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РОССИЙСКИЙ ФЕДЕРАЛЬНЫЙ ЯДЕРНЫЙ ЦЕНТР ВНИИЭФ

«EXPERIMENTS ON HYDROGEN ISOTOPES FREEZING ON THE SPHERICAL CAPSULE»

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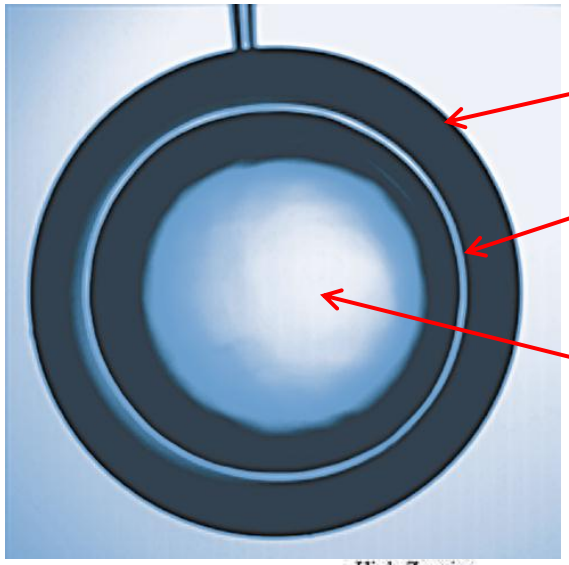
Introduction

The conducting of experiments on laser thermonuclear fusion assumes the use of the cryogenic target .

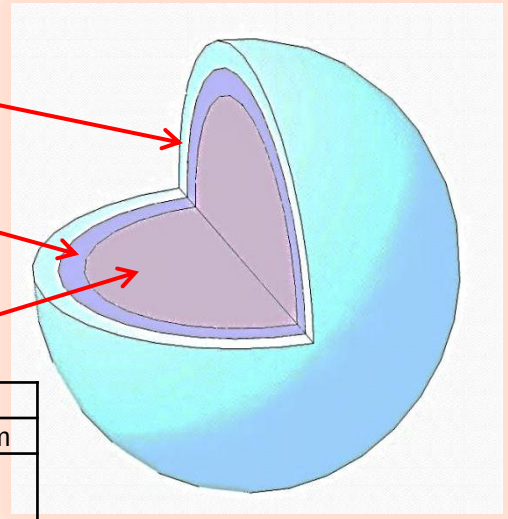
The cryogenic target - a hollow spherical capsule with smooth uniform by a layer of isotopes of hydrogen, freezing on its inner surface.

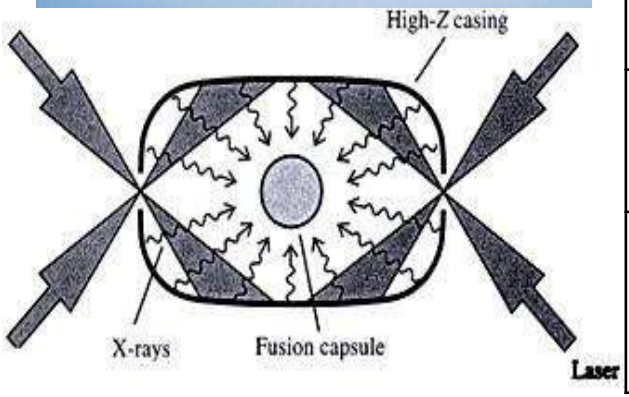


polystyrene microsphere

layer of solid fuel (D-T mixture)

vapor

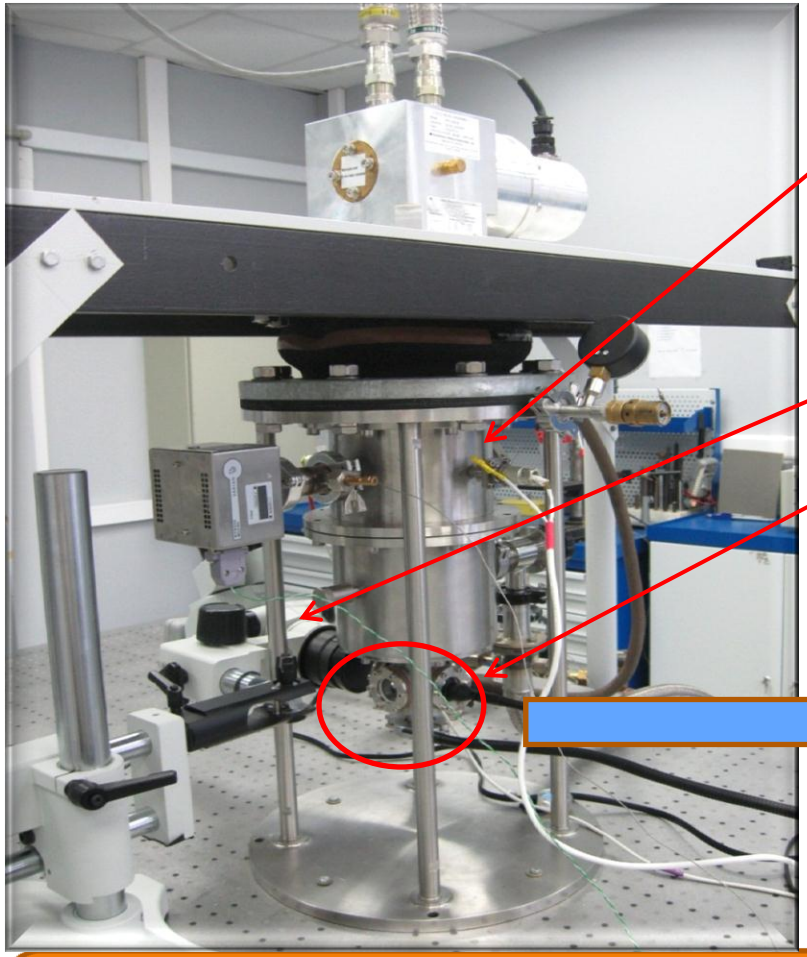




Diameter boxing	0.6-1 cm
Diameter of the holes	~1-1.5 mm
Permissible roughness of the outer surface of the capsule: - Ge alloy polymer capsule - Cu alloy capsule of Be	 10 nm 30 nm
The thickness of the DT ice - permissible gage - DT weight in the target	65÷100 μm <1% 0,2-0,3 mg
Acceptable surface roughness of the inner DT-ice: - polymer capsule - capsule of Be	 <1 μm 2 μm

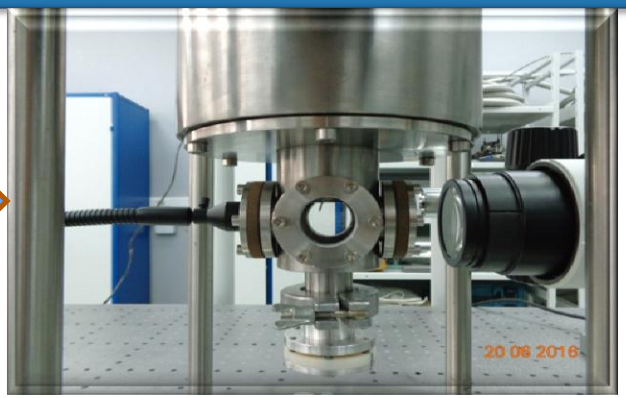
- *D.N. Bittner, B.Kozioziemski, J.Pipes. Forming uniform deuterium hydride and deuterium-tritium layers in shells. ICF Quarterly Report 4, Lawrence Livermore National Laboratory, Livermore, CA UCRL–LR–105821-98-4 (1998-), p.131-139.;*
- *И.В. Александрова, Е.Р. Корешева,* Криогенное водородное топливо для управляемого инерциального термоядерного синтеза (обзор мировых результатов) ВАНТ. Сер. Термоядерный синтез, 2015, т. 38, вып. 1

The stand for targets research at low temperatures



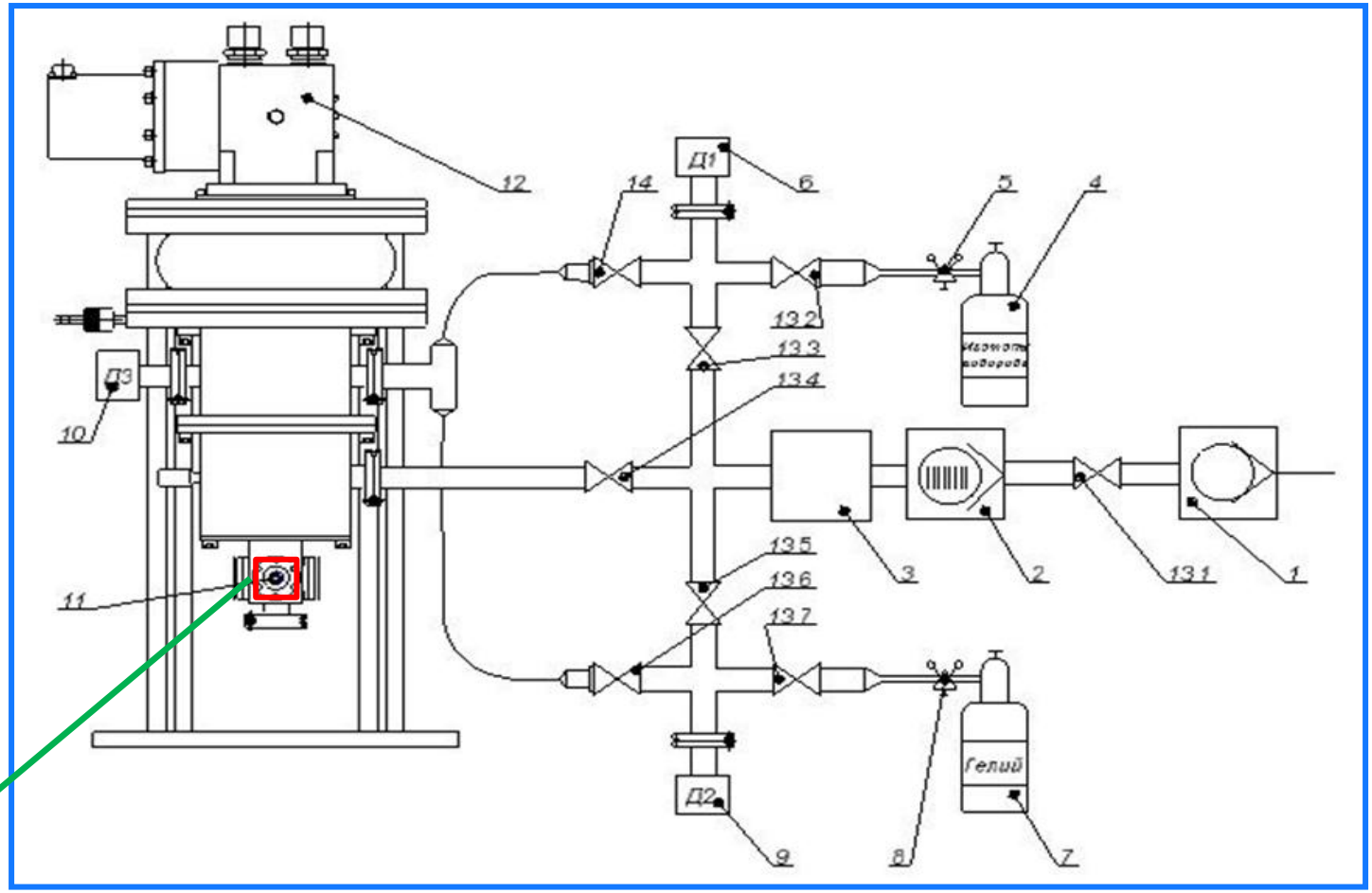
The structure of stand:

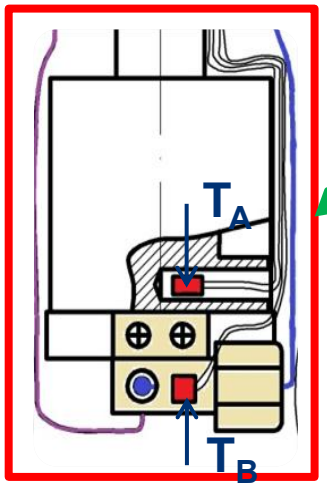
- *research cryostat;*
- *systems of simultaneous pumping out of gas channels, ;*
- *helium supplying system;*
- *hydrogen isotopes supplying system;*
- *optical system of visual control;*
- *equipment for control of temperature;*
- *experimental box.*



Necessary temperature for carrying out experiments **10°K - 20°K.**

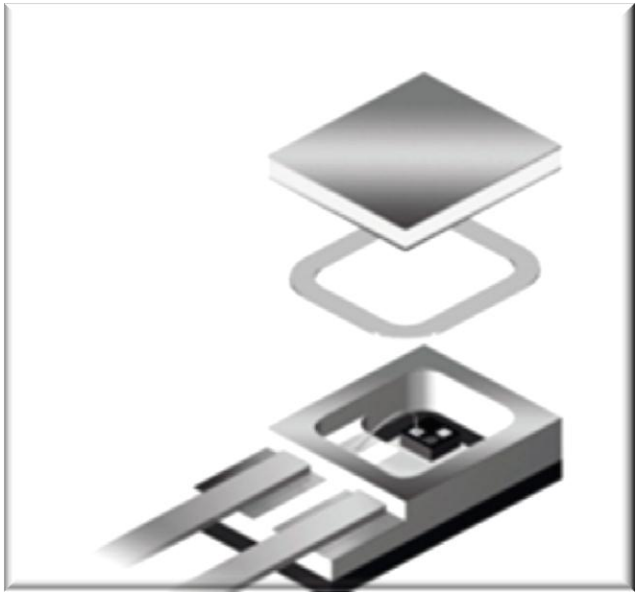
Arrangement of the stand



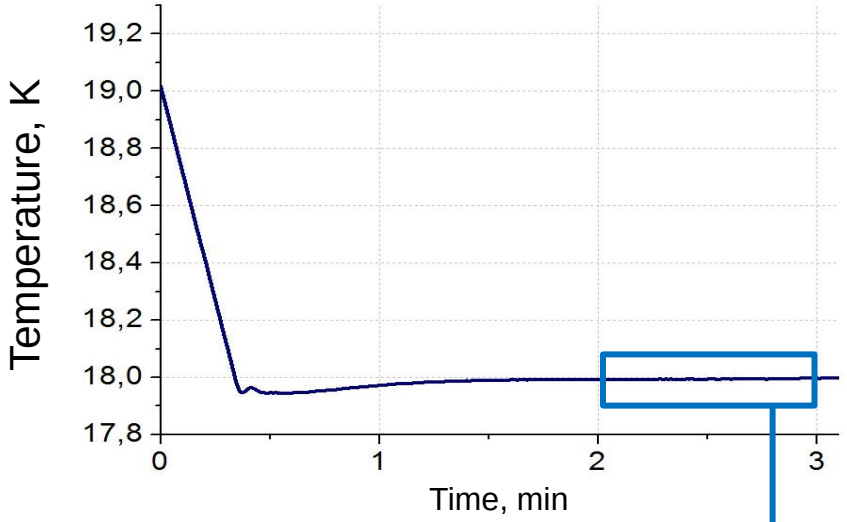


1. Backing pump; 2. Turbomolecular pump; 3. Buffer volume of the pump; 4. Hydrogen isotopes cylinder; 5. Reducer P1; 6. Pressure gauge D1; 7. Helium cylinder; 8. Reducer P2; 9. Pressure gauge D2; 10. Pressure gauge D3; 11. Box with polystyrene capsule; 12. The cryostat; 13.1-13.7. Vacuum valve; 14. Fine control leak valve.

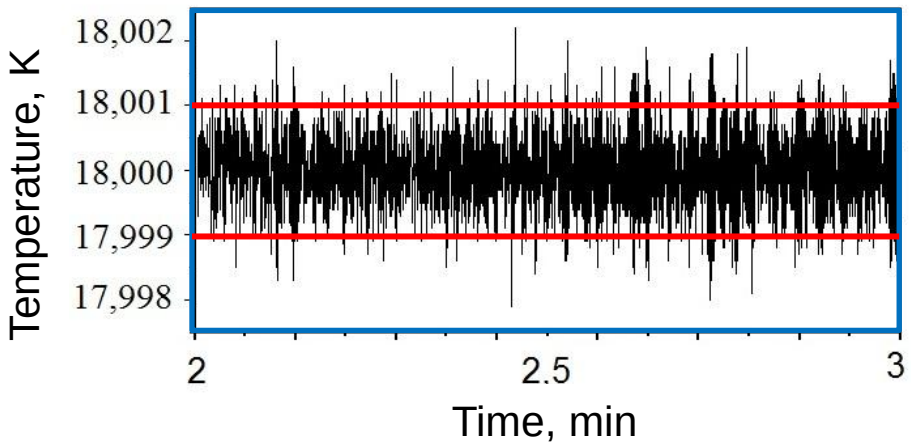
Temperature control is carried out by the controller



Sensor

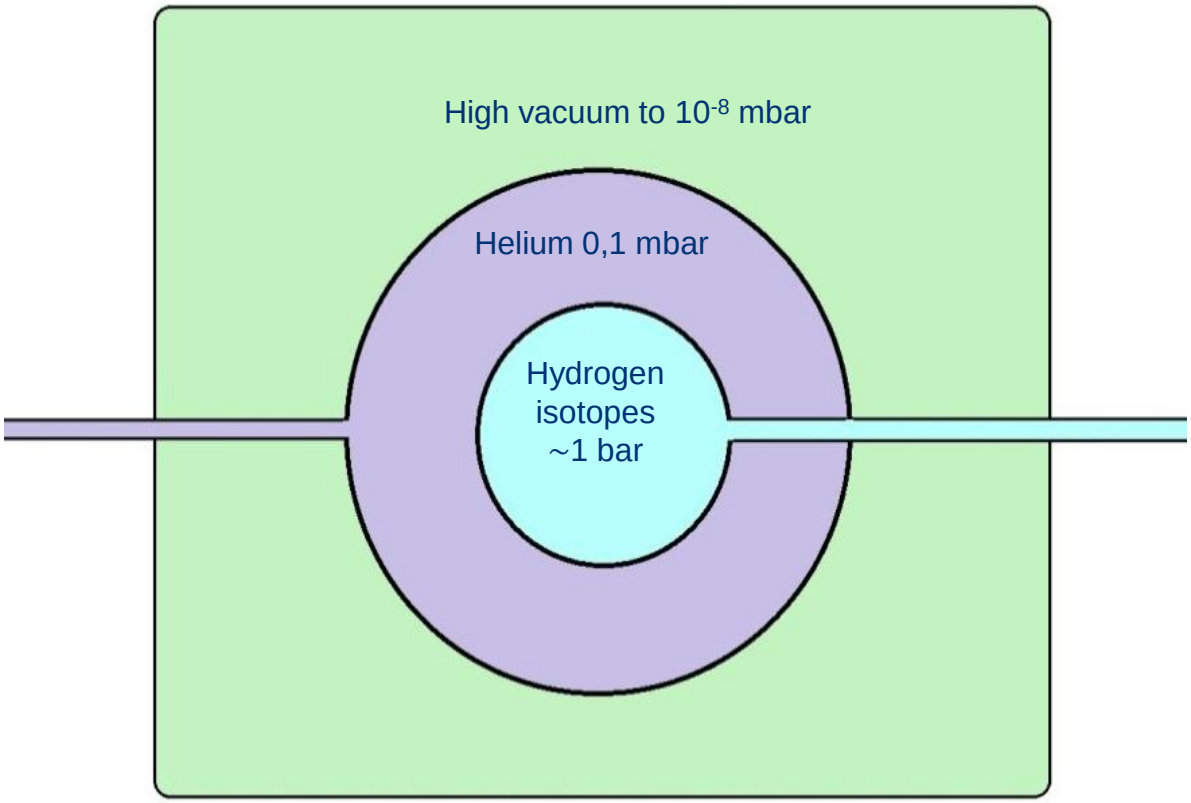


Achievement of the given temperature in a self-acting mode.



Temperature maintenance 18K by means of a heater.

Experimental box



The basic requirements to a box construction:

- *tightness*
- *simplicity of installation*
- *reliability of linkings*

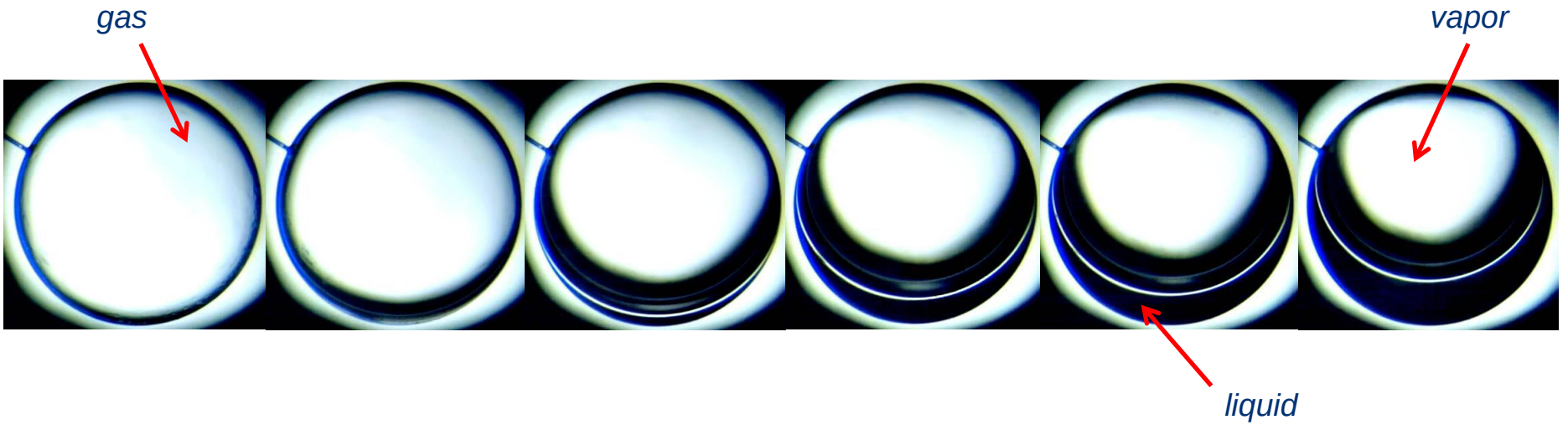
The experimental box represents a system of isolated gas volumes

Carrying out experiments on hydrogen isotopes inlet through a fill tube in spherical polystyrene capsule with the subsequent freezing.

Stages of carrying out experiments:

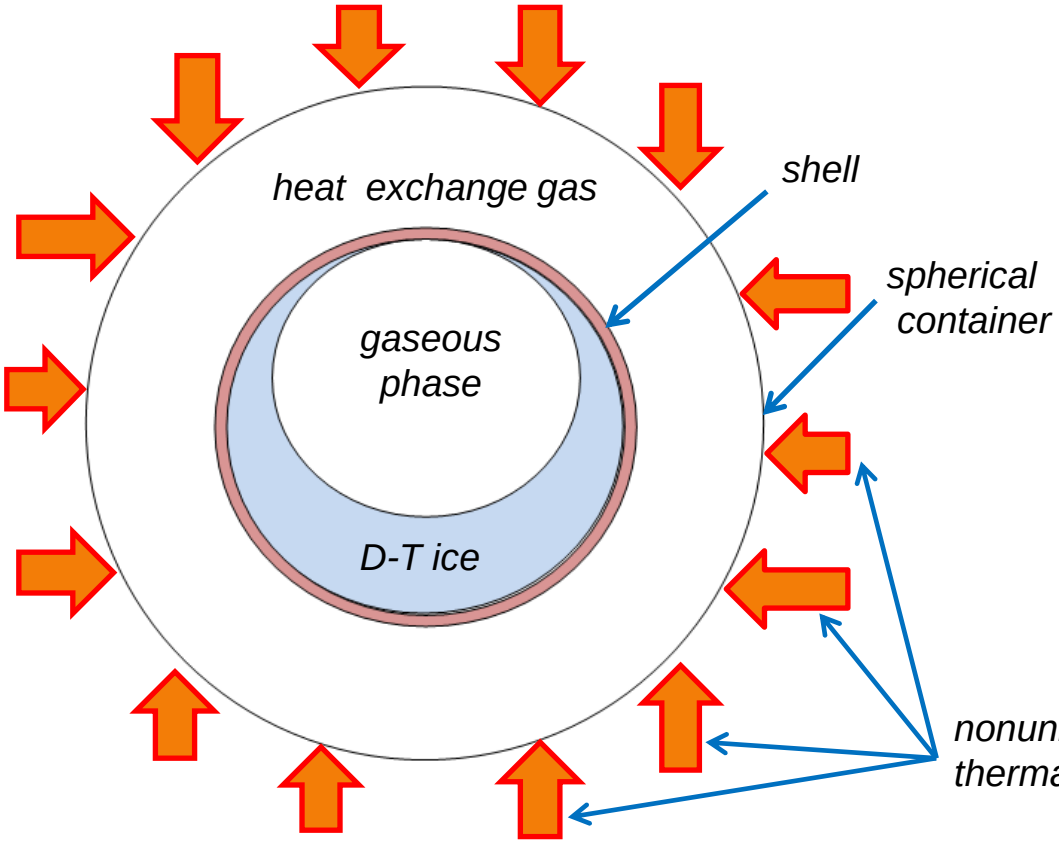
cryostat and gases supplying systems pumping out to 10^{-3} Pa → the procedure of cooling to 30K → the puffing of helium as heat exchange gas into the box cavity → the puffing of hydrogen isotopes into the capsule → cooling to $T_{triple\ point}$, dispensing to the necessary level → making of "ice cork» in a fill tube → cooling more low $T_{triple\ point}$

Process of spherical polystyrene capsule filling with liquid phase hydrogen isotopes



The three-dimensional problem of D-T fuel cryogenic layer formation in the spherical container

The problem represents a complex of equations of heat conduction of five-layer medium together with an equation of gas dynamics and an equation of state for a gas phase in an inner part.



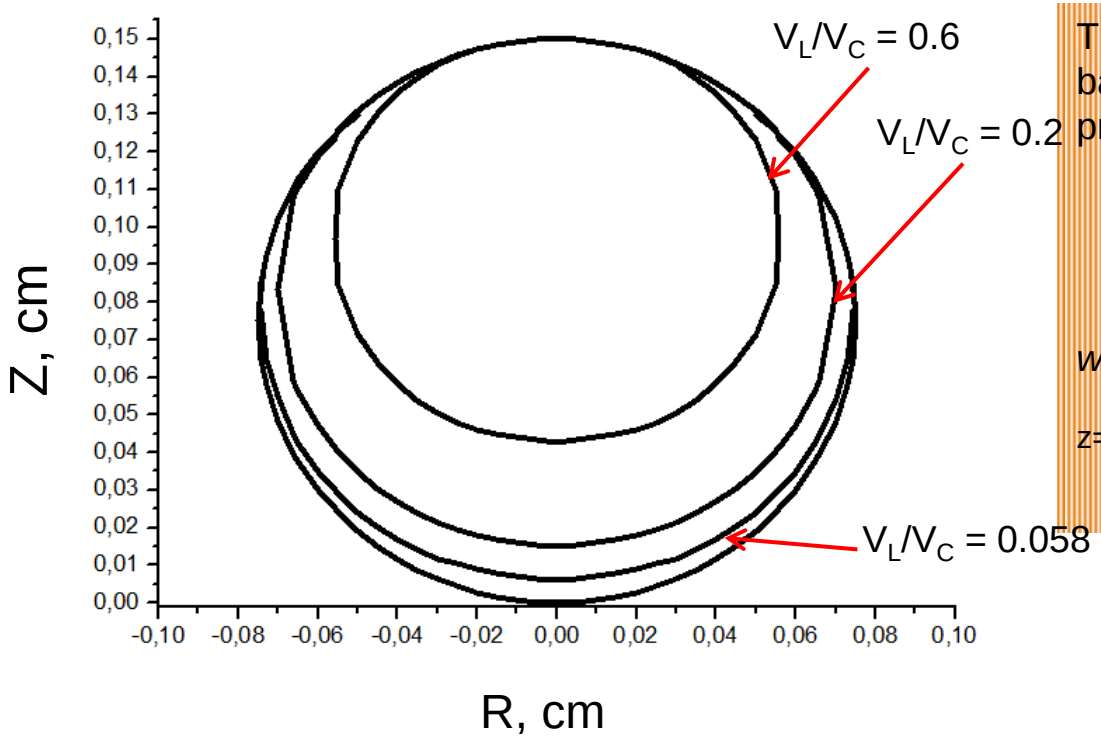
Initial and boundary conditions:

- $P_{\text{heat exchange gas}}$ = 0,1 -10Torr;
- $d_{\text{container}}$ = 5-10 mm;
- d_{shell} =1,5-3 mm;
- Accuracy of definition of temperature - 0.001 K;
- Accuracy of definition of coordinates of a phase boundary- 0,1 μm.

It is required to spot evolution in time of redistribution of temperature on radius and polar angle and location of a «vapor - solid» boundary .

Calculation of the form of the free surface of a fluid at various filling of the spherical container.

Calculation of the form of the free surface of a fluid at various filling of the container – initial conditions for the solution of a three-dimensional problem.



The nondimensional form of hydrostatic balance equation for axially symmetrical problems looks like :

$$\frac{1}{r}\frac{d}{dr}(r\sin\Phi) = \pm z + C_0,$$

where $C_0 = \frac{2}{R_0}$ (R_0 – curvature radius in the point z=0)

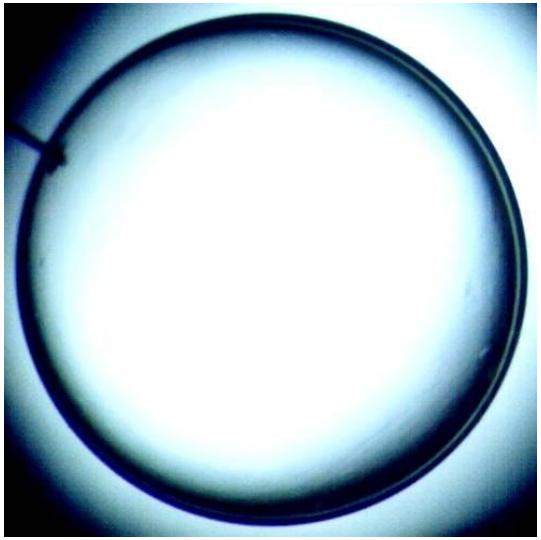
Contours of section of interfaces "liquid-gas" for three cases of filling of the shell (1 - VL/VC = 0.058; 2 - VL/VC = 0.2 and 3 - VL/VC = 0,6). VL and VC - volume of the condensed gas and the shell accordingly

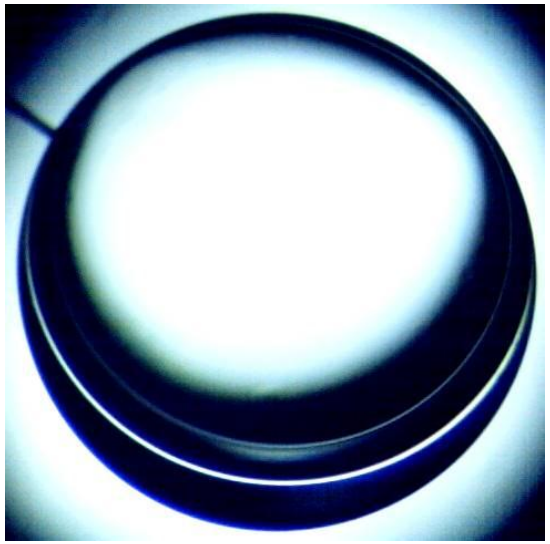
Experiments on the freezing of deuterium in a spherical capsule

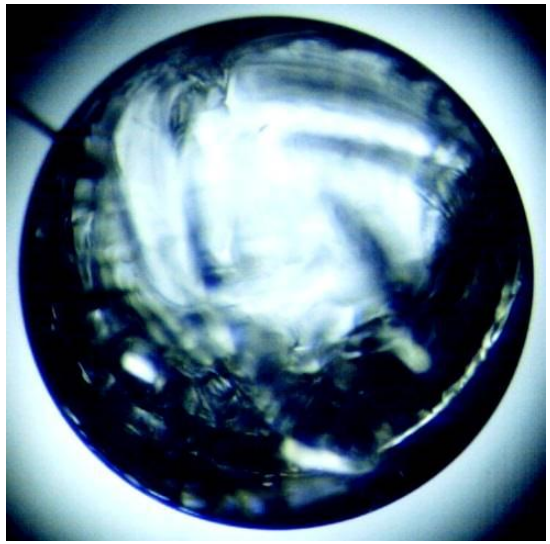
$T_{triple\ point}(D_2)=18,7K;$

Parameters experimental assemblage:

- polystyrene capsule Ø1350 μm;
- wall thickness 8 μm;
- fill tube Ø28 μm.







Dynamics of protium cryogenic layer behavior at different temperature near triple point

$T_{triple\ point}(H_2)=13{,}96K;$

Parameters of the experimental assemblage:

- polystyrene capsule Ø1325 μm;
- wall thickness 8 μm;
- fill tube Ø56 μm.

Calculated condensed gas mass value H_2=0,07mg;

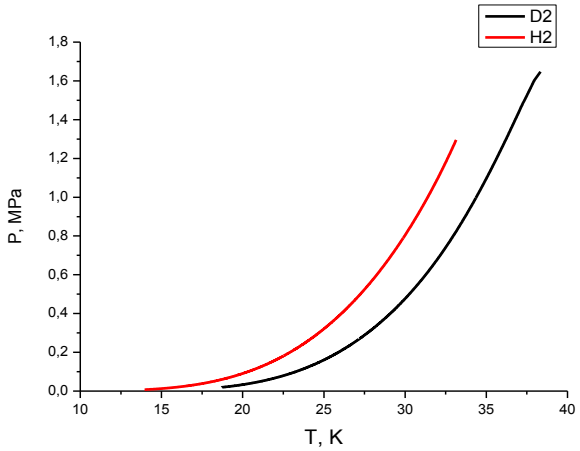
Beginning of condensation T_A =13,9K, T_B =14,7K

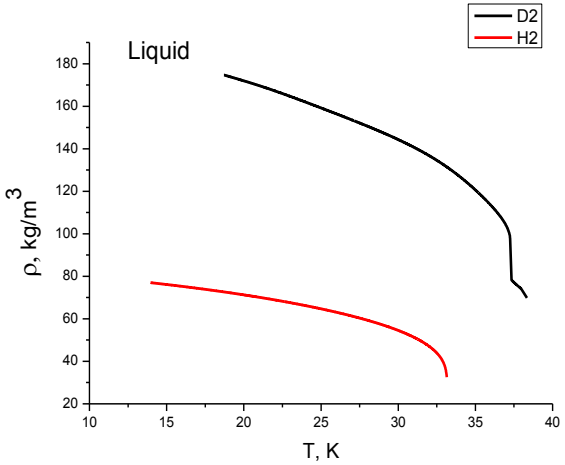
Beginning of crystallization T_A =13,8K, T_B =14,6K

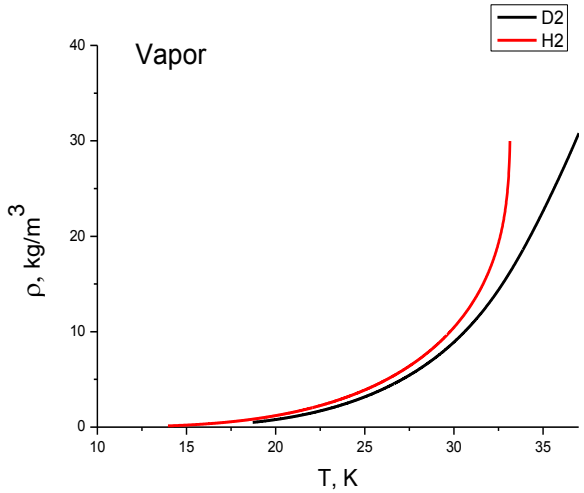
Solid phase T_A =13,4K, T_B =14,2K

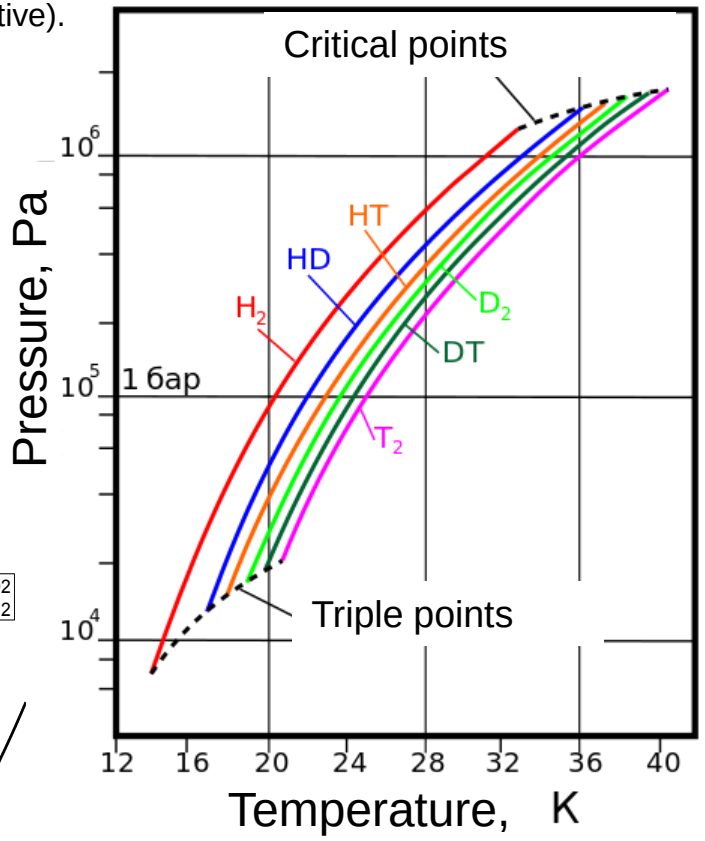
Hydrogen isotopes – fuel for capsule filling

Hydrogen is found in nature in the form of three isotopes which have individual names and chemical symbols: ^{1}H - protium (H) ^{2}H - deuterium (D), ^{3}H - tritium (T; radioactive).







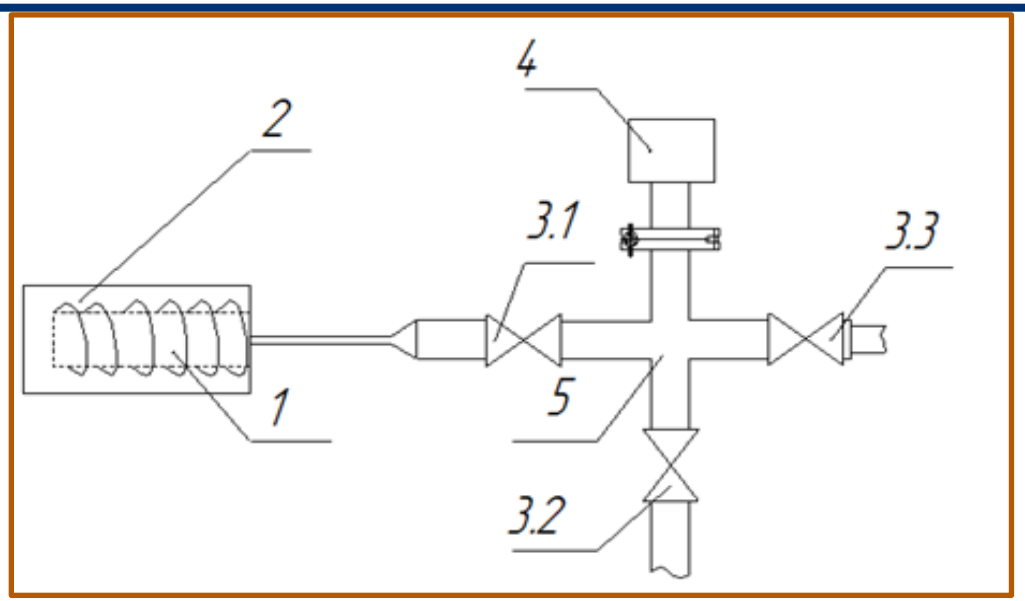


The thermodynamic state of saturated vapor of hydrogen with a different isotopic composition

Dynamic behavior of hydrogen-deuterium mixture generated metal hydride source at temperature fluctuations near triple point

$T_{triple\ point}(HD)=16,6K$

Parameters of the experimental assemblage:
- polystyrene capsule Ø1325 μm;
- wall thickness 8 μm;
- fill tube Ø56 μm.



1 - MH source, 2 – Heater,
3.1.-3.2 – Vacuum valve, 4 - Pressure gauge, 5 - Cross

The mixture:
25%H_2,
50%HD,
25%D_2

Beginning of condensation
T_A =17,5K, T_B =18,3K

Beginning of crystallization
T_A =15,81K, T_B =16,74K

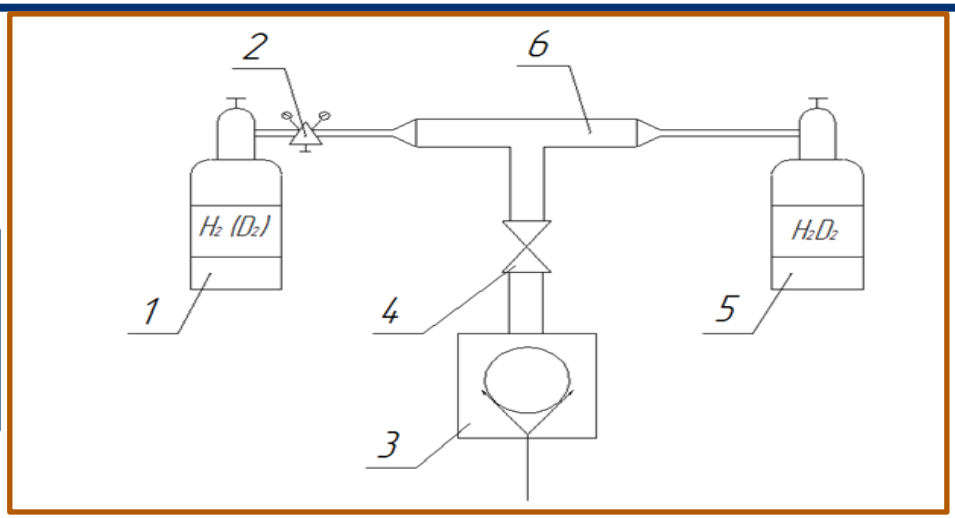
Solid phase
T_A =15,7K, T_B =16,6K

Calculated condensed gas mass mixture value 0,025 mg;

Dynamic behavior of hydrogen-deuterium mixture (H_2, D_2) at temperature fluctuations near triple point

$T_{triple\ point}(HD)=16,6K$

Parameters of the experimental assemblage:
- polystyrene capsule ø1325 μm;
- wall thickness 8 μm;
- fill tube ø56 μm.



1 - Hydrogen (deuterium) cylinder, 2 – Reducer, 3 - Backing pump, 4 - Vacuum valve, 5 - Mixture (H_2,D_2) cylinder.

The mixture: 40%H_2, 31,4%HD, 28,6%D_2 (±0,1%)

T_A =16,5 K
Beginning of condensation

T_A =14.6 K
Beginning of crystallization

T_A =14.5 K
Solid phase

T_A =14.5 K
Solid phase (focus on the front surface of the capsule)

The main results.