T3.2-02

MOBILE SAMPLING AND MEASURING COMPLEX SLARS (Subsoil Liquefied ARgon Scintillations)

Project draft copy

Sergei Pakhomov

V.G. Khlopin Radium Institute
St. Petersburg, Russia

Science and Technology 2017 Conference
Hofburg Palace, Vienna, Austria
26 to 31 June 2017

T3.2-02 **BACKGROUND**

On-site Inspection (OSI) is a key element of the verification of State Parties' compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). One of the most significant evidence of an underground nuclear explosion (UNE) is detection of Argon-37 in near surface air above its background concentrations.

Atmospheric background of argon-37 varies from 1 to 2 mBq/m3 and its background in subsoil air varies from 1 to 100 mBq/m3 /1/. As the calculations show, after the UNE with a power of 1 kt the concentration of argon-37 can exceed background from four to seven orders, depending on soil, and these excesses can remain a long time, considering its long half-life time - 35,04 days.

Argon-37 decays 100% through electron capture, emitting low-energy x-rays and Auger electrons around 2.6 keV, that considerably complicates the methods of its measurements.

T3.2-02 BACKGROUND

The sensitivity of on-site argon-37 measurements in subsoil air at the level of 20 mBq/m3 is technically feasible [2]. Currently only the MARDS argon sampling and measurement system created by INPC, China [3] is capable to measure the subsoil argon-37 at the level of 26 mBq/m3 for a 12-hour measurement.

The measuring part of the MARDS system is based on the proportional counter placed in a passive and active shield. The capacity of the counter is 2.5 liters of purified argon extracted from air, with 10% of CO2 used as quenching gas. The increase of the sample volume and sensitivity further is hard to achieve without major redesign of the system.

The Khlopin Radium Institute has developed the conception and project draft copy of Mobile Sampling and Measuring Complex «SLARS» (abbreviation of Subsoil Liquefied ARgon Scintillations). It is designed to measure argon-37 in air sample of 2m3 volume at a detection level better than 20 mBq/m3 for measurement times of 12 hours.

The scintillation light in liquid argon (LAr) is produced by ionizing radiation either by direct ionization of an Ar atom followed by excimer formation and de-excitation according to:

$Ar^* + Ar \Rightarrow Ar^*_2 \Rightarrow 2Ar + h\nu$(128 nm, 5 ns, 23%)

Or via ionization, recombination, excimer formation, and de-excitation as:

$Ar^+ + Ar \Rightarrow Ar^+_2 + e \Rightarrow Ar^*_2 \Rightarrow 2Ar + h\nu$(128 nm, 1000 ns, 77%) /4/.

Thus the light emission consists of fast and slow components, the slow component is subject to quenching owing to capture of electrons by oxygen, nitrogen and other gases.

So the light emission yield reaches 40 photons per keV. In case of argon-37 the light yield can reaches about 100 photon per decay.

For comparison, liquid xenon excitation light emission is at 173 nm and its light emission yield reaches about 70 photons per keV /4/.

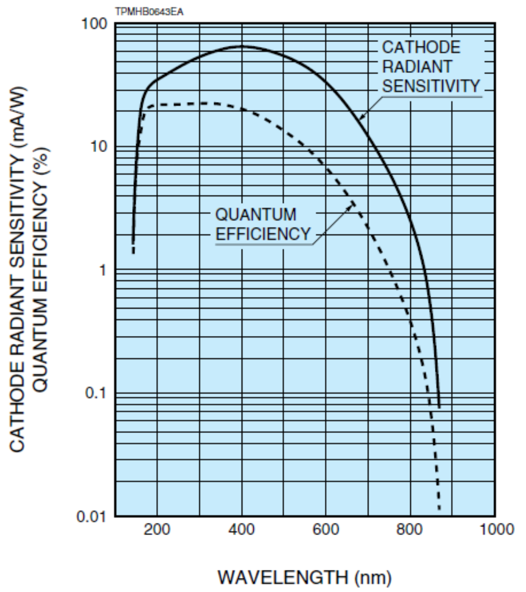
T3.2-02 CHOIS OF PHOTO-MULTIPLAING TUBES

The wavelength of the light emitted in LAr (128 nm) is in the far vacuum ultraviolet (VUV) region and its direct detection requires fragile and costly photoelectronic multiplier tube (PMT) with MgF2 windows. However, the xenon, dissolved in small concentrations (<100 ppm) in LAr provides a shift of the slow component wavelength from “original” wavelength to “xenon” wavelength (173 nm) - in a region where quartz windows are transparent /4/.

Special PMT R8520, R8780 and QUPID (QUartz Photon Intensifying Detector) are developed by Hamamatsu Photonics for efficiently detection of scintillation light with wavelengths 175-nm Xe. Recently the new high efficient low temperature PMT R11410-10 was designed. Its efficiency at minus 110 deg. C. reaches 26% at 175 nm wavelength. These PMT's are shown in fig. 1.

Fig.1. High sensitive to wavelength 175 nm PMT of Hamamatsu /4/.

As an acceptable alternative for expensive special PMT the Hamamatsu R331 PMT can be used. Its sensitive band overlaps 175 nm wavelength. Although, more specialized Hamamatsu R375 PMT can be used which efficiency reaches 20% at 175 nm wavelength. Their spectral response and other main characteristics are shown in fig. 2 .



160 nm to 850 nm Response (Multialkali)
51 mm (2 Inch) Diameter, 10-stage, Head-on Type

GENERAL

Parameter		Description / Value	Unit
Spectral Response*		160 to 850	nm
Wavelength of Maximum Response		420	nm
Photocathode	Material	Multialkali	—
	Minimum Effective Area	ϕ46	mm
Window Material		Synthetic Silica	—
Dynode	Structure	Box and Grid	—
	Number of Stages	10	—
Operating Ambient Temperature		-30 to +50	°C
Storage Temperature		-80 to +50	°C
Base		15-pin glass base	—
Suitable Socket		E678-15C (supplied)	—

* Operate in a nitrogen-purged environment for VUV detection.

Fig.2. Spectral response and main characteristics of R375 PMT.

Except the xenon dopping as a wavelength shifter it is also possible to cover the PMT window with a layer of a wavelength shifter, like tetra-phenyl-butadiene (TPB) transforming the primary photons into photons with the wavelength of 420 nanometers. – the area of maximum spectral sensitivity of more cheape PMT, such as Hamamatsu PMT R331.

T3.2-02 CHOIS OF PHOTO-MULTIPLAING TUBES

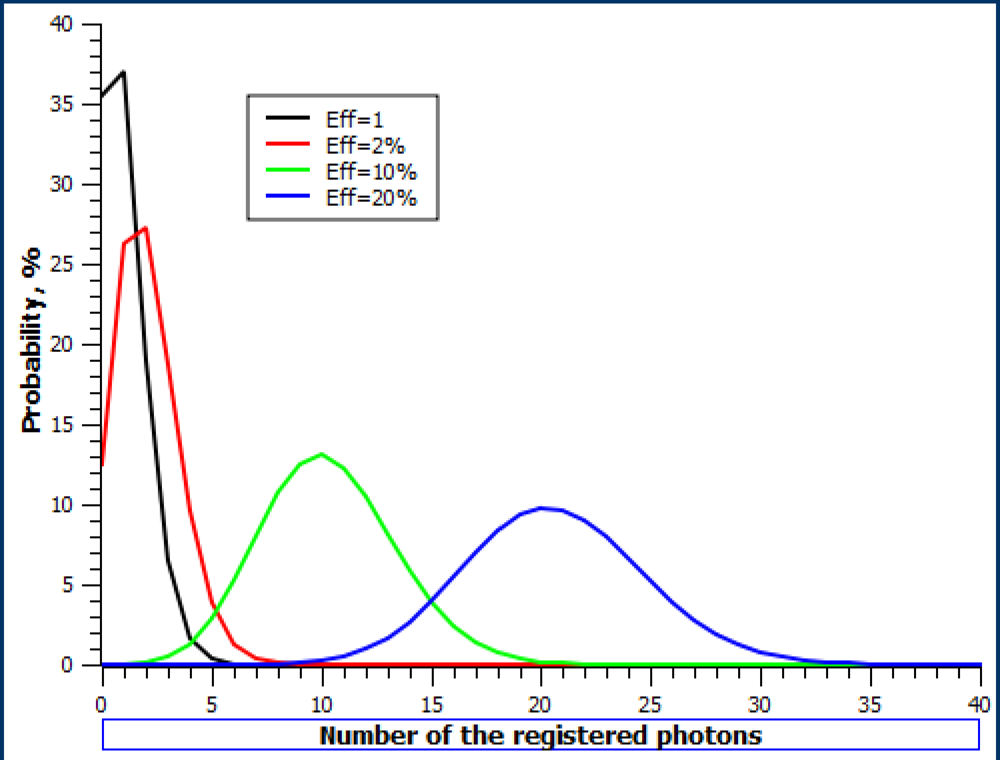


Fig.3. Probabilities of registration of number of photons depending on PMT quantum efficiency

Calculated probabilities of registration of number of photons depending on PMT quantum efficiency (1%, 2%, 10% and 20%) are shown on fig. 3.

Calculations are made in the assumption of the 100 photon emission corresponding to decay of argon-37 in liquid argon without quenching.

Apparently at efficiency more than 10% are possible forming of isolated peak corresponding to energy of 2,6 keV.

MEASURING SYSTEM SLARS

The functional scheme of a measuring system of complex SLARS is presented in fig.4.

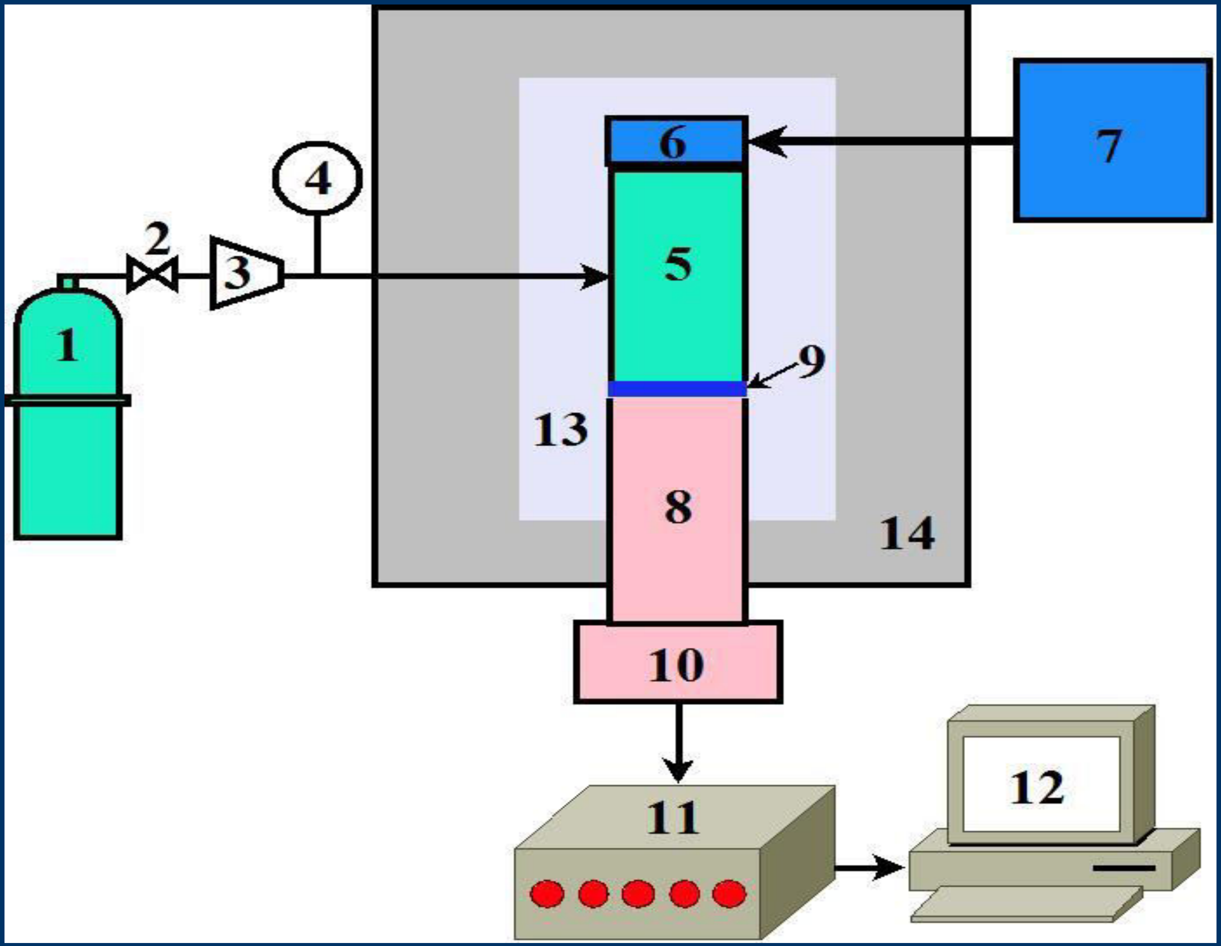


Fig.4. The functional scheme of the measuring system of SLARS

In a cylinder (1), there are from 10 to 20 liters of purified argon extracted from subsoil air sample. Via the regulator of pressure (2) argon is transferred into the measuring camera (5) where it is liquefied. The pump (3) serves for extraction of the residual argon gas from the cylinder. In the measuring camera a small excessive pressure is controlled by a pressure gage (4). The required cryogenic temperature is provided by a split system, consisting of the cooling head (6) and compressor (7).

MEASURING SYSTEM SLARS

The functional scheme of a measuring system of complex SLARS is presented in fig.4.

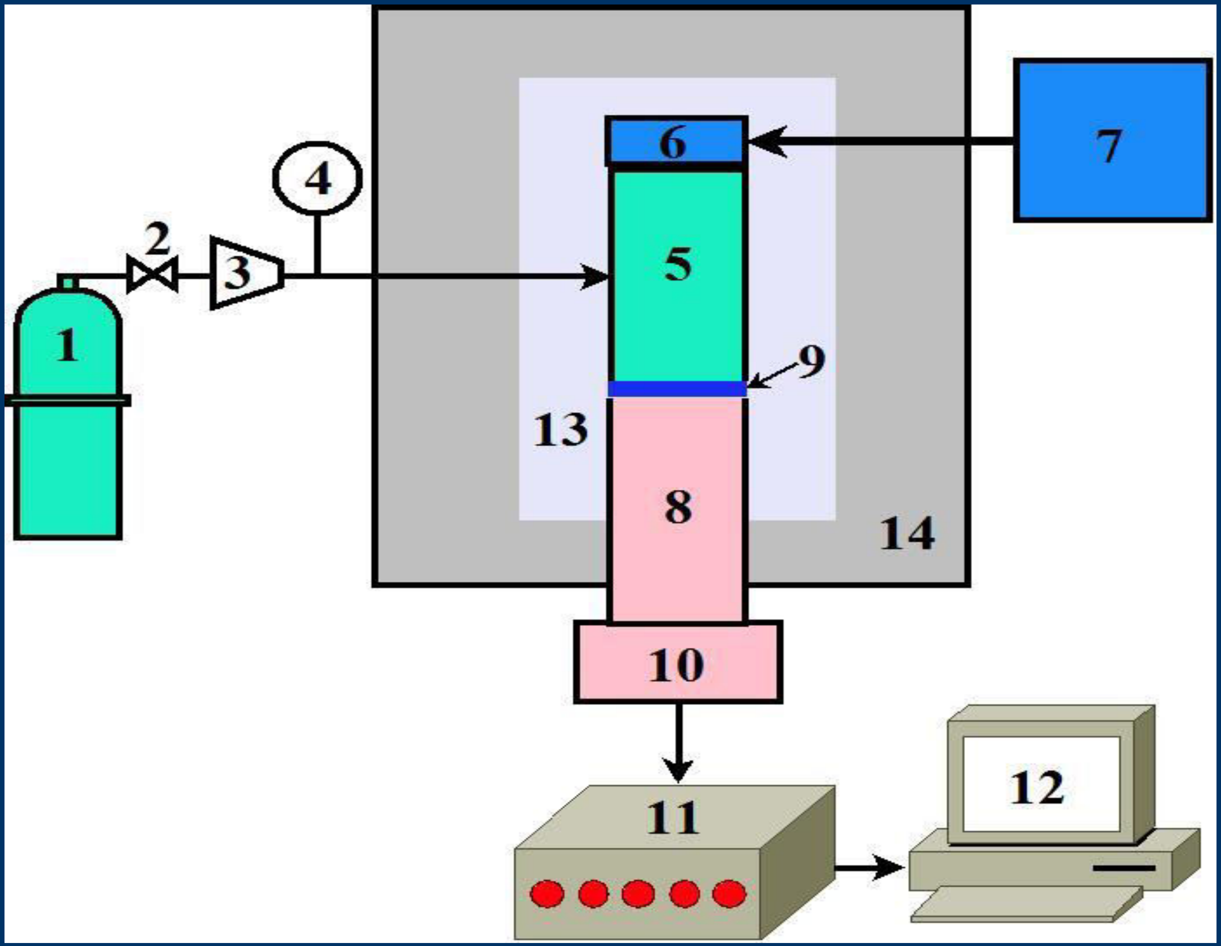


Fig.4. The functional scheme of the measuring system of SLARS

The photons are focused on an input window of Hamamathu PMT R-375, or R-331, optionally . (8). In the last case the TPB-layer (9) for a waver-lengths shifting is used.

The PMT pulses come to the "fast" preamplifier (10) than to the digital analyzer (11) and comes to PC (12) for final processing.

The cool parts are covered in the thermo-insulating shield (13) and lead shield (14).

SAMPLING SYSTEM SLARS

The principle of work of sampling part of the SLARS is based on process of short-cycle pressure-swing adsorption (PSA). The functional scheme of the sampling system is provided in fig. 5. The sampling system contains the symmetric parts working alternately. The sample of subsoil air which is previously prepared "in-situ" by means of the compressor (1) pumps in one of soft gas-holders (2) and by means of the compressor moves in the top or lower part of dividing columns (3, 4). (An the other part at this moment is regenerating). The column (3) is filled with NaX zeolite and has volume about 15 liters. The column (4) is filled with a carbon molecular sieve and has the volume of 5 liters. It is initially disconnected with a column (3).

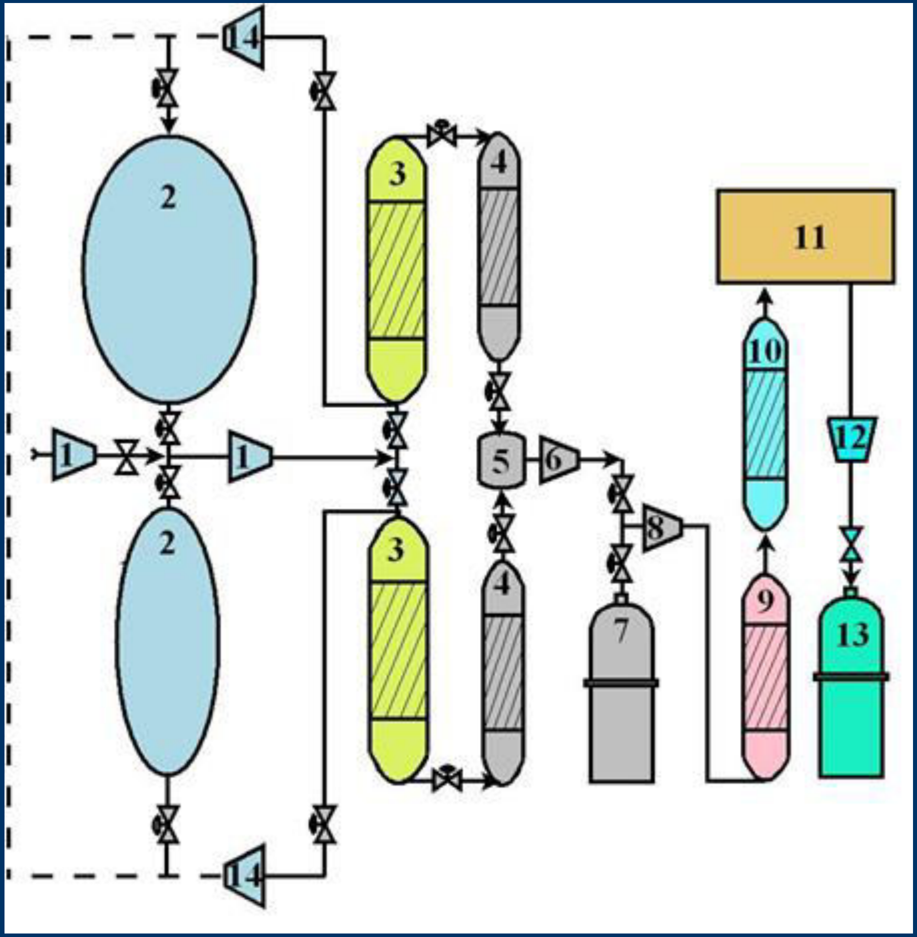


Fig.5. The functional scheme of the sampling system of SLARS

SAMPLING SYSTEM OF SLARS

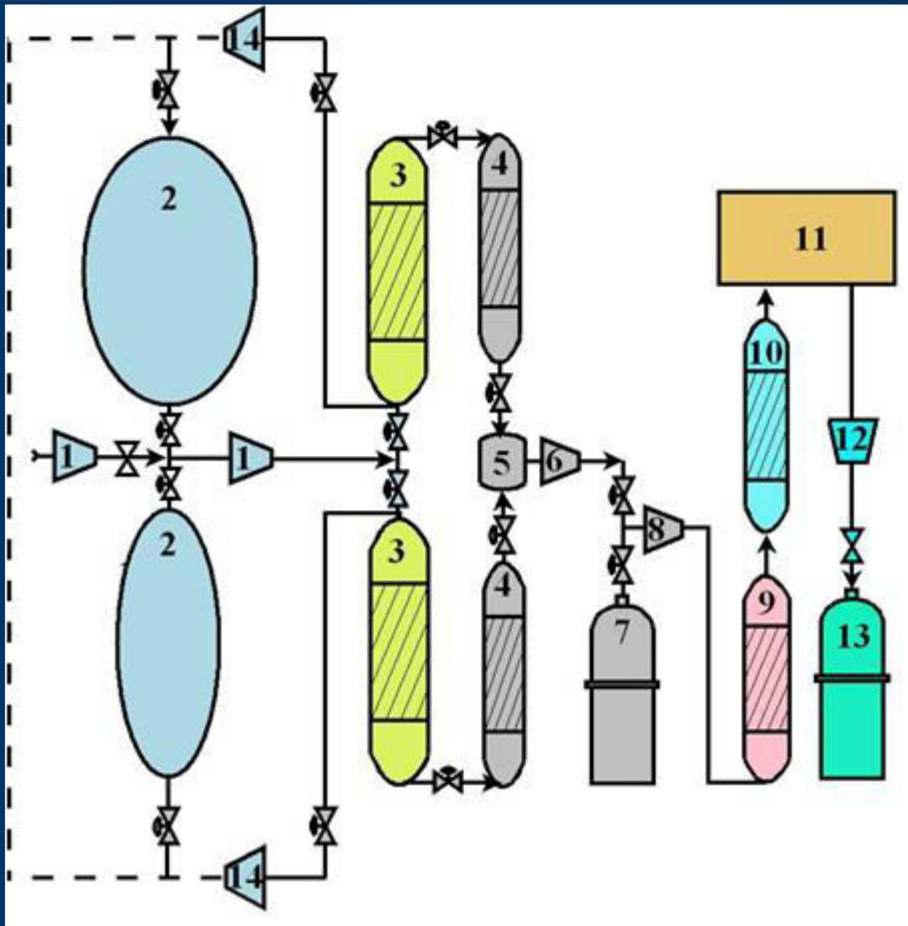


Fig.5. The functional scheme of the sampling system of SLARS

After filling under required pressure column (3) is connected with a column (4). The working cycle of a column (4) has duration about 10 sec, after its completion the column (4) is connected with buffer reservoir (5). By means of the compressor (6) obtained argon fraction is pumped into the accumulative cylinder(7). After the completion of the cycle the columns (3) and (4) are regenerated by means of the pump (14). Products of regeneration are accumulated in an opposite soft gas-holder (2) for repeated processing.

About 100 liters of air are processed on each cycle and the duration of a working cycle is about 1 min. 20 working cycles are provided all initial amount of subsoil air sample processing.

SAMPLING SYSTEM OF SLARS

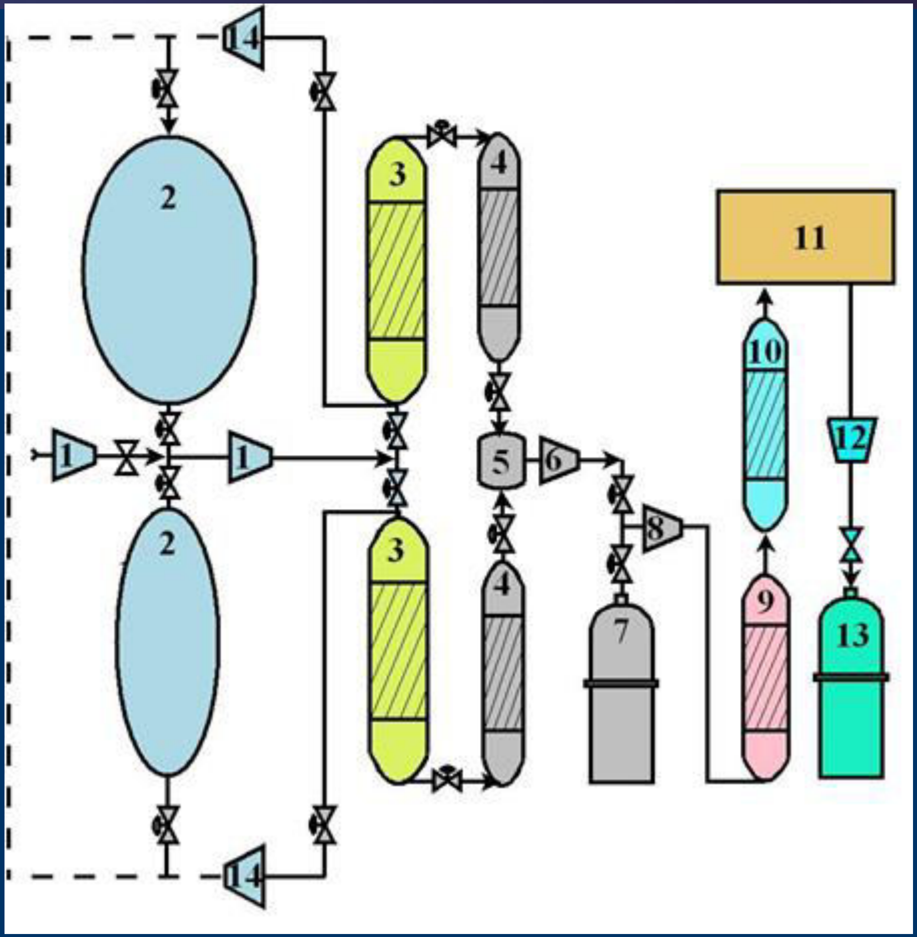


Fig.5. The functional scheme of the sampling system of SLARS

As the efficiency of extraction does not rather high, the processing is repeated 2, 3 or more times, providing the obtain a total argon output about 60%.

From the storage cylinder (7) by means of compressor (8) the raw argon is pumped into the chemical absorbers of nitrogen (9) and oxygen (10). Further purification of argon to the required level of impurity is processed by means of fine purification device (11). Obtained argon sample with impurity content <1 ppm is pumped by the compressor (12) into the final storage cylinder (13).

T3.2-02 *TECHNICAL CHARACTERISTICS OF SLARS*

The estimated main technical characteristics of of Mobile Sampling and Measuring Complex «SLARS» are:

Amount of air processed:	2000 liters;
Processing time	up to 5 hour;
Working pressure:	up to 6 bar;
Amount of the extracted argon sample:	up to 20 liters;
Content of impurity in an argon sample:	<1 ppm;
Capacity of the measuring camera :	30 cm3;
Efficiency of registration:	95%;
Background:	0,1 counts/s
Measuring time:	up to 12 h
MDC of Ar-37:	20 mBq/m3

REFERENCES

1. Roland Purtschert, Robin Riedmann, Lauren Raghoo. Ar-37 in atmospheric and sub-soil gases. 2014 Safeguards Symposium, Vienna.

2. D.A. Haas, H.S. Miley, J.L. Orrell, C.E. Aalseth, T.W. Bowyer, J.C. Hayes, J.I. McIntyre. The Science Case for 37Ar as a Monitor for Underground Nuclear Explosions. Report PNNL-19458, June 2010.

3. LI Wei, YAN Zhaotong, XIANG Yongchun, WANG Hongxia, XIANG Qingpei, ZE Rende, LIU Qiang, GONG Jian. Latest Development on MARDS – an Argon-37 Detection System. Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics. SnT2015 Vienna, June 2015.

4. P. Cennini, J.P. Revol, C. Rubbia et al. Detection of scintillation light in coincidence with ionizing tracks in a liquid argon time projection chamber. Nuclear Instruments and Methods in Physics Research A 432 (1999) 240–248.

5. Hamamatsu Photonics. Photomultiplier tubes. Catalog. Feb. 2016.

Thank You

For attantion