LAST DEVELOPMENTS ON LMJ CRYOGENIC TARGETS FABRICATION

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Outline of the talk

- Cryogenic program at CEA target department
- Cryogenic equipment
- Current development and perspectives
- Conclusion
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The cryogenic target program stopped in 2013: priority given to HEDP experiments

State of the art in 2013:
- Cryogenic targets and layering procedures were tested on the Study Filling System (SFS)
- Layered $D_2$ was obtained using infrared irradiation
- The layer was characterized using backlit shadowgraphy
- Theoretical, numerical and experimental studies were performed in parallel
  (temperature uniformity and stability, layer redistribution,…)

From 2013 to 2018, CEA developed two cryostats for cryogenic target fabrication (MVT-S & CRyOTECI)

In 2018, the cryogenic program was relaunched

Since then
- the two cryostats were tested in the target department
- a Keyhole target prototype has been manufactured
Low temperature targets will be needed for LMJ’s experiments in the next few years.

Development of new skills and means for cryogenic targets:
- Sensors and heaters assembly
- Sensors calibration
- Low temp. tightness control
- Filling and layering
- …
Cryogenic targets on the LMJ

- Two main cryogenic target families are considered for LMJ experiments

<table>
<thead>
<tr>
<th></th>
<th>Keyhole</th>
<th>Ignition target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Filling</strong></td>
<td>Liquid $D_2$</td>
<td>Layered DT</td>
</tr>
<tr>
<td><strong>Temperature range</strong></td>
<td>19 K – 23 K</td>
<td>17 K – 19 K</td>
</tr>
<tr>
<td><strong>Temp. stability requirement</strong></td>
<td>None</td>
<td>$&lt; \pm 1 \text{ mK}$</td>
</tr>
<tr>
<td><strong>Number of temp. sensors</strong></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><strong>Number of heaters</strong></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td><strong>Validation of the filling</strong></td>
<td>Absence of gaseous $D_2$ in the shell</td>
<td>Stringent constraints of layer thickness, roughness, size and number of defects, etc.</td>
</tr>
</tbody>
</table>

→ The ignition target is very challenging and imposes high quality constraints
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CRYOTECI and MVT-S

**CRYOTECI**
- Calibration of the target’s temperature sensors
- Tightness control of the target at 15 K

**MVT-S**
- Validation of the cryogenic target design and assembly
- Validation of the targets filling and layering
- Characterization of the obtained layer
CRYOTECI: Description

CRYOTECI is composed of:

- A vacuum vessel and two vacuum pumps
- A pulse-tube cryocooler
- A cryogenic gripper
- Three shields guaranteeing nearly perfect target isotherm
- A centralized command system for:
  - Process management
  - Information gathering
  - Temperature regulation
- A target sensor calibration system
CRYOTECI: Sensor calibration procedure

Temperature is measured with a high accuracy platinum sensor (1)

Sensors resistances are measured (2)

→ \( T = f(\Omega) \) is then fitted using polynomials

Repeat on a range of temperatures (3)
The MVT-S is composed of:

- A vacuum vessel and an observation chamber
- Two vacuum pumps
- Two pulse-tube cryocoolers
- A cryogenic gripper
- A thermal shield reducing radiation on cold pieces
- A centralized command system for:
  - Process management
  - Information gathering
  - Temperature regulation

Copper made gripper
MVT-S: Performances

Temperature vs time during cooling

- **First stage**: 39.5 K
- **Second stage**: 4.6 K
- **Target base**: 7.7 K

Final temperatures:

- First stage: 39.5 K
- Second stage: 4.6 K
- Target base: 7.7 K

→ Validated for ignition target
MVT-S: Temperature regulation (1/2)

Need

Obtain liquid $D_2$ → $\sim$20 K on the target base

Method

→ Rough heating in the cold heads (slow dynamic)
→ Precise regulation using heaters on the target base (faster dynamic)

Zoom next slide

6 W in each cold head
Keyhole target:

Temp. regulation is achieved by mean of a PID controller

→ $t_{r95\%} = \sim 2$ min
→ $\sim 10\%$ overshoot

Ignition target:

Regulation will be implemented directly on the supporting arms and on the hohlraum

→ Faster dynamic

→ Overshoot needs to be controlled for ignition target
MVT-S: Temperature stability

Target base temperature stability $< \pm 1 \text{ mK}$ needed for DT layering

Temperature stability
- **Second stage**: $\sim \pm 0.5 \text{ K}$
- **Target base**: $\sim \pm 0.6 \text{ mK}$

→ Temp. stability validated for ignition target
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Conception (done)

Target base

$D_2$ filling tube

Supporting arms

He filling tube

Temp. sensors

Quartz window

4-directional mirror

Diagnostics views

Cone

Shell

Cone

Shell
Keyhole target prototype development (2/2)

- Machining (done)
- Assembly (done)
- Characterizations (done)
- Temp. sensors calibration and tightness controls (in progress)
- First liquid $D_2$ filling (coming soon)
- Validation of the target design and assembly (coming soon)
Skills under development (state of the art)

Filling and layering characterization

- Backlit shadowgraphy can readily be used for the observation of:
  - Liquid filling
  - Crystal growth
  - Roughness and defects

- For opaque shells, X-rays will be used for DT layer characterization
  - CEA's target department studied X-ray phase contrast
  - Integration for DT layer characterization is currently being studied

Numerical simulations

- Optimization of the target design (geometry, materials,…)
- Evaluation of temperature uniformity inside the hohlraum
- DT layer life span
- …
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Conclusion

- After being stopped in 2013, the cryogenic program was relaunched in 2018.

- LMJ cryogenic targets are developed and tested at CEA‘s target department.

- To this aim, the CEA developed two cryostats:
  - CRYOTECI for sensor calibrations and tightness control
  - MVT-S for target assembly and design validation

- The MVT-S is designed for achieving DT layering.

- A Keyhole target design is being tested with the MVT-S.

- X-rays phase contrast is considered for DT layer characterization.

- Numerical simulation is integrated to the target fabrication cycle.
Direction of military applications
Tritium division
Laser targets department
Cryogenics and characterization lab.