P.N.Lebedev Physical Institute
of Russian Academy of Sciences

National Research
Nuclear University «MEPhI»

CONCEPTION of CRYOGENIC TARGET FACTORY for MASS MANUFACTURING & HIGH-REP-RATE DELIVERY of the IFE TARGETS

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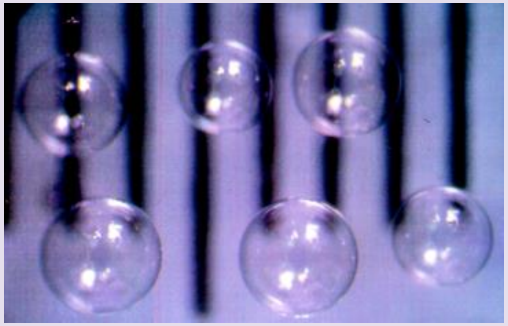
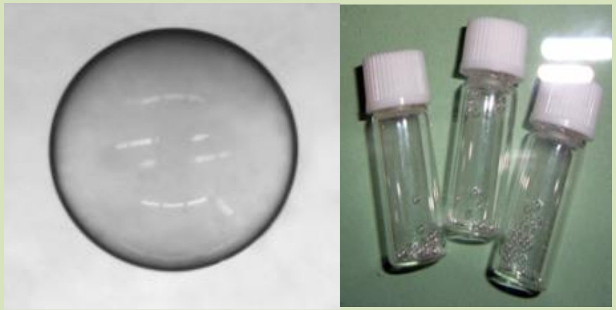
Polymer (CH) shells used in our researches

Russia



CH shells of ∅ 1,0—1,8 mm made at LPI, Russia

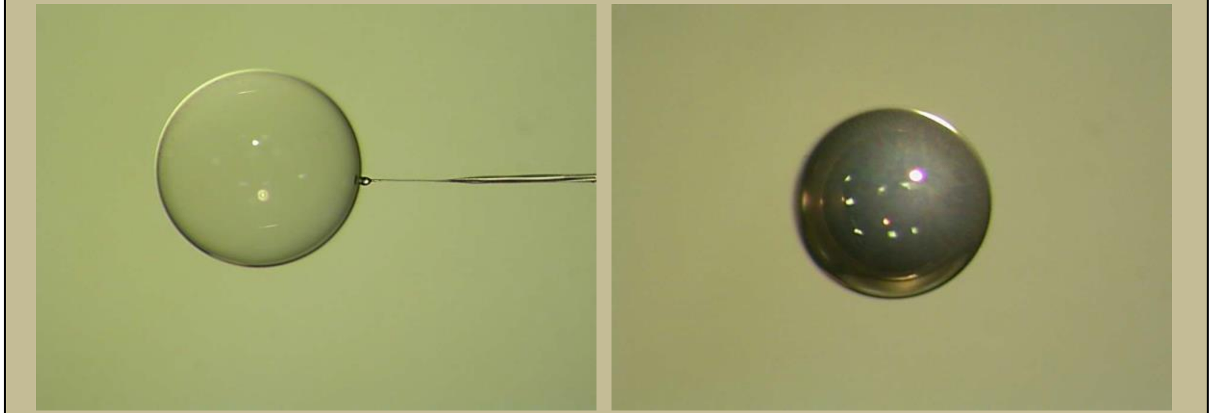
UK



CH shell of ~ ∅ 2 mm and a shell batch made at STFC, UK

CH shell is an important element of the cryogenic target

Japan



Pb coated CH shell of ~ ∅ 2 mm (at T=5K) made at ILE, Japan

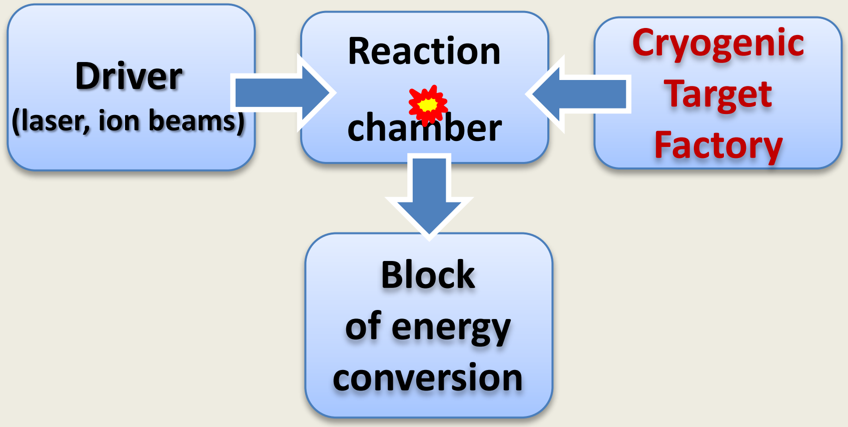
- In our research we have used CH shells (∅ ≤ 1.8 mm) made at the Termonuclear Target Lab. of the Lebedev Physical Institute (LPI, Russia)

- Large CH shells (∅ ≥ 1.8 mm) have been delivered by the Science & Technology Facility Council (STFC, UK)

- CH shells covered with a thin layer of Pb have been delivered by the Institute for Laser Engineering (ILE, Osaka Univ., Japan).

Cryogenic Target Factory (CTF) is a main building block of IFE reactor

Main building blocks of IFE reactor



Driver
(laser, ion beams)

Reaction chamber

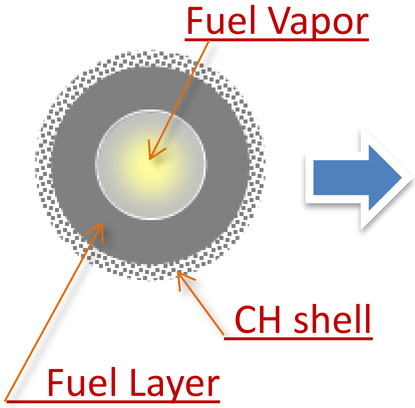
Cryogenic Target Factory

Block of energy conversion

CTF main specifications

1. **Free-standing targets mass-production:**
~ 1 000 000 targets/day (upon the average)
2. **High rep-rate target delivery:**
- injection velocity of 200 - 400 m/s
- rep-rate of ~10 Hz (laser) or 0.1 Hz (Z-pinch)
3. **Survivability of a fuel core during target delivery**
4. **On-line characterization of a flying target**
5. **Tritium inventory minimization**

Direct-drive Cryogenic Fuel Target



Fuel layer specifications

- **Thickness non-uniformity: Nu < 1.0%**
- **Inner surface roughness: δ < 1 um** rms in all modes

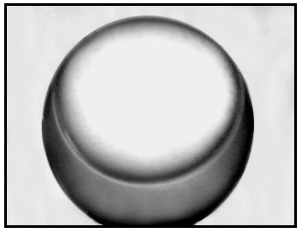
CTF critical issue:

Development of the RELIABLE, EFFECTIVE, and INEXPENSIVE METHODS of CRYOGENIC TARGETS MASS - PRODUCTION

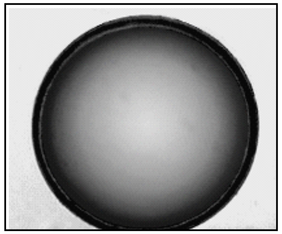
LPI CONTRIBUTION TO THE PROBLEM OF CRYOGENIC TARGETS MASS-PRODUCTION

⇒ FST LAYERING METHOD ⇒ Fuel layering in the moving free-standing targets ⇒ FST layering goes during t < 15 s. Free-standing targets move one-by-one in the LM.

Initial cryogenic target with liquid D_2-fuel



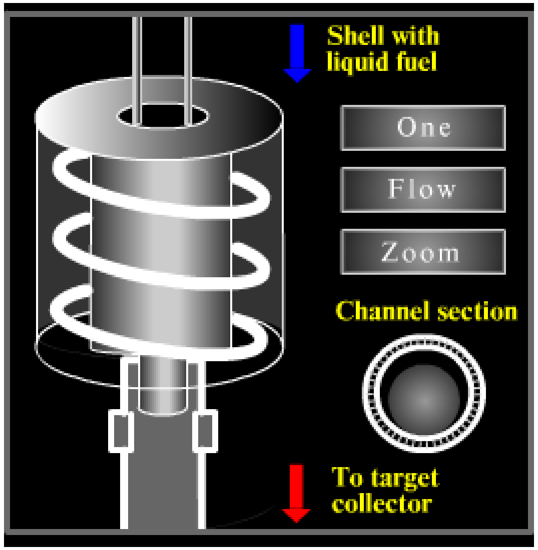
Finished cryogenic target with solid D_2 layer



CH shell: ∅ 1.23 mm
Layer: 41 um, D_2+20% Ne
Nu < 2%, δ < 0.5 um

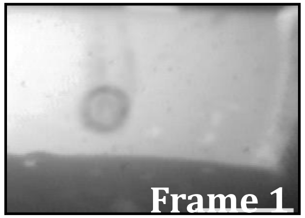
FST Layering during t < 15 sec

FST-layering module (LM): general view & physical layout

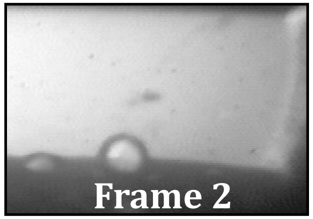


Cryogenic experiment with FST-layering module

Cryogenic target injection into the test chamber at 5 K

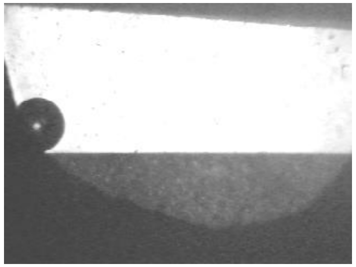


Target in free-fall

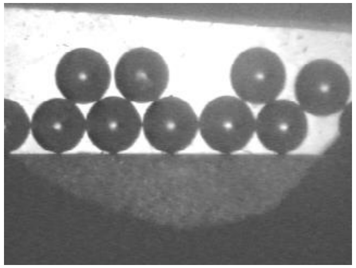


Target landing

Rep-rated injection of 1 mm targets at 5K, f =0.1Hz (batch mode)



t = 0



t = 100 s

Our calculations have shown that isotropic ULTRAFINE FUEL LAYER is required for target survival in the delivery process

SOLID H_2 ISOTOPES IN EQUILIBRIUM: ANISOTROPIC MOLECULAR HCP - CRYSTALS

◆ **HEXAGONAL CRYSTALS** ⇒ **sound velocity v depends on sound wave line about the crystallographic axes. The difference in sound velocity for H_2-crystal reach 33%** [Phys.Lett. 1972]

◆ **MOLECULAR CRYSTALS** ⇒ **mechanism of heat conduction is mainly connected with lattice conductivity, which depends on sound velocity v** (Debye`s theory): $k \sim (1/3)\, c\, v\, \Lambda$

MODELING RESULTS

Due to the thermal radiation of the reaction chamber walls, the inner surface of anisotropic fuel layer becomes non-isothermal and degrades before the target arrive at the laser focus (16 ms) [J.Phys.D:Appl.Phys. **34**, 2004]

To suppress the process of fuel surface degradation we propose to apply isotropic ultrafine fuel layers, which can be created using the FST layering method

DATA FOR CALCULATION: SOMBRERO reaction chamber: radius is 6.5 m, T_{CT} = 1758 K, j = 56 Wt/cm^2; injection velosity of a target: v_{inj} = 400 m/sec; time of target flight inside a chamber **16** msec; target T just before irradiation T=18.5K; Target : CH shell of ∅4 mm and 45 um-thick, fuel D_2–layer of 200 um-thick

The FST technology is unique and there is not alternative of that kind

- **FST principle:**

  - Targets are moving and free-standing

  - Target injection between the basic units of the LM

  - Time & space minimization for all production steps, which ensures tritium inventory minimization

- **FST result:**

  A batch mode is applied, and **high cooling rates** are maintained (1-50 K/s) to form **spherically symmetric & smooth isotropic ultra-fine solid layers** inside free-rolling targets

- **FST status:**

  FST technology and facilities created on its base are protected by the RF Patent and 3 Invention Certificates

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК
ГОСУДАРСТВЕННЫЙ КОМИТЕТ ПО ИЗОБРЕТЕНИЯМ И ОТКРЫТИЯМ
ПРИ ГОСУДАРСТВЕННОМ КОМИТЕТЕ СССР ПО НАУКЕ И ТЕХНИКЕ
(ГОСКОМИЗОБРЕТЕНИЙ)

АВТОРСКОЕ СВИДЕТЕЛЬСТВО
№ 1566437

На основании полномочий, предоставленных Правительством СССР, Госкомизобретений выдал настоящее авторское свидетельство на изобретение:
"Устройство для инжекции криогенных топливных элементов в термоядерный реактор"

Автор (авторы): Баранов Геннадий Дмитриевич, Королева Елена Ростиславовна, Листратов Владимир Иванович, Меркульев Юрий Александрович, Мишеев Геннадий Васильевич, Никитенко Андрей Иванович, Осипов Игорь Евгеньевич, Рогачев Александр Владимирович, Толоконников Сергей Михайлович и Чуманов Анатолий Николаевич

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Заявка № 4379549 Приоритет изобретения 11 января 1988г.
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ГОСУДАРСТВЕННЫЙ КОМИТЕТ ПО ИЗОБРЕТЕНИЯМ И ОТКРЫТИЯМ
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Автор (авторы): Королева Елена Ростиславовна и Осипов Игорь Евгеньевич

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ГОСУДАРСТВЕННЫЙ КОМИТЕТ ПО ИЗОБРЕТЕНИЯМ И ОТКРЫТИЯМ
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(ГОСКОМИЗОБРЕТЕНИЙ)

АВТОРСКОЕ СВИДЕТЕЛЬСТВО
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"Устройство для формирования и инжекции криогенных топливных мишеней лазерной термоядерной установки"

Автор (авторы): Королева Елена Ростиславовна и Осипов Игорь Евгеньевич

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Начальник отдела

РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ
НА ИЗОБРЕТЕНИЕ
№ 2192674

Российским агентством по патентам и товарным знакам на основании Патентного закона Российской Федерации, введенного в действие 14 октября 1992 года, выдан настоящий патент на изобретение

КРИОГЕННЫЙ СЛОЙ ТОПЛИВА,
ТОПЛИВНОЕ ЯДРО И СПОСОБ ЕГО ПОЛУЧЕНИЯ

Патентообладатель(ли):
см. на обороте

по заявке № 2001121680, дата поступления: 02.08.2001
Приоритет от 02.08.2001
Автор(ы) изобретения:
см. на обороте

Патент действует на всей территории Российской Федерации в течение 20 лет с **2 августа 2001 г.** при условии своевременной уплаты пошлины за поддержание патента в силе

Зарегистрирован в Государственном реестре изобретений Российской Федерации
г. Москва, **10 ноября 2002 г.**

Генеральный директор
А.Д. Корчагин

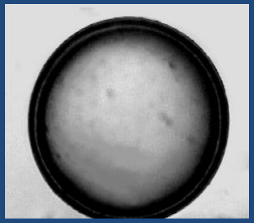
NEXT STEP: FST technology demonstration for cryogenic targets of a reactor scale with rep-rate production up to ~1 Hz and more

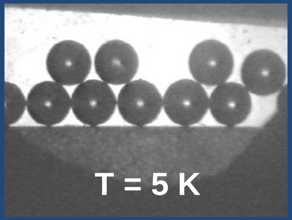
Reactor-scale targets: CH shells ∅2-4 mm, layer thickness ~200-300 um

CTF-LPI ⇒ The conception of a Cryogenic Target Factory is based on 3 approaches proposed & examined at LPI

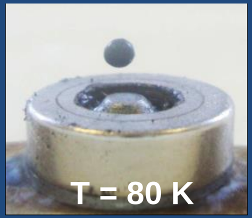
- **FST technology** ⇒ mass-production of moving free-standing targets (FST) with ultrafine fuel layer
- **Injection transport of a target between the CTF subsystems** ⇒ gravitational, electromagnetic & magnetic levitation (maglev)
- **Application of the HTSC quantum levitation effect** for almost frictionless motion of the cryogenic targets at their handling & delivery
- **Fourier holography** ⇒ for flying target tracking

The POP and computer experiments have proved the interaction efficiency of the proposed approaches


FST –layering : free-standing cryo target



Targets injection with the rate of 0.1Hz (batch mode)



HTSC coated CH shell levitating above magnet

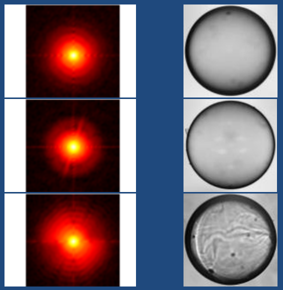
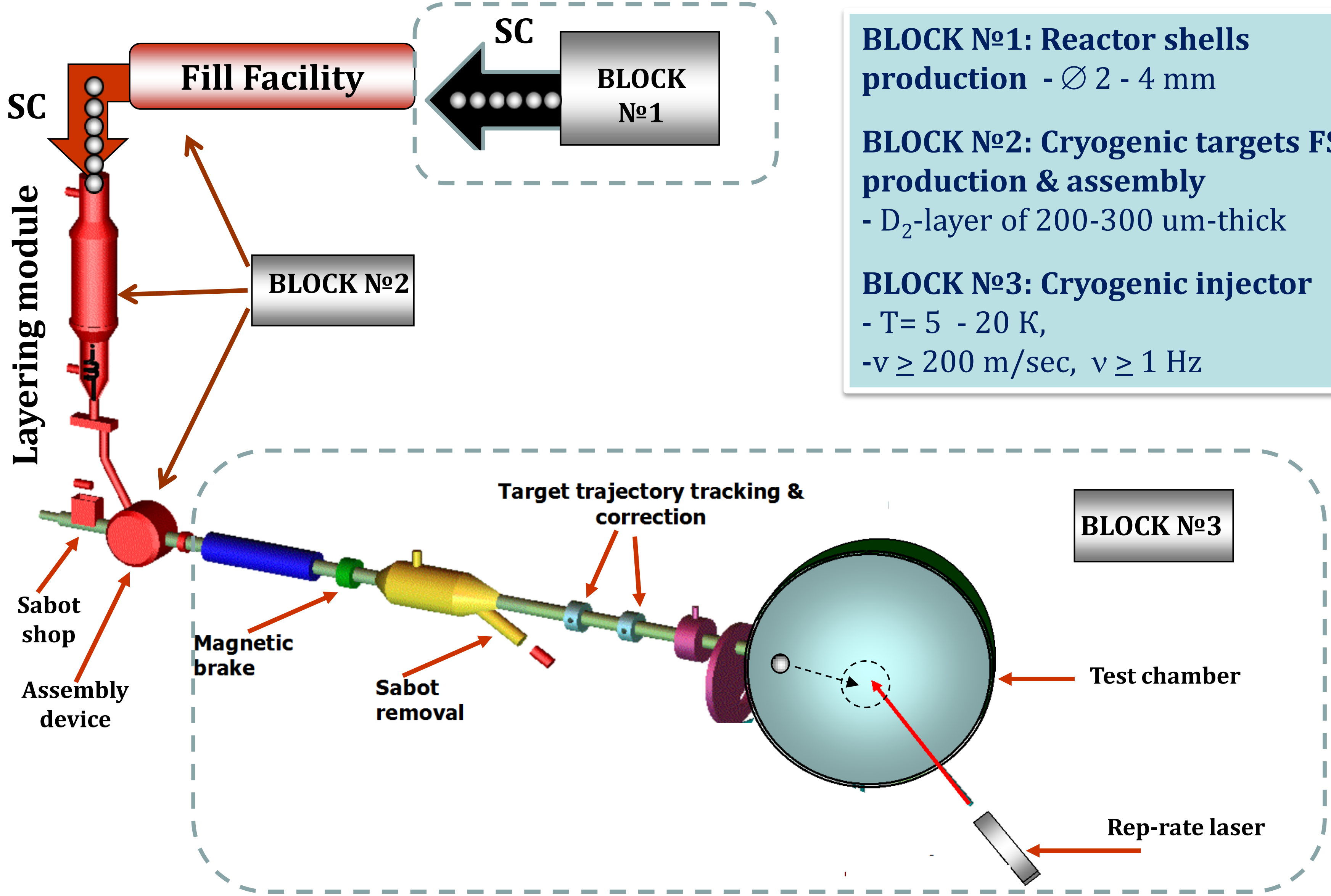


Image Fourier trans-forms of the shells with different imperfecti

CTF-LPI ⇒ modular setup for development & fine-tuning of the FST transmission line at a high rep-rate (1-10 Hz)



BLOCK №1: Reactor shells production - ∅ 2 - 4 mm

BLOCK №2: Cryogenic targets FST production & assembly
- D_2-layer of 200-300 um-thick

BLOCK №3: Cryogenic injector
- T= 5 - 20 K,
-$\nu \geq 200$ m/sec, $\nu \geq 1$ Hz

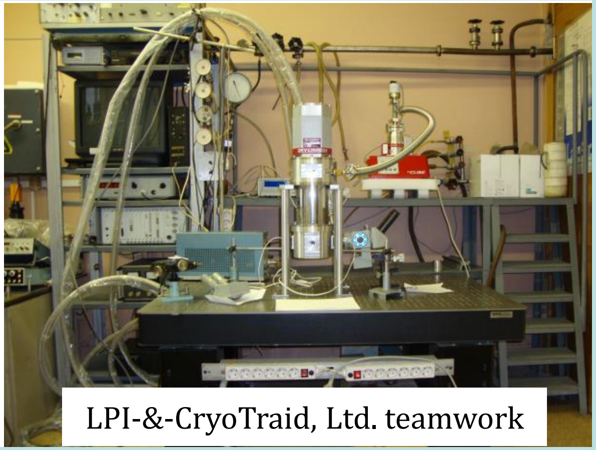
Basic elements of the CTF-LPI have been tested by LPI on the prototypical models. That allows risk minimization at the CTF construction & start-up

Layering module (LM):
FST method for fuel layering
inside free-rolling targets

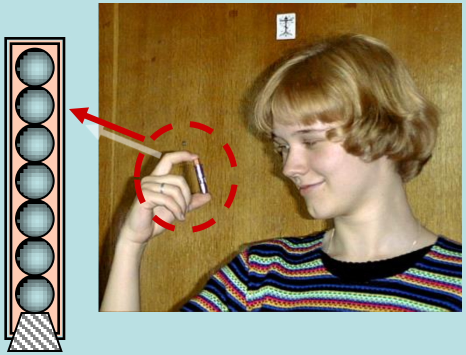
Startup of the FST facility
at the LPI in 1999

Fill facility:
Filling of CH shells with gaseous
fuel up to 1000 atm at 300K

Cryogenic target characterization:
100-projections visual-light tomograph
with 1 um space-resolution



Transport systems:
Facility for research in the area of HTSC
levitation



Handheld Shell Container (SC)
for fuel filled shells transport at
300 K from the fill system to the
FST-layering module

FST facility created at LPI: CURRENT PARAMETERS

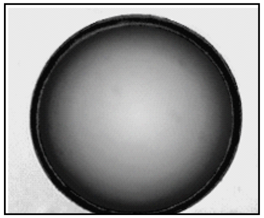
⇒ **Diffusion ramp filling of a batch of free-standing CH shells up to 1000 atm at 300 K with H_2, D_2, or their mixtures (molecular & atomic diffusion mode are available)**

⇒ **Formation of cryogenic layers inside moving free-standing CH shells ∅ 0.8–1.8 mm**

⇒ **Formation of isotropic ultra-fine cryogenic layers. Application of such layer gives the following advantages:**

– Delivery process: Enhance mechanical strength & thermal stability of a fuel layer

– Implosion process: Avoid instabilities caused by grain-affected shock velocity variations



CH shell: ∅ 1.23 mm
Layer: 41 um, D_2+20% Ne
Nu < 2%, δ < 0.5 um

⇒ **Tritium inventory minimization:**

– Fuel filling: minimal spatial scale due to close packing of free-standing targets

– Fuel layering: minimal layering time **t_f < 15 sec** (conventional methods: t_f ~ 24 hrs)

– Target transport: minimal transport time between the basic units of the CTF due to realization of injection transport process

⇒ **Rep-rate mode:** current production rate is about **ν = 0.1 Hz**

⇒ **FST layering is the most inexpensive technology** (**< 30 cents** per 1 target)

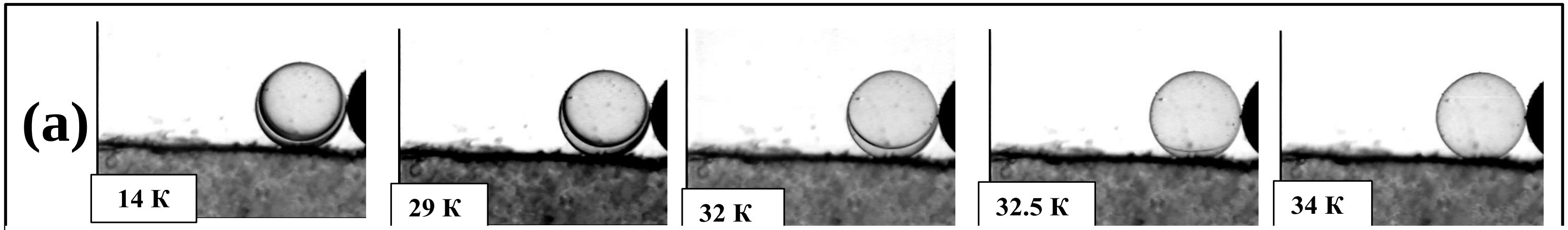
Demonstration of the fill facility operation for CH shells of ~ 1 mm diam.

Vapor bubble behavior inside the cryogenic target as function of temperature and fill pressure P_{fill} (fill density ρ_{fill}) of a fuel

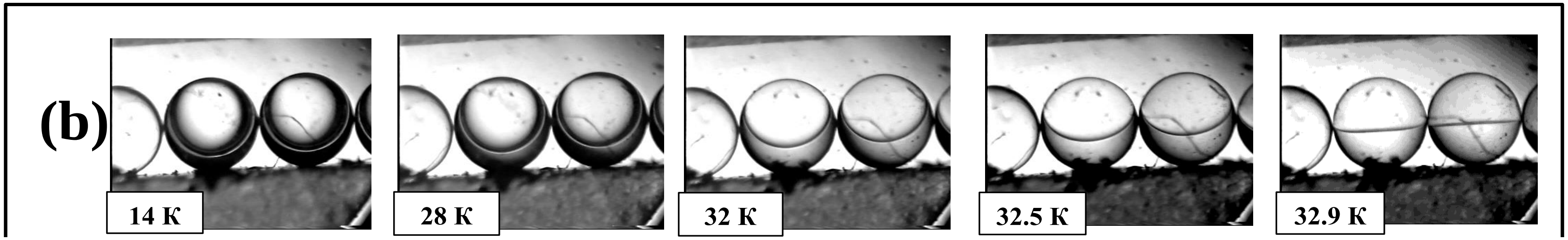
$$\frac{V_{vapor}}{V_0} = \alpha^3$$

$$\alpha(\rho_{fill}, T) = \frac{\left(\rho_{liquid} - \theta\rho_{cp}\right)^{1/3}}{\left(\rho_{liquid} - \rho_{vapor}\right)^{1/3}}$$

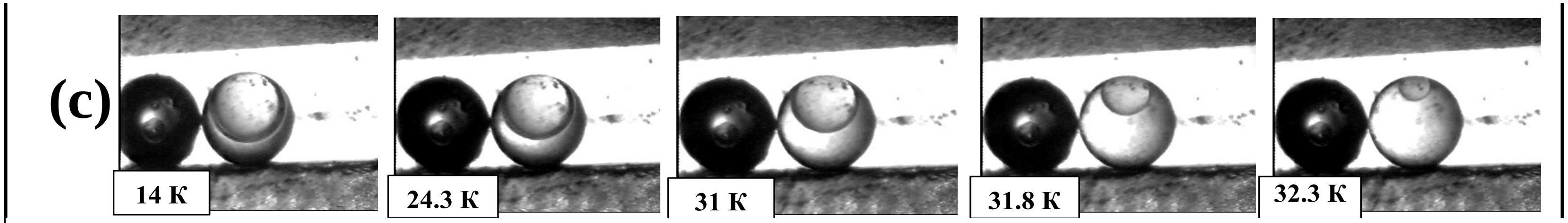
$$\theta = \frac{\rho_{fill}}{\rho_{cp}}$$



CH shell ∅ 940 um, P_{fill}= 305 atm H_2, $\theta = 0.69$



CH shell ∅ 949-953 um, P_{fill} = 445 atm H_2, $\theta = 0.93$



CH shell ∅ 980 um, P_{fill} = 765 atm H_2, $\theta = 1.32$

RESULTS OF CALCULATION: Diffusion fuel filling of a reactor-scaled target

CALCULATED TIME FOR the BODNER TARGET RAMP FILLING up to a FILL PRESSURE of 1100 atm

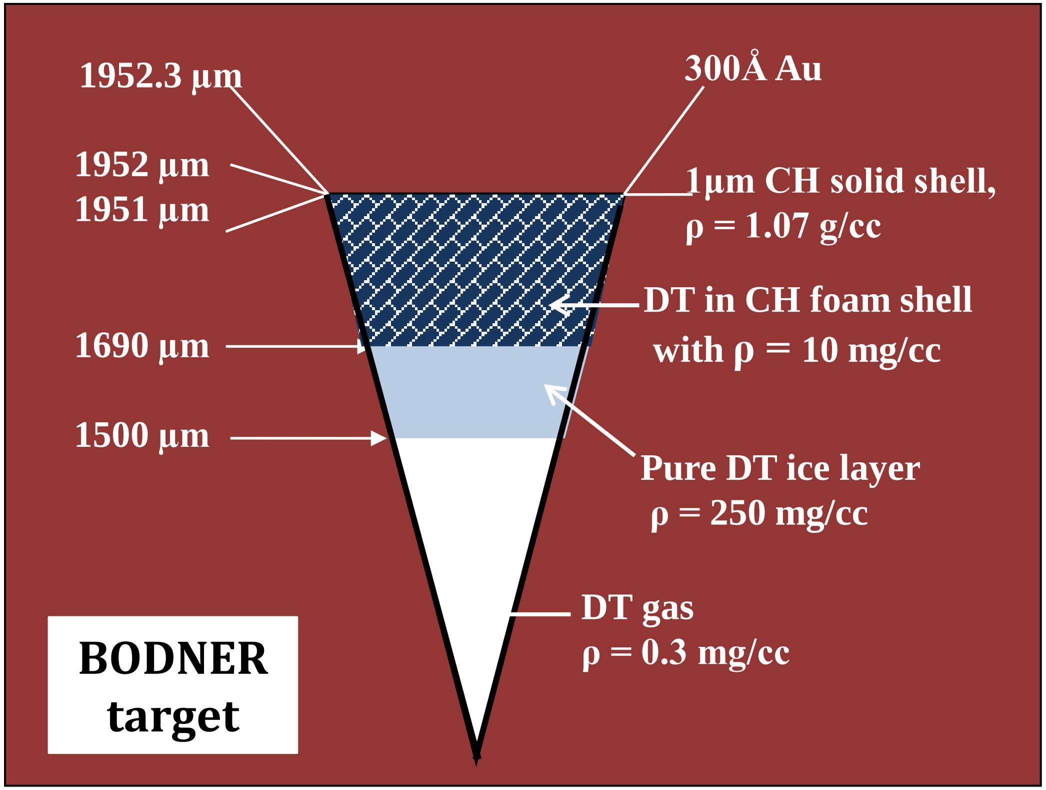
Fuel	molecular mode	atomic mode
D_2 fuel	$t_{md} = 7$ hrs	$t_{ad} \simeq 5$ hrs
DT fuel	$t_{md} \simeq 8$ hrs	under consideration

Notations:

t_{md} – time of fuel filling in molecular diffusion mode

t_{ad} – time of fuel filling in atomic diffusion mode

Shell material - polyimide, E= 15 GPa; P_{buckle}=0.3376 atm

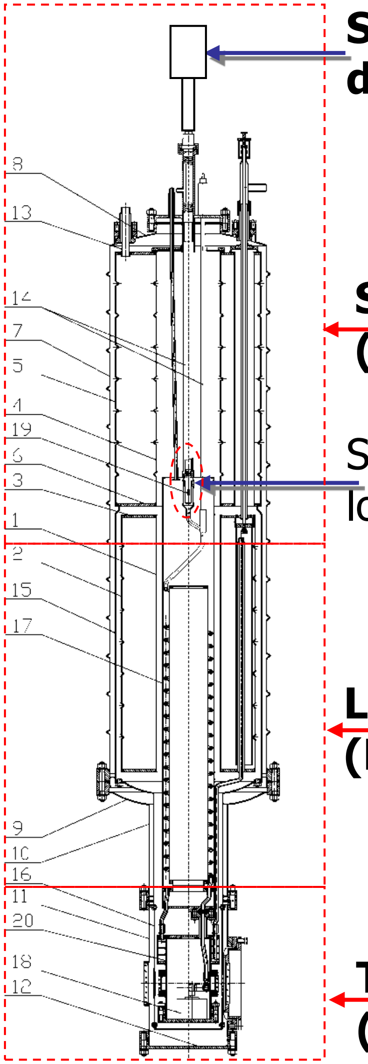


Baseline design of high gain direct-drive target

[Bodner et al. Phys. Plasmas **7**, 2298, 2000]

CTF-LPI ⇒ FST-layering module designed by LPI for EU project HiPER can serve as a prototype for 1 Hz operation in a batch mode

❑ Drawing of the FST-layering module



SC driver

Shell Container (SC) unit

SC location

Layering Channel (LC) unit

Test Chamber (TC) unit

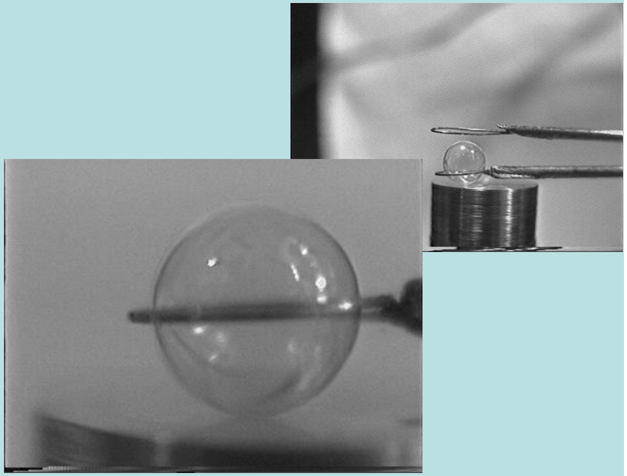
❑ General units & estimated weight

FST-layering module	Weight, kg
Helium cryostat (total)	**41,3**
Helium cryostat casing	16,8
Nitrogen vessel	10,1
Thermal screen	6,9
Outer helium vessel	7,5
Insert (total)	**5,88**
- sluice-safe unit	2,2
- layering module	2,9
- shaft of lock	0,07
- key	0,71
Optical test chamber (total)	**8.95**
- helium chamber with PD	2,4
- TC thermal screen	1,0
- TC frame	2,8
- flange	1,45
- windows	0,95
- location bracketry	0,35
Frame (total)	**13,7**
SC with interface (total)	**1,7**
SC	0,25
Interface	1,45
TOTAL	**71,53**

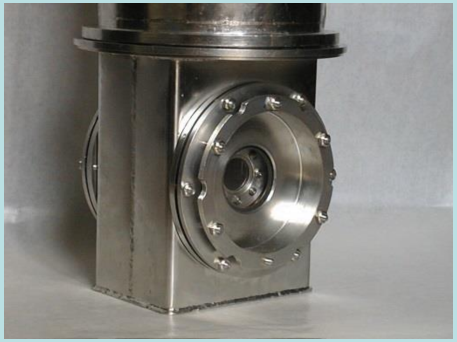
FST-layering module designed for HiPER: we have constructed a number of mockups and carried out the mockups testing to minimize possible risks

Cryostat and the sample holders for HTSC maglev study at T < 20 K

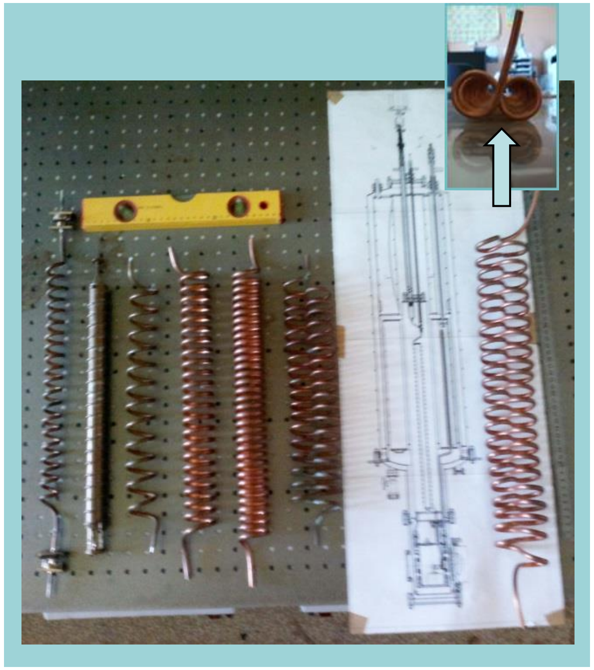
Shell container (SC)



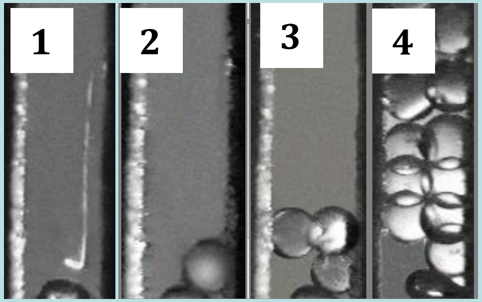
Positioning device with the ring manipulator



Optical test chamber

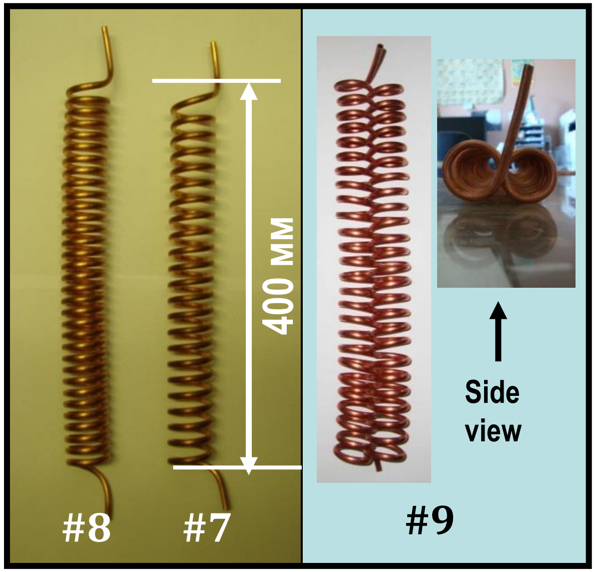


A set of the FST-layering channels (LC)



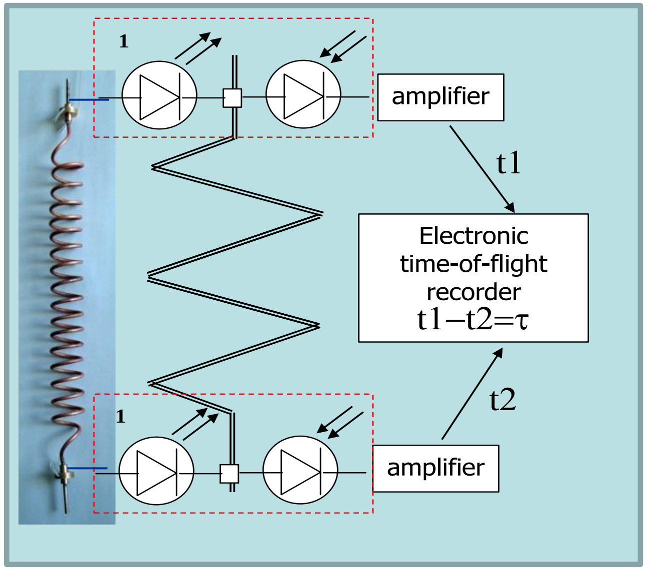
Target collector: demonstration of targets gravity injection

EXPERIMENT: a double-spiral FST-layering channel (LC) is a good prospect for reactor targets production



Mockups of the spiral LC

#7, #8 ⇒ single-spiral LC (**SSLC**),
#9 ⇒ double-spiral LC (**DSLC**),
Cupper tube OD=38mm



Schematics of measuring the time of target movement inside the LC
1 – optronics couple made from IR-diodes

Calculations

FST-layering time for reactor-class targets

$t_l \geq 16$ s

Experiment

t_m - time of target movement in a channel, data averaged for 10 shots

SSLC	DSLC
$t_m \leq 16$ s	$t_m = 23.5$ s

FOURIER HOLOGRAPHY OF IMAGE RECOGNITION: promising way for on-line characterization of a flying target

[Nikitenko, et al. Nuclear Fusion, 2006]

Computer experiments demonstrated much promise of Fourier holography because it allows

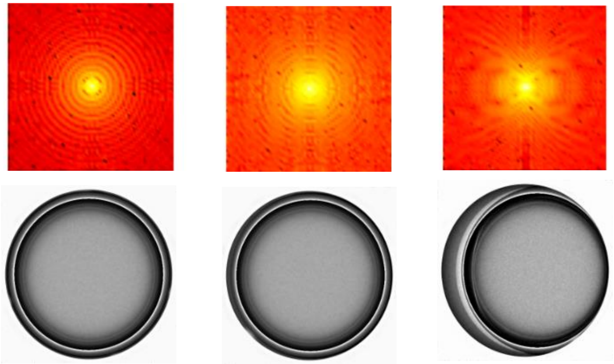
- Recognition of the target imperfections in both low- & high- harmonics
- Quality control of both a single target and a target batch
- Simultaneous control of the injected target quality, velocity & trajectory

Operation Principle:

Recognition signal is maximal if the real image is in strict conformity with etalon image

Operation Rate:

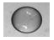
Operation rate of the Fourier holography scheme makes **several microseconds**



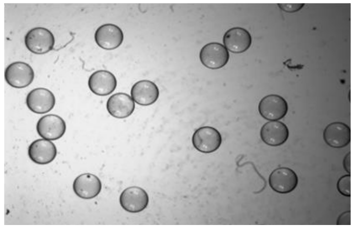
Δx/R=0 Δx/R=1.5% Δx/R=14.9%

Fourier transforms of the simulated images of cryogenic targets

► Simulation code *SHELL OPTICS MODEL* developed at LPI has been used



← Etalon image



Studied image of the shell batch

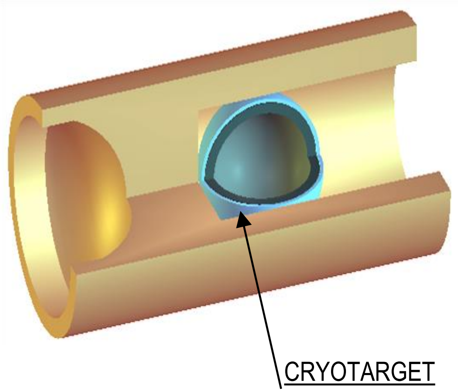
Cross-correlation matrix of the studied & etalon images

TARGET SURVIVAL RESUME ⇒ Successful target delivery requires both multiple target protective metods & ultra-fine fuel layers formation

PROTECTIVE SABOT

we have optimized

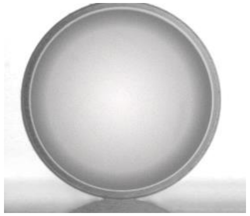
- Shape of target support
- Target injection temperature
-Sabot material



Protective sabot with cryogenic target inside it

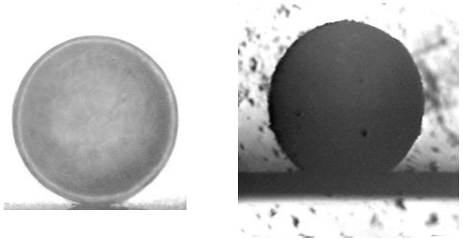
ISOTROPIC ULTRA-FINE FUEL LAYER with inherent survival features

- Withstand to higher heat- & g-loads than a crystalline layer
- No influence on shock wave propagation through isotropic ultra-fine fuel layer



Cryogenic target with the ultra-fine D_2 layer

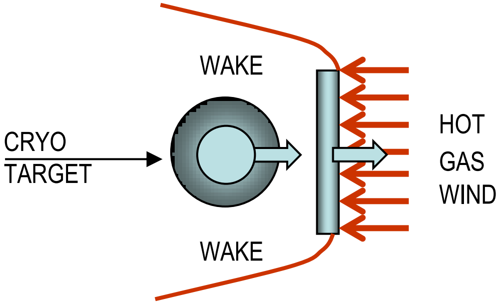
OUTER PROTECTIVE LAYERS



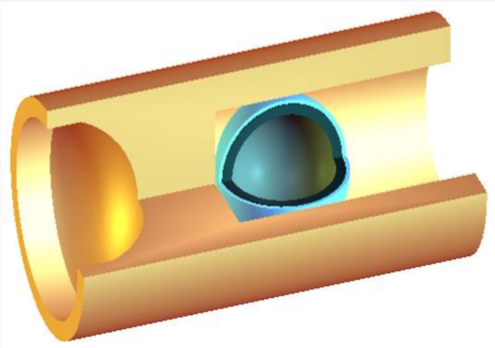
Cryogenic target with Pt/Pd outer layer (left) and with solid O_2 outer layer (right)

PROTECTIVE COVER

forms a wake area in the fill gas to avoid convective heating



SABOT is USED at a STAGE of TARGET TRANSPORT & INJECTION INTO a REACTOR CHAMBER



Target-&-Sabot assembly unit

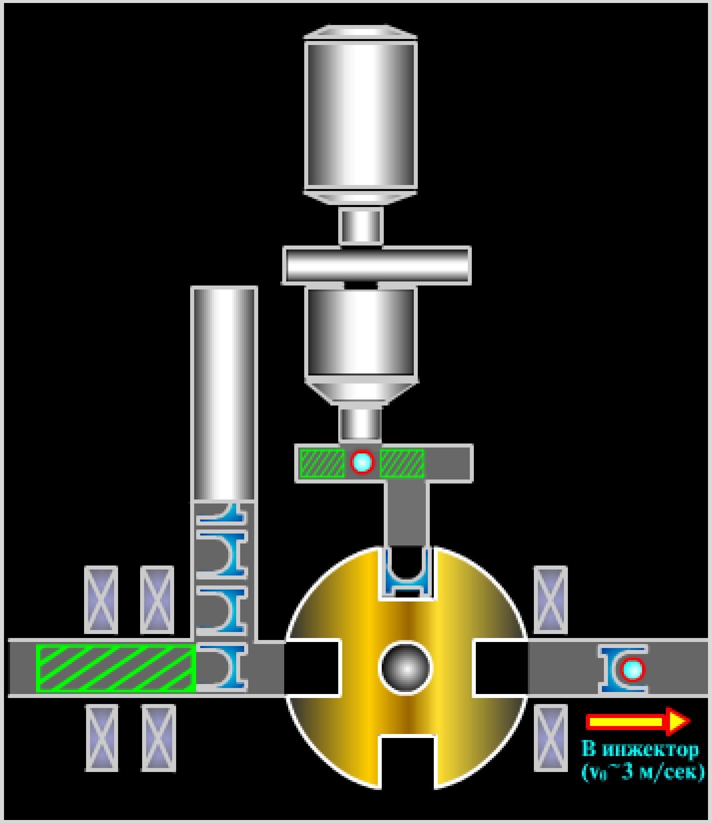
- **SABOT is used for**

- to transfer target from the LM to injector

- to transfer of an impulse of the movement on a target inside the injector

- to protect target from the heat- and g-loads arising during target acceleration

- **Concept of the device for Target-&-Sabot high rep-rate assembly**



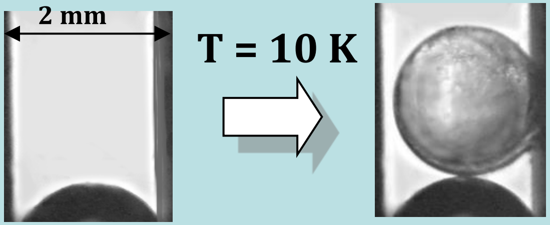
Work at T = 5 –to-20 K

Prototyping a gravity assembly of "TARGET-&-SABOT" units at T < 18K & refining a trajectory control of flying shells

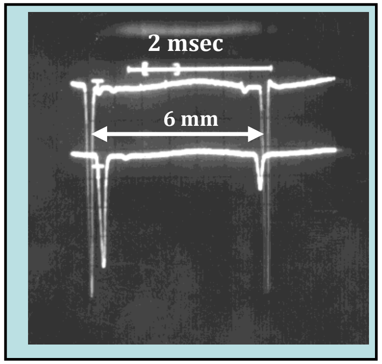
Gravity injector (test setup)

developed by the LPI and the Rutherford Appleton Laboratory (UK)
1989-1991

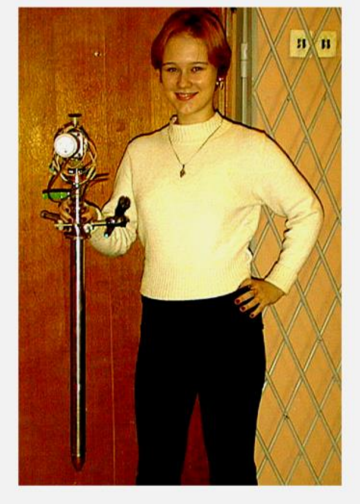
Prototyping a gravity assembly of "Target-&-Sabot" at T = 10 K



Gravity delivery of cryogenic target from the FST-layering channel into a cylindrical cavity



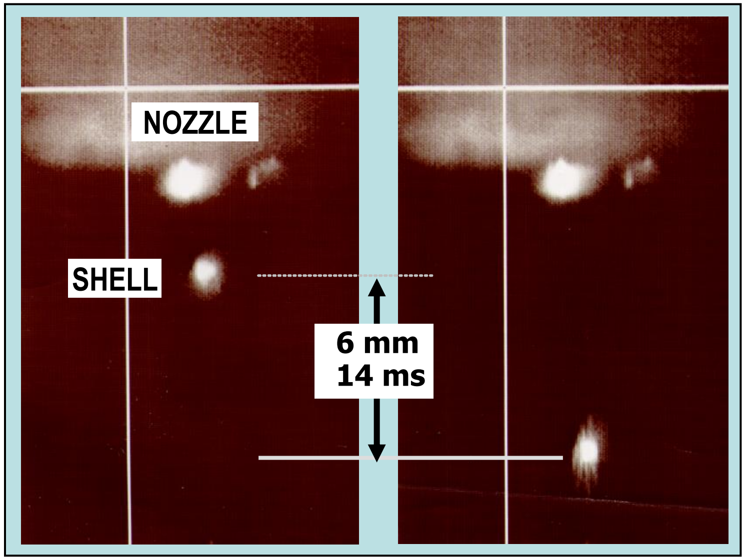
Double-beam oscilloscope data of the injected shells



Prototype of a gravity injector integrated with the FST- layering channel

High-speed video filming of injected shell into the test chamber;

Video-camera *KODAK ECTAPRO 1000 IMAGER*



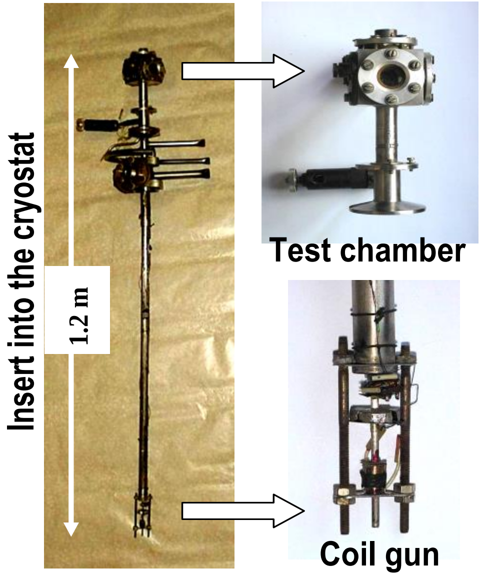
Refining *on-line* control of the flying shells trajectory

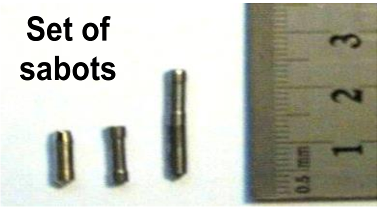
Data for 50 shots

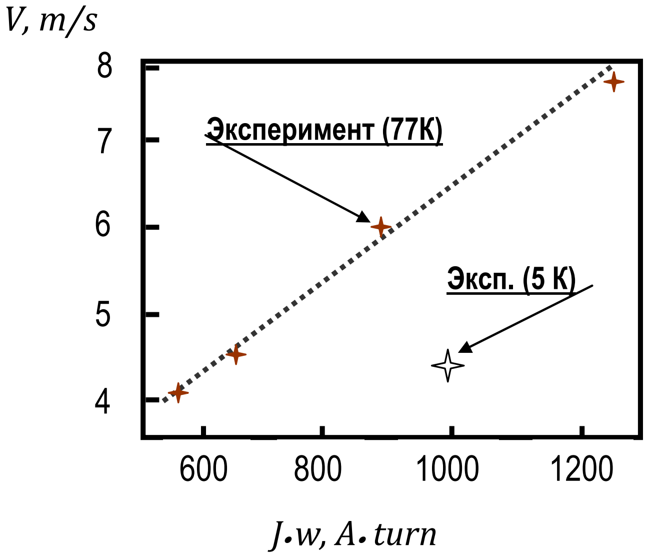
(for CH shells of ∅ ~ 1 mm)

1. **Trajectory angular spread ≤ 3 mrad**
2. **Injection velocity 0.43 - 0.55 m/s**

Demonstration of the electromagnetic transport of sabot from soft ferromagnetic at cryogenic temperatures (T = 77 -to- 5 K)







Experiment**: Sabot velocity* ***v** (m/s) at the coil exit vs.* ***Jω

Maximal overloads:

a = 320g (at v = 8 m/s)

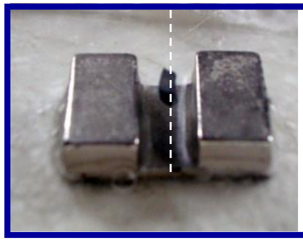
- ❑ **Experiment:** Magnetic penetration of ARMCO iron is enough high at cryogenic temperatures. This makes it possible to accelerate sabot up to 3 - 8 m/s using only one coil. These velocities ensure target transport at a start position in the injector.

❑ **Problems:**

1. **Heat-loads due to sabot/guiding bore friction**
2. **Sabot tilting & wedging inside guiding bore**

Resume: sabot trajectory correction & elimination of friction are needed

❑ **Correction of a trajectory of a cylindrical HTSC sabot using the magnetic field** (RFBR proj. #15-02-02497)



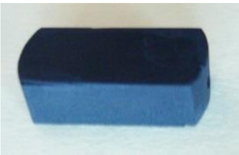
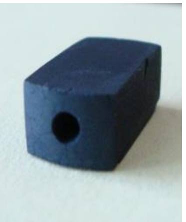
Experiment: HTSC sample *(8x2x2 mm) aligns along the line of minimal magnetic induction between 2 rectangular permanent magnets, T=80K*

HTSC QUANTUM LEVITATION EFFECT FOR TARGET HANDLING & TRANSFER:
We have studied the HTSC samples made by different technology

I

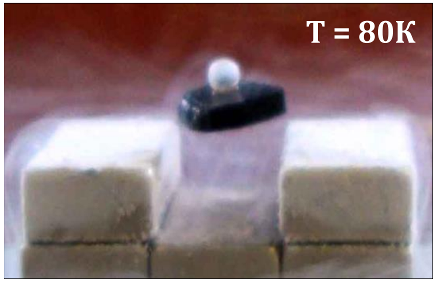
YBa_2Cu_3O samples

created by the technology of solid phase reactions (made at LPI)

Sabot. Model C2:
8 x 6 x 2 mm


Sabot. Model C3:
OD 5 mm, ID 2 mm, length 16 mm

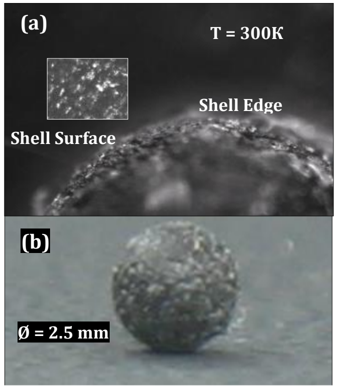


HTSC substrate (with CH shell on it) levitating over the PMG-1

II

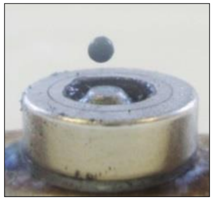
HTSC coated CH shells.

HTSC layer: YBa_2Cu_3O powder distributed over the polymer matrix (made at LPI)



CH shell with an outer Y123- layer (micro- particles ~ 30– 50 µm)

One more shell with an outer Y123- layer (micro-particles ~ 10 µm)



HTSC coated CH shell levitating over the PMG-2 at T = 80 K

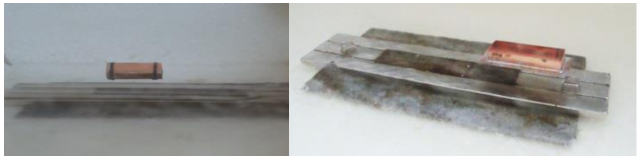
III

HTSC tape:

12 mm-width, 65-um total thickness including 1 um-thick epitaxial **$GaBa_2Cu_3O$** film
Technology: thin films deposition using laser ablation
(made at SuperOx, Moscow)

Sabot. Model CX:
8 x 4 mm, length 24 mm


Sabot. Model C1:
5 x 5 mm, length 16 mm



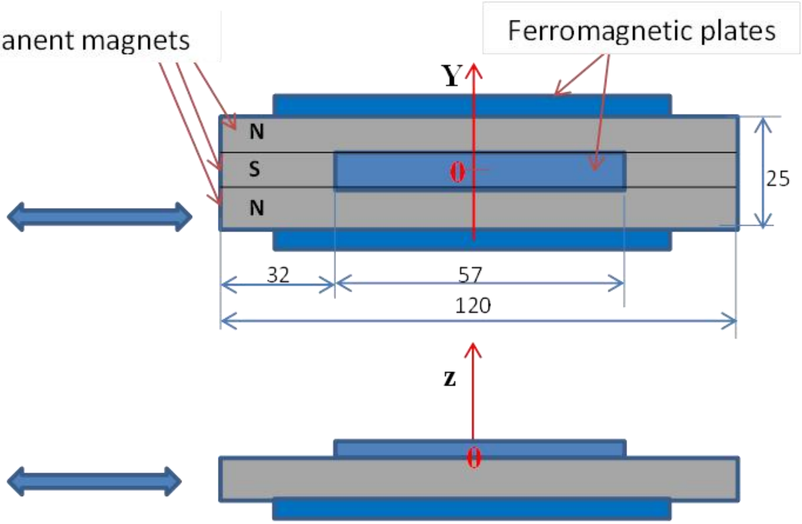
Sabots C1 and CX levitating over the PMG-3 at T = 80 K

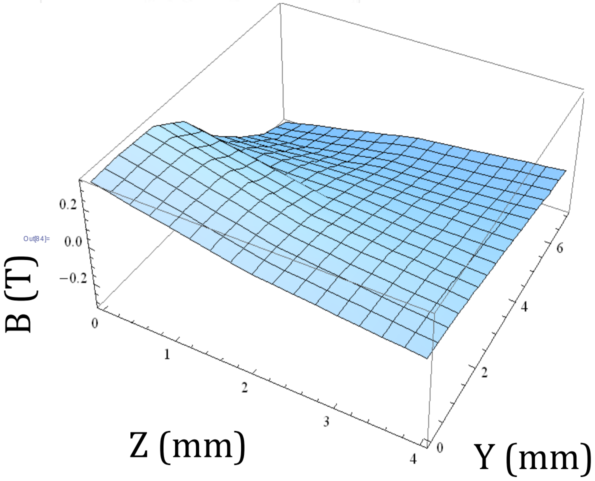
***/ PMG = permanent magnets guideway**

Permanent Magnetic Guideway (PMG-3): magnetic braking of lateral motion of the HTSC samples (demo at T = 80 K)

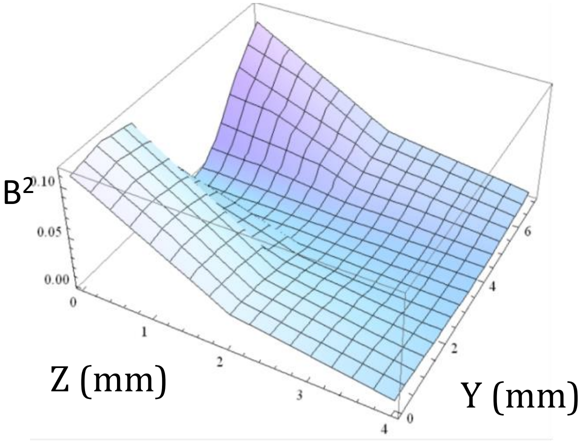
Top view

Side view



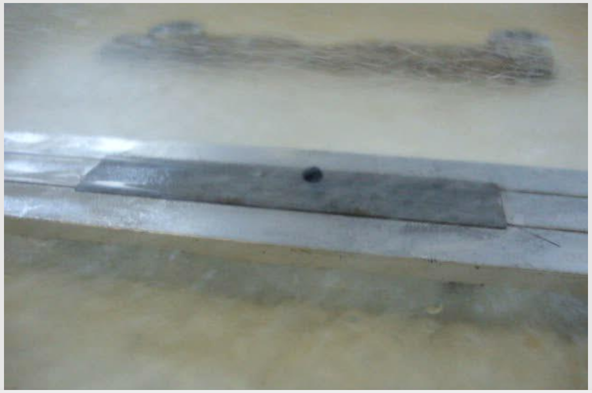


Field distribution



Distribution of B^2 : min is seen near the pole

- ☐ PMG-3 is a composition of NdFeB magnets & SFM tape
- ☐ HTSC samples made at LPI



YBa_2Cu_3O coated CH shell
of ∅ 2 mm

YBa_2Cu_3O pellet
of 12.4 mm-diam, 1-mm-thick

HTCS material study: HTSC samples stable levitation & movement in the magnetic field of the permanent magnets

❑ **Stable levitation of HTSC samples at different temperatures** (NdFeB magnets)

T = 6K -to- 18K,
HTSC sample from
YBa_2Cu_3O (made at LPI)
6x2x2 mm

T = 80 K,
HTSC sample from
YBa_2Cu_3O (made at LPI)
6x2x2 mm

❑ **Ordered motion of HTSC carrier with CH shell over the magnetic rails** (SrBa ferrite magnets)

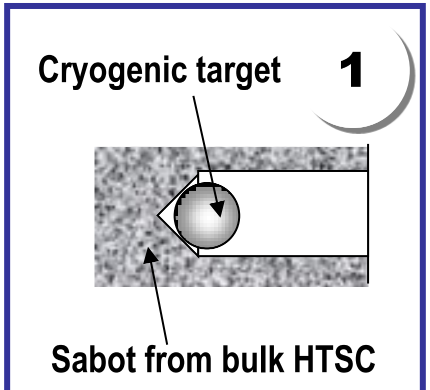
T = 80 K, PMG-3a CH shell: ∅ 2 мм (made at LPI)
HTSC carrier: ~ 5 mm^{2,} **YBa_2Cu_3O** (made at LPI)

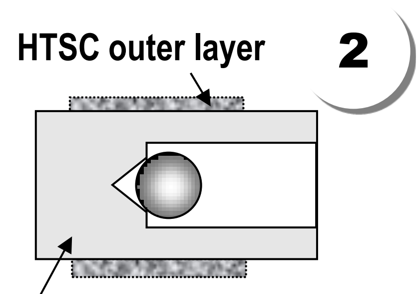
❑ **HTSC sample cycling over the magnetic rails** (NdFeB magnets)

T = 80 K, PMG-4
HTSC tape (SuperOx, Moscow)**:**
12 mm-width, 65-um total thickness including
1 micron-thick **epitaxial $GaBa_2Cu_3O$ film**

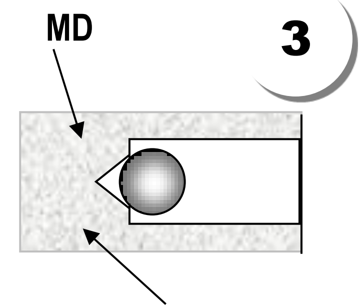
Conception of electromagnetic injector with HTSC sabot

(HTSC material is under consideration)





Magneto-dielectric (MD): Fe-particles distributed over the polymer matrix

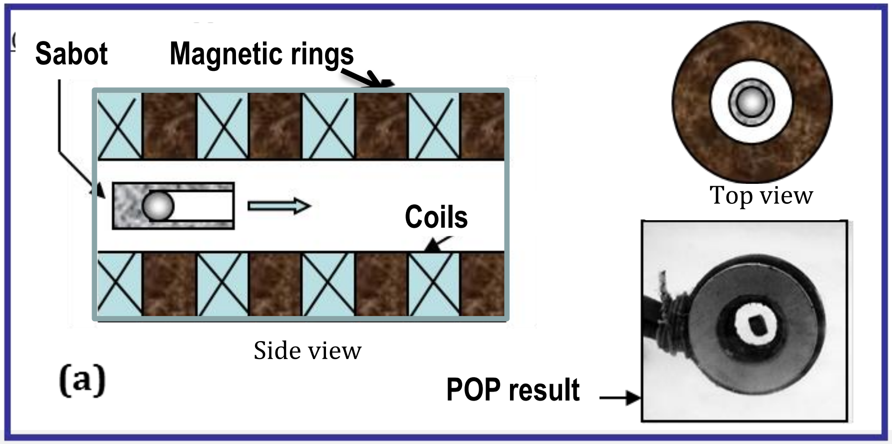


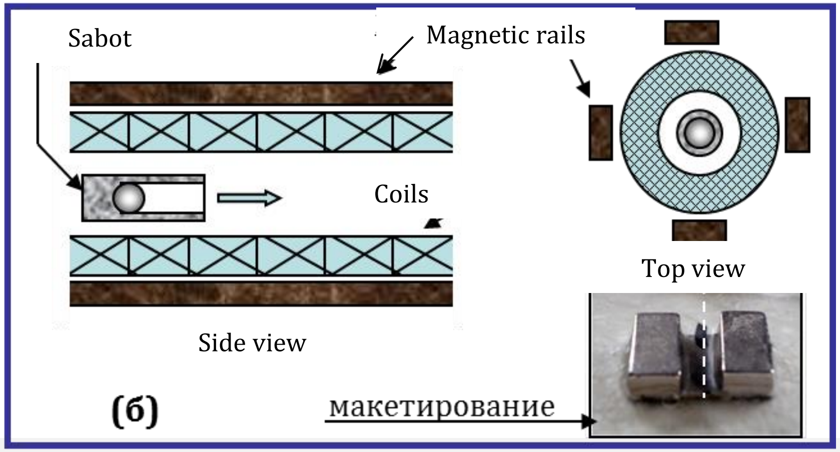
Micro-particles from HTSC & Fe, distributed over the polymer matrix

HTSC sabot acceleration using one coil (movement over the PMG-3).
Current: 200 A, 1 ms

IMG_2453++.MOV

Sabots for almost frictionless motion inside the electromagnetic injector, which enhance the operating efficiency of maglev accelerator





E-m injector + HTSC projectile. A design options with the HTSC sabot

Ref.: The possibility of HTSC sample acceleration using 2 coils has been proved in model experiments carried out in Gifu Univ., Japan [H.Yoshida, 3rd IAEA TM, Oct. 2004, Rep.Korea]

The next step is our new project started in December 2015 under IAEA contract # 20344/R0

- **Project title:** **FST transmission line for mass manufacturing of IFE targets**
- **Project goal** is modeling (exp. & theory) of the fabrication and injection processes of an FST transmission line for mass manufacturing of IFE targets.
- **Project approach** is the FST layering method developed at LPI.
- **Project targets** are CH shells of Ø ~ 4 mm, and the layer thickness of ~ 200 um for pure solid fuel and of ~ 300 um for in-porous solid fuel.
- **Our background for this project presented at**
  – 1st Meeting of IAEA CRP on Pathways to Energy from Inertial Fusion: Materials beyond Ignition (Feb. 2016, Vienna, Austria)
  – 7th IAEA TM on Physics and Technology of IFE Targets & Chambers (March 2015, Vienna, Austria)
  – 25th IAEA FEC (Oct. 2014, St. Petersburg, Russia)

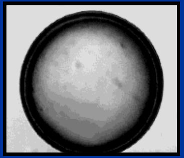
25th IAEA FEC, 2014

Work group meetings

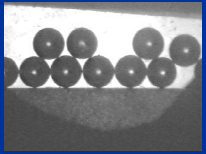
7th IAEA TM, 2015

SUMMARY

- FST layering method has been developed at LPI, which forms an isotropic ultrafine & spherical fuel layer inside unmounted free-rolling targets
- Our study has shown that application of such layers makes the risk of layer destruction minimal during cryogenic target delivery – ISTC #1557, IAEA #13871
- A full scaled scenario of the FST transmission line operation has been demonstrated at a small scale (targets < ∅ 2 mm) - ISTC #512, IAEA #11536
  - ⇒ Fueling a batch of free-standing targets (up to 1000 atm D_2 at 300 K),
  - ⇒ Fuel layering using FST technology: cryogenic layer up to 100 um-thick,
  - ⇒ Target injection into the test chamber with a rate of 0.1 Hz
  - ⇒ Target tracking using the Fourier holography approach (computer expts)
- A number of injectors has been considered to study the cryogenic target delivery, including gravitation, electromagnetic and maglev one
- A number of POP experiments prove the efficiency of using the HTSC quantum levitation effect for free-standing target positioning & transport. We continue the study in the frame of the RFBR project # 15-02-02497.
- A prototypical FST layering module for rep-rate production of HiPER-scaled cryogenic targets has been designed based on the results of calculations and mockups testing. Work was accomplished in the frame of EU project HiPER.
- LPI continue developing the R&D program on CTF-LPI in the frame of new generation project under IAEA contract # 20344/R0 (started at Dec. 2015)

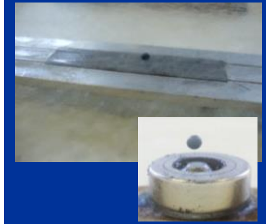


Cryo target with ultrafine fuel layer (∅1.5mm)



Targets rep-rate injection under gravity: 0.1Hz, 5K

Cryogenic gravity injector



HTSC maglev for target positioning & transport