SILICON TWO-DIMENSIONAL POSITION-SENSITIVE FAST NEUTRON DETECTOR FOR BEAM PROFILE MEASUREMENT

F.A. Aliyev[1,2*], N.I. Zamyatin[1], V.M. Bystritsky[1], N.A. Fedorov[1,4], D.N. Grozdanov[1,3], C. Hramco[1,5], Yu.N. Kopatch[1], I.N. Ruskov[1,3], V.R. Skoy[1], V.M. Slepnev[1], D.I. Yurkov[6], Yu.N. Barmakov[6] and TANGRA collaboration

[1]*Joint Institute for Nuclear Research, Joliot Currie 6, 141980 Dubna, Moscow region, Russia*
[2]*Institute of Geology and Geophysics, Azerbaijan National Academy of Sciences, H. Javid av., 119 Baku, AZ1143 Azerbaijan*
[3]*Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Sciences, Tsarigradsko chaussee 72, blvd., 1784 Sofia, Bulgaria*
[4]*Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia*
[5]*Institute of Chemistry of the Academy of Sciences of Moldova Academiei str., 3; MD-2028 Chisinau, Republic of Moldova*
[6]*All-Russia Research Institute of Automatics (VNIIA), Sushchevskaya 22, 127055 Moscow, Russia*

Abstract

Recently, a new experimental setup named TANGRA (TAgged Neutrons and Gamma RAys), for studying the neutron-induced nuclear reactions, has been created and successfully tested in the Joint Institute for Nuclear Research (JINR) in Dubna, Russia.

In the present geometry TANGRA setup is used to investigate the angular and energy distributions of gamma rays from nuclear reactions induced by 14 MeV neutrons.

It consists of: a portable 14 MeV neutron generator ING-27 with a built-in 64-pixel position sensitive α-particle detector, an array of 22 Amcrys© NaI(Tl) gamma-ray detectors and a computerized 14bit, 100MHz, 32 channel JINR-AFI electronics data acquisition system.

Silicon (Si) two-dimensional position-sensitive fast neutron detector was constructed and used for adjusting the neutron beam and measuring its profile.

In the present article we briefly describe the neutron profile meter and report some results from the characterization of the ING-27 "tagged" neutron beams.

Keywords: Silicon strip detectors; Fast neutrons; Tagged neutrons and gamma rays; TANGRA.

* Corresponding author Tel.: + 7-496-216-2131; fax: +7-496-216-5085.
email: fuad.aliyev107@gmail.com.

1. Introduction

For detailed study of the inelastic scattering of neutrons with energy of 14.1 MeV on complex nuclei, within TANGRA project (TAgged Neutron and Gamma RAys), in 2014 an installation «TANGRA» was designed and created at the Joint Institute for Nuclear Research (Dubna, Russia) [1, 2].

The operation of the TANGRA facility is based on the use of the tagged neutron method (TNM), the essence of which consists in recording the characteristic radiation (gamma-quanta, neutrons) from the inelastic scattering reactions of 14.1 MeV fast neutrons on the nuclei A of the substance, A(n, n'γ)A, in coincidence with the α particle, formed in the following neutron producing reaction:

$$d + {}^{3}H \rightarrow {}^{4}He\ (3.5\ \text{MeV}) + n\ (14.1\ \text{MeV}). \quad (1)$$

Here, the kinetic energy of the incident deuteron beam on the tritium target is ~ 80–100 keV. The α-particle and neutron are emitted nearly in opposite directions and therefore, by recording the direction of the α-particle, using a multi-pixel alpha detector mounted inside the neutron generator, it is possible to determine with good accuracy the direction of the neutron.

For precise measurement of the angular distribution of the characteristic gamma radiation produced as a result of the inelastic scattering of fast neutrons on complex nuclei, one must have an unambiguous information about the spatial distribution of the tagged neutron beams incident on the investigated material.

Currently, there is a known method for obtaining information about the distribution of the tagged neutron beams in detector's XY plane, perpendicular to the direction of their propagation, consisting of a number of mutually parallel light-protected scintillation strips [3].

Using the coincidence of signals from one of the alpha-detector pixels inside the neutron generator with one of the profilometer scintillation strips, it is possible to obtain information about the profile of each of the tagged neutron beams along the X and Y axes.

In this case, it is necessary to make measurement with two mutually perpendicular positions of the profilometer (strips horizontally and vertically orientated), relative to the direction of tagged neutron beam.

2. Experimental Setup

The setup used for determination of the beam profile of fast neutrons is shown in Fig. 1. It includes: portable neutron generator with an energy of 14.1 MeV, a collimator made of iron for the protection of gamma detectors from the direct hit in them of the neutron radiation generated by ING-27 [4], spectrometric system for recording gamma radiation based on NaI(Tl) and double-sided silicon strip detectors.

As a source of tagged neutrons was used a portable neutron generator (NG), which was developed at All-Russia Research Institute of Automatics in Moscow (VNIIA) (Fig. 2). The maximum intensity of the neutrons flux created by NG in the solid angle 4π is 5×10^{7} n/s.

The profilometer is a double-sided silicon strip neutron detector, in which the registration of fast 14.1 MeV tagged neutrons is done by detecting the charged products resulting from the neutron interaction with silicon nuclei: ${}^{28}Si(n,n'){}^{28}Si$; ${}^{28}Si(n,\alpha){}^{25}Mg$; ${}^{28}Si(n,p){}^{28}Al$; ${}^{28}Si(n,np){}^{27}Al$; ${}^{28}Si(n,n\alpha){}^{24}Mg$; ${}^{28}Si(n, d){}^{27}Al$. The design of the profilometer is shown in Fig. 3.

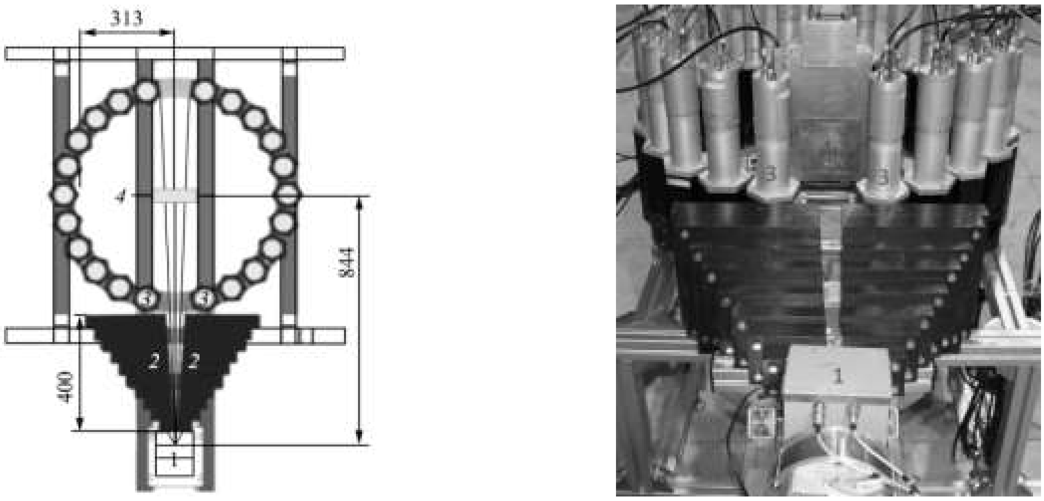

Fig. 1. Experimental setup: 1- the ING 27 neutron generator; 2 - the filter (passive shielding); 3 - the scintillation detector based on a NaI(Tl) crystal; 4 – the silicon two-dimensional position-sensitive fast neutron detector.

Fig. 2. The neutron generator ING 27.

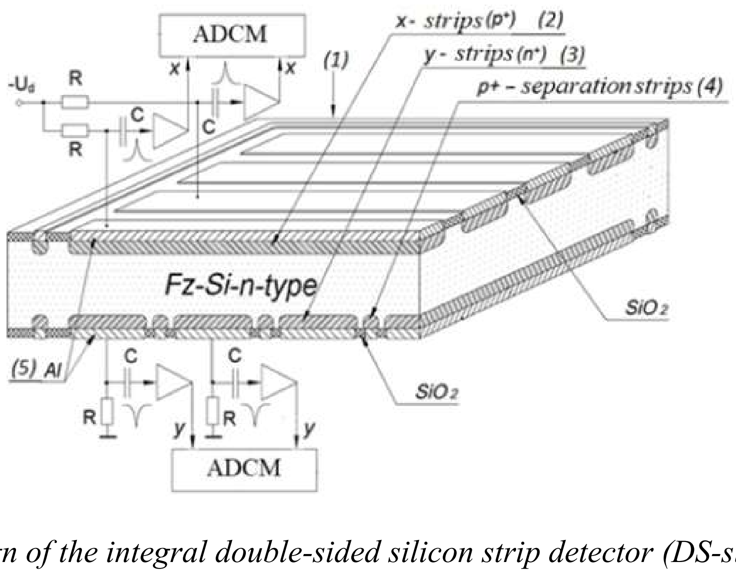

Fig. 3. The design of the integral double-sided silicon strip detector (DS-strip) and detector switching-on circuit with reading electronics.

Fig. 4 shows the mechanical design of the profilometer and its main elements. The specification of the two-coordinate plane with (64×64)-strips, consisting of 4 DS-strip/(32×32) detectors with strip's pitch of 1810 μm (1.81mm) and dimensions of each detector (60×60) mm^2, is given below:

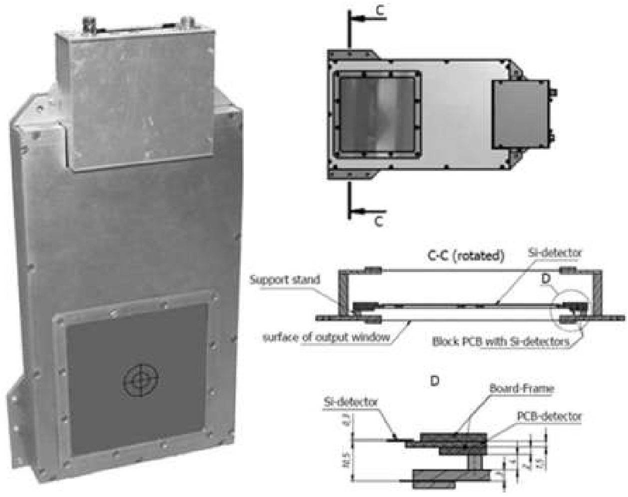

Fig. 4. Profilometer construction.

- Application – measurement of profiles and spatial distributions of neutron beams produced by fast neutron sources and dt-fusion generators (14.1 MeV);
- Detecting plane – 4 double-sided silicon strip detectors (DS-strip);
- Number of strips on the detecting plane: 64-X and 64-Y strips;
- Dimensions of each of the 4 detectors: (60×60) mm^2;
- Sensitive area: (58×58) mm^2;
- Number of strips in each detector: 32X+32Y;
- Strip pitch: 1810 μm;
- The thickness of the detector entrance window "dead" layer:
  -Al – 1.0 μm
  -(p+) – 0.3 μm (implanted layer of boron);
- Angle between the strips on the opposite sides of the detector: 90°;
- Thickness of the silicon detector: 300 +/- 15 μm;
- Dimensions of the profilometer detecting plane: (120×120) mm^2;
- The similar strips in all 4 detectors are combined in pairs on each side of the detector by ultrasonic welding (USW), forming a grid of (64×64) strips with a length of 120 mm;
- All 4 detectors are assembled on a printed circuit board (PCB), having contact pads for USW with the detector strips;
- 64 lines, on each side of the board, come out on two connectors, to which is connected the detector electronics (PA + PMT).

3. Energy calibration of the profilometer

For energy calibration of the silicon two-coordinate neutron beam profilometer, we used standard alpha sources of known activity and energy of alpha-particles (Table 1).

As an example, in Fig. 5 a) and b), are shows the calibration curves "amplitude-to-energy" of profilometer X and Y strips, correspondingly.

Using the calibration curves (Fig. 5), we calculate the energy spectra of the charged products (recoil silicon nuclei, protons, deuterons and alpha particles), produced in the reactions $^{28}Si(n, n')^{28}Si$, $^{28}Si(n, \alpha)$ ^{25}Mg, (E_{α}=2.654 MeV), $^{28}Si(n, p)^{28}Al$ (E_p=3.860 MeV) and $^{28}Si(n, d)^{27}Al$ (E_d = 9.840 MeV), as a result of the interaction of ING-27 14.1MeV neutrons with the profilometer X and Y strips (Fig. 6).

Table 1.

Source	Activity (kBq)	Energy (MeV)
^{226}Ra	39.6	7.68
^{238}Pu	30	5.49
^{239}Pu	5	5.15

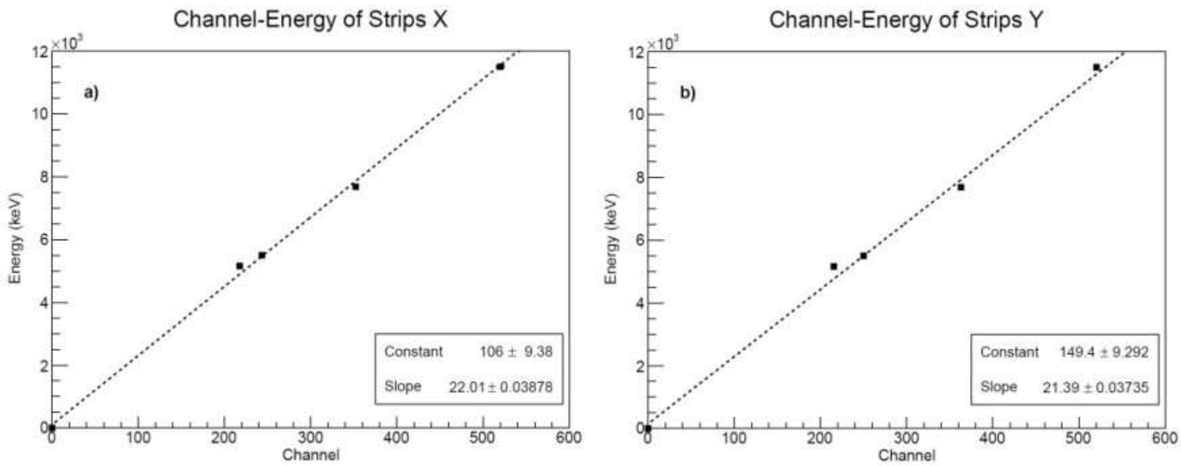

Fig. 5. Energy calibration of the profilometer X and Y strips, obtained with the following sources of alpha particles: ^{239}Pu (E_{α} = 5.2 MeV), ^{238}Pu (E_{α} = 5.5 MeV), ^{226}Ra (E_{α} = 7.8 MeV) and ^{28}Si (n, α) ^{25}Mg (E_{α} = 11.5 MeV).

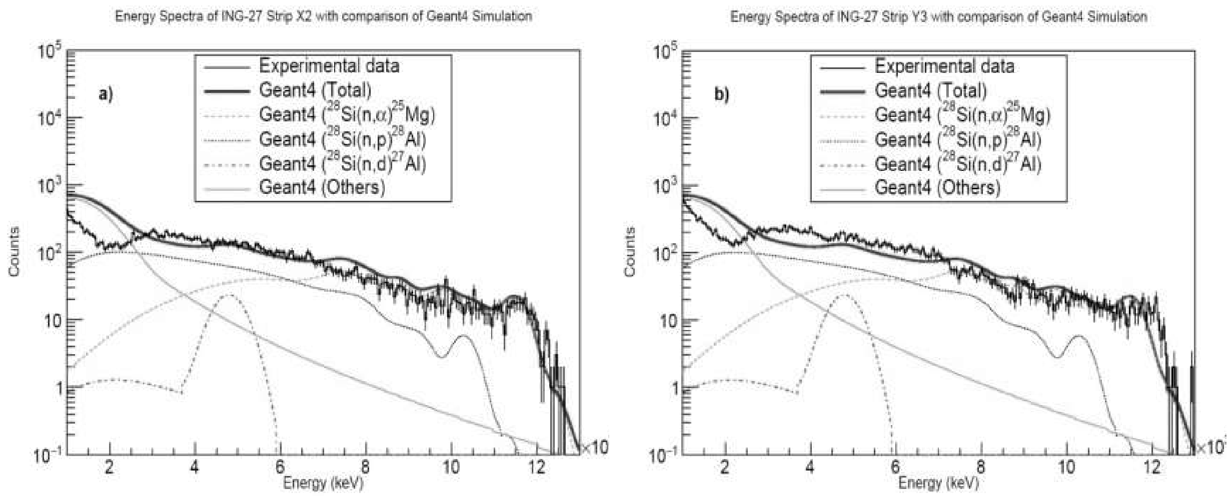

Fig. 6. Experimental and calculated energy spectra of the charged components obtained by irradiating X and Y strips with ING-27 tagged neutron flux. The calculated spectra are the result of simulation using Geant4 software.

At the Fig. 6 a) and b) show the calculated energy spectra obtained by Geant4 software [5] used for simulating the interaction of 14.1 MeV neutrons with silicon, as well as there is a fairly good agreement between our experiment data and the calculations. The registration energy threshold of the charged components is ~ 1 MeV.

4. Determination of tagged neutron beam profiles

As an example of the profilometer applications, its use to determine the profiles of 64 tagged neutron beam neutrons created by an ING-27 device is considered.

Fig. 7 shows the arrangement of the ING-27 neutron source and the profilometer, when measuring the space profiles of tagged neutron beams.

For clarity, in Fig. 7 is shown also a simplified scheme of the processes occurring during the measurement of the tagged beam profiles.

As a result of fusion reaction of a deuteron with a triton, an alpha particle and a neutron are formed, which fly apart in opposite directions. The alpha particle is detected by the ING-27 alpha detector and the neutron by the profilometer.

The intersection of strips perpendicular each other, both in the alpha detector and in the profilometer, forms the triggered pixels, which in Fig. 7 are highlighted in red. For this reason in the following text the term "pixels" is used when speaking about the alpha detector.

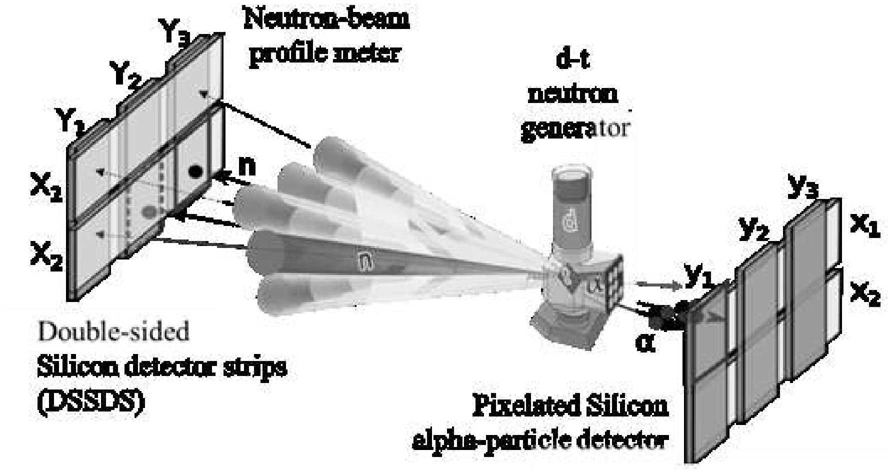

Fig. 7. The scheme of setup for measuring tagged neutron beam profiles.

In order to determine the profiles of neutron beams, the profilometer was installed in two different positions: directly at the exit window of the neutron generator ING-27 and at a distance of 40 cm from it.

Measurements of the beam profiles in two different positions make it possible to obtain correct information about all 64 tagged neutron beams.

The signals from the alpha detector in the neutron generator and from the profilometer were included in a scheme of 4-fold coincidence between the signals from x and y strips of the neutron generator α-detector and X and Y strips of the profilometer [6].

In this case, the selection of the recorded events was made only if all four of the above strips were triggered within 10 ns time interval. It corresponded to the full width of the measured distribution of the time intervals between the signals from the alpha detector and the profilometer (see Fig. 8).

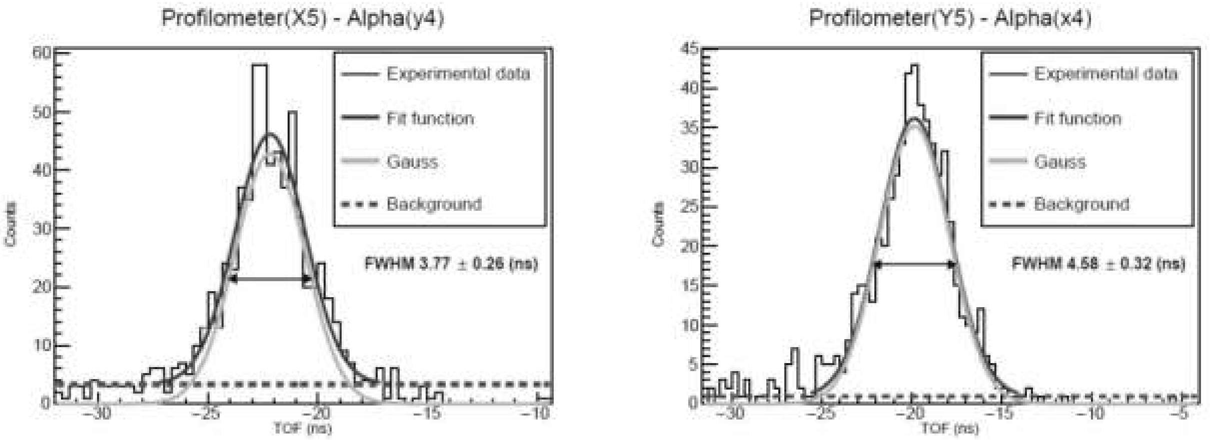

Fig. 8. Time spectra of the coincidences of signals between both X and y (left), and Y and x (right) strips of the neutron profile meter and alpha detector.

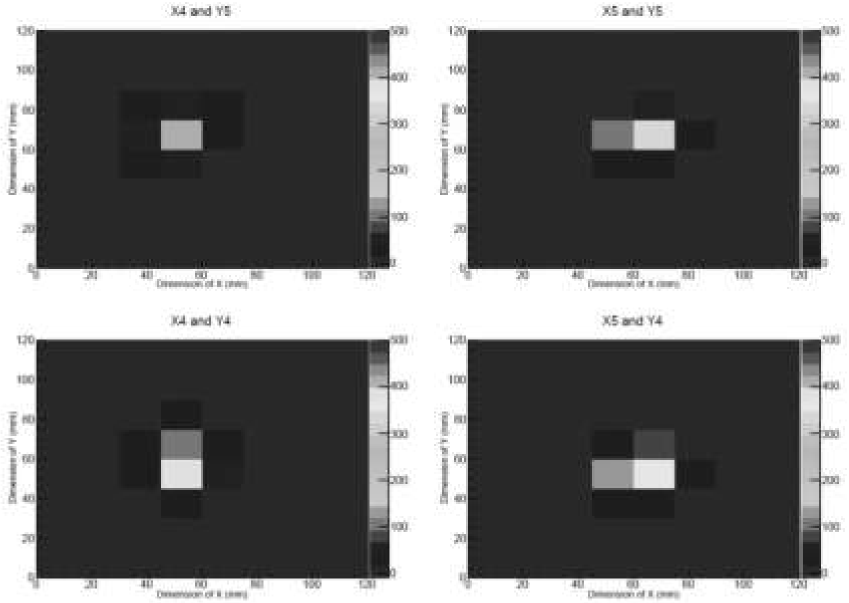

Fig. 9. Profile of the tagged neutron beam obtained at a distance of ~10 cm from ING-27 neutron producing target.

From the analysis of the results, it follows that the measured time resolution $(FWHM)_t$, averaged over all possible combinations of signals from strips of the alpha-detector and profilometer, is 5 ns.

A graphical representation of the statistics from the 4-fold coincidence of the signals, which reflects the profiles of the tagged beams corresponding to each pixel of the profilometer, is shown in Fig. 9.

Each two-dimensional histogram in Fig. 9 corresponds to a certain pixel of the alpha detector of the neutron generator; it shows the number of coincidences of signals from a given pixel of the alpha detector with each of the pixels of the profilometer. The colors of the points on the histograms reflect the number of such coincidences.

5. Conclusion

For measuring the profiles of tagged neutron beams produced by ING-27 neutron generator, we designed and created a two-coordinate detector of neutrons with an energy of 14.1 MeV.

The profilometer is a two-coordinate plane (64X×64Y), which is built on the basis of double-sided silicon strip detectors (DSSSD). The measurements were made with a configuration of the detector plane (8X×8Y).

The neutron registration is performed by detecting charged particles (silicon recoil nuclei, protons, deuterons and alpha particles) formed as a result of a number of nuclear reactions: ^{28}Si(n, n')^{28}Si, ^{28}Si(n, α)^{25}Mg, ^{28}Si (n, p)^{28}Al and ^{28}Si(n, d)^{27}Al, during the interaction of fast neutrons with the substance of the profilometer (silicon).

The measurement of the neutron beam profiles is carried out in a plane perpendicular to the direction of their propagation. The detecting plane consists of 4 double-sided silicon strip detectors.

The difference between the neutron profilometer based on silicon strip detectors and the scintillation profilometers is that the two coordinates (X and Y) of the interaction point of the neutron with silicon are measured simultaneously.

The design of the created profilometer allows its aperture to be increased by adding to it additional double-sided silicon strip detectors.

6. Acknowledgment

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