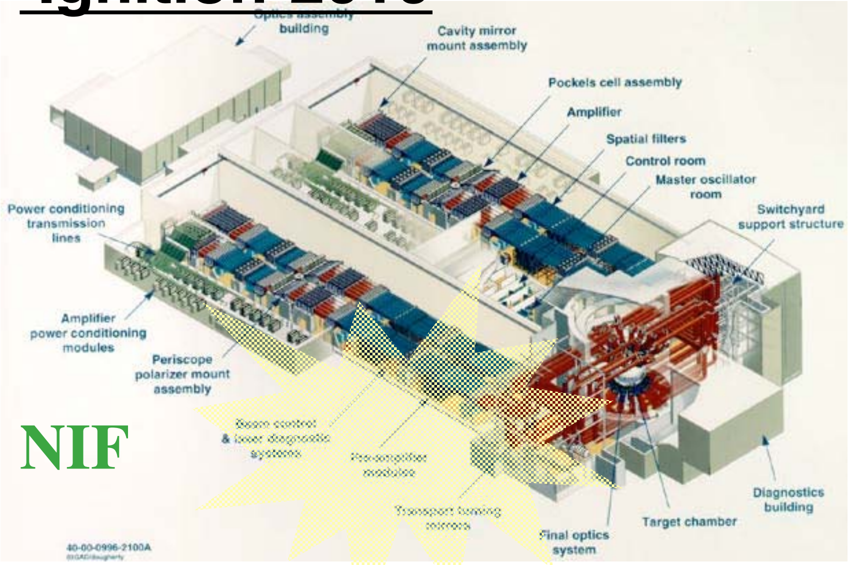
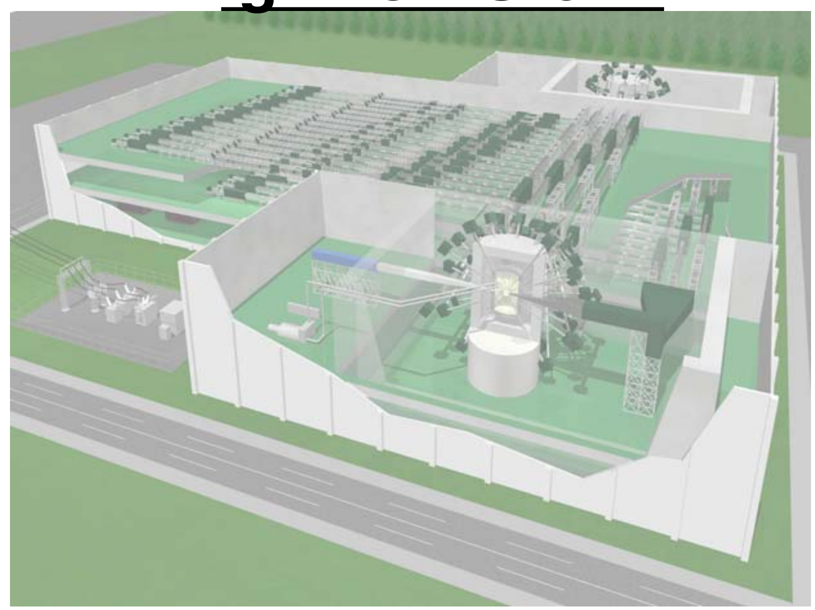
From One-of-a-Kind to 500,000 Igniting Targets/ Day
-paper FT/2-R1a, Joe Kilkenny et. al, USA
&
Development of Key Technologies in DPSSL System for Fast-Ignition, Laser Fusion Reactor -FIREX, HALNA, and Protection of Final Optics
-paper FT/2-R1b, Takayoshi Norimatsu et. al. Japan

Single shot/one of a kind Ignition-2010



Ignition @ 5Hz



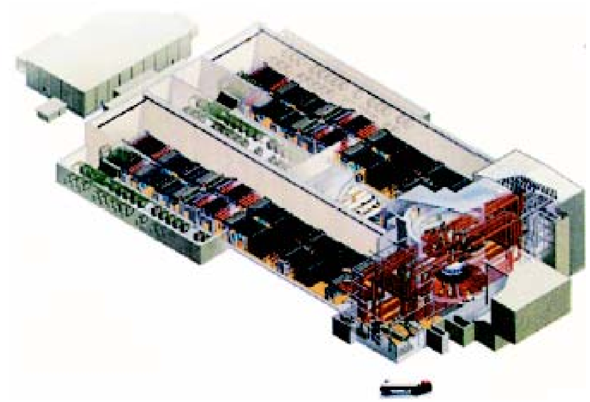
GENERAL ATOMICS

Los Alamos NATIONAL LABORATORY

IFE FORUM

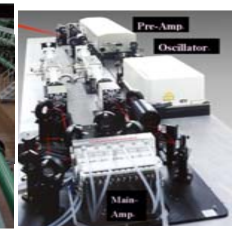
Success in Ignition Requires:-

• Drivers

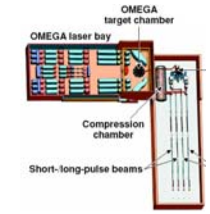


NIF

FIREX

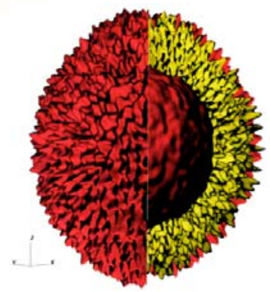


HALNA



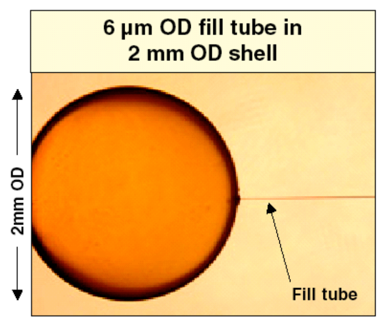
OMEGA-EP

•Simulations



3D rad.-hydro
Simulation of
igniting target

•Targets



Be fill
tube
targets

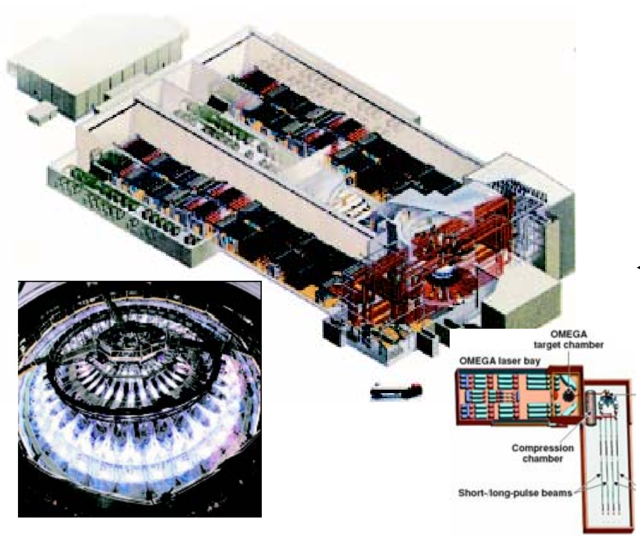
Targets for 1
minute

Single shot ignition and IFE technology demonstrations increase the credibility of IFE

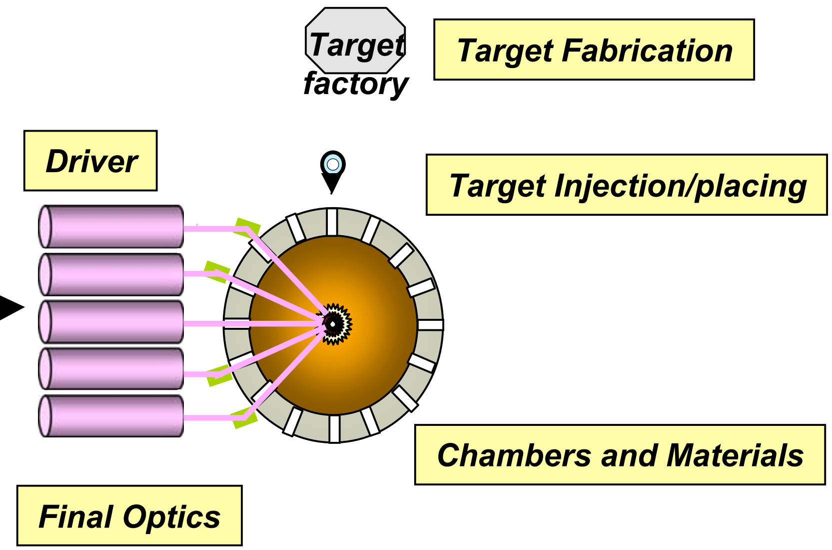
GENERAL ATOMICS

The development path for IFE, 5 ignition shots/ second, Can address many of the problems separately

<u>ICF</u>:Single shot facilities:-
NIF,LMJ,OMEGA,Z,FIREX..



<u>IFE</u>:Repetitive driver,
Target& chamber technology



<u>Goal</u>- Demonstrate
-Physics,driver,chamber &,
targets for ignition by ~ 2010
~20MJ / week?

<u>Phase I Goal</u>: Demonstrate technology
For ~100s MJ yield at ~ 5Hz:-
High Average Power Lasers
Target production facility
Chamber,optics

Some elements are reported here-laser,chamber(Japan), targets(USA)

IFE-Laser development-Japan

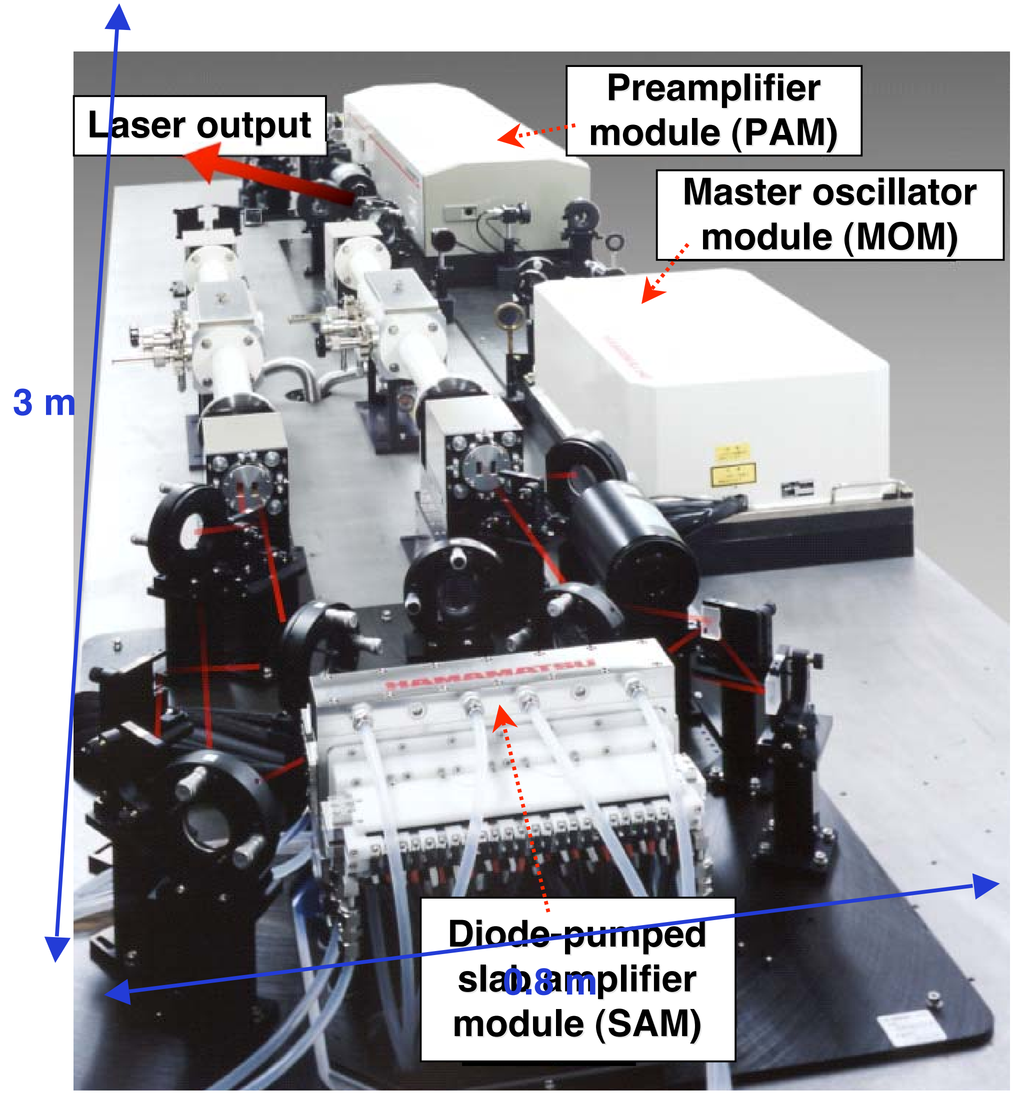
RT/2-R1b

ILE, Osaka

ILE - High Average-power Laser for Nuclear-Fusion Application (HALNA*10) runs at 10 J, 10 Hz -11/ 2003

§ IFE driver requirements:
- kJ energy scalability
- 10 Hz rep. rate
- 5x D.L. beam quality
- 10% overall efficiency

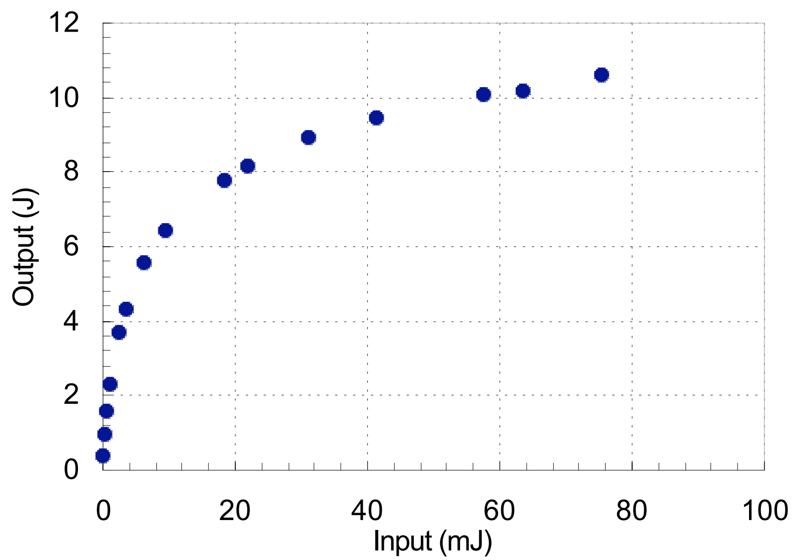
§ Solutions:
- Diode-pumping
- Nd:glass slab medium
- Zig-zag geometry
- Multi-pass amplifier

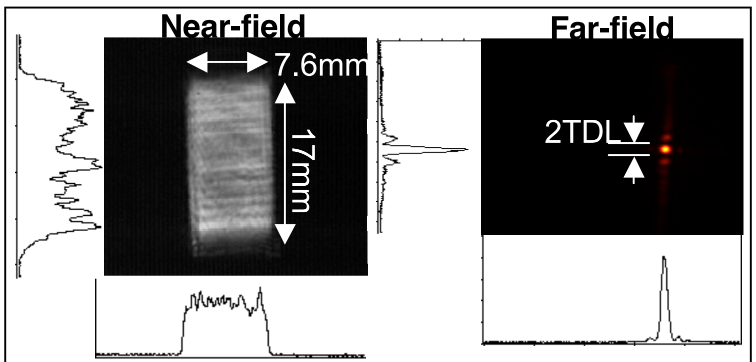


The HALNA10 has successfully yielded 75-W average power in September, 2004

ILE, Osaka

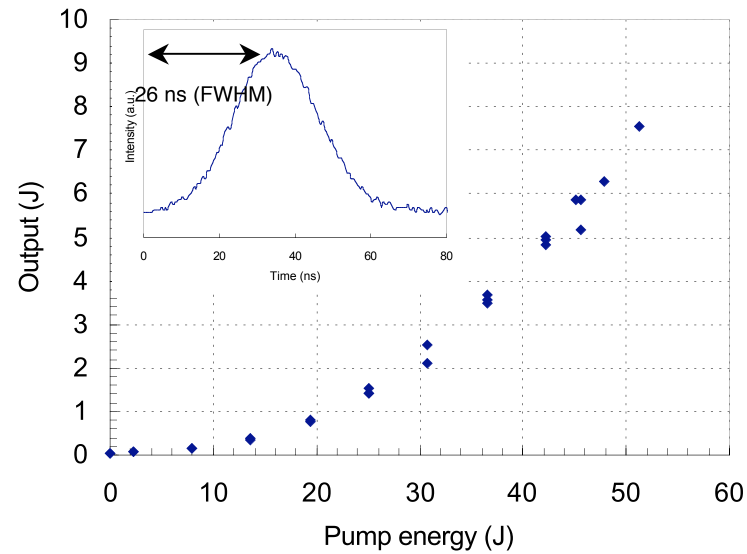
10.6 J operation at 1 Hz

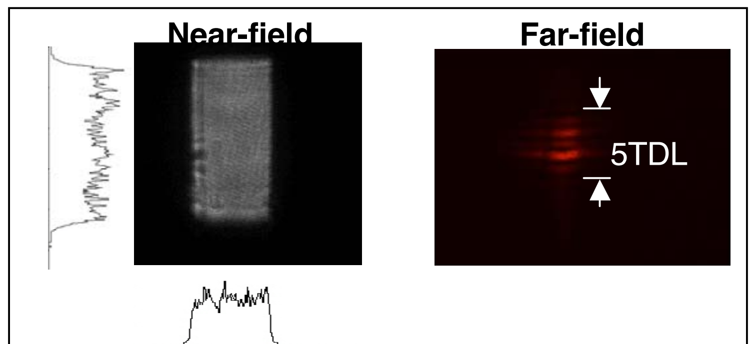




Filling factor : 49%

75 $W_{average}$ operation at 10 Hz





Filling factor : 41.5%

IFE-Laser development-Japan

RT/2-R1b

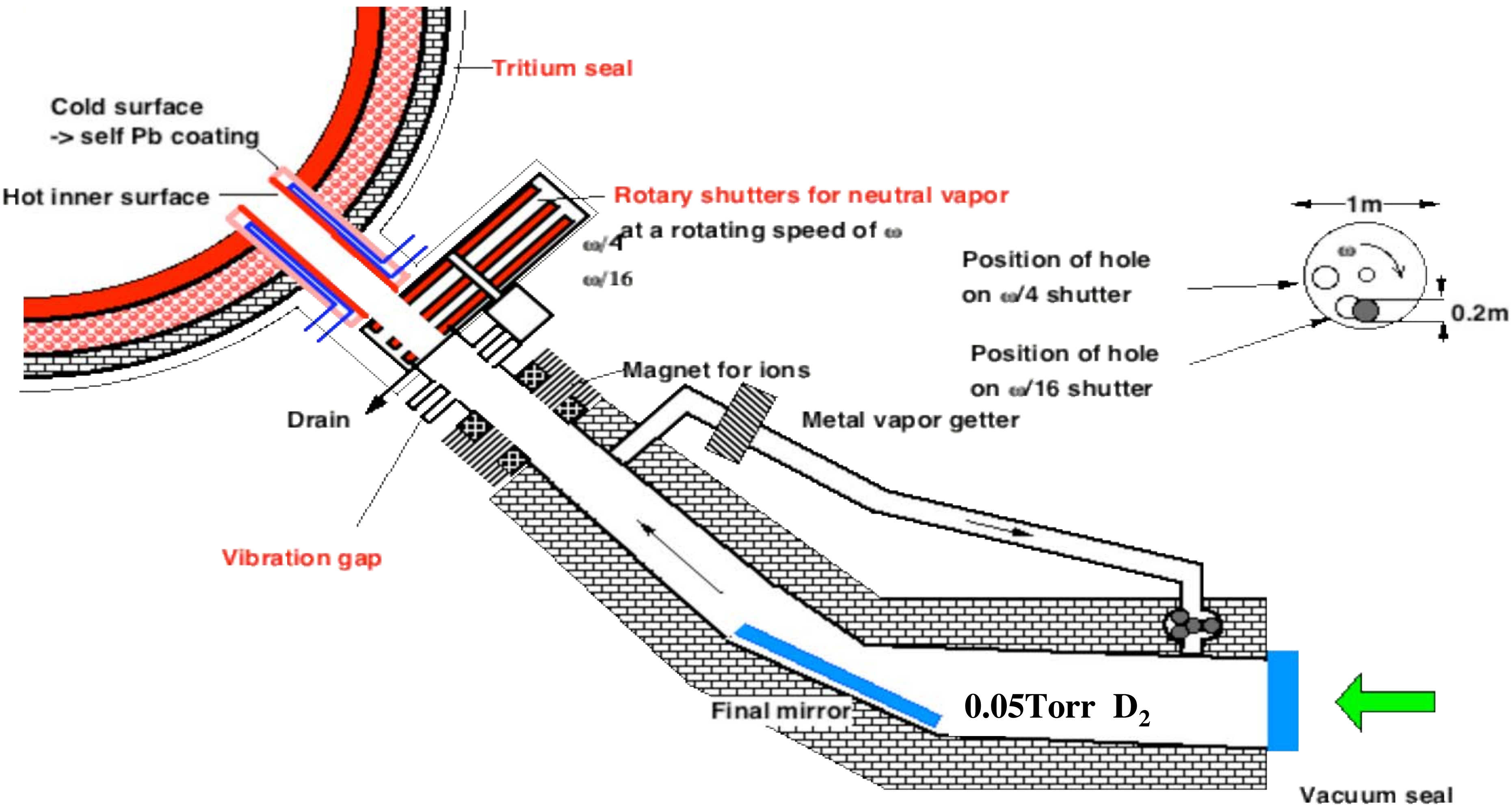
Experimental results convince us that the HALNA is a promising candidate for IFE driver

ILE, Osaka

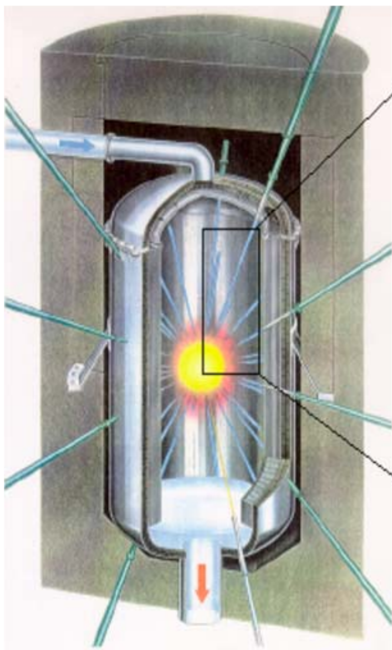
Component	Parameter	Goal	Result	
Pump diode	Output peak power	120 kW	145 kW	
	Pump intensity	2.5 kW/cm^2	2.59 kW/cm^2	
	Emission wavelength	803 ±1nm, <4 nm(FWHM)	804.1nm, 3.4 nm(FWHM)	
	E – O efficiency	55%	52%	
Slab amplifier	Small Signal Gain	10	8.5	
	Pumping efficiency	45%	45%	
Total system	Repetition rate	10 Hz	1 Hz	10 Hz
	Output energy	10 J	10.6 J	7.5 J
	Extraction efficiency	45%	43.9%	31.1%
	O – O efficiency	20%	19.9%	14.1%
	E – O efficiency	10%	10.3%	7.3%
	Filling factor	50%	49%	41.5%
	Beam quality	< 5TDL	80% (<5TDL)	60% (<5TDL)

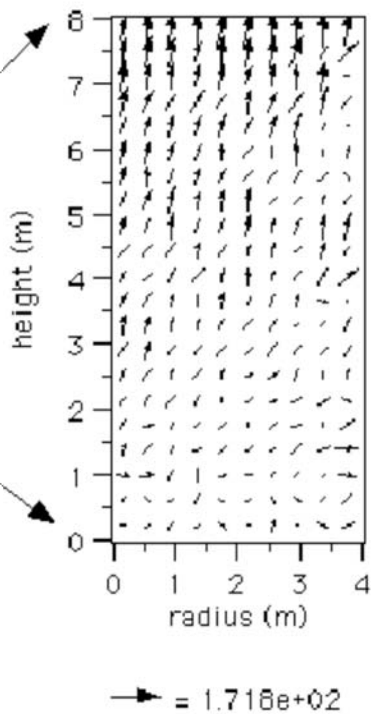
Final optics are protected by synchronized shutters

ILE, Osaka

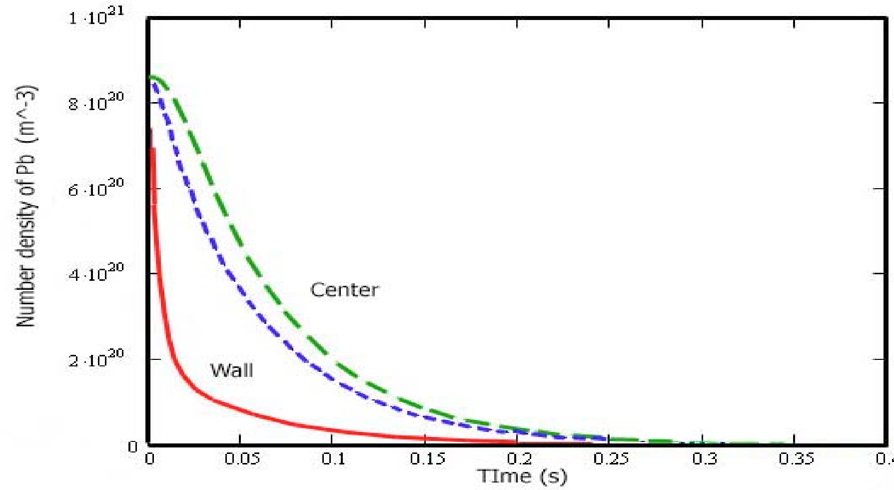


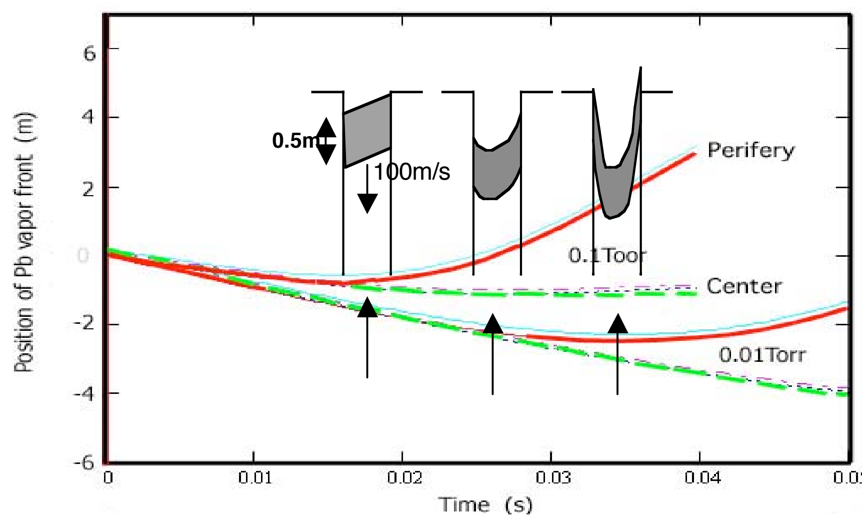
0.1 Torr buffer gas prevents Pb vapor reaching final optics





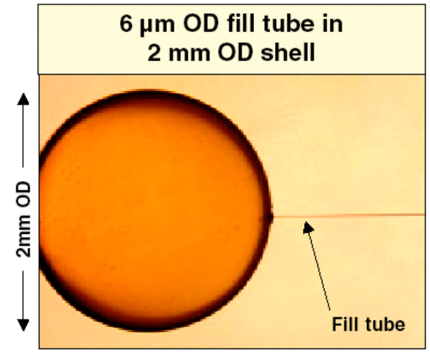
case3 (60msec)

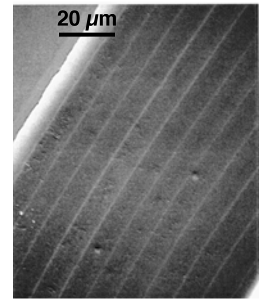




From One-of-a-Kind to 500,000 Ignition Targets Per Day

ICF: One of a kind:Target design & fabrication compensates for facility limitation. Graded doped Be targets allow a simpler cryo. system



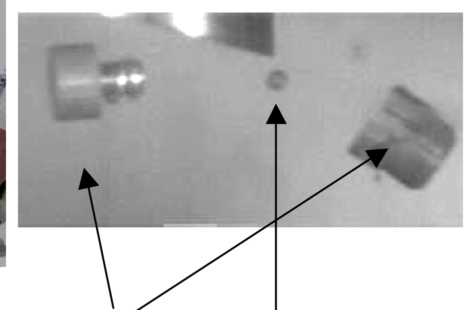


Cross-section of 100 µm thick Be shell

IFE:500,000 ignition Targets/day(at cost): feasibility demonstration

Cryogenic fluidized bed (CH)

Full scale pellet injector-GA



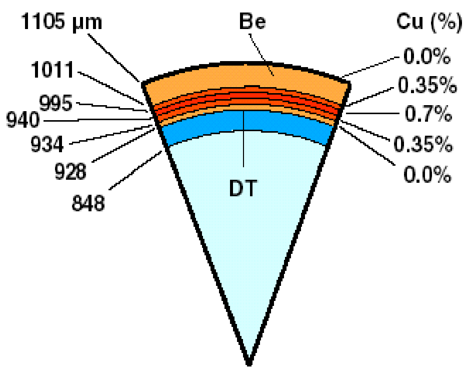
Sabot pellet separation

Target production and alignment techniques for 500,000 shots/day are being made credible by demonstration in the U.S. & Japan

On a computer, complex Be targets with fill tubes will ignite on the NIF

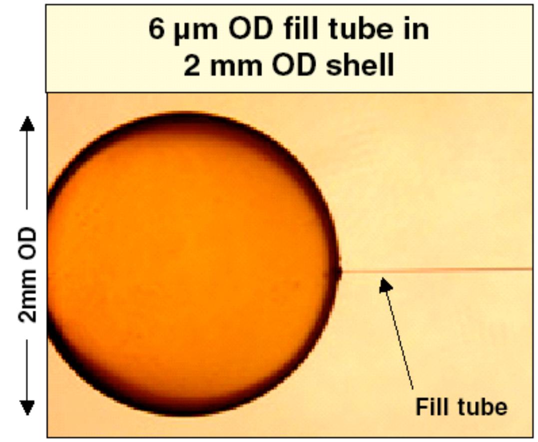
FT/2-R1a

300 eV graded-doped Be design:

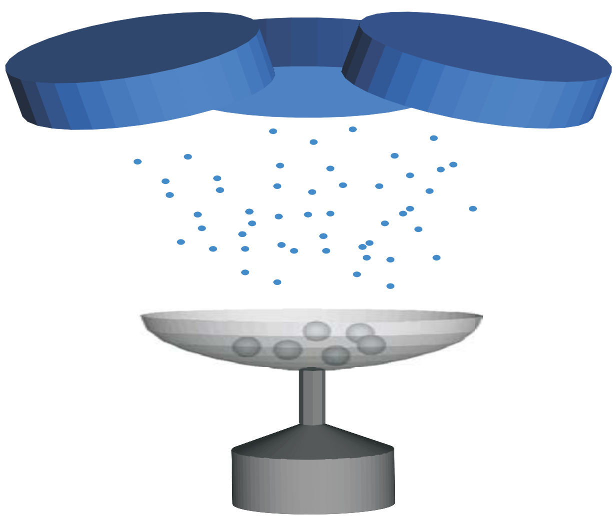


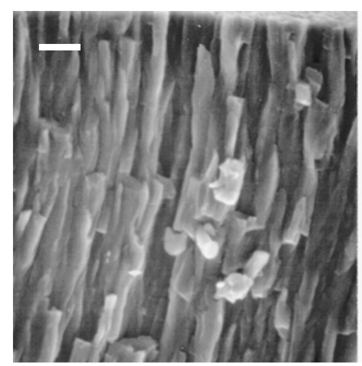
Graded Cu dopant
In Be shell

Codes

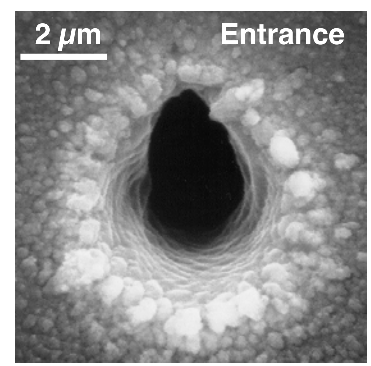


Fabrication?





Sub-micron grains



Tiny holes have been laser drilled for filling

A fill tube target allows a simpler cryo system to achieve ignition

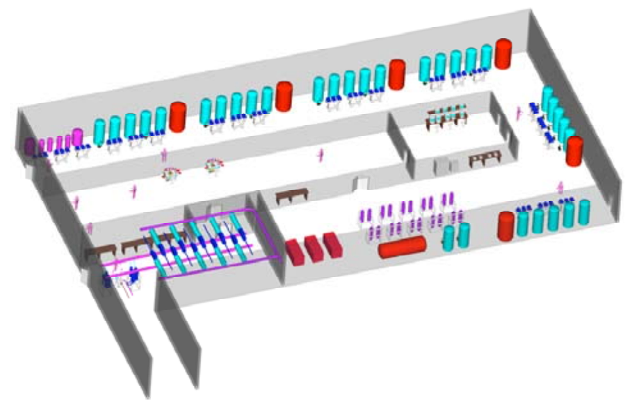
500,00 ignition targets/day

FT/2-R1a

The requirements for IFE targets are demanding

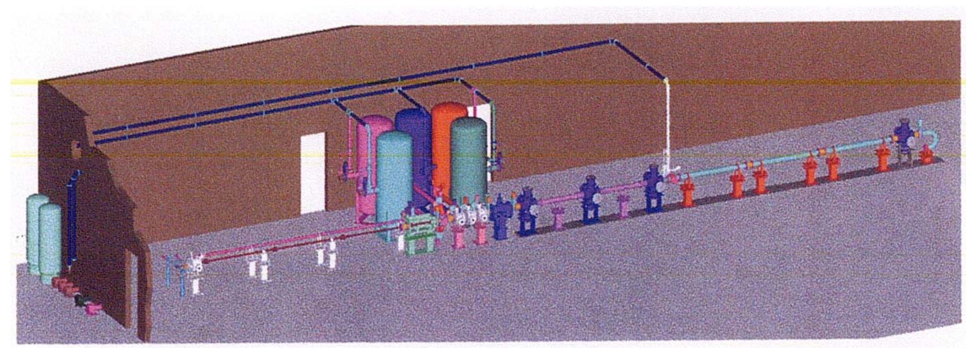
Target fabrication-feasibility

- Mass production methods to fabricate 10^6 cryogenic DT targets/day to spec.
- Mass production costing models to show targets cost < \$0.25(DD laser).



Target injection & tracking

- Build an injector that injects targets into chamber before they melt (400m/s).
- Track target position so that laser beam can hit it to :
  $\sim R_{init} / C_r$ (20 μm)



Cost goals and technical feasibility need to demonstrated

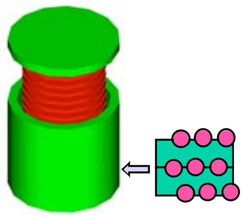
GENERAL ATOMICS

Regardless of driver, target fabrication has many common elements

FT/2-R1a

Fabricate Capsules → **DT Fuel Fill** → **DT Fuel Layer** → **Load capsule**

Microencapsulation,



Pressure cell

Cryogenic fluidized bed (CH)

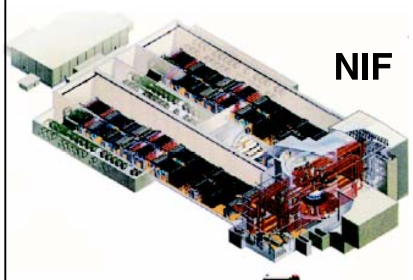
Fabricate sabot

Advanced manufacturing methods

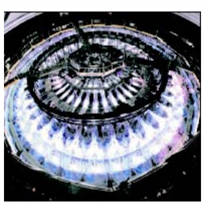
Inject/Track or insert

Injector demo experiment at GA

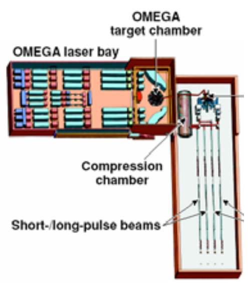
ICF facilities



NIF



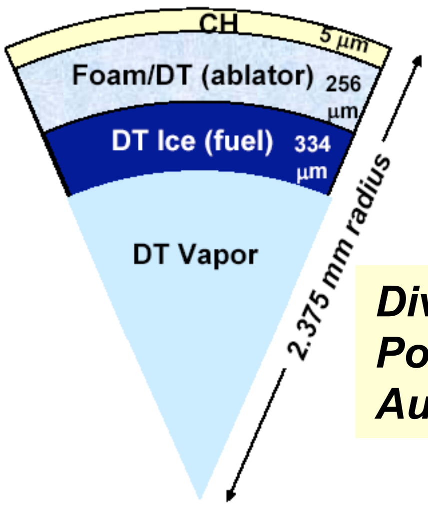
Z-R



OMEGA EP

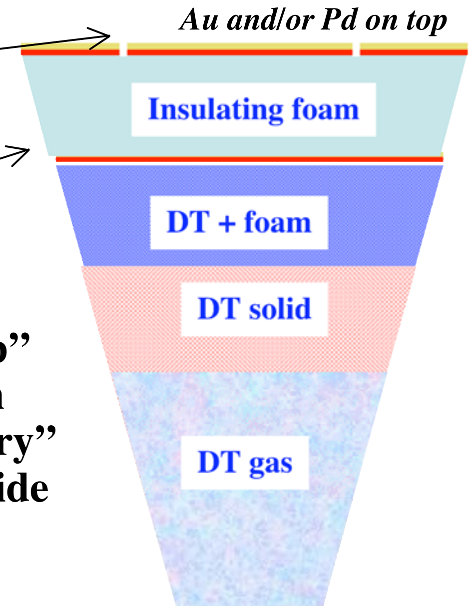
Synergy with single shot ICF programs with decades of R&D

Example: target design and requirements
-stop the target from melting during injection



(A) "Baseline" Direct Drive High Gain Target Design

Divinyl benzene foam shell
Polyvinyl phenol overcoat
Au/Pd "reflector" on top



(B) "Backup" target with additional "dry" foam to provide insulation

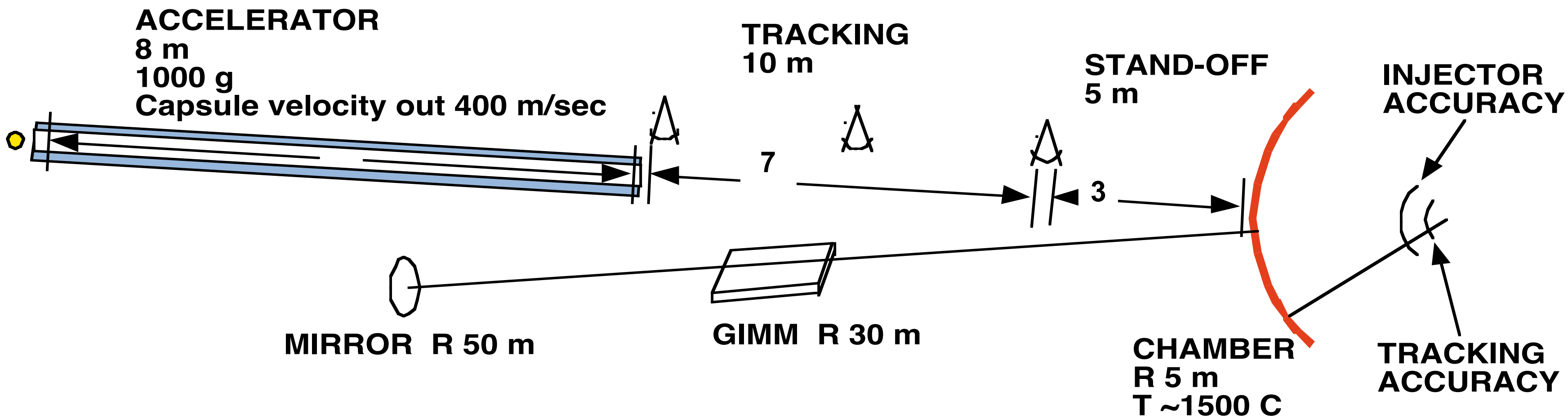
Some Expected Direct Drive Specifications	
Capsule Material	CH (DVB) foam
Capsule Wall Thickness	~260 μm
Foam shell density	100-120 mg/cc
Non-Concentricity	<1% of wall thickness
Shell Surface Finish	~20 nm RMS
Ice Surface Finish	<1 μm RMS
Temperature at shot	~15 - 18K
Alignment with beams	<20 μm

Foam-insulated target is thermally robust

1. **Baseline target (18K): <0.68 W/cm^2 (970°C and no gas)**
2. **Foam-insulated (16K): <9.3 W/cm^2 (970°C and 40 mtorr @ 4000K)**

Target design & fab prevents the target from melting during injection into the 2000K gas filled chamber

IFE’s injection & tracking requirements are “challenging”



- **Inject 500,000 targets per day - 1000 MW(e)**
- **Acc. < 1000 g, placement ±5 mm, tracking/beam steering ±20 μm**

25 m gas gun injector

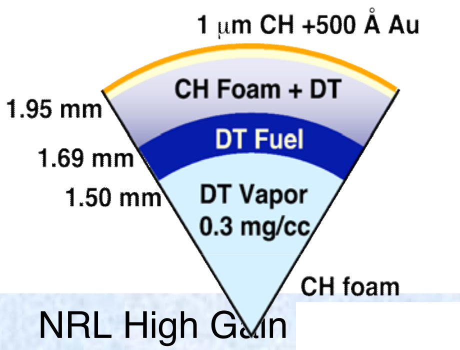
-Injection ≥400 m/s ,6 Hz, “burst” mode)
-Sabot separation and deflection
-In-flight tracking
-Target placement accuracy of ~10 mm

GA’s pellet injector is establishing credibility for IFE targets

Regardless of driver, target supply at ~500,000/day is required for IFE

Laser Fusion

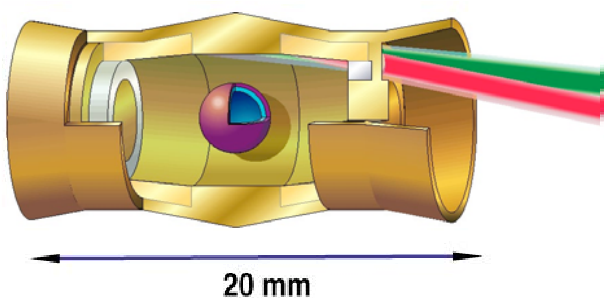
- Direct drive
- Foam capsule
- Dry wall chamber



NRL High Gain

Heavy Ion Fusion

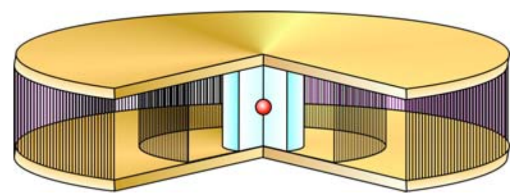
- Indirect drive
- Special materials
- Advanced manufacturing methods



LLNL Distributed Radiator

Z-Pinch IFE (ZFE)

- Indirect drive



SNL Dynamic Hohlraum

Yield (MJ)	~400	~400	~3000
$/target -1GWe	$0.17	$0.41	$3
% of E- value	5.5	13.6	~13

Reducing the costs of targets by ~ million is credible using mass production techniques

GENERAL ATOMICS

FESAC reviews of IFE have been favorable

A panel of the Department of Energy's Fusion Energy Sciences Advisory Committee (FESAC), charged with reviewing its IFE program, has urged the Department to carry out "a coordinated program with some level of research on all the key components (targets, drivers and chambers), always keeping the end product and its explicit requirements in mind."

"In sum the IFE Panel is of the unanimous opinion that the IFE program is technically excellent and that it contributes in ways that are noteworthy to the ongoing missions of the DOE."

The full FESAC endorsed the Panel report at it meeting March 29, 2004 and transmitted it to DOE Office of Science Director Ray Orbach.

The US & Japan are demonstrating feasibility of Inertial Fusion Energy

- Single shot facilities build capability in lasers(NIF,FIREX, OMEGA EP, ZR,LMJ) and target fabrication(Be shells)

- Single shot facilities will demonstrate the physics of ignition

- Components of High Average Power Lasers are demonstrated: HALNA, -7.5 J, 10 Hz, ELECTRA & Mercury in US

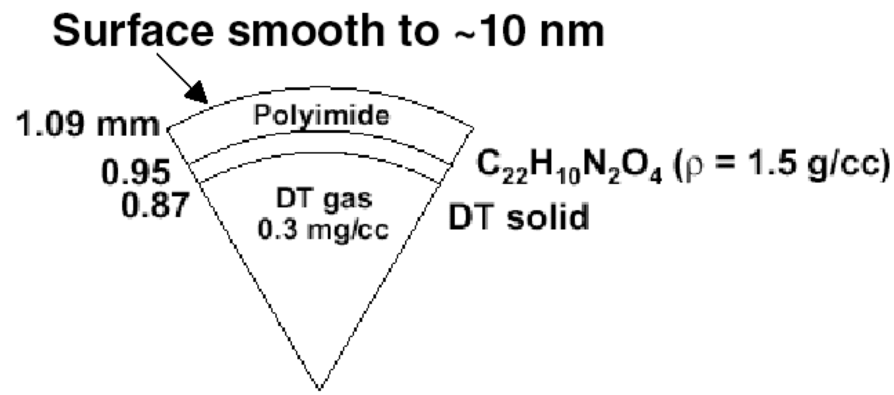
- For all three IFE concepts, target supply scenarios and and basic process steps have been identified and key processes have been demonstrated

- Target injection and tracking partially demonstrated

IFE credibility is being established by ignition on the NIF, and by demonstrating capability of key system components

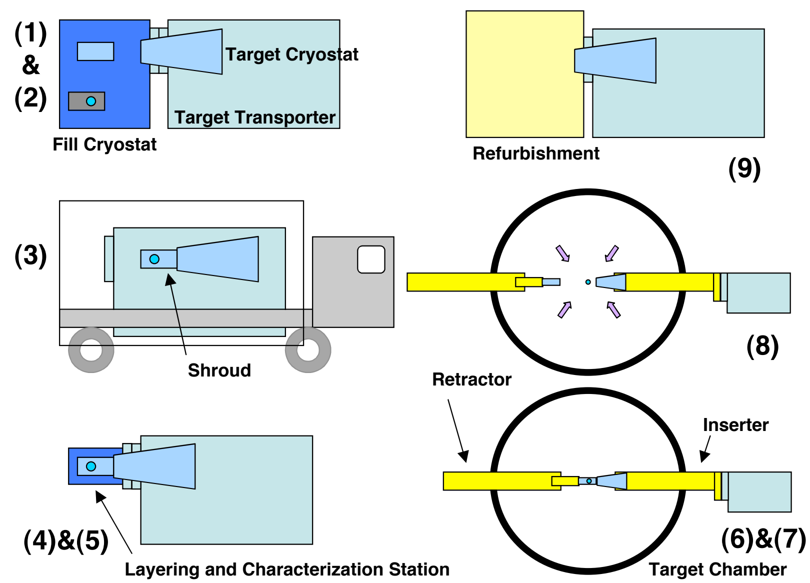
Target fabrication issues determine ignition strategies- the NIF baseline target was plastic diffusion filled

•Baseline target-diffusion fill
- Physics issues
  - -surface finish
  - -augmented β layering
  - -Optical characterization



BUT

• $ and schedule issues with The NIF cryogenic target handling system because diffusion fill/cold transport



The large number of cryo. sub-systems increases complexity & cost

GENERAL ATOMICS