STRATEGY OF EQUIPPING THE PIK REACTOR EXPERIMENTAL STATIONS WITH DETECTION SYSTEMS

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1. Introduction

Due to the appearance of new high-intensity neutron sources and new ways of application of high-performance neutron focusing optical systems, the intensity of neutron beams has increased significantly over the past 10–20 years. General technical progress and new ideas implemented into the construction of the experimental stations and creation of new detector systems allowed one to achieve great potential in the field of neutron scattering research, which recently seemed impossible.

The necessity to develop and apply new research methods for both the study of new class objects and the search for solutions of experimental tasks at the highest level requires equipping the PIK reactor instrumental infrastructure with state-of-art neutron detection systems produced in Russia and worldwide. The PIK reactor is being constructed at the PNPI.

The quality of information received within a modern experiment quite often depends directly on practical realization of a complex of interconnected (and sometimes mutually contradictory) maximum attainable characteristics of the detection systems. Namely, these specifications are the folowing: large registration area, high neutron rate requirements and spatial resolution, low noise level, high performance within the whole required wavelength range of neutrons, very low sensitivity to the background radiation, high stability of functional specifications, low cost and maintainability.

The aim of the present paper is to develop strategies of equipping the PIK reactor experimental stations with the detection systems based on three main factors:

- Analysis of experience accumulated by the leading neutron research centres over the last 40 years;
- Clear understanding of the current state over the last 10 years and ways of practical realization of the development trends of detection technologies;
- Estimation of the global trends of the development of detection technologies and definition of the concept of their further development for the next 10–15 years.

It is clear that the concept of development of neutron detectors for experimental stations of the PIK reactor should be based on the experience of the leading Russian and international neutron research centres, such as ILL (France), J-PARC (Japan), ESS (Sweden), FZ (Jülich, Germany), *etc*.

2. Analysis of experience of world research centres in the field of neutron detector construction

2.1. Over the last 40 years. Analysis of experience of the world research centre ILL, France

In order to produce neutron detectors for the experimental stations of the PIK reactor, it is essential to take into account the world experience, knowledge and achievements of specialists working in the field of development of various types of neutron detectors.

ILL is currently the unofficial world capital of neutron research (https://www.ill.eu/instruments-support/instruments-groups). Experience of neutron experiments was accumulated in this Institute for over 40 years with participation of world leading experts from many different countries contributing to it. Unique world-class experimental stations were created, and their parameters were optimized based on simulations and experiments.

According to its purpose, the structure of instrumentation base in the main neutron centres of the world is approximately the same as in ILL. The neutron flux density of the PIK reactor is expected to be similar to that of the high-flux reactor (HFR) at ILL, which essentially makes the PIK reactor a potential future successor of the HFR. For this reason, it would be reasonable to copy both the general instrumentation structure of ILL and appropriate types of neutron detectors, and to apply this knowledge to the PIK reactor installations. Various devices at ILL are brought to perfection, and their parameters are optimized basing on simulations, real testing and experiments.

Classification of the types of detectors used for ILL experimental stations and detection technologies are presented in Table 1.

Table 1

Classification of the types of detectors used at ILL

Detection technology	Type of detector	Amount
Gas-discharge detectors based on ^{3}He converters	Proportional counter (^{3}He)	9
	Multidetector and installation based on proportional counter	14
	Single- and multimodule microstrip detectors (micro strip gas chambers – MSGC)	6
	^{3}He 2*D* position sensitive detector	10
	Neutron beam monitor	4
	Total	43
Scintillation detectors based on solid-state converters (^{6}Li and ^{10}B)	Scintillation detector based on ZnS / LiF	2
	Scintillation detector ImagePlates	2
	Total	4

It is obvious that, despite the ^{3}He deficit, the leading European neutron research centre, ILL, uses detectors with ^{3}He as a converter gas in the vast majority of its experimental stations (43 out of 47).

2.2. Current status over PAST 10 years. Analysis of experience of the world research centre J-PARC, Japan

The materials and life science experimental facility (MLF) neutron research centre was founded in J-PARC (http://j-parc.jp/index-e.html). MLF uses a high-intensity pulsed spallation neutron source generated by the 3GeV proton beam with the current of 333 µA and the operating frequency of 25 Hz.

Implementation of new scientific and applied research programmes required new experimental stations equipped with new detectors. An analysis showed that in order to use ^{3}He-detectors it would be necessary to acquire more than 10 000 l of this gas. Taking into account the rise of its price, such acquisition will require a serious financial investment – more than 20 million dollars for a period of five years.

Taking into account this reason, it was decided to use scintillation technologies for detectors having the surface of complex geometry and a wide aperture (five stations). In order to comply with the required detector parameters, standard scintillators based on ZnS / ^{6}LiF were dismissed in J-PARC and ceramic scintillators based on ZnS / $^{10}B_2O_3$ were put into operation. This allowed one to improve the parameters of existing scintillation detectors with regard to enhancement of their operation speed, efficiency, decreasing their afterglow and so on. With these enhancements, the efficiency of such scintillation detectors achieved about 70% of the efficiency of ^{3}He-detectors (at 4 bars). This work required creation of a new “scintillation” infrastructure in J-PARC and more than 10 years of hard work. Currently, it can be said that the situation with the application of different types of detectors is balanced in the best way in J-PARC instruments. The proportion of experimental stations with different types of detectors is demonstrated in Fig. 1 (the stations with scintillation detectors are marked with yellow filling and the stations with ^{3}He-detectors – with red filling) [1]. It is obvious that the majority of detectors used are ^{3}He-detectors. They are used in order “to cover” large areas, to work in high-intensity neutron-beams – up to $1 \cdot 10^8$ cm$^{-2} \cdot$ s^{-1}, to work with relatively small apertures (up to 300 × 300 mm^2) when the method of delay line readout is used (with only five channels of registration electronics), which significantly reduces the cost of the detector.

The J-PARC centre is equipped with more than 21 experimental stations, most of which (about 75%) use gas-filled ^{3}He-detectors.

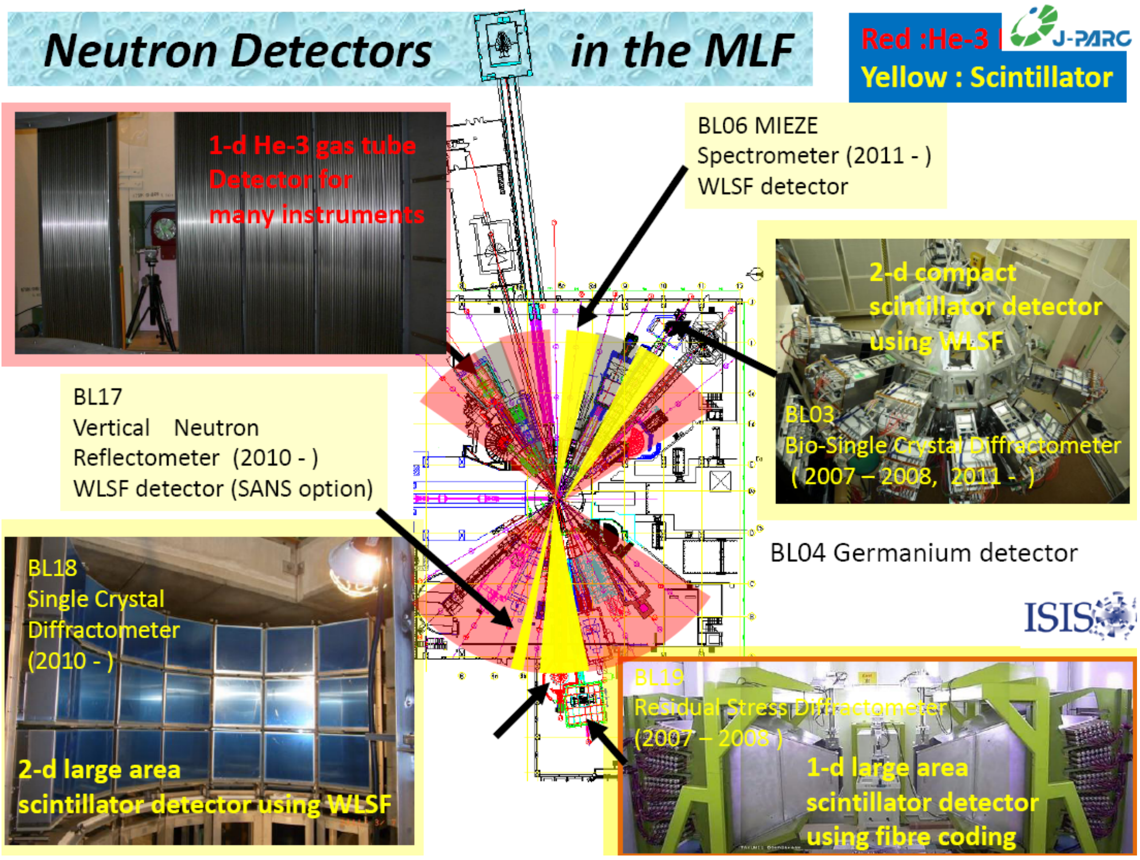

Fig. 1. Location and structure of neutron detectors at MLF experimental stations (J-PARC)

2.3. Estimation of the global trends for the next 10–15 years. Analysis of experience of the world research centre ESS, Sweden

European Spallation Source (ESS) is being actively built in Lund, Sweden. The first neutrons were planned to be generated in about 2020. It is also planned that ESS with its initial suite of experimental stations will be put into operation no later than in 2025. An international expert group was formed in order to perform an analysis of technical requirements for ESS experimental stations and the neutron detectors required for them [2]. The analysis presented here is based on the initial suite of 22 instruments, put forward in the ESS technical design report in 2013.

It appeared that the total area of neutron detectors exceed 280 m^2. More than a half of the area is reserved for three installations – three chopper spectrometer instruments (80, 50 and 30 m^2). The total number of channels of registration electronics is quite large as well, it exceeds 60 000. It is worth noting that only two experimental stations should have the spatial resolution of 0.1 mm. The spatial resolution of other detectors should vary in the range of 1–10 mm, which is possible to achieve with the existing technology. In the course of the analysis, all detectors were divided into four categories according to their registration area: large-area detectors (two stations); high-resolution medium-area detectors (nine stations); small-area detectors with the area of 1 m^2 and less (nine stations) and ultrahigh-resolution detectors (two stations).

The detectors from the first two categories occupy about 90% of the total area of all the detectors. In order to produce them using the ^{3}He-technology, it would be necessary to acquire more than 25 000 l of ^{3}He, which is quite a large sum with respect to the current European prices – about 50 million dollars. The need to decrease the expenses involved in acquisition of ^{3}He essentially defined the choice of the strategy of the detector production.

1. First two categories of detectors are to be based on detectors that do not use ^{3}He.

2. Small area detectors (the third category) are to be based on the ^{3}He-detectors with the aim to ensure maximum attainable parameters. Such are 9 of 22 experimental stations (40%).
3. Ultrahigh-resolution detectors can be produced based on scintillation detectors or gas-filled detectors gas electron multiplier (GEM) or micromesh gaseous structure (Micromegas).

Production of detectors that do not use ^{3}He will be implemented in three basic directions. Their development requires significant financial investments and significant efforts of the international community [3]:

- ^{6}LiF / ZnS and B_2O_3 / ZnS scintillation detectors with the wave length shifting fibers readout;
- Gas detectors with ^{10}B solid converters;
- Position sensitive gas detectors based on BF_3.

At ESS, the primary choice for ^{3}He replacement technology was decided to be gaseous detectors with a ^{10}B solid converter.

On the way to the creation of new detector technologies, there is a lot of open questions and difficult outstanding issues that should be solved for the technical parameters of new detectors to come as close as possible to the parameters of modern ^{3}He-detectors.

The developers will have to take into account the following parameters: efficiency of new detectors should be equivalent to that of ^{3}He-detectors; the capability of operating in high-intensity neutron beams; a low sensitivity to γ-background – the key factor for many experiments; an essential reduction of the cost of large area detectors.

2.4. Peculiarities of detector infrastructure in several other world leading scientific neutron centres

2.4.1. Current state of neutron detectors and trends of their development in Russian research centres

The neutron detectors that are currently most widely used in the Russian Federation can be divided into two main categories: gas-filled detectors and scintillation detectors.

Gas-filled detectors. Russian experts made a notice of favourable conditions for production of ^{3}He position sensitive detectors (PSD) up to 300 × 300 mm^2 in Russia. The PNPI and Joint Institute for Nuclear Research (JINR) groups are successfully developing and producing such detectors and are experienced in this field. A group from the Institute for Nuclear Research of the Russian Academy of Sciences (INR RAS, Troitsk) works now with such detectors as well. Many years of activity in this direction have allowed one to develop stable technologies for production of gas-filled PSDs. Relative availability of ^{3}He in Russia and its lower price (in comparison with the global prices) act as a powerful motivation to continue the work with ^{3}He gas-filled PSDs.

Detection systems based on helium counters operate at the IBR-2M reactor of JINR Laboratory of Neutron Physics (further – LNP) as a part of the experimental stations NERA, SKAT, EPSILON, DN-12, DIN-2PI and at the reactor VVR-M of PNPI. The possibility to measure both coordinates by means of mutually orthogonal cathode planes in a proportional chamber allows one to use 2*D* PSDs in order to perform measurements using the methods of small-angle neutron scattering. Detectors of this type are used in spectrometers REFLEX, GREINS, DN-2 at LNP JINR and at INR RAS (Troitsk), *etc*.

For neutron beam monitors, low efficiency is needed – typically in the region of a tenth-thousandth of a percent. In order to reach such a low level of detection efficiency, the monitor was filled with a gas mixture of 50 mbar ^{3}He + 950 mbar CF_4. The monitor was used to measure the profiles of the IBR-2M reactor beams. N_2 was added to the mixture as a converter-gas in order to be able to work with ultra-high fluxes ($\geq 10^7$ cm^{-2} · s^{-1}).

Scintillation detectors. Scintillation methods are particularly attractive in time-of-flight neutron spectrometers. This is caused by the fact that in scintillation detectors, the detection layer is by an order of magnitude thinner and, consequently, their time-of-flight resolution is better compared to the gas-filled detectors. A higher sensitivity of scintillation detectors to γ-background does not affect the results of time-of-flight experiments. In addition to a high efficiency of thermal neutron registration ($\lambda \leq 1$ Å) and time resolution of less than a microsecond, such detectors are capable of a spatial resolution of about 100 µm.

JINR and PNPI jointly developed a scintillation detector already in the end of 1990s. The design solution was further developed in the RASTR detector for a diffractometer ($\lambda \leq 1{,}53$ Å, the interplanar spacing resolution being $\Delta d / d = 0.2$–0.3%) of the Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences. The experience of production of modern scintillation detectors gained by LNP JINR is the basis for the future joint PNPI and JINR developments, which will be used at the PIK reactor.

2.4.2. Forschungszentrum Jülich (FZ Jülich, Germany)

FZ Jülich possesses over 30 experimental stations, most of which are at FRM II in Germany, three of which are at ILL, three – at the spallation neutron source (SNS), two – under construction (http://www.fz-juelich.de/jcns/EN/ Leistungen/InstrumentsNEW/_node.html). Several instruments are planned as a contribution to the ESS. The majority of these stations are designed for the investigation of processes of elastic (15 instruments) and inelastic (13 instruments) neutron scattering.

The analysis shows that more than 70% of the stations use ^{3}He-detectors that are implemented as 2*D* PSDs (with the aperture – up to 500 × 500 mm^2, the spatial resolution – 2 mm) and proportional counters (from 100 to 1 000 mm long).

2.4.3. Brookhaven National Laboratory (BNL, USA)

BNL no longer has a research reactor, but implemented previously a research development programme focused on creation of high-precision thermal neutron PSDs and equipped with them the experimental stations of national research centres (USA), in particular for the SNS for structural biological and chemical research (http://www.inst.bnl.gov/programs/gasnobledet/neutrons/neutron_brochure.pdf).

All the BNL detectors are ^{3}He-detectors based on proportional chambers with the data readout from cathode strips.

2.4.4. Some other centres

In other centres, for instance Rutherford Appleton Laboratory (RAL, UK) at the spallation neutron source ISIS or Oak Ridge National Laboratory (ORNL, USA; SNS and the HFIR reactor), the correlation of gas-filled and scintillation detectors is a little more balanced. RAL successfully used scintillation technologies for neutron registration. The higher importance of the time resolution at a pulsed spallation source, along with the better efficiency for lower wavelength neutrons, is the primary motivation behind the higher fraction of scintillator detectors for spallation sources.

3. Final analysis of the global trends of neutron detector development

Basing on the analysed experience of the most significant Russian and international neutron research centres and on their development trends drawn out in the course of the analysis (some of them were mentioned above), one can propose a strategy for development of neutron detectors and equipping the experimental stations of the PIK reactor. The results of the analysis and prediction of the detection technology development based on it demonstrate clearly the development strategies of neutron detectors over the period of more than 60 years (40 years of past + “the current” period of the last 10 years + about the next 10 years of the future) based on three main international neutron centres.

1. Using the example of the ILL experimental stations, an analysis of the neutron detector structure established over the last 40 years is presented.

In the course of these 40 years, unique world-class experimental stations were created, and their parameters were optimized based on simulations and experiments. The absolute majority of detectors (90%) are gas-filled devices using ^{3}He as a neutron converter.

2. The current state and practical implementation of the “current” development trends of detection technologies (over the last 10 years) were analysed on the example of the MLF centre operating as part of the neutron research centre at J-PARC (Japan).

About 75% of the detectors are gaseous detector devices using ^{3}He as a neutron converter. Implementation of new scientific and applied programmes required creation of new complex experimental stations (five units) equipped with the detectors based on scintillation technology.

3. The estimation of the global trends of the detection technology development and generation of their development strategies (for the next 10 years) were considered based on the baseline ESS instrument suite from the technical design report as an example.

Small-aperture detectors (1 m^2 and less) are in many cases planned to be produced based on the ^{3}He-technology. Such are 9 of 22 experimental stations (40%).

Nine more detectors (40%) having medium and large aperture (from 1 to 80 m^2) will be created based on the following technologies: scintillation detectors and gaseous detectors based on the ^{10}B solid convertor. It is assumed that for the next 5–7 years these technologies will reach such a level that their parameters can come close to those of ^{3}He-detectors.

So, the gas-discharge ^{3}He-detectors will be the basic development direction at least for the next 10 years. This is connected with the outstanding combination of properties of the detectors using ^{3}He as a neutron converter, which defined the inclination of neutron centres towards the use of such detectors for their experimental stations throughout their history.

A transition to different detection technologies based on ^{6}Li and ^{10}B converters that are being currently developed is mostly caused by the necessity and has the aim to reduce the cost of devices by means of abandoning the use of ^{3}He in large volume detectors. At the same time, it should not cause an intention to upgrade all the detector knots of the instruments, since, on the one hand, it would require a significant financial investment, and on the other hand, it would guarantee a change of a number of characteristics of devices for the worth: registration efficiency, spatial resolution, γ-background sensitivity and so on.

It is necessary to perform a detailed and thorough analysis of applicability of different detection technologies to a specific physical task, to a specific physical instrument. For instance, scintillation detectors are effective in the cases when it is necessary to achieve a high spatial resolution (≈ 100 µm) and to build a complex geometry shape of the registration surface.

4. Analysis of the issue of ^{3}He deficit

An analysis of the ^{3}He demand for the equipment of neutron detectors operating as a part of the neutron scattering research at large international neutron centres has been presented (http://dx.doi.org/10.1080/10448632.2012.725325, http://www.tandfonline.com/doi/full/10.1080/10448632.2012.725325) see Table 2. It should be noted that this is a minimum estimate of a global ^{3}He demand. For instance, Table 2 does not include the information of ESS detectors requiring more than 25 000 l of ^{3}He.

Based on the comparative analysis of the data presented in Table 2, it is possible to state that the demand of experimental facilities of the PIK reactor for ^{3}He is relatively small, around 900 l, which is a great deal less than the amount required by any more or less significant national or international centre.

One can see (Tables 3 and 4) that about 70% of neutron detectors are ^{3}He-detectors, which corresponds well with the global development trends. The cost of ^{3}He for the PIK reactor is relatively low (one-time investments of ~ 0.9 million dollars USA) and the advantages gained by the PNPI international neutron research centre based at the PIK reactor are positively significant. Such as:

- Detectors based on ^{3}He have a generally accepted unique complex of performance characteristics;
- PNPI already possesses technologies necessary for development and production of neutron detectors with aperture of up to 300 × 300 mm^2 (and larger), which guarantees compliance with the complex of requirements for modern neutron detectors. It does not require significant financial investment in technology. A technological modernization would be necessary due to creation of detectors with aperture of 1 000 × 1 000 mm^2;
- There are almost no sources of ^{3}He acquisition in Europe, and its price there is rather high;
- For this reason, the European scientific community is actively searching for alternative neutron converters and conceptually new construction ideas in order to create detectors that could replace ^{3}He detectors.

^{3}He is available in Russia, and its price is several times lower than the European one. For this reason, detectors based on ^{3}He are our competitive advantage over Europe, which certainly should be used to the fullest extent.

Table 2

Analysis of ^{3}He demand in the leading neutron centres of the world

Neutron centers	Exploitation of detectors and research, l/year	New small-aperture detectors, l	New large-aperture detectors, l
ORNL (SNS)	100	1 300	25 000
ORNL (HFIR)	100	1 210	2 500
Los Alamos	100	1 994	12 362
NIST	100	560	40
BNL	50	180	–
FRM II	100	650	4 500
HZ Berlin	100	520	7 850
ILL	100	1 000	3 000
JCNS	40	15	7 200
LLB	50	600	600
PSI	50	–	2 000
STFC	100	400	11 300
J-PARC	100	40	16 100
JRR-3	31	71	–
KAERI	150	–	2 000
CSNS	200	–	21 000
Total	1 431	8 540	115 372
The PIK reactor	10	900	0

Table 3

Types of detectors proposed for applications at the PIK research complex and their quantity

Device / detector	Gas neutron converter (^{3}He)		Solid neutron converters (^{6}Li and ^{10}B)	
	Proportional counter and 2*D*-module based on LPSC counter	2*D* position sensitive detector	Scintillator	Solid-state detector
Powder diffractometer	3 (D1, D2, D3)	–	–	–
Crystal diffractometer	–	3 (DC1, DC3, DC5)	3 (DC3, DC4, DC6)	–
Inelastic scattering spectrometer	2 (IN4)	1 (IN2)	3 (IN1, IN3, IN5)	–
Small-angle instrument	2 (S2, S3)	3 (S1, S4, S5)	–	–
Reflectometer	4 (R1–R4)	4 (R1–R4) 2 (R2, R3)	–	–
Total number	11	13	6	–

Table 4

Detectors operating in neutron beams of different intensity at PIK

Intensity of neutron beams, s^{-1}	Experimental station	Number of detectors, un.	Detector technology
Up to $1 \cdot 10^5$	S1	1	2*D* PSD (^{3}He)
	D2, IN2, IN4 (2 un.)	3	^{3}He proportional counter and LPSC
	IN1, IN3	2	Scintillators
Up to $1 \cdot 10^6$	DC1–DC5, DC7, S3, S4, S5, R1, R2, R3, R4	12	2*D* PSD (^{3}He)
	D1, D3, S2, R1–R4	7	^{3}He proportional counter and LPSC
	DC3, DC6, IN5	3	Scintillator
Up to $1 \cdot 10^7$	Beam monitor (R2, R3)	2	2*D* PSD (^{3}He-technology)
	None	0	^{3}He proportional counter and LPSC
	None	0	Scintillator
–	Total	30	–

5. Analysis of the PIK reactor planned instrumental facility and recommendations on equipping the experimental stations with neutron detectors

An analysis of the PIK reactor instrumental facility with regard to compliance of the neutron detectors with all the required operation parameters has been performed based on the information on detectors and strategic trends of their development in the leading neutron research centres of the world and analogous centres in Russia [4].

Detectors that are planned to be used at the experimental stations of the PIK reactor are listed in Table 3. Requirements for the loading capability of detectors with ^{3}He-converter are presented in Table 4. The background level and the γ-background sensitivity are stated as the maximum loading capability / background count of $\geq 10^6$ and the minimum possible sensitivity to the γ-background ($< 1 \cdot 10^{-7}$).

It is clear from Tables 3 and 4 which detection technologies should be given a high priority for the development at PNPI.

^{3}He detection technologies necessary for equipping the majority of experimental stations of the PIK reactor either exist at PNPI or can be produced there since there are technological capabilities for their development and realization.

1. PNPI already possesses technologies necessary for development and production of neutron detectors with aperture up to 300 × 300 mm^2 (and larger), which comply with the requirements of the current physical experiments (Fig. 2). Creation of such detectors does not require now any significant financial investments in their development stage. Based on these technologies, one can fabricate ^{3}He-detectors of different structural variations including the capacity to operate in vacuum.
2. Beam intensity: up to $1 \cdot 10^6$ s^{-1}. For the existing 2*D* PSD ^{3}He-detectors to be able to work in intensive neutron fields, it is necessary to change the data readout method from a delay line readout to channel-by-channel readout from the cathode strips.
3. Beam intensity: up to $1 \cdot 10^7$ s^{-1} and higher. If the experiment requires the detector to operate in a counting mode with efficiency close to 100%, then it is necessary to perform a detailed analysis of new detection technologies such as, 2*D* linear position sensitive counters (LPSC), GEM-technology, pad-structural gas-discharge detectors, scintillation detectors, *etc*.
4. Neutron beam monitors have a very low efficiency, which allows them to work in neutron beams of very high intensity ($1 \cdot 10^8$ s^{-1}).

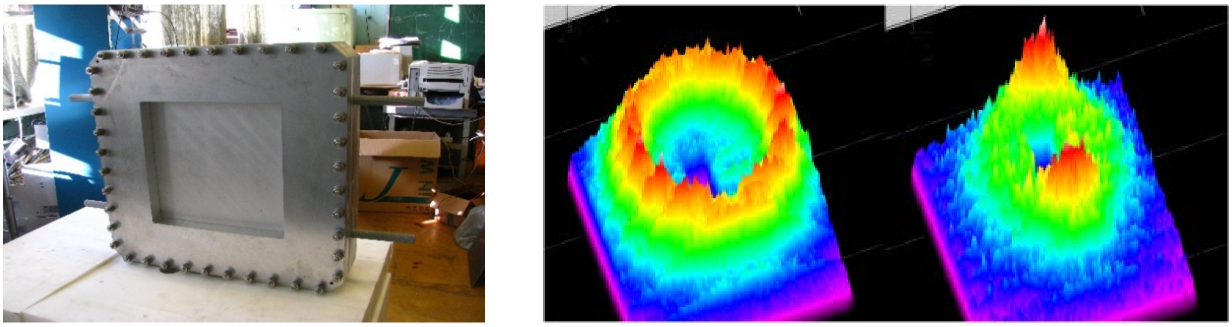

Fig. 2. Neutron detector (*left*); asymmetric scattering of neutrons on a fluoroplastic film before its deformation and after (*right*)

In order to create 2*D* detectors with aperture of 1 000 × 1 000 mm^2 based on LPSC, it is necessary to update the technological line, to develop prototype models and registration electronics.

The production of banana-type detectors based on LPSC-technologies (or microstrip gas chambers) requires a separate development.

Special attention should be paid to the development of scintillation detection technologies: the PIK reactor experimental stations are not yet fully equipped with such technologies, which are being actively developed in the world and have their own technological niche, such as:

- Fabrication of wide-aperture detectors of complex geometry;
- Neutron beam monitors;
- Practical applications of neutron tomography requiring the creation of detectors with high spatial resolution at the level of 0.1 mm (and higher), *etc*.

Taking into account the insufficient technological potential existing at PNPI in this field and quite significant financial investments needed to be done in the future, it is necessary to join efforts and support the joint activities of the developing collaboration of PNPI, JINR and INR RAS aimed at the applied development of scintillation technologies.

Neutron imaging for the purposes of tomography and radiography is a separate research field that is widely developing in modern sources, but is still not listed among the PIK reactor research stations.

The most advanced installations for neutronography and neutron tomography in Europe are located at the FRM II reactor in cold and thermal neutron beams and at the PSI – cold and thermal neutrons. The analogs are put in operation at the National Institute of Standards and Technology – NIST (USA).

Currently, the development of this field is possible only with the development of scintillation technologies.

6. Conclusion

An analysis of the PIK reactor instrumental facility with regard to compliance of the neutron detectors with all the required operation parameters has been performed based on the information on detectors and strategic trends of their development in the leading neutron research centres of the world and analogous centres in Russia over the period of more than 60 years (40 years of past + “the current” period of the last 10 years + about the next 10 years of future). We have come to the conclusion that the global trends for the next 10 years of creation of new neutron detection technologies are developing in several main directions (they are arranged in priority order):

- Modernization and development of gas detectors based on ^{3}He neutron converters;
- Development of gas detectors based on ^{10}B solid converters;
- Development of scintillation detectors based on spectrum-shifting optical fibers;
- For specific cases another type of detectors, such as GEM, Micromegas, solid state semiconductor detectors and so on.

Despite the high price of ^{3}He, a global neutron community still considers gas-discharge ^{3}He-detectors to be the basic development direction, first of all, for the detectors with aperture of up to 1 m^2. The reason for this is a unique combination of such properties as high efficiency for neutron registration and low γ-background sensitivity.

A possible transition to different detection technologies based on ^{6}Li and ^{10}B converters, which are being currently developed in Europe, is mostly caused by necessity and has the aim to reduce the cost of devices by means of abandoning the use of ^{3}He in large and medium volume detectors with aperture from 1 to 80 m^2 and larger.

He-3 detection technologies. These technologies necessary for equipping the majority (about 70%) of experimental stations of the reactor PIK either exist at PNPI or can be produced there, as there is a technological capability for their development and realization. The aperture of these detectors does not exceed 1 m^2 and consequently they do not require a large amount of ^{3}He (about 900 l). ^{3}He is available in Russia, and its price is several times lower than that in Europe. For this reason, detectors based on ^{3}He is Russia's competitive advantage over Europe, which certainly should be used to the fullest extent.

Scintillation detection technologies. Groups of experts professionally working with scintillation detectors and having some interesting activities have been formed at PNPI, JINR and INR RAS. The greatest experience in development of large-area ZnS(Ag) scintillation detectors was accumulated by JINR (LNP). Several such detectors have been created there and are successfully put into operation at some Russian scientific centres. In order to succeed with any further activity in this area, it is necessary to join efforts of at least three Russian scientific centres, and it is reasonable to base this joint activity on the experience of JINR (LNP) developments.

To perform a detailed and thorough analysis of applicability of different detection technologies (today's and future) and to guarantee the best realization of its advantages, its competitive strengths in comparison with other neutron sources in Russia and abroad, it is important to organize a fruitful collaborations between PNPI and the world leading scientific centres such as: ESS (Sweden), ILL (France), FZ Jülich (Germany), J-PARC (Japan).

In the process of development of the neutron detector technique, it is necessary to apply widely the ideas and technologies developed for charged-particle detectors in high energy physics (and other research fields). It is necessary to strive for unification of the equipment used and ready-made technological solutions. It is also reasonable to develop a unified detection electronics for the detection systems, as well as electronics for data accumulation and processing. It is necessary to standardize interfaces and software at a lower level.

Acknowledgements

Special thanks for our collegues from JINR (Dubna, Russia) and from PNPI HEPD and NRD (Gatchina, Russia) for their fruitful discussions and assistance during preparation of this article.

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