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Further Improvement and Testing of a Prototype for the Measurement of a Liquid Argon Scintillation

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INTRODUCTION

Khlopin Radium Institute develops detecting system based on registration of own scintillations of liquefied argon samples containing argon-37. Testing of the developed prototype revealed paucity of sensitivity due to low registration efficiency and high background.

METHODS/DATA

To eliminate the identified shortcomings following work was carried out:
-Optimization of the geometry;
-Optimization of the technology of TPB coating;
-Improvement of the computer program;

START

RESULTS

- Developed a device for TPB vacuum deposition.
- Developed a conical measuring chamber.
- Developed an improved computer program for PSD analysis.
- Conducted experiments with Fe-55, Pu-238 and Ni-63.
- Planned work to increase the sensitivity.

CONCLUSION

After the successful improvement of light collection and UV light conversion efficiency, further improvement of the characteristics of the prototype setup is possible by replacing the PMT with a less noisy, more efficient and good single-electron resolution one.

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INTRODUCTION

One of the key evidence of a violation of the CTBT is the detection in the subsoil air elevated concentrations of the argon-37 which is formed in large quantities during the interaction of a nuclear explosion neutrons with soil calcium: 40Ca (n, α)37Ar.

The concentration of argon-37 retains high values for much longer time than xenon radionuclides, so it is the "ideal witness" of a nuclear tests.

Therefore the Ar-37 is a relevant radionuclide for the CTBTO On-Site Inspection (OSI) and development of new equipment and methods for its measuring at the background level in various media is very urgent.

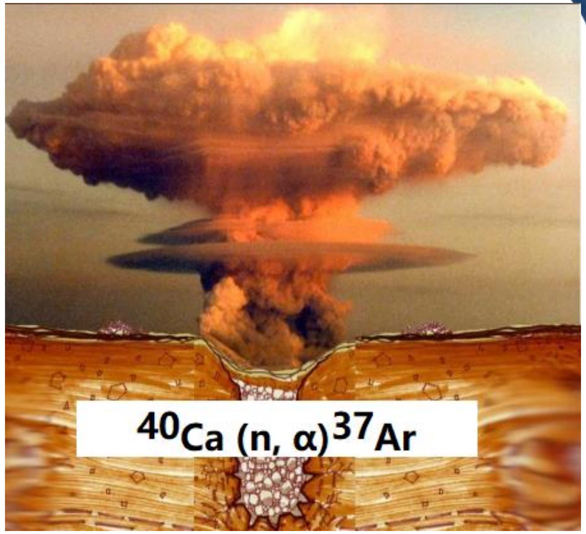

Fig.1. General view of prototype.

A prototype installation for measuring liquid argon scintillations was developed and constructed at the Radium Institute under a contract with the CTBTO. Tests of the prototype showed the functionality of the prototype, but revealed a low efficiency of registration of 37Ar Auger electrons and a high background.

To eliminate the identified shortcomings, a new contract "Further Improvement and Testing of a Prototype for the Measurement of a Liquid Argon Scintillation" was signed between the CTBTO and the Radium Institute, with a deadline until the end of 2023.

FUNCTIONAL SCHEME OF THE PROTOTYPE AND DESIGN OF THE DETECTION UNIT.

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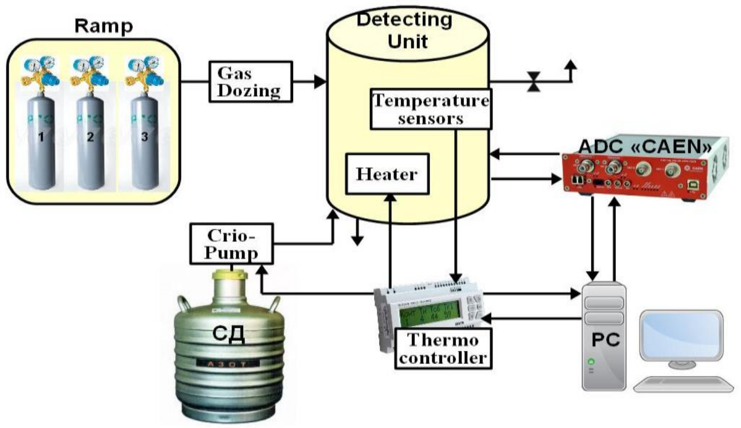

Fig.2. Functional scheme of prototype.

A sample of 37Ar in argon is fed under a small excess pressure of ~ 1.5 bar into detecting unit where it is liquefied in a 100 cm3 measuring chamber.

The required temperature provided using a liquid nitrogen cryogenic pump and heater under control of domestic thermo-controller TPM138.

Signals from the detecting unit are processed by the CAEN DT5790 250 MS/s 12-bit waveform digitizer.

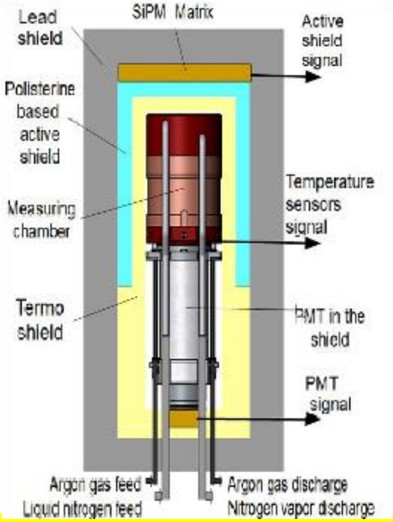

Fig.3. Detecting unit Inside active shields.

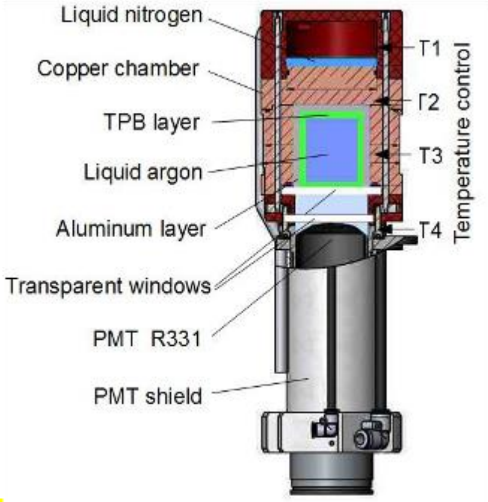

Fig.4. Sectional view of the detecting unit.

Fig.5. Detecting unit assembly

On the upper part of the measuring chamber placed a cooler with liquid nitrogen. A thin-walled aluminum cylinder is located inside a thick-walled copper chamber. In lower part there is a protective transparent window, which is optically connected with the PMT Hamamatsu R331-05.

The inner surface of the aluminum cylinder and the surface of the window are coated with a TPB layer that converts the primary 128nm photons of liquid argon scintillations into visible light.

To maintain an acceptable temperature of the PMT photocathode not lower than -30 ^{0}C local heating is provided.

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

IDENTIFIED SHORTCOMINGS AND WORKS FOR ELIMINATION OF THIS

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To eliminate the identified shortcomings of the installation prototype, the following work was carried out under the current contract:

- Optimization of the geometry of the measuring chamber;
- Manufacturing of a light guide;
- Carrying out experiments with a model source based on tritium in order to confirm the improvement in light collection;
- Optimization of the technology for applying the wavelength shifting coating;
- Improvement of the computer program in order to analyze the ratio of fast and slow components;
- Purchase of a laboratory system for argon purification up to grade 6.0;
- Carrying out model experiments using ^{55}Fe and ^{238}Pu in order to check the purity of the gas;
- Find ways to reduce the background.

Three versions of light-collecting measuring chambers were made of high-purity aluminum: cylindrical and conical, with opening angles of 11 and 16 degrees, as well as a light guide made of organic glass, are shown in Fig. 6.

Fig.6. measuring chambers and light guide.

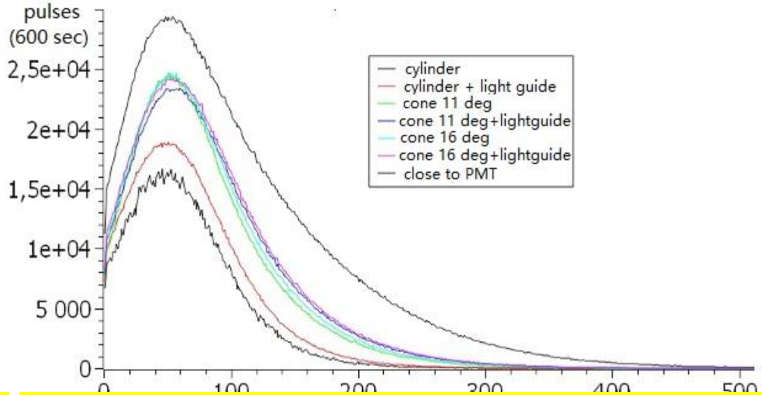

Fig.7. Results of measurements for different variants of light collection.

Measurements were carried out using a model tritium source (1.24E4 Bq in the Ultima Gold scintillator) and 3 variants of the light collection chamber: cylindrical and two conical: with different angles (11 and 16 degrees), with and without an light-guide. The results are shown in Fig. 7. As seen, 16 degrees conical chamber in conjunction with a light guide leads to an improvement of light collection by 1.96 times and its value reaches 70.1% relative to cylinder without light-guide.

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

OPTIMIZATION OF TPB APPLICATION TECHNOLOGY USING THE THERMAL VACUUM DEPOSITION METHOD.

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The efficiency of the TPB coating applied by thermal vacuum deposition (TVD) (as well as the registration efficiency) is significantly higher than that applied by other methods (airbrush or brush spraying with polymer plasticizers), as seen in Fig. 8 given in /1/.

Therefore, we made a device for implementing this method, shown in Fig. 9, 10 and 11. The device consists of the deposition device itself, placed in an evacuated volume, and components that ensure the deposition process - a forevacuum pump, a vacuum gauge, a thermocouple, a temperature controller and a heater power supply.

According to /2/, the optimal thickness of the TPB coating is 2–3 μm (200–300 μg/cm^2), and according to /3/, coatings with a thickness of up to 200 μg/cm^2 are resistant to immersion in liquid argon. This thickness was chosen as the base when applying the TPB by the TVD method.

Before the start of deposition, the device with the installed light guide is kept in vacuum at a temperature of 175 ^{0}C /4/ to remove volatile impurities, deposition is carried out for 3 hours at a temperature of 220 ^{0}C, then it is allowed to cool under vacuum and the thickness is determined by the gravimetric method.

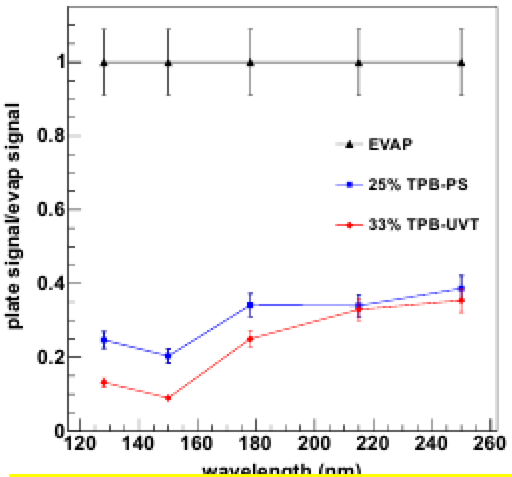

Fig.8. Comparison of TVD and other methods.

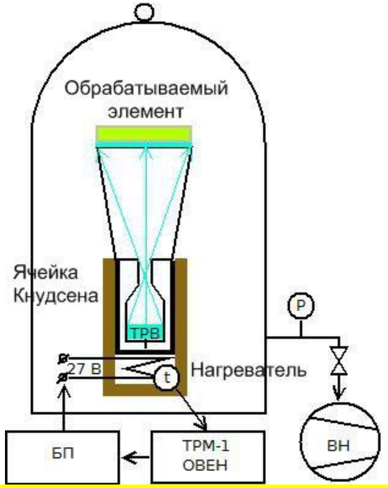

Fig.9. Functional scheme of TVD installation

Fig.10. Knudsen cell and TPB-coated light guides..

Fig.11. Complete TVD installation.

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

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IMPROVEMENT OF THE COMPUTER PROGRAM

To control the operation of the CAEN DT5790 digitizer /5/ and record spectrometric information, the standard branded program PDD-DPD (Digital Pulse Processing for Pulse Shape Discrimination) /6/. The analyzer discover events (pulses), performs their timing and integrates the charge in the long and short time windows specified by the user. DPP saves to the PC disk as an ASCII text file or in binary format.

Information about events registered in the Qlong and Qshort windows is used to calculate the pulse shape discrimination parameter - the PSD parameter:

$$PSD=100\,(Qlong - Qshort)/Qlong \quad (1)$$

The use of the PSD parameter for rejecting false events makes it possible to reduce the background without reducing the useful signal and thereby increase the sensitivity of the spectrometric tract to registering targeting events.

The improved program whose main window is shown in Fig. 11) in addition to the previous version, it reads the spectra in binary format and allows you to analyze events using the PSD parameter (Fig. 12).

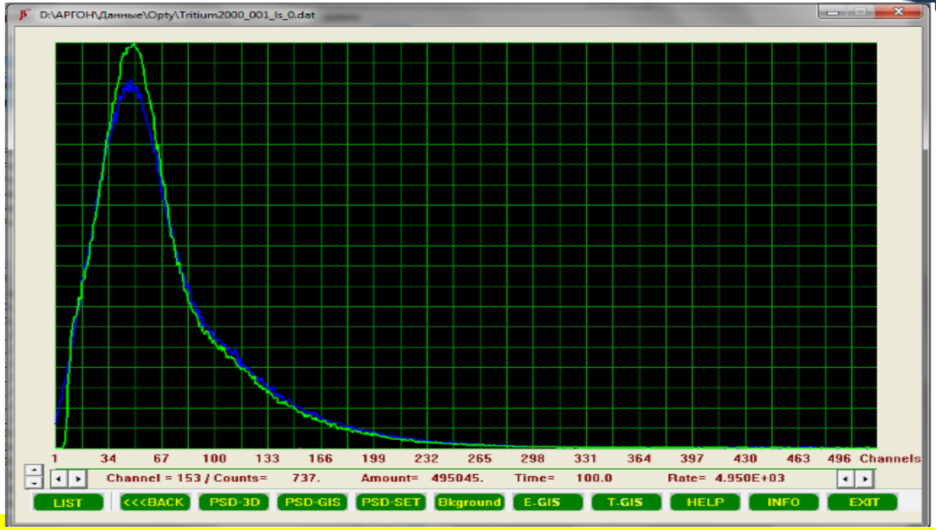

Fig.11. The main window of program.

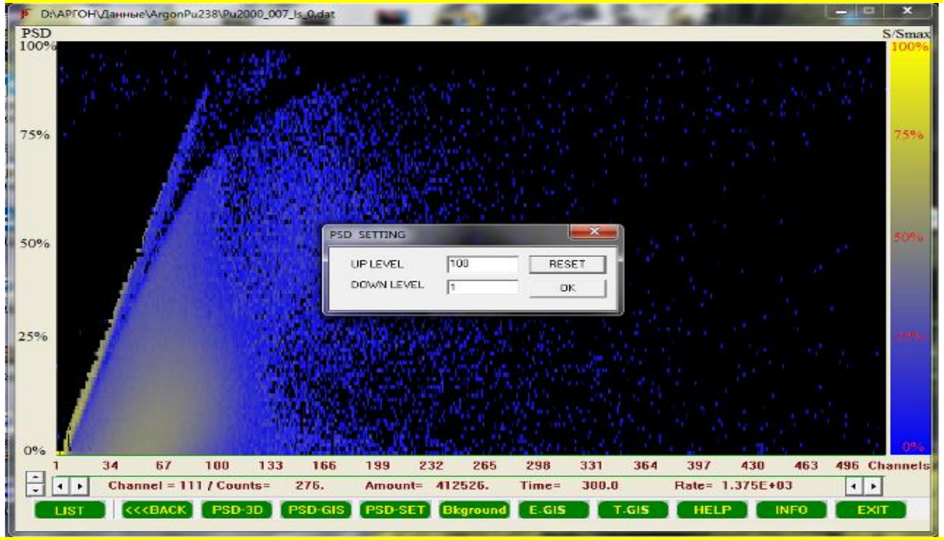

Fig.12. 2D histogram of PSD values at energy

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

EXPERIMENTS USING MODEL RADIONUCLIDE SOURCES FE-55, Ni-63 AND PU-238

To test the purity of argon, we measured the scintillation spectrum of Pu-238 (2.5 kBq), Fe-55 (5 kBq), and Ni-63 (2.7 kBq) sources placed in a measurement chamber filled with testing argon gas. The measured spectra are shown in Figs. 12, 13, 14. Also, these figures show projections of 2D spectra of PSD parameter values characterizing the ratio of the fast and slow components and, consequently, the purity of argon. According to /7,8/, the proportion of the slow component of the component for alpha radiation is 15% of the total photon yield, which does not contradict the data in Fig. 14.
Therefore, there is no reason to doubt the purity of the argon we use.

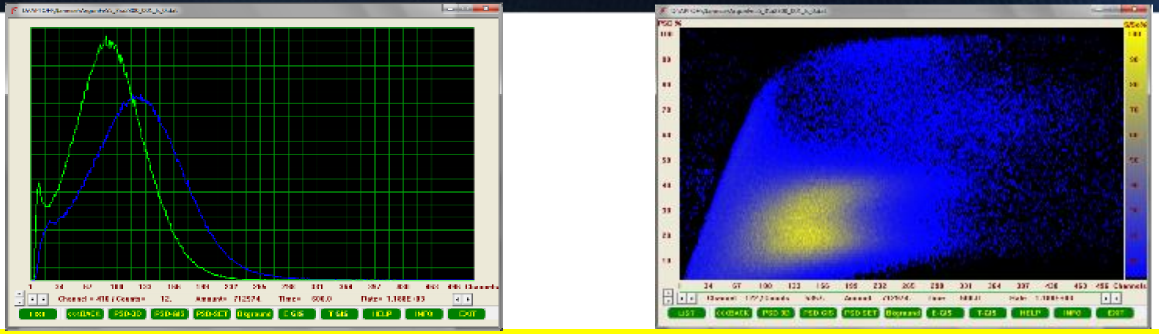

Fig.12. Spectrum of ^{55}Fe source and its PSD histogram, 2300 V.

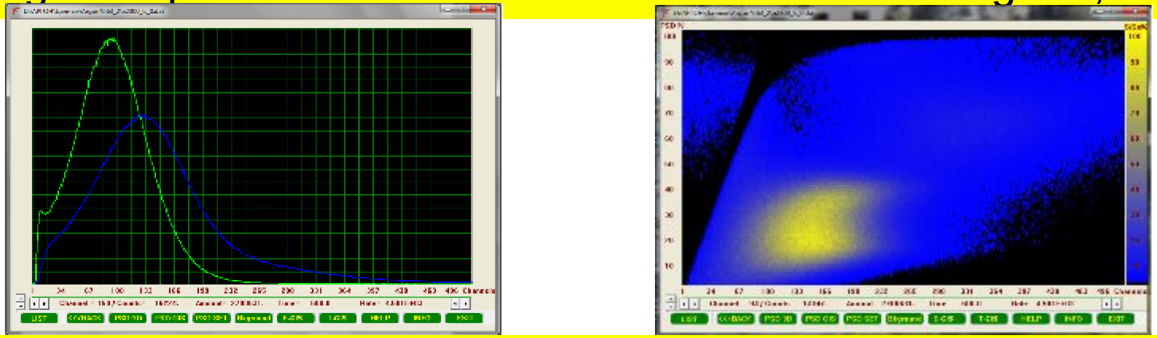

Fig.13. Spectrum of ^{63}Ni source and its PSD histogram, 2300 V.

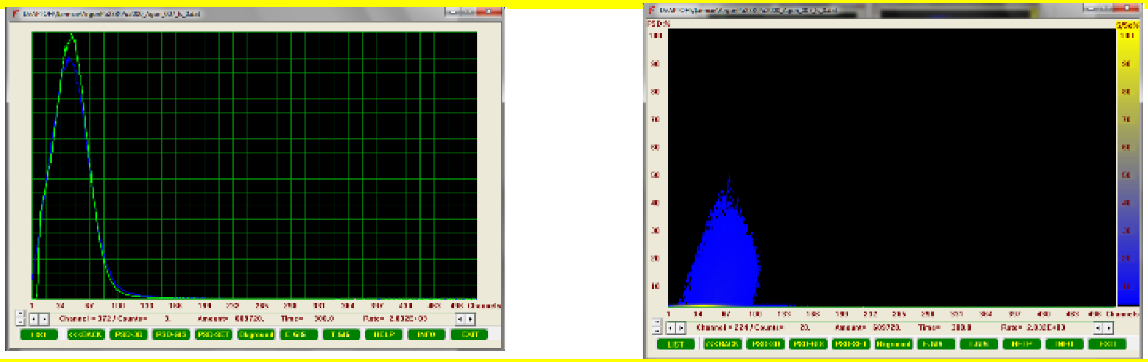

Fig.14. Spectrum of ^{238}Pu source and its PSD histogram, 2000 V.

DEVELOPMENT OF METHODS FOR BACKGROUND REDUCTION

After the work carried out to improve the light collection and improve the technique for applying the TPB coating, further improvement in the sensitivity of the system is determined by measures to reduce the background that do not reduce the value of the detection efficiency. Among these measures are:

1) PMT noise reduction;
2) increase the amplitude of the useful signal;
3) selection of the area of interest (ROI) away from the noise area;
4) the use of passive protection (available);
5) use of active protection (available);
6) rejection of false impulses by the PSD parameter (the program has been developed);
7) use of single-electron photomultipliers capable of registering single photons (available).

Figure 3 shows the dependence of the Figure of Merit (E^2/B) on the supply voltage for FEU143 of NPO ELECTRON and R331-05 of Hamamatsu. It can be seen that the characteristics of the first of them are more good. In addition, FEU143 is characterized by good single-electron resolution (Fig. 16). We are currently studying the possibility of using it as part of ongoing work to improve the performance of the facility.

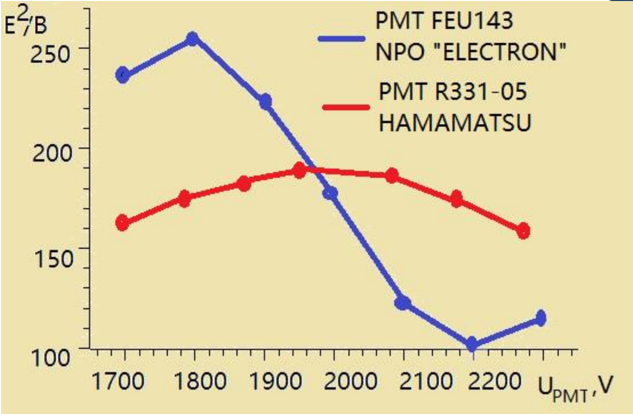

Fig.15. Figure of merit for FEU143 and R331-05 PMT

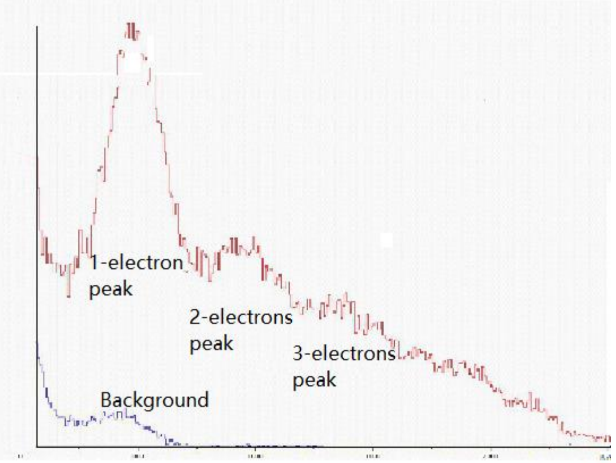

Fig.16. Single-electron resolution of FEU143 PMT

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

CONCLUSIONS

RADIUM INSTITUTE
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1. A laboratory device for vacuum deposition of a TPB wavelength converter has been developed and manufactured.
2. A technology has been developed for applying TPB to the optical elements of the measuring chamber by vacuum deposition.
3. A technological methodic for deposition TPB have been developed.
4. An improved design of the measuring chamber has been developed, which provides a 2,5 times increase in the efficiency of light collection.
5. Experiments were carried out using a model radionuclide source of tritium to determine the efficiency of light collection with an improved measuring chamber and to set the optimal PMT supply voltage.
6. An advanced computer program has been developed for processing data obtained using the DT5790 digitizer.
7 Considered measures to reduce the background.
8. Experiments were carried out using model radionuclide sources of Fe-55, Pu-238 and Ni-63.
9. Further improvement of the characteristics of the prototype is possible by replacing the PMT with a less noisy and more efficient one with good single-electron resolution.
10. The advantages of the domestic FEU143 PMT over the R331-05 PMT of HAMAATSU were revealed.

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