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Target fabrication technologies and noncontact delivery systems to develop a free-standing target factory operating in the repetition mode at the IFE relevant level

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ABSTRACT

- Our objective of the study was to develop conceptual designs of the FST factory including IFE target muss-manufacturing followed by their rep-rate delivery at the reactor chamber. In this report, the detailed modeling and proof-of-principle (POP) experiments are outlined and discussed.

BACKGROUND

- The main processes related to mass-fabrication and rep-rate delivery of the cryogenic targets (everywhere further − Target) to the burn area are as follows: (1) fuel filling (T=300 K); (2) fuel layering (T < 18.5 K); (3) “Sabot+Target” rep-rate assembly and transport to the start point of the injector (v ~1 m/s, T<18.5 K); (4) “Sabot+Target“ acceleration (v ~ 200 − 400 m/s, overloads a < 500 g, T < 18.5 K) (5) Sabot separation from the Target followed by the Target injection into the reaction chamber; (6) on-line characterization of the flying Target.
- The LPI developed the main principles to realize the above processes [1, 2]: 1. Diffusion filling of a shell batch using the created facility; 2. FST-layering method for in-line target production with an isotropic fuel layer; 3. Using of high-temperature superconductors (HTSC) & permanent magnet guideway (PMG) systems to develop magnetic levitation (HTSC-maglev) technology for noncontact Target delivery. Propulsion system includes the field coils to generate magnetic travelling waves that act on the assembly of “HTSC-Sabot + Target” for its transport with levitation in the PMG of linear or cyclic type. 4. Fourier holography for application to on-line characterization of flying Target in terms of its quality & trajectory.
- General schematics of the FST-Factory proposed by LPI is shown in Fig.1.

CHALLENGES / METHODS / IMPLEMENTATION

The units of the FST-Factory considered in this report are: (1) module for in-line Target fabrication, & (2) module for Target delivery.

FST-LAYERING METHOD FOR IN-LINE PRODUCTION OF CRYOGENIC TARGETS

Three processes are mostly responsible to keep fast (due to high cooling rates 1−50 K/s) isotropic layer formation in the moving targets (Fig. 2): (1) target rotation results in a liquid layer symmetrization; (2) heat conduction through a small contact area results in a liquid layer freezing; (3) isotropic fuel structure is formed by using a special doping to the main fuel.

NONCONTACT TARGET DELIVERY BASED ON QUANTUM LEVITATION

The high-power laser experiments with repetition rates of 1-to-10 Hz require developing noncontact delivery systems for safe, stable and friction-free Target transport at the laser focus. In our approach the operational delivery principle is based on a quantum levitation effect of HTSCs in the mutually-normal magnetic fields. Our estimations promise a stable and self-controlled levitation to accelerate the Targets placed in the HTSC-sabot up to the required injection velocities 200 m/s and beyond.

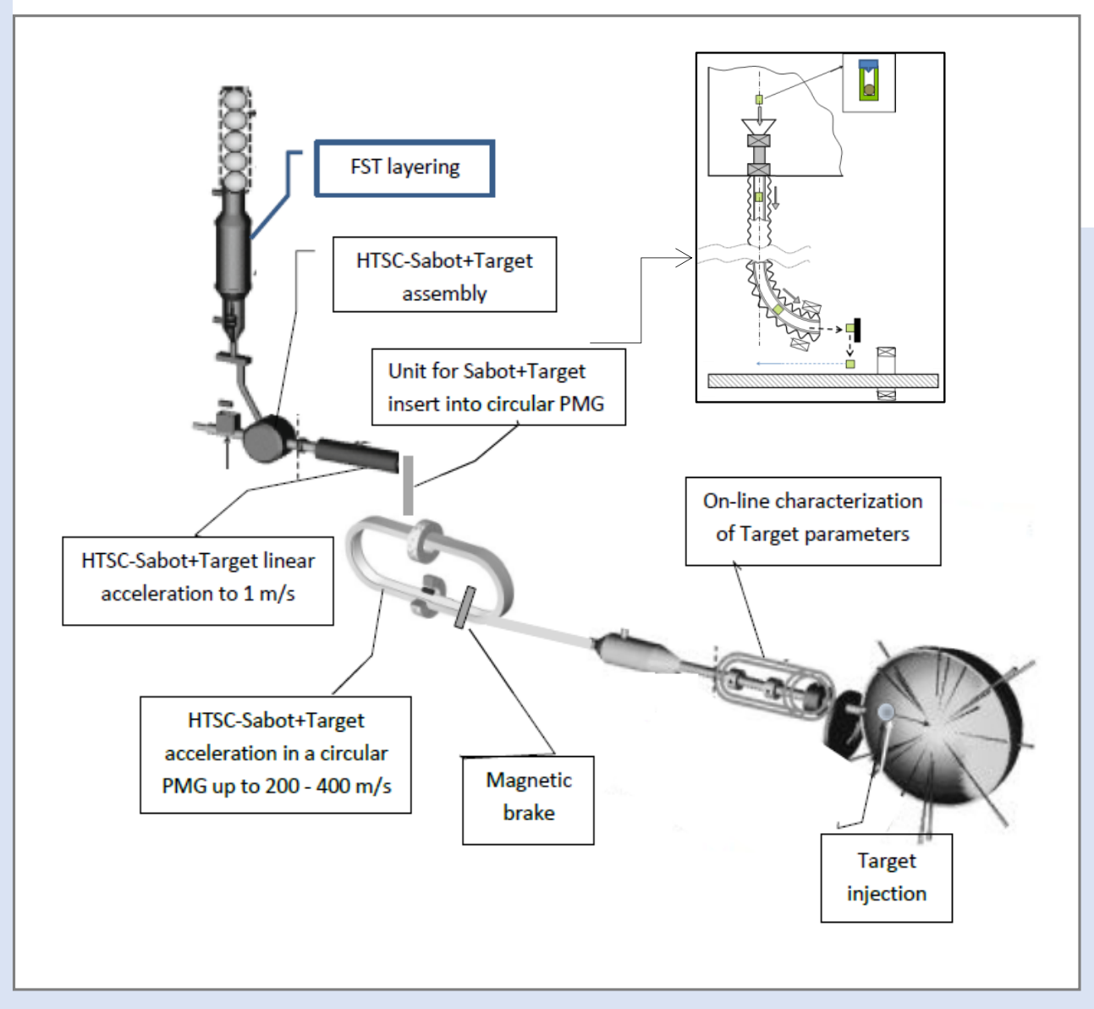
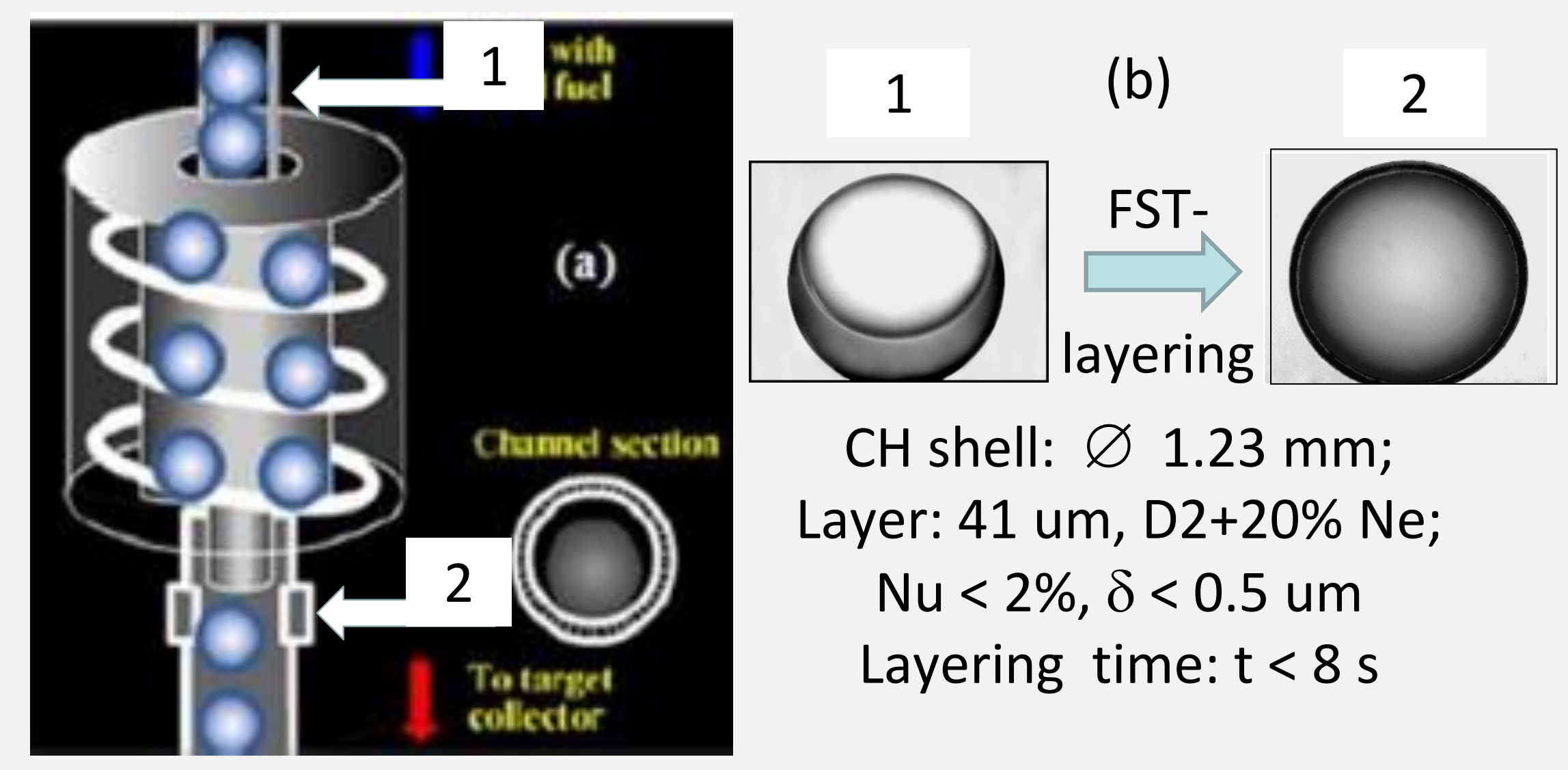


Fig. 1. Schematics of the FST-factory



CH shell: ∅ 1.23 mm;
Layer: 41 um, D2+20% Ne;
Nu < 2%, δ < 0.5 um
Layering time: t < 8 s

Fig. 2. Schematics of the FST-layering module (a) and the FST-layering result (b)

OUTCOME

ISOTROPIC FUEL LAYER FABRICATION USING THE FST-LAYERING METHOD

Application of the FST-layering method using high cooling (q = 1−50 K/s) combined with fuel doping (neon, argon) results in creation of stable isotropic cryogenic layer structure (Fig. 3).

“HTSC-SABOT+TARGET” DELIVERY: CALCULATIONS & MOCKUP TESTING

- **Mockup test results** (Fig. 4): HTSC-Sabot acceleration with levitation, in (a) linear accelerator scheme; in (b−c) mockup of the HTSC-Sabot acceleration up to 1 m/s at T = 80 K over the linear PMG under the action of electromagnetic pulse of 1 coil.
- **Results of calculation**: The driving body from MgB_2 superconducting coils as an HTSC-Sabot component (I_{CR} = 5000 A, B = 0.25 T) allows reaching the injection velocities 200 m/s under 400g overload at 5-m-acceleration length (the number of the field coils 200). Schematic of the linear accelerator in shown in Fig. 5.
- **Optimization**: Recent LPI results may help improving the design of the linear accelerator by using a cyclic one with a PMG system having a magnetic track as an oval-shaped rail. It allows significant reduction of the accelerator dimensions and the number of the field coils. Fig. 6a,b shows a schematics and a mockup of the cyclic accelerator.

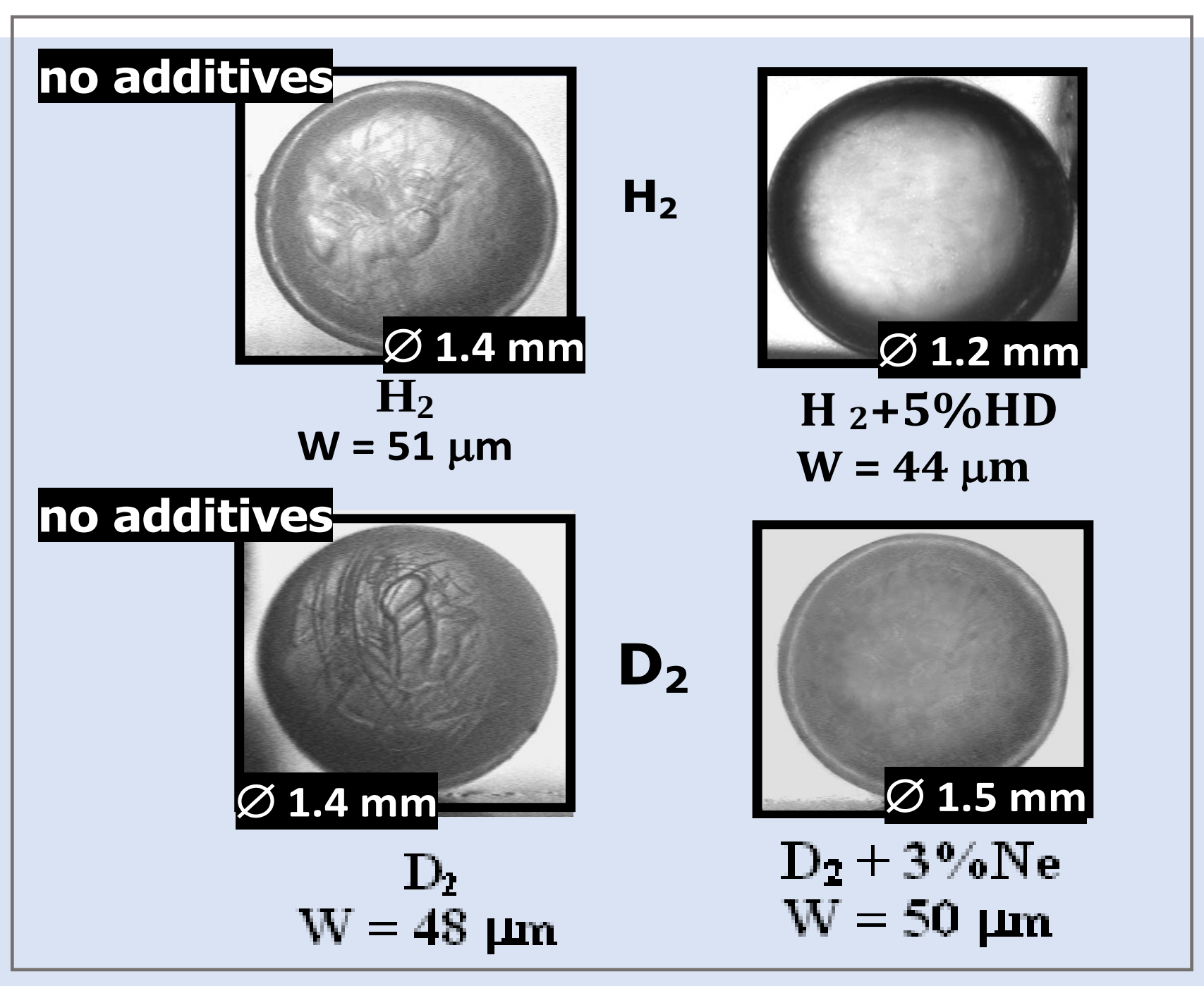
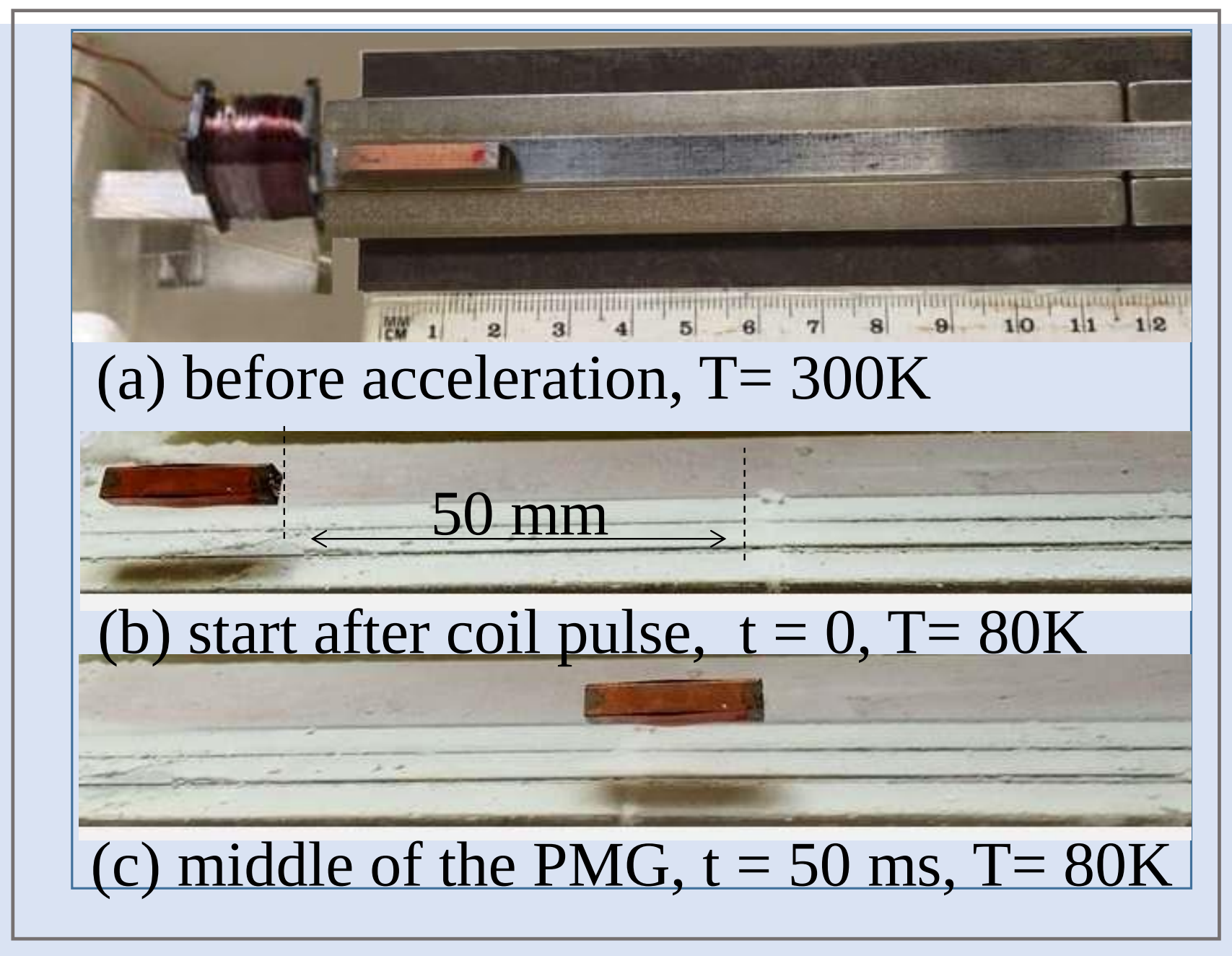


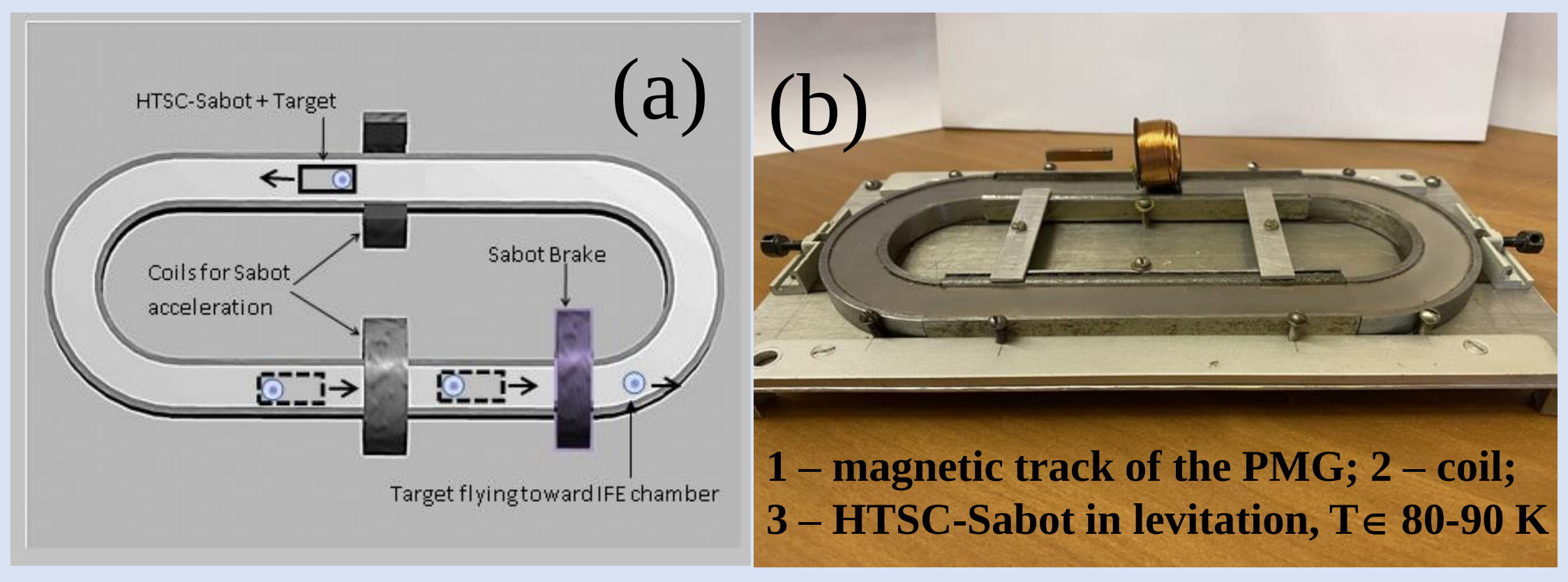
Fig. 3. Comparative FST-layering results carried out without (left) and with (right) doping application


(a) before acceleration, T= 300K

(b) start after coil pulse, t = 0, T= 80K

(c) middle of the PMG, t = 50 ms, T= 80K

Fig.4. Linear accelerator testing (one coil application): v = 1 m/s



1 – magnetic track of the PMG; 2 – coil;
3 – HTSC-Sabot in levitation, T∈ 80-90 K

Fig. 6. Cyclic accelerator schematics (a) and first version of mockup testing (b)

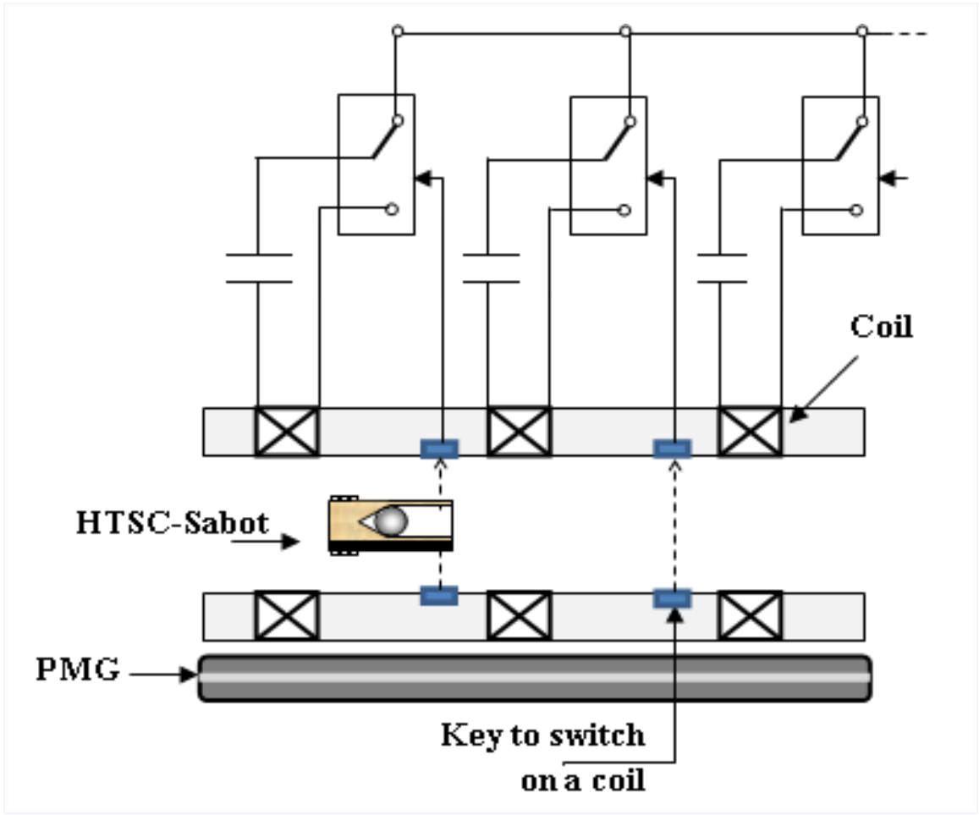


Fig. 5. Schematic of linear accelerator

CONCLUSION

Recent results obtained at the LPI continue to develop a unique scientific, engineering and technological base aimed at creating a prototype of the FST-Factory for mass targets production with the isotropic fuel layer and noncontact target delivery at the laser focus. The LPI is currently making major efforts to develop HTSC-maglev transport technologies for reaching the injection velocities of 200–400 m/s and realizing target survival conditions under different environmental effects.

ACKNOWLEDGEMENTS / REFERENCES

This work has been realized under IAEA support (RC #24154 and #20344)

[1] I.V. Aleksandrova et al., p. 269, in: *Pathways to Energy from Inertial Fusion: Structural materials for Inertial Fusion Facilities*. Final Report of a CRP, IAEA-TECDOC-1911, IAEA, Vienna (2020)

[2] I.V. Aleksandrova et al. Appl.Sci. **10** (2020) 686; 10.3390/app10020686