Report on the closing theme **"Development of Experimental Facilities for Condensed Matter Investigations with Beams of the IBR-2 Facility"** with the project **"Development of PTH sample environment system for the DN-12 diffractometer at the IBR-2 facility"** and proposal for extension of the theme and the PTH project for 2018-2020 and opening of a new project **"Development of a wide-aperture backscattering detector (BSD) for the HRFD diffractometer"**

Theme Code:	04-4-1122-2015/2017
Laboratory:	Frank Laboratory of Neutron Physics
Department:	Spectrometers' Complex (SC)
Theme Title:	Development of Experimental Facilities for Condensed Matter Investigations with Beams of the IBR-2 Facility
Leaders:	S.A.Kulikov, V.I.Prikhodko

Scientific Program:

Development and construction of a control system of the cryogenic moderator CM-201 for IBR-2 beamlines № 1, 4, 5, 6, 9. Design of equipment, electronics and software for the complex of IBR-2 spectrometers; development of the FLNP information and computing infrastructure according to the needs of the Laboratory and the development strategy of the JINR computer network.

Expected results upon completion of the theme:

1. Development and construction of a control system of the CM-201 moderator. Start-up and adjustment of CM-201 after the completion of installation. Carrying out of trial loading of the moderator chamber. Maintenance and routine modernization of the CM-202 cryogenic moderator with control systems. Carrying out experiments to study radiation resistance of materials.
2. Development and application of VITESS and other software packages for simulation of neutron scattering in samples and in individual components of spectrometers. Complex calculations and optimization of spectrometers.
3. Equipping of IBR-2 spectrometers with detectors. Study of the possibility to use high-current operation modes of gas detectors for neutron detection. Development of detectors with a non-helium neutron converter. Development of a prototype of a position-sensitive detector with a resolution less than 1 mm and study of its characteristics.
4. Development and construction of a horizontal/vertical cryostat with a superconducting magnet and a temperature range of 4-300 K for the DN-12 diffractometer. Development and modernization of cryostats on the IBR-2 spectrometers.
5. Development of data acquisition systems, control systems of actuating mechanisms, of sample environment equipment and spectrometer choppers. Upgrading of spectrometers' software.
6. Development of the FLNP network and information technology infrastructure according to the needs of the Laboratory and the development strategy of the JINR computer network.

Part 1. Activity Report

During 2015/17 all activities specified in annual Topical Plans have been successfully carried out. The results of the work are reflected in the annual reports and reports of the FLNP Director at PAC sessions for Condensed Matter Physics, JINR Scientific Council and in reports of the Department staff at international and national conferences, as well as in numerous journal publications (http://flnp.jinr.ru/37/). The results of the work formed the basis for corresponding sections of the Laboratory's proposals to the seven-year plan for the development of JINR in 2017-2023 (Condensed Matter Physics).

The work under the theme was performed by the staff of the **Department of the IBR-2 spectrometers' complex** in close cooperation with the staff of other divisions of the Laboratory working under themes 1121 and 1105. First of all, it might be well to mention the **Department of Neutron Investigations of Condensed Matter** (collaboration in the construction and development of spectrometers) and **Mechanical and Technological Department and Service Groups of IBR-2** (work on the cryogenic moderators). Below are the brief reports on the main directions of research and development performed in the framework of theme 1122.

1. Complex of cryogenic moderators CM-201, CM-202 of the IBR-2 reactor and radiation research facility

In the reporting period of 2015-2017, studies were conducted on a special stand of a cryogenic pelletized moderator with an inclined section at an angle of elevation of 40° in the direction of experimental beamlines № 1,4,5,6,9 (**Fig.1.1**).

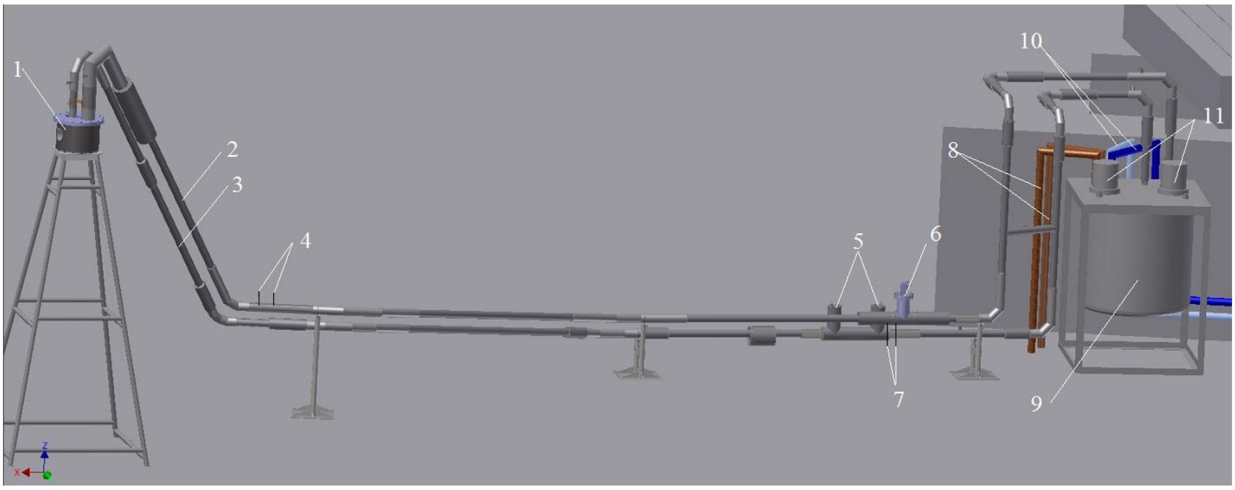

Fig. 1.1. 3D-model of a test stand of CM-201 cryogenic moderator: 1 – simulator-chamber in a vacuum cylindrical housing; 2 - pipeline for feeding helium to the simulator-chamber; 3 – pipeline for removing helium from the simulator-chamber; 4, 7 – leads for differential pressure sensors to monitor movement of pellets in the pipeline; 5 – Pitot tubes; 6 – dosing device; 8 – pipelines for feeding and removing helium of KGU, 9 – cryostat with a heat exchanger, 10 – pipelines for feeding and removing helium of CM-202 moderator, 11 – helium gas blowers.

As a result of the experiments, the chamber of the stand has been fully loaded with frozen pellets for several times (**Fig.1.2**). Despite a rather "steep" climb, the pellets easily move up the inclined section of the pipeline and pneumatic transportation proceeds in the usual mode. Hardware and software of the stand have demonstrated stable and trouble-free operation during all experiments and in the future will be used in a real moderator CM201.

Fig. 1.2. Photo of the chamber during the experiment. Temperature inside the chamber is T = 80 K. About 15,000 pellets (0.5 l) are loaded.

A device for nitrogen-free charging of frozen pellets into the moderator chamber (Fig. 1.3) and a diaphragm for measuring the flow rate of gaseous helium in the moderator pneumatic pipeline have been developed and successfully tested on the laboratory test stand.

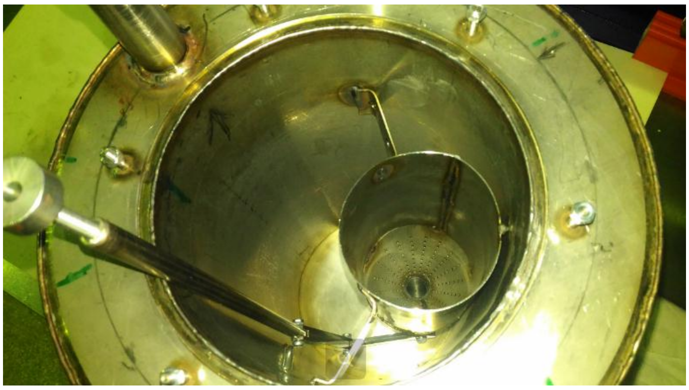

Fig. 1.3. A device for nitrogen-free charging of frozen pellets into the CM202 chamber.

The regular operation of the cryogenic moderator CM-202 for physics experiments continued. In the reporting period the moderator has operated in six cycles of the IBR-2 reactor. During the entire period of its trial operation since 2012 the cold moderator has operated trouble free for more than 2500 hours.

In the framework of investigations carried out with the cold moderator, the aromatic hydrocarbon triphenylmethane has been studied and compared with the currently used substance – a mixture of mesitylene and m-xylene. It has been found that the radiation resistance of triphenylmethane is ~ 10 times higher than that of the mixture. The study of the cold neutron yield of triphenylmethane at different temperatures and comparison of the results with those of the mixture continue on the DIN-2PI and HEPA-PR spectrometers.

A technical specification for a screw-type discharging device for the CM-201 moderator (**Fig. 1.4**) has been developed. This device is designed for continuous replacement of a moderating substance in the moderator chamber.

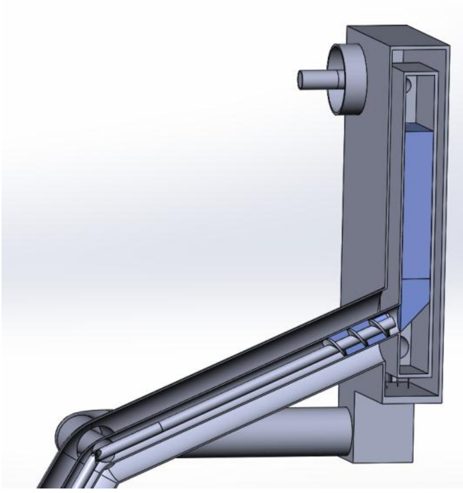

Fig. 1.4. Screw-type discharging device (model).

The modernization of the radiation research facility on IBR-2 beamline 3 is in progress, specifically, the control panel is being replaced with the newly developed and manufactured control unit; biological shield has been designed and manufactured and is being assembled at present. At the facility a number of experiments on irradiation of diamond single crystals (**Fig. 1.5a**), magnetic 3D Hall sensors (**Fig. 1.5b**) and Ir-193, Mo-98, Te-131 isotopes have been performed and the nature of radiation defects in topaz minerals (**Fig. 1.5c**) and samples of silicon scintillators (**Fig. 1.5d**) after irradiation has been studied.

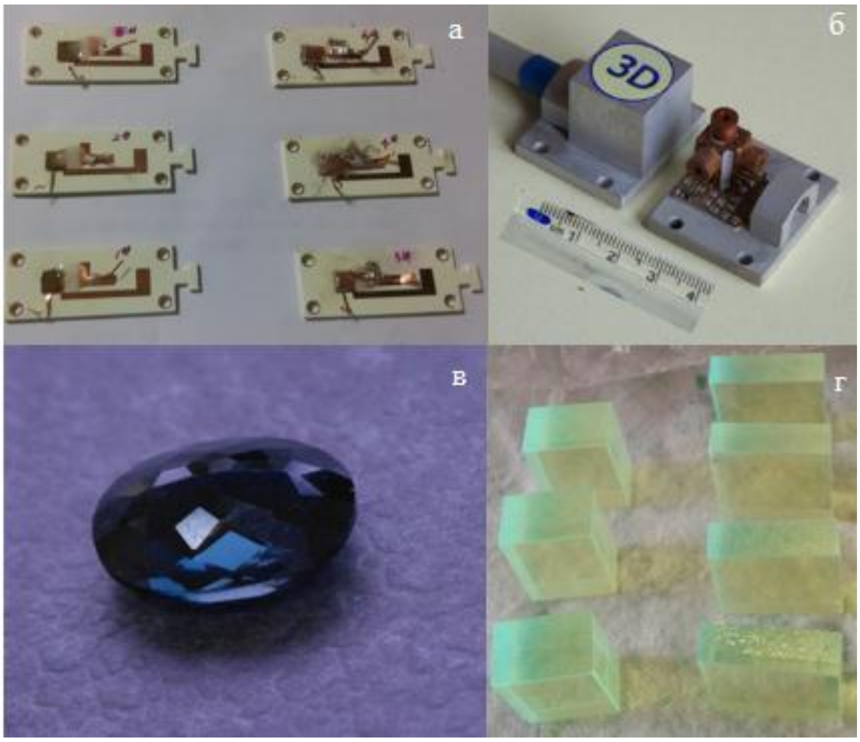

Fig. 1.5. Samples for the experiments conducted at the radiation research facility: a – diamond single crystal; b – magnetic 3D Hall sensors; c – topaz, d – silicon scintillators.

Recently, with an active participation of specialists from the FLNP Spectrometers' Complex Department, possible variants of the future pulsed neutron source at JINR are being considered and analyzed, since the service life of the IBR-2 reactor will expire by about 2032. The aim of this work is to study the possibility of development of such a neutron source (specifically, on the basis of Np-237) (**Fig. 1.6**), so that it can successfully compete with other existing and projected pulsed neutron sources, including sources abroad.

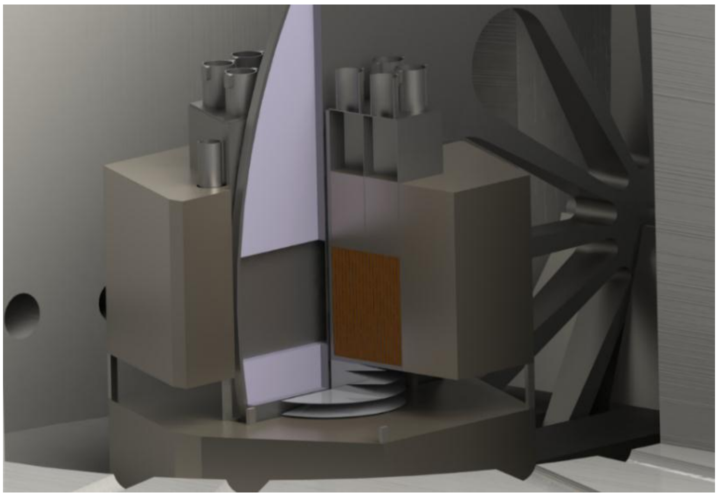

Fig. 1.6. Design of Np-237 based reactor.

2. Calculations and simulation of spectrometers

During the reporting period, programs for simulating neutron spectrometers and experiments for the VITESS complex (Virtual Instrument Tool for European Spallation Source) have been developed, tested and put into service. Almost half of all VITESS modules have been developed in FLNP; in particular, the tasks of simulating neutron tools with polarized neutrons have been almost completely realized. The simulation of various flippers and spin-echo spectrometers with constant and time-dependent magnetic fields has been successfully carried out. The magnetic fields can be both model (built into modules) and calculated by an external program (MagNet, Ansys, etc.). Virtually all existing neutron-optical elements (neutron guides, benders, mirrors, lenses, prisms and their combinations) have been built into VITESS (and successfully used) as well as the possibility of simulating neutron detectors (including position sensitive ones) with time focusing has been provided.

It can be noted that to date, for the major part, the development of special mathematical models and corresponding programs for simulating full reflectometric and GISANS experiments with samples, including multilayer rough samples and magnetic scattering, has been completed. Various modifications of the kinematic approximation have been developed taking into account the penetration depth, refraction and renormalization of collected data. The developed programs have the format of input and output data compatible with the known software package BornAgain that uses the Distorted Wave Born Approximation (DWBA) method.

Particular emphasis has been placed on the simulation of specular reflection using the modified kinematic approximation and the diffraction pattern of a neutron beam from regularly ordered nanostructured objects on the surface, as well as on the comparison of the obtained results with the real experiment and DWBA simulation. It has been shown that the modified kinematic approximation used in the simulation of specular reflection, which takes account of the effect of neutron wave refraction at an interface, gives fairly good agreement with the available experimental data and the Parratt method, which is considered to be the most accurate method of the dynamic theory. It has also been found that for the modified kinematic approximation the application of the penetration depth in the process of simulation is of utmost importance because it allows one to successfully suppress spurious signals from the sample substrate.

Below are the results of the simulation of two virtual full reflectometric experiments (diffraction from gold columns on a silicon substrate (**Fig. 5**)) in the modified kinematic approximation.

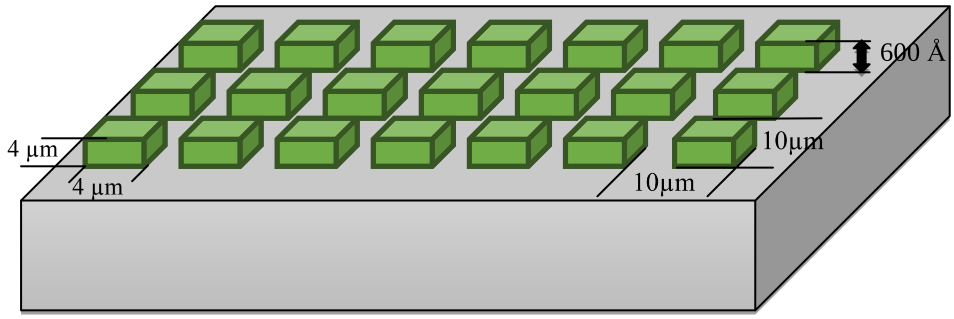

Fig. 2.1. System of gold columns on a silicon substrate (column height – 600 Å, column width – 4×4 µm, spacing in the horizontal plane – 10×10µm).

The results of the simulation of the system presented in **Fig. 2.1** for a full reflectometric experiment are shown in **Fig. 2.2**.

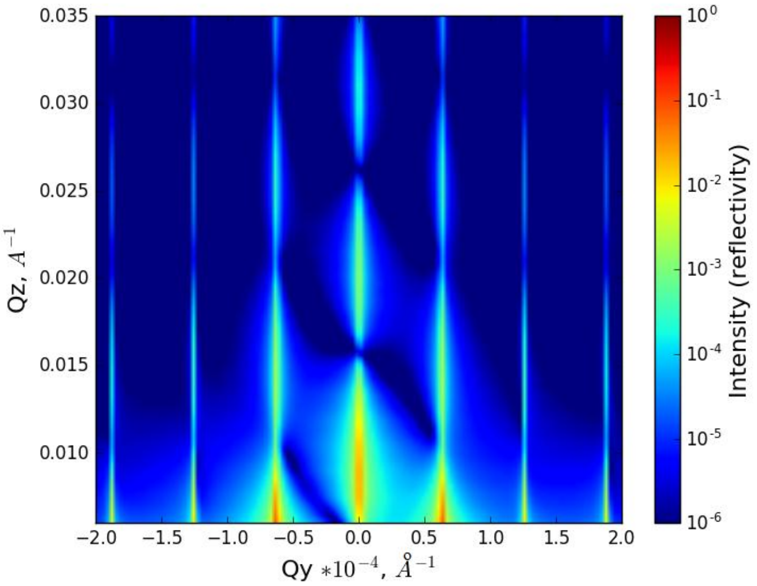

Fig. 2.2. Simulation of a full reflectometric experiment in the modified kinematic approximation of the system of gold columns on a silicon substrate.

The results of the simulation of specular reflection of the system shown in **Fig. 2.1** using four methods are presented in **Fig. 2.3**:

1) Parratt method, dynamic theory (the most accurate method);
2) Born approximation;
3) kinematic approximation with consideration of refraction from the columns;
4) kinematic approximation with consideration of refraction from the columns and silicon substrate.

The modified kinematic approximation that takes into consideration the refraction from both the columns and substrate has demonstrated the best agreement with the Parratt method. Thus, taking account of refraction is crucial when using the kinematic approximation.

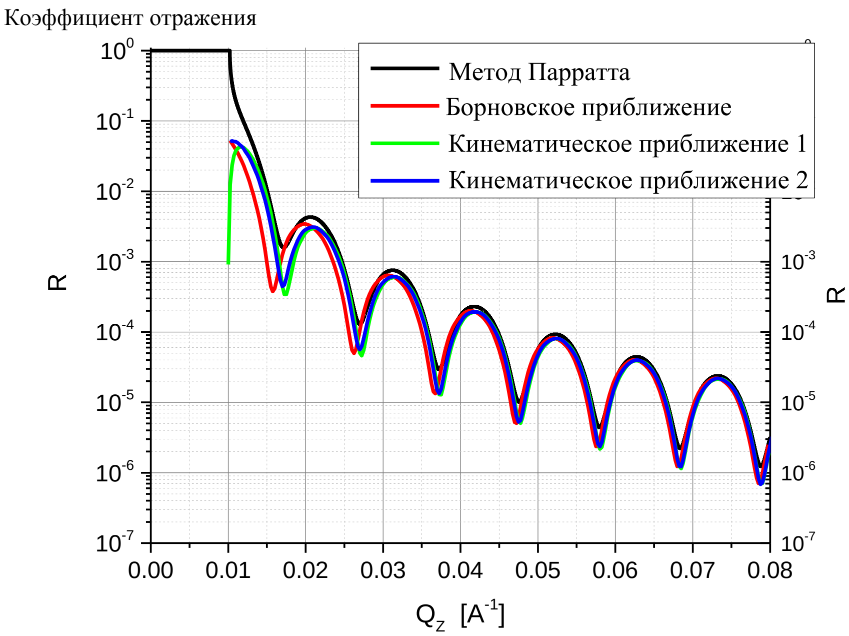

Fig. 2.3. Simulation of specular reflection for the system presented in Fig. 2.1 using various methods.

A more detailed description of the work in this area as well as links to numerous journal papers can be found in the FLNP Annual Reports.

3. FSS spectrometer

In cooperation with the FLNP NICM Department and PNPI (Gatchina), work has been continued on the construction of a new high-resolution Fourier diffractometer on IBR-2 beamline 13 on the basis of units of the FSS spectrometer from the GKSS research center (Geesthacht, Germany.

Neutron guide sections (**Figs. 3.1, 3.2**) and vacuum equipment have been installed, as well as the positioning of optical sections and vacuum sealing of the neutron guide have been done.

Fig. 3.1. Starting section of the curved neutron guide and Fourier chopper on IBR-2 beamline 13.

Fig. 3.2. Exit section of the neutron guide.

Work has been carried out to measure beam characteristics at the exit of the neutron guide and to improve the background conditions at the diffractometer. The distribution of beam intensity along the x-axis at the exit of the neutron guide is shown in **Fig. 3.3**.

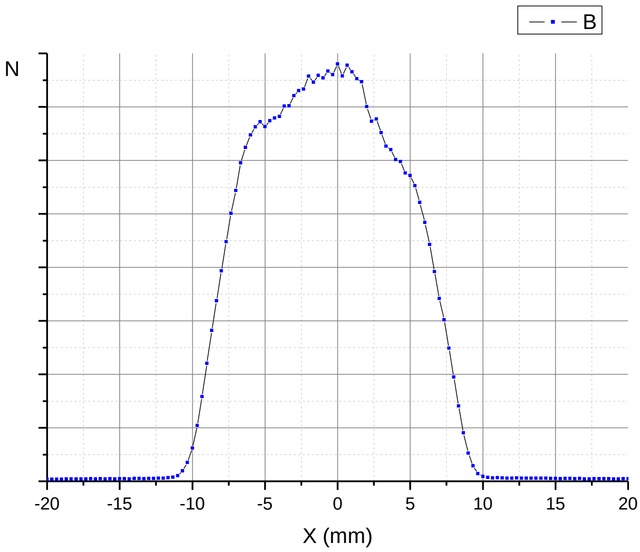

Fig. 3.3. Distribution of beam intensity along the x-axis at the exit of the neutron guide.

Figure 3.4 illustrates a comparison between the output beam intensity distribution calculated by the Monte Carlo method (reflection coefficient used in the calculations was R = 0.99) and the spectrum obtained for a vanadium sample placed at the exit of the mirror neutron guide used in GKSS. Positions of the maxima of the measured and calculated spectra coincide. The narrowing of the measured spectrum can be explained by the low quality of the coating of the mirror neutron guide. The measured maximum flux density across the beam is about 5 x 10^5 n/(s·cm^2).

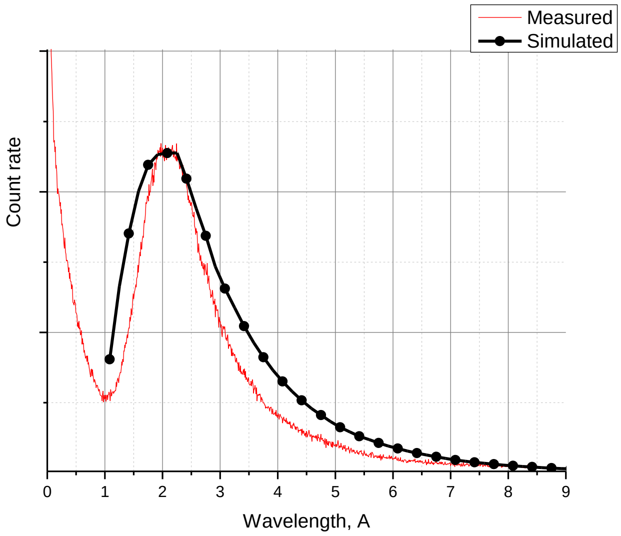

Fig. 3.4. Calculated and measured distributions of neutron beam intensity at the exit of the mirror neutron guide.

For acquisition and accumulation of data from two lithium-glass scintillation detectors the detector electronics modules received from GKSS (Germany) have been adjusted. In addition, a 32-channel discriminator module and MPD-32 controller have been manufactured and adjusted (**Fig. 3.5, Fig. 3.6**).

Fig. 3.5. A sample table with a goniometer and 90° scintillation detectors "Ost" and "West" on IBR-2 beamline 13.

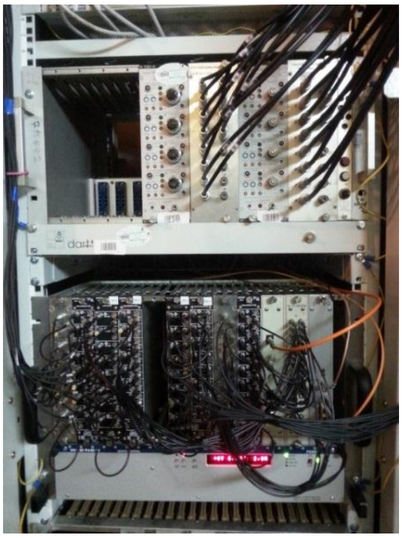

Fig. 3.6. Electronics of high-voltage power supply of detectors (top crate), modules of detector electronics and data acquisition electronics (bottom crate).

A control system of the FSS Fourier chopper has been put into operation (see Section 6).

Further activities on this diffractometer within the framework of the theme will mainly be related to the development of the detector system, the replacement of the neutron guide sections and the modernization of the Fourier chopper.

4. Cryogenics and vacuum systems

Major activities in the area have been carried out in accordance with the project "**Development of PTH sample environment system for the DN-12 diffractometer at the IBR-2 facility**" on the development of a cryostat for temperature and magnetic investigations of condensed matter under pressures of up to 10 GPa at the DN-12 spectrometer. The project is aimed at the development of a horizontal cryostat DN-12 for experiments in the temperature range of 300-4 K. A significant extension of the range of scientific problems solved by means of this diffractometer has required the construction of a cryostat with a variable temperature and magnetic field, which will allow us to successfully distinguish between the effects from various types of interactions when studying complex magnetic structures, build detailed magnetic phase diagrams of magnets under study and thoroughly investigate mechanisms of magnetic phase transitions.

The magnet is a Helmholtz pair of magnets made of a high-temperature superconducting tape of the second generation YBCuO (manufactured by "SuperOx", Russia). The magnet is cooled by a closed-cycle cryocooler. The cryostat with a high pressure cell, which in its turn is cooled by another closed-cycle cryocooler, is inserted into the center of the magnet through a horizontal shaft. The temperature of the cell is regulated by a controller in the range of (4 - 300) K.

The project is being implemented in cooperation with the National Institute of Research and Development in Electrical Engineering ICPE-CA, Bucharest, Romania.

The following major activities have been carried out in the framework of the project:

- Design documentation for the cryostat and magnet producing a magnetic field of 4 T was prepared.
- Machine for HTSC tape winding was developed and manufactured;
- Cryostat for cooling the magnet was manufactured.
- Magnet was produced.
- Horizontal cryostat for cooling high-pressure cells was manufactured and tested. This cryostat with a high-pressure cell is inserted into a magnetic field of the superconducting magnet.
- Power source for the superconducting magnet with an operating current of up to 300 A was put into operation.
- To increase the field strength, work is being carried out to improve electrical contacts and thermal couplings.
- Preliminary tests of the cryostat with a magnet were carried out at a current of 90 A. The magnet constant was measured to be 0.0154 T/A. A magnetic field of 1.386 T was obtained.

Figure 4.1 presents a general view of the cryostat.

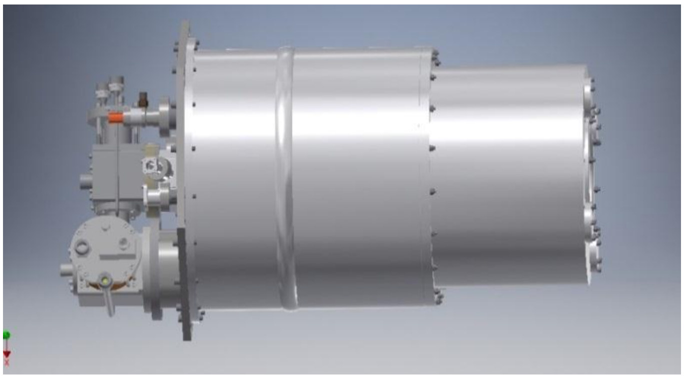

Fig. 4.1. General view of the cryostat.

Figure 4.2 shows the cryostat on a cryogenic test bench during tests in the SC department and **Figure 4.3** illustrates the process of manufacturing of magnet windings on a special machine.

Fig. 4.2. Cryostat on a cryogenic test bench.

Fig. 4.3. Manufacturing of magnet windings on a special machine.

Figure 4.4 shows graphs of temperature in different parts of the cryostat when cooling. The achieved terminal temperatures of the magnet prototype (16 K), warm ends of HTSC current leads (58 K), and sample (2.8 K) correspond to the design values.

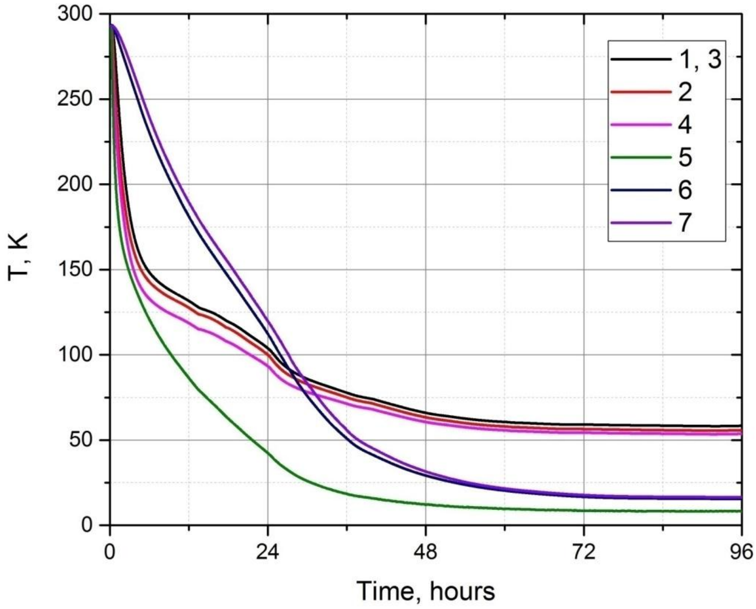

Fig. 4.4. Graphs of temperature in various parts of the cryostat versus time. Temperature of magnet – 6, 7; temperature of warm ends of HTSC current leads – 1, 3; temperature of second stage of cryorefrigerator – 5, temperature of first stage of cryorefrigerator – 2, 4.

When carrying out the start-up and adjustment work together with the Romanian colleagues, we repeated test experiments and detected the degradation of the properties of the tape in one of the magnet coils, which showed up as a decrease in the critical current value and, correspondingly, the magnetic field strength. To determine the causes of the observed effect, we carried out additional studies, which revealed that the most probable reason is the discrepancy between the actual characteristics of the tape and the characteristics specified by the supplier.

At present, negotiations are being conducted with the supplier of the tape (Russian company "SuperOx") in order to find out the reasons for the tape degradation and to receive a free replacement.

In 2015/16, the spectrometer DIN-2PI was equipped with a cryostat with a closed-cycle pulse tube cryorefrigerator. The cryostat was tested. **Figure 4.5** is a photo of the cryostat in the shaft of the spectrometer, and **Figure 4.6** shows temperature dependences for the sample chamber and the second stage of the cryorefrigerator as a function of time during a temperature change.

Fig. 4.5. Photo of cryostat with cryorefrigerator in the shaft of the DIN-2PI spectrometer.

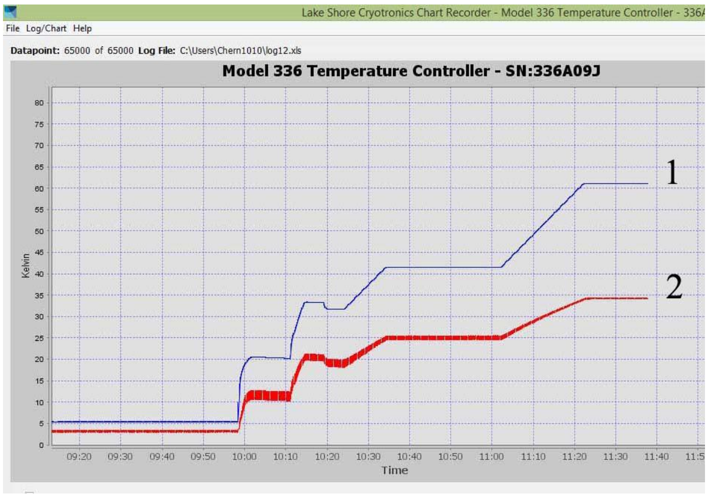

Fig. 4.6. Time dependence of temperature of sample chamber as temperature changes: 1 – temperature of sample chamber, 2 – temperature of cryorefrigerator second stage.

Work was carried out to extract the gas fraction from gaseous helium of the cold moderator from mesitylene after the reactor operation for 10 days. For this purpose, a setup with a closed cycle cryorefrigerator was assembled, in which a chamber with a sorbent was cooled to absorb hydrogen present in helium after mesitylene decomposition in a neutron beam. As a result of the experiment it has been found that the content of the by-product gas fraction in helium is no less than 5% at the end of the reactor cycle with cold neutrons.

Vacuum systems of mirror neutron guides on IBR-2 beamlines 13 and 9 have been put into service.

5. Detectors and electronics

In 2015, on the DN-6 diffractometer a new ring neutron detector for obtaining neutron spectra at a scattering angle of 90° was put into operation. The detector consists of 16 sections with 6 independent detector elements each (helium proportional counters) with background shielding and collimation. Charge-sensitive preamplifiers (96 channels), three modules of 32-channel amplitude discriminators and a 192-channel digital data acquisition and accumulation module (MPD) were developed and manufactured specially for this detector. The electronics was adjusted and all the equipment with the software of the diffractometer was tested. The available multi-section ring detector relocated to the scattering angle of 45° and the new one was integrated into a single measurement system (**Fig. 5.1**).

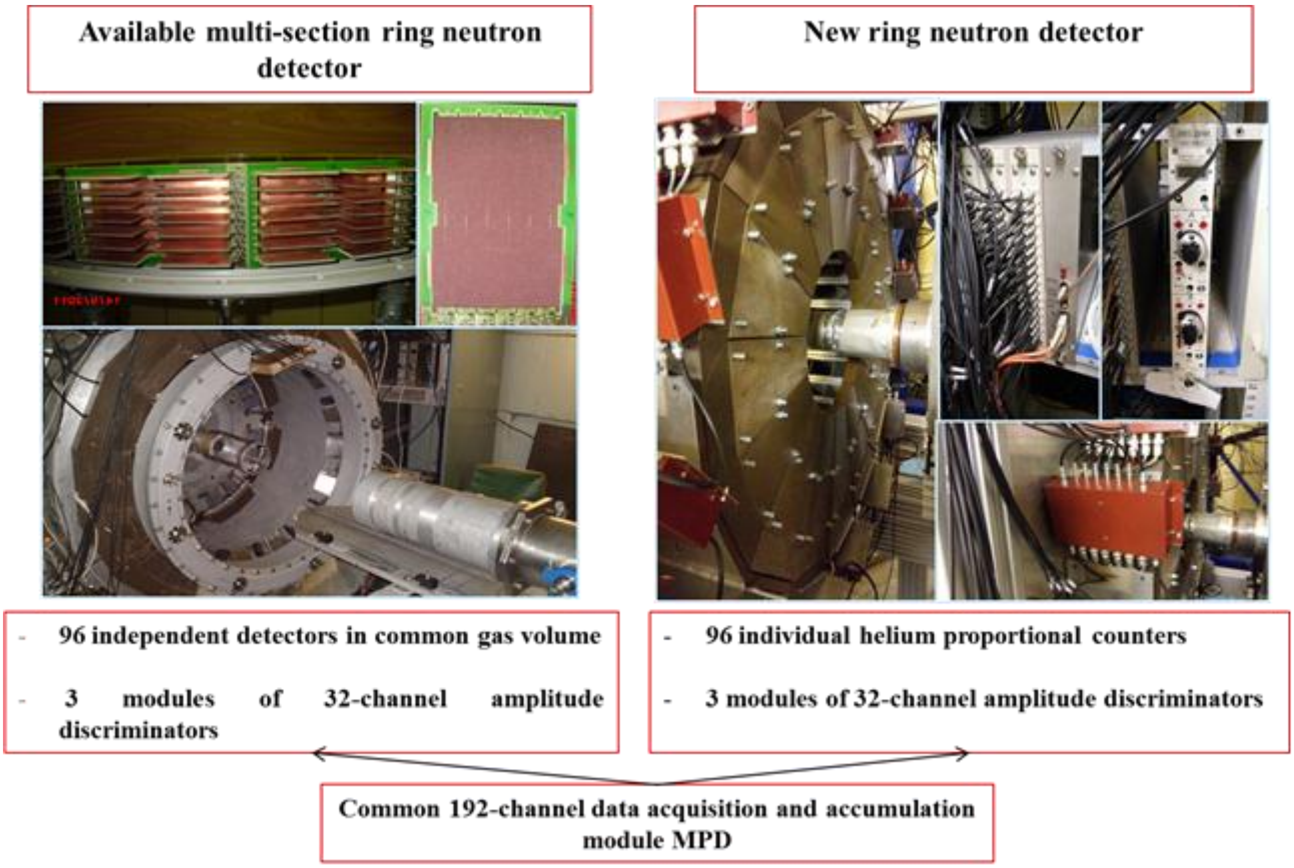

Fig. 5.1. New detector system of the DN-6 diffractometer.

In 2016, the design of a new ring gas detector was developed for detecting small-angle scattering of thermal neutrons on the RTD diffractometer. Photos of the detector elements are presented in **Fig. 5.2**.

Fig. 5.2. Photos of the housing (left), internal part of the detector and 9 independent coaxial rings (right).

The detector is divided into 9 independent equidistant coaxial rings. The cathodes of each ring are divided into 16 independent sectors. The signal pickup is performed from anode wires (shared by all rings) and from each of the 16 cathodes. Thus, this detector system consists of 144 independent detectors. To eliminate the effect of impulse noise and reduce the electronic noise, the preamplifiers of detector elements are arranged inside the gas volume.

The analog electronics boards (144 measuring channels) and mechanical components of the detector were manufactured in SPA “Atom”. The digital data acquisition and accumulation electronics are based on the previously developed in FLNP unified MPD modules. In 2016-2017, the assembling of the detector and its testing are to be carried out.

The completion of the testing of the detector and putting it into operation are scheduled for the end of 2017.

A new proton-telescope-based spectrometer developed in FLNP has been adjusted and handed over to be put into trial operation along with the electronics and software specially designed for it. The spectrometer is intended for experimental studies of energy distributions of fast neutron fluxes. The measurement of energy distributions of neutron fluxes is performed by measuring the kinetic energy of recoil protons elastically scattered at small angles as a result of (n, p) interaction in a gas hydrogen-containing medium. A detailed description of PT can be found in JINR Patent http://www.freepatent.ru/images/patents/13/2445649/patent-2445649.pdf.

In 2016, the spectrometer was delivered to the National Fusion Research Institute (Daejeon, Republic of Korea) in accordance with Protocol №4519-4-15/17 of 15.06.2015 to study characteristics (in the first place, plasma temperature in the $D(d,n)^3He$ reaction) and perform diagnostics of the nuclear fusion reactor KSTAR (Korea Superconducting Tokamak Advanced Research fusion reactor). First physical data have been obtained and processed. In 2017, we plan to continue this work with the purpose of improving the energy resolution and enabling the operation in a wide range of neutron energies. The photo of the electrode system of the spectrometer is presented in **Fig. 5.3** and the photo of the spectrometer at KSTAR is shown in **Fig. 5.4**.

Fig. 5.3. Housing and electrode system of recoil proton telescope.

Fig. 5.4. Spectrometer on the basis of a recoil proton telescope at the KSTAR nuclear fusion reactor.

A new 2D position-sensitive detector (2D PSD) of thermal neutrons has been put into operation on the REMUR spectrometer. We have also conducted studies to determine the cause of high-frequency noise on this setup. Their source has been found to be a magnet of the spin-flipper. Recommendations on the elimination of the problem have been made. The 2D PSD on the REMUR spectrometer and measurement results are shown in **Fig. 5.5**. Similar detectors have been put into service on the RTD and REFLEX diffractometers. In 2017, it is planned to equip the IBR-2M spectrometers with two more detectors of this type.

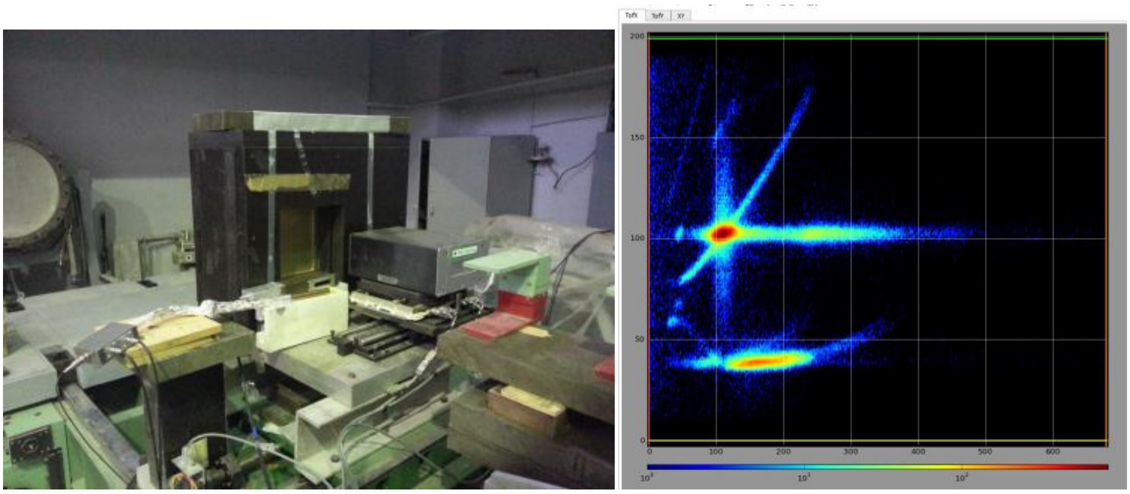

Fig. 5.5. 2D PSD on the REMUR spectrometer (left) and measurement results (right).

We have carried out a series of methodological studies aimed at increasing the PSD service life and the optimization of its gas mixture for use in direct beams. A prototype of PSD on the basis of a multiwire proportional chamber with a ^{10}B converter has been developed and tested (**Fig. 5.6**, **Fig. 5.7**). These activities have been performed in the framework of the collaborative work on the ESS project (Lund, Sweden). In 2017, studies to improve the coordinate resolution of the prototype were performed. A coordinate resolution of 0.9 mm along the X axis was obtained.

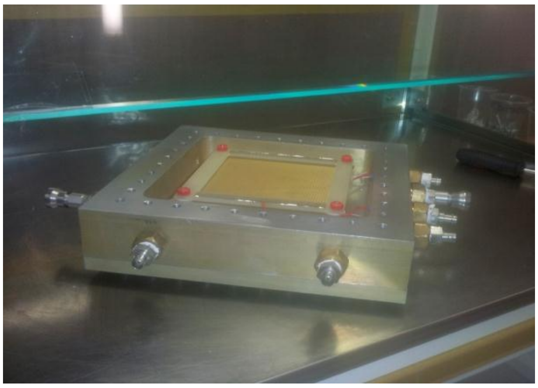 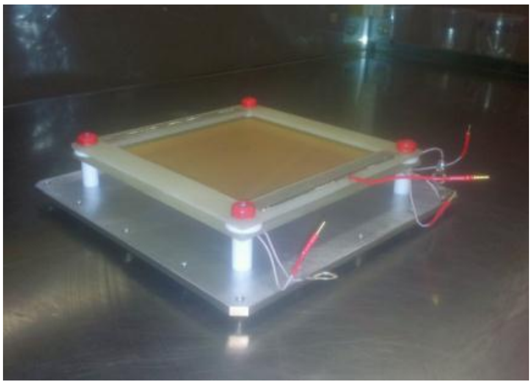

Fig. 5.6. Prototype of PSD with ^{10}B converter (left). Electrode system of prototype (right).

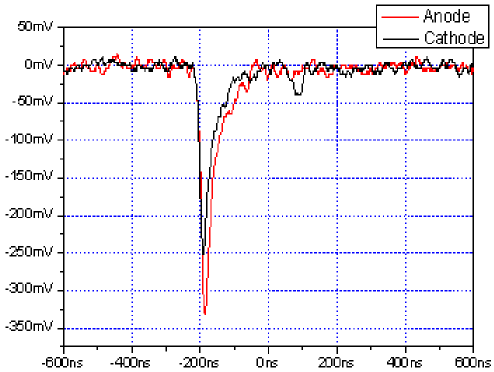

Fig. 5.7. Shape of anode and cathode signals (filling gas – CF_4 at 1 atm.).

In 2015, we completed the manufacturing and commissioning of scintillation counters of the fourth section of the ASTRA detector on the FSD diffractometer (**Fig. 5.8, Fig. 5.9**). In the process of this work a new design of the counters and a more convenient scheme of their arrangement in the ASTRA detector were proposed. The new design makes it possible to significantly reduce the material and human resources required for the manufacturing of the detector. In 2016, the necessary calculations of the geometry of the detector and its optimization were done for the maximum unification of elements. A 3D model of one of the planes of the new “Astra” detector is shown in **Fig. 5.10** and their arrangement in the detector is in **Fig. 5.11**. A technical project for the ASTRA-M detector system has been developed and work on the manufacturing of its components has started. The installation of the system on the FSD spectrometer and first test measurements are scheduled for 2018.

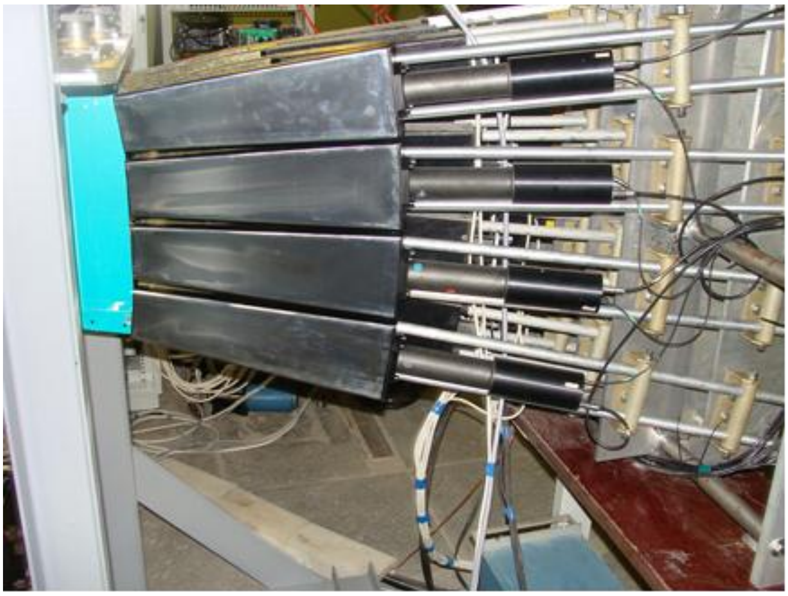

Fig. 5.8. Scintillation counters of section 4 of the ASTRA detector, which are installed on the FSD diffractometer.

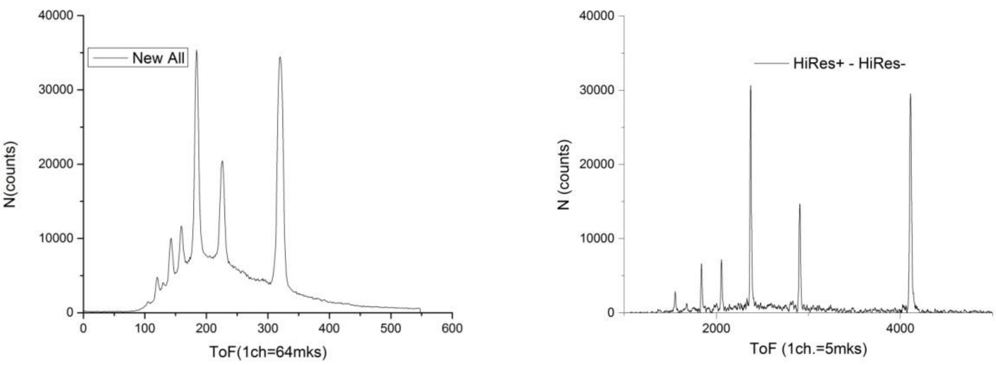

Fig. 5.9. Measurements on the FSD diffractometer. Spectra of low (left) and high (right) resolution obtained using section 4 of the ASTRA detector.

Fig. 5.10. 3D model of one of the planes of the new ASTRA-M detector.

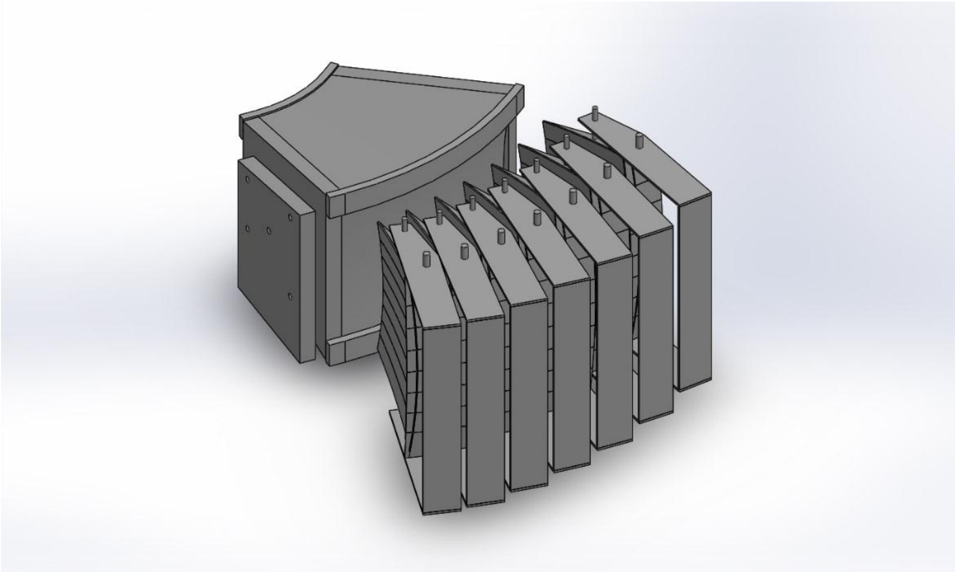

Fig. 5.11. 3D view of the left arm of the ASTRA-M detector.

A technical design specification has been developed and a project of creating a wide-aperture scintillation backscattering detector for the HRFD diffractometer has been prepared (its draft is presented at this PAC session and will be implemented under the extended theme 1122).

At the requests of the researchers measurements of the neutron beam profiles on IBR-2 beamlines 1, 5, 9, 10 and 13 have been performed using a monitor PSD.

The improvement of the infrastructure for the development and construction of neutron detectors is being carried out. An order has been prepared for the modernization of the clean room for assembling detectors, its area is to be increased, and purity class is to be enhanced, which will allow us to work with detectors of larger sizes.

All the detectors described above are equipped with the unified blocks of analog and digital electronics and software developed in FLNP. The digital data acquisition systems consist of two basic electronic modules, (Delidaq 1,2 and MPD), one of which processes and accumulates data from one- and two-dimensional PSD, and another – from an array of point detectors (gas and scintillation counters). All parameters of the modules are programmed. New systems allow one to work both in the histogram mode and in the mode of accumulation of raw data – ListMode (with subsequent off-line processing).

Since 2016 methodological work has been in progress on the investigation of possibilities of using multichannel digitizers to acquire data from 1D and 2D position-sensitive neutron detectors.

6. Control systems of actuators, sample environment equipment and spectrometer choppers

During the reporting period a large amount of work has been carried out to upgrade the actuators of the IBR-2 spectrometers, neutron beam choppers, sample temperature control systems, as well as control systems of these devices.

6.1. Control systems of actuators

Due to the unified structure of control systems of IBR-2 spectrometer actuators, their inclusion into the number of new devices is significantly easier:

- an additional controller or sensor is installed in the control system, which is assigned the next number;
- parameters of new devices are specified in the software of the system.

The control system of the actuators of the REMUR spectrometer for 32 control channels is presented in **Fig. 6.1**.

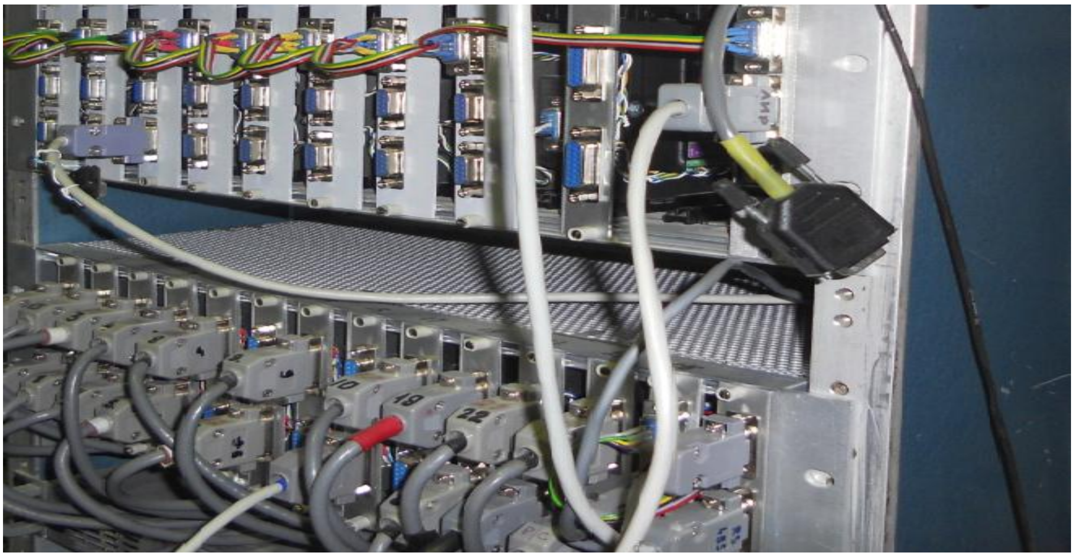

Fig. 6.1. Control system of actuators of the REMUR spectrometer for 32 control channels.

The controllers for stepper motors and absolute multi-turn angular sensors used in the control systems have also been unified. All this allowed us to reduce the time of modernization of the spectrometers' automation systems and made them more technologically adaptable and convenient to use.

Absolute linear displacement wire-type (0-2 m) sensors on the basis of absolute angular multiturn sensors have found application on the REMUR spectrometer and gasholder of the control system of the CM-202 cold moderator. The SSI interface has ensured their inclusion in the unified control system.

On the YuMO spectrometer a control system for sample changing (**Fig. 6.2**) has been put into operation. The number of samples in the cassette has been increased from 14 to 25 and the time required for automatic sample change has been reduced. The position adjustment procedure for two detectors in the horizontal and vertical directions in the range of up to 100 mm has been automated, which allows one to accurately position the detectors relative to the beam along the whole path of their movement (**Fig. 6.3**).

On the new FSS diffractometer a Huber goniometer, which provides positioning of the sample by *x*, *y*, *z* coordinates and rotation around the vertical axis (**Fig. 6.4**.) has been automated.

The number of control channels on each of the GRAINS, ESPILON, YUMO and REFLEX spectrometers has exceeded 32, and their total number on the IBR-2 spectrometers is more than two hundred.

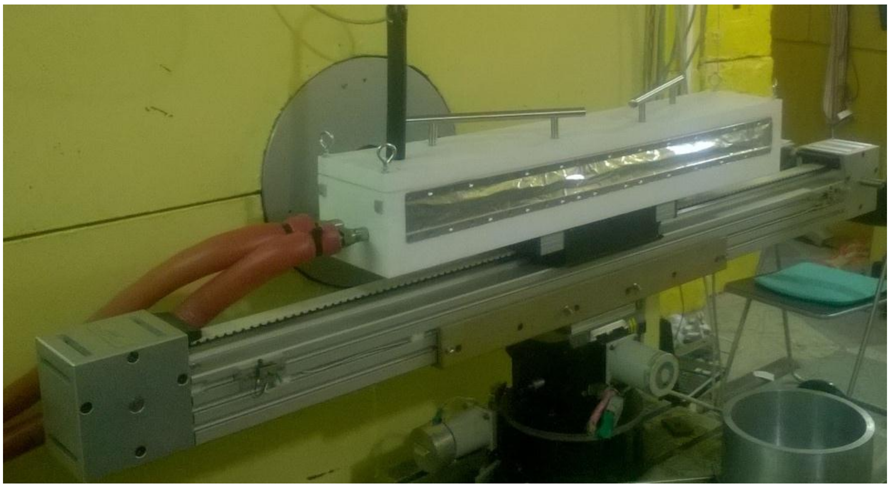

Fig. 6.2. Automatic sample changer for 25 samples at the YuMO spectrometer.

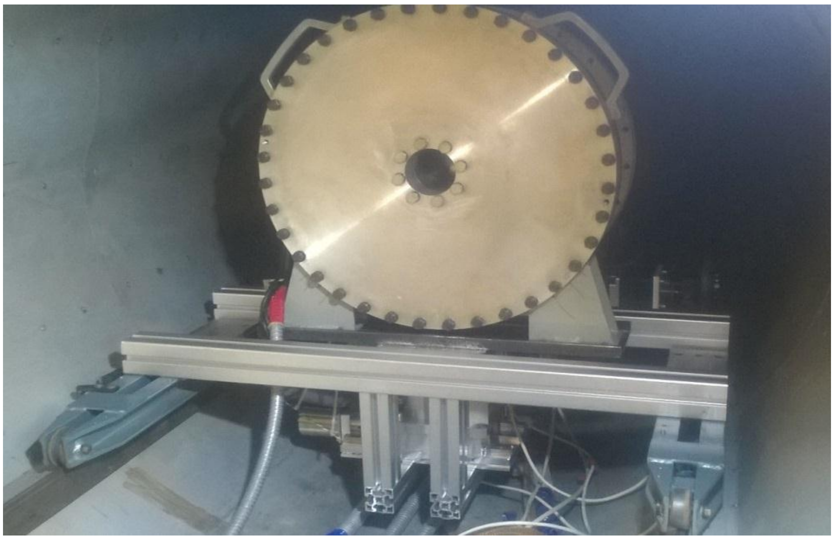

Fig. 6.3. Platform with a detector mounted on the position adjustment mechanism for moving in the horizontal and vertical directions.

Fig. 6.4. Huber goniometer of the FSS spectrometer.

6.2. Control systems for monitoring spectrometer parameters

On all spectrometers we have modernized the control systems for the parameters of the experimental setup, as well as communications with the controllers of individual parameters of the spectrometer. A unified communication panel of the spectrometer has been developed, which provides:

- connection of up to 5 devices via RS485 or RS232 interface;
- control over 4 relay signals on the status of the setup;
- connection of up to 10 devices via a USB interface;
- Galvanic isolation of computer and control devices.

Fiber-optic USB interface extension cable 30 m long allowed us to place the communication panel of the control system (**Fig. 6.5**) to an area close to the sample.

Fig. 6.5. Control system on the basis of AS4 (USB-RS485) and AC3-M (RS485-RS232) interface converters.

6.3. Temperature control systems.

When modernizing the temperature control systems of the sample, Eurotherm 902 and Euroterm 906 controllers were replaced with LakeShore 325 and LakeShore 336. The latter are oriented towards the use in cryogenic systems with DT670 sensors. For unification and software compatibility, however, when modernizing temperature control systems in the range of 0-1000°, we used the same controllers, but with K-type thermocouples.

Temperature control systems based on "LakeShore" controllers have been put into operation on FSD, HRFD, NERA-PR, RTD and REMUR spectrometers. Modernized temperature controllers with AC4 (USB-RS485) and AC3M (RS485-RS232) interface converters installed on the device housing are shown in **Fig. 6.6**. LakeShore 218 temperature controllers providing the collection of readings from 8 DT670 sensors and communication with PC via USB have been upgraded as well.

Fig. 6.6. LS325 controllers after modernization.

6.4. Control systems of spectrometer choppers

On the IBR-2 spectrometers the modernization of choppers and their control systems has been continued. In particular, a new drum-type chopper on the basis of 2.2 kW asynchronous motor with a standardized variable frequency drive VFAS1-4022 (**Fig. 6.7**) has been put into service on the REFLEX spectrometer.

A chopper opening sensor on the basis of a magnet and reed switch MKA-10110, which makes it possible to use it in the IBR-2 ring corridor, has been developed and installed. The accuracy of chopper phasing is +/– 150 μs.

Fig. 6.7. New drum-type chopper on the REFLEX spectrometer.

A control system of the Fourier-chopper on the FSS spectrometer has been assembled and a new control system of the Fourier-chopper (developed by the Hungarian company Mirratron) (**Fig. 6.8**) has been put into trial operation on the HRFD diffractometer.

Fig. 6.8. Fourier-chopper on HRFD diffractometer.

7. Software infrastructure

In the reporting period the development of the **software package Sonix+** was continued, in which a number of components were added at the request of users or further improved following the operating experience. Among the most important activities were the following:

- development of new components for controlling equipment of a number of spectrometers (RTD HRFD, REMUR, GRAINS, DN-6, FSD, FSS);
- supplementation of a basic set of widgets and improvement of programs of graphical user interface (**Fig. 7.1**);
- development of a new version of the command library for reflectometers, in which preliminary data processing is conducted simultaneously with the continuation of exposure (one of the examples is shown in **Fig. 7.2**).

A common (for all spectrometers) version of the user interface has been installed on the DN6 and DN12 spectrometers. A Sonix+ version for the FSS diffractometer has been prepared for practical testing.

An improved version of **WebSonix 4.7** (**Fig. 7.3**) for remote control over experiments, has been developed and put into operation. Eight spectrometers (YuMO, HRFD, FSD, SKAT, NERA-PR, EPSILON, DIN-2PI, REFLEX) have been connected to this service.

The **Journal program** has been debugged and put into trial operation on the GRAINS and HRFD spectrometers.

Programs for monitoring the state of the CM-201 cold moderator and a new graphical interface have been developed (**Fig. 7.4**).

The development of software tools for debugging and testing digital electronics for data acquisition systems has been continued.

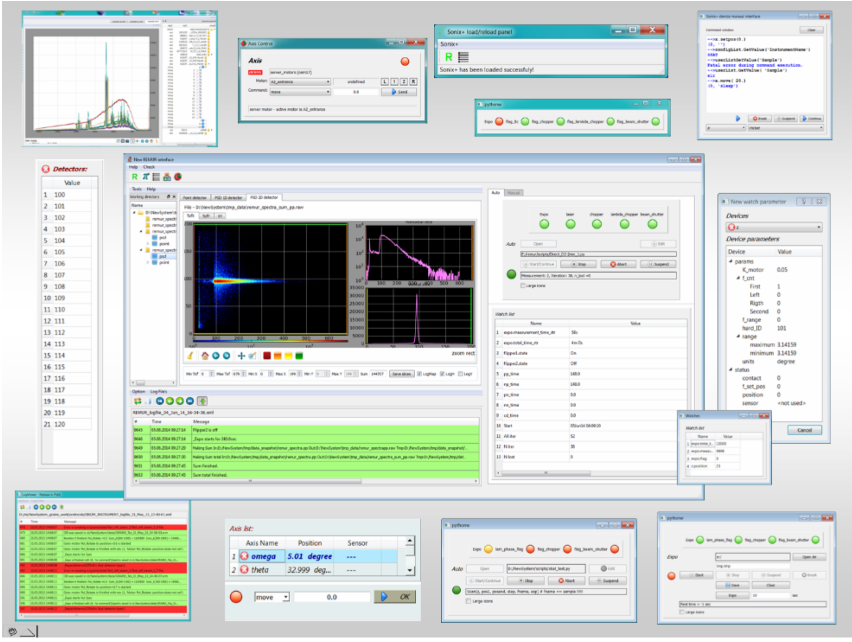

Fig. 7.1. Unified user interface of Sonix+ with a basic set of widgets.

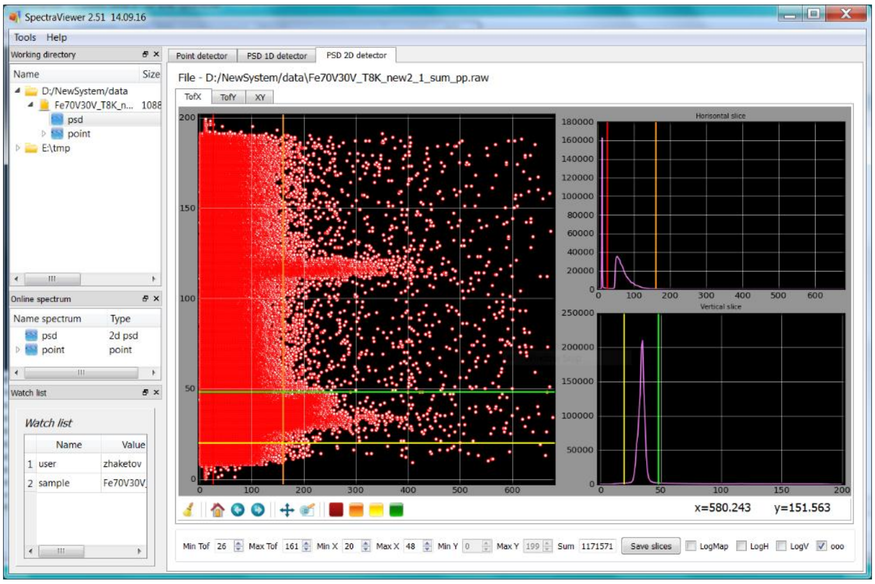

Fig. 7.2. New mode of *SpectraViewer* program to facilitate visual search of the reflected beam when tuning reflectometers.

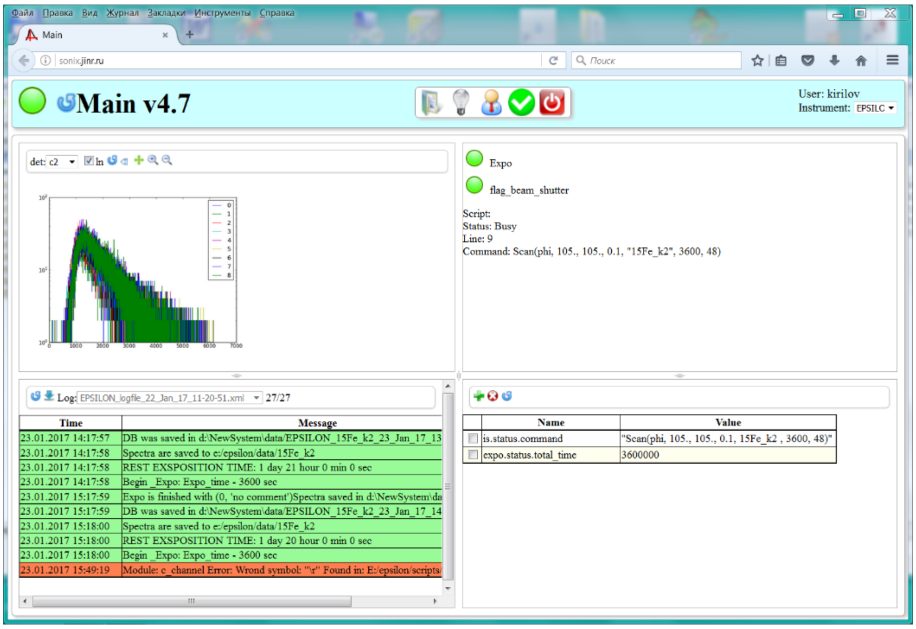

Fig. 7.3. Main window of the new version of WebSonix using the example of EPSILON spectrometer.

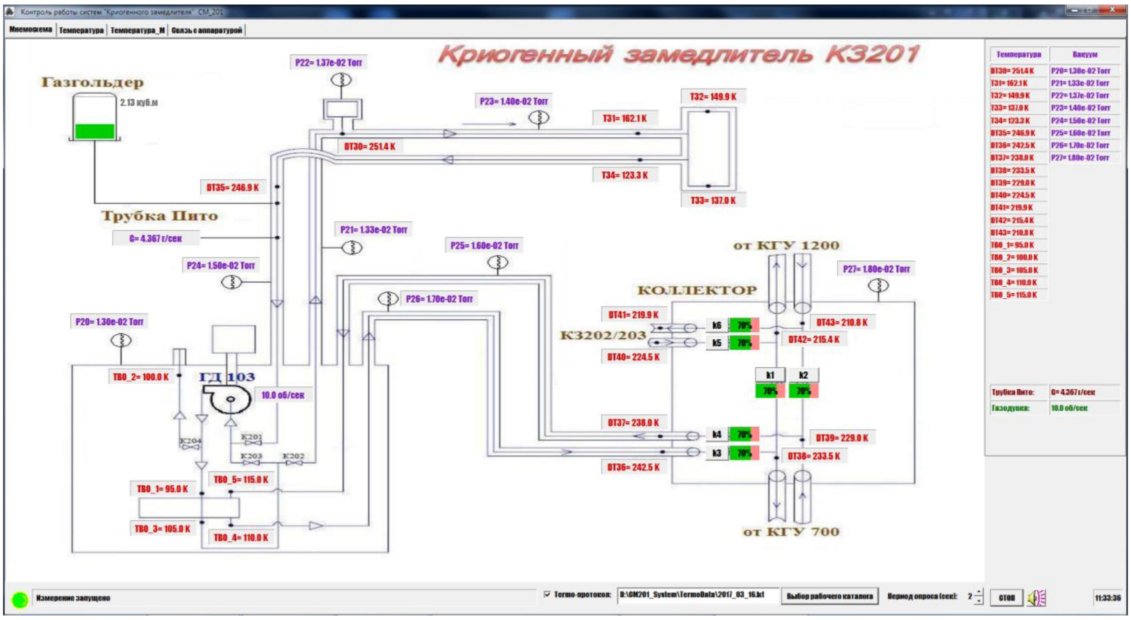

Fig. 7.4. New graphic interface for CM-201 cold moderator.

8. FLNP local area network

In the FLNP local area network the number of WiFi access points in buildings 42, 44 and 117 has been increased. The creation of access points in the IBR-2 reactor premises is technically difficult and has been temporarily postponed. The routers in the reactor control building and experimental hall №1 (building 117) have been upgraded to provide a data rate of 10 Gbit/s.

The outdated network switches in buildings 42 and 42a have been replaced to provide a data rate of 1 Gbit/s for all end users in the offices of physicists and Directorate of the Laboratory.

Until recently, physicists accumulated and stored experimental data on control computers of spectrometers. Data transmission to the central server of the Laboratory was performed by each user manually when required. At the same time there was always a risk of accidental erasure of data, network failure, losses in case of disk drive failure, etc. To eliminate these problems, a **centralized network data storage** was organized on the basis of a file-server Supermicro with two CPU Intel Xeon, 16 GB RAM and 72 TB disk memory (characteristics and description of the software of the server are given in the Annual Report 2014 and 2015). On the basis of the long-term trial operation of the centralized network data storage the following decisions were taken:

− freely distributed **CentOS 7**, which proved to be a fault-tolerant and high-performance OS, was selected as the operating system;

– server drives were combined into a RAID 6 array on the basis of SAS RAID controller, which makes it possible to tolerate the loss of up to 2 drives.

This storage system provides an automatic transfer of data from the control computer to the file-server during the experiment. The storage capacity is quite sufficient for recording and storing data from all IBR-2 spectrometers.

The installation of an FLNP LAN standby server *nfserv-d* (CPU: E5-2650 V3 (2×10 cores); 64 GB RAM; 12 TB disk space) has been completed, on which the Linux operating system is installed. The server has been put into trial operation and used for computational purposes, as well as for methodological studies to enhance the fault tolerance and operational efficiency of LAN servers.

The current configuration of the local area network is shown in **Fig. 8.1**, and **Fig. 8.2** presents a photo of the servers and communication equipment of the FLNP Central Computer Complex (CCC).

Preliminary processing of raw data. If the accumulation is conducted in the List-mode, the amount of data can reach several terabytes and their preliminary processing (for example, neutron time focusing, calculation of the cross-correlation function between the intensity of neutrons recorded by a detector and the sequence of delayed functions of modulation of the neutron flux from the pulsed reactor and chopper and reconstruction of high-resolution spectra from initial diffraction data collected on Fourier diffractometers) may take a long time (several hours).

To accelerate the process of data treatment, specialists of the NICM Department have developed a fast algorithm for calculating the cross-correlation function and programs for parallelizing calculations on several processors allowing a several-fold reduction of processing time. Another method to speed up the computation is the application of computing nodes with graphics processors (for example, graphics accelerator GPU NVIDIA can provide a 10-fold acceleration). Such parallel data processing can be organized within individual physics groups or on the central computing servers of FLNP, but we cannot provide their normal load, therefore it is reasonable to use the available computing resources of LIT: heterogeneous cluster "HybriLIT" (http://hybrilit.jinr.ru/) and cloud services (https://cloud.jinr.ru/).

Both of these resources can also be used for calculations and simulation, in particular, using the Monte Carlo method. The efficiency of their application will depend on whether it will be possible to parallelize calculations.

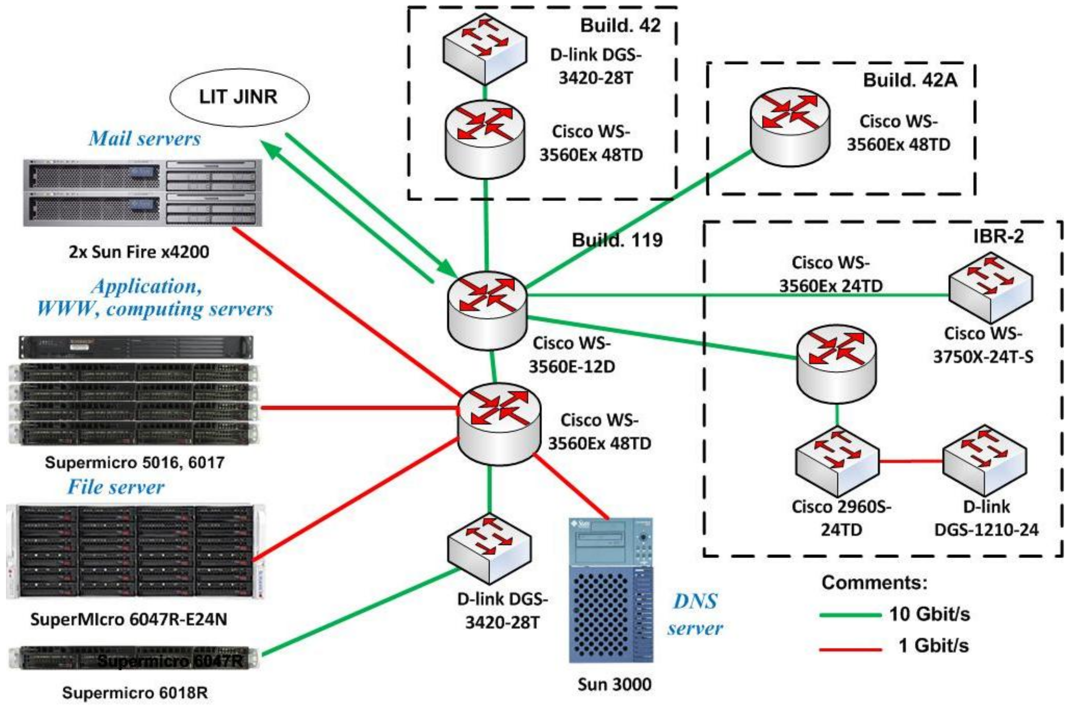

Fig. 8.1. FLNP local area network in 2017.

Fig. 8.2. FLNP central computer complex.

Thus, the main tasks set when theme 1122 was opened, have been successfully accomplished.

During the period from 01.01.2015 to 01.05.2017, 29 papers in specialized journals have been published and over 20 reports were presented at conferences and workshops.

Starting from 2010, the International School for Young Scientists and Students "**Instruments and Methods of Experimental Nuclear Physics. Electronics and Automatics of Experimental**

Facilities” has been held annually in Dubna. The main objectives of the school are to acquaint young scientists, undergraduate and graduate students with the current state of the art and recent trends in the development of the instrumental and methodological base for carrying out neutron experiments; to identify problems and trends in the development of the component and instrumentation base for the creation of modern experimental facilities; to present and discuss the possibilities of the Laboratory to organize the undergraduate training and preparation of diploma works, the conditions of admission to the post-graduate courses of the JINR University Center and the prospects for further employment at the FLNP within the topics and research areas covered by the School.

Group photo of the participants of the 7th School (November 7-11, 2016).

Series of studies "Development and construction of a pelletized cold neutron moderator at the IBR-2 reactor" and "Development of gas detectors for neutron investigations" carried out within the framework of theme 1122 won the second prize in the JINR competition in 2015 and 2016. Doctorate (Kulikov S.A.) and PhD (Bulavin M.V.) theses have been prepared and presented.

PART 2

SCIENTIFIC-TECHNICAL JUSTIFICATION FOR EXTENSION OF THE THEME “DEVELOPMENT OF EXPERIMENTAL FACILITIES FOR CONDENSED MATTER INVESTIGATIONS WITH BEAMS OF THE IBR-2 FACILITY” AND THE PROJECT “DEVELOPMENT OF PTH-SAMPLE ENVIRONMENT SYSTEM FOR THE DN-12 DIFFRACTOMETER AT THE IBR-2 FACILITY” FOR 2018-2020

Theme Code: 04-4-1122-2015/2020

Laboratory: Frank Laboratory of Neutron Physics

Division: Division of Condensed Matter Research and Developments (DCMRD)

Department: Department of Spectrometers Complex (DSC) IBR-2

Research Area: Condensed Matter Physics and Radiobiological Research (04)

Theme Title: "Development of Experimental Facilities for Condensed Matter Investigations with Beams of the IBR-2 Facility"

Leaders: S.A. Kulikov, V.I. Prikhodko

Brief annotation:

As we see from the report on the theme, during the period of 2015-2017 significant progress has been achieved in all the areas of methodical investigations and developments, as well as starts have been given for future plans - a key to the successful implementation of the development program of the IBR-2 spectrometers complex and conducting condensed matter investigations. All these research areas are included in the 7-year plan for the development of JINR for 2017-2023, accordingly **it's suggested to extend the current theme for the period of 2018-2020**.

A report upon the project "Development of PTH-sample environment system for the DN-12 diffractometer at the IBR-2 facility" has also been presented with a completion period in 2017, at the realization of which while carrying out pre-commissioning activities and testing operations of the magnet there has been found degradation of the high temperature superconducting tape YBCuO. This led to the necessity of decreasing current in the winding and to the corresponding reduction of the magnetic field which didn't allow to obtain project parameters on the critical current. At present negotiations are conducted with the supplier of the tape (Russian company "Superox") aimed at finding out the reasons for the tape degradation, replacing it and solving the encountered problems. Anyway, even if a firm recognizes a defect in the tape and agrees to its replacement, at least a year is needed for the supply of the tape, manufacture of new coils, installation, testing and other activities. In relation to this, **it's considered to be reasonable to extend the present project along with the theme.**

The staff of the department of Spectrometers complex IBR-2, taking part in the implementation of the work on the theme and the project, possesses high qualification and great experience of international cooperation. The personnel of the department in a number of 49 members is divided into 6 thematic groups which form the structure of the department. The members of the staff are: 17 researchers, 20 engineers and 12 laboratory assistants and workers, among them - 8 candidates of Sciences, 1 PhD and 14 employees possessing the status of junior researchers and specialists. Such staff structure is quite sufficient for the execution of tasks on the theme.

Improvement of measurement techniques, a rise in the number of controlled parameters, the increasing number and sophistication of the detectors and sample environment systems used in the experiments, higher requirements to the accuracy and operation speed of detecting equipment, the necessity of ensuring remote control over subsystems of spectrometers and experiments on the whole, demand continuous development for both the spectrometers, and the IBR-2 research nuclear facility (in particular, the complex of cold moderators).

The user-operation mode of the IBR-2 spectrometers sets out supplementary requirements towards the equipment of spectrometers, control systems, as well as to data acquisition systems: ease of mastering and use, convenient graphic interface, access to results of measurements via Internet and etc.

Fulfillment of these requirements is the main goal of the activities on the theme under completion in 2017 and still remains to be the key objective to its extension for the staff of the department of spectrometers' complex and IBR-2. The forthcoming work is the natural continuation of the activities executed in 2015-2017.

We are going to highlight some important features of the activities both carried out and upcoming:

- **Up to present time certain experiment on the operation of the cold moderator CM-202 has been tested** for the beams № 7, 8, 10, 11. **It's the first and unique moderator in the world** in which the moderating substance consists of solid mesitylene (the mixture of mesitylene and m-xylene) in a shape of pellets which are loaded into the moderator chamber under the action of a circulating flow of gaseous helium. **The CM-202 comprises** unique devices and developments, applied for the first time. Such devices may be considered: a bead-dispensing device, a helium-aided bead-feeding system, a helium consumption control system, a bead jam monitoring device. Development and construction of the bead-loading system as well as of the control system of the moderator for the beams №1, 4, 5, 6, 9 on the new moderator CM-201 appeared to be a more complicated task as it was needed to provide continuous lifting of pellets in the moderator chamber via helium flux to a height of 4 meters (angle of ascent - 50 degrees), yet this task is successfully realized. Activities in searching different ways for the extension of time needed for operations of the pelletized cold moderator on the physical experiment have already been started and are to be continued. Thus, for example, triphenylmethane is investigated and a comparison is drawn between it and the substance used at present – the mixture of mesityelne and m-xylene. As it has been stated, the radiation resistance of the triphenylmethane is ~ 10 times better than that of the mixture. The study of cold neutron yielding from the triphenylmethane (possibly, from other materials, too) at various temperatures and the comparison of the results with the mixture will be continued in the framework of the extended theme.

The forthcoming development and creation of an off-loading facility of a screw-type for the moderator CM-201 can be noted as well which will allow to carry out uninterrupted shift of the moderating substance in the moderator chamber.

Installation of the cryogenic moderators complex at the IBR-2 reactor will allow a considerable reduction in time spent on a wide range of experiments by means of advanced yield of cold neutrons from the moderator surface and will ensure the IBR-2 reactor to maintain and strengthen its leading position among neutron sources in the field of condensed matter physics in the nearest future.

- The main tasks in the creation of new data acquisition and atomization systems for neutron spectrometers are reliability, cost, time of the development and putting into operation as well as the possibility of fast adaptation of systems to any changes in the demands of the experiment. Adaptability possesses a principal sense, for it provides with quite enough flexibility for the fulfillment of requirements for future experiments.

In the multilevel architecture of the data acquisition system (DAS) it's only software to be taken under modification relatively with ease. Practically it means that the digital processing of signals should be started as soon as possible. Just such an approach was applied by us for the creation and implementation of the previous generation of DAS (on the basis of VME standard) and the new generation of electronical modules, which are directly connected to PC and possess flexibility for fast adaptation to any kind of changes in experimental conditions and to an increase in the number of spectrometer devices. The chosen architecture of these systems fits well into the network infrastructure and ensures ease and low cost of their continuous modernization in accordance with the progress in the computer engineering and communication technologies.

At present data acquisition systems of all the IBR-2 spectrometers consist of 1-2 basic electronic modules, one of which - De-Li-DAQ processes and accumulates data from one- and two-dimensional PSD, and the other – MPD – from an array of point detectors (gaseous and scintillation counters). From the viewpoint of hardware the basic modules are identical; the task of all parameters, operation modes and algorithms, specific to a certain spectrometer is realized on the level of microprograms which are stored and executed in programming logical matrixes (FPGA) of the respective module. All these data are stored in a general configuration file of the spectrometer computer and are recorded by a control program in FPGA at initialization. The new DAS-systems make possible to operate both in the histogram and the **raw data accumulation** modes which in some cases is of principal importance.

It should be noted that the manufacture technology of modern electronic units is rather complicated and requires expensive equipment which is paid for only at serial production. For this reason we study the possibility of applying multi-level digitizers starting up at the market in the DAS-system on the IBR-2 spectrometers for data acquisition from 1D and 2D PSD which is one of the main tasks of the extended theme. One of the main goals of the operations in this field of study is the acquisition of harmonious combination of computer engineering and measurement technology.

- In the experiments on the IBR-2 reactor a kind of special equipment is widely used for creating certain conditions on the sample (for example, temperature, the pressure of magnetic or electric field and etc.), for moving and spatially orienting samples, as well as for changing them. Within the framework of theme 1122 significant progress is achieved in providing the IBR-2 spectrometers with such equipment, in its standardization as well as in the unification of the control systems. An important feature of the new systems is that they all are constructed in a single unified system; control systems are realized as an independent module, connected to PC via USB interface; all the basic elements of the systems (sensors, engines, positioning main controllers, temperature controllers and etc.) and their interfaces are unified. Therewith, industrial equipment is used wherever possible. With the aim of effective use of expensive equipment when designing sample environment systems, detector systems and etc. efforts will be focused on the possible application of such systems on several spectrometers.
- The works in the framework of the project **“Development of PTH-sample environment system for the DN-12 diffractometer at the IBR-2 facility”** aimed at the construction of cryostat with a varied temperature in a range of (300-4) K and magnet filed (up to 4T) are of particular importance which will allow essentially widening the range of tasks carried out on this diffractometer.

As a conclusion, a few words should be said about the **competitiveness** of the activities on the proposed extended theme. The work on cryogenic moderators is a pioneer project and, of course, is beyond competition. The designing of cryostats and detector systems with electronics and software conform to world class level, evidenced by the won tenders for their delivery to NPI (Řež, the Czech Republic), as well as their application in SRINS (Daejeon, the Republic of Korea); HZB (Berlin, Germany) and in several RF organizations.

Projects on theme:

1. Project **“Development of PTH-sample environment system for the DN-12 diffractometer at the IBR-2 facility” is suggested to be extended** for 2018-2020. Manufacture of new windings and assembling of magnet, installation of the equipment, testing operations, implementation of preparatory works for IBR-2 beamline №12 and putting into operation of the combined horizontal-vertical cryostat with superconducting magnet for the DN-12 diffractometer are planned for this period.

2. Project **“Development of a wide-aperture backscattering detector (BSD) for the HRFD diffractometer”,** leader of the project **– V.V. Kruglov,** the period of execution – **2018-2020.**

The activities will be carried out in accordance with the plan-schedule of the project.

Workplans for 2018-2020:

The main tasks of the theme are development in cooperation with DNICM methods of neutron investigations of condensed matter, as well as the improvement of technical features and the enhancement of experimental capabilities of the current and newly constructed spectrometers of the IBR-2 reactor in accordance with the 7-year plan for the development of JINR. Activities will be carried out in the following basic fields of study:

1. Cold moderators:

1.1 Development and construction of the control and automation systems of the moderator CM-201 for IBR-2 beamlines № 1, 4, 5, 6, 9. Carrying out trial loading of the moderator chamber CM-201 without power and at the IBR-2 reactor power. Routine modernization and maintenance of the equipment of the moderator CM-202 complex system.
1.2 Study of the radiation resistance and the moderating features of hydrogen-containing materials of the cold moderator for extending the time of operation on the physical experiment.
1.3 Development and study of the working conditions of the auger-type off-loading facility for the moderator CM-201.
1.4 Study of the radiation resistance of materials on the facility for radiation research.

2. Calculations and simulation of spectrometers:

Development and application of the VITESS and other software packages for simulation of neutron scattering in samples and separate components of spectrometers. Complex calculations and optimization of spectrometers.

3. Cryogenics:

3.1. Development of continuous-flow cryostats on the basis of closed cycle cryocoolers for experiments on the IBR-2 reactor. Development of the current cryogenic stand and its adaptation for development, manufacture and adjustment of the continuous-flow cryostats’ elements.

3.2. Manufacture of new tapings and installation of superconducting magnet for the DN-12 diffractometer. Testing of the combined horizontal-vertical cryostat with superconducting magnet on the DN-12 diffractometer and putting it into operation

3.3 Development and implementation of new equipment as well as support of the current cryogenic and vacuum equipment on the IBR-2 spectrometers.

4. Detectors and electronics:

4.1 Completion of the manufacturing activities on “Astra-M” detector system at the FSD spectrometer and putting it into operation in 2018. Modernization of the NERA-PR spectrometer detector system.

4.2. Development and manufacturing of the back-scattering detector units at the HRFD diffractometer in accordance with the plan-schedule of the BSD project.

4.3 Development and manufacturing of the multi-detector system units for the DN-12 diffractometer and development of a new data acquisition and accumulation system from multilevel systems on the basis of PSD.

4.4 Developments of the prototype of small-angle detector measurements, spectrometer detectors of fast neutrons, monitor of the IBR-2 reactor beams and detectors on the basis of boric-converter.

4.5 Equipping of all detector systems with current electronics MPD and DE-Li-DAQ, shown in 4.1-4.4, and development of the infrastructure for creation of neutron detectors.

5. Control systems of actuators, sample environment equipment and spectrometer choppers:

5.1 Further activities on the development of control systems for actuators:

- modernization of actuators on the YuMO and REFLEX spectrometers;
- putting new mechanisms into the structure of spectrometers at the request of users;
- equipping of the REMUR spectrometer with position sensors.

5.2 Improvement of control systems for physical instruments and temperature regulation systems:

- change of temperature controllers Eurotherm on Lakeshore;
- putting into new measurement devices and controllers upon the requests of the persons responsible for the facility;
- unification of amplifiers used in the temperature regulation systems.

5.3 Modernization of control systems for choppers on the beams № 11 and 13.

6. Software:

6.1 Maintenance and development of the software package Sonix+ at the request of users.

6.2 Development of concept of central storage organization of measurement results on the IBR-2 reactor and its implementation, putting the storage into operation.

7. Local area network:

7.1 Development of the FLNP network infrastructure in accordance with the development strategy of the JINR computer network.
7.2 Modernization of the FLNP CNC power supply system.

In 2018-2020 joint activities on the construction of new spectrometers and the current modernization of existing devices with the Department of NICM will be in process. These operations will be carried out both according to the previously agreed working plans and to the technical tasks of the physical groups.

Projects on theme:

Project	Leader	Status (realization period)
1. Development of PTH-sample environment system for the DN-12 diffractometer at the IBR-2 facility	A.N. Chernikov	1 (2015-2020)
2. Development of a wide-aperture backscattering detector (BSD) for the HRFD diffractometer	V.V. Kruglov	1 (2018-2020)

List of activities:

Activity or experiment: Laboratory or other divisions of JINR	Leaders / Main researchers	Status
1. Construction and putting into operation of the control system of the moderator CM-201 for IBR-2 neutron beamlines № 1, 4, 5, 6, 9	**S.A. Kulikov** **E.P. Shabalin**	Realization 2018-2020
FLNP	M.V. Bulavin + 5 engineers, A.S. Kirilov + 1 engineer, A.P. Sirotin + 2 engineers, K.A. Mukhin	
2. Calculations and simulation of	**A.V. Belushkin**	

the spectrometers' elements. Development of the VITESS software package.		Realization 2018-2020
FLNP	S.A. Manoshin, S.A. Kulikov + 1 engineer	
3. Study of the radiation resistance of materials and electronic components.	**M.V. Bulavin** **S.A. Kulikov**	Realization 2018-2020
FLNP	E.P. Shabalin+ 4 engineers	
4. Test operations of a combined horizontal-vertical cryostat with superconducting magnet for the DN-12 diffractometer. Development and modernization of the cryostats on the IBR-2 spectrometers.	**A.N. Chernikov** **S.E. Kichanov**	Realization 2018-2020
FLNP	E.V. Lukin, N.A. Kovalenko + 2 engineers	
5. Development of continuous-flow cryostats on the basis of closed cycle cryocoolers.	**A.N. Chernikov**	Realization 2018-2020
FLNP	N.A. Kovalenko + 2 engineers	
6. Development and implementation of gas-filled and scintillation detector systems at the IBR-2 spectrometers.	**A.V. Churakov** **V.V. Kruglov**	Realization 2018-2020

FLNP

V.M. Milkov+ 3 engineers,

A.A. Bogdzel + 4 engineers,

V.V. Zhuravlev + 3 engineers,

A.S. Kirilov + 1 engineer

7. Development of data acquisition, control and experiments automation systems, as well as of the software package Sonix+ at the IBR-2 spectrometers.

V.I. Prikhodko

A.P. Sirotin

A.S. Kirilov

Realization

2018-2020

FLNP

A.A. Bogdzel + 4 engineers,

V.V. Zhuravlev + 3 engineers,

N.D. Zernin + 1 engineer,

S.M. Murashkevich + 2 engineers

8. Development of the FLNP network infrastructure in accordance with the development strategy of the JINR computer network.

V.I. Prikhodko

Realization

2018-2020

FLNP

G.A. Sukhomlinov + 2 engineers,

A.S. Kirilov + 2 engineers,

S.A. Manoshin + 1 engineer

LIT

V.V. Korenkov + 2 engineers

Expected results upon the completion of the theme:

1. Development and construction of the control system of the moderator CM-201. Start-up and adjustment of CM-201 after the completion of installation. Carrying out of trial loading of the moderator chamber. Maintenance and routine modernization of the CM-202 cold moderator with control systems. Carrying out of experiments on the study of materials for cold moderators.
2. Study of the radiation resistance of materials and electronic components on the irradiation facility of the beam №3 on the IBR-2 reactor.
3. Development and application of VITESS and other software packages for simulation of neutron scattering in samples and separate components of spectrometers. Complex calculations and optimization of spectrometers.
4. Development of neutron detectors (including with non-helium converters), detector electronics and data acquisition and accumulation systems for equipping of the IBR-2 spectrometers.
5. Development of continuous-flow cryostats on the basis of closed cycle cryocoolers. Testing of the combined horizontal-vertical cryostat with a superconducting magnet and a changing temperature with a range of 4-300K on the DN-12 diffractometer and putting the cryostat into operation. Development and modernization of cryostats on the IBR-2 spectrometers.
6. Development of control systems of actuating mechanisms, of sample environment equipment and spectrometer choppers.
7. Improvement of the IBR-2 spectrometers software. Development of the FLNP network and computing infrastructure in accordance with the demands of the Laboratory and the development strategy of the JINR computer network.

Expected results in 2018:

1. Development and testing of the control system of the moderator CM-201 for the beamlines № 1, 4, 6-9; carrying out of trial loading of the moderator chamber without the reactor power. Current modernization and operations of CM-202. Regular application of the device for nitrogen-free charging of pellets and the diaphragm for the measurement of gas flow on the CM-201 and CM-202 moderators. Investigation of neutron-physical features of the alternate materials of the cold moderator aimed at extending the period of its activities on the physical experiment. Construction and testing of an auger-type device for unloading pellets for the CM-201 moderator on the laboratory stand, as well as conducting tests upon it on a full-scale testing stand.
2. Study of radiation resistance of materials on a device for radiation research.
3. Development of new programs for simulation of full reflectometry experiments in kinematic approximation.
4. Execution of the work on manufacturing the “Astra-M” detector system and putting it into operation on the FSD diffractometer. Development of the technical project of the back-scattering detector for the HRFD diffractometer. Development of the project of the detecting module and data accumulation system for the multi-detector system of the DN-12 spectrometer, testing of elements for the accumulation system on the neutron beamline. Development of the detecting module prototype with analogous electronics for modernization

of NERA-PR spectrometer detector system. Development of the infrastructure for the creation of neutron detectors.

5. Development of the technical project of continuous-flow cryostat with Helium-4 circulation by the frozen closed-cycle cryocoolers for supplying temperature with a range of below 2K, selection and purchase of equipment and complementary articles. Manufacture of new windings and assembling of the superconducting magnet for the DN-12 diffractometer.
6. Modernization of control systems with the actuators of REFLEX and GRAINS spectrometers.
7. Maintenance and development of the Sonix+ software package at the request of users, adaptation of the Sonix+ for the work with DAQ-controllers on the basis of USB-3. Development of the conception for the central data storage with regard to FLNP specifics.

Collaboration:

Country or International Organization	City	Institute or Laboratory
Bulgaria	Sofia	INRNE BAS
Belarus	Minsk	BSTU
Russia	Moscow	NNRU “MEPhI”
	Moscow	NRC KI
	Moscow, Troitsk	INR RAS
	Gatchina	PNPI
	Yekaterinburg	IMP UB RAS
	Dubna	University “Dubna”
Romania	Bucharest	INCDIE ICPE-

		CA
Ukraine	L’viv	LPNU
Czech Republic	Rez	NPI ASCR
Argenitina	Bariloche	CAB
Great Britain	Didcot	RAL
Hungary	Budapest	Wigner RCP
Germany	Berlin	HZB
	Julich	FZJ
Republic of Korea	Daejeon	NFRI
Sweden	Lund	ESS ERIC
Switzerland	Villigen	PSI

RSA	Pretoria	NECSA

Implementation deadlines:

Activities in the framework of the theme will be executed in 2018-2020 in accordance with the topical plans of research activities carried out each year and with the international cooperation of JINR. The full funding of the theme upon the economic budget items, corresponding to the scheduled figures of the 7-year plan for the development of JINR for 2017-2023, is shown in Table 1.

Table 1

Activities	Cost of operations, kUSD		
	2018	2019	2020
Development of the control system for neutron cold moderators and actuators	250	255	220
Development of detectors, sample environment systems, cryogenic equipment, data acquisition and accumulation systems; development of the FLNP computing infrastructure	1120	1215	1360
Total:	**1370**	**1470**	**1580**

Other financial sources:

Grants of the plenipotentiaries of JINR member-countries (Romania, Belarus, the Czech Republic), contract with MAGATE.