CRYOGENICS FOR HYDROGEN OR DEUTERIUM SOLID TARGETS

Targetry Workshop 9th -11th Oct 2013 - Garching
Cryogenics at CEA/Grenoble (1957 birth of the lab)

Linear scale

- 293.15 K (0°C)
- 273.15 K (0°C)
- 173.15 K (-100°C)
- 73.15 K (-200°C)
- 0 K (-273.15°C)

Logarithmic scale

- +58°C (331 K) Lybie
- -92°C (181 K) Antarctique
- -263.15°C (4.2 K) He liquid
- -272.15°C (1 K)
- -273.05 K (0.1 K)

Louis NEEL

Equipe Cryo LMI - SBT et LAIC - mars 2005
Helium (4.5K), Helium II (1.8K) and other gases
thermohydraulic studies, supraconducting magnets cooling
hybrid magnet 33T, LHC 24 kW à 1.8K, ITER project
heat exchange and turbulence

Cryocoolers for space
He³ or He⁴ adsorption cryocoolers (<1 K 30μW/300mK)
P.T.(single or double stage) 100W/80K, 3W/20K et 30W/40K

Nuclear fusion cryogenics
High speed pellet injector (D₂ 4500m/s)
LMJ project (inertial fusion)
From fundamental research to applications

Realization
« customers » (ESA, CEA, ITER & BA,…), companies

Finalized research
Prototyping, tests bed …

Fundamental Research
Universités, CNRS…
Croytechnology for fusion by magnetic confinement
Two stage gas gun for pellet injection 1/2

1st stage

Piston

Pump tube

D2 pellet

Condensation cell 7K

Acceleration curve

\[ a(t) \text{ sound velocity} \]

\[ dV/dt \approx P(t)[1-(\gamma-1)/2*V(t)/a(t)] \]

Wave pressure velocity

\[ c(t) \approx a(t)-(\gamma-1)/2*V(t) \]

Only the 350 µs pressure impulse after the BP are efficient

Garching October 2013 - Targetry Workshop
Two stage gas gun for pellet injection 2/2

Pellet velocity versus breech pressure acceleration $10^7$ ms$^{-2}$

- 2.5 $10^{21}$ D atoms
  - 2560 m/s

- 1.35 $10^{21}$ D atoms
  - 3570 m/s
Continuous pellet injection

OBJECTIVES
1000 m/s @ 1000s @10 Hz
1 shot per minute to 10Hz

Reduction of propellant gas mass
< 1 time pellet mass

guide tube 14 m injection HFS

Garching October 2013 - Targetry Workshop
Croytechnology for fusion by inertial confinement
Laser MegaJoule project (1/3)

For CEA/CESTA
- Storage
- Conformation
- Positionning

CEA/B3
- project management

CEA/Valduc
- filling DT (1300 bars)
- Characterisation
- Transfer 25 K

CEA/Grenoble (1993 → …)
- Expertise / Concept
- Prototyping
- Validation of technology

Garching October 2013 - Targetry Workshop
Laser MegaJoule project (2/3)

- Laser beam 300 m
- Hall 30 m
- Chamber Φ 10 m
- Laser
- Hall 30 m
- Cavity Au
  - L = 10 mm
  - Φ = 6 mm
- Target
  - μballon Φ = 2 mm
  - 200 μm DT
  - Ep. à 1%
  - Ra = 0.5 μm
- Base
- Targetry Workshop

Garching October 2013 - Targetry Workshop
Laser MegaJoule project (3/3)

program > 20 years

1994 1st feasibility study
2000 - 2009 validation of the solution « scale 1 »
2014 1er laser shot

200 µg DT
e = 200 µm +/- 1 µm
18 K +/- 1 mK
X,Y,Z +/- 25 microns

Garching October 2013 - Targetry Workshop
Solidification (to PT à 1 mK/min; $T_{\text{tir}} = 18.2$ to $19.72$ K ± 1mK)

- Positionning ± 15 µm with an hexapode
- Thermal gradient < 75 µK
When the target is cooled down, convection movements appear. The heat exchanges are higher in the upper cell than in the lower cell. For this reason the layer thickness will be not uniform.
Cryogenic Transfers at 20 K

- Robots working under vacuum
- Target thermal control
- Reliability of electrical and thermal contacts at 20 K

Thermal regulation
(± 1 mK à 12.5 K)

- Software, signal analysis,
- Sensors, wiring…
Cryogenic equipments

Cryotarget carrier (PCC)

Shroud remover (PET) 0.5 m into 100ms

Target time life 180 ms (numerical calculations)
Some pictures…..

prototypes

transfer

hexapod

loading
Goal: To produce targets of solid $H_2$ dedicated to laser/matter interactions

Possible application to proton-therapy
Two projects

1.- Based on $H_2$ solid extrusion
   • $H_2$ film of 100µm to 10µm in thickness

2.- Based on $H_2$ condensation on a cold tape
   • $H_2$ layer of few tens nm in thickness

Possibility to use $D_2$ or Ne or other gas
Extrusion principle (SBT patent)

- No moving part
- Utilization of the thermodynamical properties of the fluid
High pressure is required

\[ P = 2^* \sigma * H/e \] (20MPa for \( \sigma = 50kPa \), \( H = 2mm \), \( L = 1mm \) and \( e = 10\mu m \))
Hydrogen properties

H₂ phase diagram and isodensity
First experiments were performed in a 20mm x 100mm cell
A new cryostat is under fabrication

4 windows to characterise the H2 film
Next step: tests in 2014 on ELFIE at LULI and after on PALS in Prague.

ELFIE: 100TW (100fs)
3 shots/hour

Helium tank 100 l.
Transfer line
Cryostat
Vacuum vessel of ELFIE

LISA project
Next step: tests in 2014 on ELFIE at LULI and after on PALS in Pragues

Goal

- Produce protons from several hundred kev to some MeV
- Improve the understanding of physics of ion/plasma interaction

Diagnostic means

- Two Thomson parabolas
- Xray spectroscopy
Required pumping means

\[ Q(l.\, s^{-1}) = 22.4 \times 10^5 \frac{S \cdot V \cdot \rho_{sol}}{M \cdot P} \]

S  Foil section
V  Foil velocity
\( \rho_{sol} \)  Solid density (80 kg/m\(^3\))
M  0.002 kg/mole
P  Pressure in Pa

Example: for a foil of 1mm x 100µm having a velocity of 10mm/s, if the pressure in vessel is 10\(^{-1}\) Pa, a pump of 800l/s is required (compatible with ELFIE facility)  H2 management (exhaust outside )
« Tape condensation » (SBT patent)

- Spring
- Wheel
- 4K (rub)
- Pumping
- Thermal shield
- H2 Injection
- Laser
- Particles
- Metallic or plastic tape (Wound on wheel)

Garching October 2013 - Targetry Workshop
Tape temperature

Phase diagram of H2

Pressure (Pa) vs. Temperature (K)

- Solid phase
- Gas phase

Pressure $P_T = 7030$ Pa
Temperature $T_T = 13.8$ K
Conclusions

- Low Temperatures Laboratory can work as a partner or as an expert or as a sub-contractor for the scientific community.

- It can solve critical problems which can not be sent to industry.

- It can propose new and innovating solutions with the respect of cost and delay.
Thanks for your attention