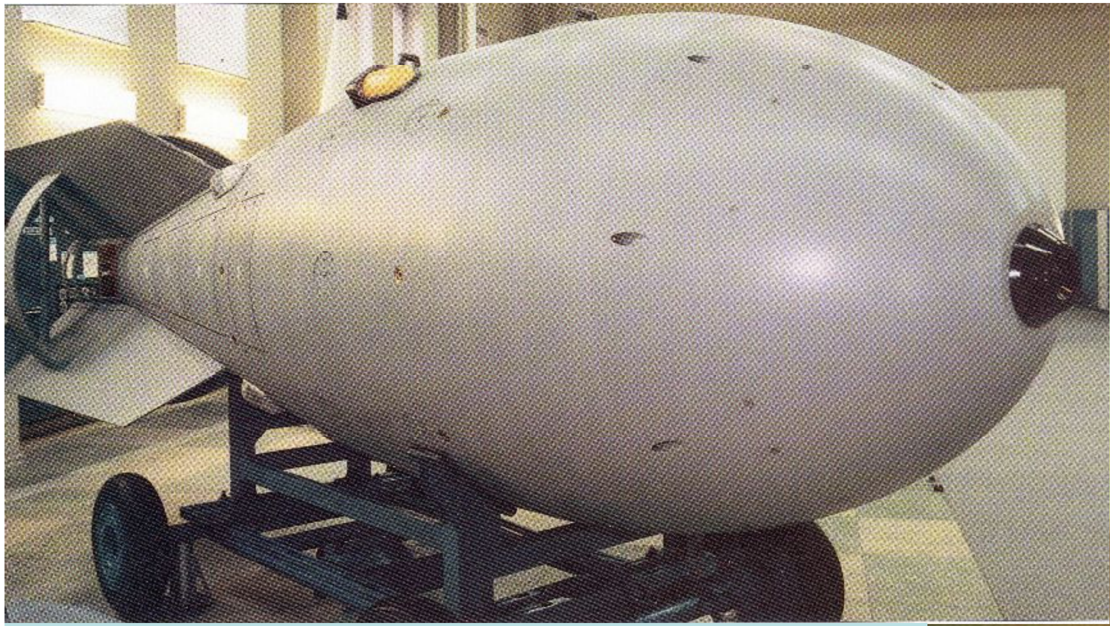
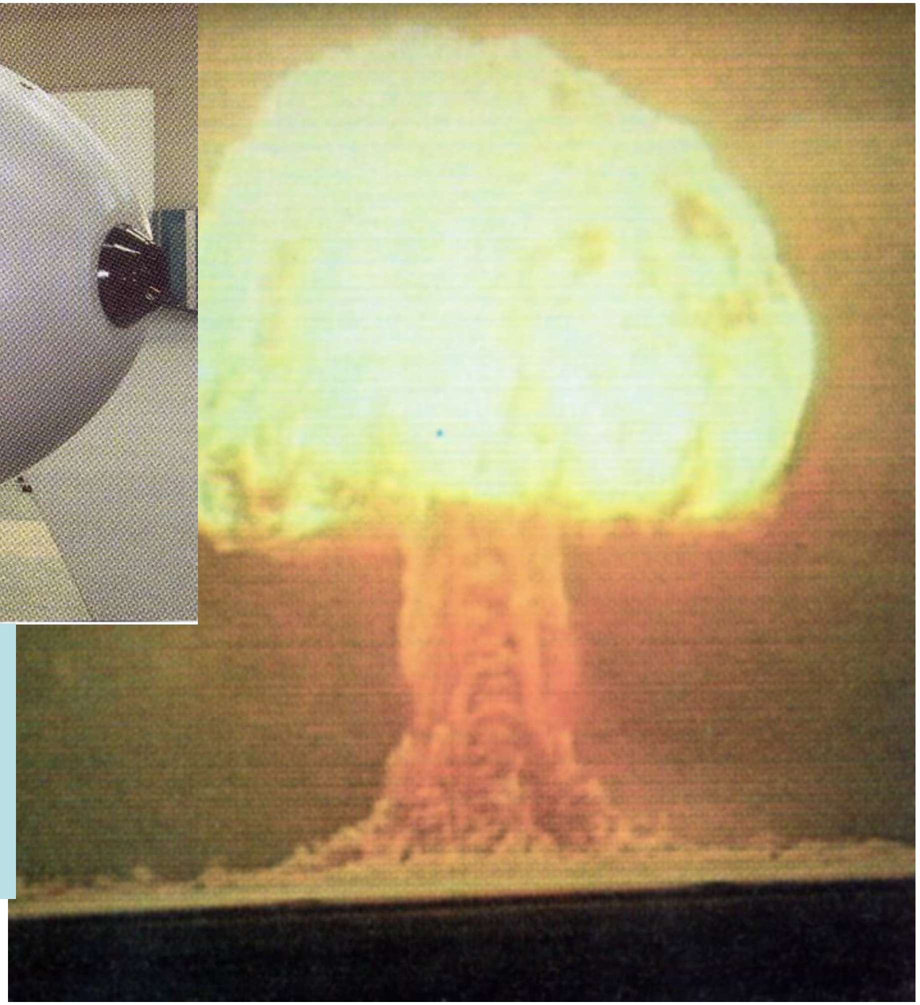
Hydrogen isotopes gas handling systems for physical experiment

Arkadiy A. Yukhimchuk

e-mail: arkad@triton.vniief.ru
Tel./fax: +7 83130 43216

First thermonuclear bomb





400 kt

12 August 1953,
Semipalatinsk testing area

ISTC Project #025-95

Muon Catalyzed Fusion and its Applications

- **Spring of 1993.** **Phone V.P. Dzhelepov to Academician Yu.A. Trutnev (Arzamas-16) and Prof. Zinov visited to Arzamas-16.**
- **One week late.** **Meeting Prof. L.I. Ponomarev, Prof. V.G. Zinov and A.A. Yukhimchuk. Start of ISTC project preparation.**
- **01/09/1995.** **Start of ISTC Project #025-95.**
- **December of 1996.** **Transportation of Complex to Dubna.**
- **Spring of 1997.** **First run with TRITON installation.**
- **1997-2004.** **Systematic study of MCF phenomena.**

Installation & targets	HPTT 300-800K 1200(1500)bar	LTHPTT 20-300 K 1200bar	DHPT 80-800 K 1500bar	CTT 6-300 K 10bar	HPHTTT 300-1600 K 1200bar

Related application Science

- **Materials Science**
  - HI interaction with SM including of welded SM
  - Interaction of ^{3}He saturated SM with HI
  - Protective coating
- **Mixture content analysis**
  - Radio chromatography
  - Raman spectroscopy
- **Pd filter**
- **High pressure V-based HI sources**
- **Tritium monitoring**
- **Automation**

MCF phenomena investigation

#25-95 ISTC Project.

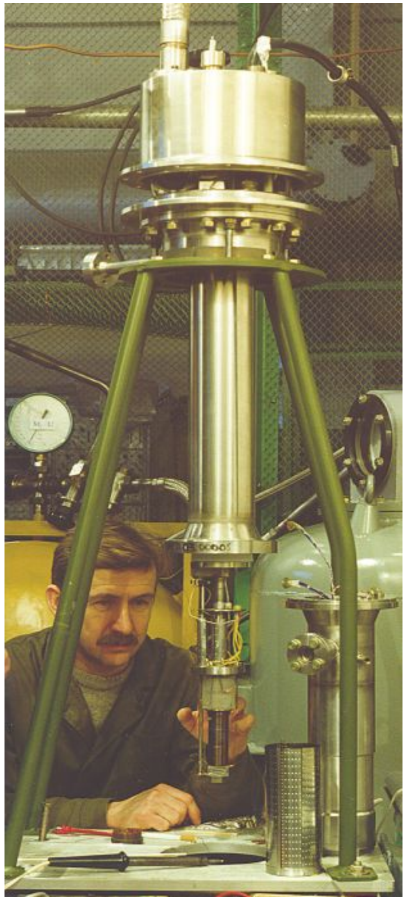
Complex of gas mixture preparation

- **Amount of tritium – 10kCi (in gas), 100kCi (total);**
- **Preparation of a needed HI mixture;**
- **Purification HI mixture to the level 10^{-7} *v. p.;***
- **Molecular analysis of the HI mixture;**
- **Closed tritium cycle;**
- **Safety and reliability;**
- **Autonomy;**
- **Automatic monitoring and control of the working parameters.**

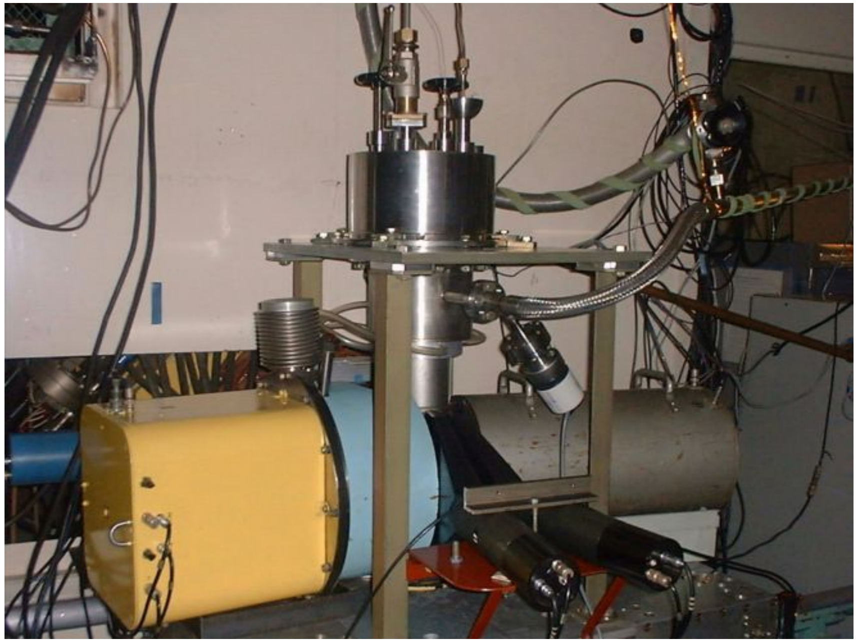
High pressure tritium targets

P= 1600bar

T=300-800K



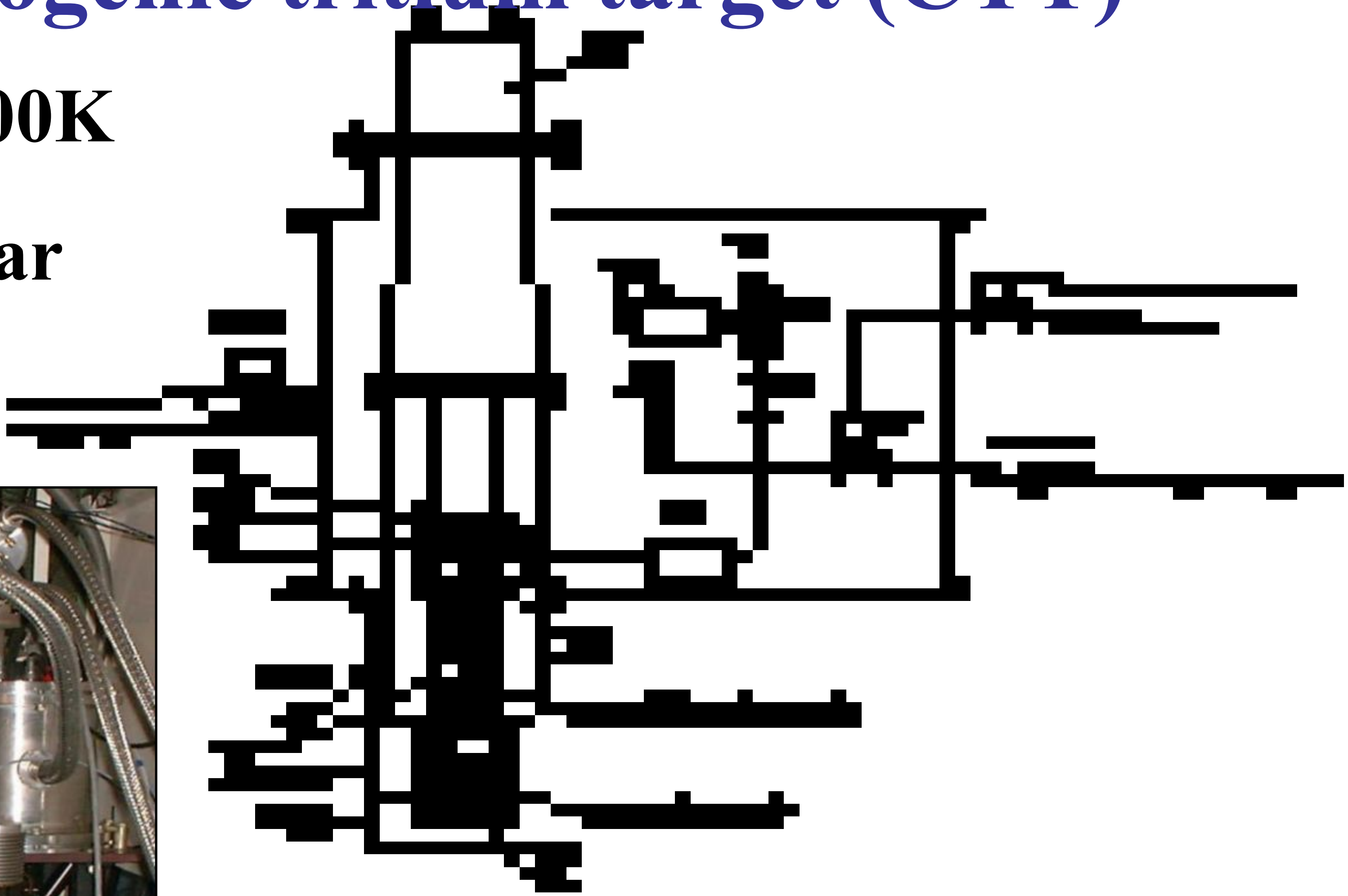
P= 1200bar
T=20-300K

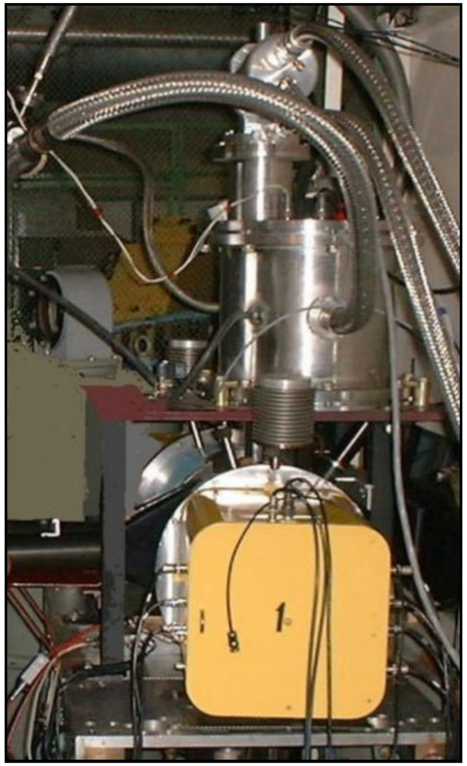


Cryogenic tritium target (CTT)

T = 6-300K

P= 10 bar

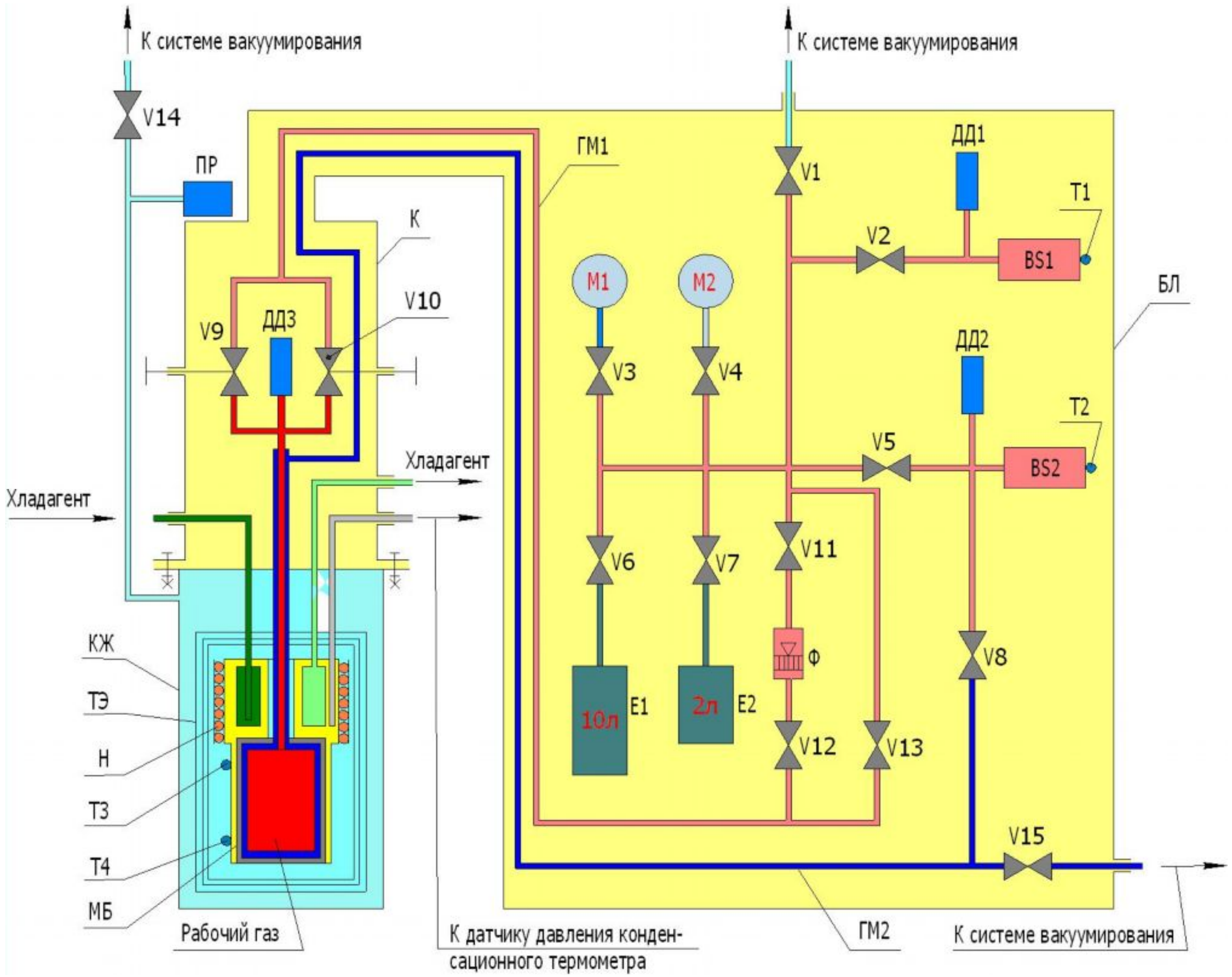




Deuterium high pressure target

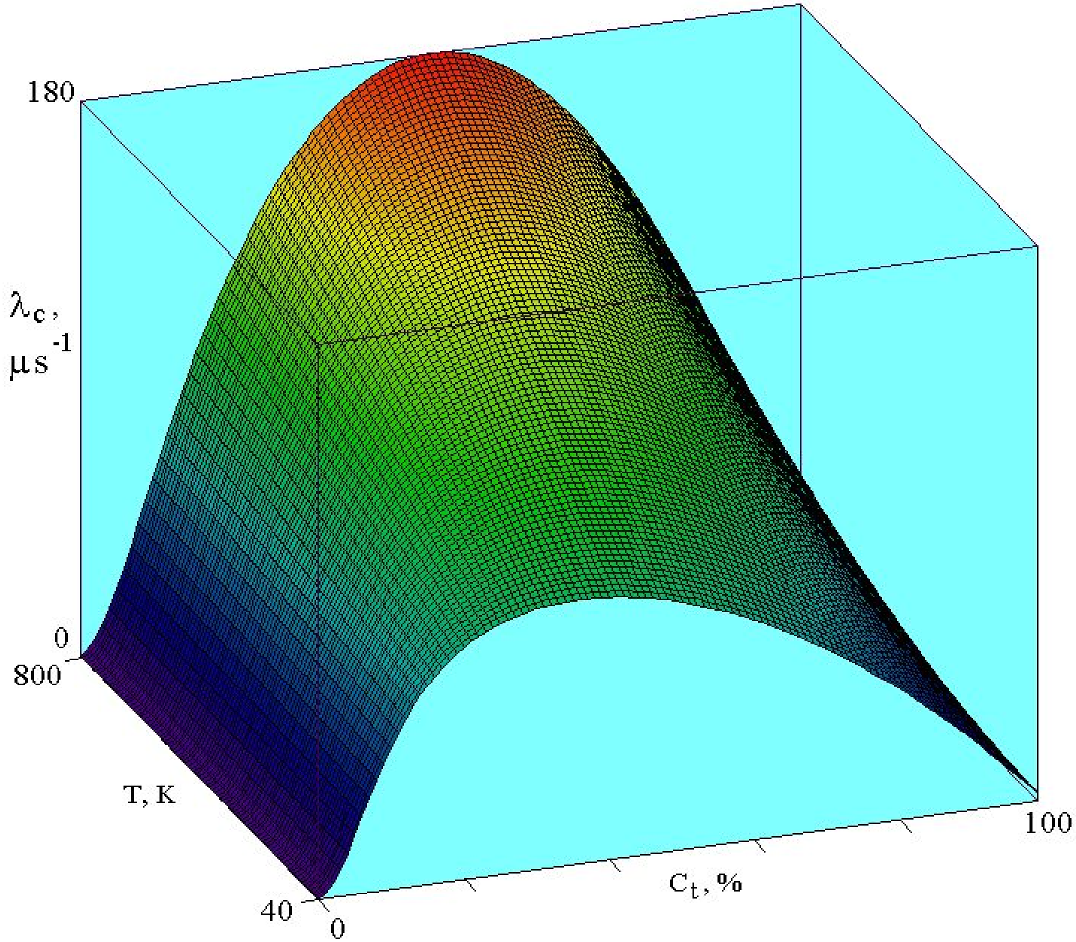
T=80-800K

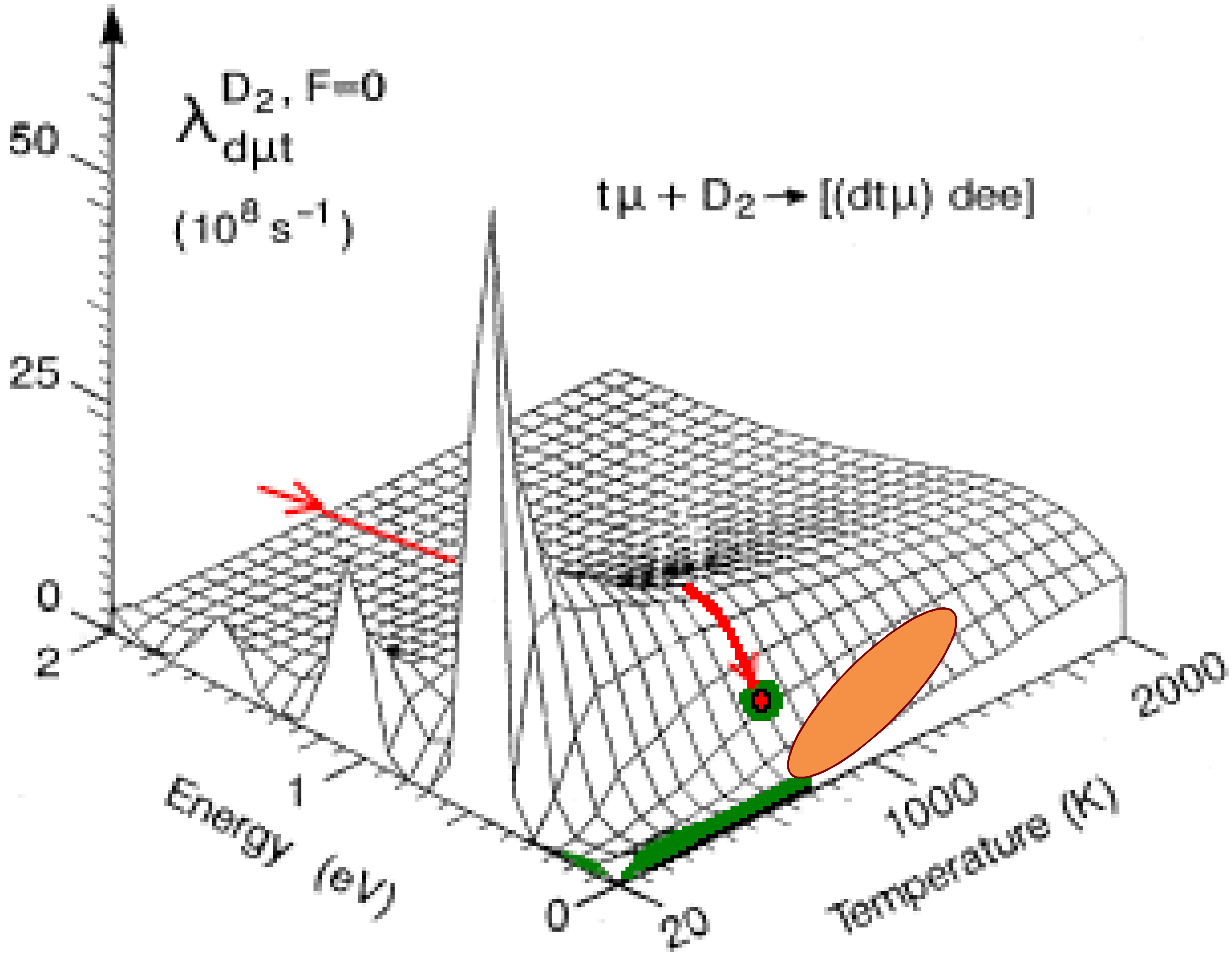
P=1500bar



Velocity of MCF cycle dependences from temperature and T_2 concentration

$N = 120 \pm 15\ \mu^{-1}$

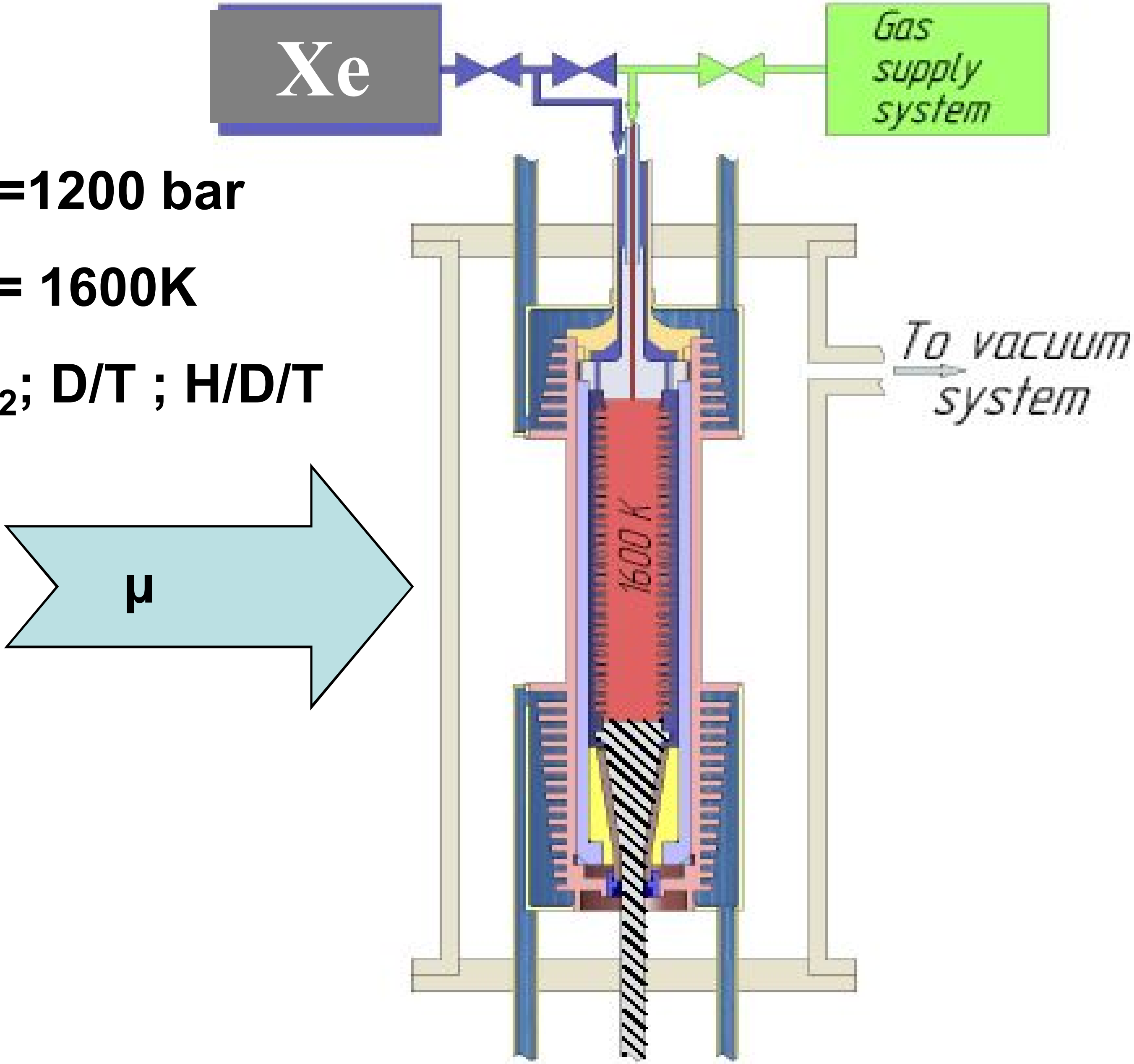



$\lambda_{d\mu t}^{D_2, F=0}$
$(10^8 s^{-1})$
50
25
0
2
1
0
$t\mu + D_2 \rightarrow [(dt\mu)\ dee]$
Energy (eV)
20
1000
2000
Temperature (K)

P=1200 bar

T= 1600K

D_2; D/T ; H/D/T



Installation & targets	HPTT	LTHPTT	DHPT	CTT	HPHTTT
	300-800K	20-300 K	80-800 K	6-300 K	300-1600 K
	1200(1500)bar	1200bar	1500bar	10bar	1200bar

Related application Science

Materials Science
- HI interaction with SM including of welded SM
- Interaction of ^{3}He saturated SM with HI #2673 + #3672
- Protective coating #1110

Mixture content analysis
- Radio chromatography
- Raman spectroscopy #025/2

Pd filter

High pressure V-based HI sources

Tritium monitoring

Automation

MCF phenomena investigation #3487

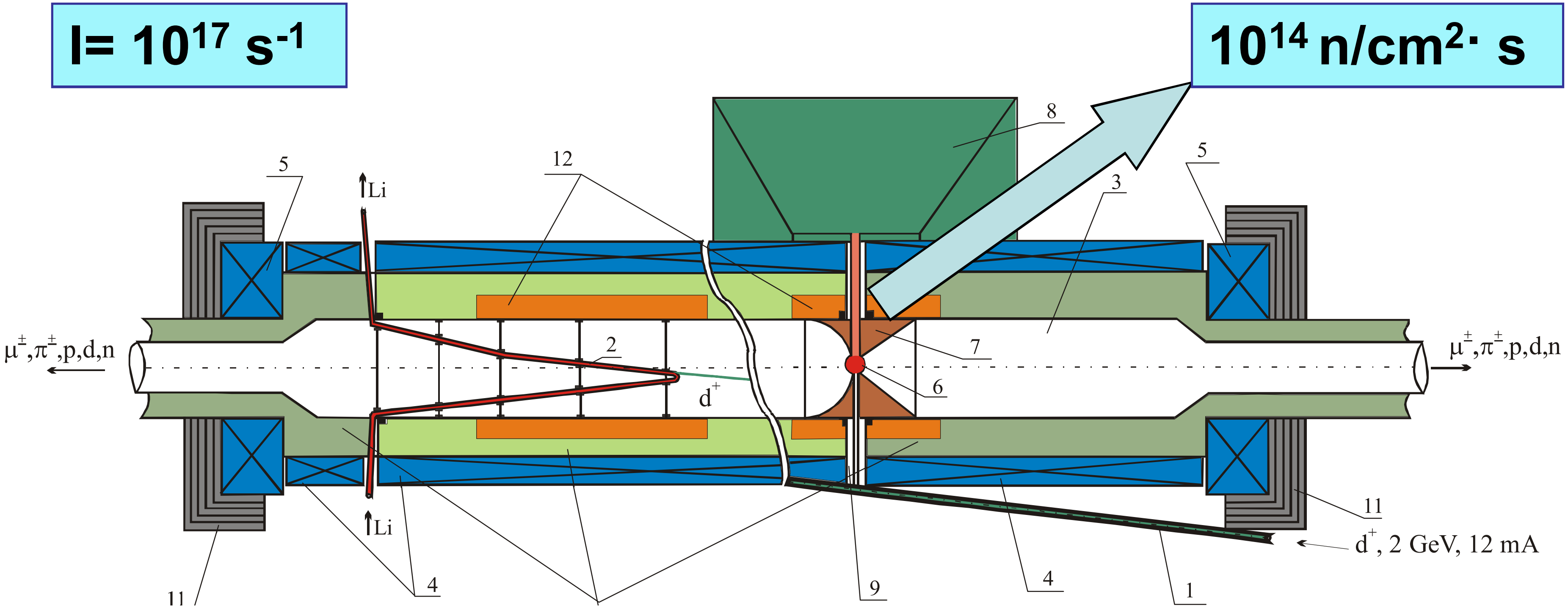
ISTC Proposal #3487

Investigation of the muon-catalyzed fusion process in muonic molecules of deuterium and tritium

The aim of the Project is:

- the *obtaining of new experimental data* in the region where MCF was poorly studied or was not studied at all and where it *represents the most interest for the modern theory and for the future practical application*. MCF *d+t reaction parameters at high temperatures*, where theory predicts the high intensity of the process.
- the study of the MCF *d+d reaction at lowest temperatures*, where the *exotic mechanisms of the muonic molecule formation* determined by phonon effects in solid and liquid deuterium come into action.
- the study of the mechanism of the *t+t reaction catalyzed by muon*, enabling the possibility to obtain the *unique information about the structure of nuclei with A=6*.

MC INS for study of fusion reactors materials



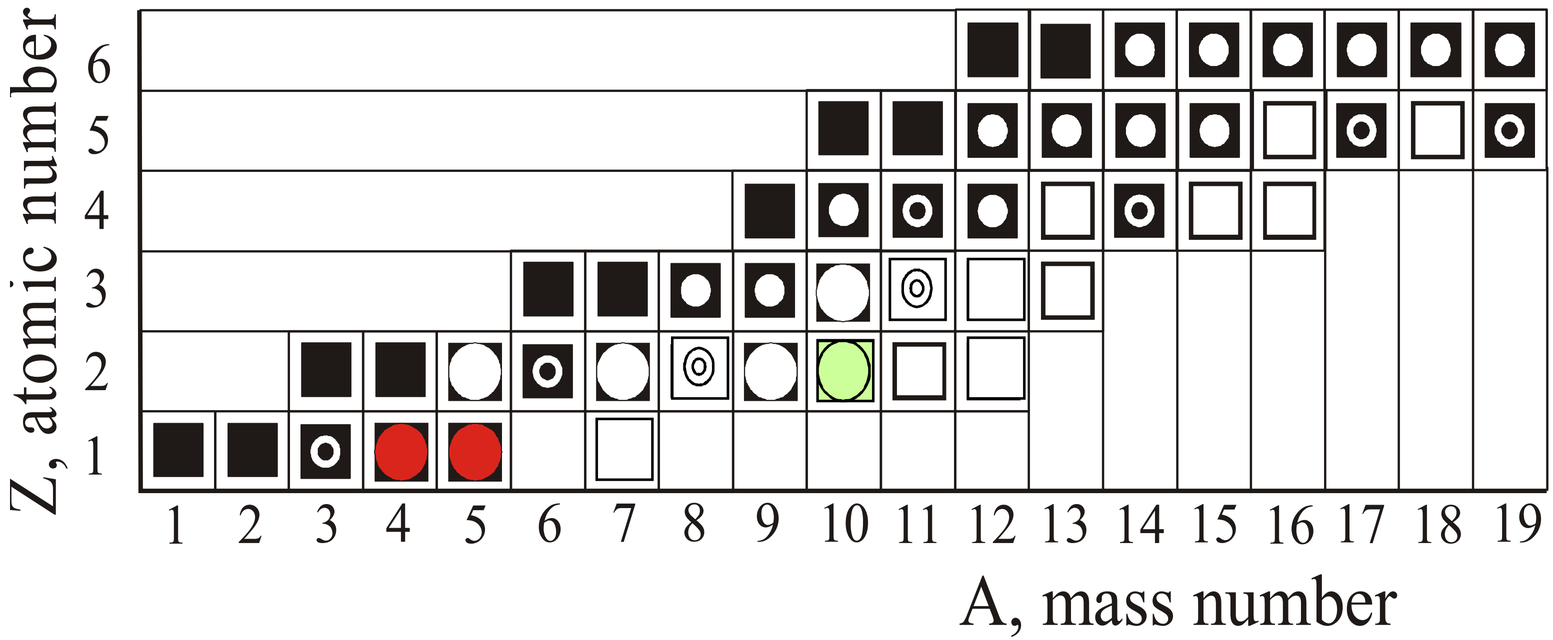
1 - deutron beam chanel; 2 - primary target; 3 - converter;
4 - superconductive solenoid; 5 - magnetic mirrors; 6 - synthesizer;
7 - specimens area; 8 - systems of tritium fuel loop;
9 - insert of synthesizer; 10 - shielding;
11 - magnetic screen; 12 - ^{3}He blanket.

V.V.Anisimov et al. Fusion technology V.39, N.2, 2001, p. 198-227.

V.V.Anisimov al. Hyperfine Interactions 119(1999)329-339.

A.A. Yukhimchuk and V.A. Arkhangelsky. Fusion Science & Technology, 41 (2002) 826-830

Light neutron –rich nuclei



Stable isotope

Radioactive nuclei

Resonance states nuclei ~10^{-21}s

Nuclei with neutron hallo

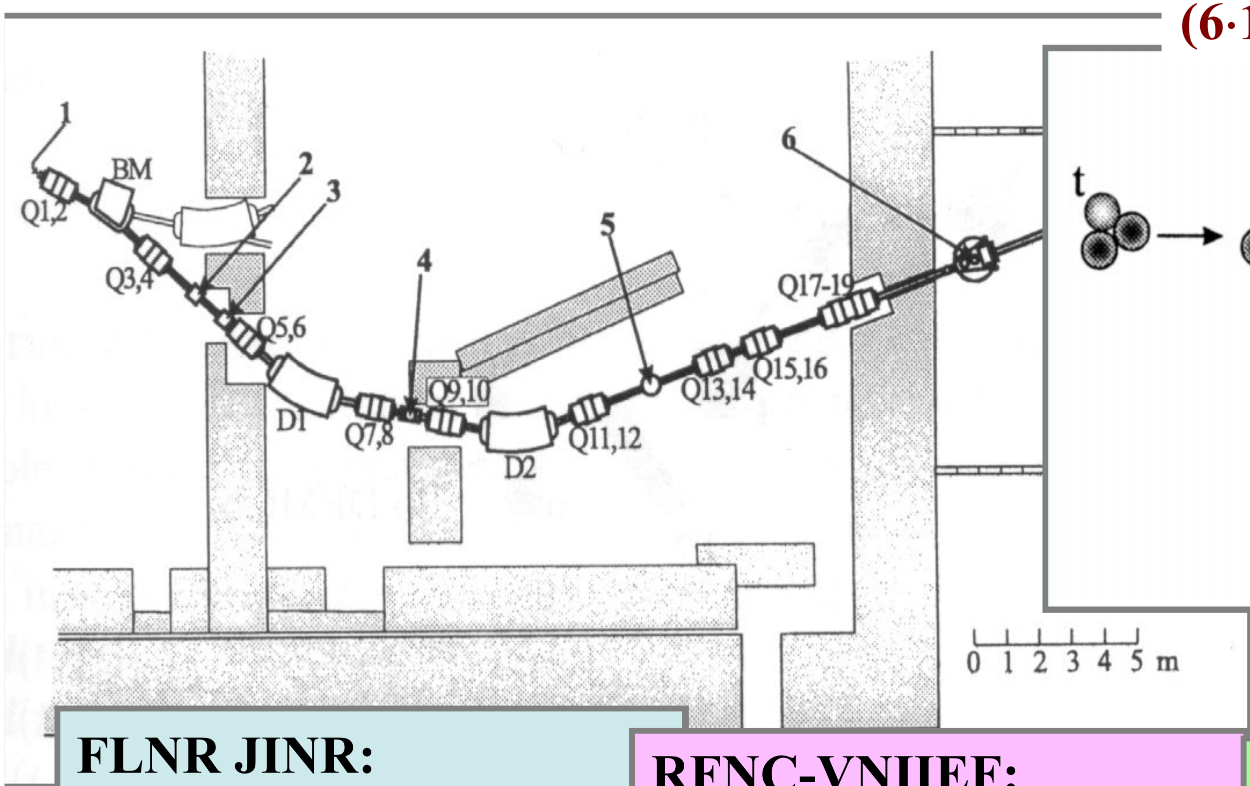
Unstable nuclei

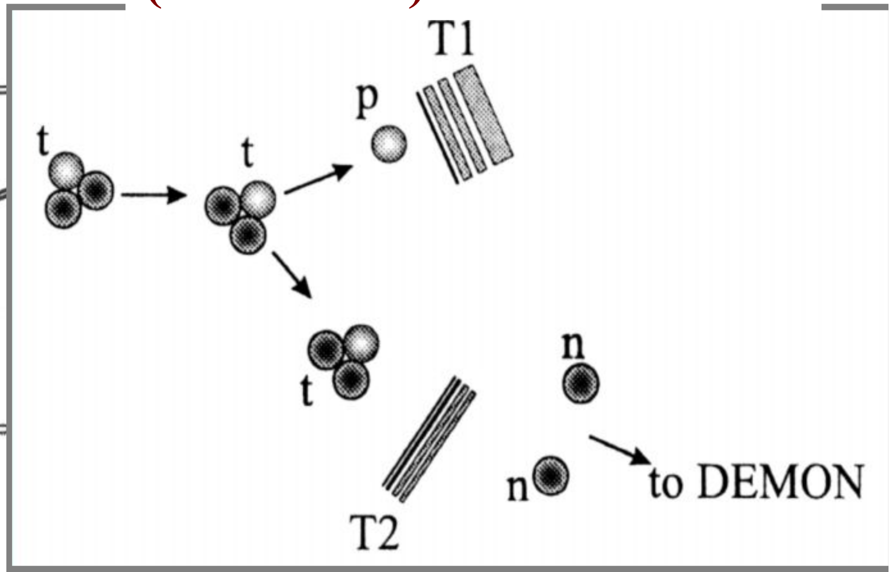
ISTC Proposal #1930

Structure of the Lightest Nuclei on the Border of Neutron Stability

FLNR JINR: $t+t \to {}^{5}H+p$, $t+t \to {}^{4}H+d$ and $t+d \to {}^{4}H+p$, ${}^{8}He+t \to {}^{10}He+p$

Tritium beam current ~10 nA
($6 \cdot 10^{10}$ ion/s)





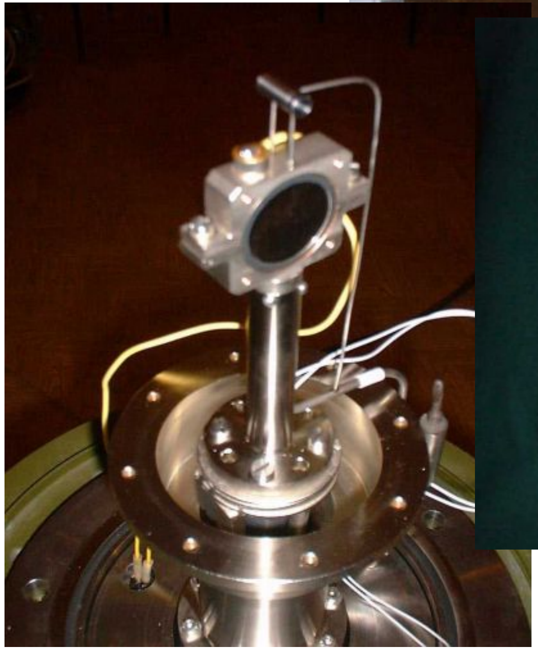
FLNR JINR:
- ❑ U-400M cyclotron
- ❑ ACCULINNA separator
- ❑ scattering chamber
- ❑ detectors

RFNC-VNIIEF:
- ❑ Liquid tritium target
- ❑ Gas feeding system for U-400M cyclotron ion source

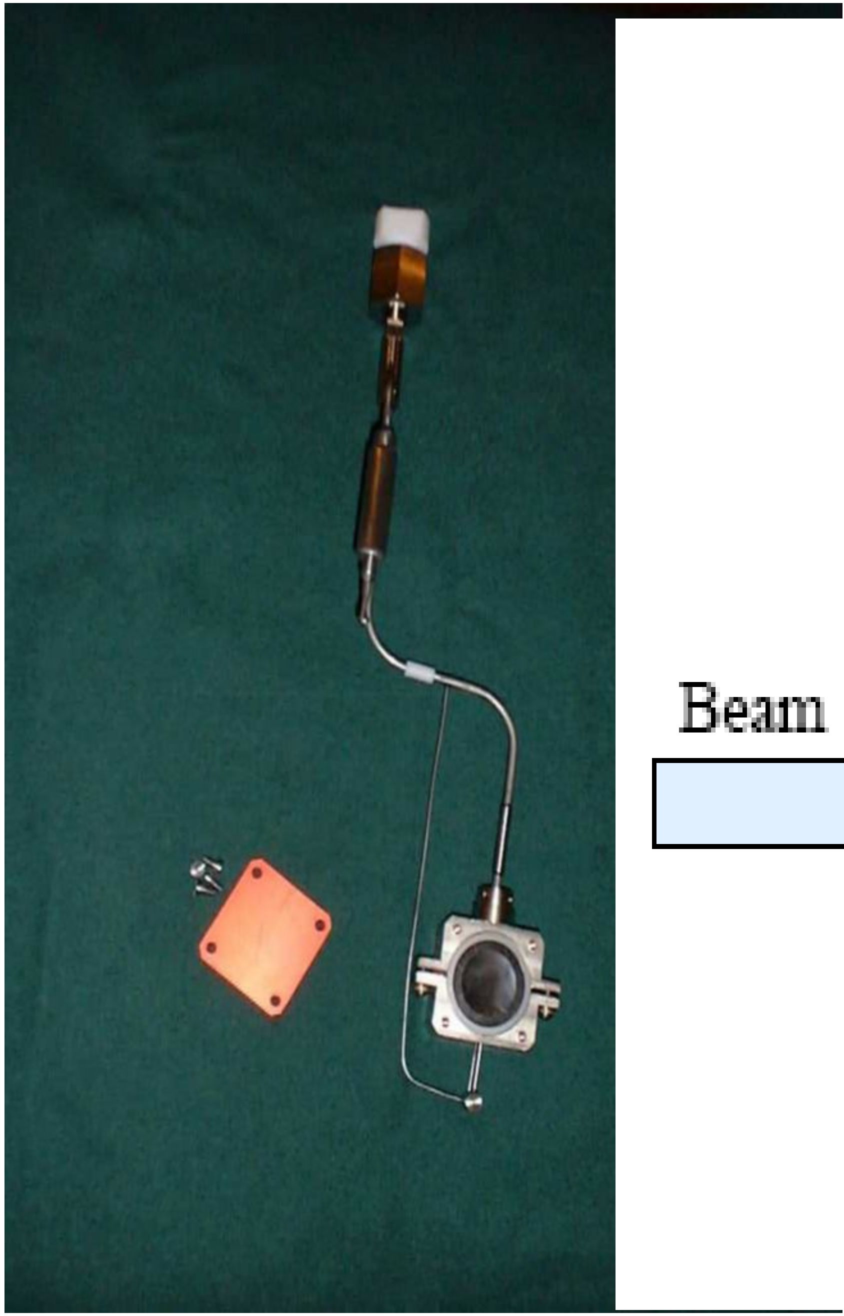
GANIL, Caen, France
Strasbourg, IPN
Brussels University
RIKEN, Japan

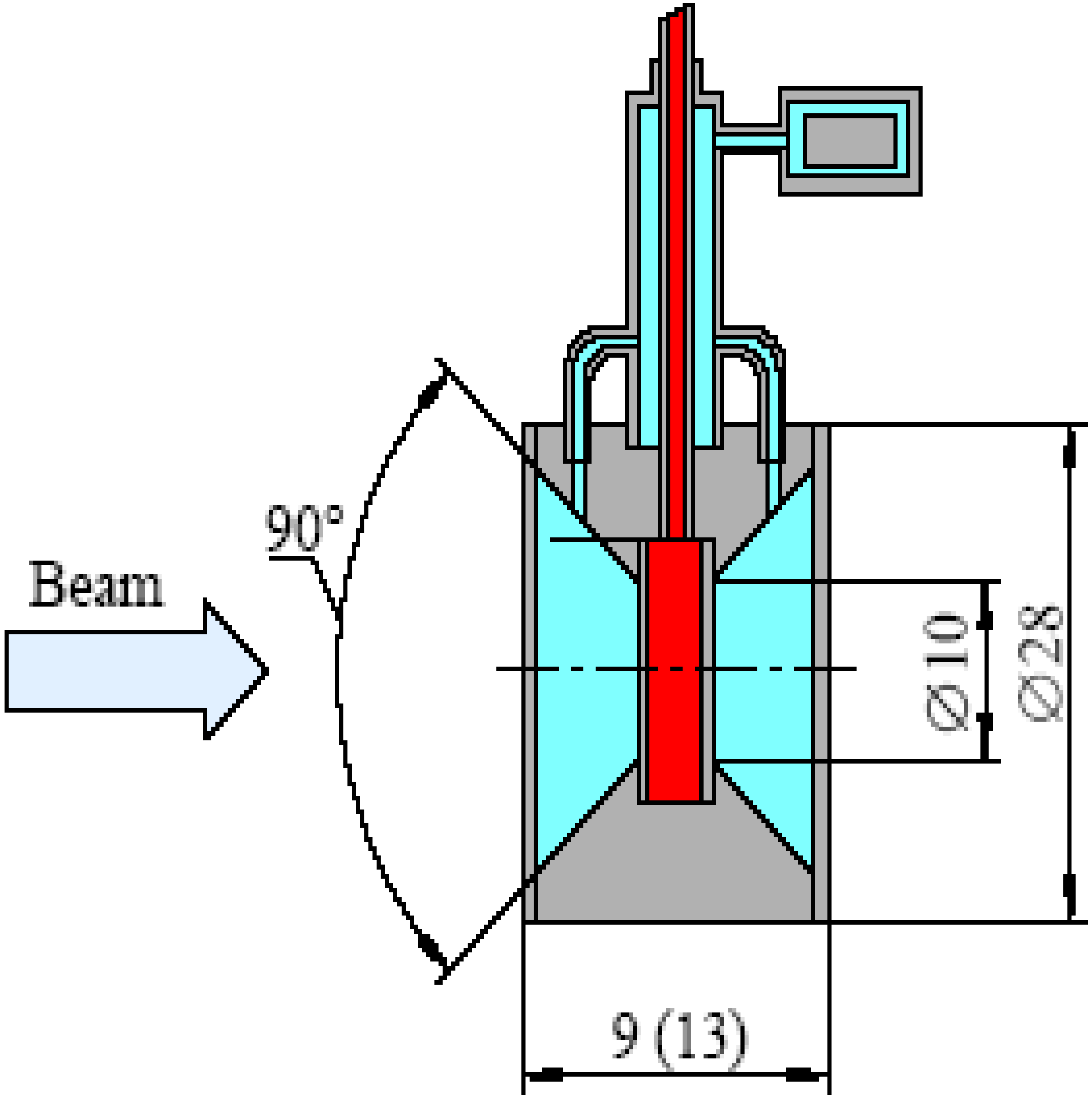
Equipment for study of neutron-rich nuclei

- **Cyclotron U400-M ion source feeding by the hydrogen isotopes**
- **Filling of the tritium target by the hydrogen isotopes and ^{3}He, ^{4}He**
- **Evacuation and utilization tritium from the target**
- **Control of working temperature with the accuracy ±0,1K**
- **Monitoring of the radiation environment**
- **Automatic monitoring and control of the working parameters**

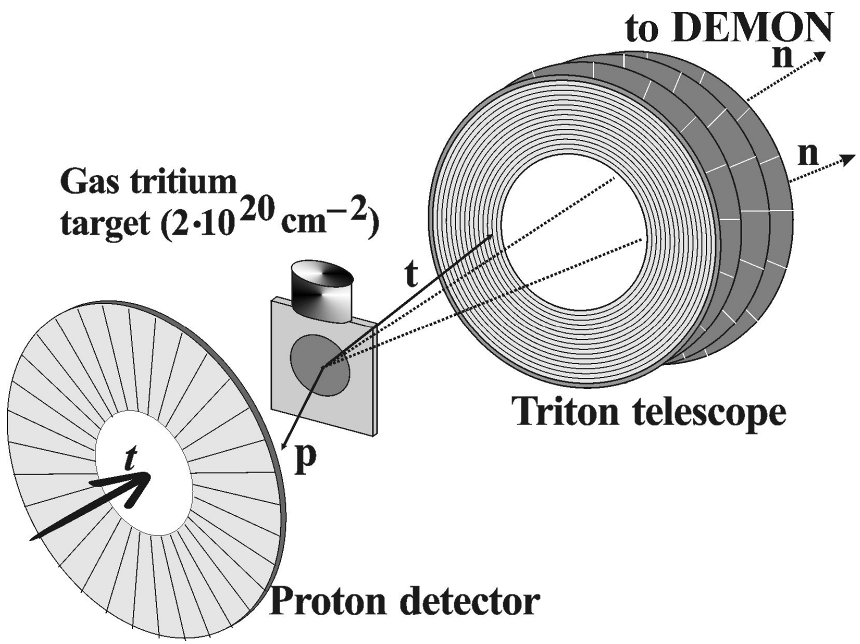


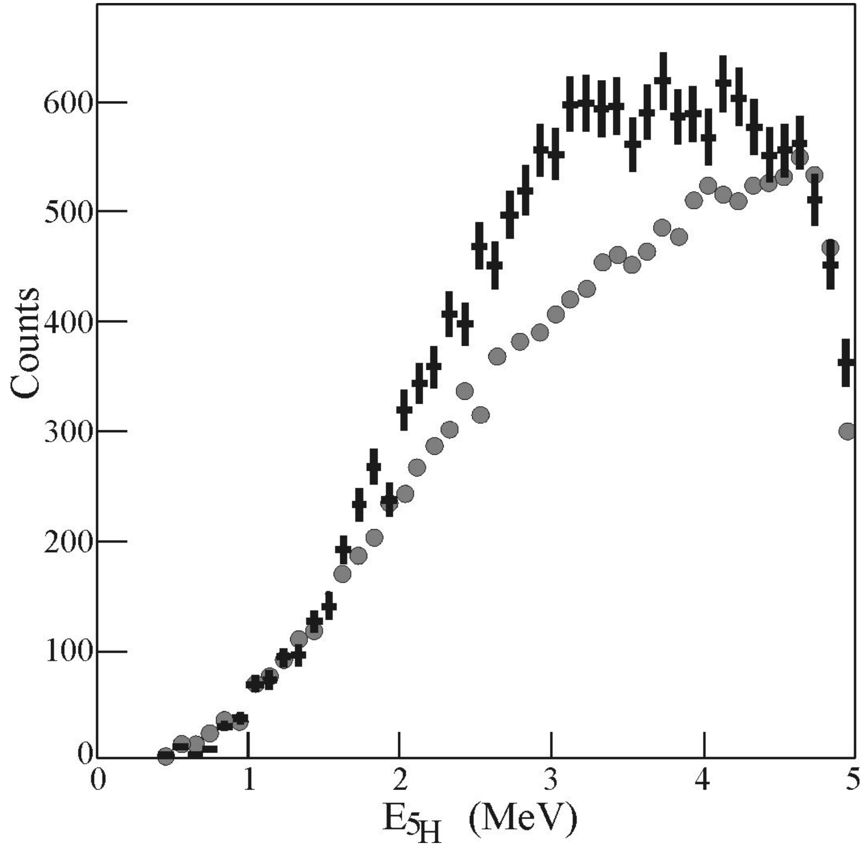
Tritium target





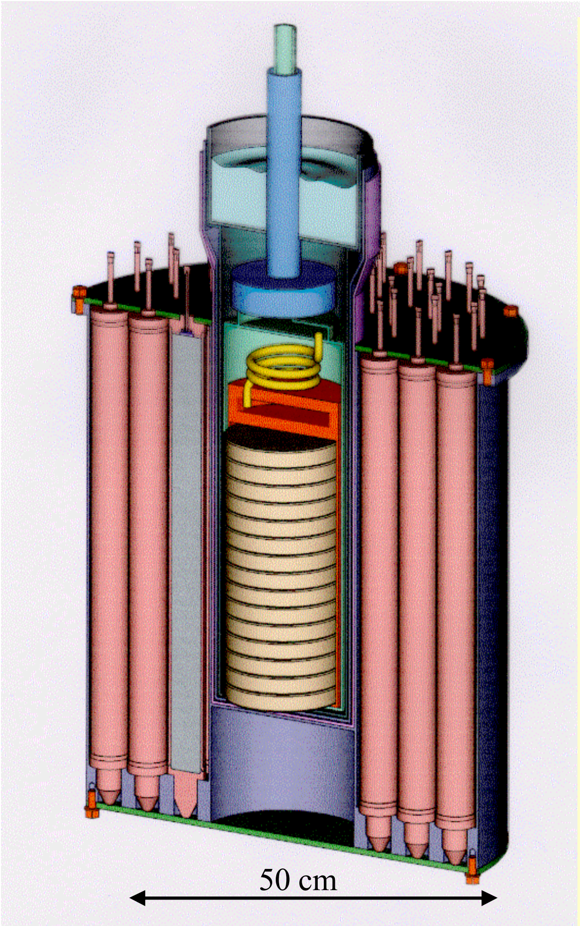
Determination parameters ^{5}H





New Experiment

SEARCH FOR THE NEUTRINO MAGNETIC MOMENT



Conceptual layout of the ν-e scattering experiment with 40 MCi tritium source

$\tilde{\nu}_e$ - e scattering

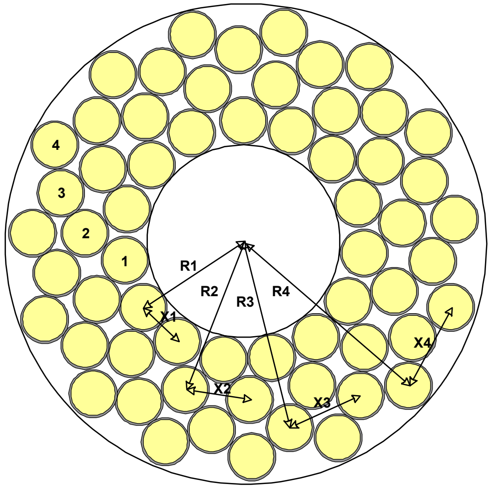
- ν_e **TRITIUM SOURCE of 40 MCi activity (4 kg ^3H) with flux density of 6×10^{14} cm^{-2}s^{-1}**
- **ULTRA-LOW-THRESHOLD DETECTORS E_{th}~10 eV:**

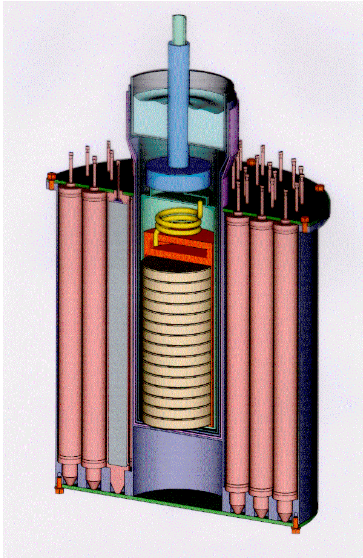
•**SILICON CRYODETECTOR (T=10mK) 15×100cm^3, M=3kg,** ***ionization-into-heat conversion effect (JINR-CWRU-Stanford)***

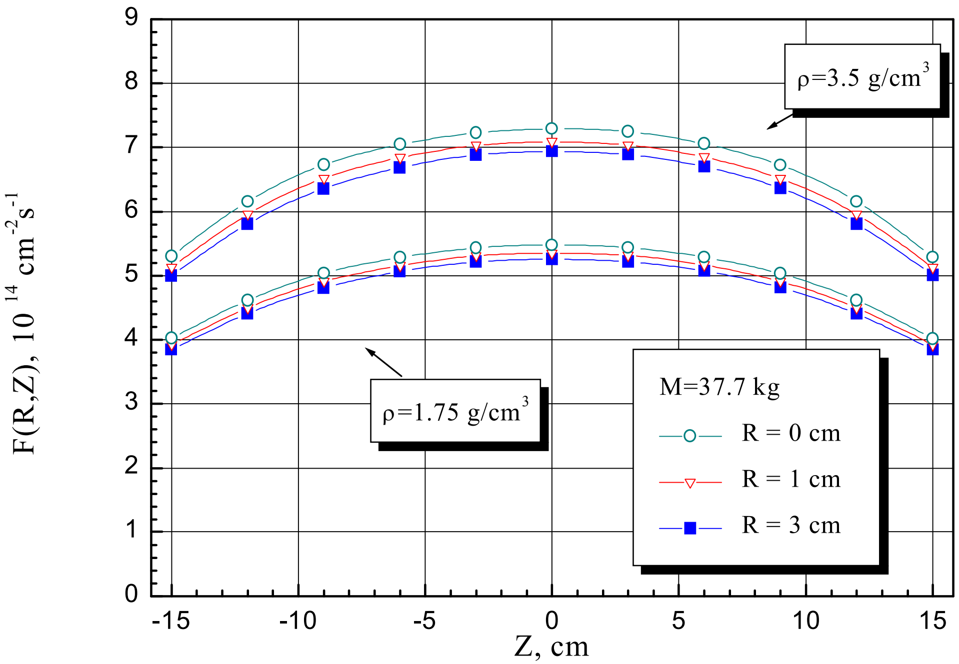
•**HIGH-PURITY-GERMANIUM DETECTOR 6×150cm^3, M=4.8kg,** ***internal proportional signal amplification by avalanche multiplication in the electric field (ITEP)***

SENSITIVITY (95% C.L.): $\mu_\nu \leq 2.5 \times 10^{-12} \mu_B$

Neutrino flux inside the source





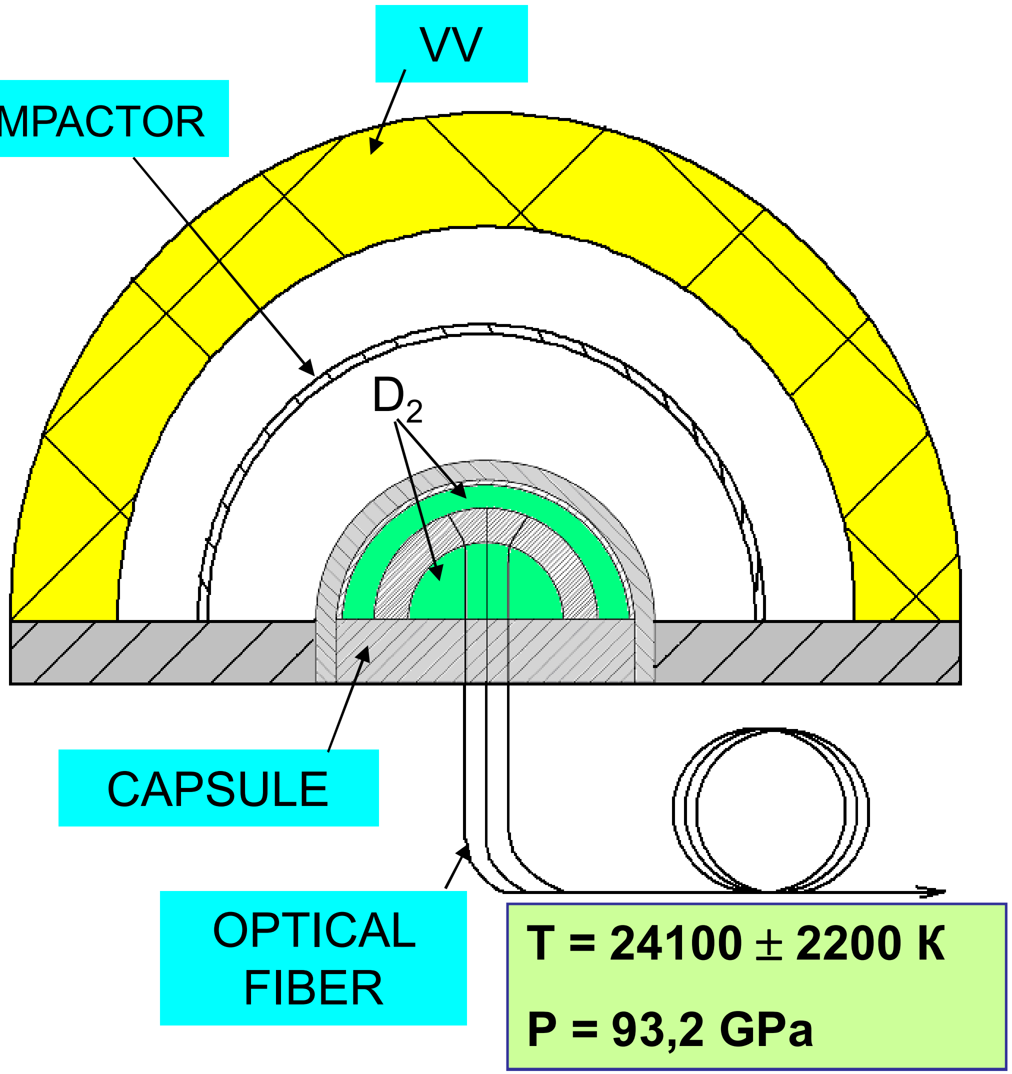


Source construction of packed copper tubes filled with tritium tritide

½ model

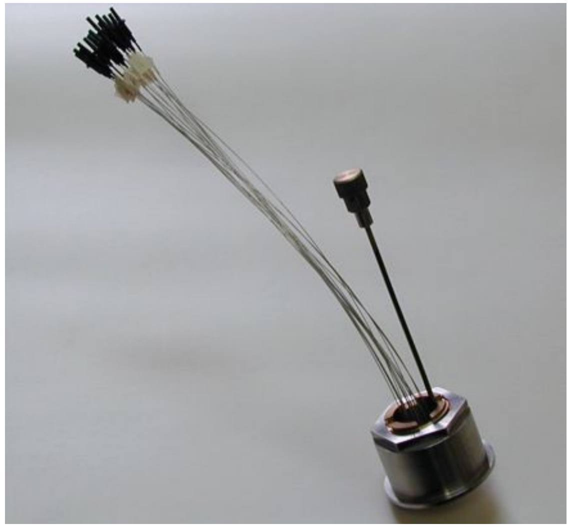
Neutrino flux density $F \approx 6{\cdot}10^{14} cm^{-2} \cdot s^{-1}$ along the detector Z-axis for multi-cylinder source design

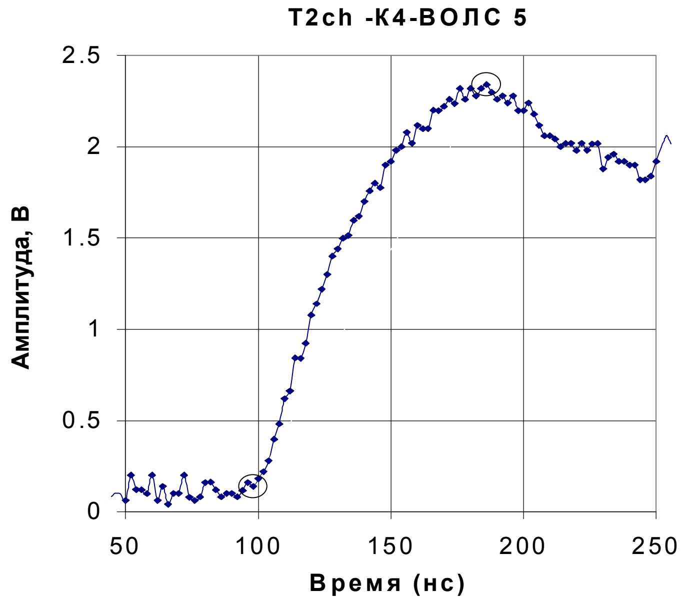
HEMISPHERICAL CAPSULE FOR MEASUREMENT COMPRESSIBILITY AND TEMPERATURE IN DENSELY SHOCK-COMPRESSED GASEOUS DEUTERIUM (HELIUM) AT INITIAL PRESSURE 200 MPA

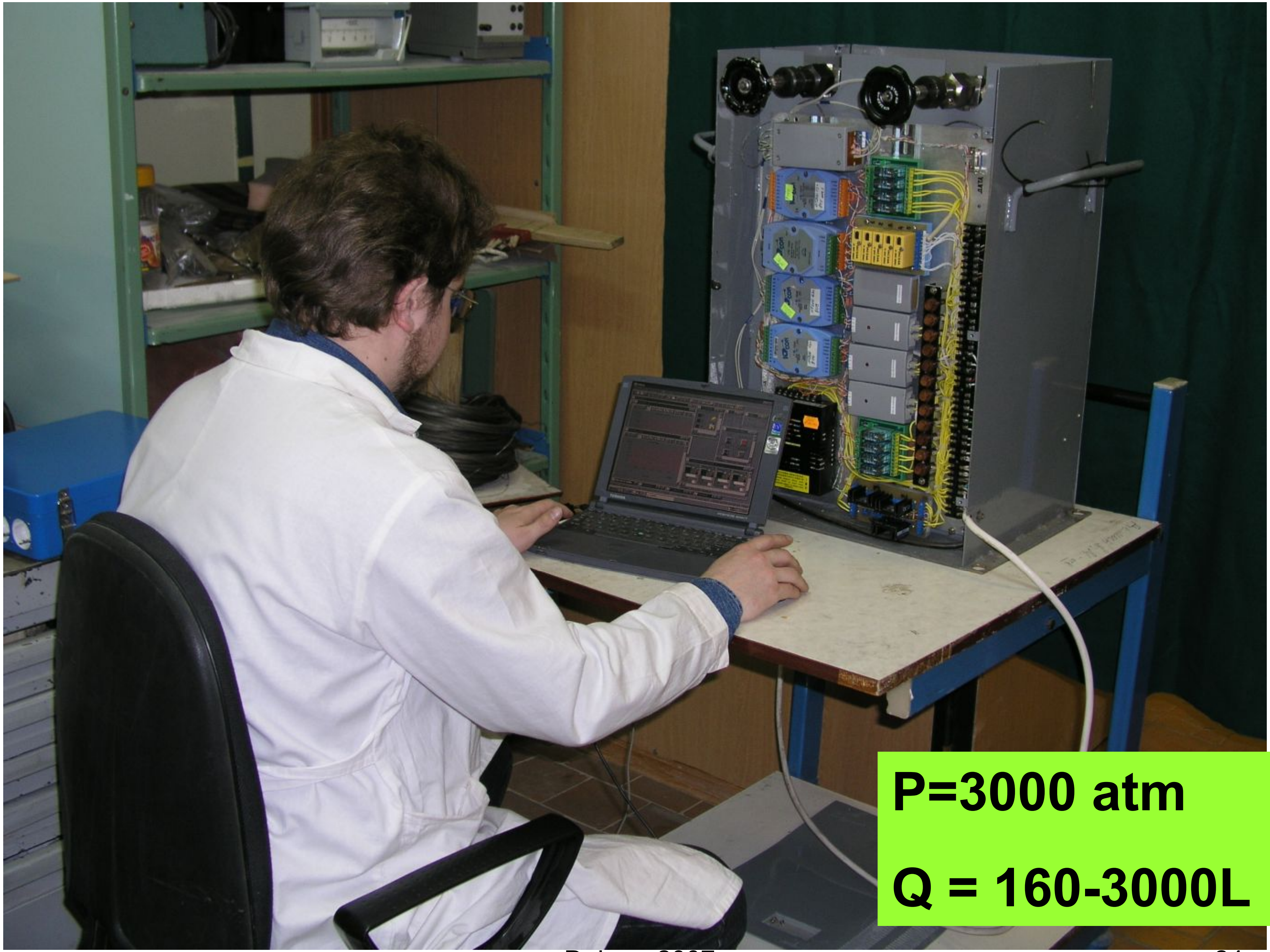


T = 24100 ± 2200 K

P = 93,2 GPa





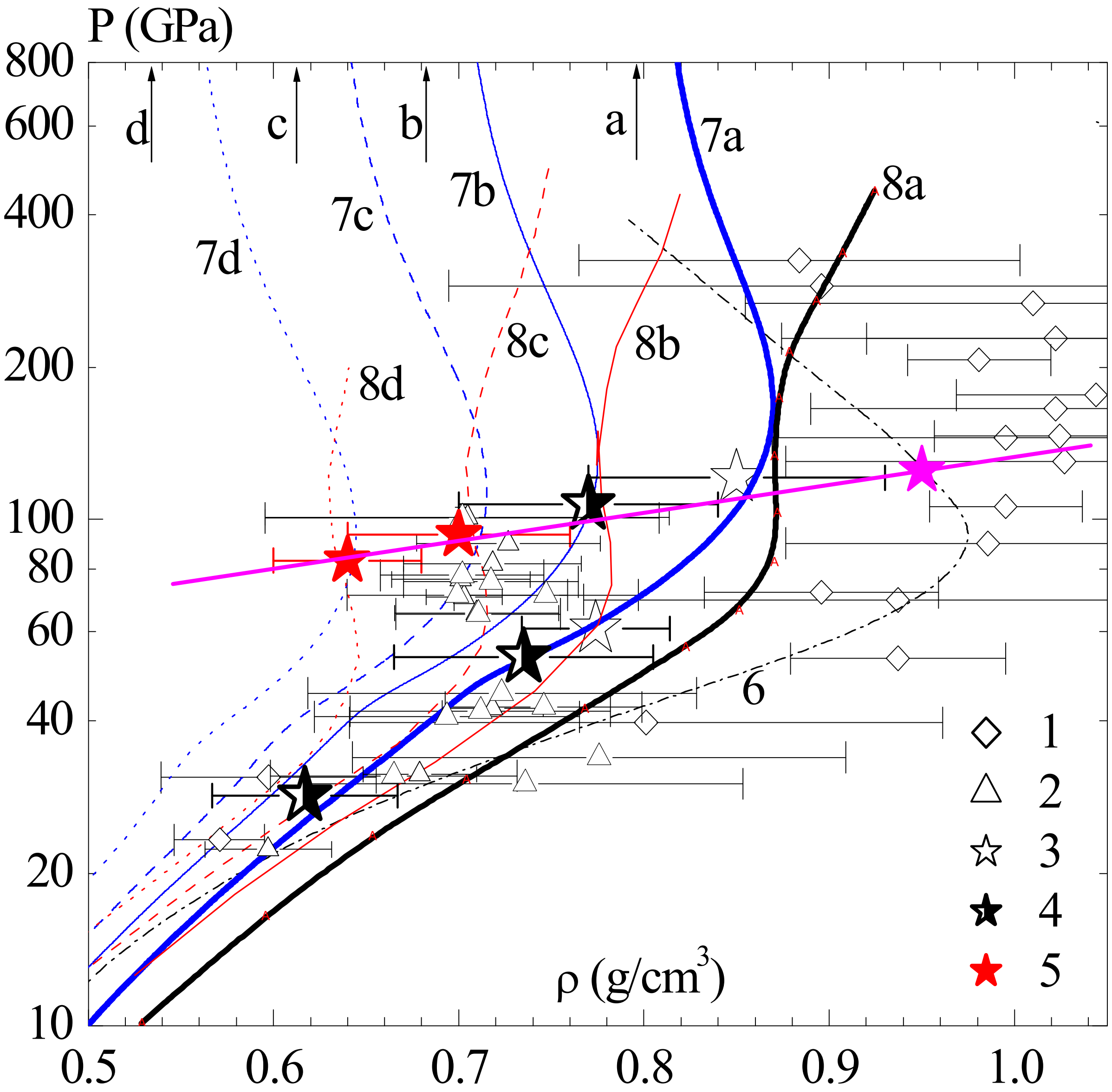


P=3000 atm

Q = 160-3000L

Filling system with source M69.

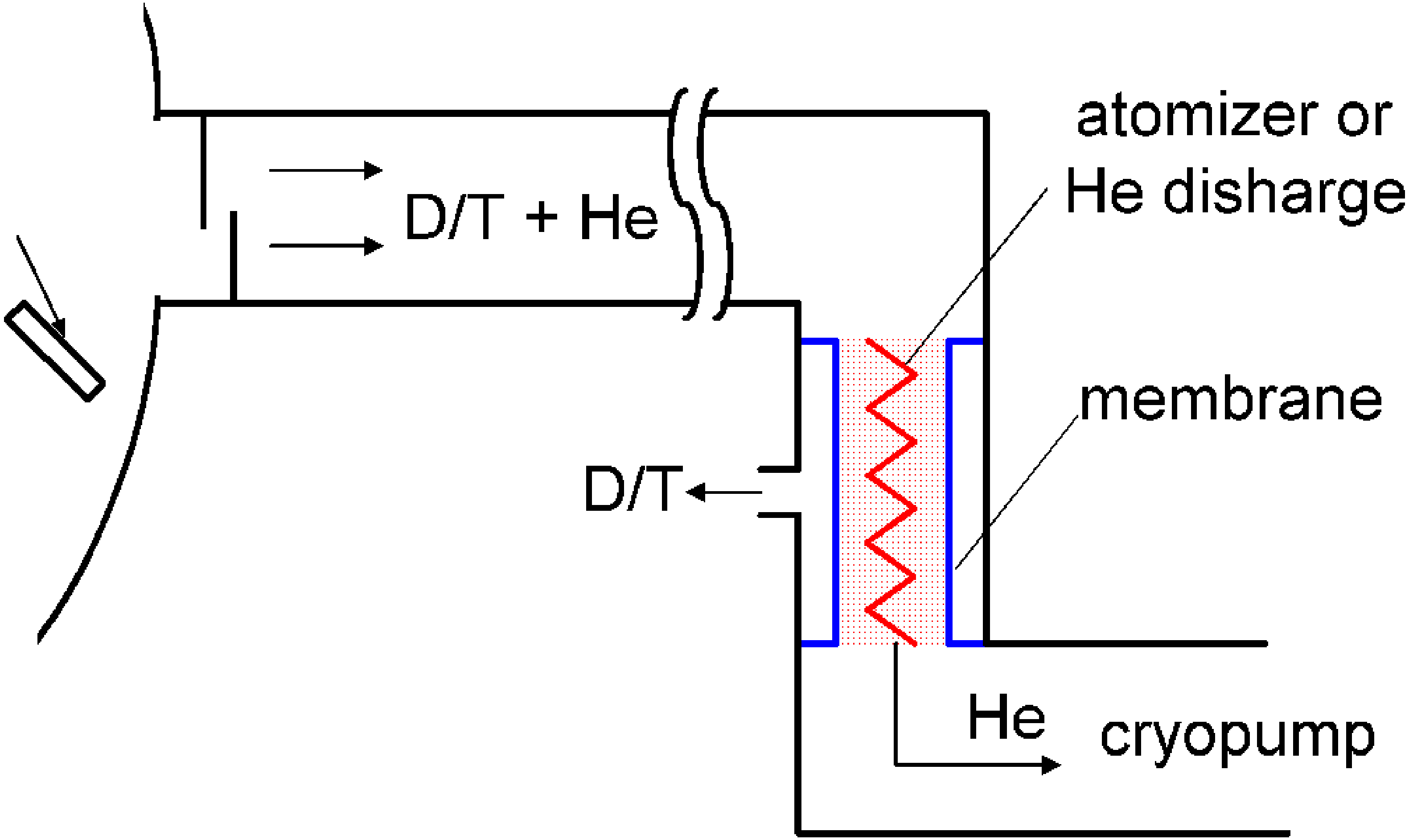
Percussive adiabat of deuterium



- **Experiment:**
- **1 – [LLNL],**
- **2 – [Sandia].**
- **3, 4, 5 – [VNIIEF],**
- **Calculation -**
- **6 – [Ross],**
- **7 – Caxa-IV,**
- **8 - MCK [VNIIEF],**
- **: ρ_0 = 0.199 g/cm³,**
- **: ρ_0 = 0.171 g/cm³;**
- **: ρ_0 = 0.153 g/cm³,**
- **: ρ_0 = 0.1335 g/cm³.**

Limit pressing is show by arrow ($\rho / \rho_0 = 4$) for each percussive adiabat

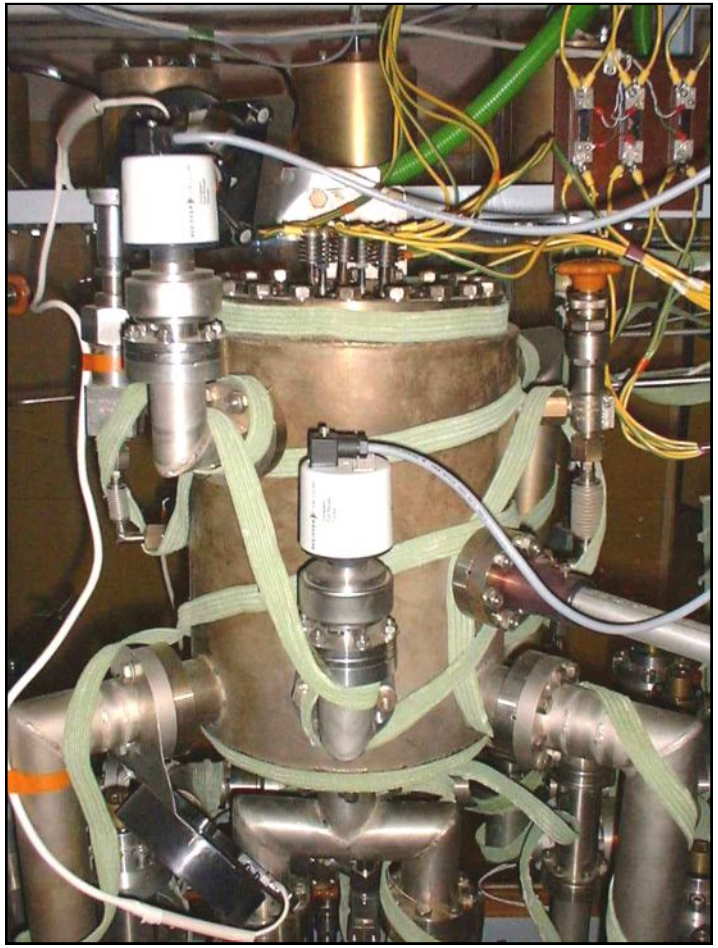
Superpermeable membrane for purification the fuel mixture in thermonuclear reactor

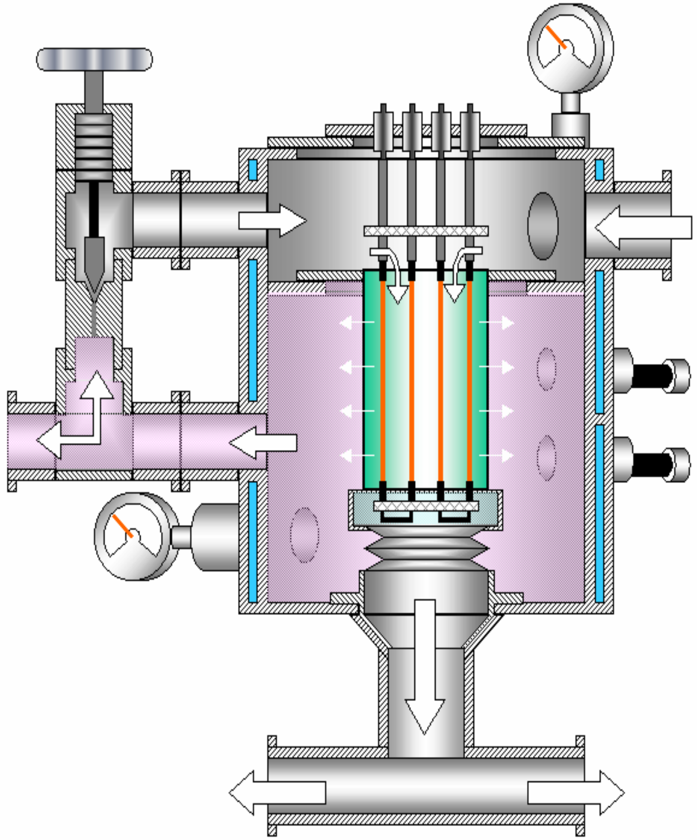


«Prometheus» facility

ISTC Project #1110

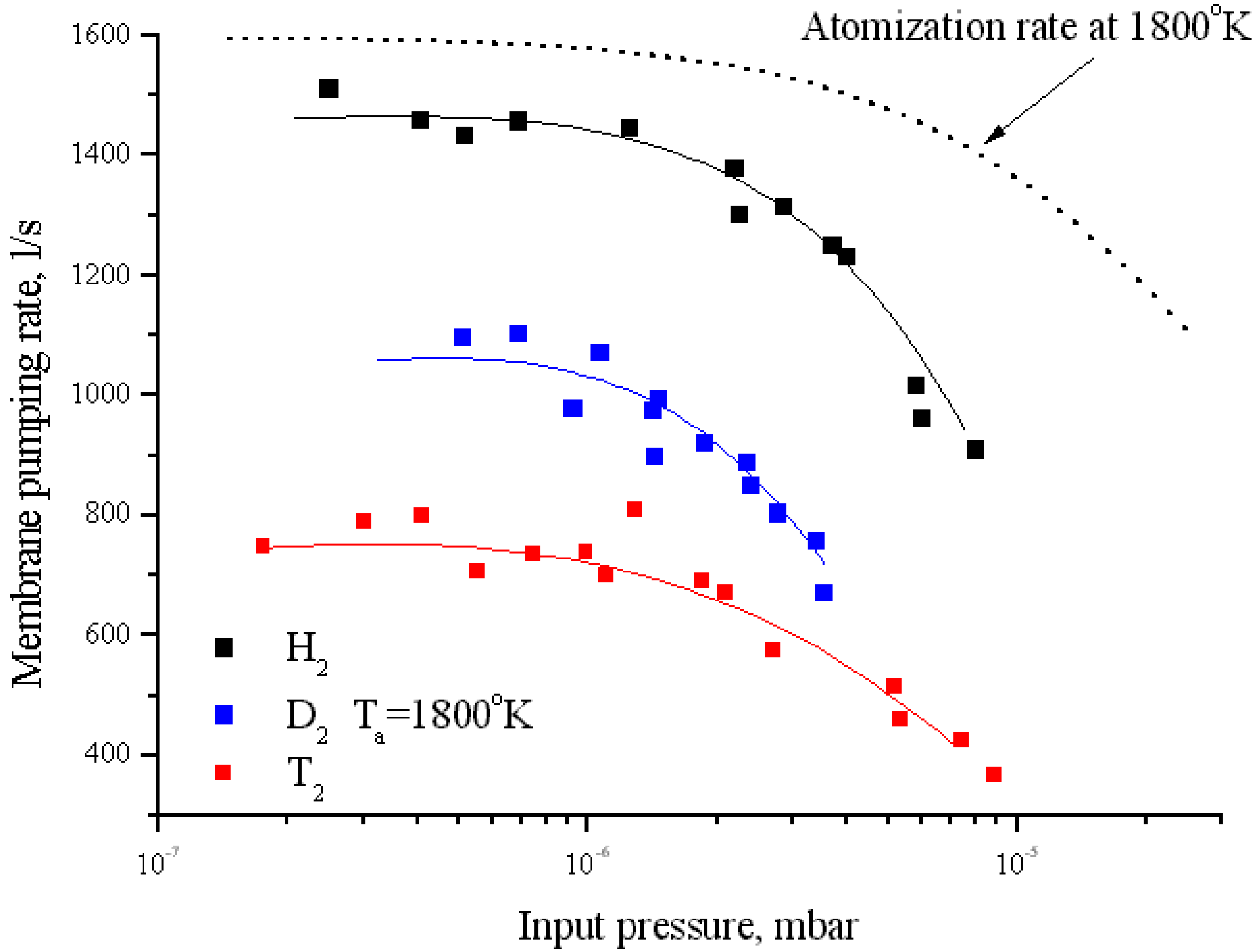
Cell for investigation of supermeability



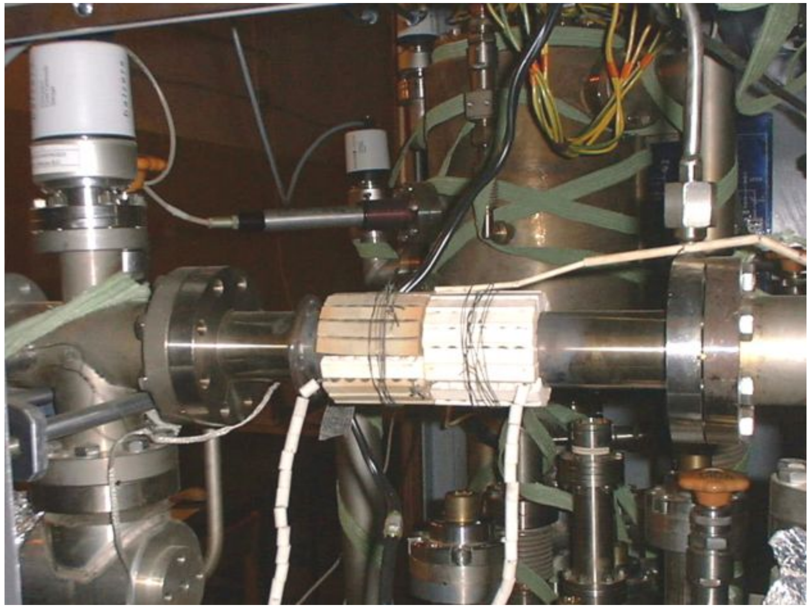


Membrane size: ∅10cm, height 18cm;
pressure: inlet $10^{-4} – 10^{-7}$ mbar
outlet up to 0,1mbar
Atomizers temperature up to 2300K

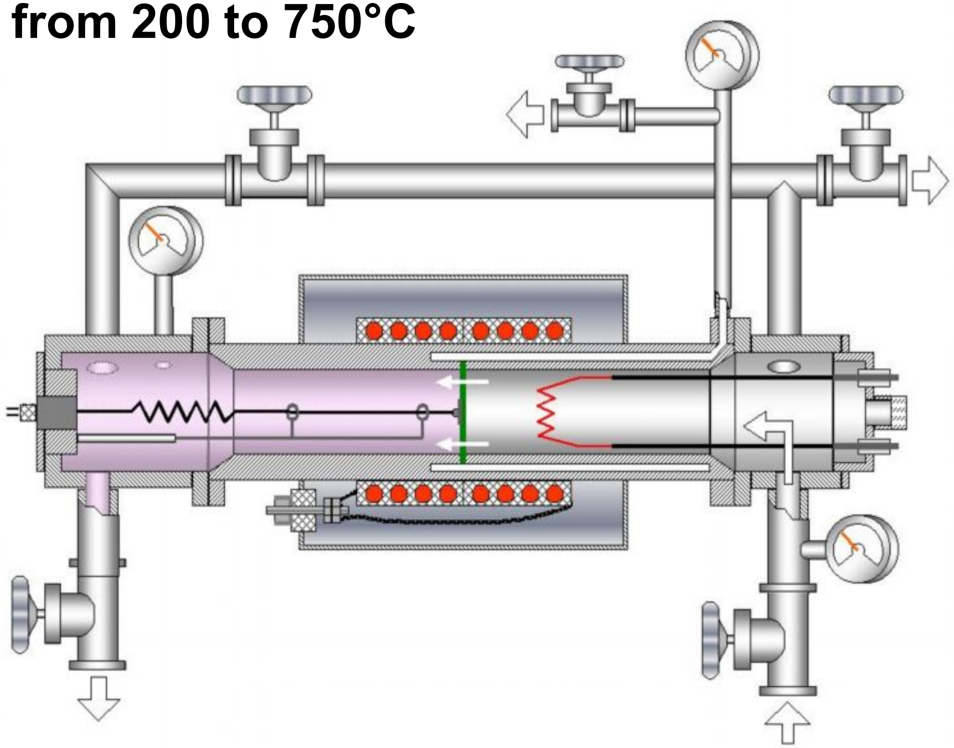
Pumping velocity for HI



Cell for Investigating permeation through SM



Size of flat membrane: ∅30mm
Temperature interval from 200 to 750°C



Operating pressure:
- **Up to 5 mbar for tritium;**
- **1000 mbar for protium and deuterium**

Interaction of tritium with SM

Tritium impact

?

=

Hydrogen impact **+** **^{3}He impact**

ISTC #2276 "Hydrogen and helium in metal"

ISTC Project #2276
Hydrogen and Helium in metals

Yukhimchuk A.A., Grishechkin S.K., Malkov I.L., Boitsov I.E., Zlatoustovskiy S.V., Khudomiasov, Lebedev B.S., Panina E.V., Perevozchikov V.V., V.I., Pershina V.M., Shirnin P.V. **Russian Federal Nuclear Centre – All-Russian Scientific Research Institute of Experimental Physics (RFNC-VNIIEF) Sarov, Nizhniy Novgorod region, Russia**

Kurdumov A.A., Gabis I.E., Denisov E.A., Evard E.A., Kanashenko S.L., Kompaniets T.N. **V.A.Fock Institute of Physics Saint-Petersburg State University, Saint-Petersburg, Russia**

R. Causey **Sandia National Laboratories, Livermore, California, USA**

A. Hassanein **Argonne National Laboratory (ANL), Argonne, Illinois, USA**

M. Glugla **Tritium Laboratory, Forschungszentrum Karlsruhe, Karlsruhe, Germany**

«Saturation" SM ^{3}He using "tritium trick"

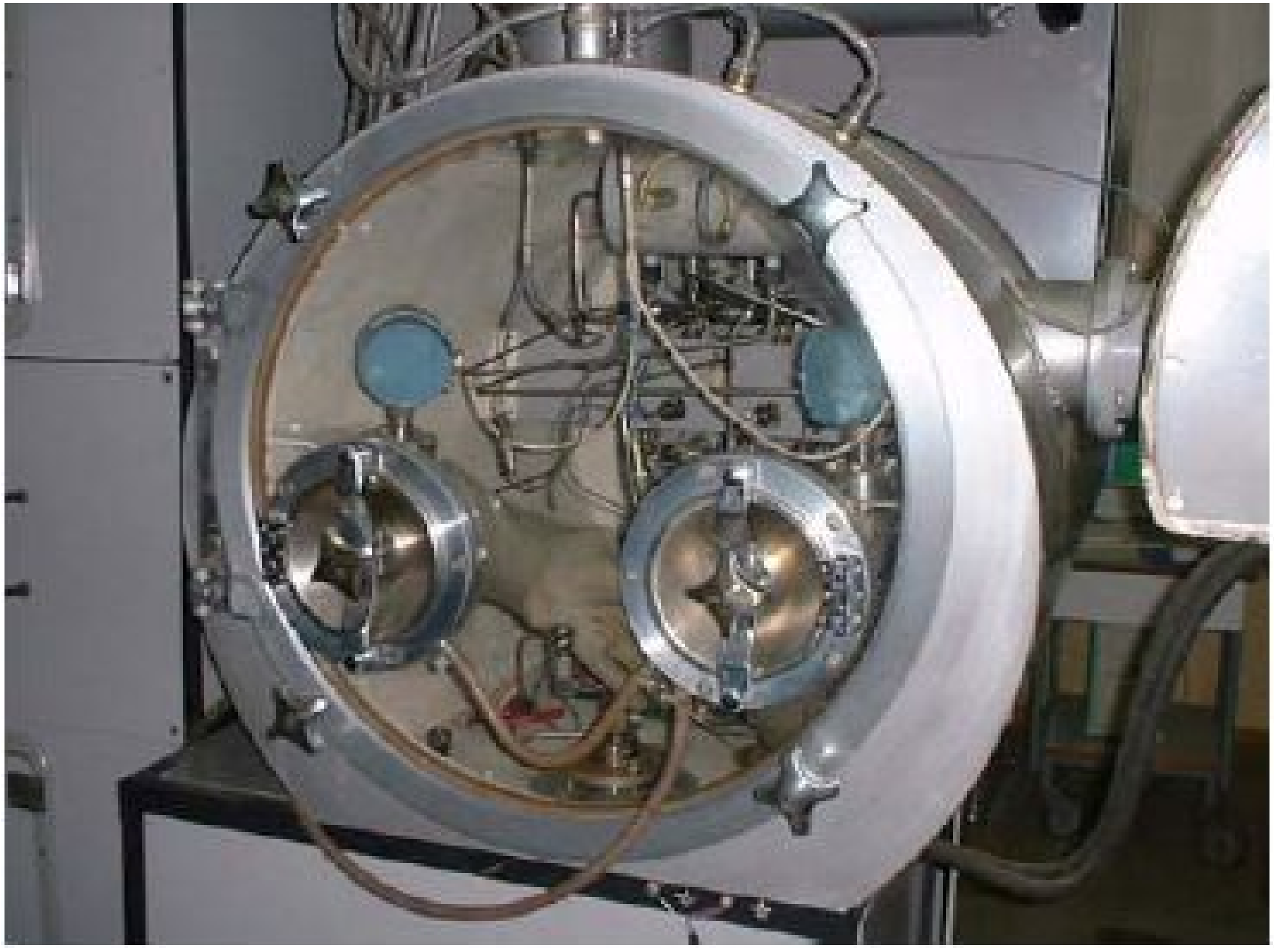
P=500 atm

T=500^{0}C

700 hour +

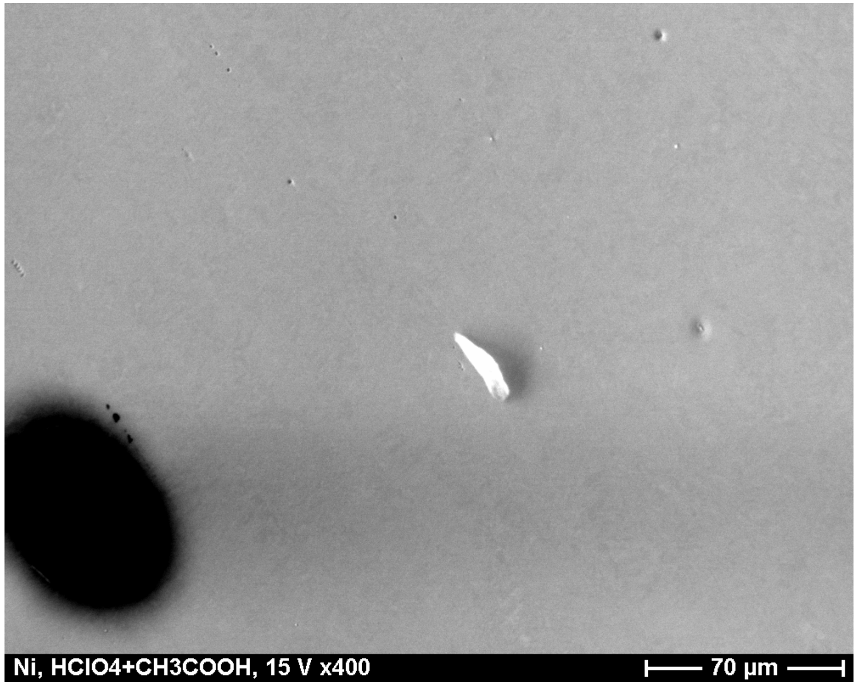
Technological interruption

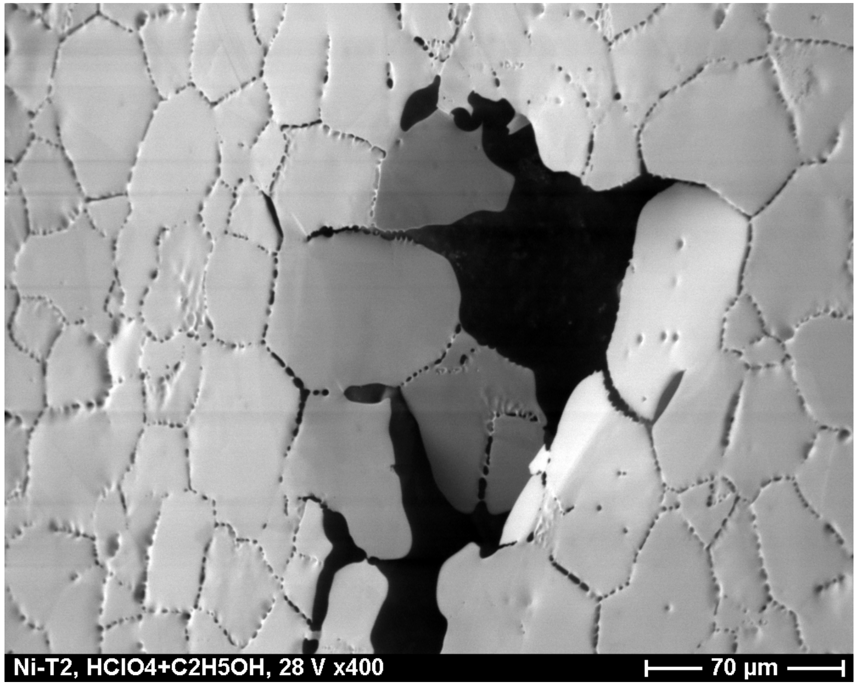
~140 appm



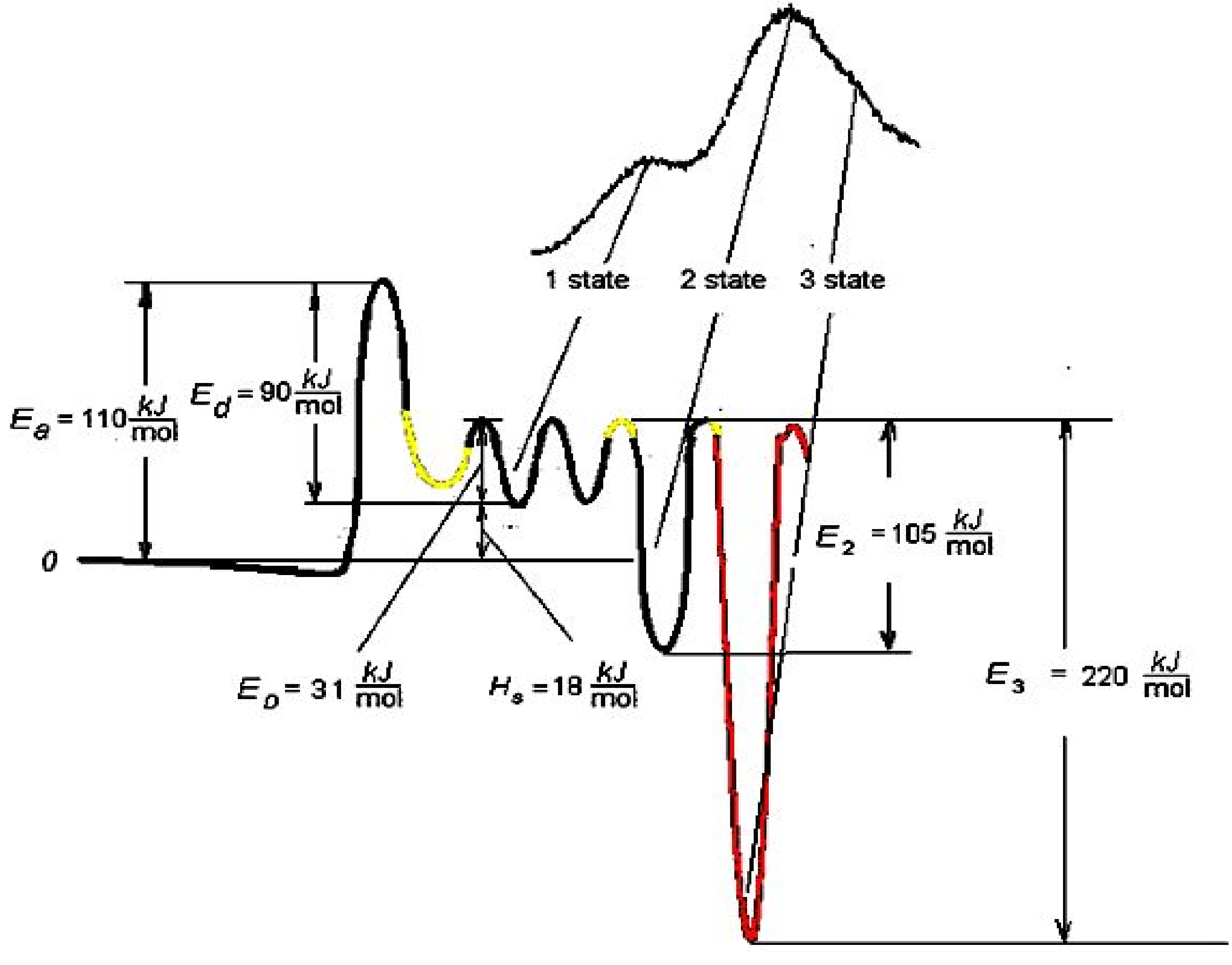
Ni
SEM images

Initial state **After tritiation and detritiation**

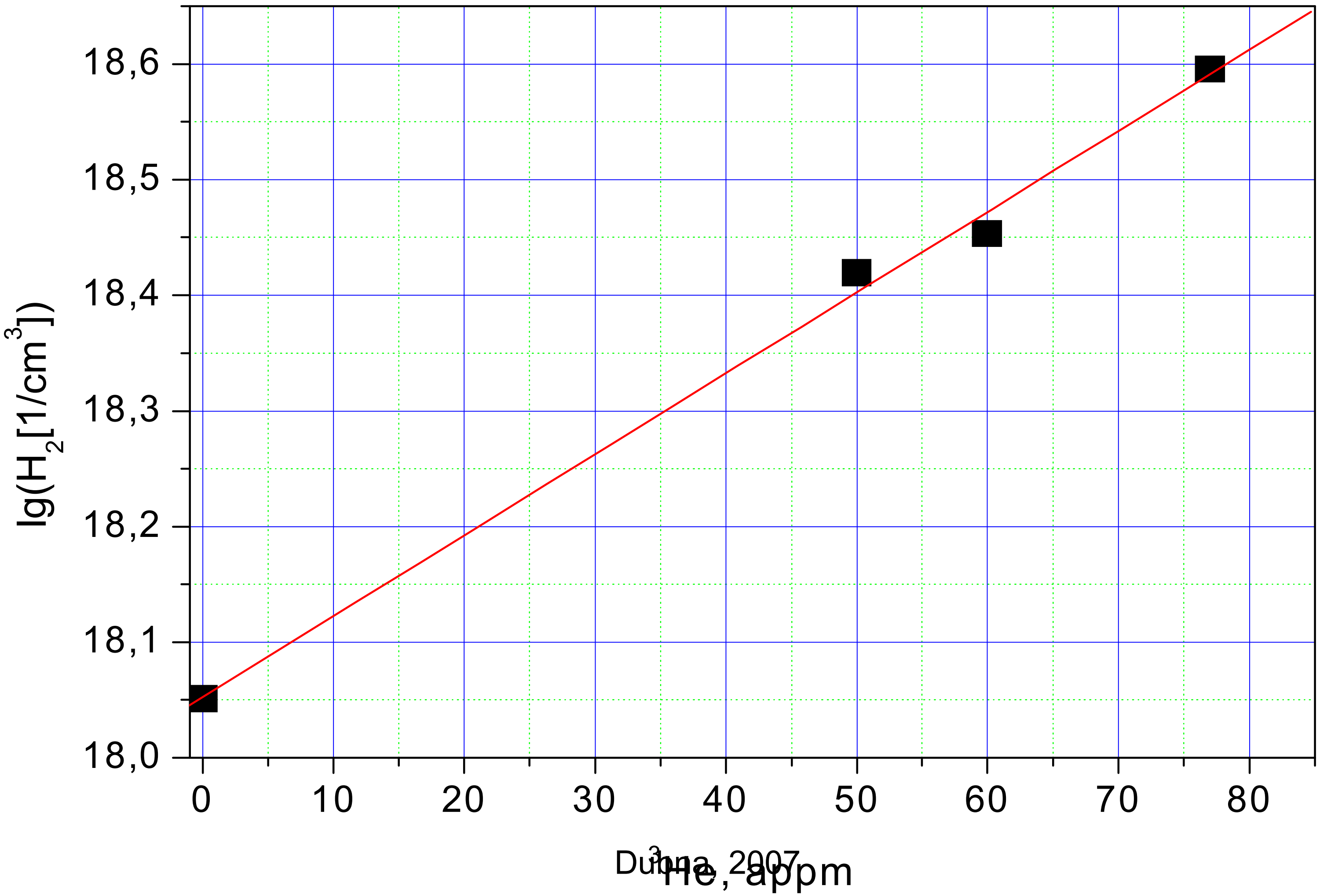




Potential energy diagram



Amount of trapped hydrogen in SS versus from ^{3}He content

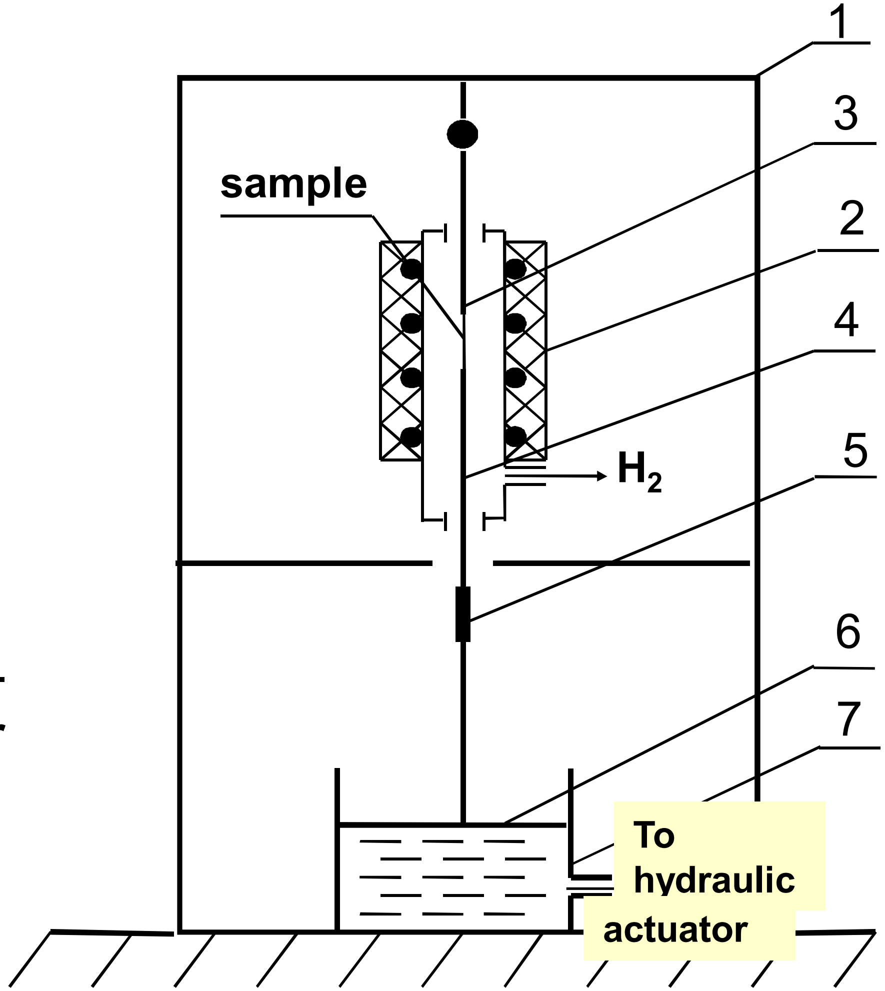


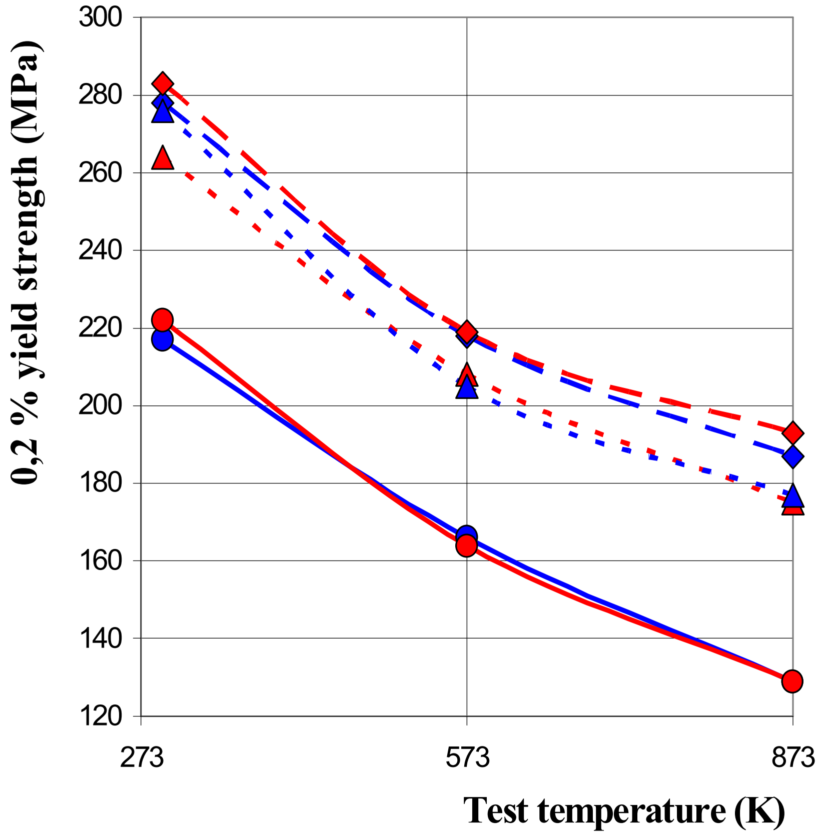
Scheme of installation for tensile test in gas media at high pressure

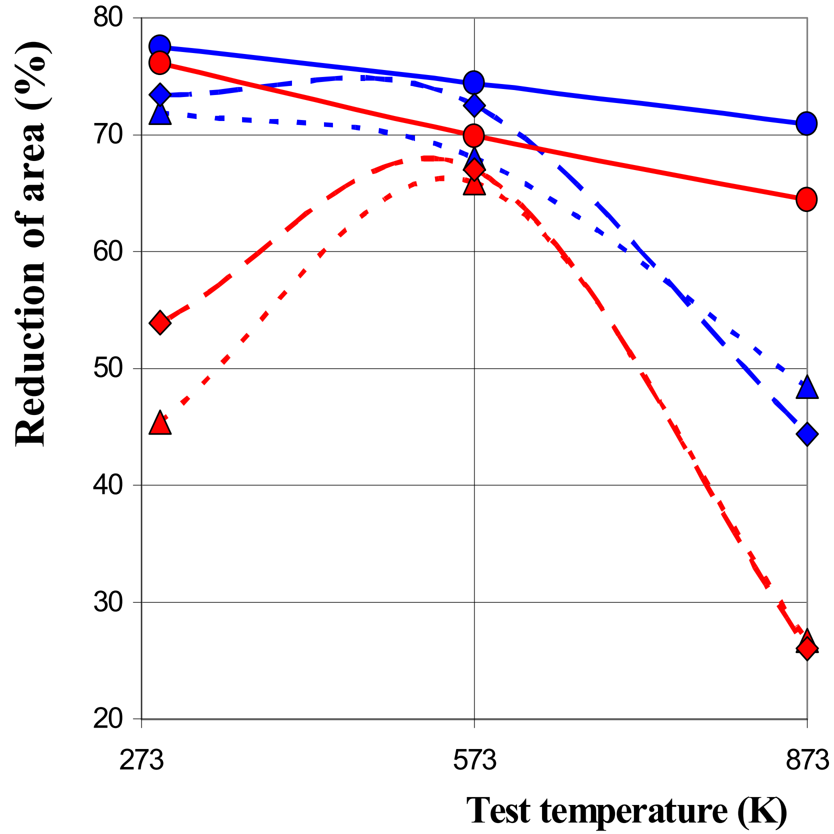
<u>**Technical data:**</u>

Maximum loading - 20kN;
Working area (length/diameter)- 120/12mm;
Maximum rod stroke – 15mm;
Deformation velocity - $2.2 \cdot 10^{-3}$ s^{-1};
Medium pressure - 50...150МПа;
Test temperature - 300...1100K.

1 – frame; 2 – testing vessel wit heater; 3 – upper rod; 4 – bottom rod; 5 – strength sensor; 6 – hydraulic actuator piston; 7 – hydraulic actuator cylinder.







(● , ▲ , ◆) - tests in helium environment at 80 MPa;
(● , ▲ , ◆) - tests in hydrogen environment at 80 MPa.

Concentration of ^{3}He in specimens:
(● , ●) – without ^{3}He; (▲ , ▲) – 75 appm ^{3}He; (◆ , ◆) - 130 appm ^{3}He.

What is next?

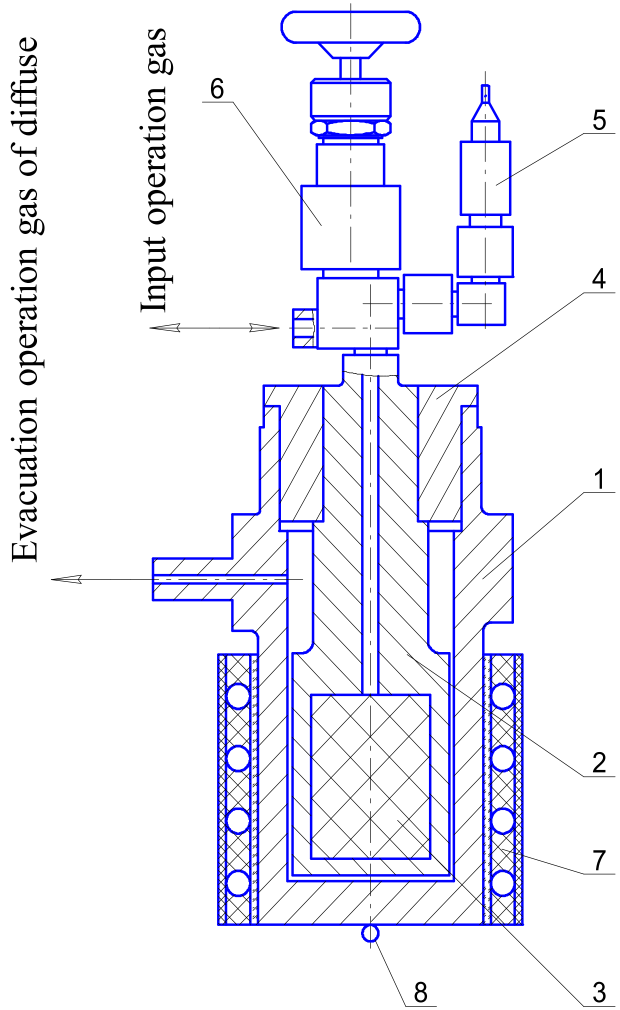
We have additional samples with tritium in which ^{3}He is forming.`

In framework of the Project #3672 we are planning obtain:

- **data on the effect ^{3}He (at concentration >100 appm) on the structure of SS;**
- **data on the effect of ^{3}He (at concentration >100 appm) on kinetics of diffusion, sorption, trapping, permeation and accumulation of hydrogen isotopes in SS;**
- **data on the synergistic ^{3}He / hydrogen effects on mechanical properties of in SS at ~200appm ^{3}He;**
- **refined models of hydrogen transport in metal in the presence of ^{3}He and of ^{3}He induced defects.**

1 year - $70,000

High-Pressure Hydrogen Isotopes Sources Based on Metal Hydride



More then 10 modification

P up to 500MPa

Q up to 2000L

Radioactive gas sources R48

- **Working pressure: 300 MPa**
- **Gas volume: 70 liters**
- **Working gas: T2, D2 and mixtures of these gases**

- **Applications:**

- **research in muon-catalyzed fusion;**
- **Study of radiogenic He-3 impact on mechanical properties of structural materials;**
- **Filling of microtargets to study nuclear laser fusion.**

Gas sources M69 (with furnace)

- **Working pressure: 100 MPa**
- **Gas volume: 3000 liters**
- **Working gas: D2**

Application: activities aimed at the refinement of D2 equation of state at high pressures.


ПАТЕНТ

International Conferences organized with VNIIEF:

1999 Potential of Russian Nuclear Centers and ISTC in Tritiun Technology. PRITT-99.

2001 Interaction of hydrogen isotopes with structural materials. IHISM'01.

2004 2-nd International Seminar «Interaction of hydrogen isotopes with structural materials. IHISM'04».

2005/06 1-st & 2 International School for **young Scientists** «Interaction of hydrogen isotopes with structural materials. IHISM_Junior'05/06».

2007 3-rd International Conference & School for **young Scientists** «Interaction of hydrogen isotopes with structural materials. IHISM'07».