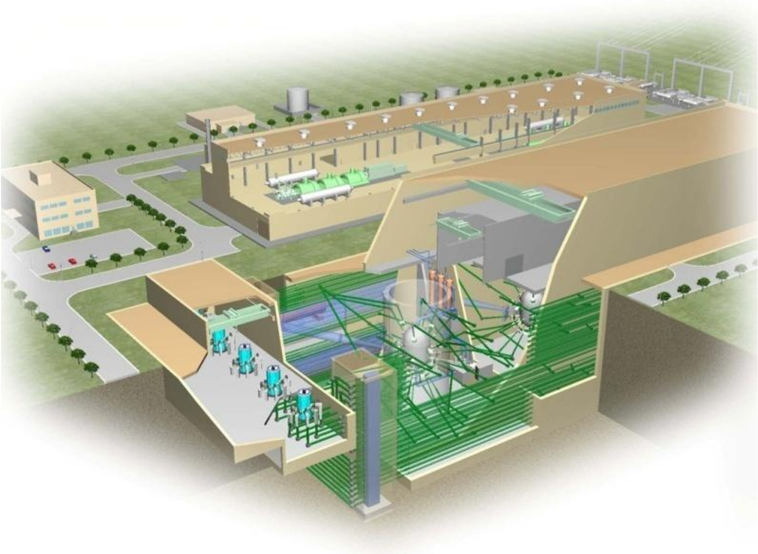
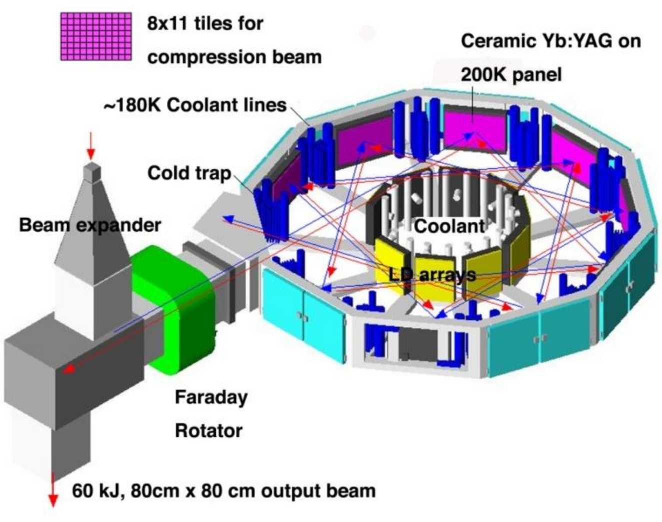
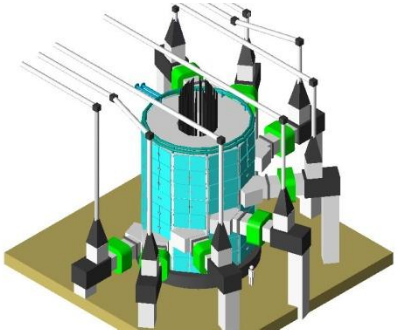




- Electric output power 1018MW
- Laser (1.1MJ+150kJ)x16Hz
  (13%)   (5.4%)
- Target gain 148
- Fusion yield 200MJx16Hz
- Blanket gain 1.2
- Thermal efficiency 41%
- Circulating power for laser, 193MW



Compression and heating lasers based on identical amplifier architecture

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	Compression laser		Heating laser
	Main pulse	Foot pulse	
Energy/pulse	1.1 MJ	TBD	150 kJ
Wavelength	UV (3ω) 343 nm	Visible (2ω) 515 nm	1030 nm
Band width	Narrow band	Broad band 1.6 THz	Broad band (rectangular pulse) ~3 nm
Efficiency	Efficient	Sacrifice of efficiency	（Sacrifice of efficiency）
Laser material	Cooled Yb:YAG ceramic		
Method for broad band	Arrayed beam with different wavelength ~0.1 nm@1030 nm (0.08 THz@343 nm)	Broad-band OPA pumped by 3ω, Spectral angular dispersion	Broad-band OPCPA pumped by 2ω

OPA: optical parametric amplifier
OPCPA : optical parametric chirped pulse amplifier

Lasers

Why Cooled Yb:YAG ?

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Because there are dramatic Improvements in;

1. Wide Tuning Range of Emission Cross Section (Saturation Fluence)

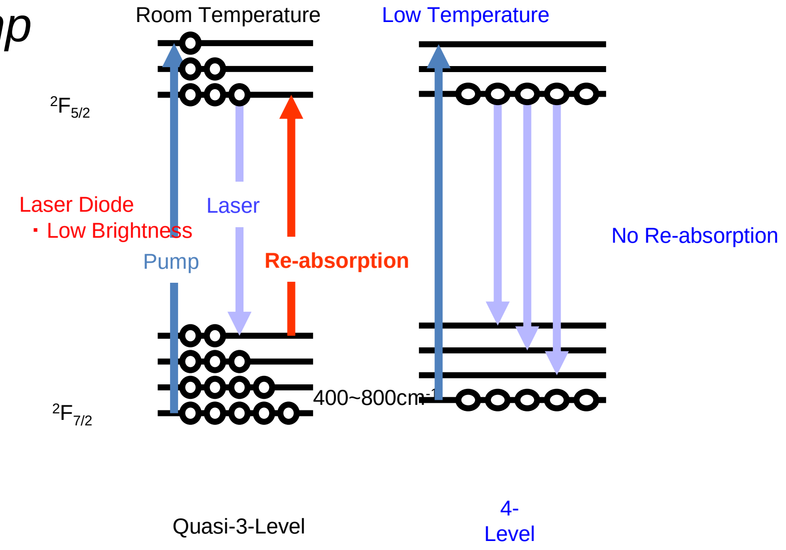
Realize an efficient energy extraction without optics damages

2. 4-Level Laser System

Enough Laser gain even in diode-pump

3. Improved Thermal Characteristics

High average power operation



Lasers

Cooled Yb:YAG ceramic is promising as the laser driver material.

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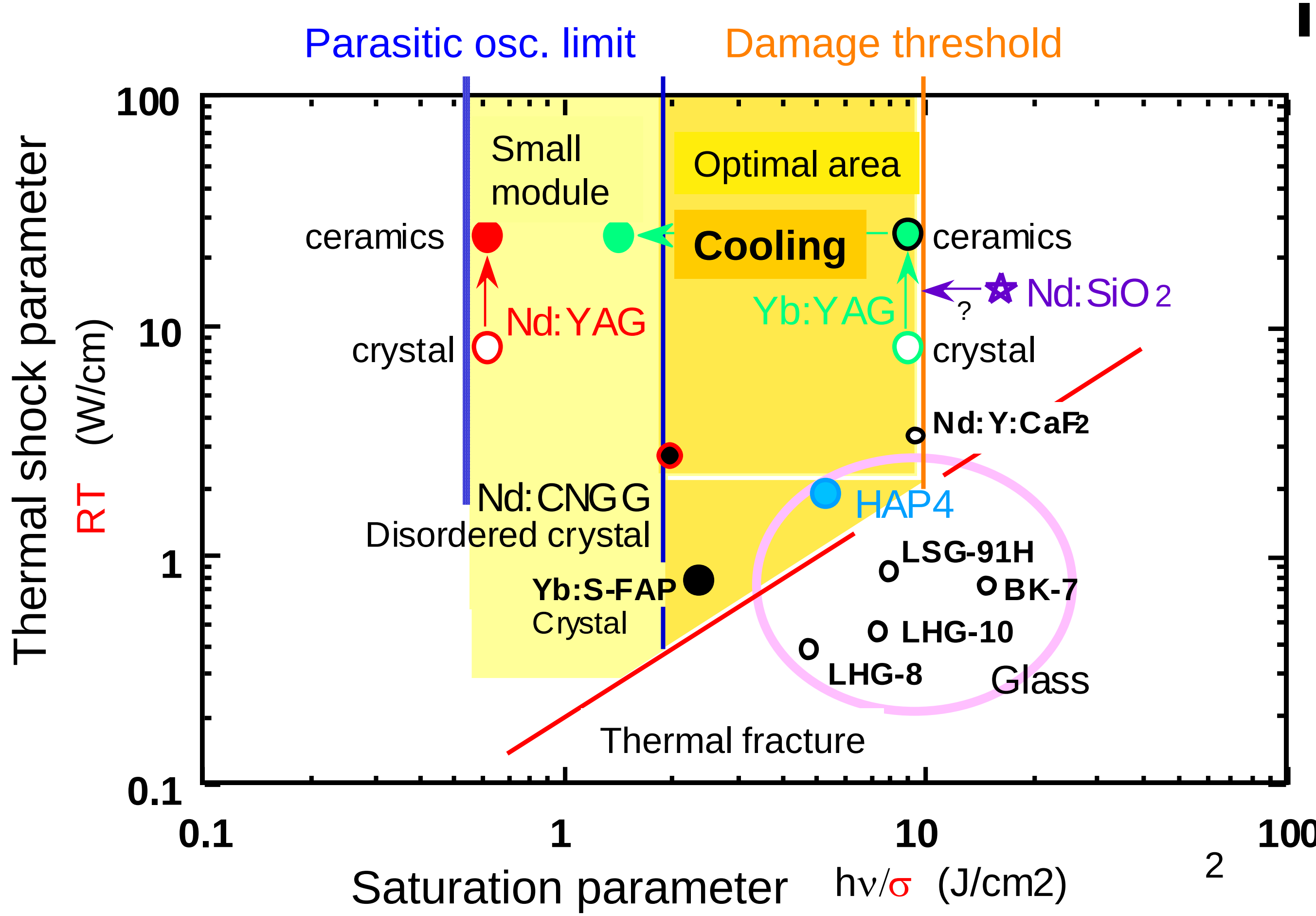

Artificial control of emission cross section → **Cooled Yb:YAG ceramic** ← Practical use of ceramic technology

We experimentally confirmed performance of cooled Yb;YAG

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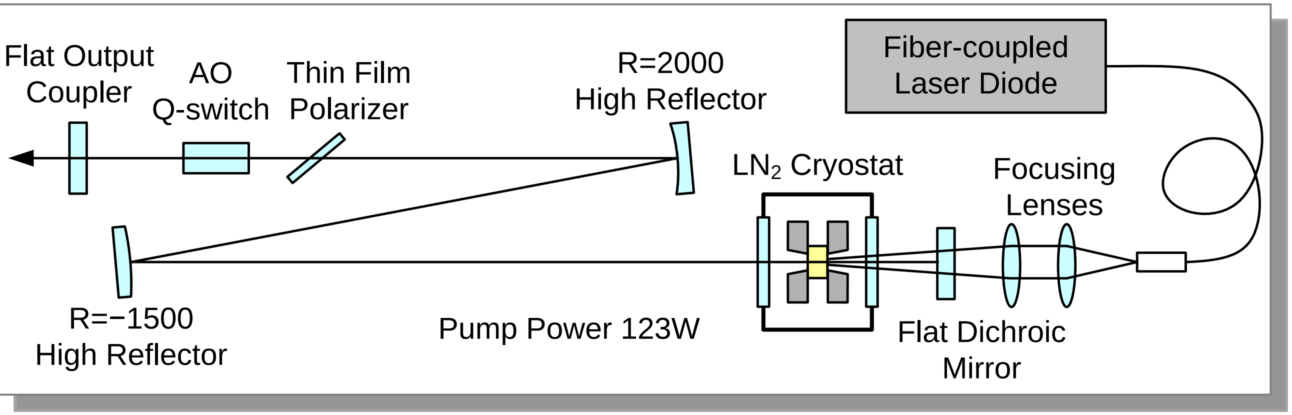

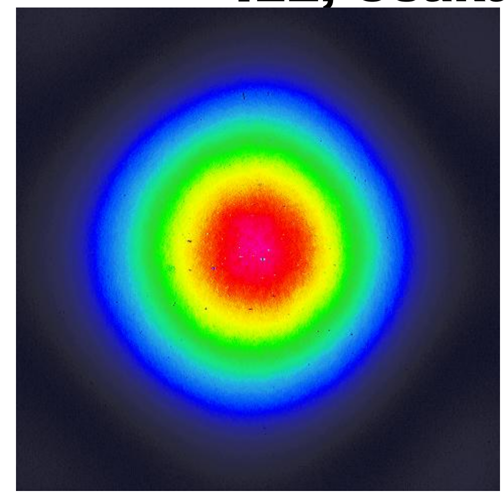

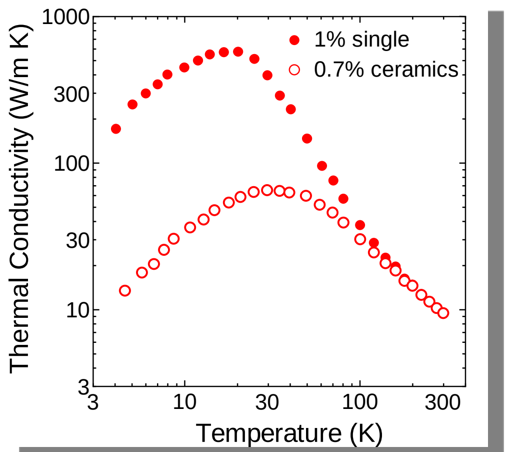

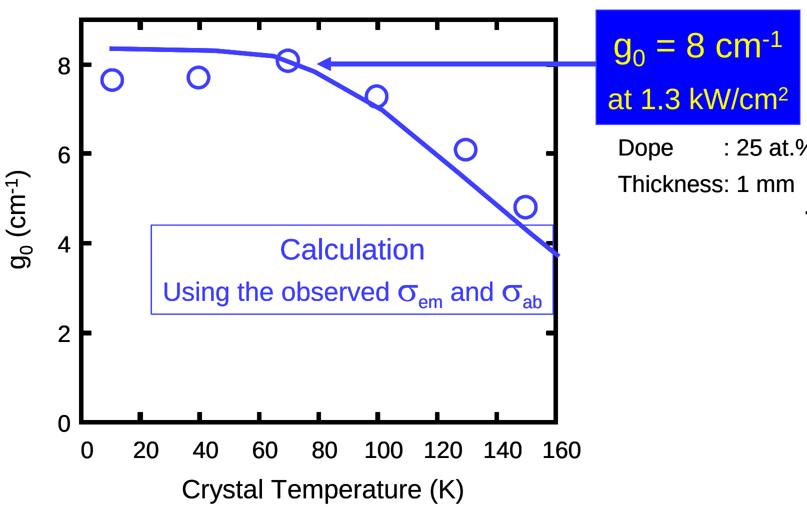

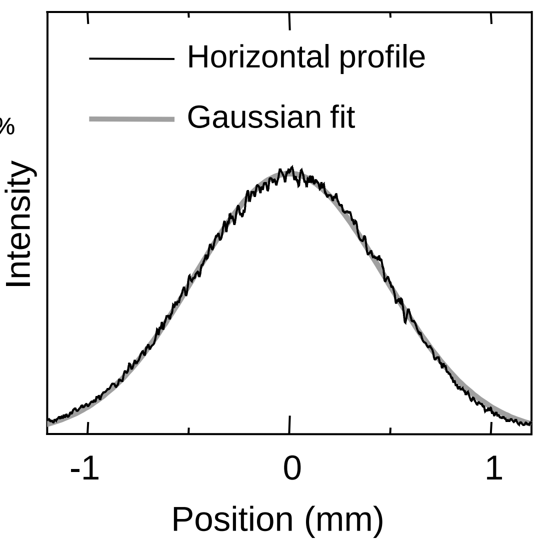

Experimental results obtained by HALNA-20 showed DPSLL is a powerful candidate for the reactor driver.

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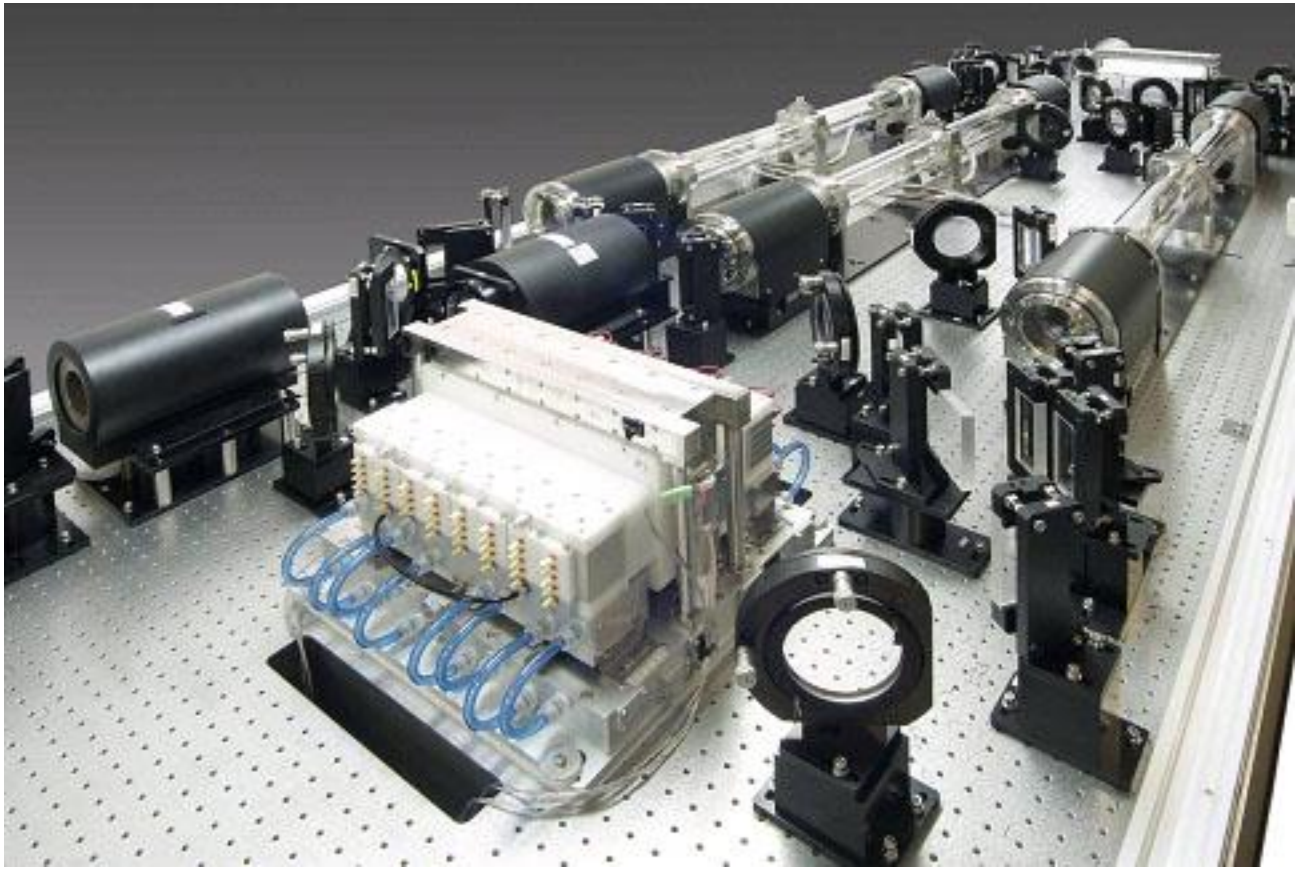

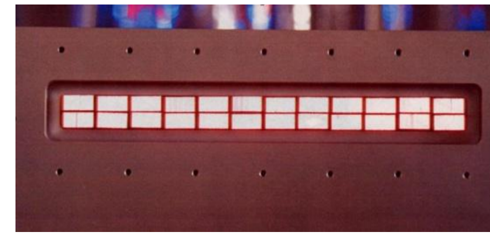

20J x 10Hz
Diode pumped
solid state laser
HALNA-20

How to access reactor driver? Key: cooling

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- Current Nd glass, flush lamp, air, room temperature
  - 3 shot/ day（9×10^{-5}Hz)
- Flush lamp → LD Spectrum fits to pump Nd, by 100
  - 1 shot / 1000 sec（9×10^{-3}Hz)
- Glass → Ceramic Thermal conductivity, by 30
  - 1 shot / 30 sec（ 0.03 Hz）
- Nd → Yb Quantum efficiency, by 3
  - 1shot / 10 sec（0.1Hz）
- 300K → 200K Thermal conductivity, by 3
  - 1shot / 3 sec（0.3Hz)
- Air cooling → Freon Cooling rate, by 100
  - 30 shot / 1 sec (30Hz)
- High shoot rate is possible!!!

Lasers

Beam arrays of implosion and hearting lasers

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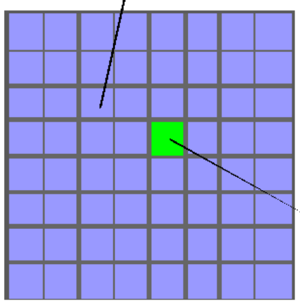
Compression laser beam (343 nm)



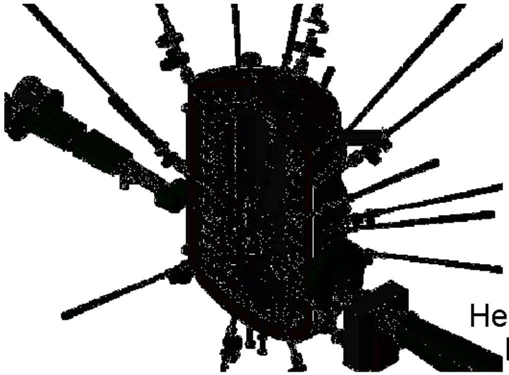
$\Delta\lambda$ = 0.1 nm @fundamental ($\Delta\nu$ = 0.08 THz)

Absorber

Foot pulse beam (515nm)

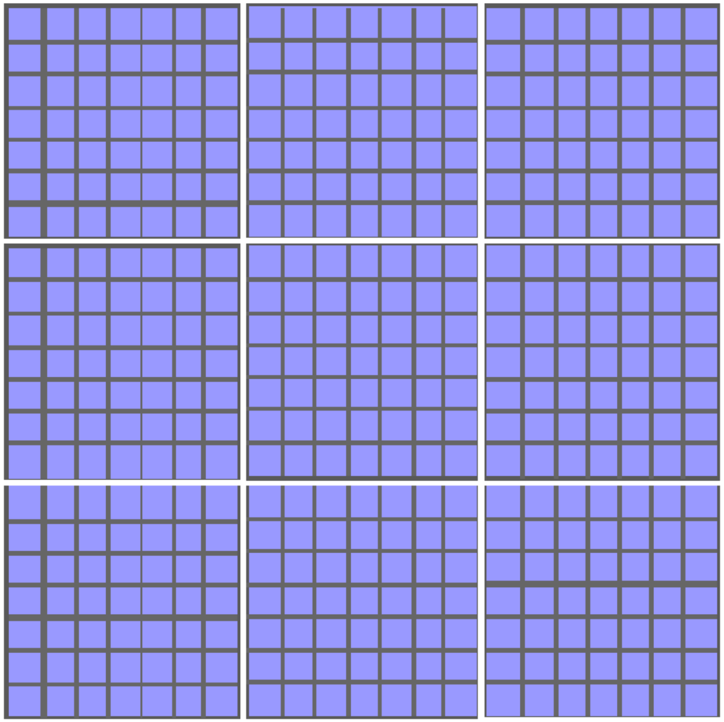
8x8 incoherent arrays
80cm × 80cm,
32 beams

(DT = 10 J/cm^2)



Heating laser beam

Heating laser beam (1030 nm)



210cm × 210cm,
21x21 coherent arrays or
9 bundles of 7x7 coherent arrays

(Grating DT = 3 J/cm^2)

Lasers

Illustration of main amplifier using active mirror concept

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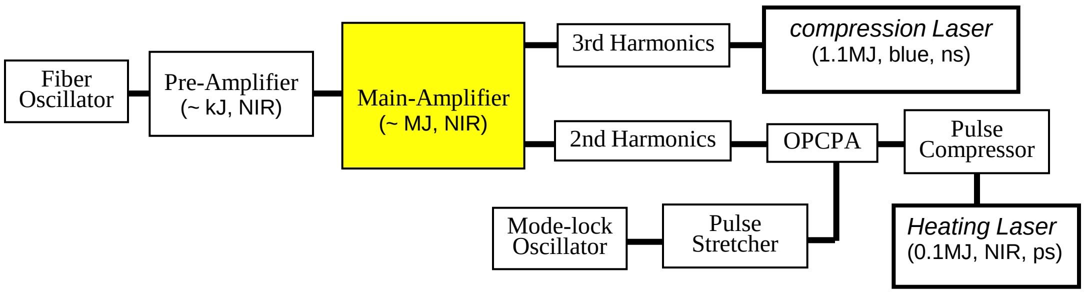

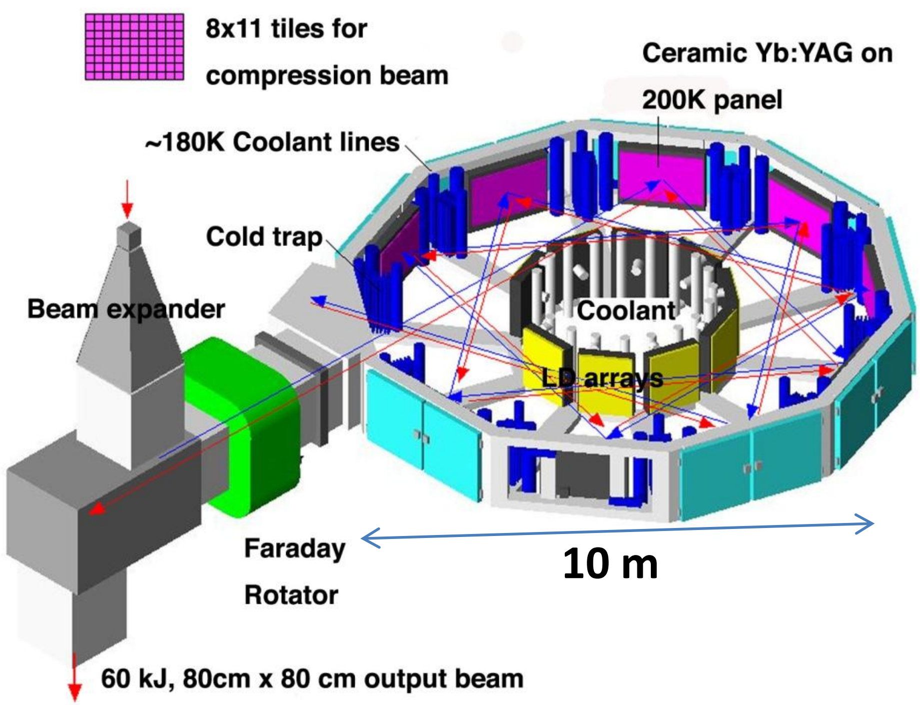

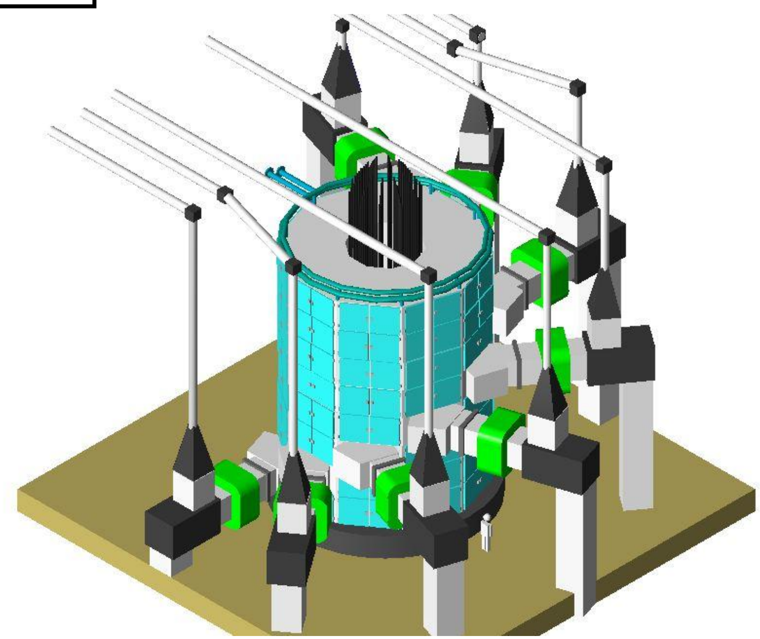

60kJ x 8 beams

Large diameter laser beams will be distributed to 4 modular reactors using rotating corner cubes.

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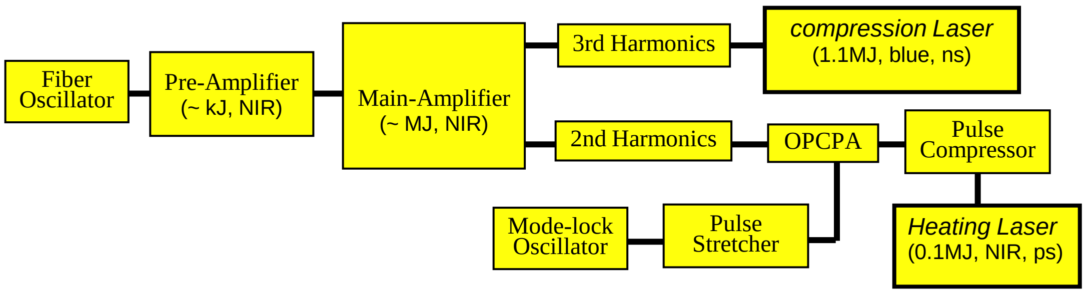

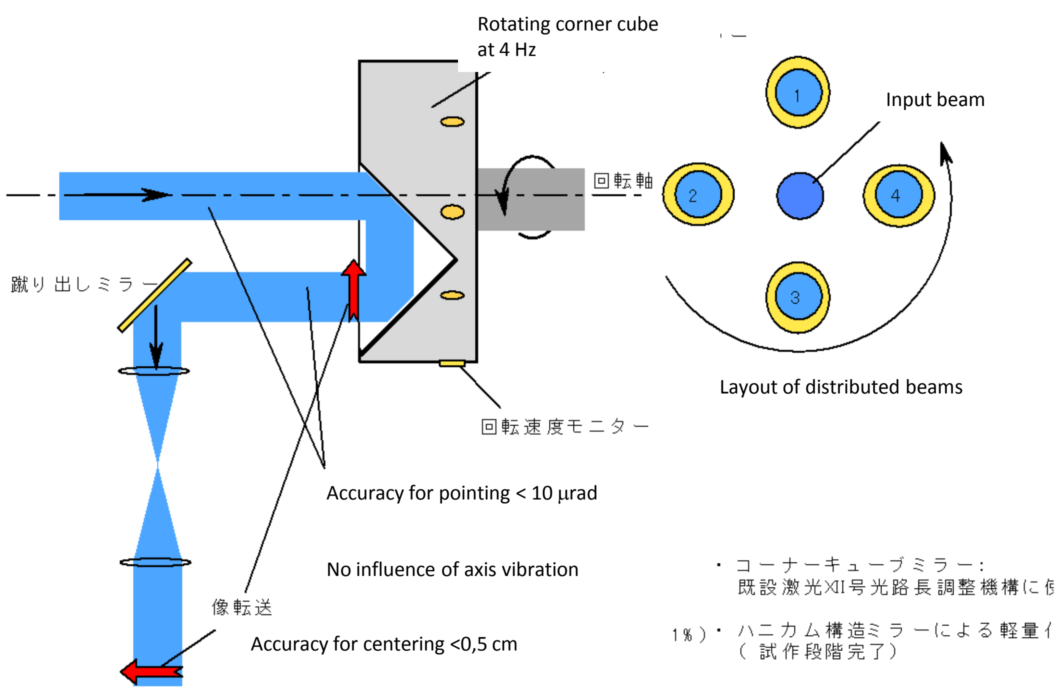

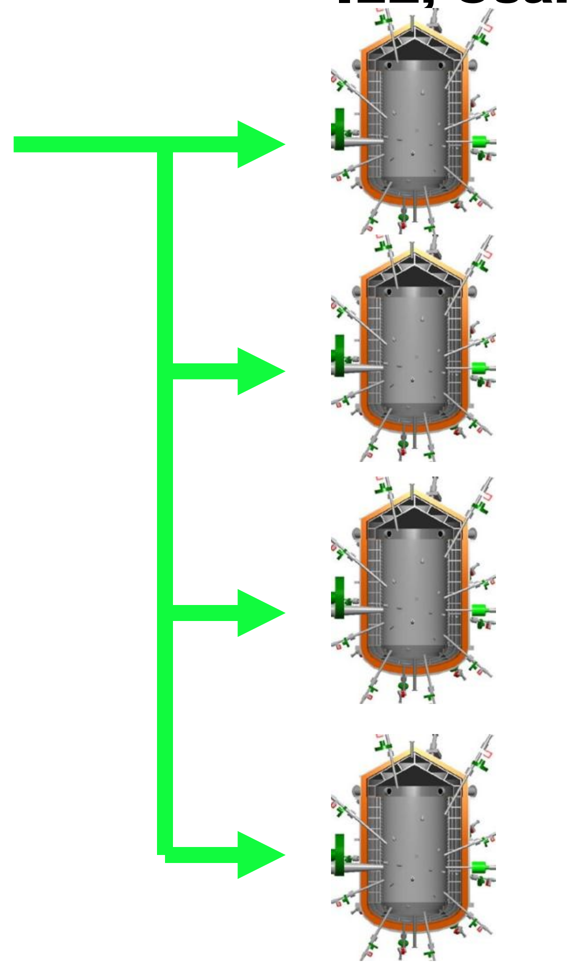

Lasers

Cooling system with 2MW at 200K can be constructed with existing technology.

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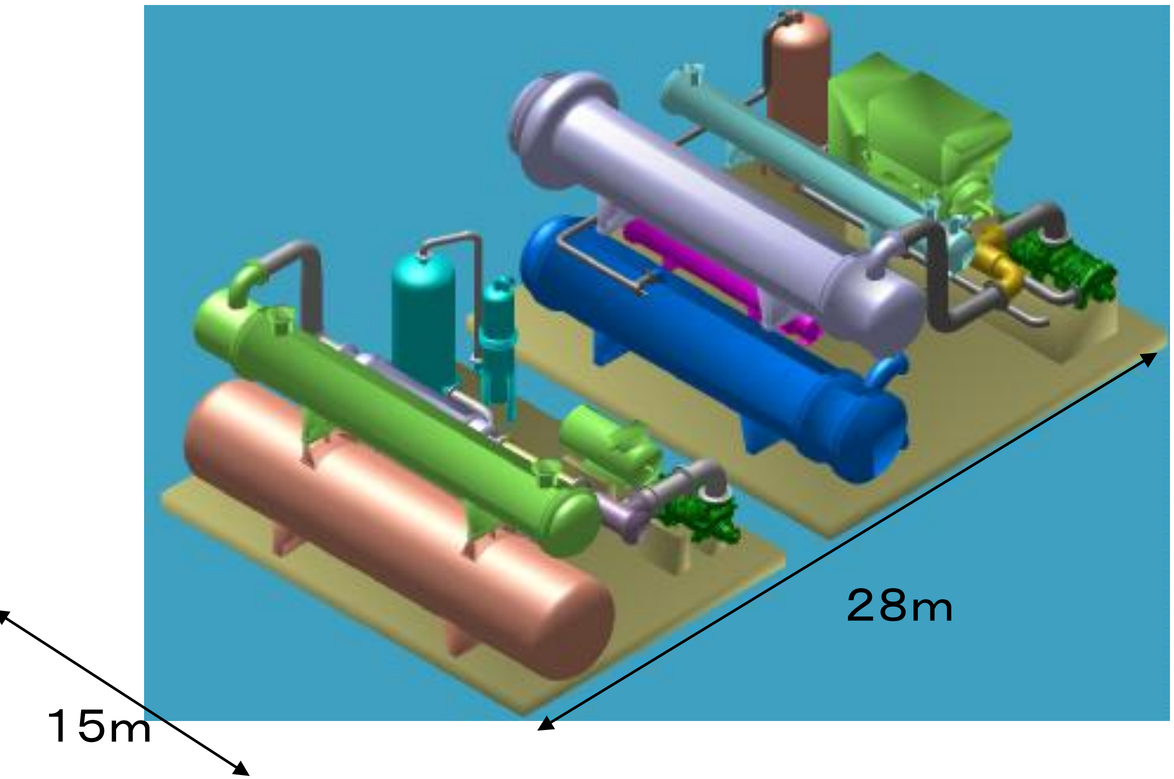

Image of 600kW, two coolants refrigerator*

This image was produced by Maekawa MFG. Co. LTD.

Electric input power	**3600+1500kW**
Cooling water	**1300m^3/h (32-37^{o}C)**
Cooling power	**2MW at 200K (δT=5K)**
Efficiency	**>30%**
Coolant	**R507A（High）＋R23(Low)**

Overall Efficiency from Electricity to Laser

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	Implosion Laser	Heating Laser
Laser Power	17.6 MW(1.1MJ, 16 Hz)	1.6 MW(0.1MJ, 16Hz)
LD Electrical – LD Optical	60%	
LD Optical – 1ω	42%	
LD Electrical – 1ω	25.2% (= 0.6 x 0.42)	
1ω – 3ω	70%	-
1ω – 2ω	-	80%
OPCPA Eff.	-	40%
Pulse Compression Eff.	-	80%
Transportation Eff.	90%	90%
Harmonic Generation and Transportation	63%	23%
Electric Input Power	111 MW	27.6 W
Crystal Heating Power	7 MW	0.7MW
Cooler Electric Power	23 MW	2.1 MW
Electric Power Demands	134 MW	30 MW
Total Electric Power	164 MW	
Overall Efficiency	12% (13% + 5.4%)	

Lasers

After fast ignition, share of lasers in the construction cost becomes minor.

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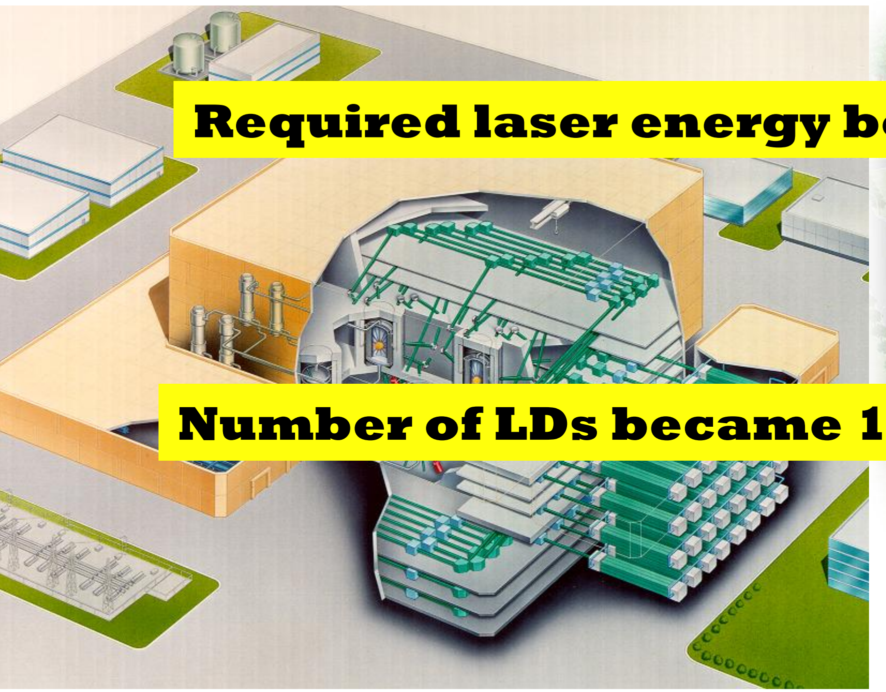
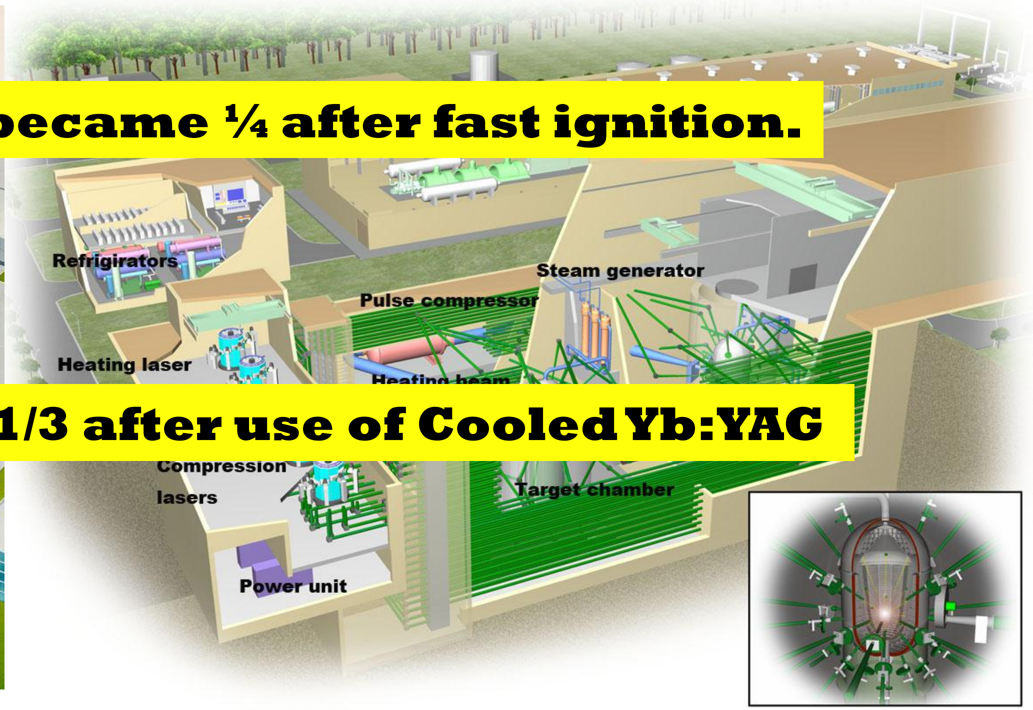
Required laser energy became ¼ after fast ignition.

Number of LDs became 1/3 after use of Cooled Yb:YAG



Central ignition KOYO



Fast ignition KOYO-F

Issue of KOYO-F

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- Following issues remained because of limited data
  - Stability of LiPb flow
  - Chamber clearance
  - Tracking and beam steering
  - Tritium barrier in heat exchanger
  - Swelling of structural wall
  - Life of final optics
  - Control of impurity in LiPb

Collaborators

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- After the Reactor design committee of KOYO-F (2004-2006), elemental researches on the critical issue of KOYO-F have been continued through bilateral collaboration of NIFS in Japan.

Many thanks to;

1 R. Tsuji, Ibaraki Univ. on tracking,
2 Y. Kajimura, JAXA, on beam port protection,
3 H. Yoshida, Gifu Univ. on beam steering,
4 T. Kunugi, Kyoto Univ. on liquid wall,
5 H. Furukawa, ILT Osaka, on chamber clearance,
6 T. Endo, Hiroshima Univ. on Injection,
7 S. Fukada, Kyusyu Univ. on Tritium issue.

H. Azechi, H. Shiraga, T. Jistuno, J. Kawanaka, H. Nagatomo, S. Fujioka, Y. Arikawa (ILE, Osaka)

Outline

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- Introduction
- Issues on liquid wall
  - Stability of LiPb (by T. Kunugi)
  - Chamber clearance (by H. Furukawa)
- Tritium control
- Issues on neutron damage

Ablation depth and profiles of ablated plume obtained by simulation

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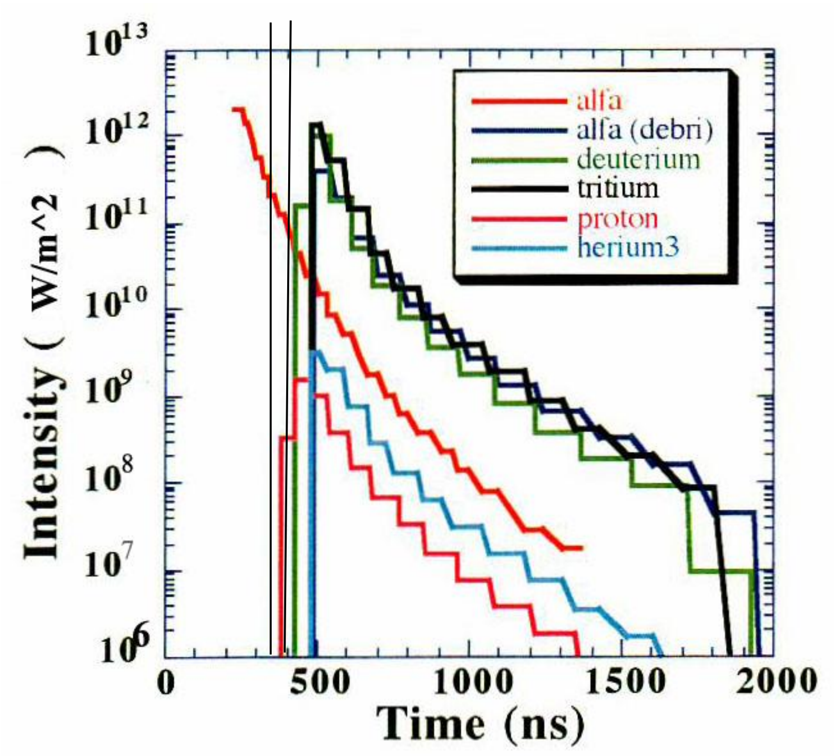
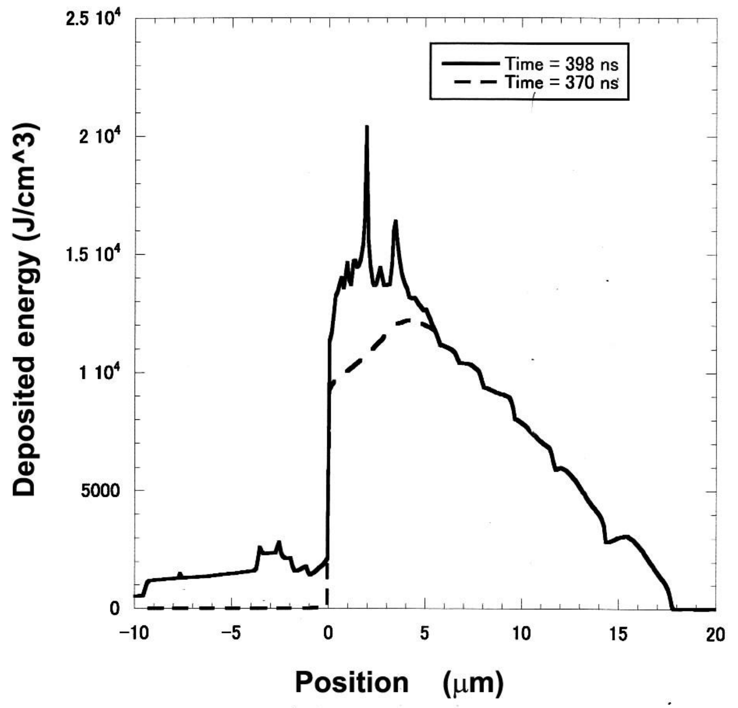
Temporal profile of particle loads



Spatial profile of deposited energy



Volumetric heating
Bragg's peak

KOYO-F

Non-symmetric chamber with cascade flow of liquid LiPb

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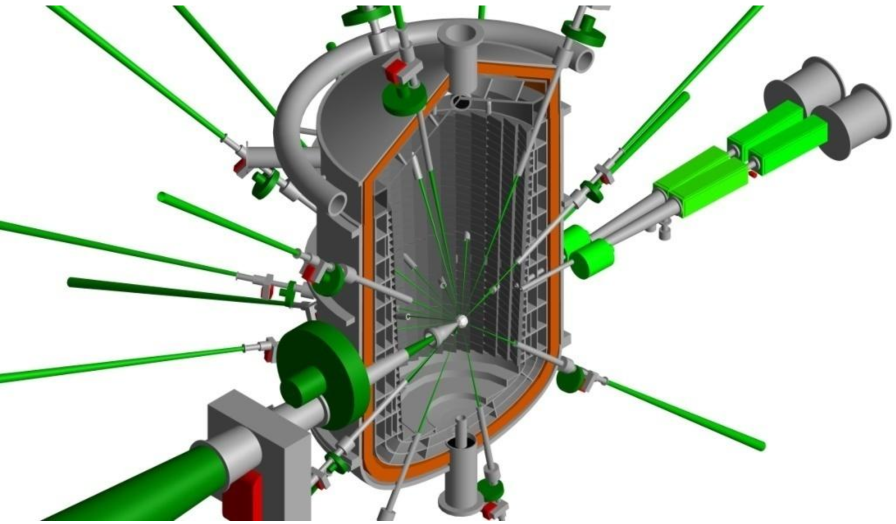

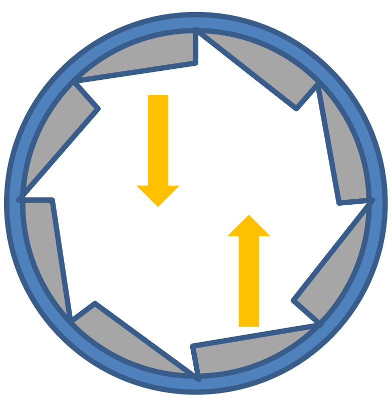

- Dimensions
  - Inner diameter 3m
  - Inner height 10m+3m

  Fusion Yield: 200MJ/shot

  Blanket: Liquid LiPb

  First wall: Liquid LiPb
  - 5mm thick cascade flow on side wall
  - Thin laminar flow on ceiling
- Serrated inner wall to prevent the stagnation of ablated materials.

Cascade flow of KOYO-F

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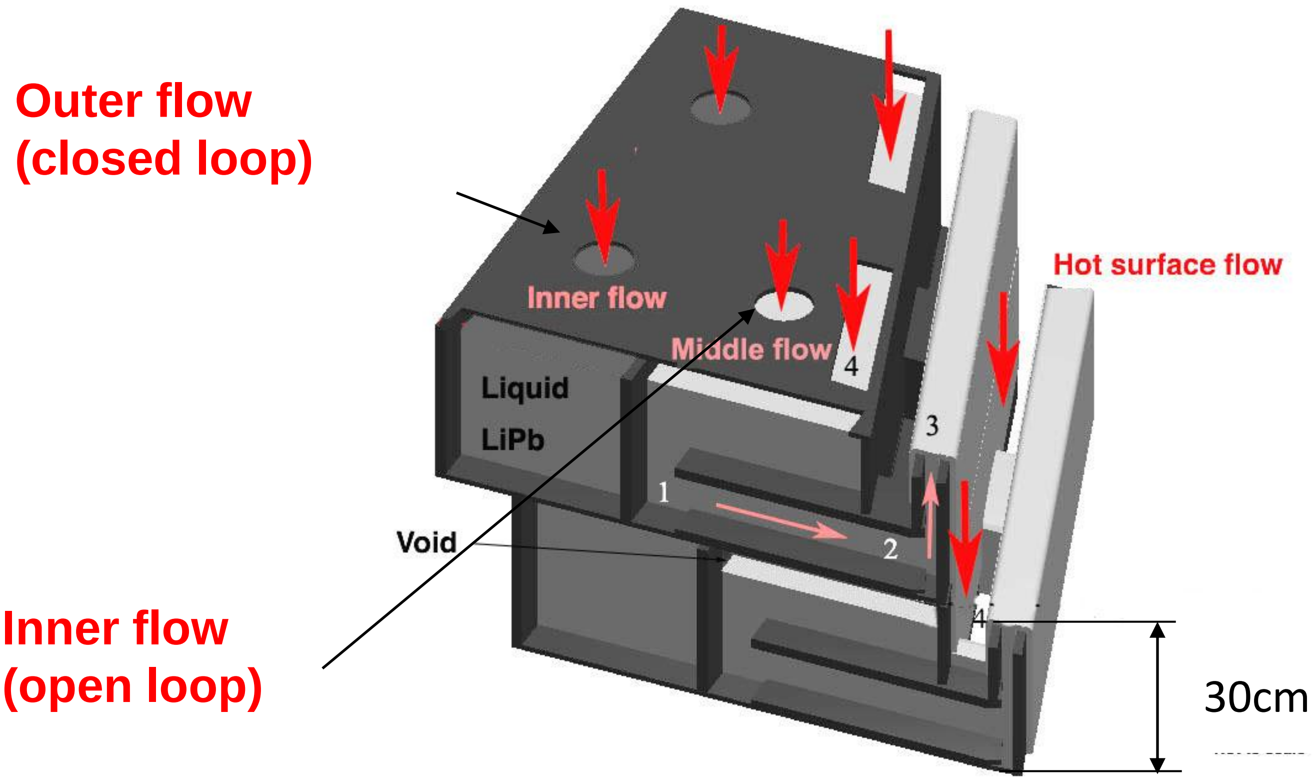
1) The height of cascade is 30 cm that comes from free fall distance in 0.25 sec (4Hz).
2) There is a void at the top of each step to obtain a stable flow.



Design base of mockup

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

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

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

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

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

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

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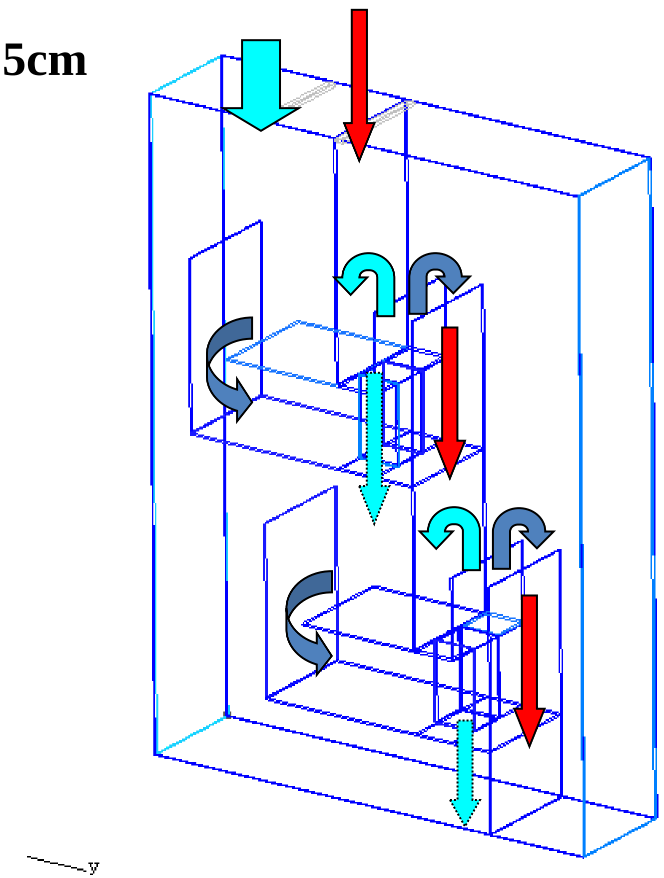
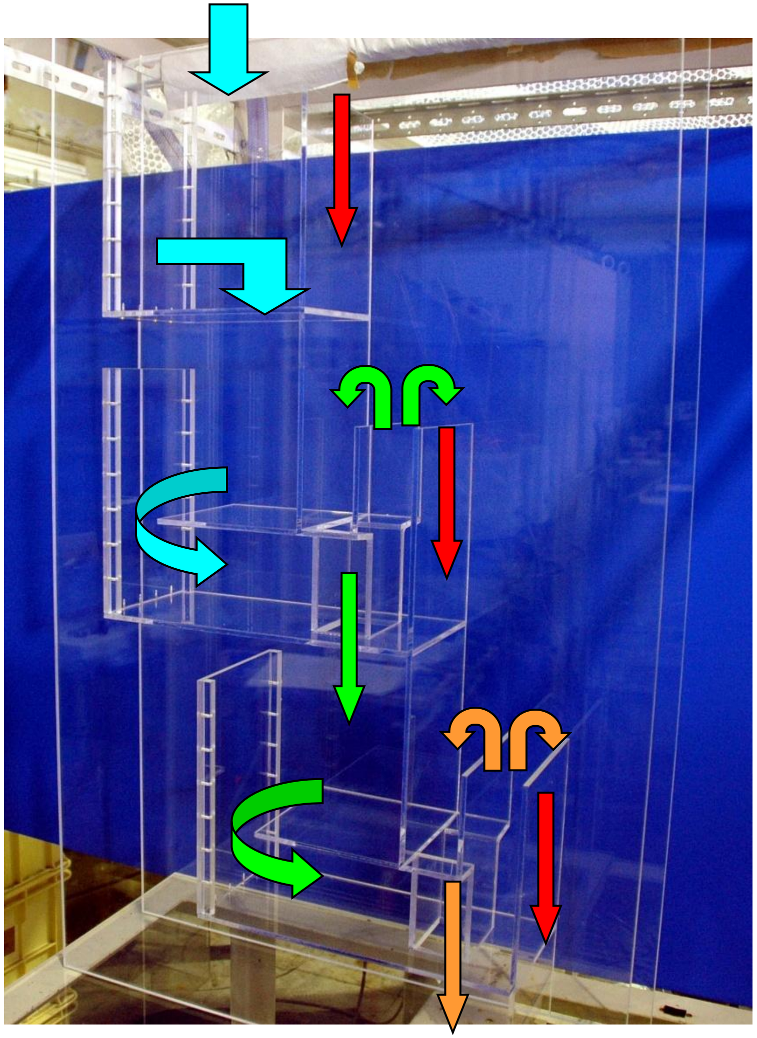
15cm





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

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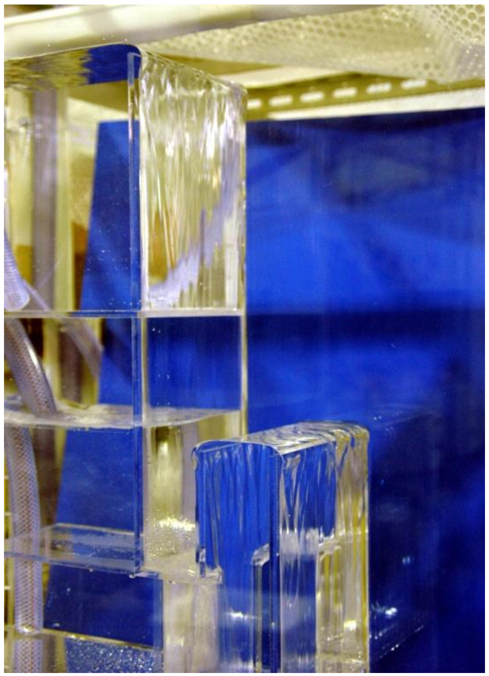
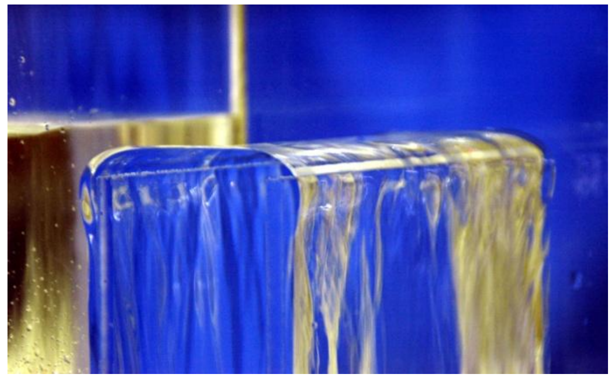
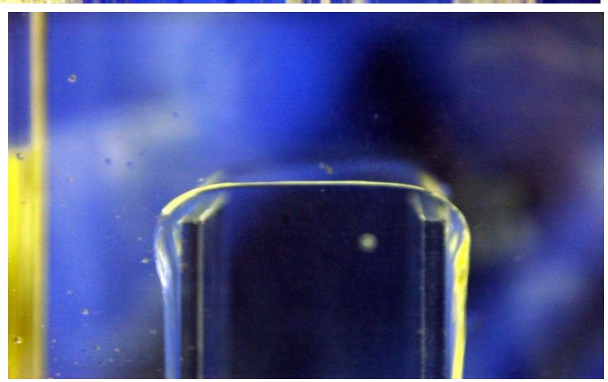
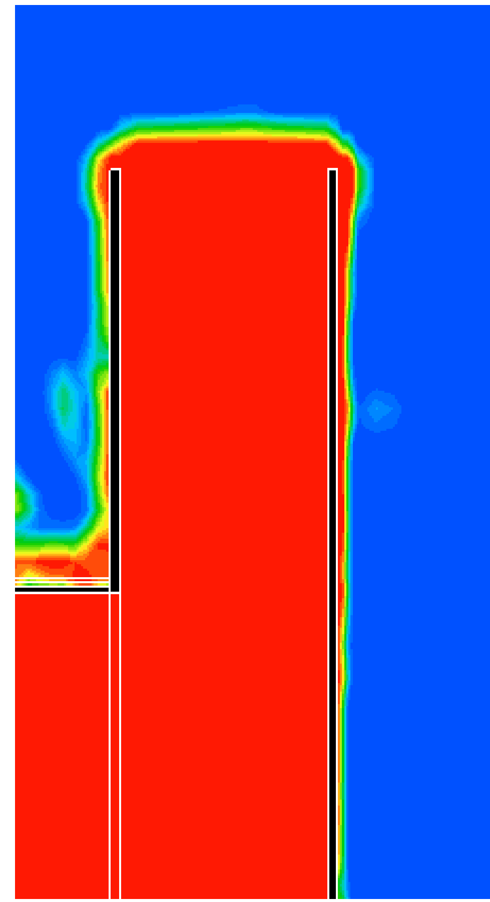


1st and 2nd steps





3rd step



Numerical simulation

Mixing of hot surface flow with cold inner flow was experimentally confirmed.

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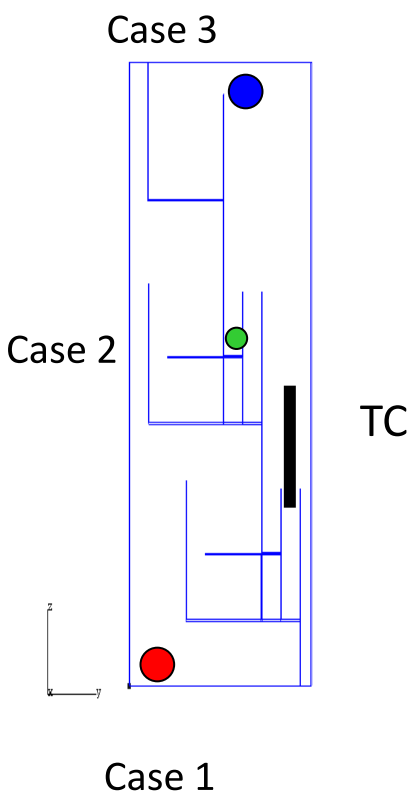

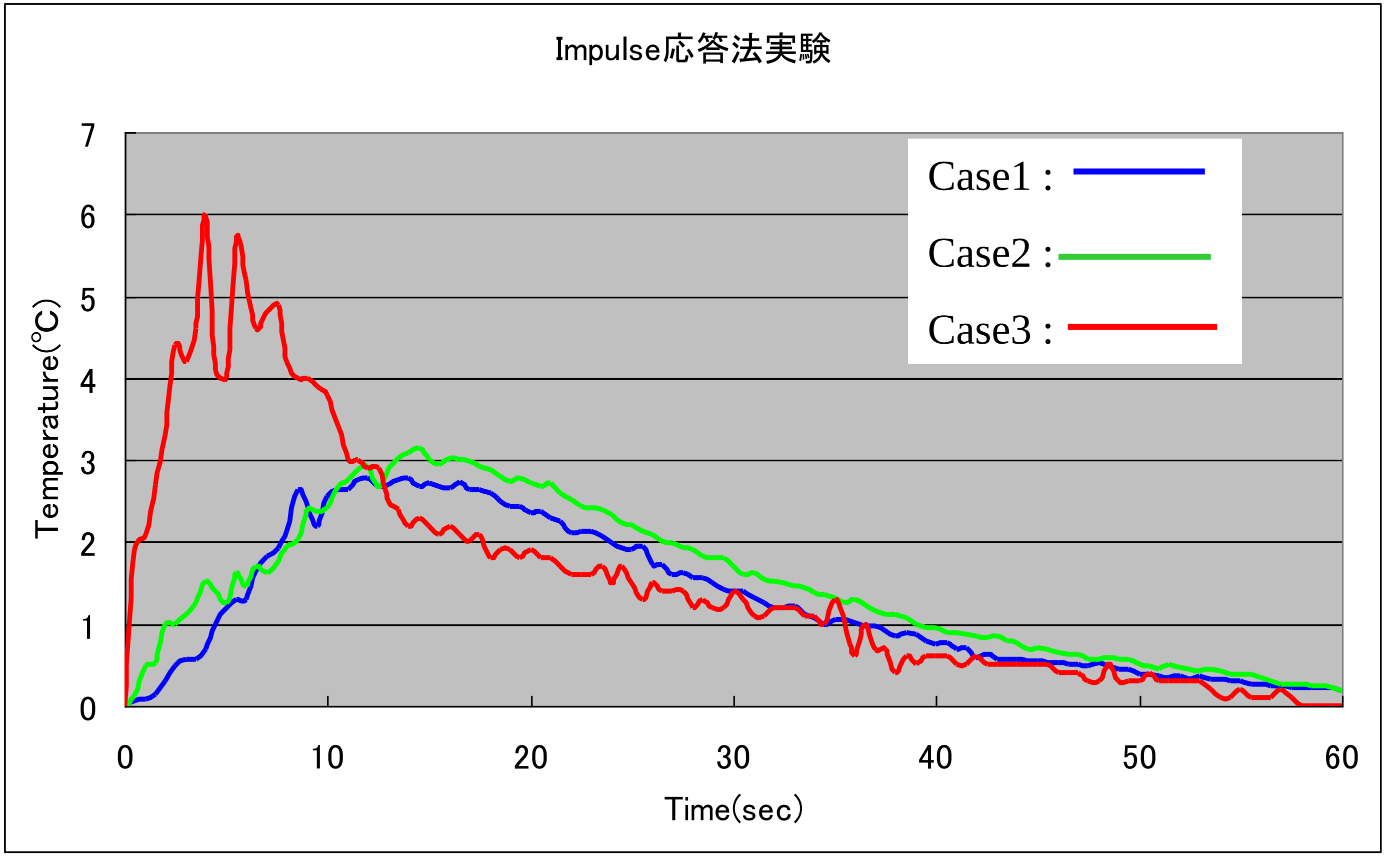

by T. Kunugi

To simplify protection scheme of ceiling, KOYO-F has vertically unsymmetrical configuration.

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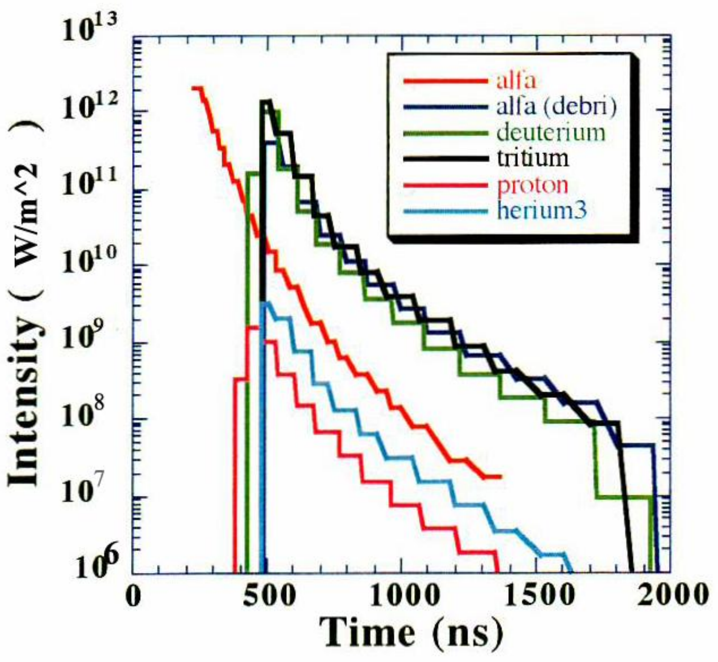
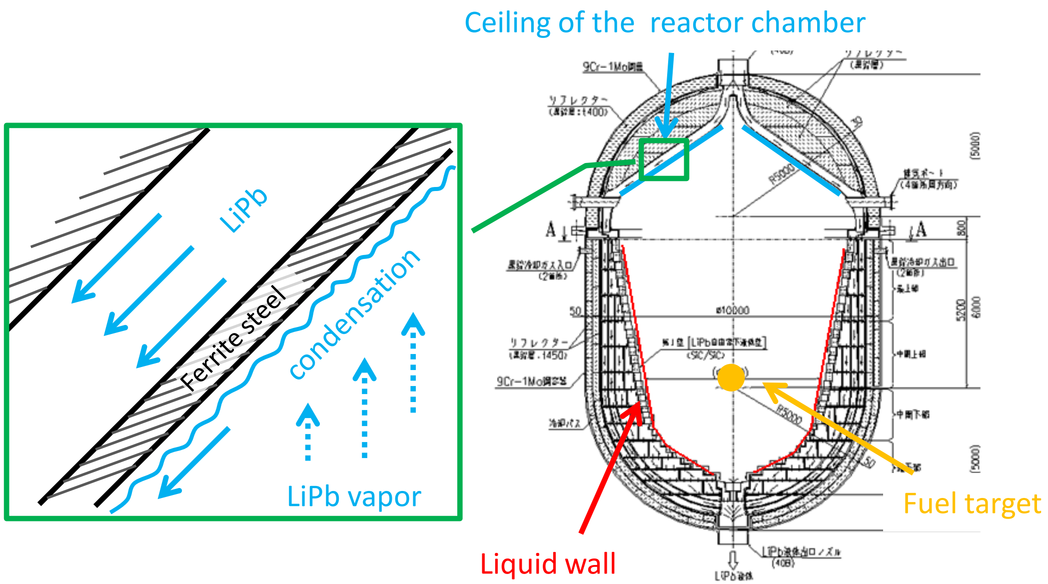
- The thermal load on the ceiling is close to that of a dry wall chamber. But blistering due to alpha particles seems critical.
  → We need a protective layer on the ceiling.



Thermal load at r=3m



by T. Kunugi

POP experiment was conducted at KYOTO university.

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- In order to confirm the behavior of the liquid film formed on the ceiling of the reactor chamber, proof-of-principle (POP) experiments and numerical simulations were conducted regarding the liquid-film flow on the ceiling wall.

- In order to obtain information of the liquid-film flow, measurements were taken of the liquid-film thickness formed on the inclined wall surface by using a confocal laser scanning microscopy.

by T. Kunugi

Procedures of condensation experiments

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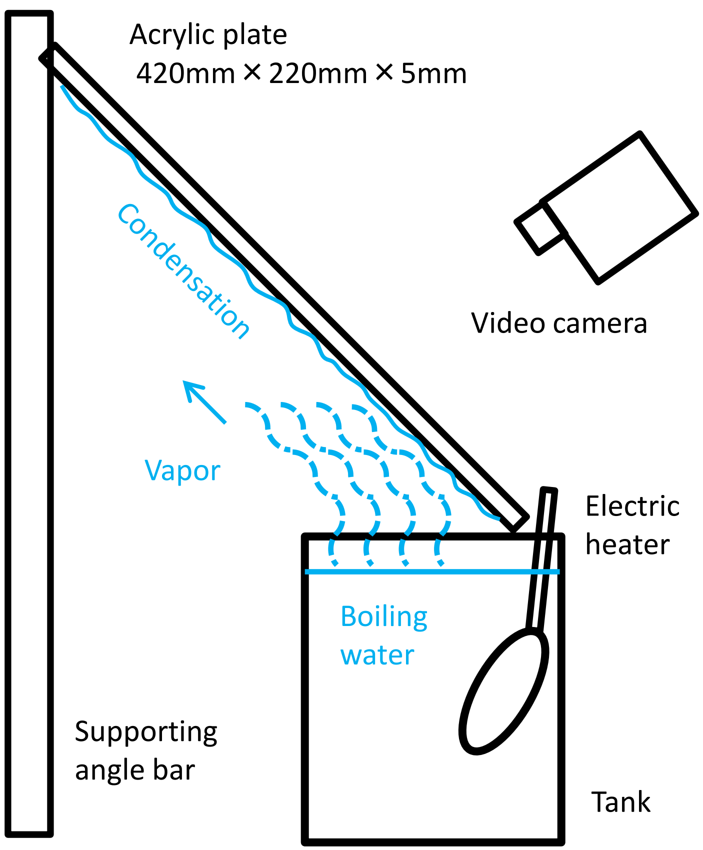
- In the actual design, the ceiling of the reactor chamber has the cone-type structure inclined at an angle of 45 degrees.



Experimental apparatus

● Condensation experiments were conducted by using an inclined plate which was sloped at an angle of 45 degrees.

- Experimental conditions
  - Working fluid : Water
  - Material of the plate : Acrylic resin
- POP experiments regarding wettability
- Observation of the behavior when vapor was condensed on the surface of the inclined plate

by T. Kunugi

Results of condensation experiments

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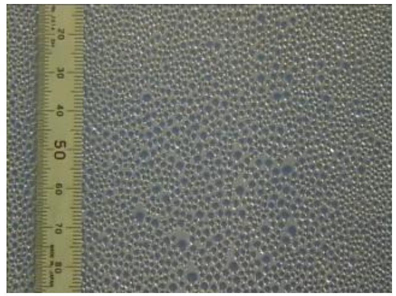
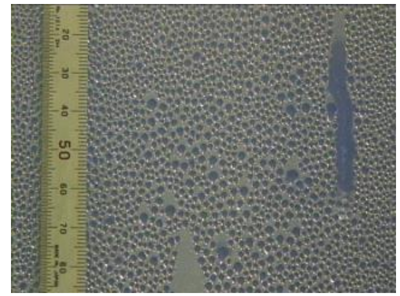
■Contact angle was large (=poor wettability)

A few minutes



A few minutes



①Generation of many tiny droplets on the wall surface

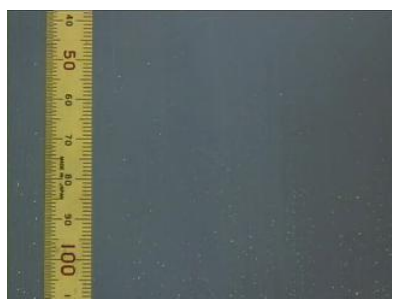
②Grow and coalesce with surrounding droplets

③Flow down along the wall entraining surrounding droplets

The liquid falling away from the wall surface was observed at third process

■Contact angle was small (=good wettability) ⇐ hydrophilic coating on wall surface

Several tens of seconds



Several tens of seconds

①Generation of many tiny droplets on the wall surface

②Grow and coalesce into thin liquid film

③Flow down along the wall surface

The liquid never fell away from the wall surface at third process

➢Once the liquid film is formed on the wall surface, the liquid will flow down along the ceiling wall and will not fall away from the wall surface as long as vapor will be supplied

by T. Kunugi

Procedures of measuring liquid-film thickness

■Contact angle was small (= good wettability)

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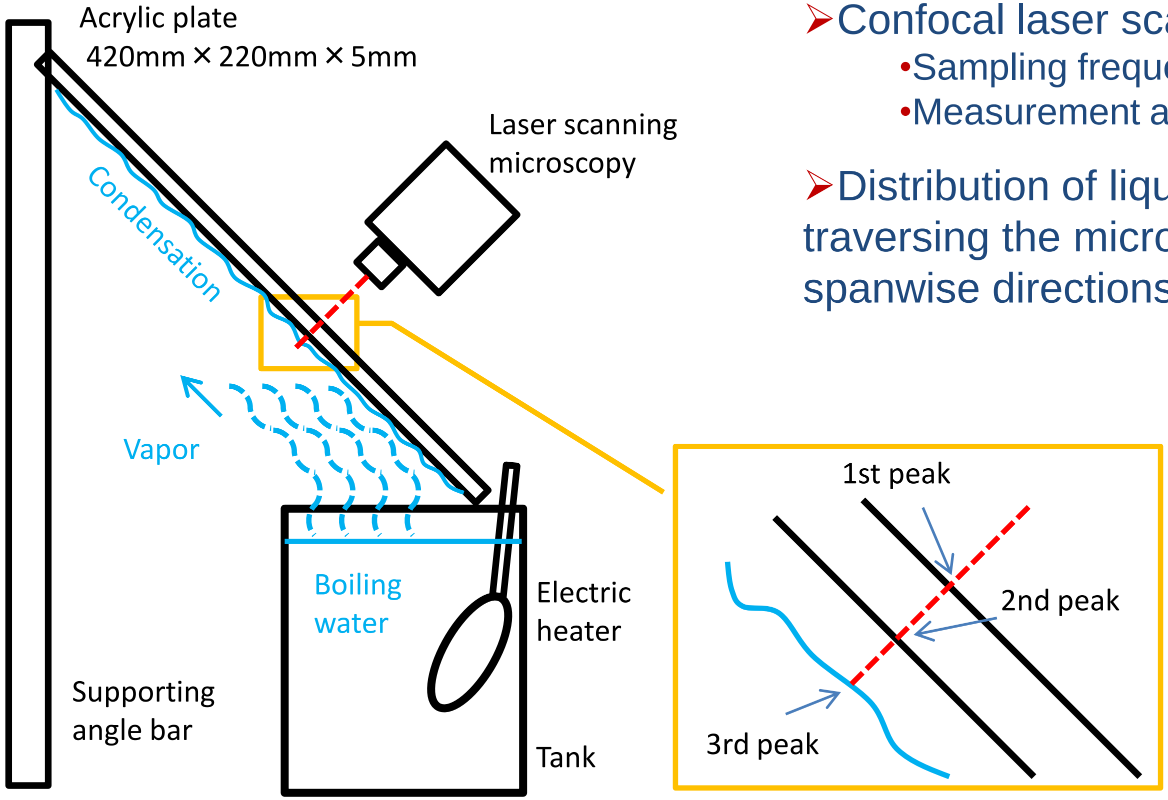
●Measurements of the liquid-film thickness formed on the inclined wall surface were performed with a confocal laser scanning microscopy.

- Confocal laser scanning microscopy
  - Sampling frequency : 1000 Hz
  - Measurement accuracy : micro-meter order
- Distribution of liquid-film thickness obtained by traversing the microscopy in longitudinal and spanwise directions



Liquid film was transparent medium

Thickness of liquid-film could be obtained by measuring the distance between 2nd and 3rd peak of the light intensity

Experimental apparatus

by T. Kunugi

Results of measuring liquid-film thickness

ILE, Osaka

- Contact angle was small (= good wettability)

➤Surface coated one time

Average thickness of liquid-film

Y (mm) \ X(mm)	0	30	60	80
0	152 μm	173 μm	154 μm	168 μm
20	150 μm	122 μm	128 μm	120 μm
40	135 μm	151 μm	141 μm	171 μm

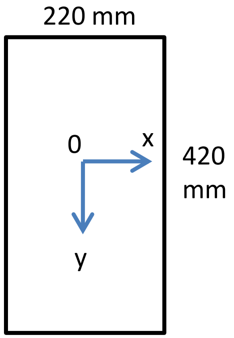
- Overall averaged thickness : about 150 μm

➤Surface coated twice

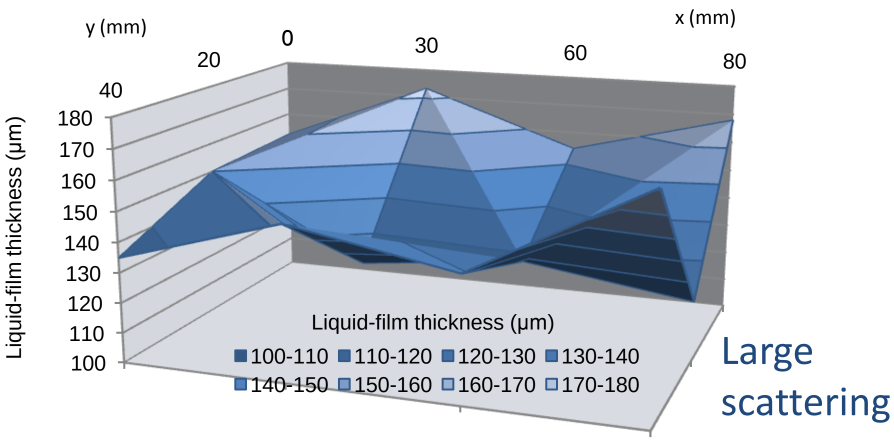
Average thickness of liquid-film

Y (mm) \ X(mm)	0	30	60	80
0	210 μm	214 μm	213 μm	211 μm
20	202 μm	195 μm	194 μm	196 μm
40	199 μm	205 μm	200 μm	210 μm

- Overall averaged thickness : about 200 μm

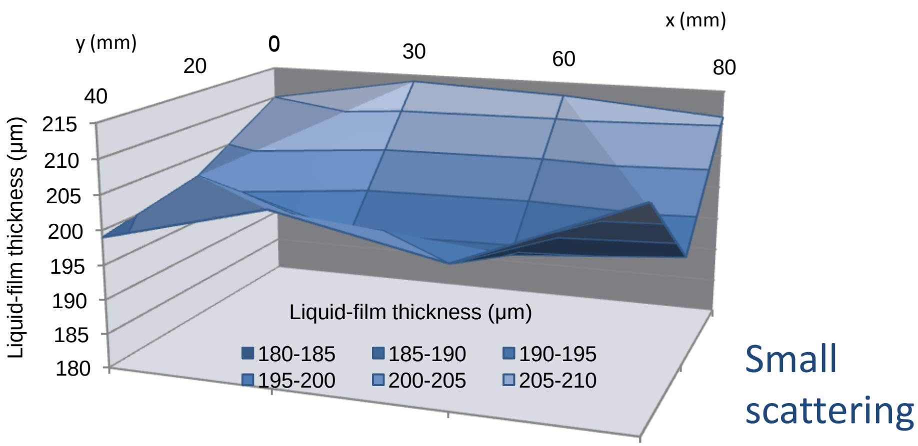


➡ Thickness of one coating layer was about 50 μm, and actual thickness of liquid film was about 100 μm



Large scattering

Distribution of average thickness in case coated one time



Small scattering

Distribution of average thickness in case coated twice

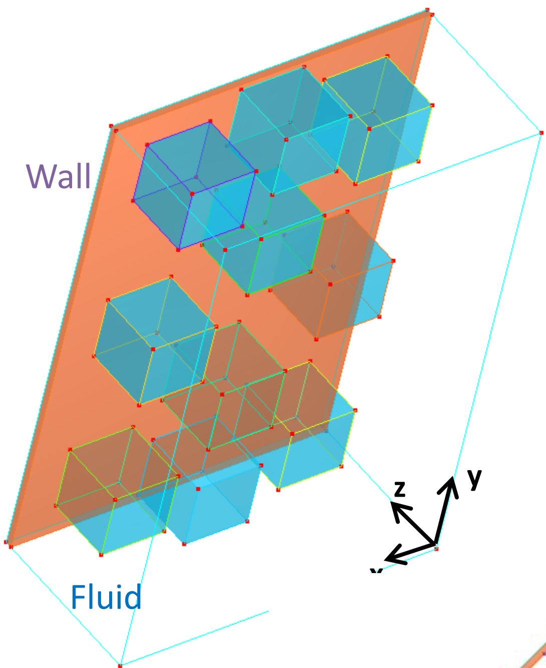
by T. Kunugi

Numerical simulations

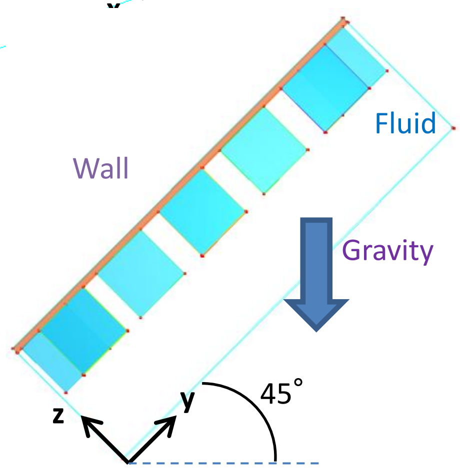
ILE, Osaka

●Numerical simulations were performed with the STREAM, which was an unsteady 3D thermo-fluid numerical analysis code.

- ➢Computational domain modeled on the test section inclined at an angle of 45 degrees
- ➢Tiny droplets placed on the wall surface as an initial condition, in order to simulate the behavior of droplets and liquid film



Cubic of 200μm on a side



Computational domain

Numerical conditions

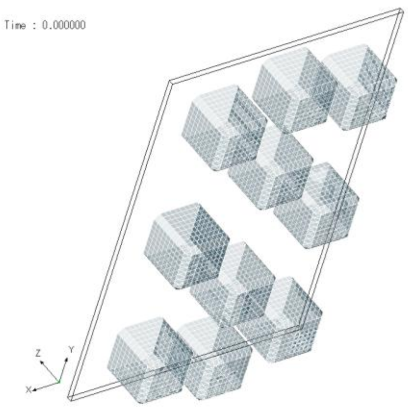
- ●Analytical area : Hexahedron area of 1000 μm × 1500 μm × 500 μm
- ●Number of mesh : 50 × 75 × 25 = 93,750
- ●Size of mesh : 20 μm
- ●Temperature : 20℃
- ●Kind of fluids : Incompressible air and water
- ●Material of wall : Acrylic resin
- ●Flow field : Laminar flow in gravity field
- ●Interval time : 1.0×10^{-5} sec
- ●Boundary conditions
  - ➢Wall surface : No-slip condition
  - ➢Both ends of X side : Free-slip condition (Symmetry plane)
  - ➢Both ends of Y side and bottom of Z side : Outflow condition

by T. Kunugi

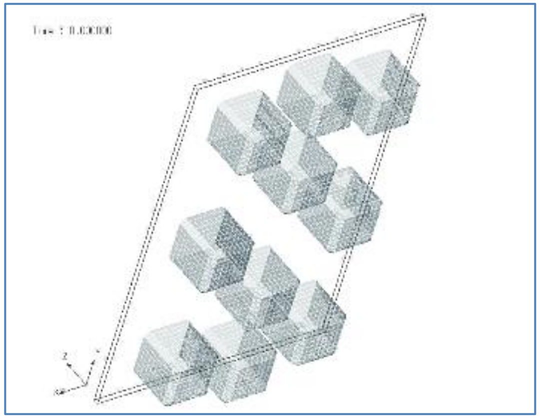
Numerical results

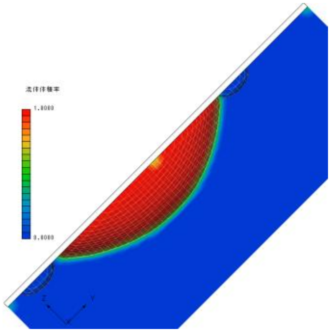
ILE, Osaka

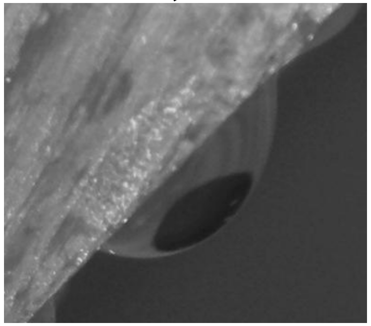
➢As an initial condition, tiny droplets were placed on the wall surface



Contact angle is large (45 degrees)

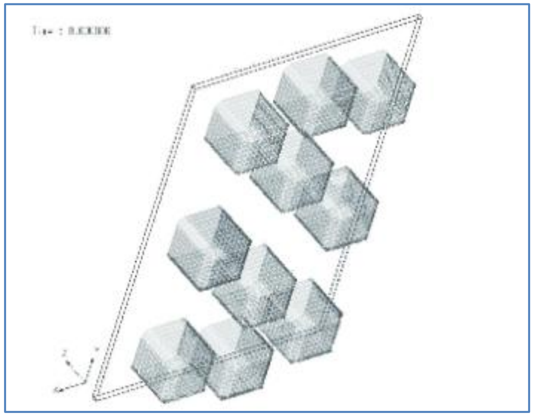


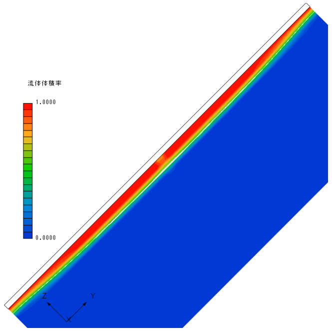


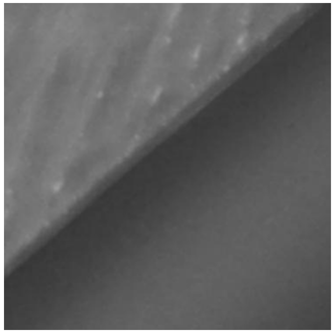


◆Tiny droplets coalesced into large droplet, and the large droplet flowed down along the wall surface

Contact angle is small (10 degrees)







◆Tiny droplets coalesced into thin liquid film, and the thin liquid film flowed down along the wall surface

➡ The numerical simulations can retrieve the experimental results

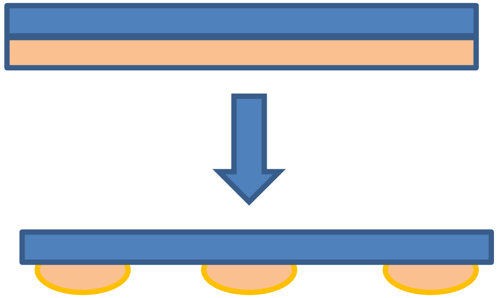
Summary of POP experiment for protection of ceiling

ILE, Osaka

- POP experiments and numerical simulations were conducted regarding the liquid-film flow on the ceiling wall.
- Once the liquid film is formed on the wall surface, the liquid will flow down along the ceiling wall and will not fall away from the wall surface as long as the vapor will be supplied.

- This experimental result indicated that a layer wettable with liquid LiPb is necessary on the ceiling.
- Future work
  - Erosion of the wettable layer
  - Life time of continuous layer after condensation of blast vapor

On hydrophobic surface

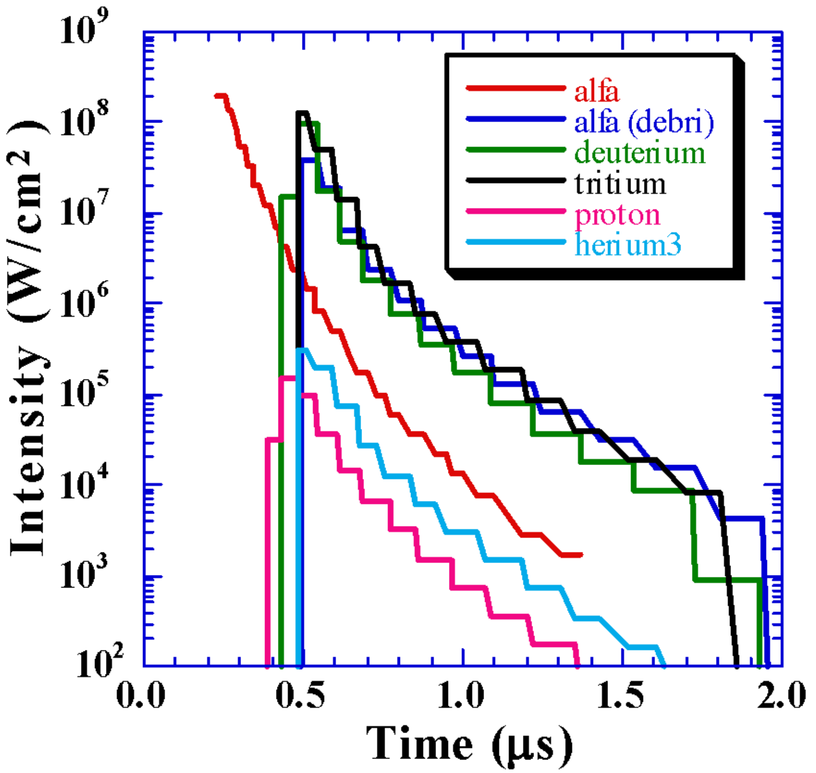


If τ> 250 ms, it can work as protector

By Furukawa

Irradiation Intensities of α particles and Debris Ions at the surface of Liquid Wall

ILE Osaka

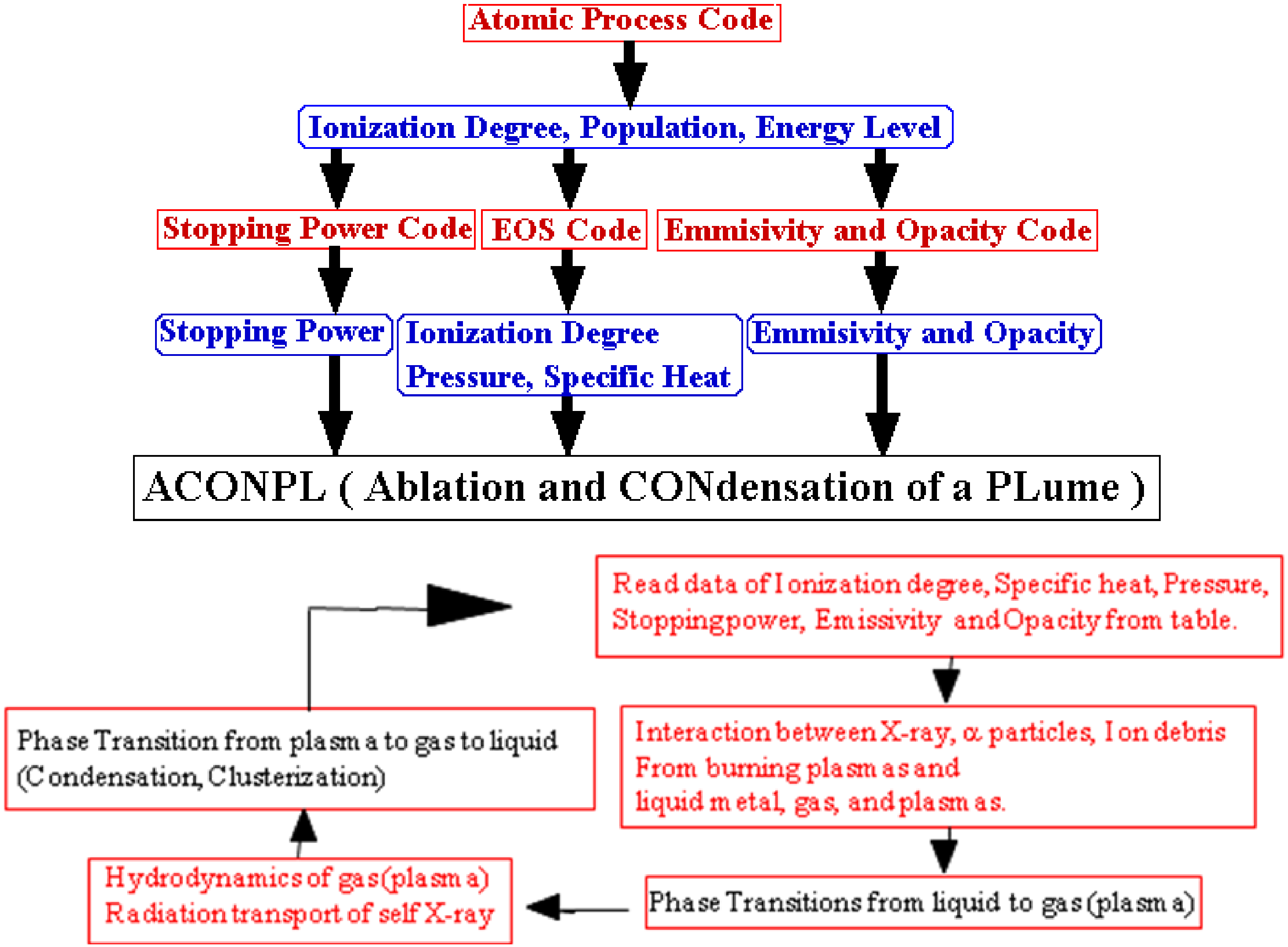


- When heating laser is irradiated on target,
- I set time = 0.
- Characteristic time in an ablation of liquid wall of laser fusion is roughly sub nano second.
- The physics in an ablation of liquid wall of laser fusion is quite deferent from that of burning plasmas and magnetically confinement fusion.

By Furukawa

The simulation code covers microscopic energy deposition and macroscopic expansion processes

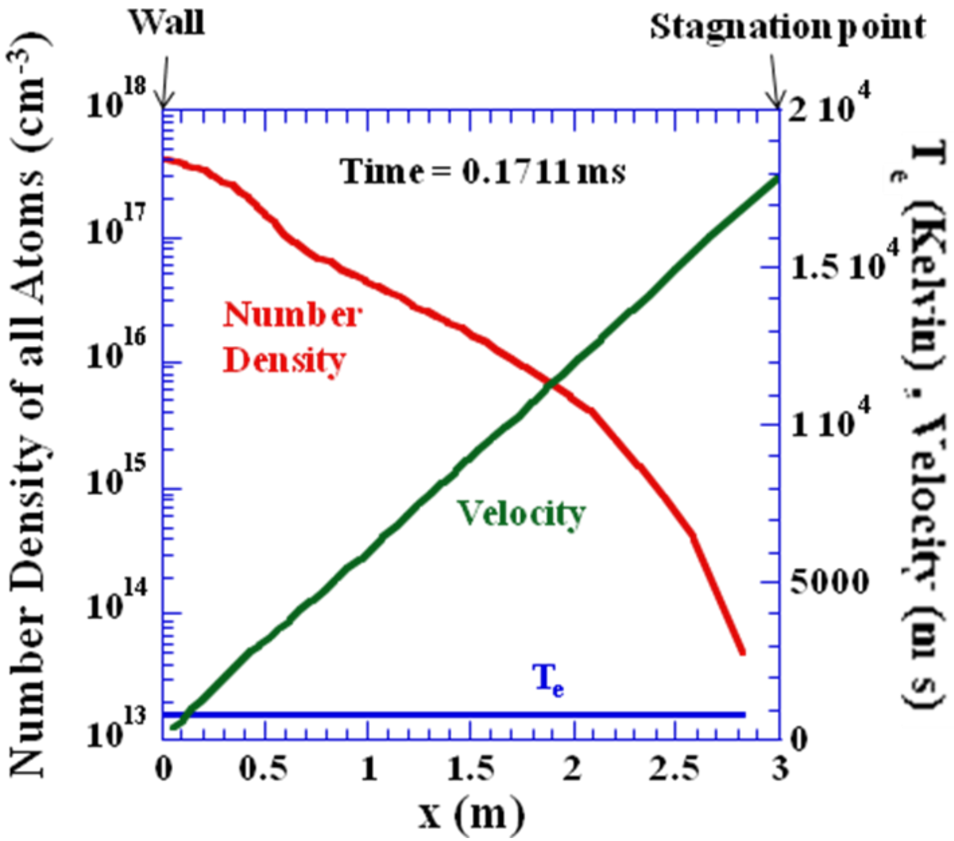
ILE Osaka

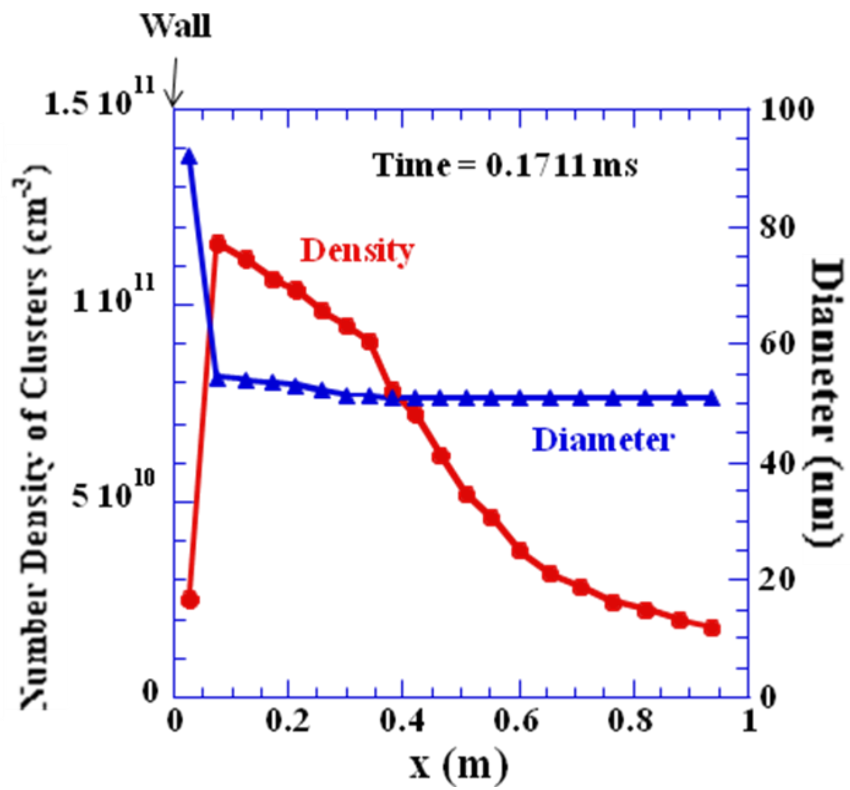


By Furukawa

Large clusters are formed near the surface. The peak of number density is at 0.3m form the surface when the plume front reaches the center.

ILE Osaka

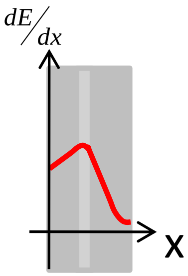




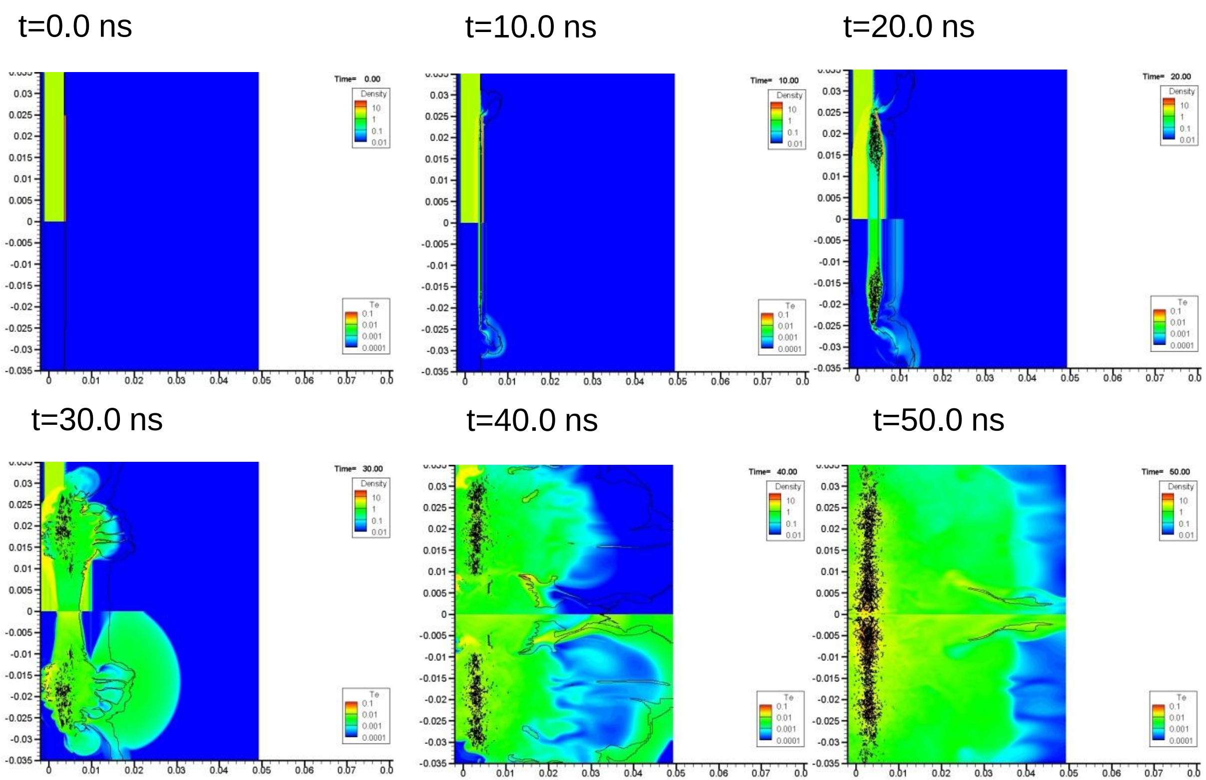
By Nagatomo

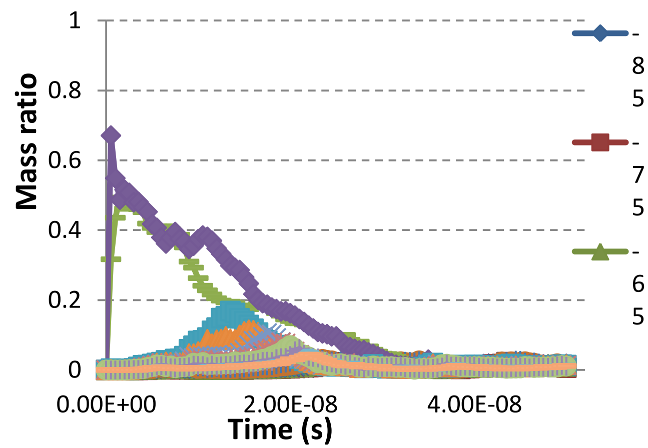
2D calculation indicated that the mass toward the center is 1/10 of ablated vapor

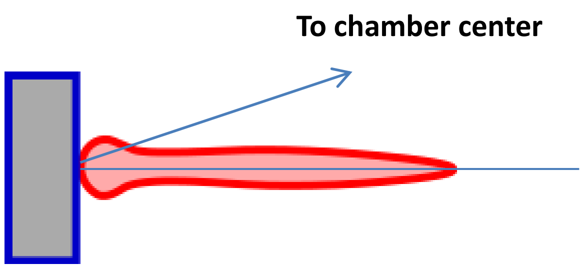
ILE Osaka



Due to energy deposition process of alpha particles, ablated vapor is accelerated from inside. As the result, instabilities happen.







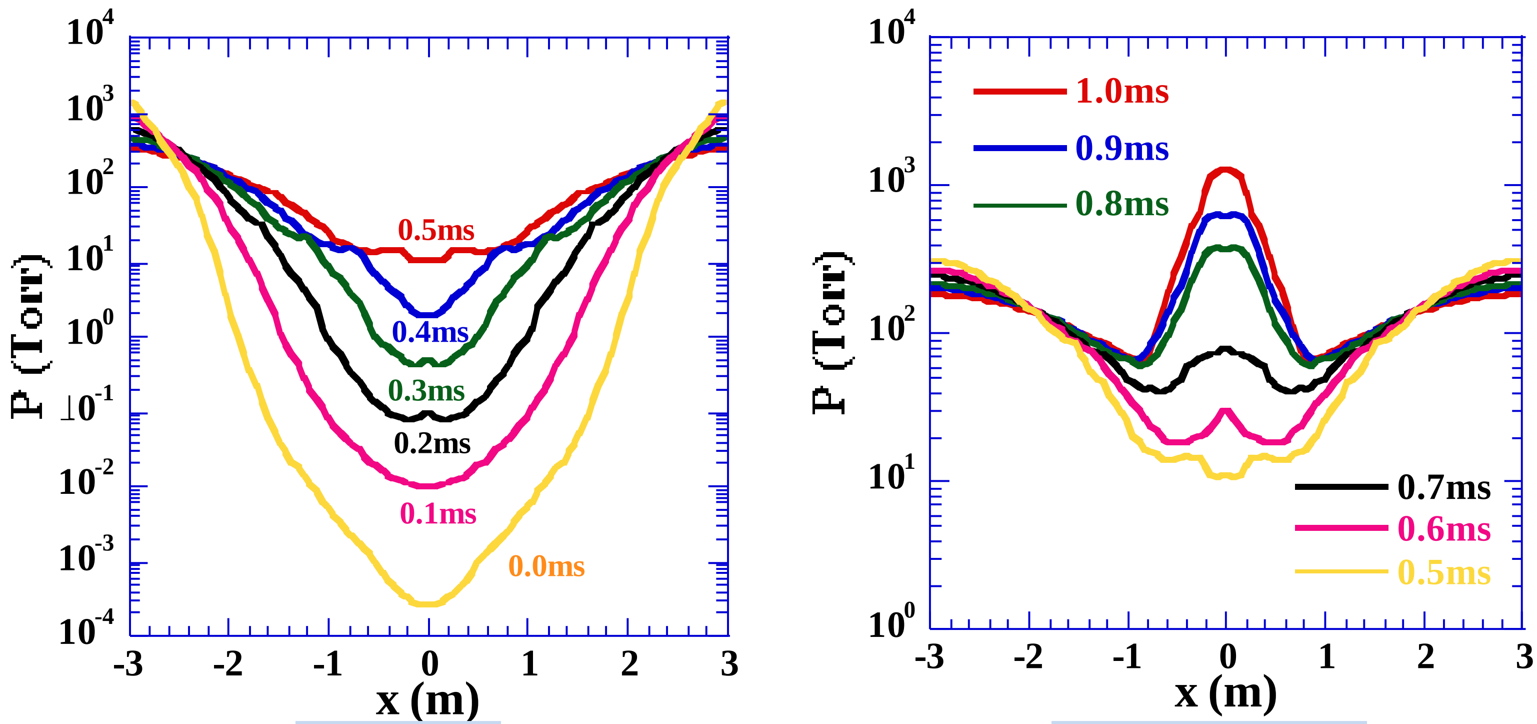
Time integrated angular distribution of Ablated materials.

By Furukawa

We estimated that possibility of collisions of aerosols is 1/100

ILE Osaka

Spatial distribution of ablated materials at the first bounce.

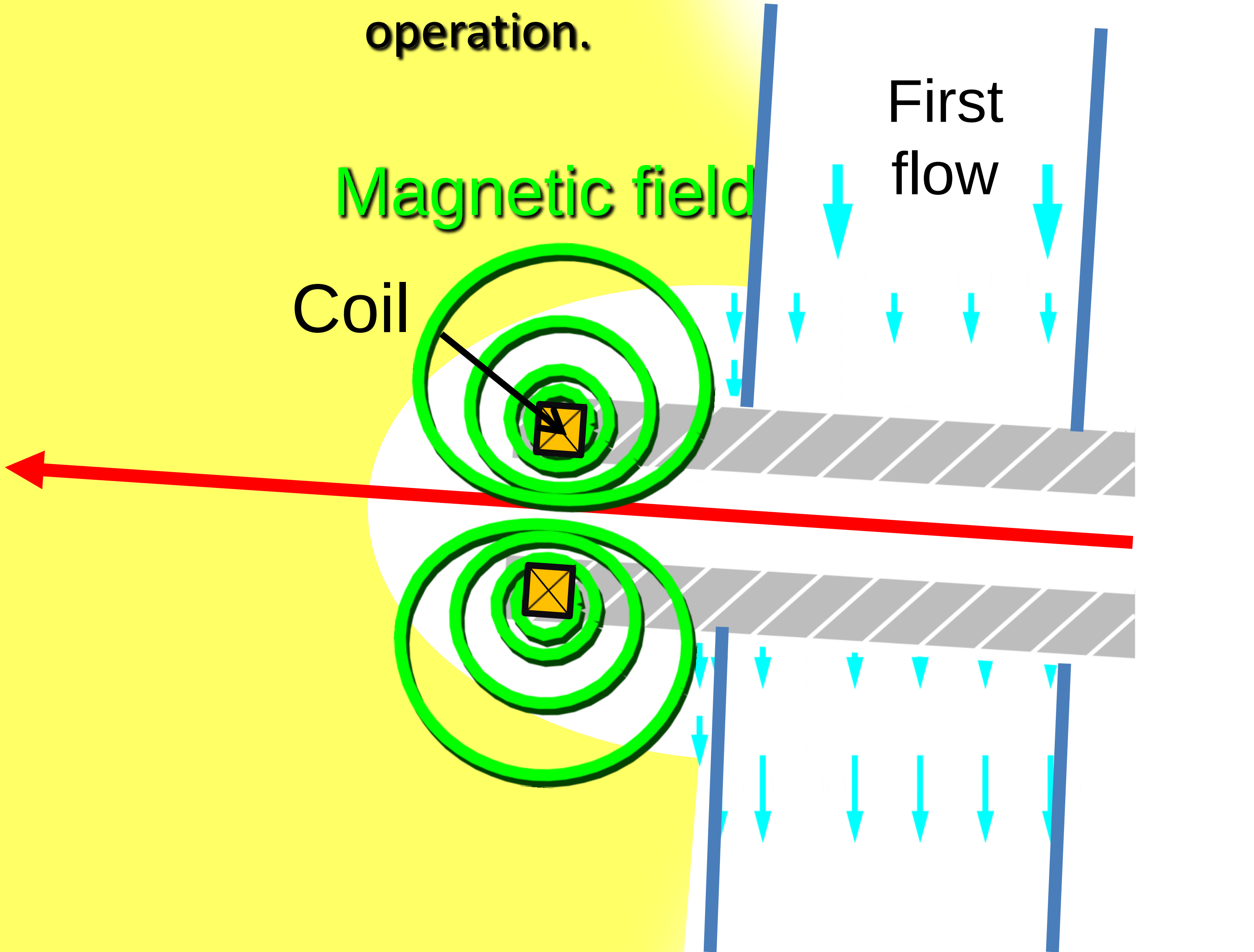


t<0.5ms

0.5 ms<t<1ms

Gas component makes a hot, dense peak at the center but most of aerosols pass through the core without collision. As the result, the stagnation and precipitation of ablated material seems not so critical.

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.



Three dimensional hybrid code was used.

ILE, Osaka

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

Equation of motion of ions

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

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

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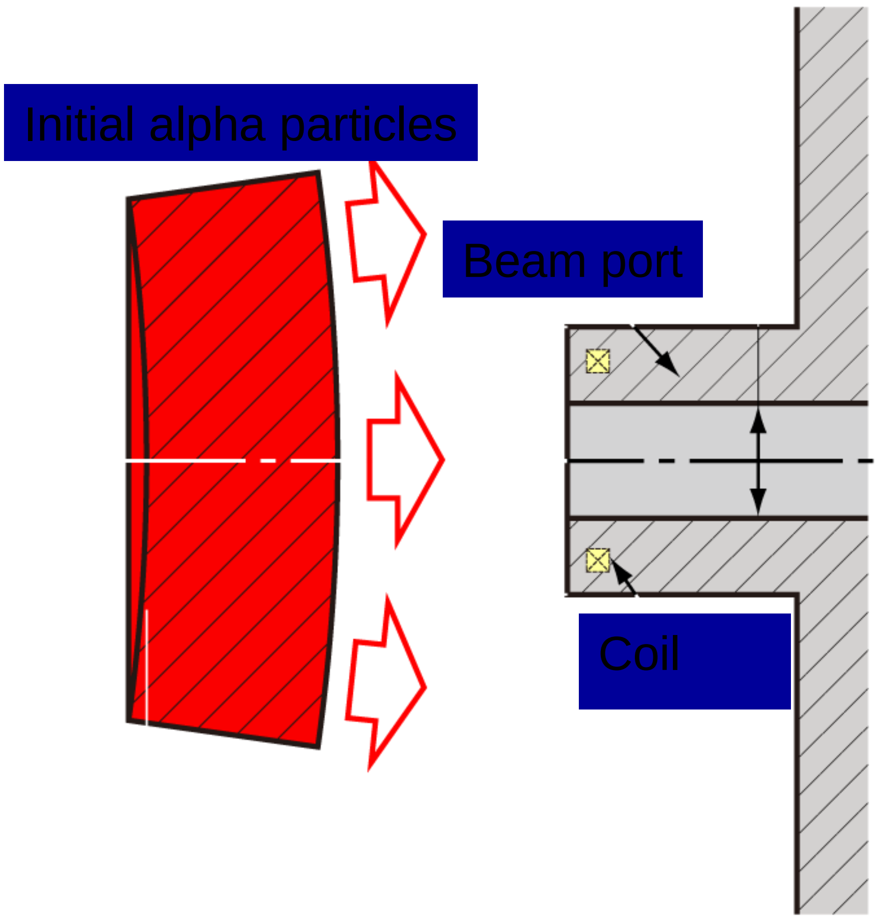
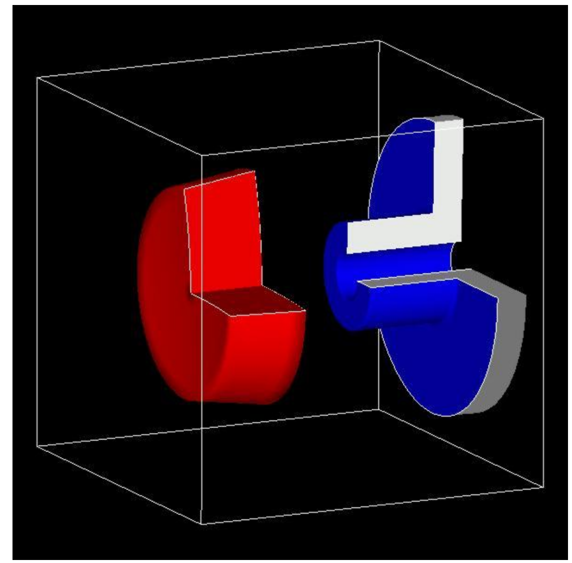


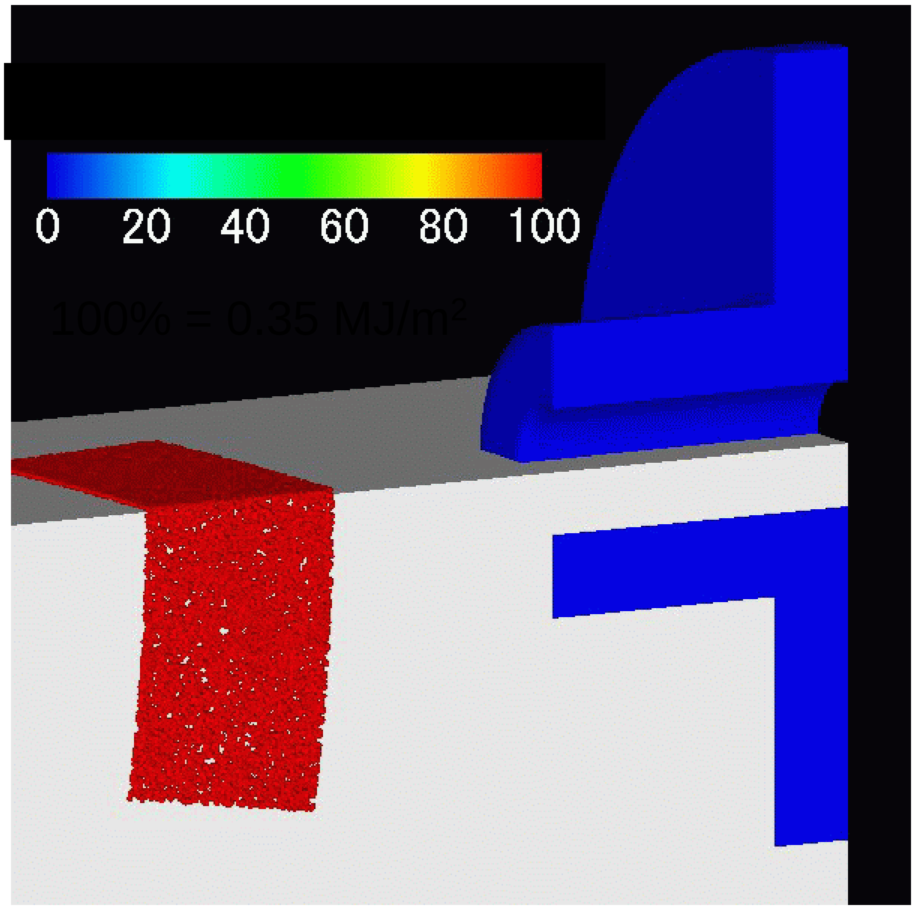


$N\alpha = 2.5 \times 10^{18}\ /m^3$

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

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

ILE, Osaka



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.

Outline

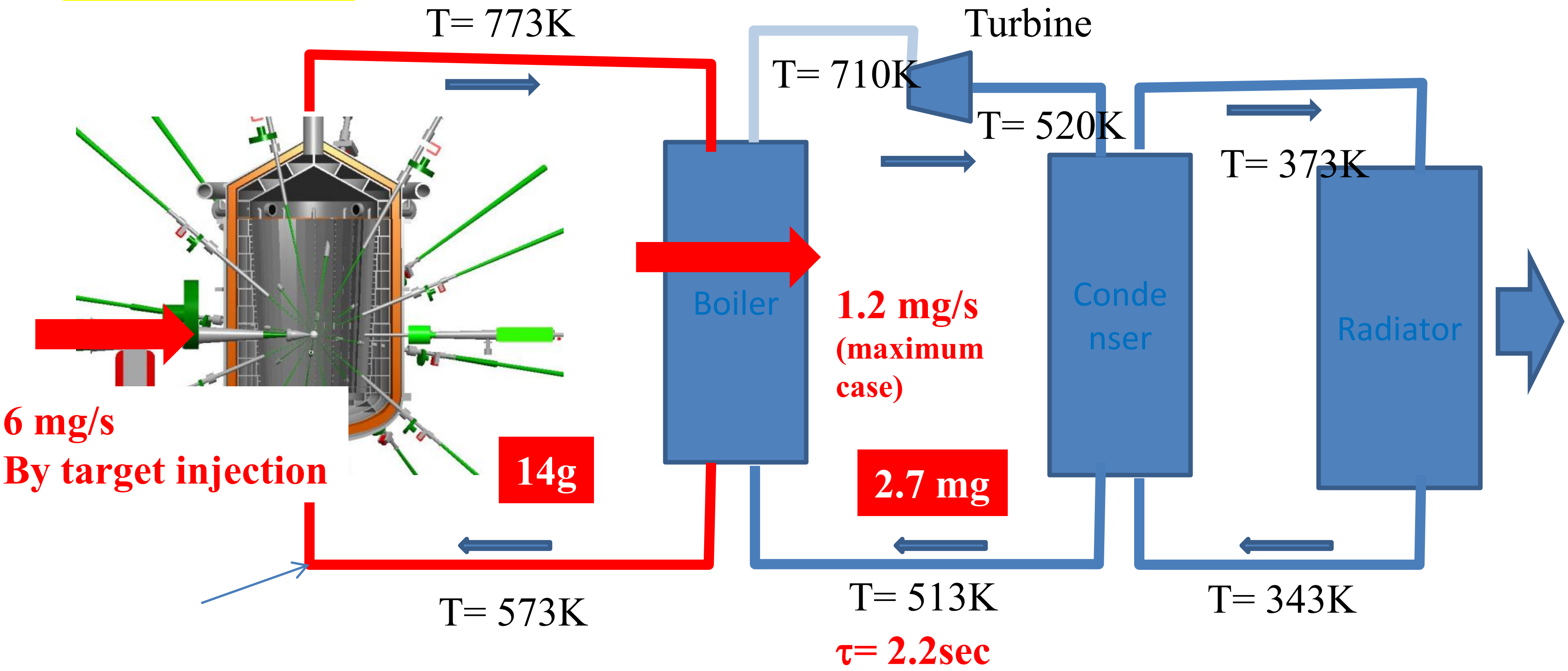
ILE, Osaka

- Introduction
- Issues on liquid wall
- Tritium control
  - Tritium barrier in heat exchanger
- Issues on neutron damage

Tritium diffusion through heat exchanger is critical issue of fusion plant.

No barrier case

ILE, Osaka

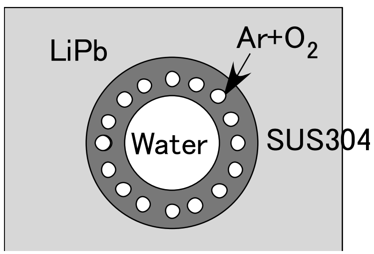


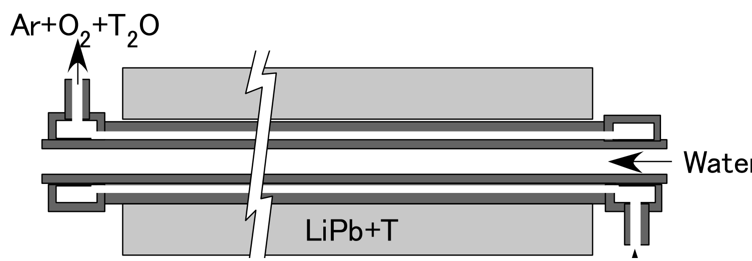
If there is no tritium barrier, tritium spreads quickly over heat cycles.
1/5 of injected tritium goes to the second water loop in the worst case.
Coating of Er2O3 enables tritium recovery as fuel, but insufficient in safety view point.

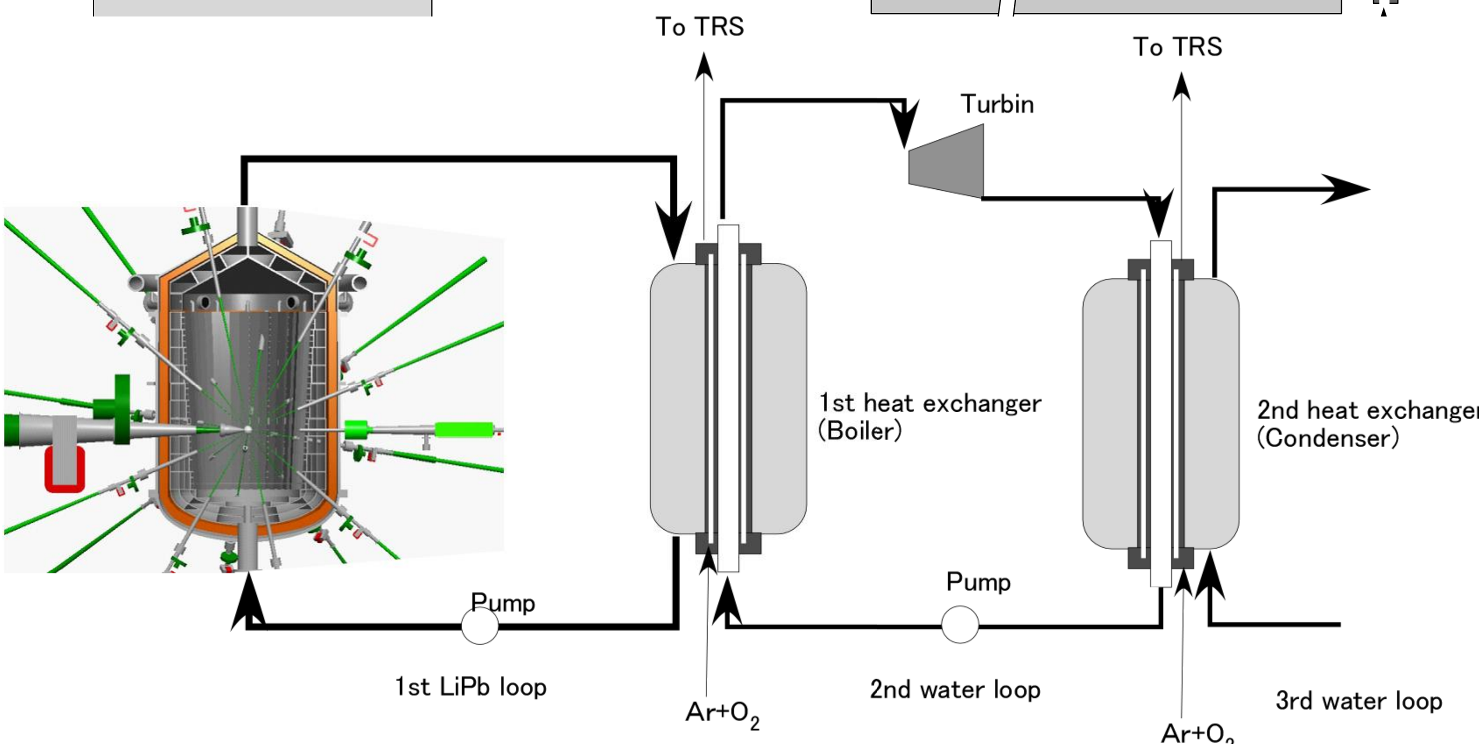
We are going to use double tubes. Thin lines in the wall are filled with carrier gas and oxygen to convert tritium to HTO.

ILE, Osaka

This method is compatible with a coating barrier such as Er_2O_3 and ZrO_2.







With 12 lines for tritium trapping

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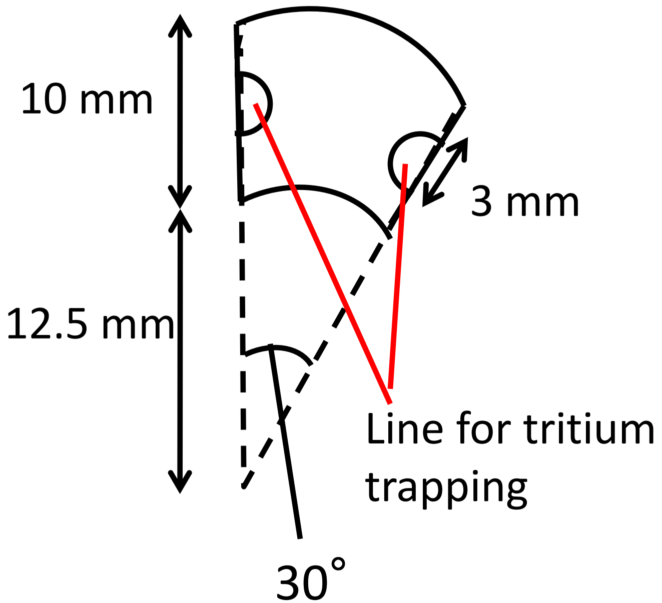
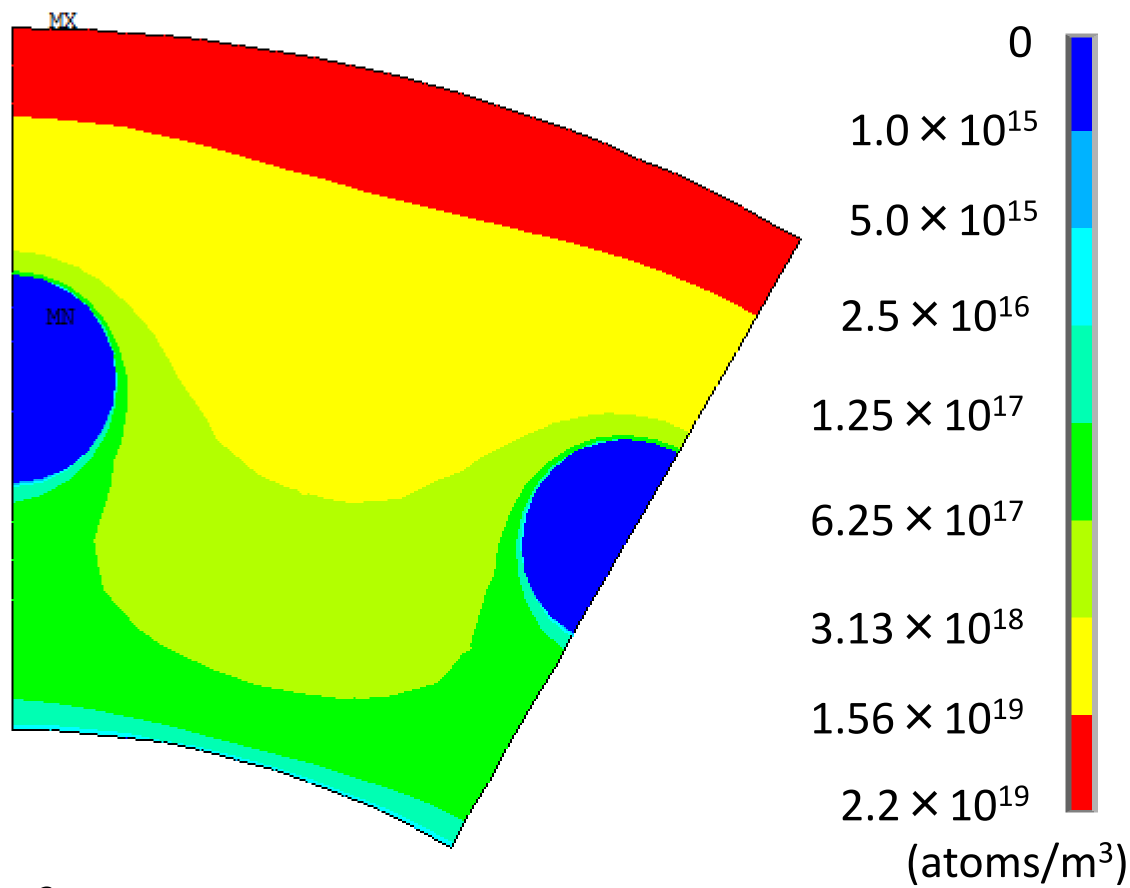
Partial pressure of tritium in the trapping tube is assumed to be zero.





Tritium flux 1.06×10^{16} atoms/m^2・sec

Heat flux 1.63×10^{5} W/m^2

With 30 lines, tritium permeation was reduced to $2/10^5$ of base line tube.

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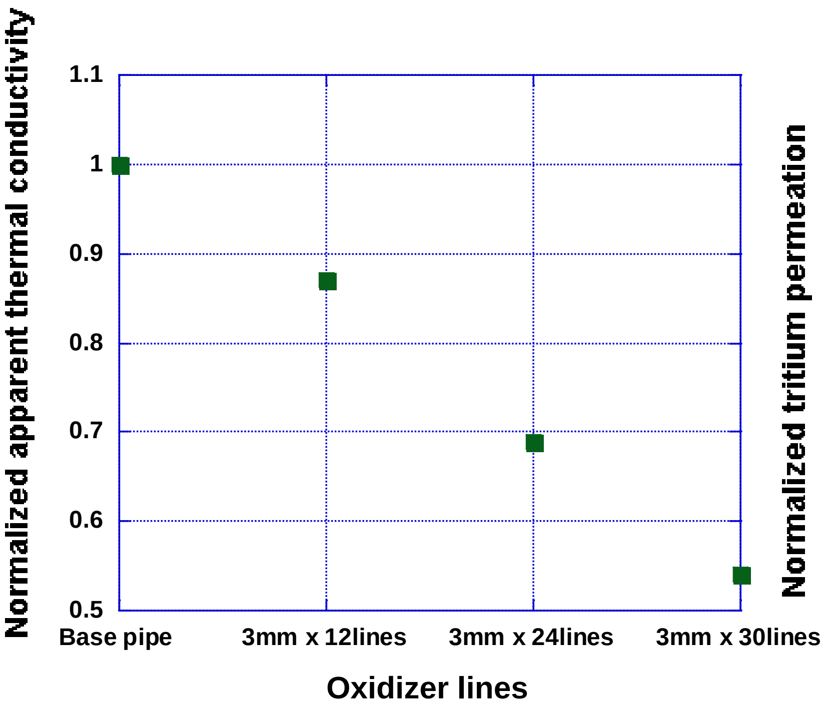
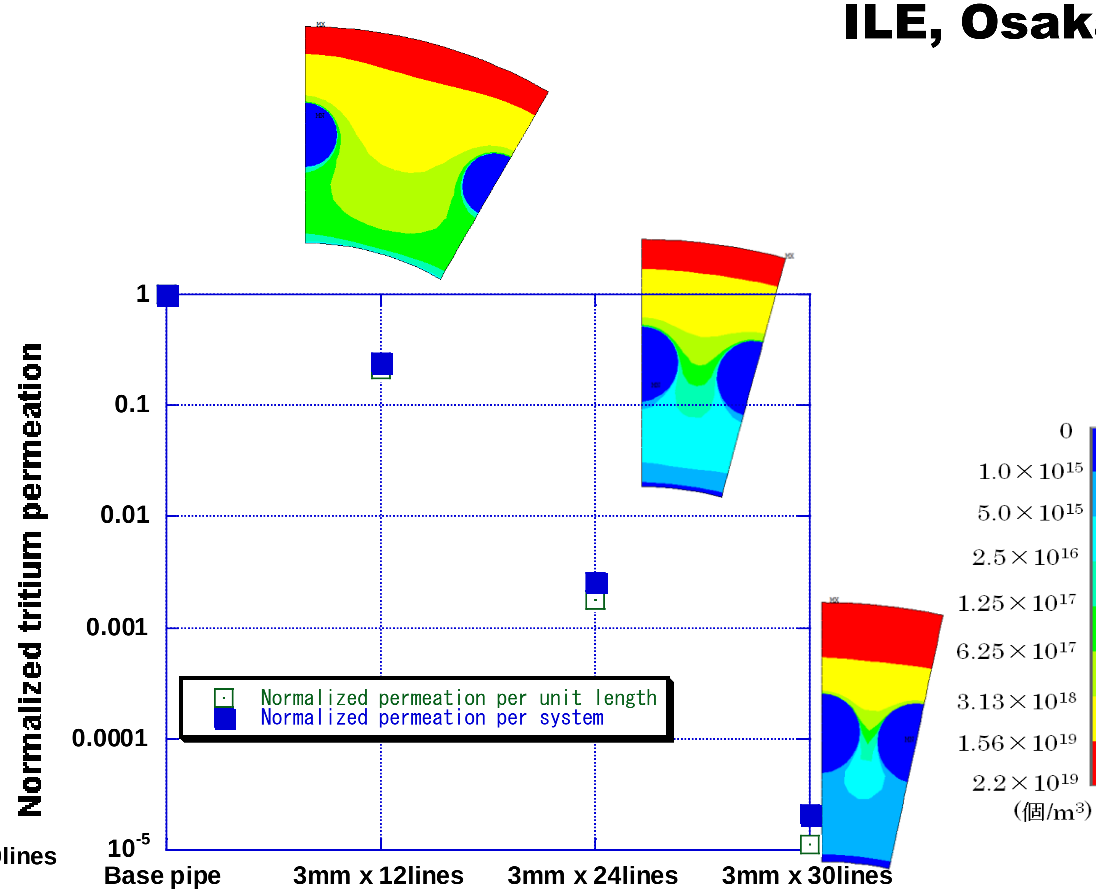


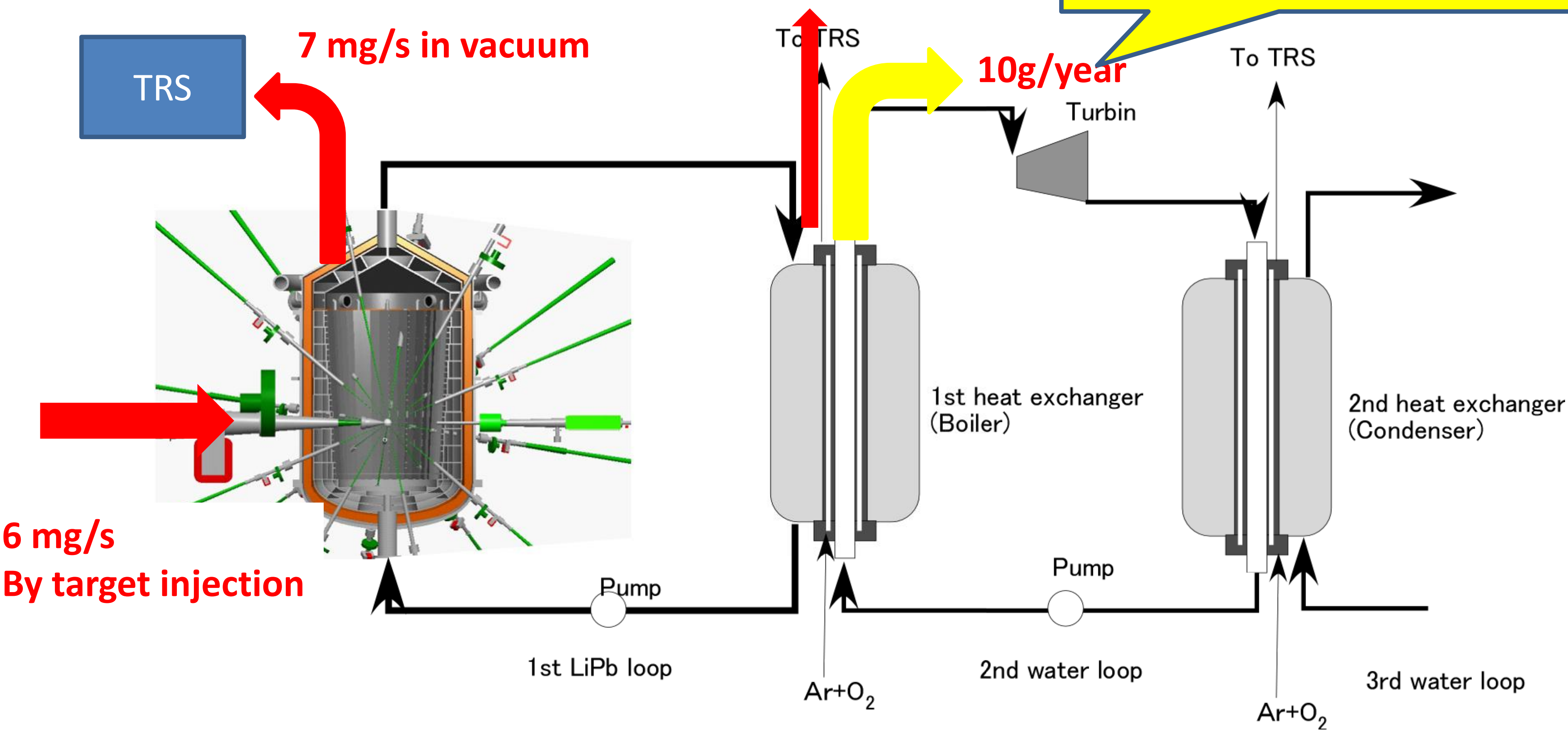


Tritium flow after reduction of 1/10^5

Accumulation of tritium after 1 year full operation = 200MBq/cc

cf. tritium in Fugen (ATR) after 25 year operation
250MBq/cc

1.2 mg/s in highly concentrated tritium water



Summary of tritium barrier

ILE, Osaka

Tritium

- We propose a tritium filtering system for a heat exchanger, which is compatible with coating technique.
- By using both techniques simultaneously, we can reduce the tritium accumulation in the second water loop to an acceptable level.

Outline

ILE, Osaka

- Introduction
- Issues on liquid wall
- Tritium control
- Issues on neutron damage
  - Concept for first structural wall
  - Final optics

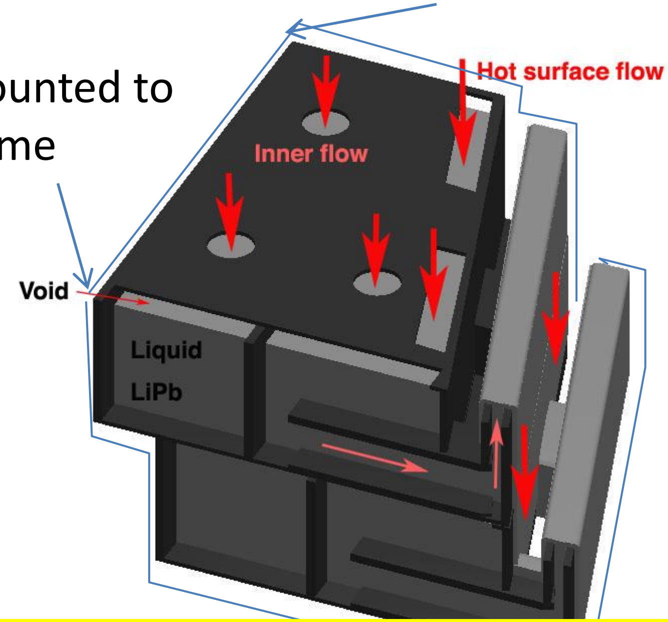
How to deal with neutrons damage of the first structure wall?

ILE, Osaka

- The neutron load on the first structure wall of KOYO-F is 40 - 70 dpa/y. So, swelling of the blanket wall is unavoidable.

Sliding support

Mounted to frame

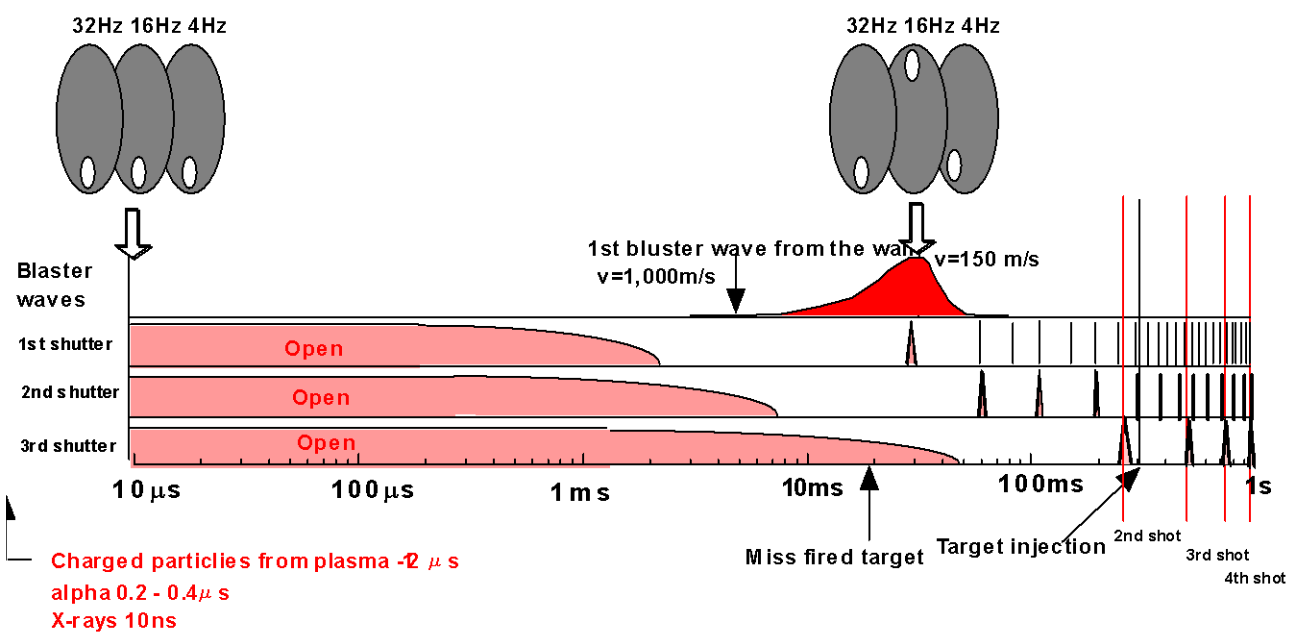


To allow expansion, we keep gaps between cells and the cell is mounted on the frame at one fixed point and two sliding points. -> we expect 2 year continuous operation.

How to protect the final optics

ILE, Osaka

- α particles, ions — Magnetic field
- Neutral vapor — Synchronized rotating shutter and inert gas in beam duct
- Neutrons — Distance



Neutron load on final optics of KOYO-F

ILE, Osaka

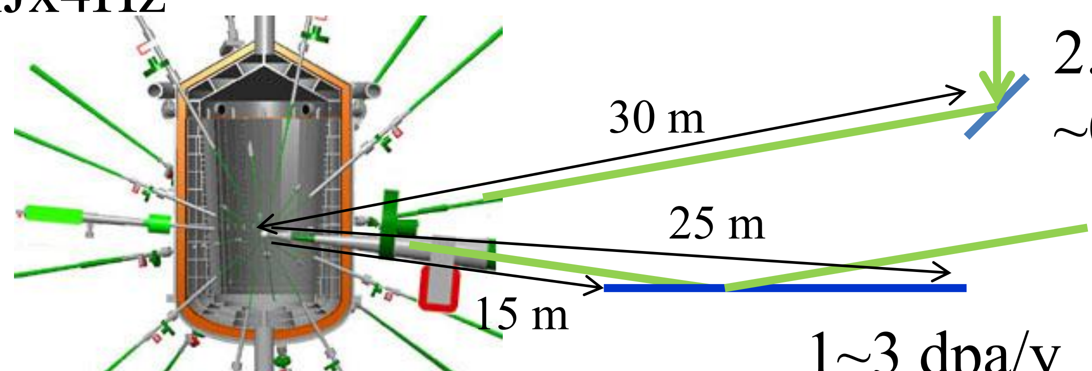
- Compression beam (L=30m)
  2.5×10^{12} n/s cm^2. (8×10^{23} n/m^{2}FPY)
- Ignition beam (L=15 – 25 m)
  $5 \times 10^{12} - 1.5 \times 10^{13}$ n/s cm^2

→ Replace mirrors every 2 months

→ GILMM

Fy=200MJx4Hz

65kJx4 Hz



2.5×10^{12} n/s cm^2
~0.7 dpa/y

1~3 dpa/y
GIMM[*1,2] or GILMM[3]

*1 M. S. Tillack et al, Fusion Science and Technology, 56 (1) July 2009, 446-451.
*2 M. E. Sawan, et al, Fusion Science and Technology, Vol. 52, No4, pp938-942, 2007.
*3 R. W. Moir, Fusion Eng. And Design, 51-52 (2000) 1121.

This estimation is moderately supported by Snead's experiment.

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Energy of neutrons～0.1MeV
0.1 dpa

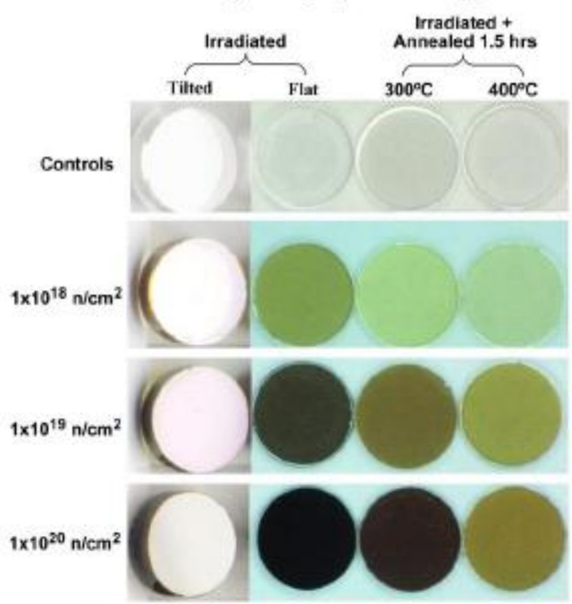


Fig. 5. Optical inspection of HfO_2/SiO_2 mirrors in the non-irradiated and neutron irradiated condition as a function of post-irradiation annealing temperature.

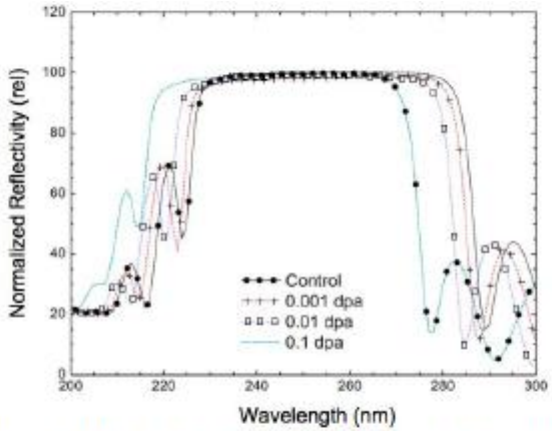


Fig. 8. Effect of neutron irradiation on the relative reflectance of HfO_2/SiO_2.

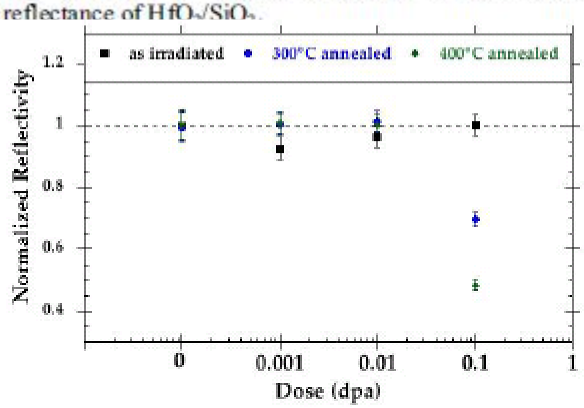


Fig. 11. Absolute reflectivity of non-irradiated, irradiated, and irradiated/annealed HfO_2/SiO_2 mirrors.

From L. L Snead, et al., FUSION SCIENCE AND TECHNOLOGY VOL. 56 (2009) pp1069

We estimated that the life of reflective mirror is 2 month.

ILE, Osaka

- Attenuation of SiO_2 optical fiber by DT neutrons
  $I_{in}/I_{out} = 1 \times 10^{-19}$ dB/cm/(n/cm^2)

  (From T. Iida, et al., Nucl. Sci. Technol., 24(12), pp1073 (1987))

- Thickness of multilayer coating <10 μm
- Total absorption of laser light < 1kW (water cooling from back side of mirror)

Life of mirror 2 - 4 months

Cost for mirrors is acceptable.

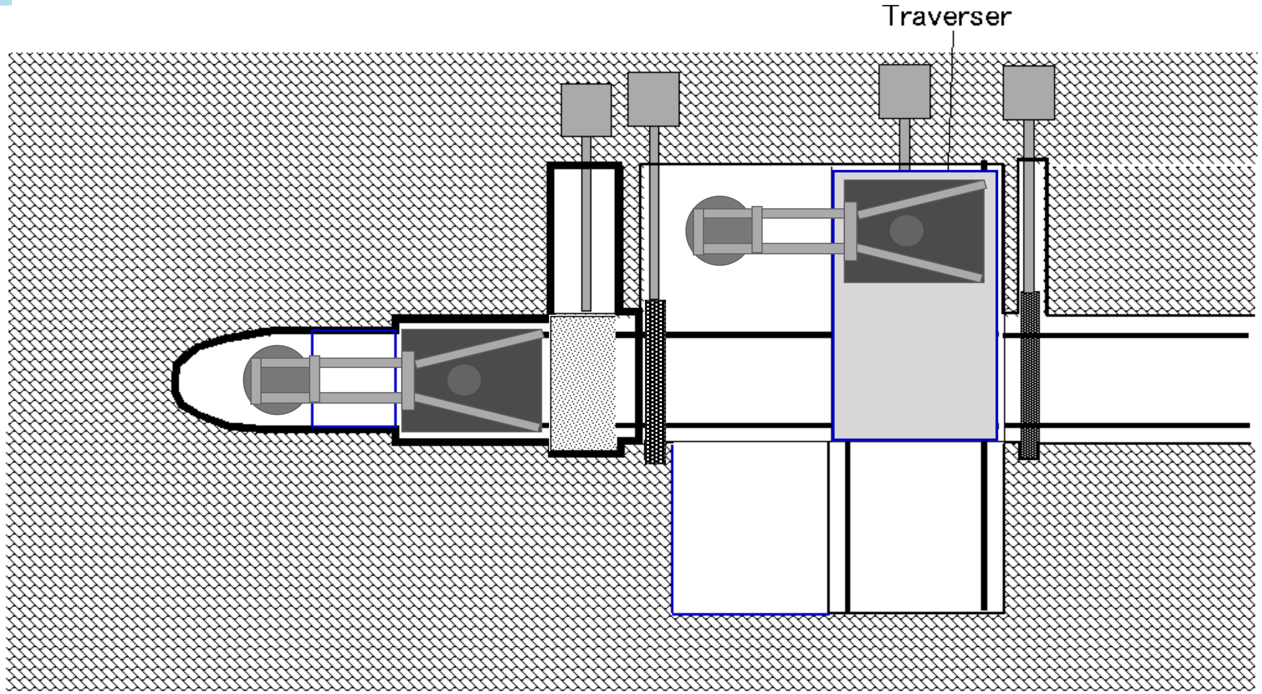
ILE, Osaka

- Current cost for a 30cm-diameter mirror is 10k $.
- If we replace all mirrors for compression beams every 2 month in a short halt of laser operation.
- The cost for mirrors 1.4 M$/2 months
- Target cost 16 M$/2 months (@ 20C/target)
- Sale 150 M$/2 months(@ 10 C/kWh)

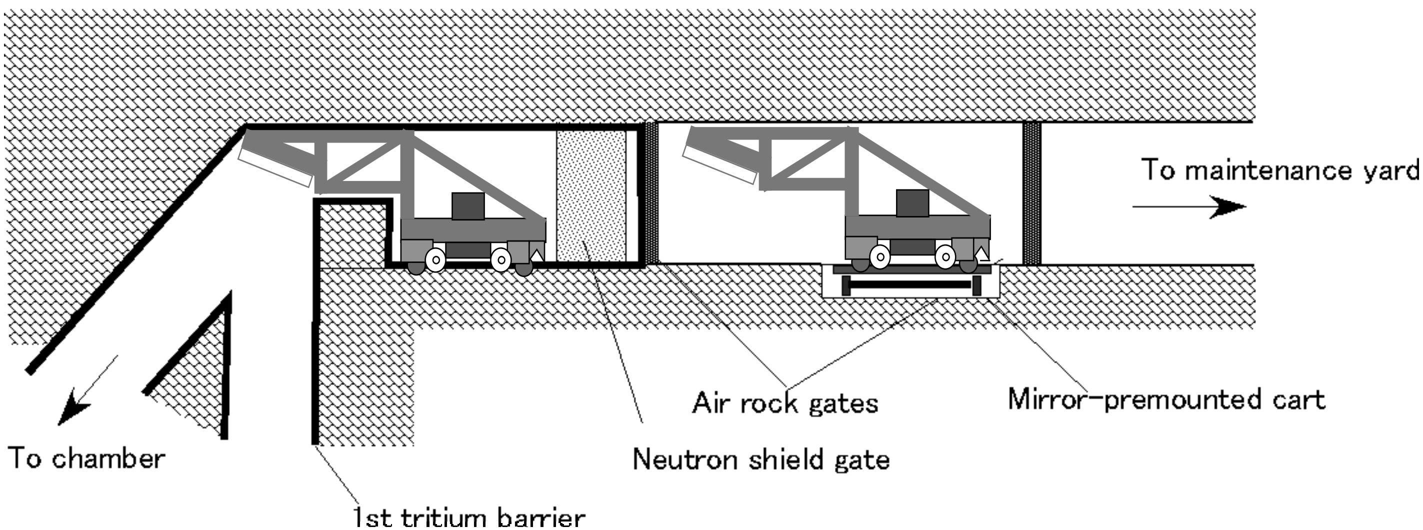
- Running cost for mirrors is less than 1% of total sale, which is acceptable.

Final optics

Top view



Side view



The critical issue of KOYO-F is the final optics for the heating 150kJ/30ps laser.

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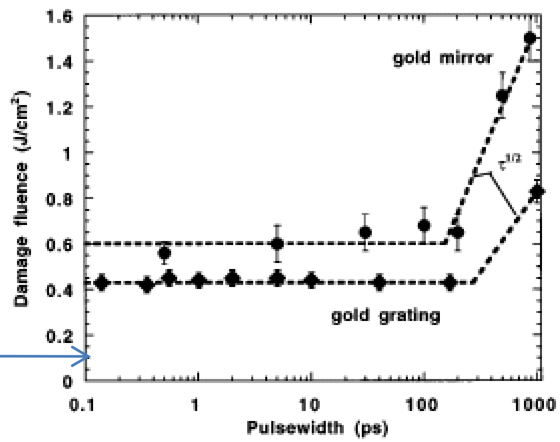
- The diameter of heating laser is about 3m. So, periodic replacement of expensive multicoated mirror seems inappropriate.
- Conventional GIMM and GILMM*[1] are also critical due to bent of base frame.



Liquid Pb (estimated)

Fig. 4. Pulse-width dependence of damage threshold of a gold grating and a gold mirror at 1053 nm.

Because of low damage threshold, metal mirror becomes big.

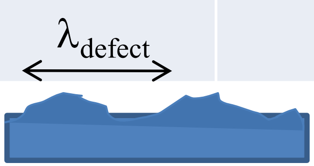
*1 R. W. Moir, Fusion Eng. Design, 51-52, (2000) pp1121.

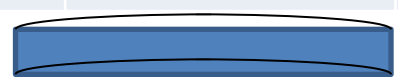
B. C. Stuart, J. Opt. Soc. Am. B/ 13, 458 (1996)

Neutron damages on glass lense and metal mirror

ILE, Osaka

	Defects and size	Defect source	Effect on laser beam	When defects appear?
Lenses	Defect in grid (Color center)	Collision	Increase of absorption	Life:5 min for 3cm thick optics
	$\lambda_{defect}<\lambda_{\lambda aser}/10$	Sputtering	No influence	
Mirror	$\lambda_{defect}=\lambda_{aser}$	Blistering by He	Scattering	>1 dpa, 1 year
	$\lambda_{defect}>10\lambda_{laser}$	Swelling of structure by He	Defocusing	>1 dpa, 1 year

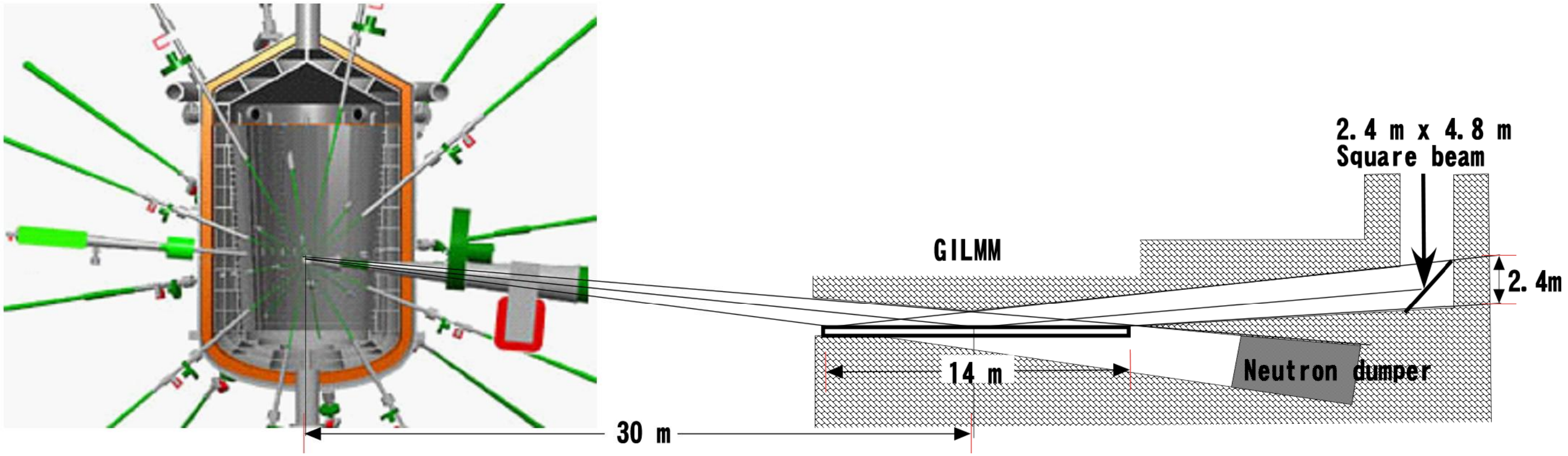




Swelling of support frame would increaser the focusing size. Estimated life time of GIMM is 1 year.

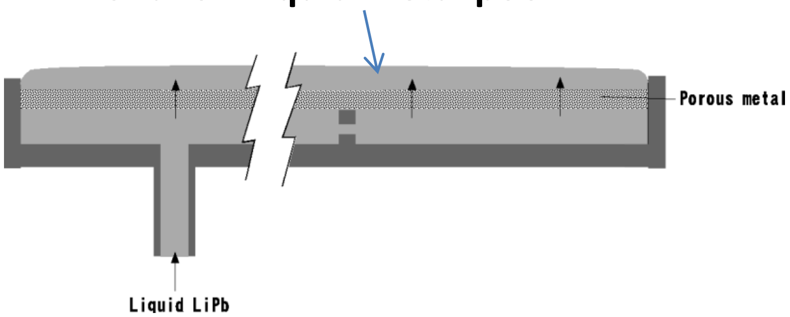
Level, Grazing Incident Liquid Metal Mirror* will be used for 150kJ/30ps heating laser.

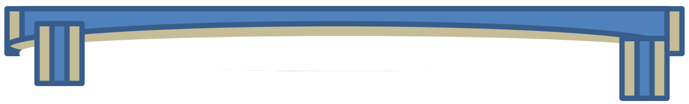
ILE, Osaka



Damage threshold of liquid Pb is estimated to be 0.15 J/cm^2

Shallow liquid metal pool





This concept can equalize deformation of frame.

***R. W. Moir, Fusion Eng. Design, 51-52, (2000) pp1121.**

Summary 1
Issue of KOYO-F and the current solution

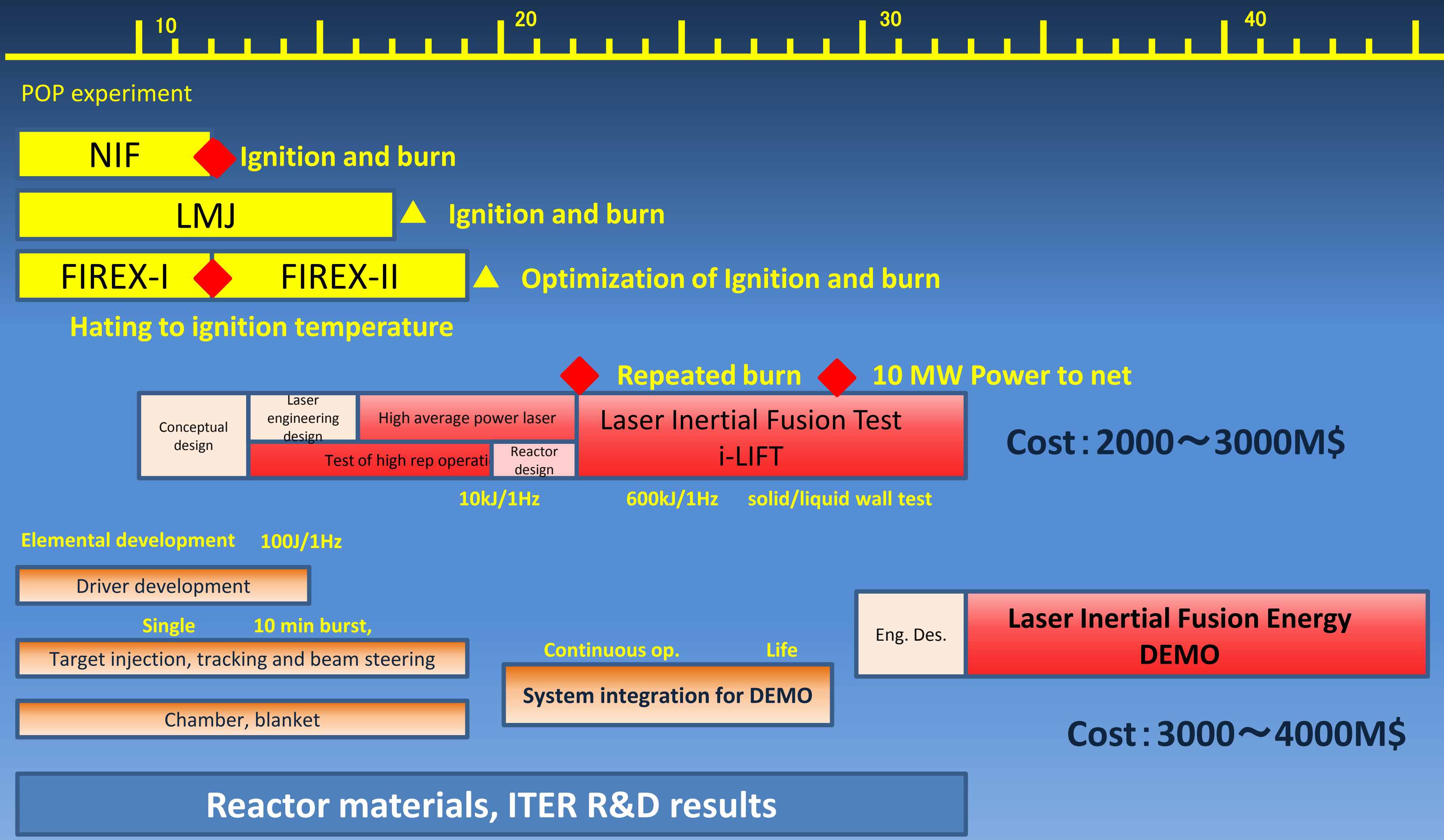
ILE, Osaka

- Stability of liquid flow
  - Cascade flow. OK
  - If wettable Ceiling, OK
- Tracking and beam steering
  - Tracking, OK
  - Damping of large mirror to be studied.
- Life of final optics
  - Implosion beam OK by replacing them every 4 M.

- Tritium barrier in heat exchanger
  - Er_2O_3 coating + double tube concept +TRS in the 2nd loop
- Swelling of structural wall
  - Scale scheme for blanket cell
  - Textile blanket wall
- Impurity control in LiPb

Summary 2 and
Roadmap to laser fusion power plant

i-LIFT can be fabricated using existing materials and improved technologies.



Thank you for your attention!