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IFE Roadmap and power plant concept based on fast ignition laser fusion

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Outline

-IFE Road map based on fast ignition concept

- What is changed by fast ignition ?
- Small sized experimental reactor generating net electric power .
- Critical issues and necessary technology development program

-Design study of fast ignition laser fusion power plant

- Design windows of fast ignition laser fusion power plants
- Chamber pulse conditions and free surface liquid wall concepts

IFE road map committee by IFE Forum (2002~2003)

Chair	Ken Tomabechi	Central Research Institute of Electiric Power Industry
Co-chair	Yasuji Kozaki	ILE, Osaka University
	Hiroshi Azechi	ILE, Osaka University
	Kenichi Ueda	The University of Electric-communications
	Takuma Endo	Nagoya University
	Yoshiro Owadano	National Institute of Advanced Industrial Science and Technology
	Kunihiko Okano	Central Research Institute of Electiric Power Industry
	Yuichi Ogawa	University of Tokyo
	Hirobumi Kan	Hamamatsu Photonics
	Tomoaki Kunugi	Kyoto University
	Hiroyuki Kubomura	NEC Corporation
	Akira Koyama	Kyoto University
	Tetsuyuki Konishi	Kyoto University (former Japan Atomic Energy Research Institute)
	Akio Sagara	National Institute for Fusion Science
	Yoshito Souman	Japan Nuclear Cycle Development Institute
	Satoru Tanaka	University of Tokyo
	Yasuyuki Nakao	Kyusyu University
	Hitoshi Nakano	Kinnki University
	Masahiro Nishikawa	Osaka University
	Takayoshi Noriamatsu	ILE, Osaka University
	Kunioki Mima	ILE, Osaka University
	Noriaki Miyanaga	ILE, Osaka University
	Takeo Muroga	National Institute for Fusion Science
	Masanobu Yamanaka	ILE, Osaka University

Introduction

- The progress of implosion physics and DPSSL (Diode Pumped Solid-State Laser)

  In 1997 IFE Forum organized "The Committee on Development Program of Laser Fusion Energy" (chair Y.Kozaki), members of universities, national laboratories and industries in Japan, and proposed IFE road map which had two major facilities, HGX(High Gain Experiment) and LFER (Laser Fusion Experiment Reactor) using a MJ class DPSSL.

- Fast ignition concept is attractive, as a high gain is achieved by small laser energy. The fast ignition experiment by PW laser at Osaka University demonstrated the heating efficiency of 20 % at the ignition equivalent laser intensity in 2002. FIREX-I (Fast Ignition Realization Experiment) project has started in 2003 for demonstrating the heating up to ignition temperature, and FIREX-II is considered for demonstrating ignition.

- The recent progress of fast ignition physics may bring a big change to an IFE road map, then IFE Forum organized a new committee "The Committee on Road Map for Laser Fusion Energy" (chair K.Tomabechi, co-chair Y.Kozaki) in 2002.

Purpose of The Committee on IFE Roadmap

- To investigate conditions of achieving laser fusion energy and asses the possibility of fast ignition reactor concepts,
- To identify milestones and necessary facilities,
- To identify critical paths and estimate cost and manpower,
- To propose a reasonable road map using fast ignition features and make a strategy of development including collaboration with industry.

1 keV heating was achived in 2002.

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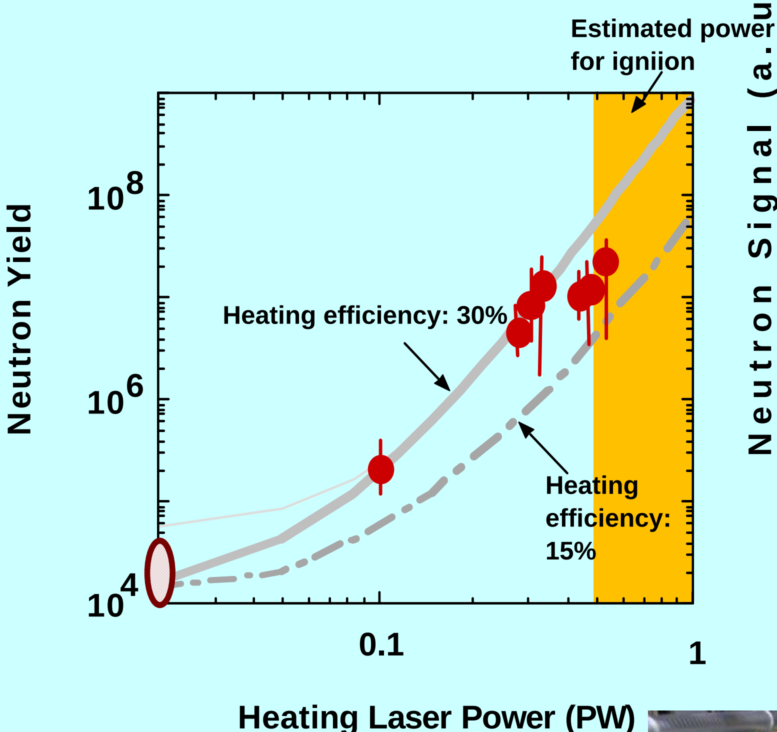
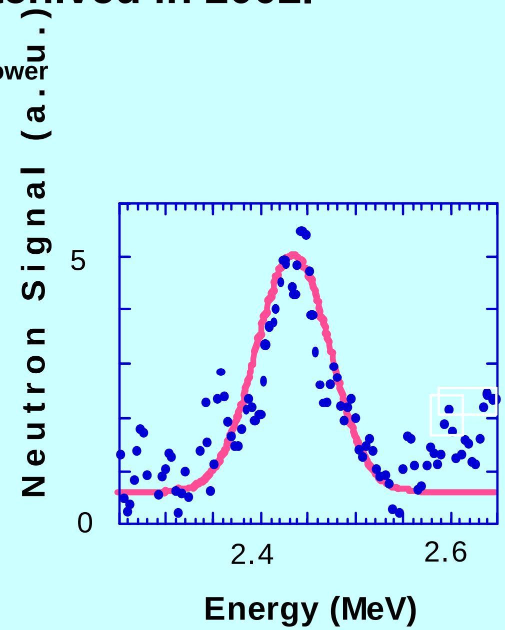
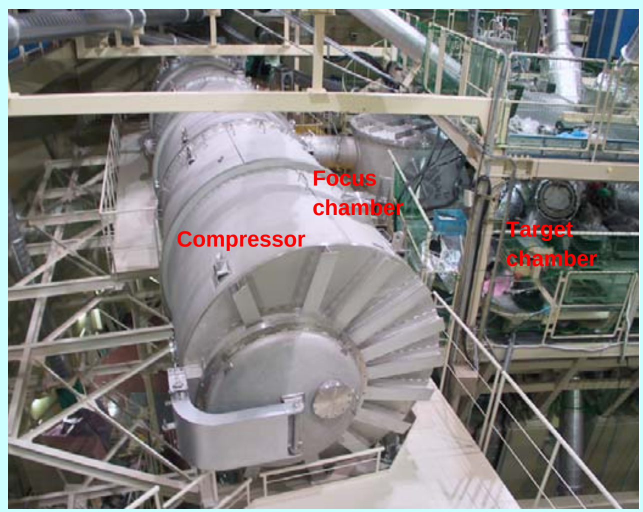
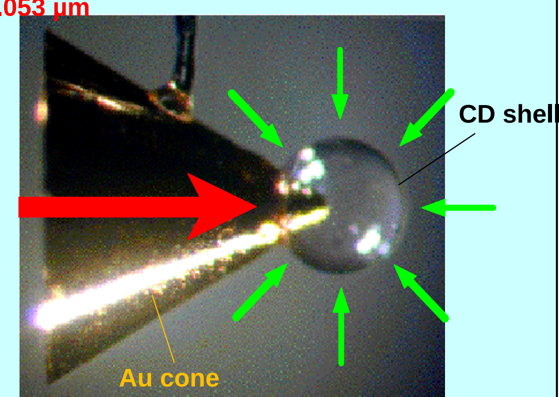




R. Kodama et al. Nature 2002.



Heating lase
1 PW
Wavelength
1.053 μm



Implosion laser
Gekko XII, 9beams
1.2 kJ / 1ns
Wavelength 0.53μm

Estimates of ignition burn on the FIREX project and prospects high gain

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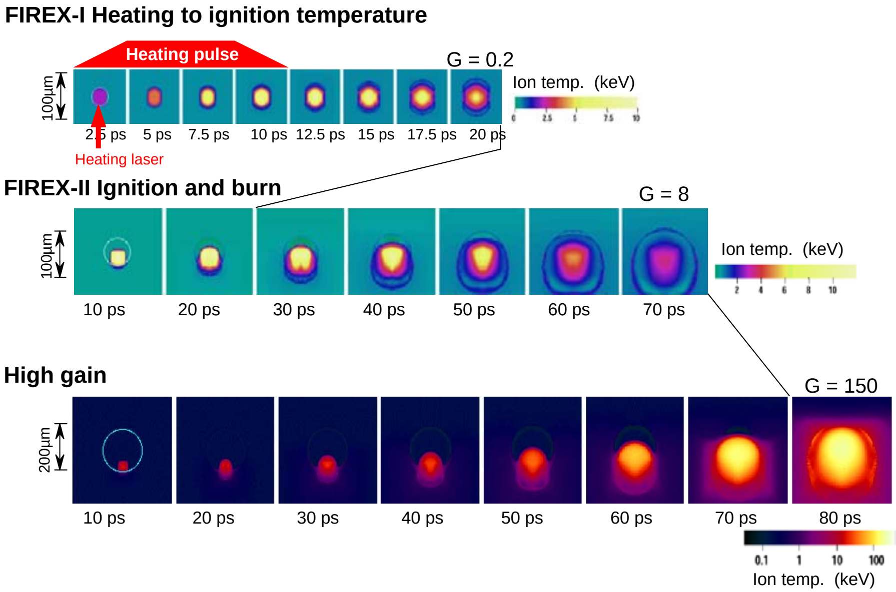
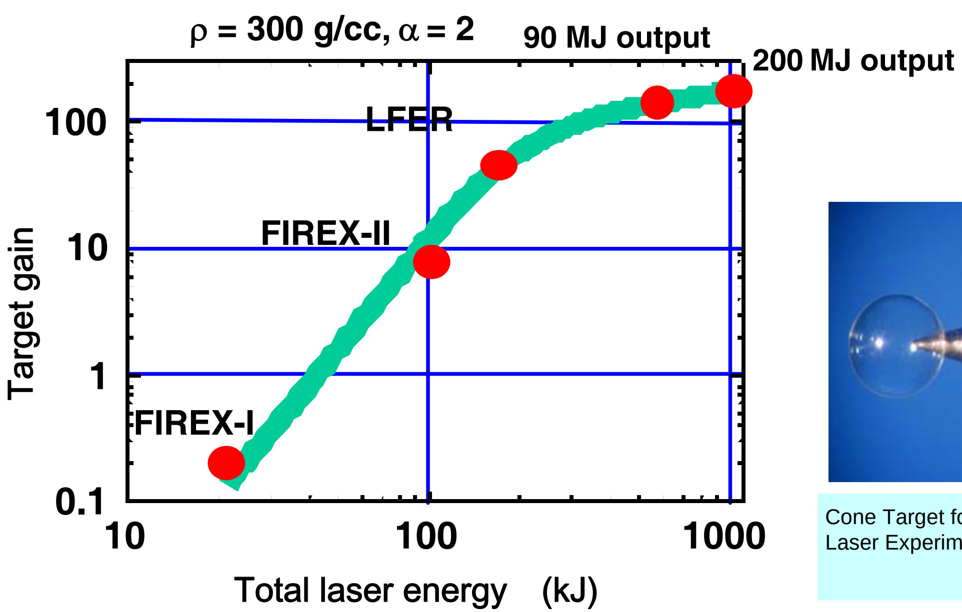
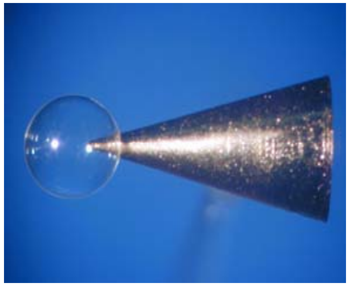


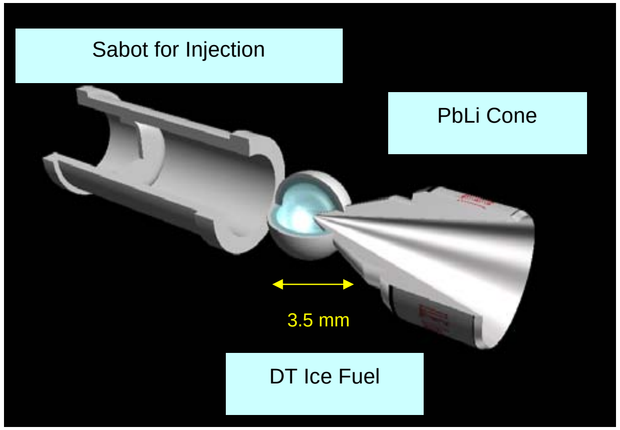
Cone targets for a PW experiment and for a reactor of 90 MJ fusion yield.

Cone targets irradiated by heating laser through from the cone have big merits not only to eliminate the affection of ablated plasma but also to reduce the requirements for laser beam focusing and target injection technologies.





Cone Target for PW Laser Experiment (ILE)

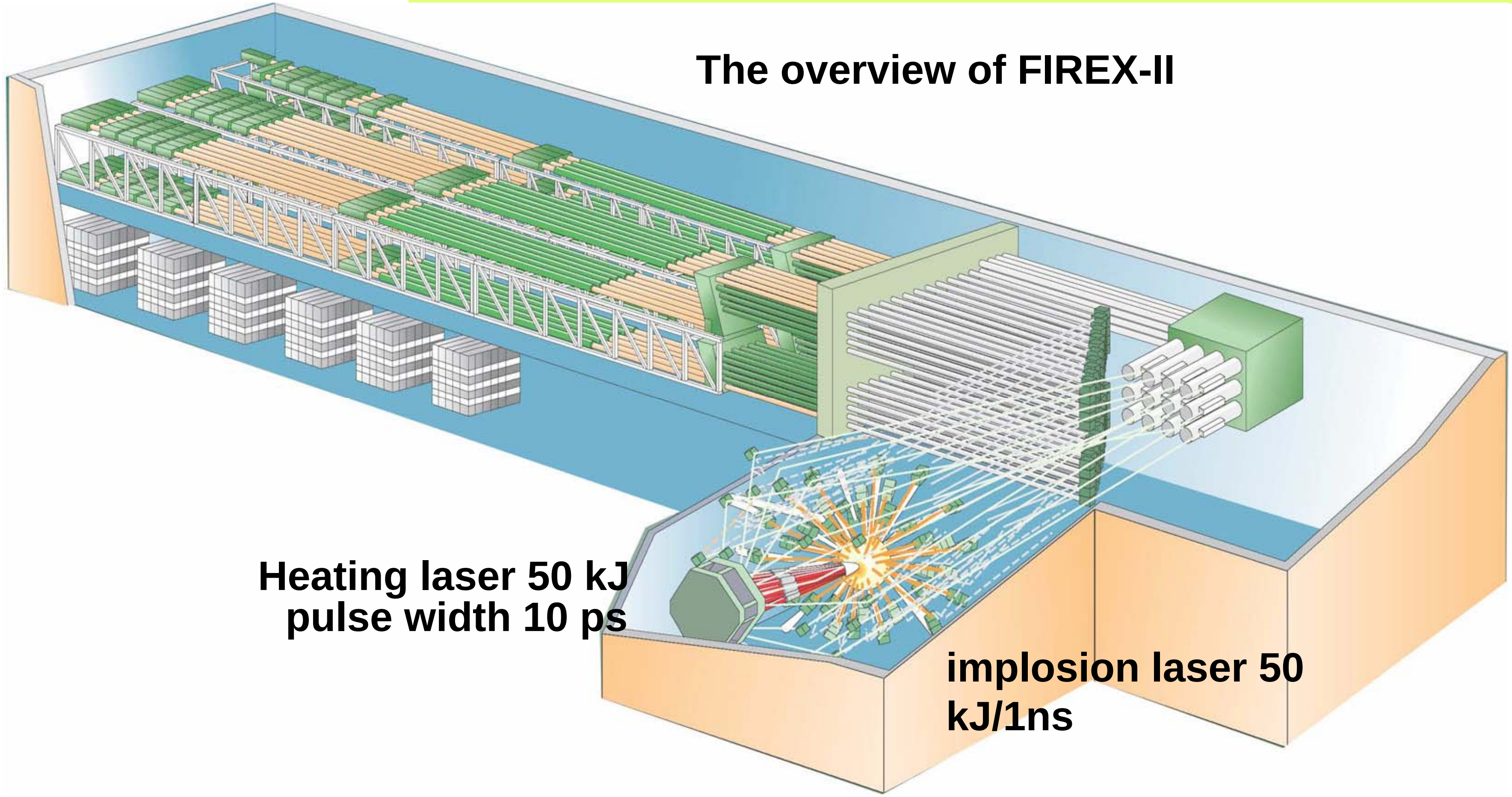


Cone Target for 90 MJ Fusion Pulse

FIREX (Fast Ignition Realization Experiment)

Purpose: Establishment of fast ignition physics and ignition demonstration
Starting Conditions : high denisity compression(already achieved)
: heating by PW laser (1keV already achieved)

The overview of FIREX-II

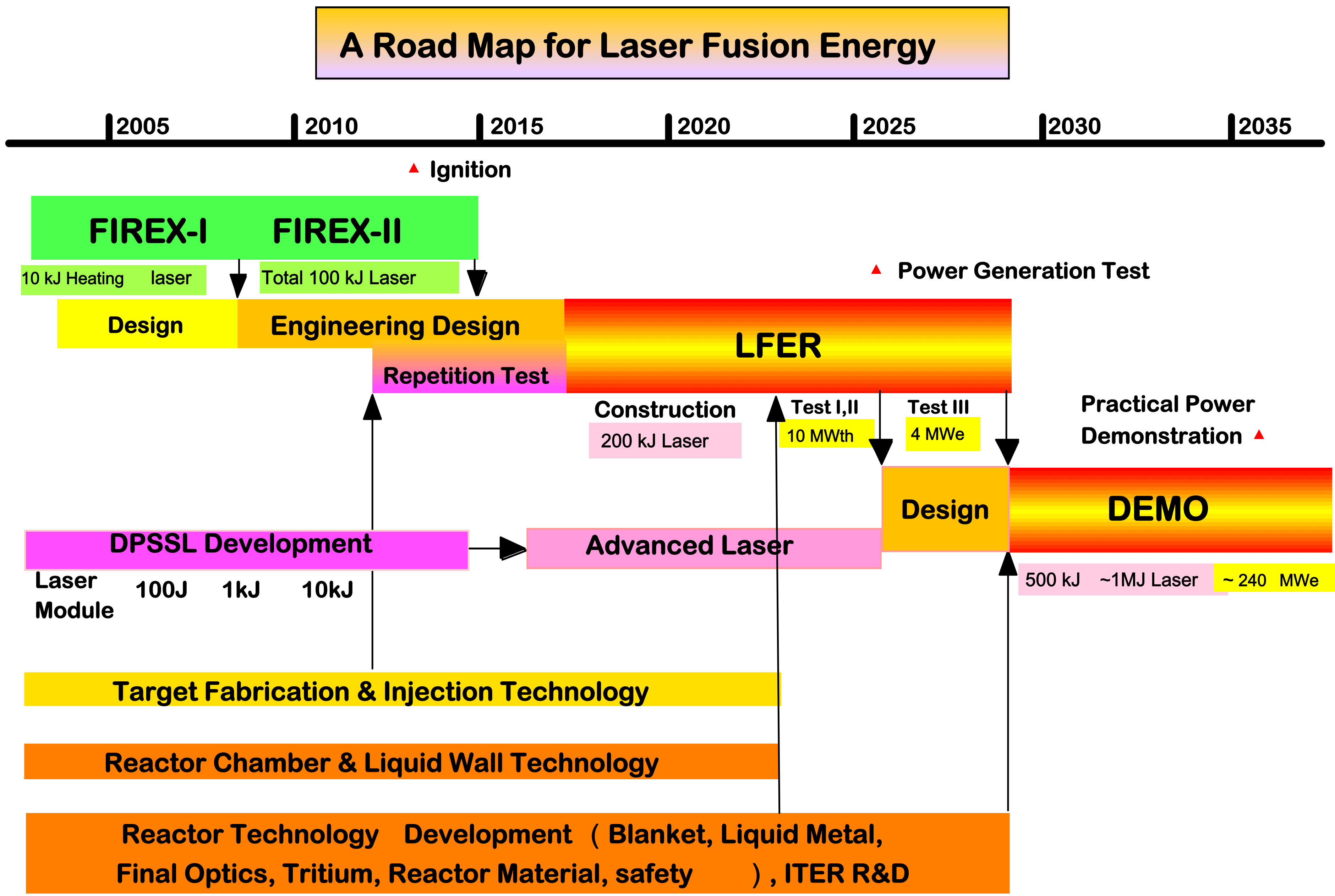


Specification of laser fusion power plants

	Laser energy MJ	Fusion gain	Fusion pulse yield MJ	Rep rate, Hz reactor (laser)	Net electric power MWe	
					Per reactor	Modular plant
Fast ignition	~0.3	~80	~20	3	20	
				12	80	
	0.6	150	90	3.3 (10)	100	100× 6 600MWe
	1.0	200	200 (KOYO-Fast)	3 (15)	240	240× 5 1200MWe
Central ignition	2	100	200	3 (15)	240	240× 5 1200MWe
	4	100~150 (KOYO)	400~600 (KOYO)	~3 (6)	~600	600× 2 1200MWe

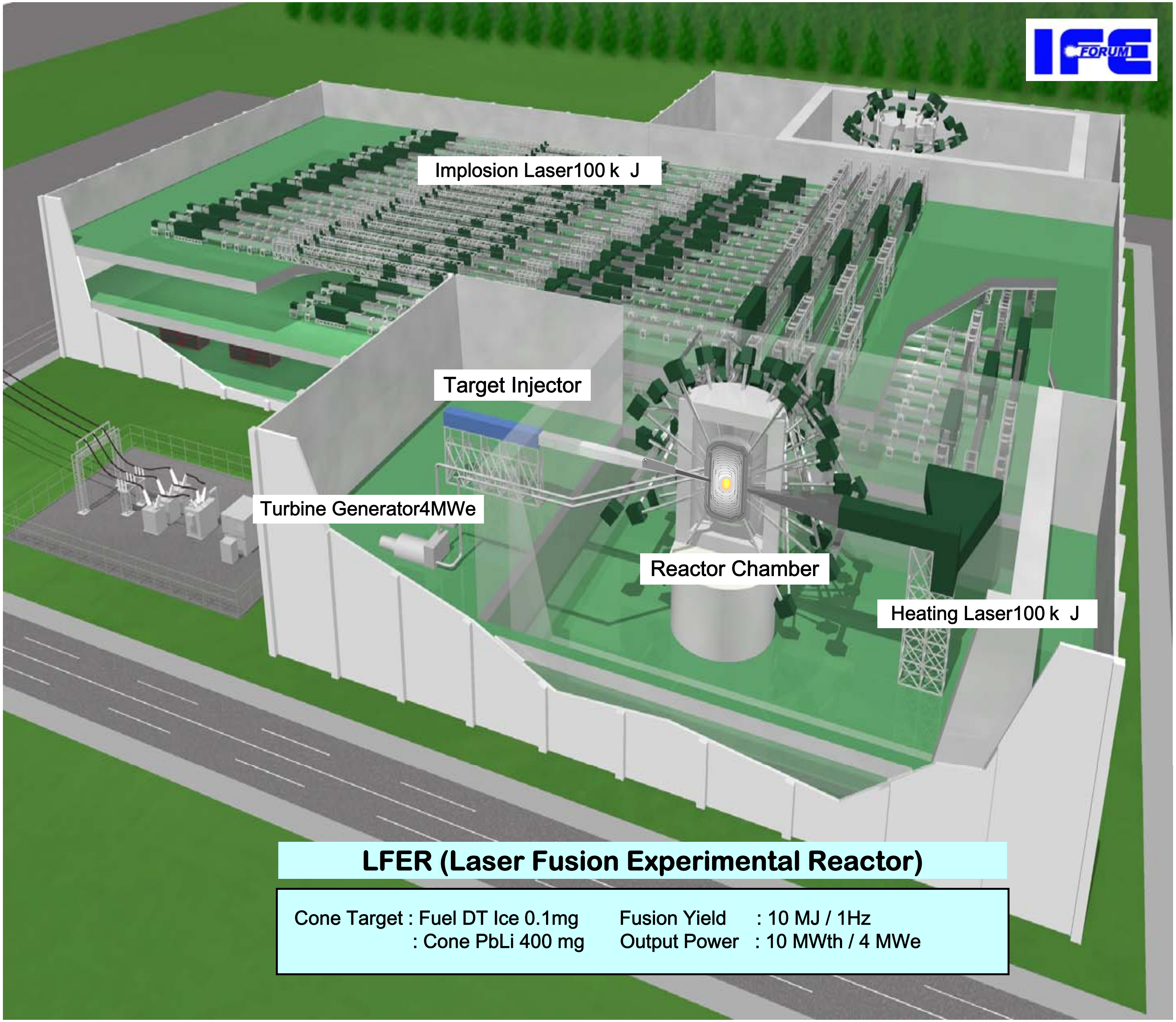
Milestones for Laser Fusion Power Plants

- **Fast Ignition Research Experiment (FIREX)**
  - **Purpose: Establishing physics of fast ignition, and demonstration of ignion**
  - **Starting Conditions: high denisity compression(already achieved),**
    heating by PW laser (1keV already achieved)
- **Laser Fusion Experimental Reactor (LFER)**
  - **Purpose:Intergration of technologies necessary for laser fusion power plants, and demonstration of net electric power generation**
  - **Starting Conditions for engineering design**
    - **: Clarify physics by FIREX-I (Heating to ignition temperature)**
    - **: prospecting of key technologies (1kJ high rep-rate laser, target injection and tracking, chamber, blanket, tritium technologies, etc.)**
  - **Starting Conditions for construction**
    - **: Ignition and burning by FIREX-II**
    - **: Establishment of above technologies in elemental level**
- **Demonstration Reactor (DEMO)**
  - **Purpose: Demonstration of practical power generation including of economical, environmental, and safty prospection**
  - **Starting Conditions : Demonstration of net electric power and establishing technologies for practical power plants**


A Road Map for Laser Fusion Energy
2005
2010
2015
2020
2025
2030
2035
Ignition
FIREX-I
FIREX-II
10 kJ Heating laser
Total 100 kJ Laser
Power Generation Test
Design
Engineering Design
LFER
Repetition Test
Construction
200 kJ Laser
Test I,II
10 MWth
Test III
4 MWe
Practical Power
Demonstration
Design
DEMO
DPSSL Development
Advanced Laser
Laser
Module
100J
1kJ
10kJ
500 kJ ~1MJ Laser
~ 240 MWe
Target Fabrication & Injection Technology
Reactor Chamber & Liquid Wall Technology
Reactor Technology Development (Blanket, Liquid Metal,
Final Optics, Tritium, Reactor Material, safety) , ITER R&D

Major facilities and milestones for fusion power plants

Facility	FIREX	LFER	DEMO	Commercial plants
Milestones	Fast ignition physics establishment and ignition demonstration	Demonstration of integrated reactor technologies and net electric power	Demonstration of practical power generation	-
Objectives	Phase I (FIREX-I) : Heating to ignition temperature (~10 keV) Phase II (FIREX-II) : Ignition and burning	Phase I : high rep-rate burning Phase II : Solid wall with test blanket, and liquid wall chamber Phase III : Net power generation , long time operation	- Demonstration of a reactor module for practical power plants -Credibility and economics demonstr-ation	- Economically, environmentally attractive plants (Competitive COE) - Modular plants for scale up, flexible construction
Laser	~100 kJ implosion 50 + heating 50	200 kJ (~ 1 Hz)	0.5~1 MJ (~ 3 Hz)	0.5~1 MJ (10~ 30 Hz)
Fusion pulse energy/power output	~1 MJ (1 shot / hour)	10 MJ 10 MWth/ 4 MWe Net output 2MWe	100 ~200 MJ 330 ~ 660 MWth 100 ~ 240 MWe	100 ~200 MJ 3 Hz× (5~10) reactors 600 ~ 1200 MWe
Construction cost	300 ~ 400 M$	~ 1600 M$	~ 2300 M$	~ 2700 M$ / 1GWe


IFE FORUM
Implosion Laser100 k J
Target Injector
Turbine Generator4MWe
Reactor Chamber
Heating Laser100 k J
LFER (Laser Fusion Experimental Reactor)
Cone Target : Fuel DT Ice 0.1mg
: Cone PbLi 400 mg
Fusion Yield : 10 MJ / 1Hz
Output Power : 10 MWth / 4 MWe

Basic Concept of LFER

1) A small fusion experimental reactor using fast ignition cone targets and DPSSL laser systems. Reactor chamber sizes are determined primarily by pulse heat load on the first wall. We consider LFER chambers, having a radius and pulse thermal load of 2.5 m and 2.5 J/cm2 for solid wall (phse-I, -II), and 1 m and 16 J/cm2 for liquid wall (phase-III).

2) Two 100 kJ DPSSL (Diode Pumped Solid-State Laser) systems, for implosion and heating. For a heating laser, large final optics (10 m^2) and a long beam line (30~50 m) are placed oppositely to a target injector.

3) Two chambers, a solid wall chamber used in Phase-I and II, and a liquid wall chamber used in Phase-III for net electric power demonstration. Around the chambers, there are about 60 final optics and beam lines of implosion lasers in spherically symmetric layouts.

   In regard to the final optics of the heating laser and the shielding of laser beam-lines, there are still many remaining problems to be examined in detail.

4) Although in a small scale, we could foresee the basic configurations, layouts, and sizes of the fast ignition laser fusion plants.

Size comparison of major fusion facility

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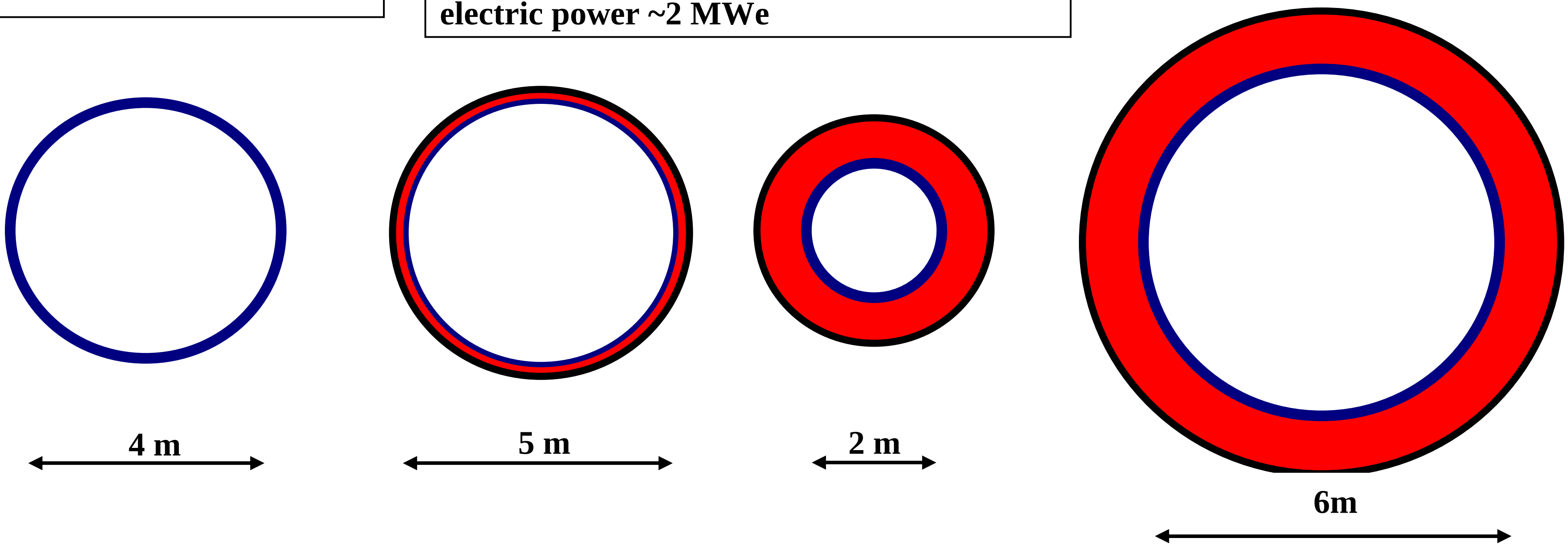
FIREX
Gain~10
Laser100 kJ

LFER 10 MWth
Phase I : High rep pulse Test 10 MJ ,1 Hz
Phase II :10 MWth steady operation, net electric power ~2 MWe

DEMO 200 MWe
laser 3Hz



Fusion pulse 1 MJ

single shot

Fusion pulse 10 MJ,1 Hz

Solid wall radius 2.5 m liquid wall radius 1 m
Pulse heat load 2.5 J / cm^2 16 J / cm^2
Average heat load 2.5 W / cm^2 16 W / cm^2

Fusion pulse 200 MJ, 3 Hz

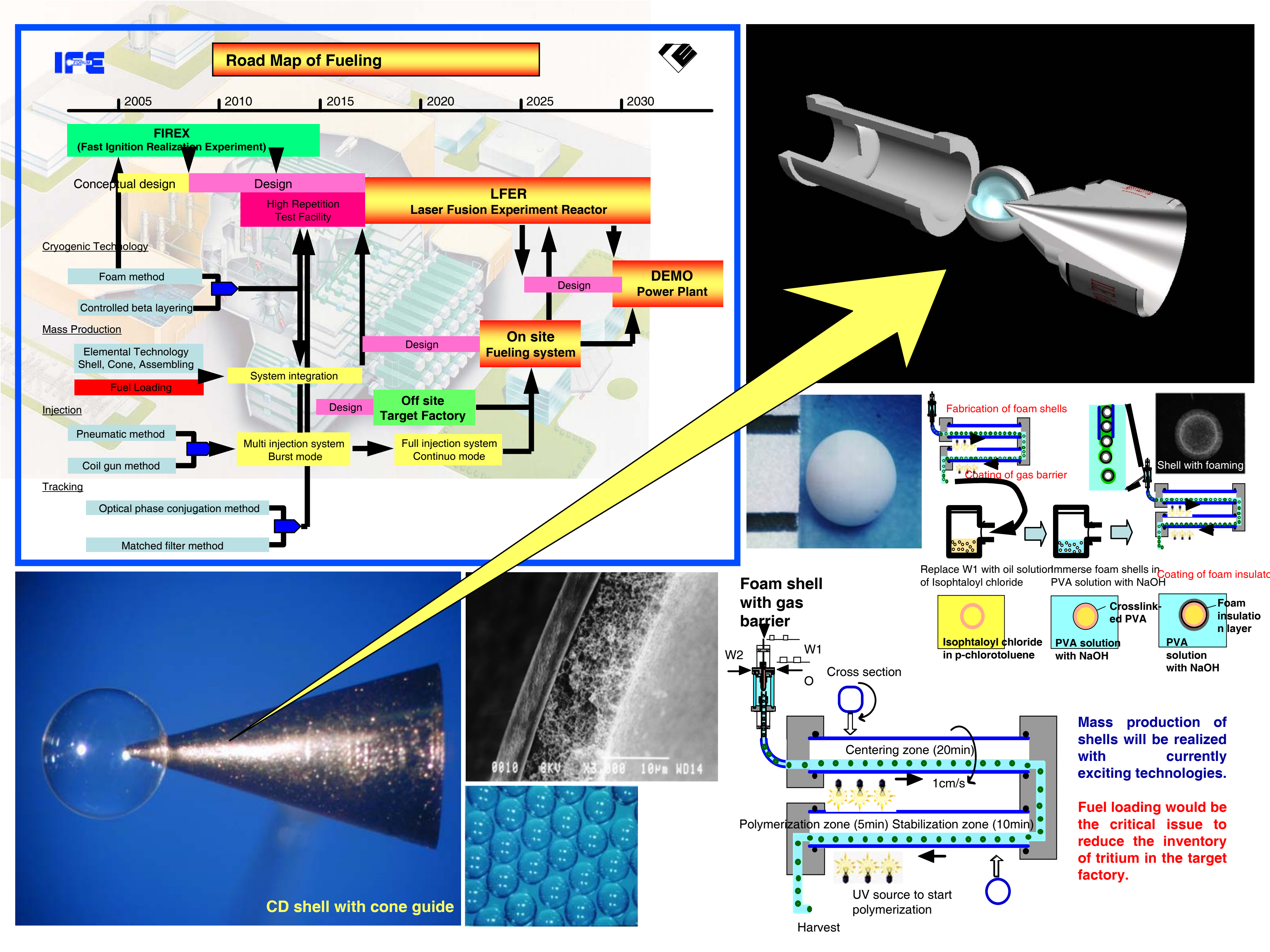
Chamber inner radius 3 m
Pulse heat load 35 J / cm^2
Average heat load 106 W / cm^2
Neutron wall load 4.2 MW / m^2

Missions and Phase Operation of LFER (Laser Fusion Experimental Reactor)

Pase- I : High gain targets and integrated high rep-rate technologies tested.

Phase-II : Reactor technologies tested comprehensively, such as testing blanket modules for tritium breading and power generation, using solid wall chamber.

Phase-III : Using liquid chamber with full blanket, tested for net power generation. After achieving these missions, used as a material test reactor by long hour operation as a self-sustaining reactor.


Road Map of Fueling
2005
2010
2015
2020
2025
2030
FIREX
(Fast Ignition Realization Experiment)
Conceptual design
Design
High Repetition
Test Facility
LFER
Laser Fusion Experiment Reactor
Cryogenic Technology
Foam method
Controlled beta layering
Design
DEMO
Power Plant
Mass Production
Elemental Technology
Shell, Cone, Assembling
Fuel Loading
System integration
Design
On site
Fueling system
Injection
Design
Off site
Target Factory
Pneumatic method
Coil gun method
Multi injection system
Burst mode
Full injection system
Continuo mode
Tracking
Optical phase conjugation method
Matched filter method
CD shell with cone guide
Fabrication of foam shells
Coating of gas barrier
Shell with foaming
Replace W1 with oil solution
of Isophtaloyl chloride
Immerse foam shells in
PVA solution with NaOH
Coating of foam insulato
Foam shell
with gas
barrier
W2
W1
O
Isophtaloyl chloride
in p-chlorotoluene
Crosslinked PVA
PVA solution
with NaOH
Foam
insulation layer
PVA
solution
with NaOH
Cross section
Centering zone (20min)
1cm/s
Polymerization zone (5min) Stabilization zone (10min)
UV source to start
polymerization
Harvest
Mass production of shells will be realized with currently exciting technologies.
Fuel loading would be the critical issue to reduce the inventory of tritium in the target factory.

Characteristics and issues of cone target

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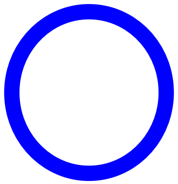
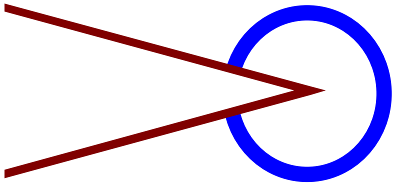
- size and mass

r = 2 mm
M(fuel) = 2 mg

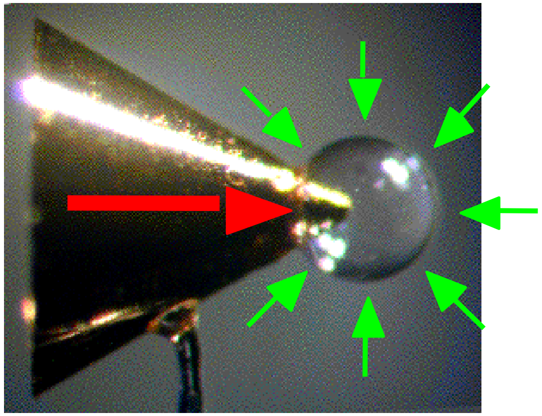


240 MJ DT target
without cone

r (cone) = 3 mm, 8 mm h
M(cone) = 40 mg Pb



240 MJ cone target

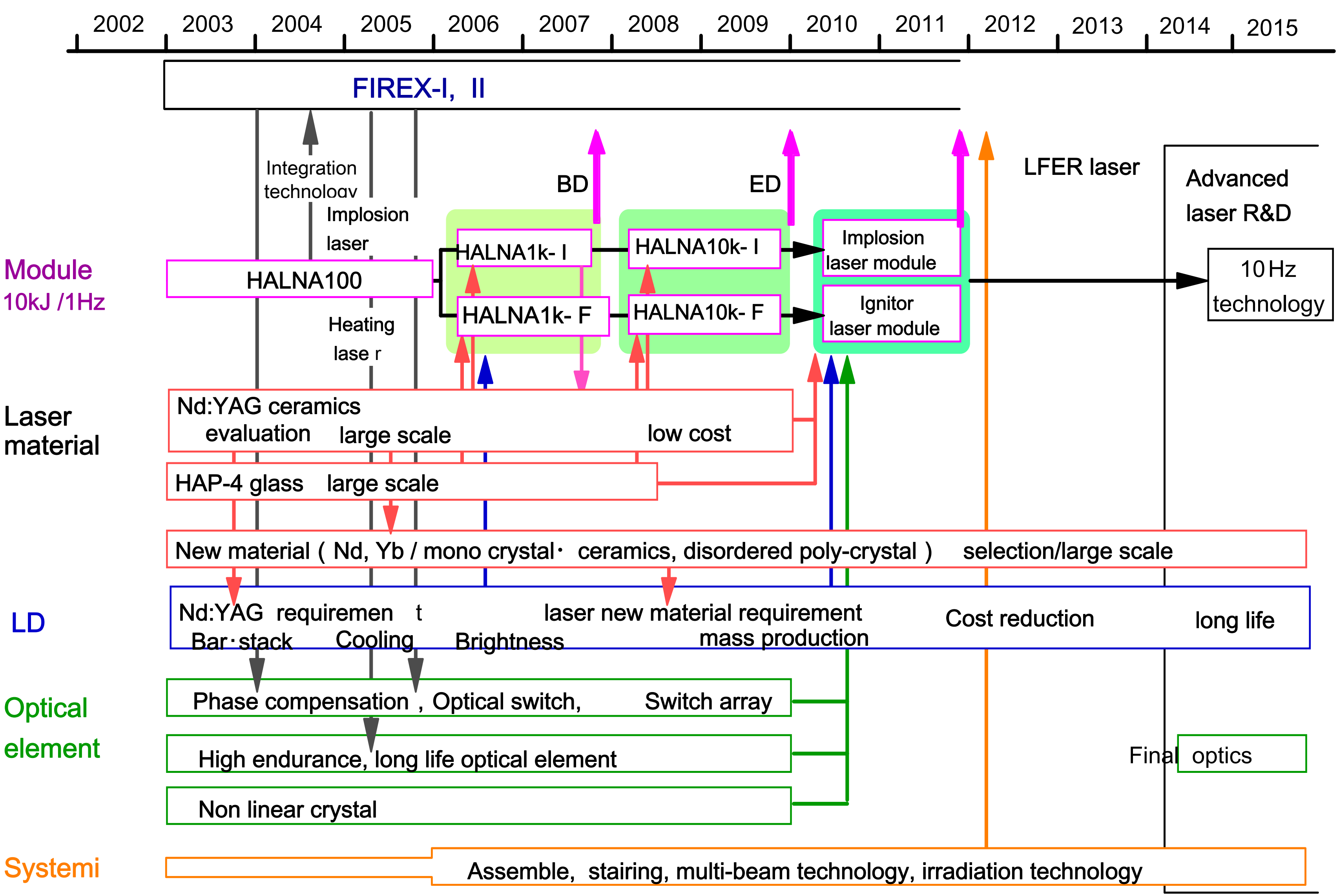


Cone Target
Experiment

Issues : Estimation of energies and spectra of ions from cone targets, and consideration of optics protection from cone debris

Merit :
- Laser beam focusing by cone without interfering corona plasma
- Cone make guard for cryo targets from vapor and aerosol
- Cone mass give high injection accuracy
- To mitigate requirements for chamber conditions make high rep-rates possible.

Road map of laser driver R&D



New laser material for broadband

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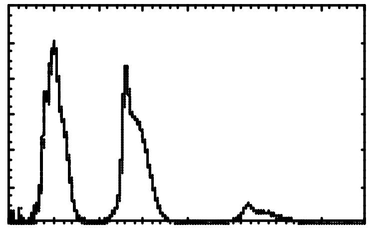
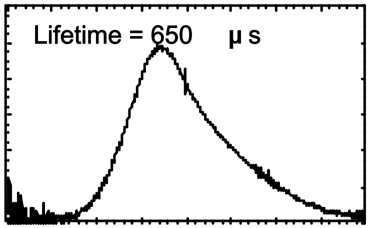
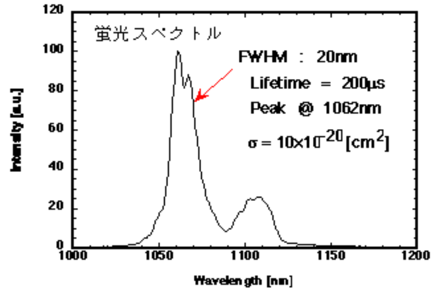
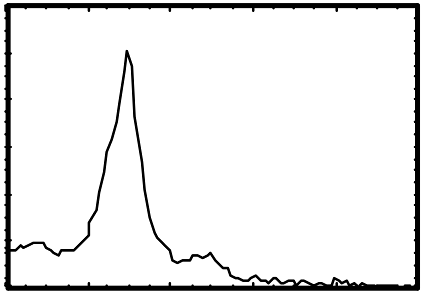


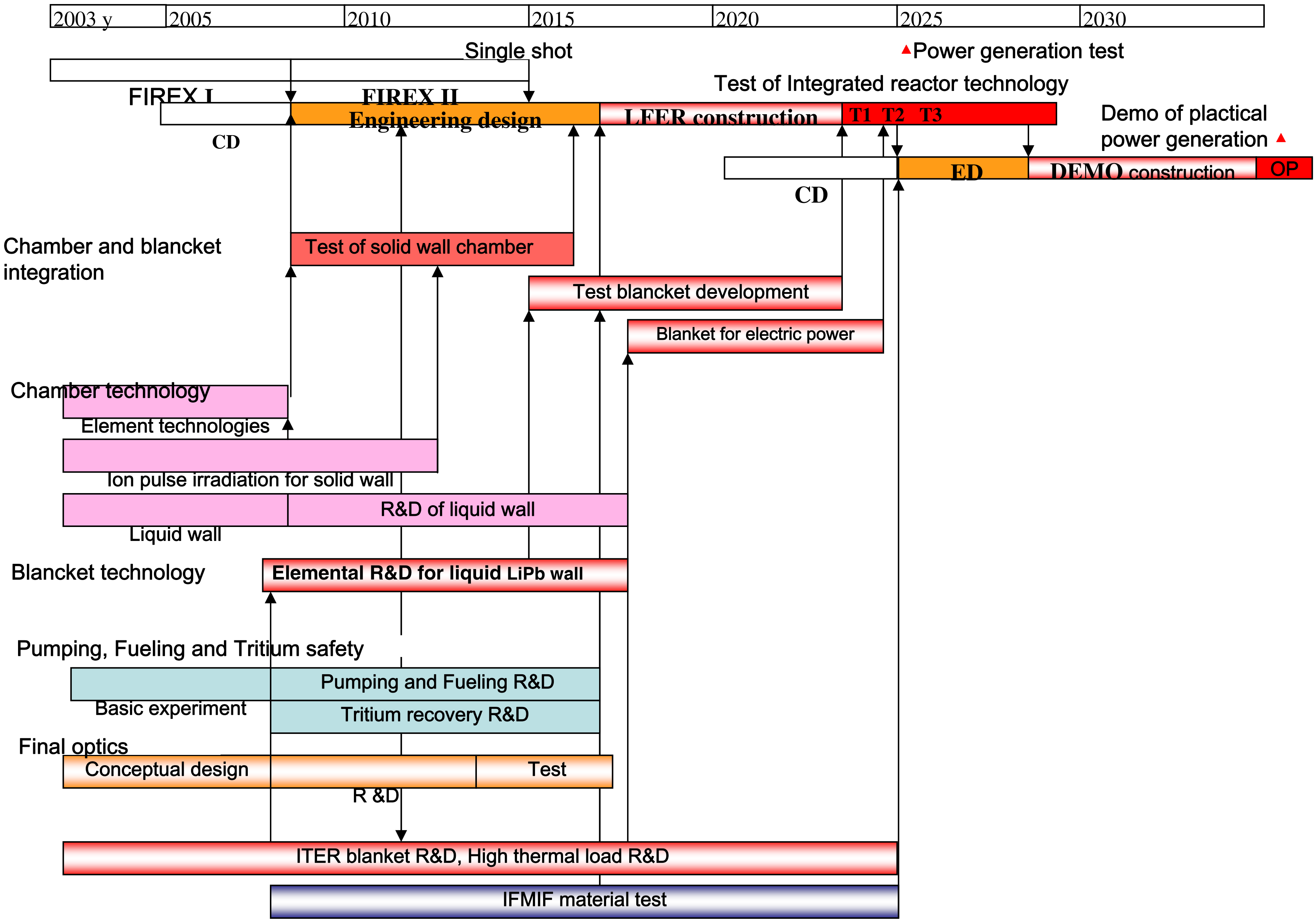


Nd:CNGG disordered poly-crystal





Roadmap of Reactor System Development



Analysis of program schedule

- Establishing physics of fast igniton （Ignition and burn by FIREX）

  < FY2013

- 10kJ laser driver and integration test on high repetition technologies:

  < FY2015

- Demonstration of integrated fusion technologies and power generation

  （LFER）

  < FY2026

- Demonstration of practical power generation （DEMO plant）

  < FY2036

Estimation of program cost

- **FIREX** (100kJ single shot glass laser) 300~400M$

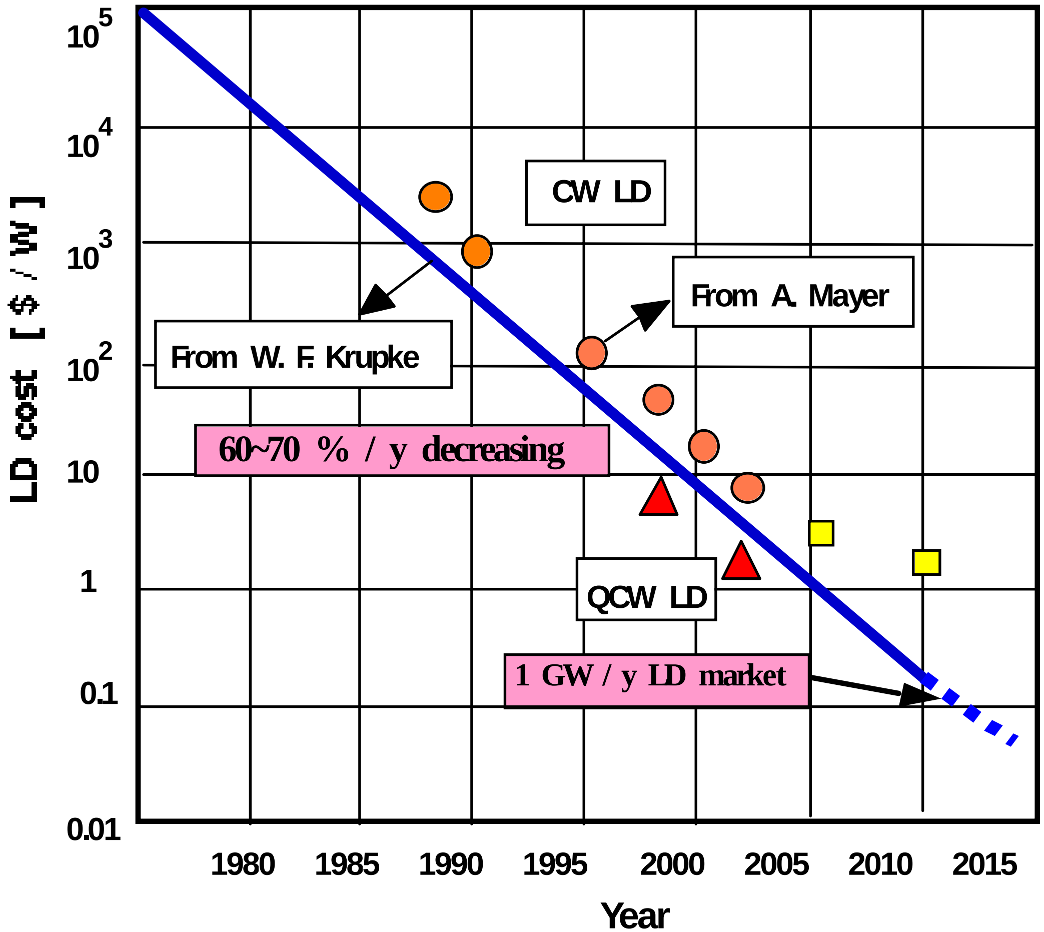
- **Development of laser module for reactor, repetitive target irradiation technology**
  (DPSSL 10 kJ for compression, 10 kJ for ignition)
  ~360 M$ (Cost of LD is 180 M$ estimated from LD 600 MW, LD unit cost 30 cent/W assumption)

- **LFER** (200 kJ laser、Themal~10 MW、Electricity~4 MW)
  ~1600 M$ (Cost of LD is 600 M$ estimated from LD 6 GW, LD 10 cent/W)

- **DEMO** (1MJ laser、Thermal 200 MJ、3 Hz、Net electric power 200 MW)
  ~2300 M$ (Total laser driver cost is 1350M$ estimated from LD 6 cent/W)

- **Commercial plant** (600~1200 MWe with multi reactor modules)
  2700 M$/GWe (Total laser driver cost is 1000~1500M$)

Prospection of Laser Diode cost reduction



· 100 J module, 2005y
: LD 3 MW, 3 M$ (1 $ / W)

· 1 kJ module, 2005~2008 y
: LD 20 MW, 10 M$ (0.5 $ / W)

· HRX(high rep), 20 kJ, 2008~2011y
: LD 600 MW, 180 M$ (0.3 $ / W)

· LFER 200 kJ, 2015~2020
: LD 6 GW, ~600 M$ (0.1 $ / W)

· DEMO(200MWe) ~1 MJ, 2027~2030
: LD ~20 GW, 1200 M$ (0.06 $ / W)

· Comercial plants (1 GWe) ~1 MJ,
: LD ~20 GW, 1000 M$ (0.05 $ / W)
→ 10 GWe / year plants construction
→ LD 200 GW / year
→ 10 B$ / y LD market in the world

Prospection of LD cost reduction (Kozaki, data by W. F. Krupke, Izawa, 2002.11)

From KOYO to KOYO-Fast

- **KOYO design (Central hot spark ignition)**
  - laser energy 4 MJ
  - Fusion yield 400~600 MJ
  - Reactor module ~ 600 MWe
  - Laser cost ~4000 M$ (assumption of LD unit cost 5cent/W)
  - Large output modular plant ~2400MWe (for competitive COE)

- **KOYO -Fast design (Fast ignition)**
  - laser energy 500kJ~1 MJ
  - Fusion yield 100~200 MJ
  - Reactor module 100~300 MWe
  - Laser cost 500~1000 M$ (LD unit cost 5 cent/W)
  - Small output modular plants 600~1200MWe
    (for a variety of future energy needs)

Summary

1. The inertial fusion energy development based on the fast ignition concept may offer a possibility to develop a practical small fusion power plant that may greatly enhance usefulness of fusion power to meet flexibly a variety of future energy needs.

2. The present assessment delineated a possibility to demonstrate electricity generation with a small power plant in a reasonably short time. It may be achieved by coordinated development efforts on relevant individual fusion technologies such as those of laser, reactor chamber, and fuel target, taking into account the characteristic advantages of the fast ignition concept.

3. It is important to advance both fast ignition physics research and reactor technology development in a coordinated manner, through the FIREX program and the reactor technology development program. Thus, it may become possible to move smoothly into the program to construct a laser fusion experimental reactor.

Design windows of power plants and an experimental reactor (summary 2)

1. We have examined the design windows and the issues of the fast ignition laser fusion power plants, and shown the possibility of small size, ~300 MWe fusion reactors, with ~200 MJ fusion pulse energy, ~4Hz rep-rates, by ~1 MJ laser. Using these reactor modules we can flexibly design large scale, ~1200 MWe modular plants driven by a ~16 Hz high rep-rate laser system. The small pulse energies mitigate technical constraints of the chamber as well as the final optics issues.

2. We have also shown the possibility of a very small fusion experimental reactor with fast ignition concept. We propose a small laser fusion experimental reactor (LFER), having fusion pulse energies of 10 MJ with 200 kJ laser, i.e., 100 kJ for implosion and 100 kJ for heating. LFER is aimed at integrating the technologies necessary to power plants and demonstrating net electric power generation in a small scale and short operation time, but scalable to a DEMO plant.

3. With LFER, we could consider a possibility to demonstrate electricity generation in a reasonably short time. It may be achieved by coordinated development efforts on relevant individual fusion technologies. It is important to advance both fast ignition physics research and reactor technology development in a coordinated manner.

From KOYO to KOYO-Fast

- KOYO design
  - 4 MJ laser →600 MJ → 2400 MWe plant
    - →laser cost→ 400 Byen / 800 Byen(plant total)
    -
- KOYO -Fast design
  - 1 MJ laser →200 MJ → 1200 MWe plant
    - →laser cost→ 100 Byen /300 Byen(plant total)

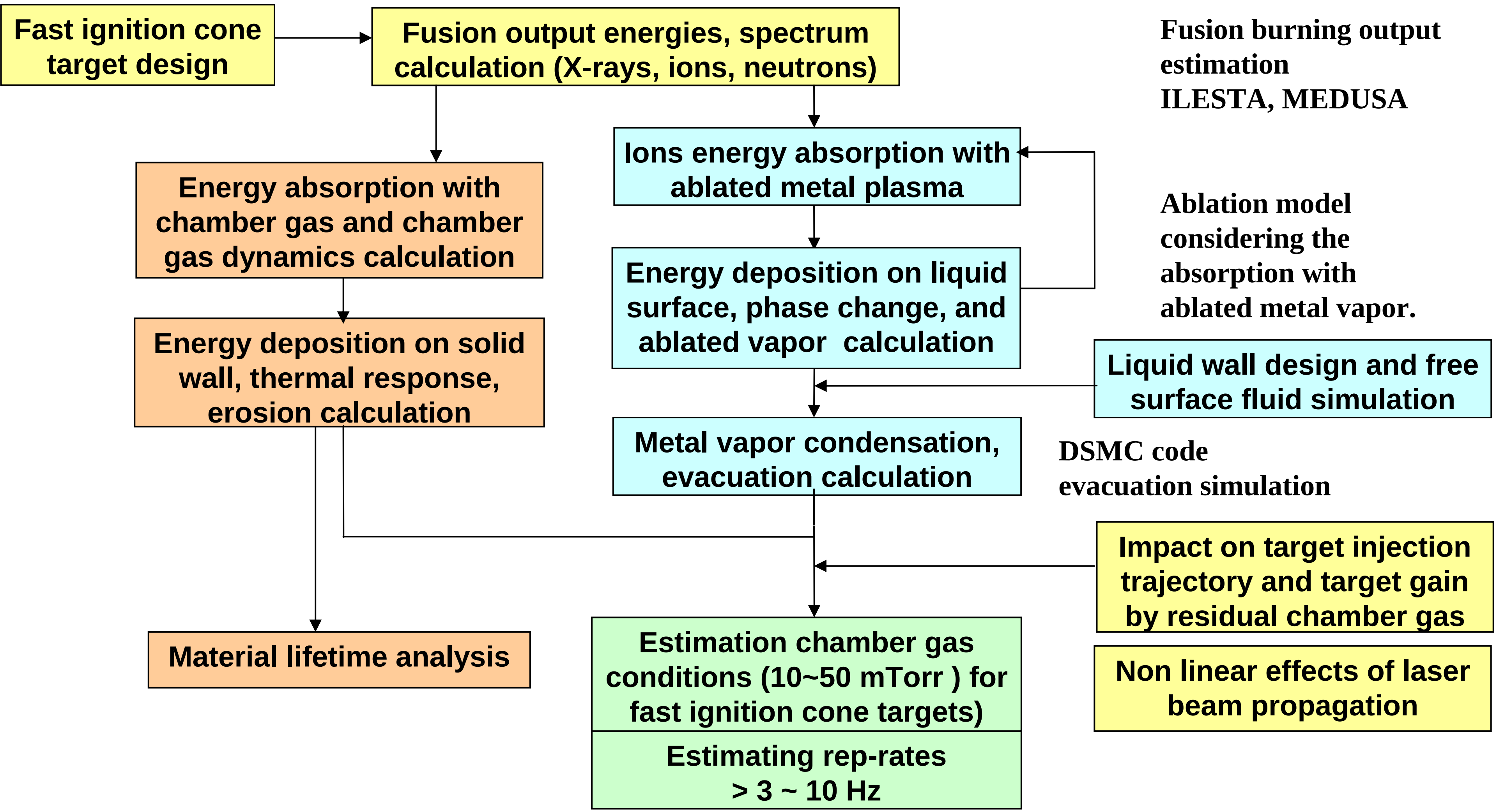
Design specification for KOYO-Fast (2004-2005)

– Net output	1200 MWe (300 MWe x 4)
– Reactor module net output	300 MWe
– Laser energy	1.2MJ
– Target gain	167
– Fusion pulse out put	200 MJ
– Reactor pulse rep-rate	4 Hz
– Reactor module fusion outputr	800 MWth
– Blanket energy multiplication	1.13
– Reactor thermal outpu	904 MWth
– Total plant thermal output	3616 MWth (904 MWth x 4)
– Thermal electric efficiency	42 %（LiPb Temperature ~500 C)
– Total electric output	1519 MWe
– laser efficiency	8.5% (implosion) , 5% (heating)
– Laser pulse rep-rate	16 Hz
– Laser recirculating power	240 MWe（1.2 MJ x 16 Hz / 0.08)

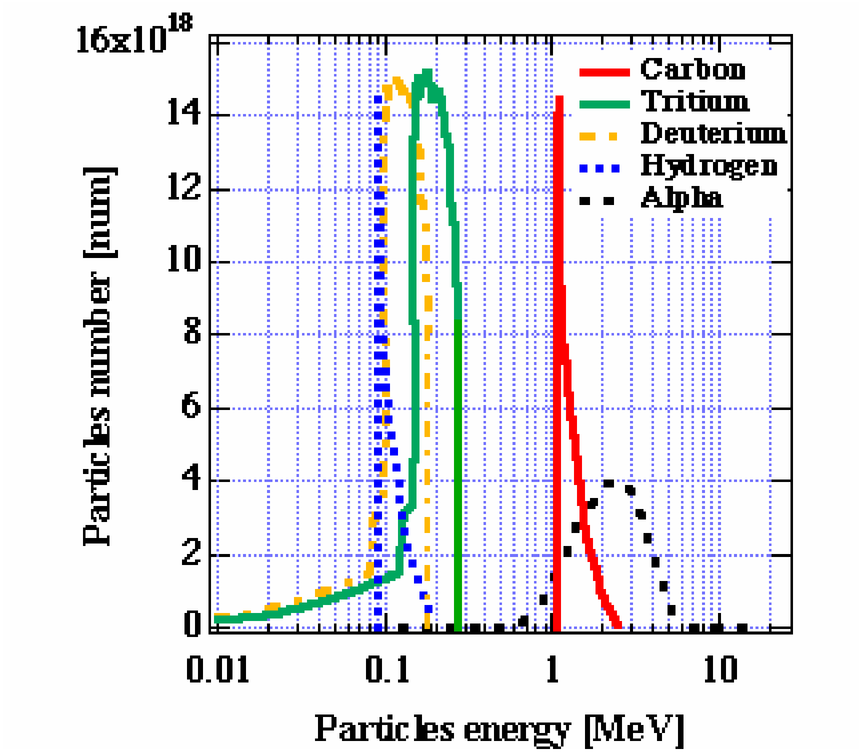
(Comparative study on cooling power and laser performance; Yb-YAG laser operating 150K or 220K)

– Net plant out put power	1200 MWe(1519MWe - 240MWe - 79MWe Aux.)
– Total plant efficiency	33.2 %(1200 MWe/ 3616 MWth)

Tasks of analysis for liquid wall chambers and solid wall chamber



Energies and spectra of ions from 400MJ target



Energies and spectra of ions
(KOYO 400 MJ target)

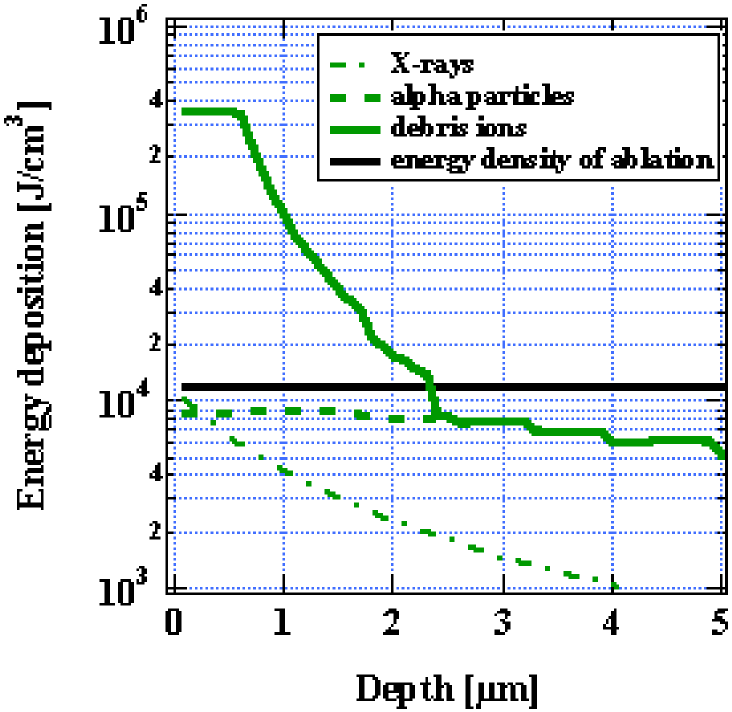
TABLE ENERGIES AND SPECTRA

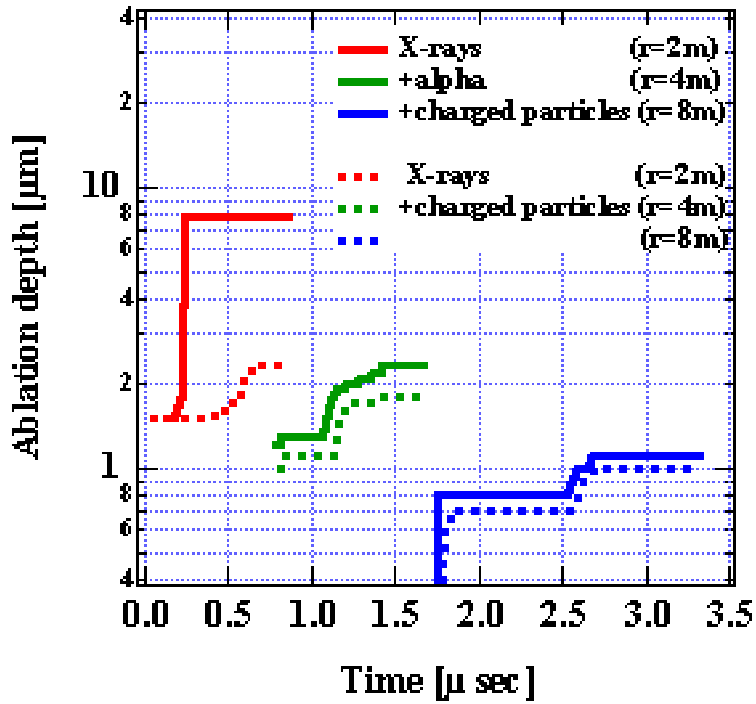
	Average Energy	Range* μm	Energy MJ (%)
X-rays	35 keV		4 (1.0%)
α particles	3.5MeV	14	
		0.5	58 (14.5)
		20	

X-rays, alpha particles, debris ions and neutrons from a typical central spark target (KOYO 400 MJ)

*** Ions range for Pb**

Energy deposition and ablation depth from 400MJ target





Energy deposition by X-rays, alpha and debris ions from 400MJ target (chamber radius 4m case)

Ablation depths of liquid surface with/ and without considering alpha particles

- **Alpha particles have long range, then deposit most their energies in ~10 µm layer.**
- **Debris ions (C and low energy H, D, T) deposit in short range, 0.5~2 µm layer.**
- **The ablation depths depend on the alpha particles beyond a certain intensity (2~4m chamber radius), but almost only depend on debris ions in the larger radius cases.**

Pulse heat loads on chamber walls (20,100MJ targetÅj

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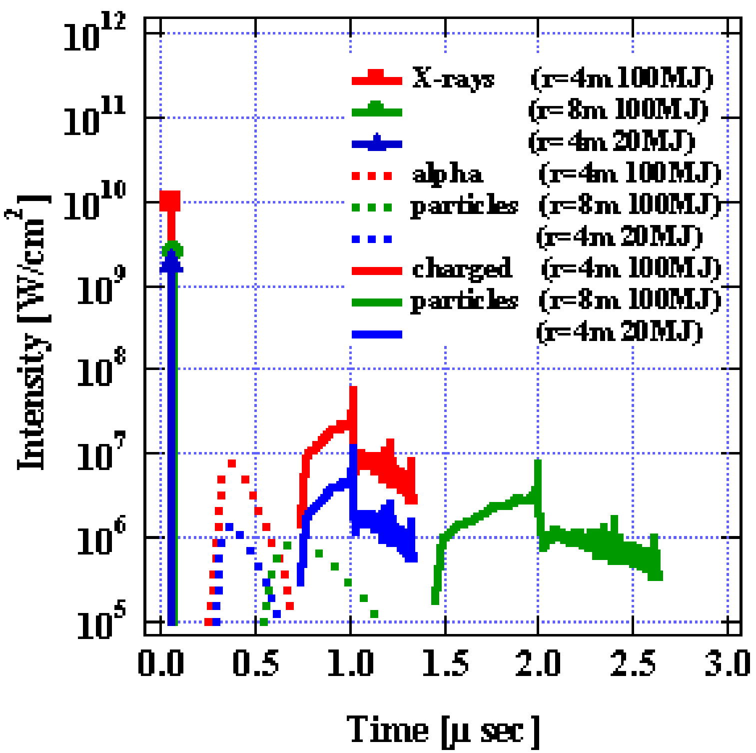

Pulse loads on the first wall from 20 MJ, and 100MJ targets, in radius 2m, 4m, and 8m cases.

	20MJ r=4m	100MJ r=4m	100MJ r=8m
Laser energy kJ	200	500	500
Gain	100	200	200
X-ray peak 10^{10} W/cm ^{2}	0.2	1.0	0.25
α peak 10^{8} W/cm ^{2}	0.015	0.075	0.009
Ions peak 10^{8} W/cm ^{2}	0.16	0.8	0.08
Total load J /cm ^{2}	1.6	9.0	2.25
Average power 10Hz,W /cm ^{2}	16	90	23
Neutron load 10Hz, MW /m ^{2}	0.7	4.1	1.0

Fast ignition solid chamber concepts (240 MWe)

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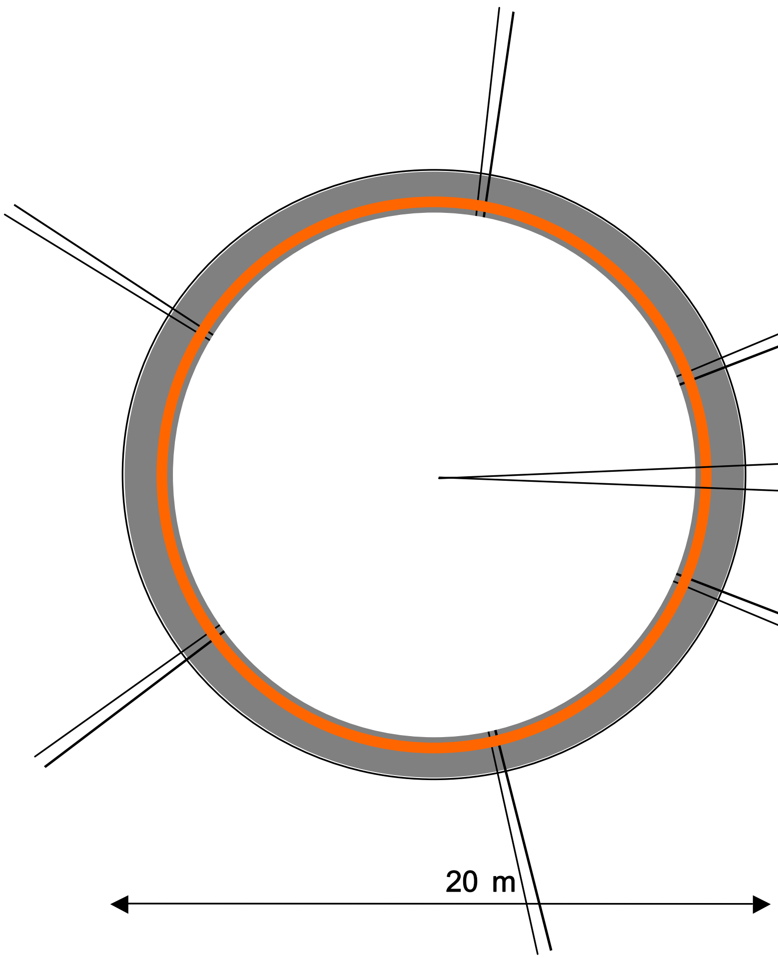
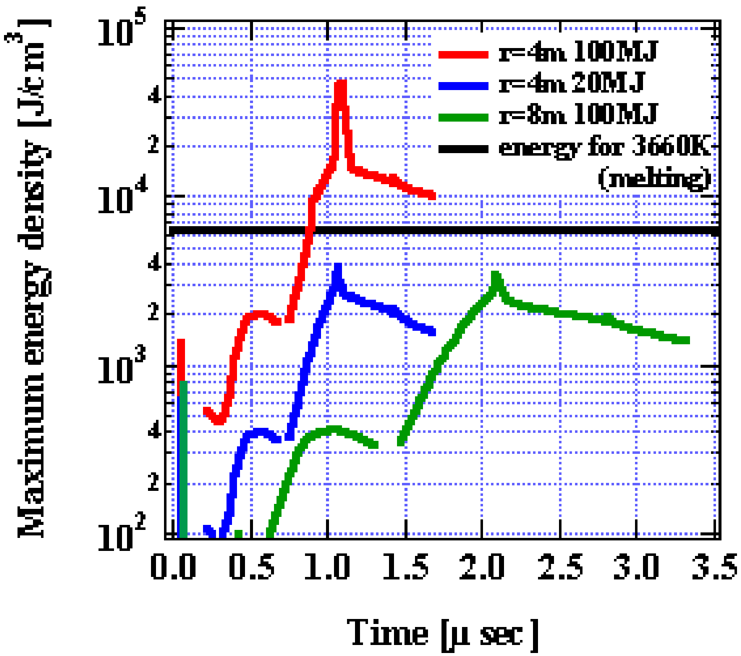


Fusion output	90 MJ /pulse, 600 MW
Chamber inner radius	8 m
Pulse heat load	2.2 J / cm^2
Pulse rep-rates	6.7 Hz
average heat load	15 W / cm^2
Neutron wall load	0.6 MW / m^2
Chamber outer radius	9.5 m
Tritium breading Li_20	
	Heating Laser 100 kJ
Armor/coolant	W coated SiC/ He
	in 700 °C
	out 900 °C

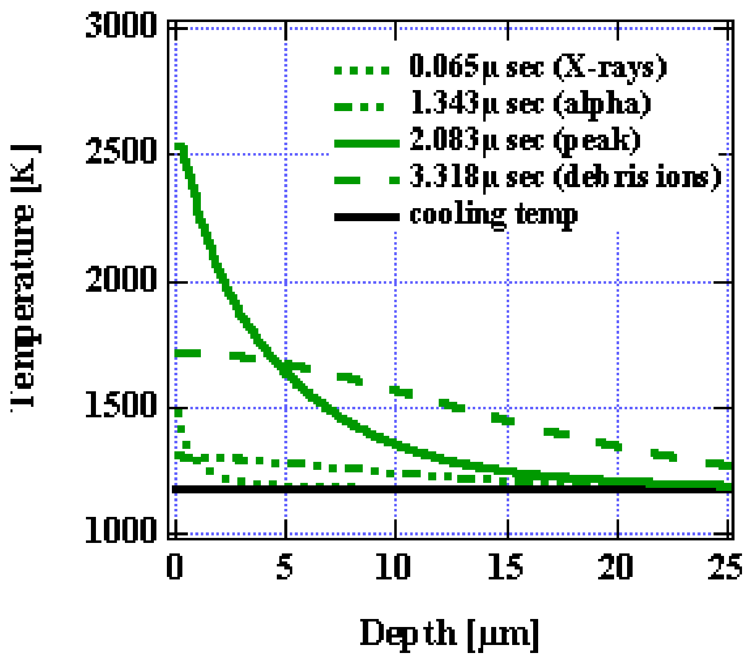
Blanket coolant He

Implosion laser beam number	32
Heating laser beam number	1
Heating laser final optics	30 m from center
	surface area 10 m^2

Peak energy densities and Temperature profiles of the dry wall surface (20 MJ, 100 MJ targets)



Energy deposition by X-rays and ions from 20 MJ, and 100MJ targets



Ablation depths of liquid surface (r=8m, 100MJ case)

- The energy deposition in a r=8m case by 100MJ targets are less than for melting, but in a r=4m case, the temperature of surface exceeds over melting temperature.

- The energy deposition in r=4m case by 20MJ targets are less than for melting
- The effect by instantaneous temperature rising should be considered.

Fast ignition liquid chamber concepts (240 MWe)

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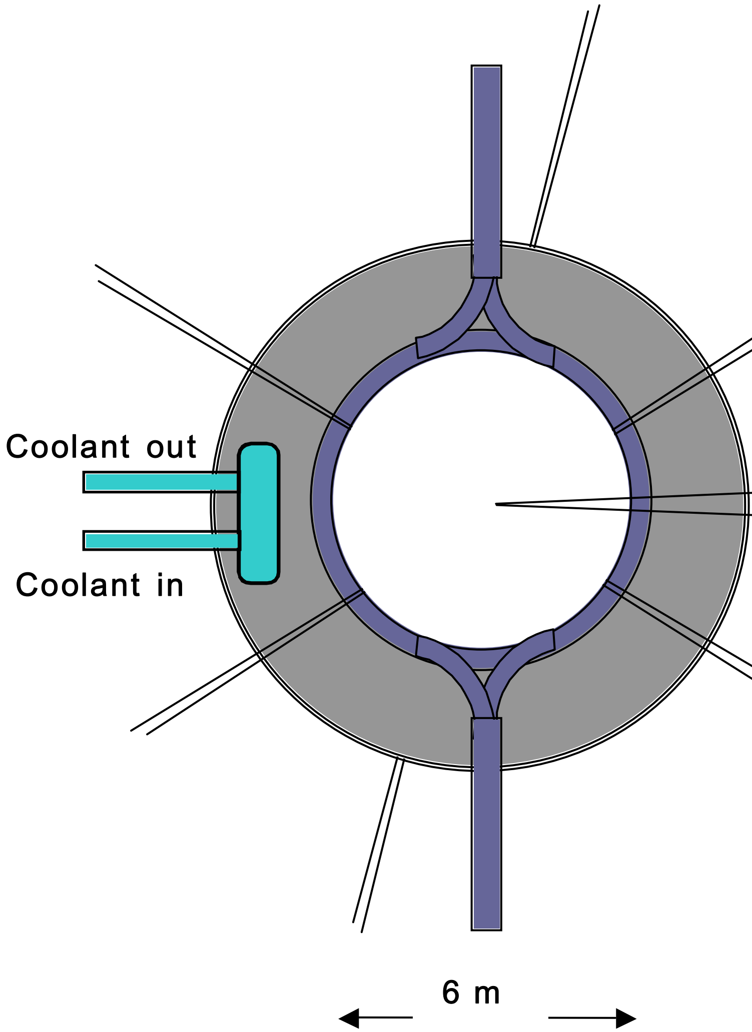
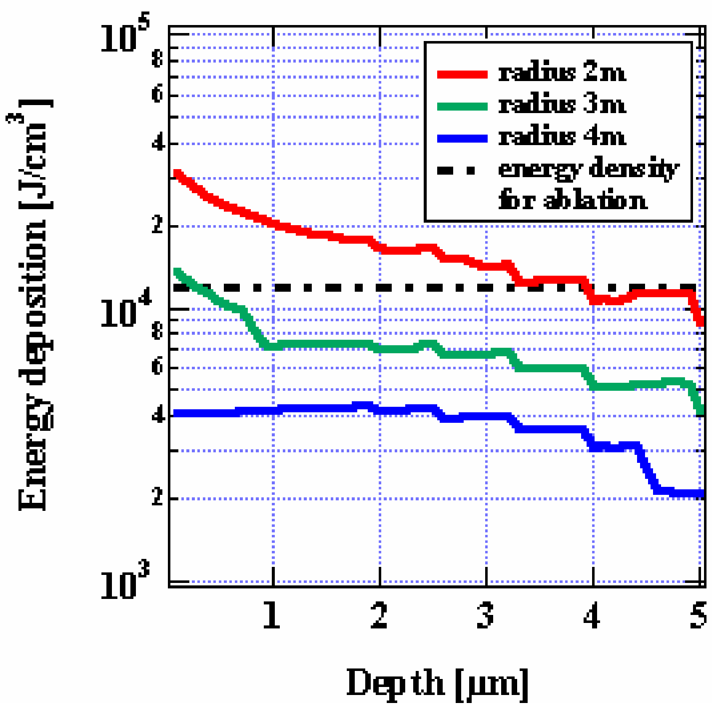


Fusion output 200 MJ /pulse, 600 MW
Chamber inner radius 3 m
Pulse heat load 35 J / cm^2
Pulse rep-rates 3 Hz
average heat load 106 W / cm^2
Neutron wall load 4.2 MW / m^2
Chamber outer radius 4.5 m
Tritium breading LiPb

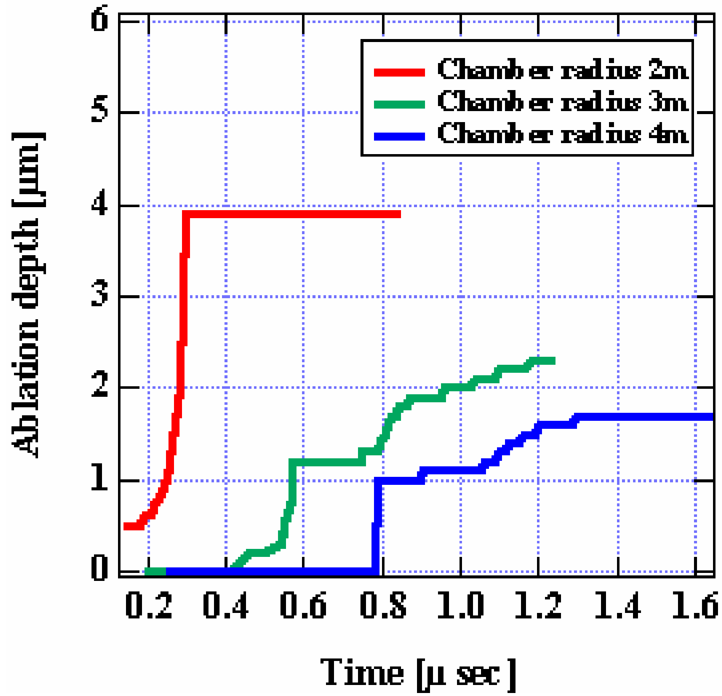
Heating Laser 100 kJ

Liquid wall LiPb in 350 °C
out 450 °C
Blanket coolant Water in 300°C
out 400 °C
Implosion laser beam number 32
Heating laser beam number 1
Heating laser final optics 30 m from center
surface area 10 m^2

Energy deposition and ablation depth by α particles



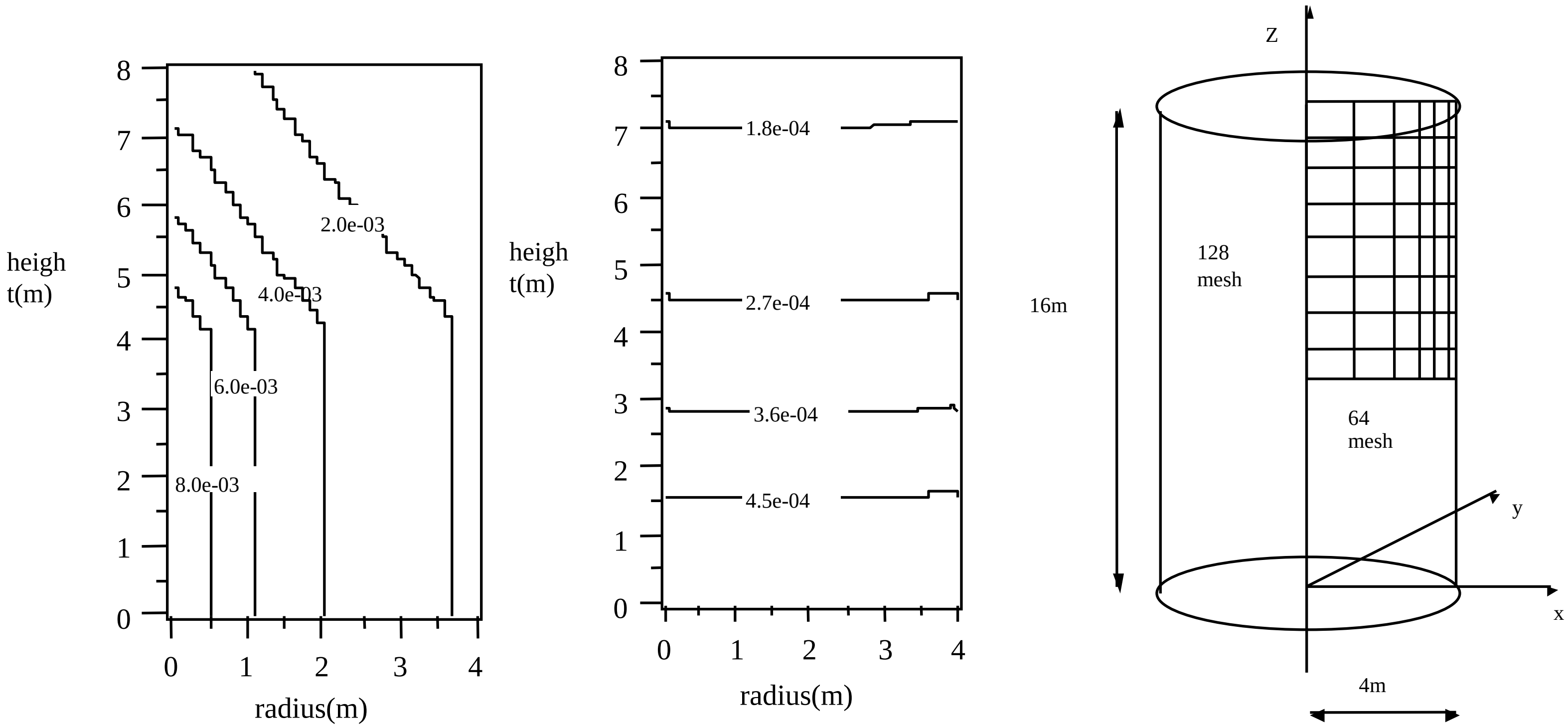
Energy deposition by X-rays and alpha particles from 200MJ target



Ablation depths of liquid surface (200MJ target)

As the energy deposition of alpha particles in 2m radius case gets above the ablation threshold, the ablation depth is much larger than in large radius cases(about 2μm in r=3m, 4m cases), caused by alpha particles long range.

The energy rates of direct loss alpha particles from the fast ignition targets increase over three times larger than central ignition cases, the estimation of ablation depth by alpha particles is much important for chamber design.



(a) after 20 msec **(b) after 40 msec** **(c) KOYO chamber geometry**

**Fig.2 The chamber gas pressure distributions simulated by TSUNAMI code,
(a) after 20 msec, (b) after 40 msec, and (c) KOYO reaction chamber geometry.**

The pressure distributions simulated by DSMC code

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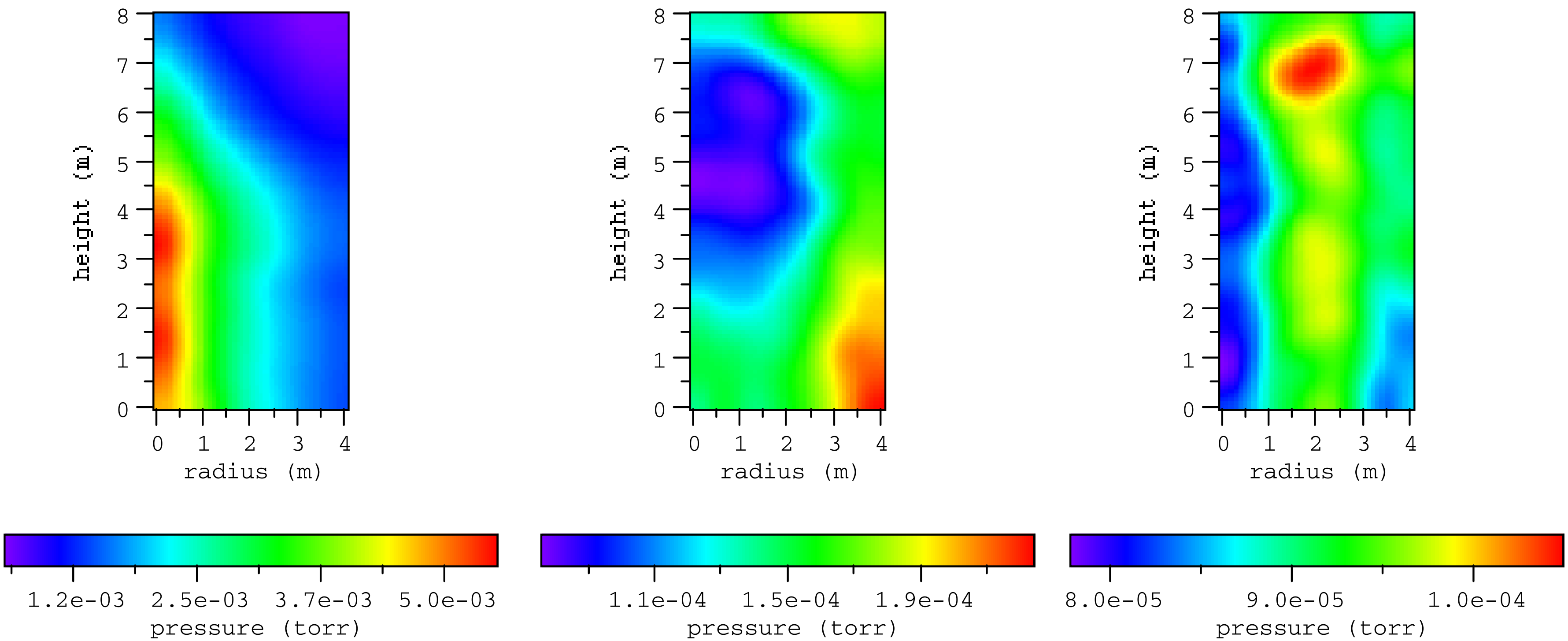
The chamber gas pressure goes down fast to the saturated vapor pressure with radial flow and axial flow.



0.02sec

0.05sec

0.1sec

The velocity distributions simulated by DSMC code

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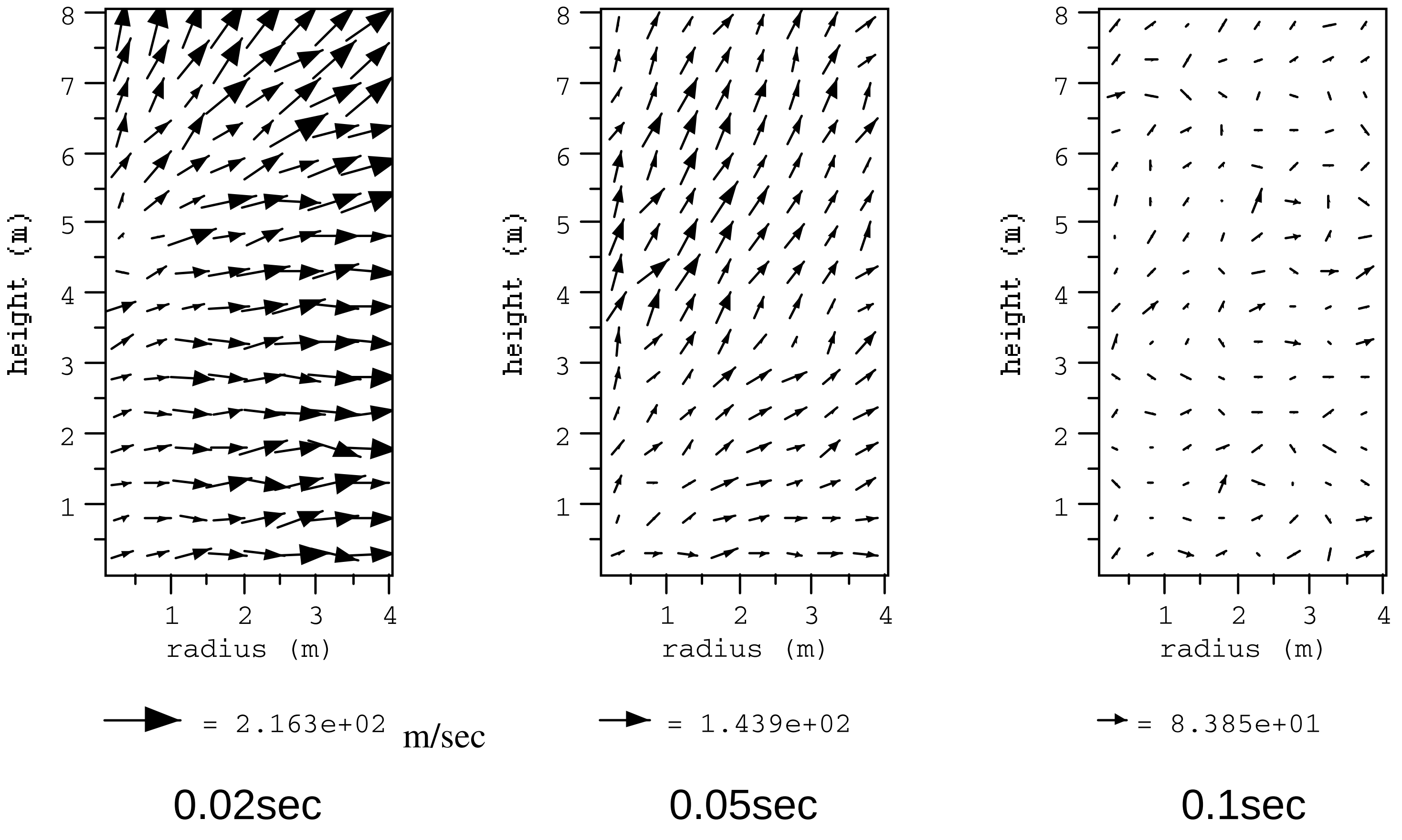
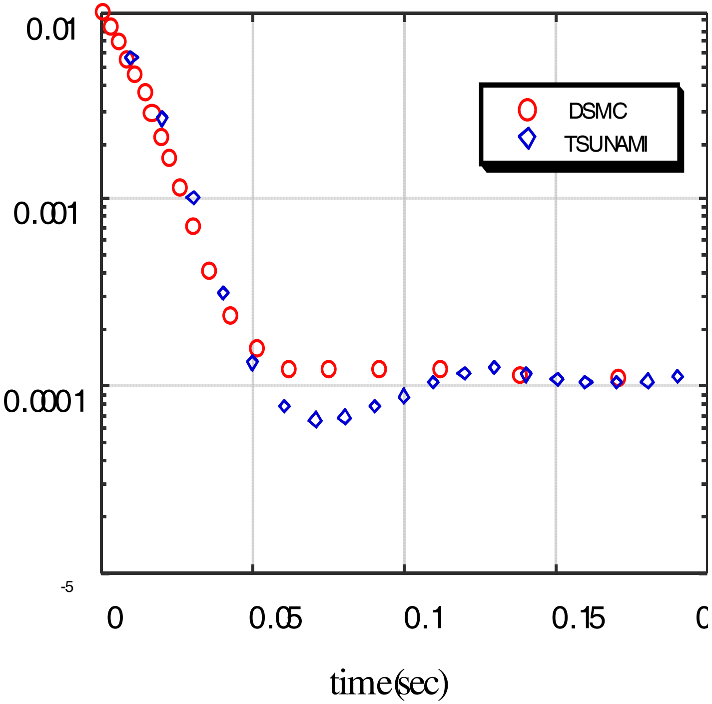




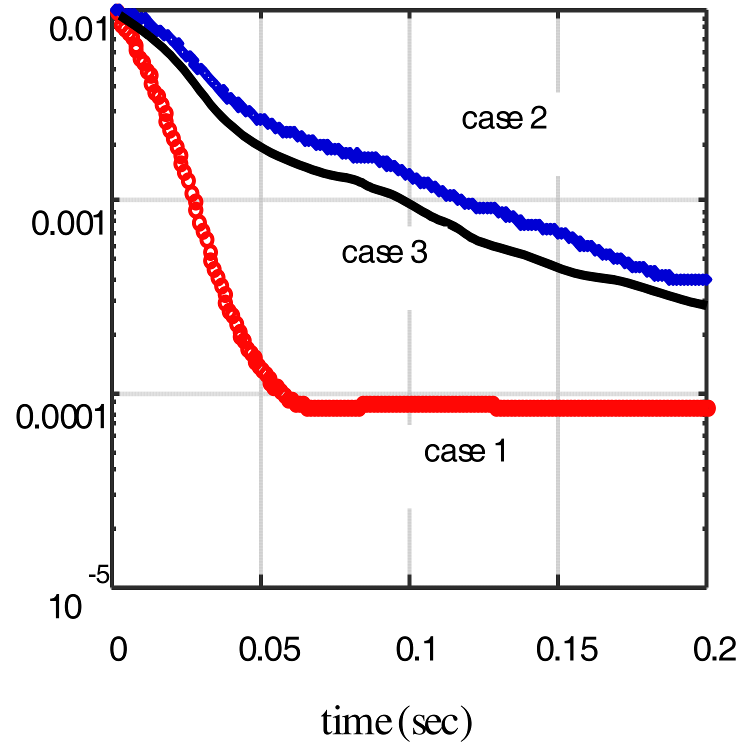


Fig.3 The average gas pressure by DSMC code and TSUNAMI (case1: surface temperature 550 °C)

Fig.4 The average gas pressure by DSMC code (case1 and case2)

Case1: The temperature of liquid surface is same as coolant temperature 550 °C
Case2: Cooling only by thermal conduction (2mm thick liquid film cooled by coolant)
Case3: The surface temperature of side walls are same as case2, while those of the upper and bottom walls are cooled to coolant temperature 550 °C.
(Simulation initial conditions: 0.01 Torr Pb gas pressure uniformly in chamber)

The gas flow around the pressure 10^{-3}~10^{-4} Torr is very sensitive to the liquid surface temperature. The average chamber pressures of case 2, and case 3 go down slowly, as the surface temperature of liquid film goes down very slowly only by thermal conduction.

- As the gas exhausting speed depends on the liquid surface temperature, it is necessary to cool liquid surface not only by thermal conduction but also by surface flow.

- Liquid wall design guideline:

- **Designing the free surface wall which can be cooled fast.**

- **Designing the surface flow for making renewal surface (Estimating the possibility to get ~4 Hz repetition) .**

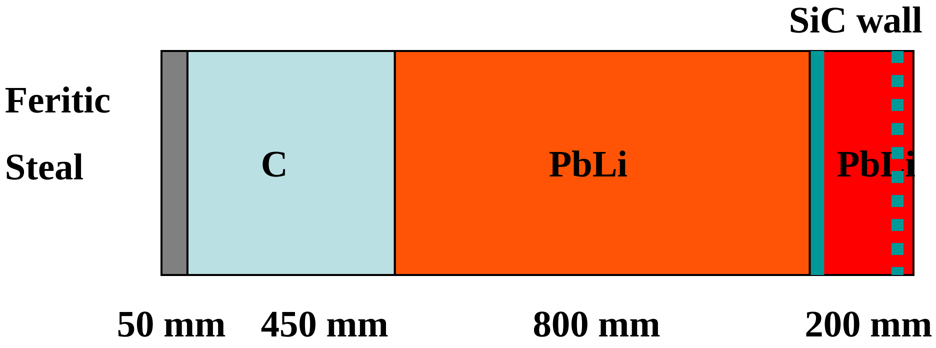
- **Considering free surface such as,**

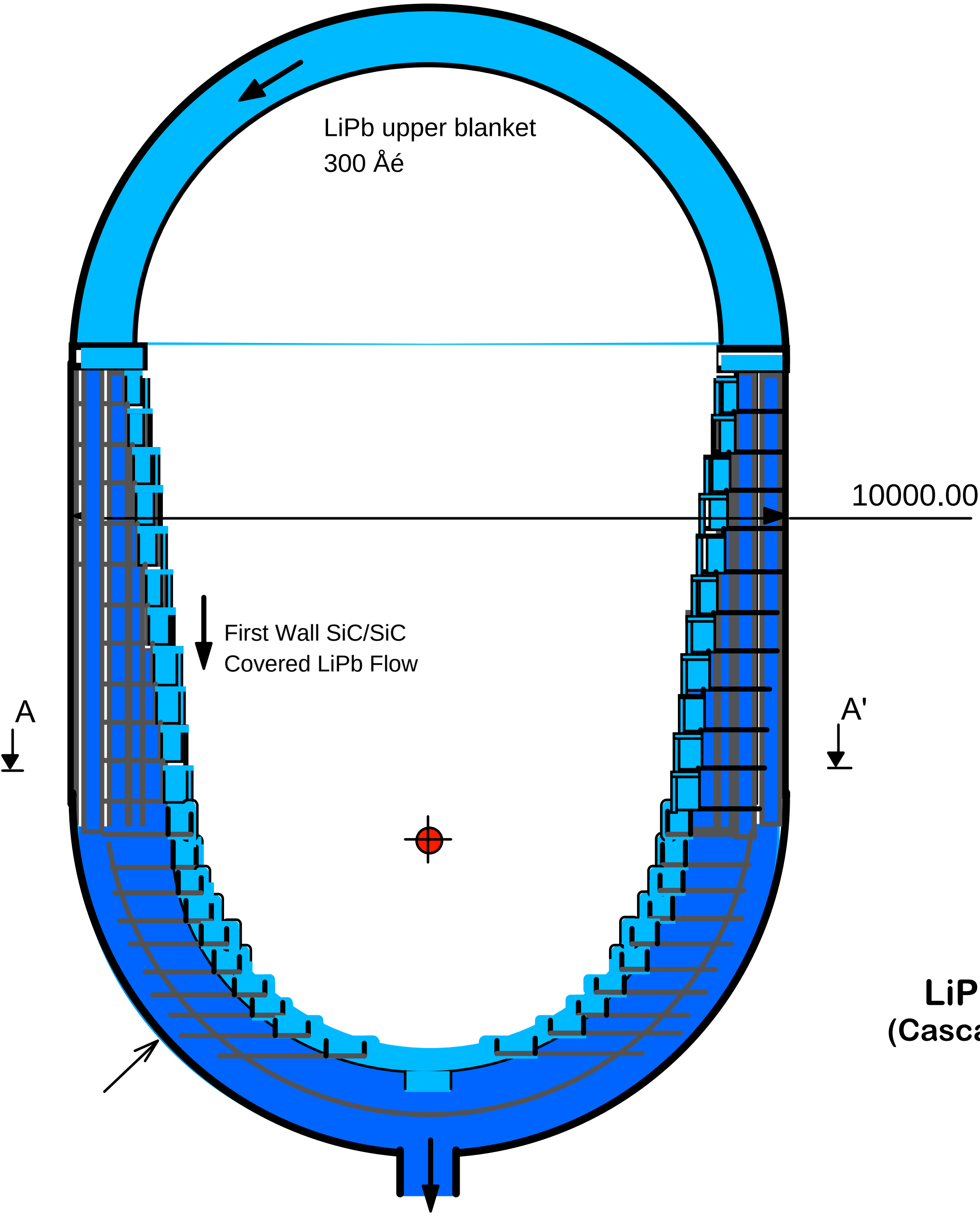
    - **Free liquid fall with short pass (cascade structure of ~20cm pitch for renewal in 200 msec)**

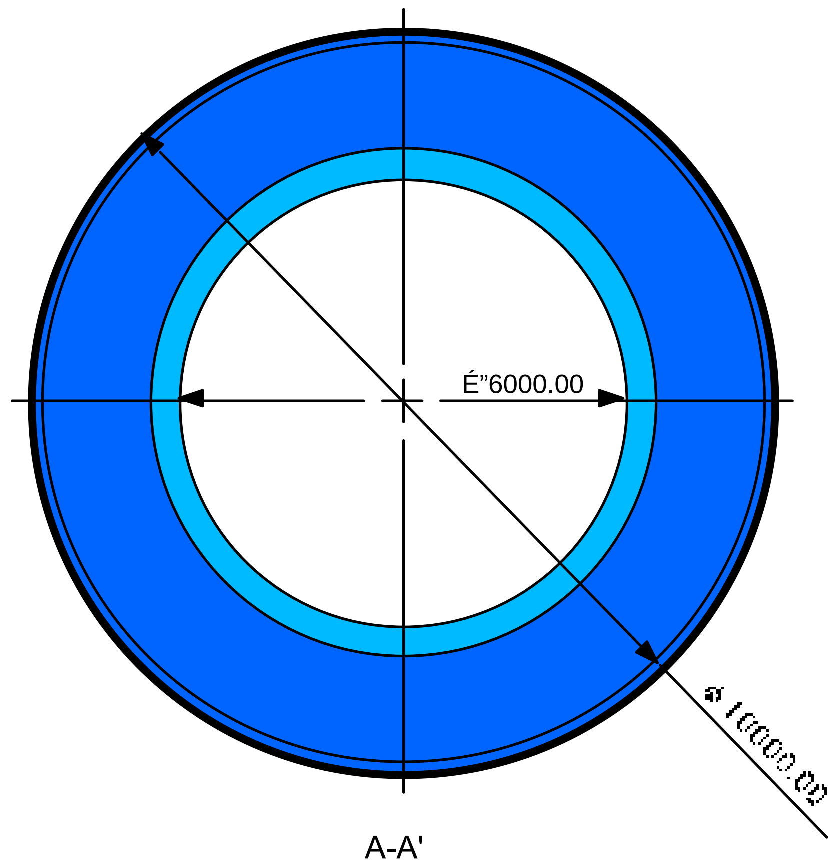
    - **Divergent flow from bulk flow to surface flow thorough by holes or slits.**

Design philosophy and basic concept for PbLi chamber

1) **No pressurized pipe or vessel in the chamber** vessel for avoiding high pressure in chamber in accidents, and for achieving simple maintenance and long life use.
2) **Fast cooled free surface wall** using divergent flow thorough from bulk flow (small holes or slit structure)
3) Feritic steal for cylindrical vessel and upper dome cover vessel
4) **Sic/Sic septate wall** withoout pressure bulkhead
5) Adjusting holes or slits on the septate to controle divergent flow for stabilizing and fast cooling free surface
6) Two layers LiPb blankets (~20 cm for free surfacefirst wall and ~80 cm for blanket necessarry to tritium breeding) and ~45cm grafite neutron reflector.



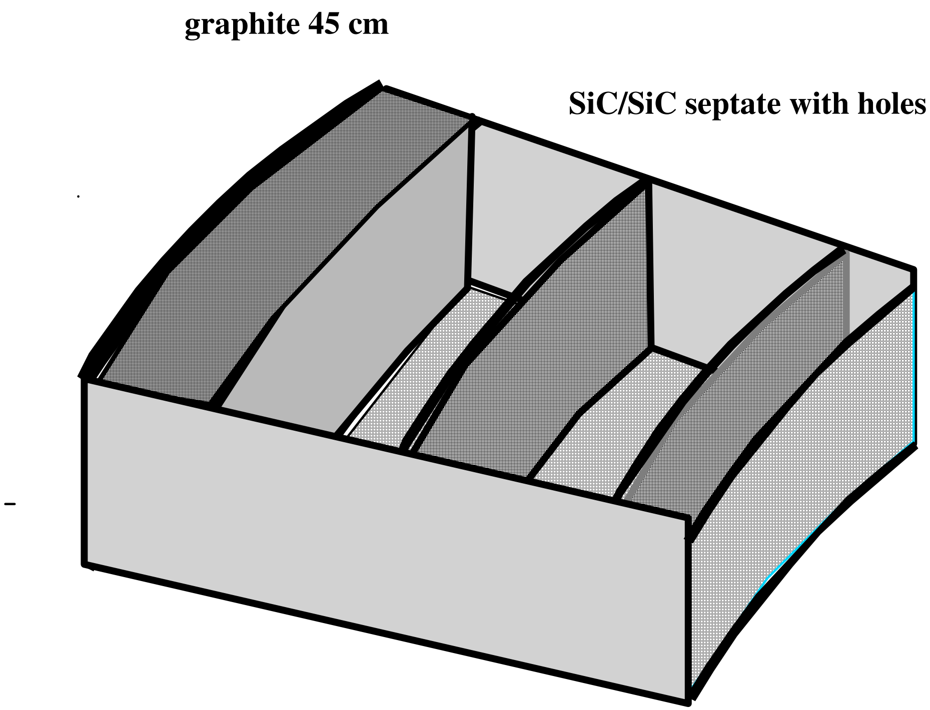


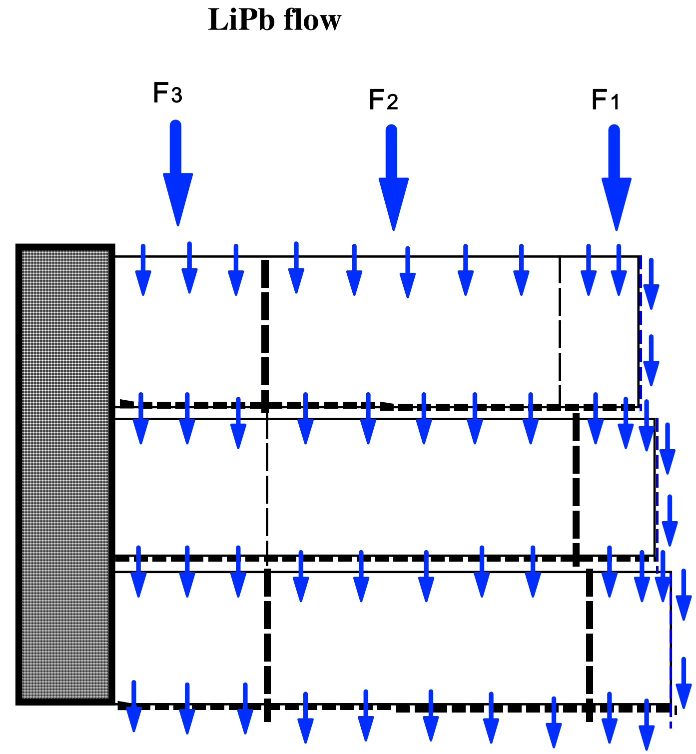


LiPb Fast Renewable Liquid Wall Chamber Concept

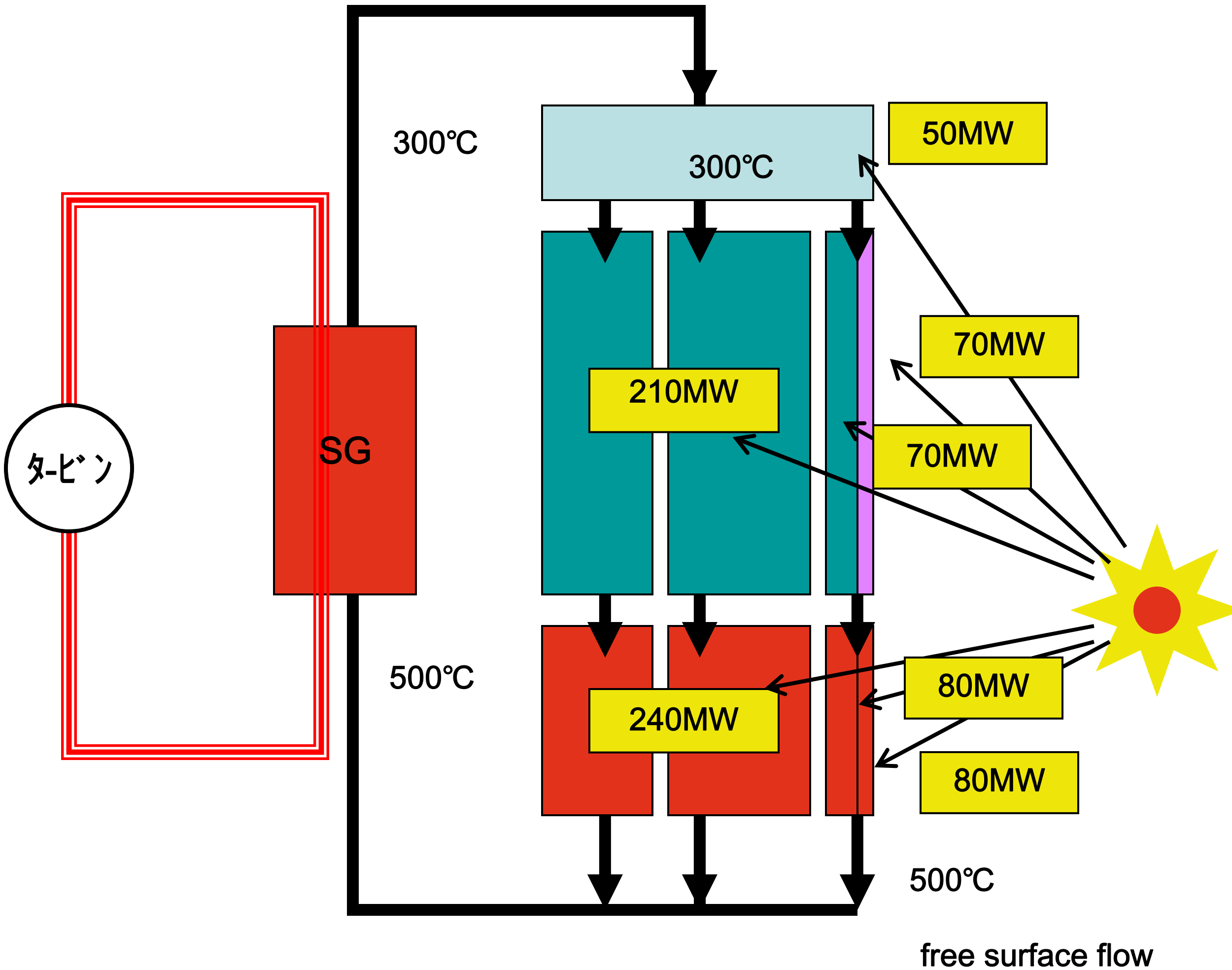
LiPb Fast Renewable Liquid Wall Cascade Flow ChamberC

(Cascade Flows and PbLi Condensed Werred Walls) 1/100 mm





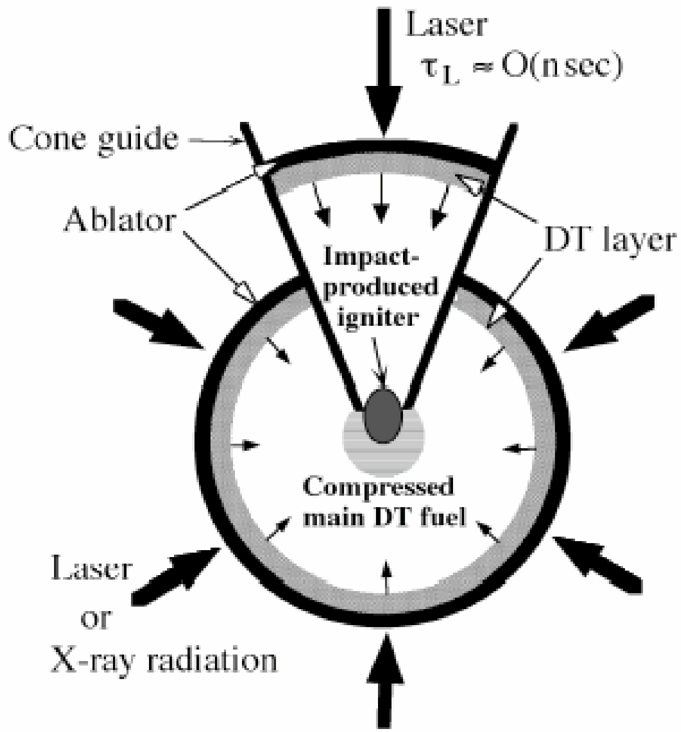
SiC/SiC Chamber septate with holes controlling free fall flow



Chamber heat deposit and power flow for generation

Critical Issues and Major Tasks

- **Physics issues and major tasks (2002~2015)**
  - **Fast ignition physics establishment and demonstration of ignition and burning (FIREX with high density implosion cone target)**
- **Driver issues and major tasks (~2012)**
  - **High repetition high power laser (100J and 1kJ DPSSL module, and excimer laser module development)**
  - **LD cost down (not only mass production but also technical breakthrough)**
  - **Long-lifetime and wide spectrum laser-material development (coupled with LD development)**
- **Target technologies issues and major tasks (~2012)**
  - **Cryo-target fabrication and cone target technologies**
  - **Target injection, tracking, and shooting technologies**
- **Reactor technologies issues and major tasks (~2012)**
  - **Chamber wall protection technologies (for FIREX , and the high rep-rate burning experiment)**
  - **Liquid wall chamber feasibility studies, simulation on liquid wall ablation, evacuation, and free liquid surface control**
  - **Reactor structural material and final optics (pulse irradiation with charged particles and neutrons)**
  - **Final optics development for heating laser(life time evaluation or searching new alternative concepts such as impact ignition)**
  - **Self consistent reactor design (for guiding key technology R&D and preparing LFER design)**



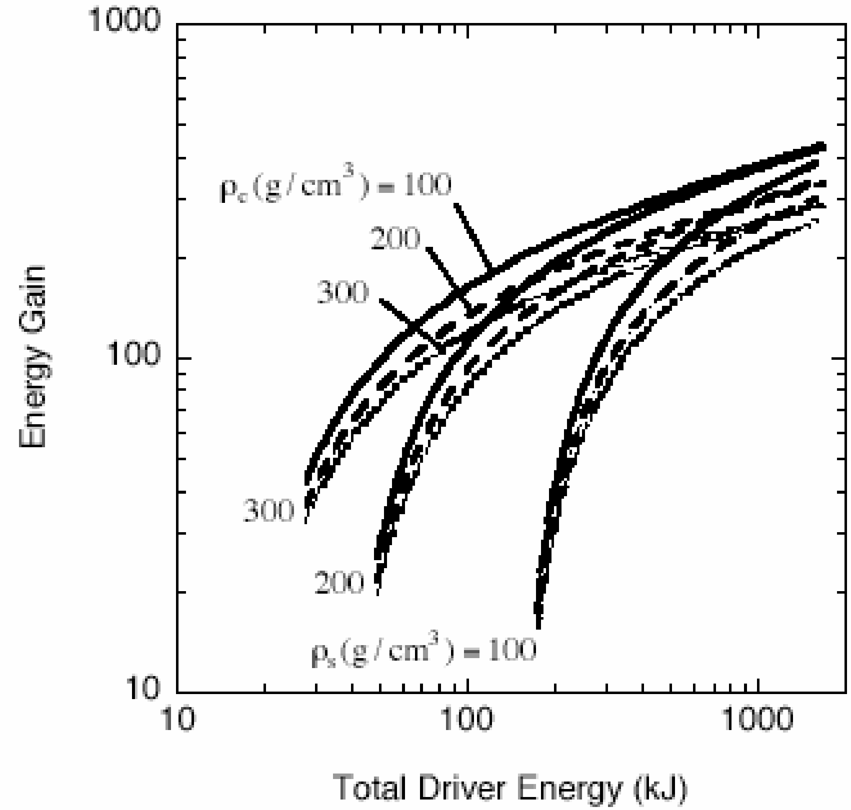


Fig. 1

Target concept and gain curve of impact ignition(by Murakami)

Conditions of economically attractive fusion plants

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IFE (Laser)

Fusion gain G ⇨ laser energy

power balance ηG ≧ 10

⇨ laser cost

pulsed operation ⇨ pulse rep-rate

geometry ⇨ separability

⇨ final optics

MFE (DT)

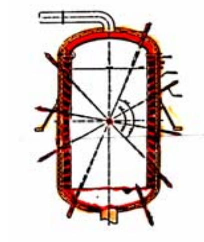
plasma β ⇨ magnet cost

neutron wall loading

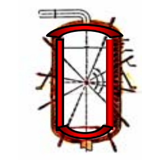
⇨ reactor size

geometry ⇨ complex

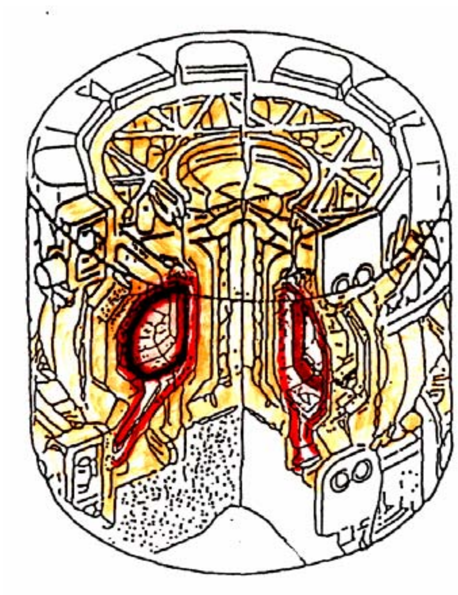
⇨ maintainability



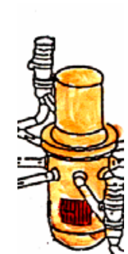
Laer Fusion700 MWe



Laer Fusion200 MWe



TOKAMAK 1200 MWe



LWR 1100MWe

20 m

[Comparison of reactor size]