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Highly intensive antineutrino tritium source: Specifics of physical experiment.

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Intensive Antineutrino Tritium Source (ATS) [1,2] for neutrino magnetic moment experiment

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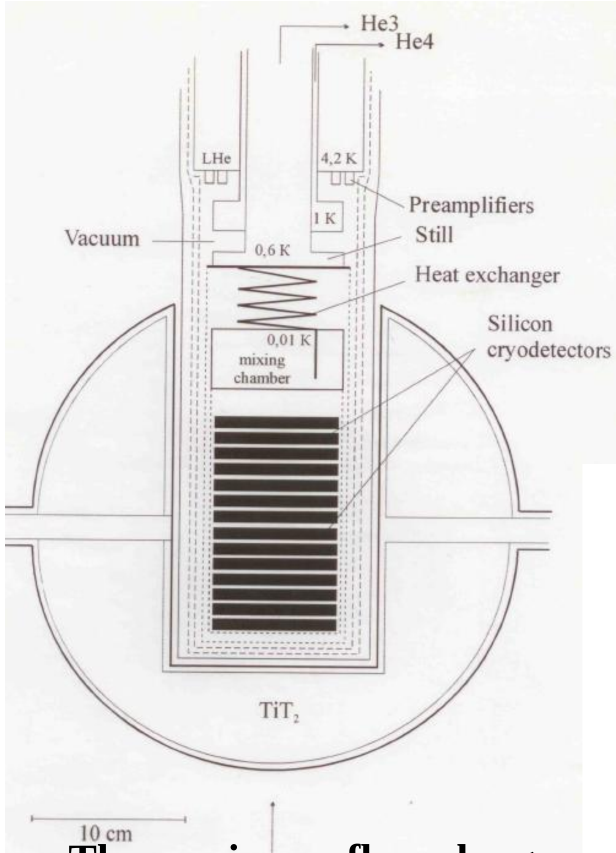
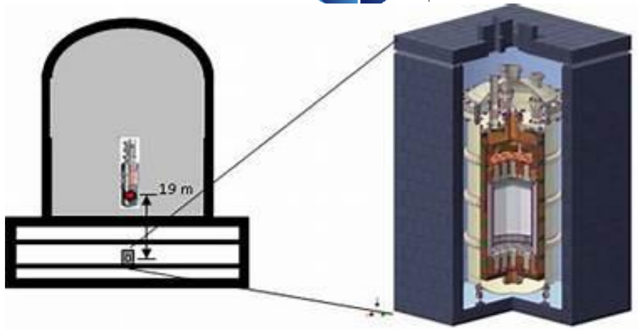
Advantages of the tritium antineutrino source

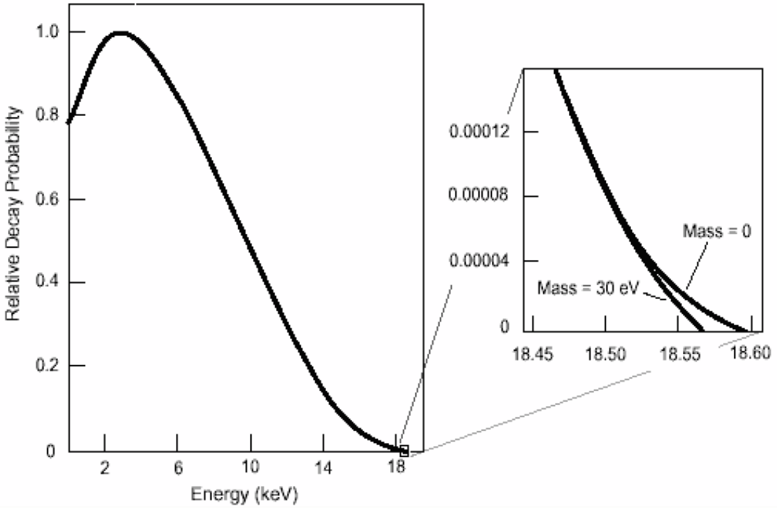
- More intensive antineutrino flows as compared with the reactor and accelerator sources;
- Strongly suppressed correlated background;
- Small sizes allowing using low-background underground laboratories and flow modulation for the non-correlated background deduction;
- Knowledge of the antineutrino spectrum with high precision;
- Low boundary energy of the decay spectrum (E_0 = 18.6 keV) – the bremsstrahlung radiation doesn't go beyond the limits of the source, there is no necessity in the passive protection between the source and detector.



The maximum flow along the detector axis is $6 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$



For the reactor with the power of 1 GW such flow may be obtained in the detector at the distance of 10 m from the reactor core.



1. *V.N. Trofimov, B.S. Neganov, A.A. Yukhimchuk. Measurement of the neutrino magnetic moment at a level better than 10^{-12} μ_B with a tritium ν-emitter and cryodetector (project). Physics of atomic nuclei.1998. T.61. No.8. p.1271-1273.*
2. *B.S. Neganov, et al. Status of the experiment on the laboratory search for the electron antineutrino magnetic moment at the level $\mu_\nu \lesssim 3 \cdot 10^{-12} \mu_B$. Physics of atomic nuclei. 2001. T.64. №11. p.2033-2039.*

The First ATS Design for Measuring the Neutrino Magnetic Momentum

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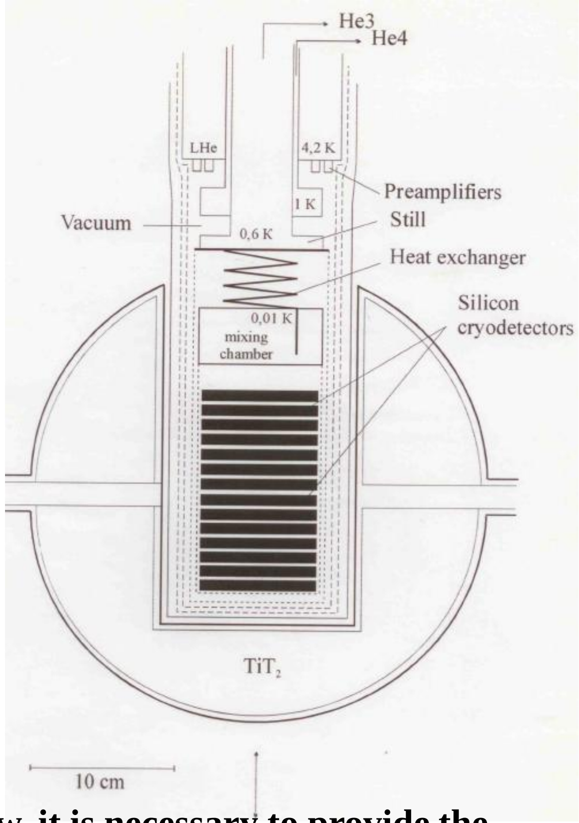
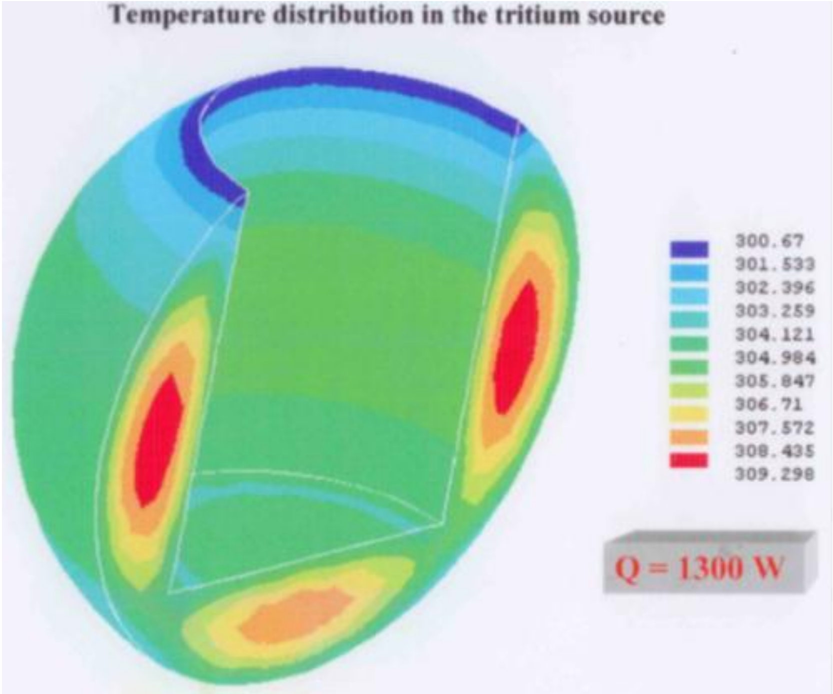
Material*	H_2 capacity		T dis., ^0C	$P_{eq.}$, torr at 25^0C
	cm^3/g	cm^3/cm^3		
UH_3	~140	~1570	420-430	10^{-6}-10^{-4}
TiH_2 TiT_2	~468	~1700 ~1700	550-620	$\sim10^{-9}$
Mg_2NiH_4	~418	~1074	~240	$\sim10^{-2}$
$ZrCoH_3$	~186	~1415	340-350	$\sim10^{-5}$
$LaNi_3Mn_2H_6$	~127		270	$\sim10^{-2}$
$LaNi_{5-x}Al_xH_6$ $x=0\div1;y=6,7\div4,1$	80-100	550-690	180-250	$\sim10^{-1}$-10
PdH	~105	~800	~150	30-50
H_2 liquid		780	-253	760
T_2 liquid		1000	-251	760





0.328 W/g; 1.954 W/mole

In order to reach the maximum density of the (anti)neutrino flow, it is necessary to provide the maximum bulk tritium activity in the structure of the source. Also, such source should be absolutely safe in all, including extreme, circumstances. The most suitable for that is tritium storage in the chemically bound condition using hydride-forming metals, which on the on hand have a higher bulk density of the hydrogen contents, and on the other hand tritium there has low equilibrium pressures at the room temperatures.

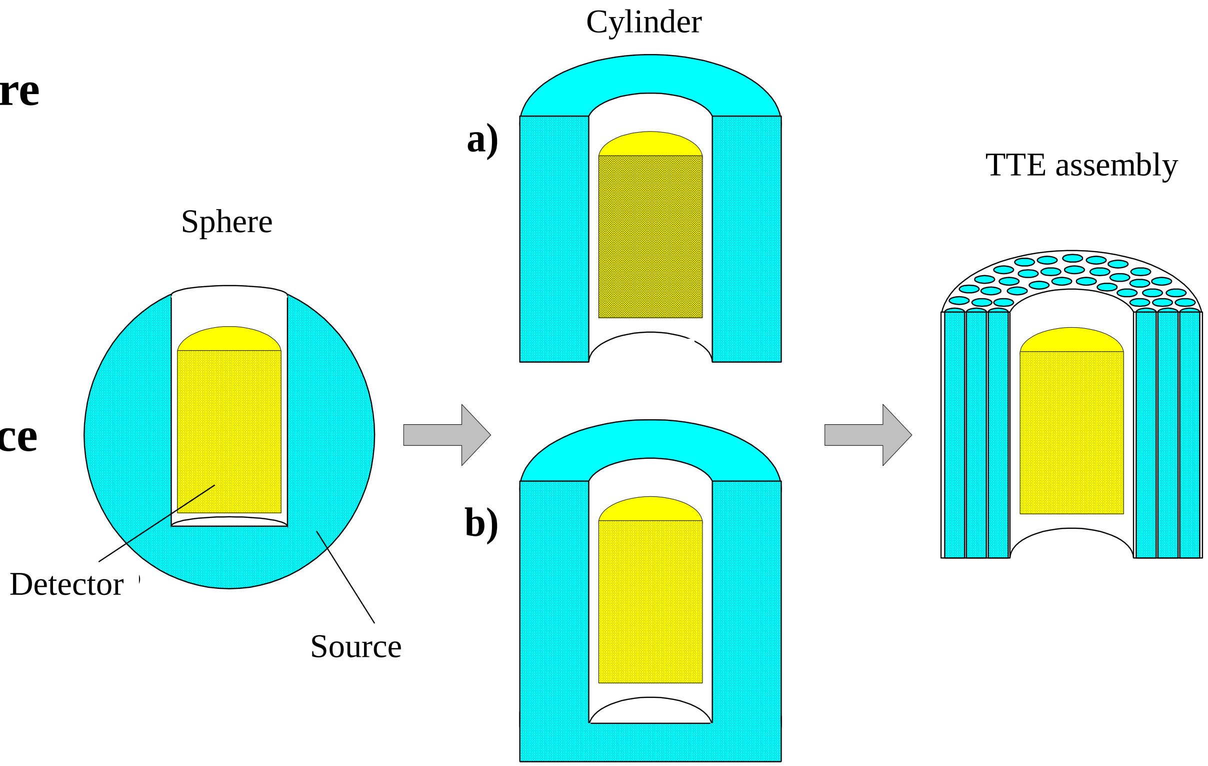
Titanium dehydrate is chosen. There is a low equilibrium pressure. The bulk content of tritium per Ti is practically 1.7 times higher than in case of tritium in the liquid state. There is the opportunity of safe operation at up to 500°C, while in order to keep tritium in the liquid state, it is required quite a powerful refrigerating facility allowing sustaining the tritium temperature at about 20K (with account for its heat release).

The ATS heat calculation in the conditions of natural storage showed its considerable heating. In the center of the source the temperature exceeded 309°C that caused certain difficulties in the course of transportation, storage and operation of such source. Besides, its manufacturing would require a special process facility.

The Evolution of Views on the ATS Design

We have performed the works aimed at the ATS design optimization [3, 4]. In doing so, the following factors were taken into account:

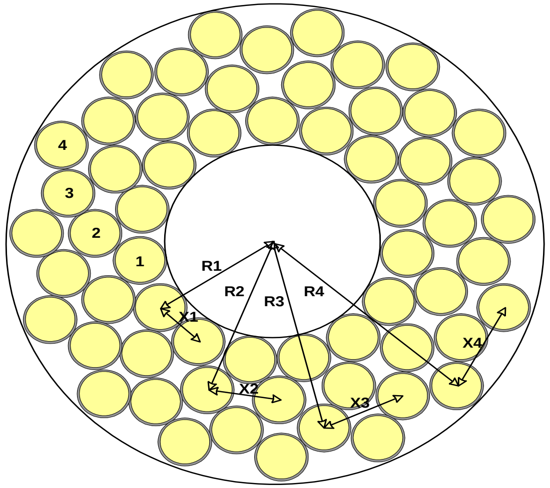
- **Having the available tritium amount, we aimed at obtaining the maximum number of the events of neutrino interaction with the detector material;**
- **Detector sizers and shape;**
- **Technological capabilities of manufacturing the source structural elements;**
- **Possibility of obtaining titanium tritide (TiT) of the necessary density;**
- **Behavior during the operation;**
- **Safety at all the ATS operation lifecycle stages;**
- **Convenience of mounting and dismounting.**

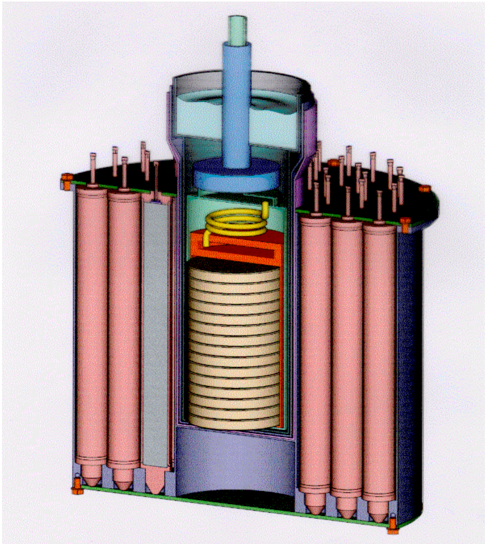


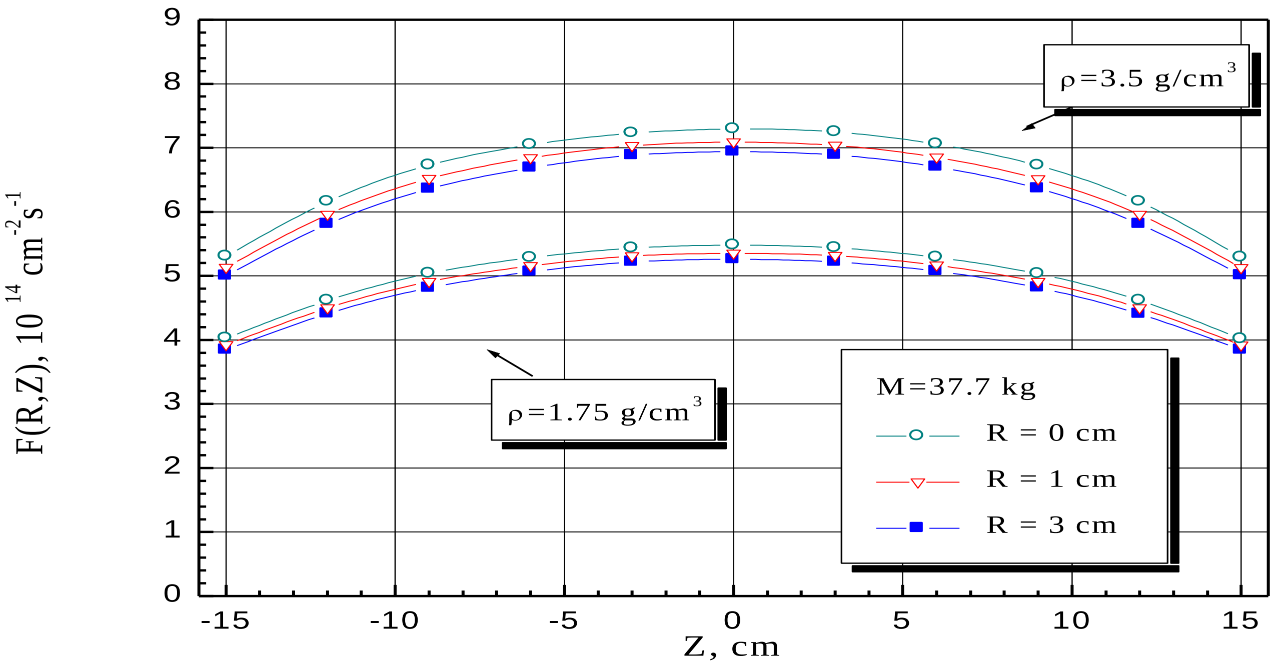
3. *Yu.I. Vinogradov et al. Optimization of the tritium source design for the experimental facility. In the collected papers "Hydrogen isotopes and applied research" edited by A.A. Yukhimchuk, FSUE "RFNC-VNIIEF", 2009, P.212-221.*

4. *A.A. Yukhimchuk et al. Status of works a 40-MCi-activity source for the measurement of the antineutrino magnetic moment. Fusion Science and Technology, 48 (2005) 731-736.*

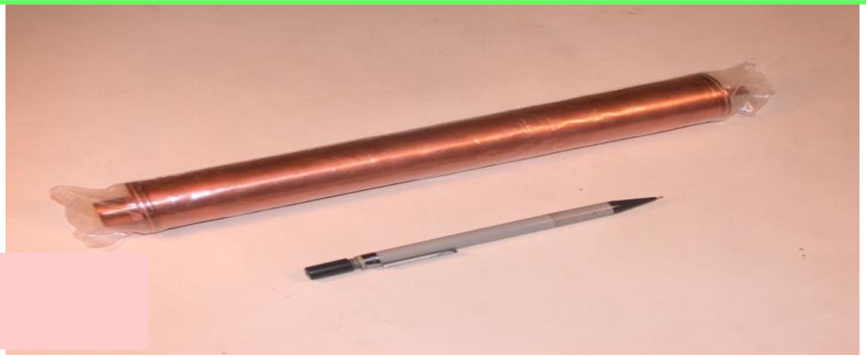
The Results of Optimization







The source design includes 80 copper tubular elements with titanium tritide.

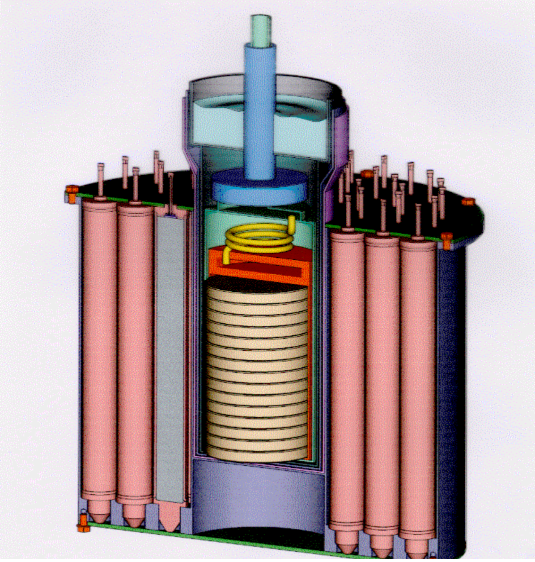


½ Model

The neutrino flow density is

$F \approx 6 \cdot 10^{14} cm^{-2} \cdot s^{-1}$ along the axis Z of the detector

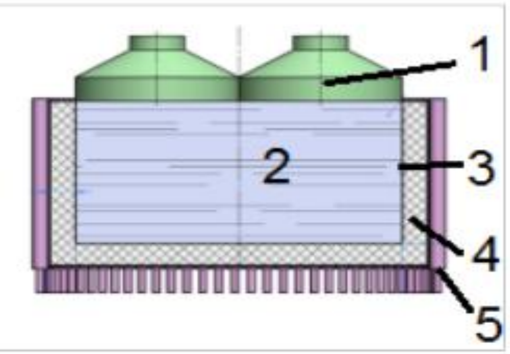
Previous Projects Aimed at Defining the in-Lab Lower Limit of Neutrino Magnetic Momentum $\mu_\nu \sim 10^{-12}\ \mu_B$ with the ATS with the Activity of 40 MCi

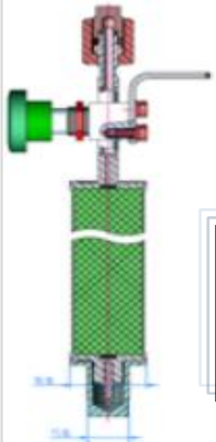


The project "Mammoth"

- **ITNS – the flow density: 6×10^{14} cm^{-2}s^{-1}** ***(RFNC-VNIIEF)***
- **Detectors with the ultra-low threshold E_{th}~10 eV:**
- **Silicon cryodetectors** (T=10 mK) 15×100cm^3, M=3kg, *the effect of the ionization transformation into heat (JINR-CWRU-Stanford)*
- **HPGe detectors** 6×150cm^3, M=4.8 kg, *the internal proportional amplification of the signal (the avalanche amplification) in the electric field (ITEP)*

The project of the SRC "Kurchatov Institute" and RFNC-VNIIEF





- **The effect of neutrino scattering at electrons of liquid helium atoms → excitation → relaxation of helium atoms with emitting a photon in the ultraviolet part of the spectrum → conversion of the ultraviolet spectrum into the visual one → recording of the photons using a photoelectronic multiplier [5]**

5. V.P. Martemyanov, et al. Probing of the Neutrino Magnetic Moment at the Levev of $10^{-12}\ \mu_B$ with an Intense Tritium Source of (Anti)Neutrino and Helium Target (Project). Fusion Science and Technology, V.67, N.2&3 (2015) 535-538.

Technical, technological and organizational issues of the ITNS development (of any intensity) were resolved.
The questions connected with using the ITNS with respect to particular conditions may appear.
The projects were not implemented because of the problems connected with the development of the necessary detection systems.

Tritium Experiment Specifics

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Tritium properties

Half-decay constant, $T_{1/2}$, years $T_{1/2}$, days		12.232 ± 0.004 (1 год=365.25 days) 4500.88 ± 1.46
Decay energy, max., keV average, keV		18.582 5.685
Decay heat release		0.328 W/g; 1.954 W/mole
Specific radioactivity T_2 (gas)		355.9 TBq/g (9.619 kCi/g) 2146.9 TBq/mole (58.023 kCi/mole) 2.589 Ci/cm3=0.386 cm^3/Ci (at n.c.) 2.372 Ci/cm^3=0.422 cm^3/Ci (at n.c.)
Density T_2 (gas) at n.c., 10^3 g/cm^3		0.269122
Run of β^- particles in the air (n.c.), cm T_2 (has, n.c.), cm water (dry material, oil, polymers at ρ=1 g/cm^3), mcm steel, mcm		0.036 (5.7 keV); 0.45 (18.6 keV) 0.26 (5.7 keV); 3.2 (18.6 keV) 0.42 (5.7 keV); 5. 2 (18.6 keV) 0.06 (5.7 keV)

Organization of the works: licensing, arrangement of sites and premises, requirements to the equipment, ventilation, water supply and sewage, arrangement of the radiation control etc. However, with respect to the experimental facilities and complexes, fulfilment of all these requirements to the full extent is not possible, and the development of new approaches and technical decisions is required, in order to create the radiation-safe equipment for tritium operations at existing physical facilities along with observing the RF regulatory base.

Approach: development of devices containing tritium or its compounds classified as *covered radioactive sources*

According to NRB 99/2009, "A covered radioactive source is a device, the design of which excludes the excursion of radionuclides contained therein into the environment under conditions of the application and wear, which it is calculated for".

Recent Proposal [6]

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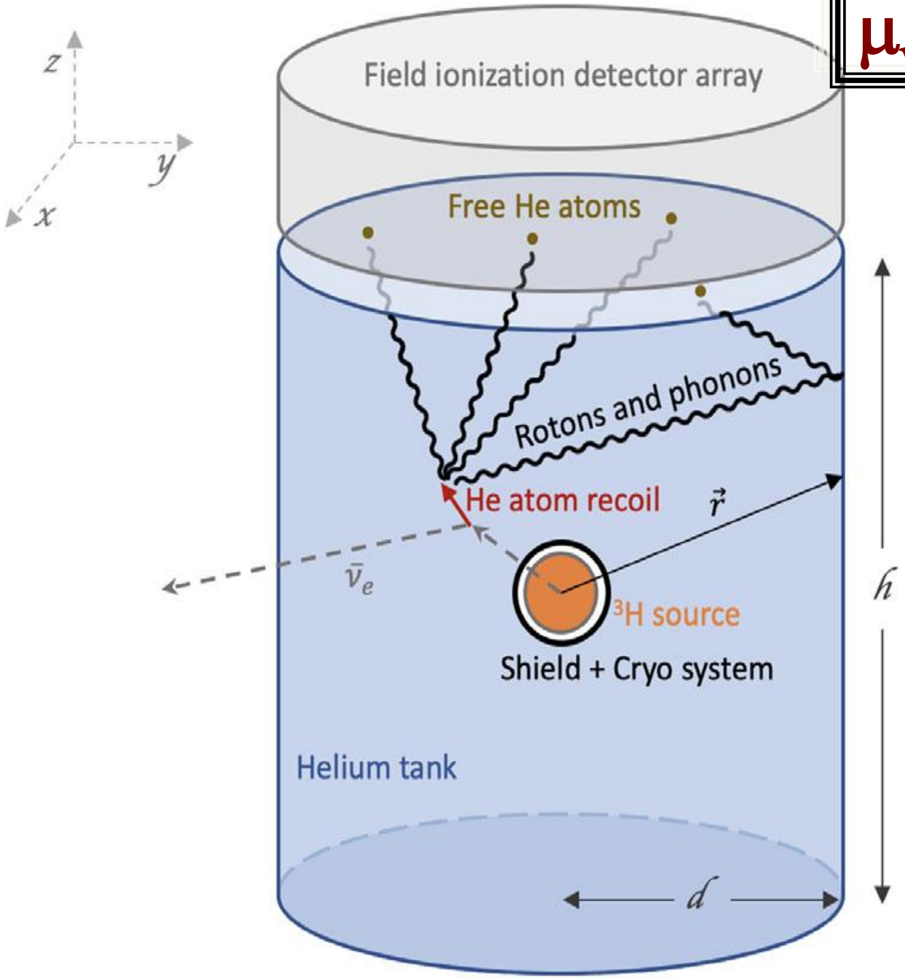
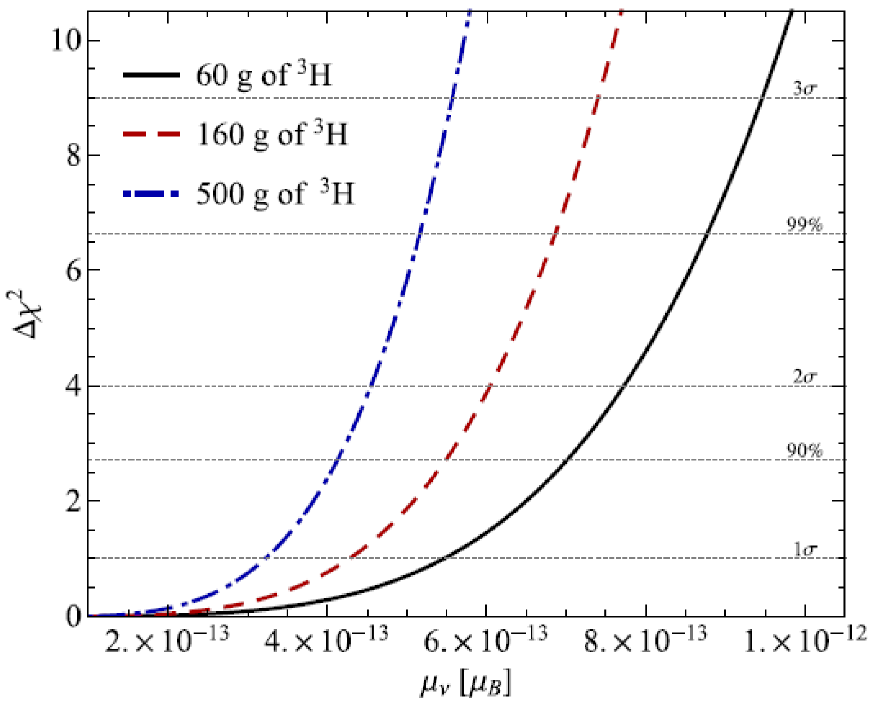
$\mu_\nu \sim 4{,}1 \times 10^{-13}\ \mu_B$: 500 g T_2



The response of a helium atom after scattering at it of an electronic antineutrino from the tritium source in the center leads to the excitation of phonons and rotons, which upon reaching the upper surface cause the quantum evaporation of helium atoms (i.e. their cutting off from the surface as a result of the phonon or roton absorption). With the help of the detector matrix (using the method of the filed ionization) mounted above the upper surface the amount of the evaporated helium atoms is determined.



1-4 kgT_2 : $\mu_\nu \sim$???? μ_B

6. M. Cadeddu, F. Dordei, C. Giunti, K.A. Kouzakov, E. Picciau, and A.I. Studenikin et al. Potentialities of a low-energy detector based on ^{4}He evaporation to observe atomic effects in coherent neutrino scattering and physics perspectives. Phys. Rev D 100, 073014 (2019) .

The Project within the Framework of the National Physics and Mathematics Center (Sarov). Measurement of neutrino electromagnetic properties using ITNS

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The project is prepared jointly with the MGU scientific group for neutrino physics led by Professor A.I. Studenikin.

Proposed:

ATS with the activity of up to 40 MCi (4 kg of tritium). At the first stage it is considered the source with ~ 10 MCi (1 kg).

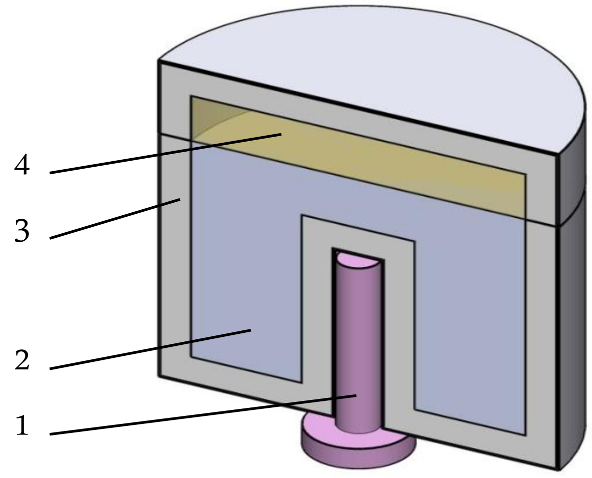
Detector – liquid helium in a super-fluid condition (the temperature is ~0.1К), neutrino scattering at helium atoms, recording of the quantum helium evaporation from the liquid surface, using the field ionization method.

Other detector types are considered!!!

Low-background laboratory for suppression of harsh cosmic radiation.

According to evaluations, ~ 6-10 m of concrete are sufficient.

Available: 0.5 m of concrete, 5 m of sand, 7 m of the ground. ?? Is it enough??



The detector-source structural diagram:
1 – tritium at titanium, 2 – liquid helium 0.1 К, 3 – thermal protection, 4 – detector matrix (the field ionization method).

Other detector types are welcome!!!

Other ideas of using the ATS are welcome!!!

Collaboration: VNIIEF, MGU, PA "Mayak", JINR, SRC "Kurchatov Institute" ……is open for participation!!!

You are invited to the mutually beneficial collaboration!

Thank you for your attention