1.3. NOVEL DEVELOPMENT AND CONSTRUCTION OF EQUIPMENT FOR THE SPECTROMETER COMPLEX of the IBR-2 FACILITY

In 2013, work in the framework of the theme was focused on several activities connected with the construction and modernization of the equipment, electronic data acquisition and accumulation systems as well as the information-computation infrastructure of the IBR-2 spectrometer complex.

Cryogenic moderator.

In January, 2013 during the last and longest operation cycle of the moderator at a reactor power of 2 MW the research activities were carried out in the framework of the CM-202 commissioning program. All in all, during the start-up period there was five CM operation cycles with fresh loadings of beads composed of a frozen mixture of mesitylene and m-xylene with the duration of the cycles ranging from several hours to 178 hours (the reactor operated for up to 350 MW-hr).

As a result of the analysis of the CM-202 operation in the specified cycles the key questions, which are important for ensuring efficient and long-term operation of the moderator were answered:

- Time of loading beads into the moderator chamber – minimum 4 hours (according to the design 8-10 hours are allowable). Loading proceeds without jams and noticeable defragmentation of beads at a gas flow rate of 1.2-1.5 g/s and a temperature of 80-85 K.
- Hydraulic resistance of the contour and parameters of a gas blower ensure a helium flow rate of 6 g/s (design value is 7 g/s).
- A KGU-700/15 cryogenic refrigerator cools beads in the CM-202 chamber at a reactor power of 2 MW down to an average temperature of 32-33 K (design value is 23-25 K).
- Gain factor for cold neutrons with wavelengths of 8-10 Å is 13-14 (**Fig. 41**) design value is up to 20 at 20 K. Degradation in the cold neutron (6-10 Å) flux for 350 MW-hr is no more than 5-7%; the flux of neutrons with shorter wavelengths increases with a radiation dose.
- Discharge of the spent liquid proceeds rather quickly; the initial solution viscosity increases no more than 10 times after operating for 7.3 days (**Fig. 42**).
- Filling of the chamber and subsequent discharge of mesitylene have no effect on the reactivity of the IBR-2 reactor.

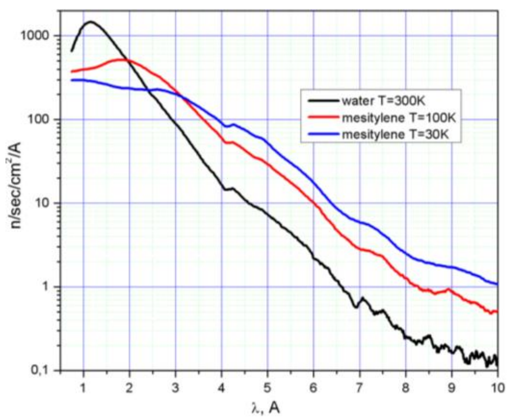

Fig. 41. The differential neutron flux density at the location of a PSD detector for an empty chamber (black line) and for the filled one at temperatures of 100 K and 30 K (left).

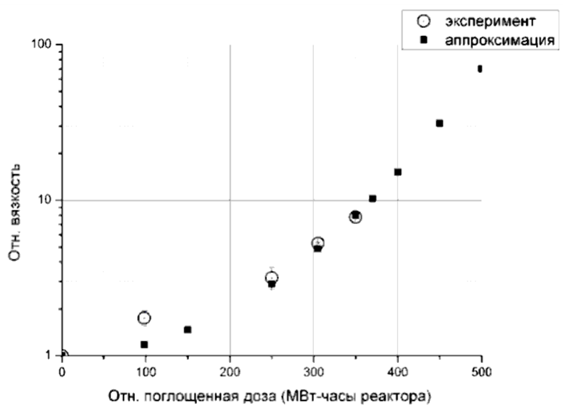

Fig. 42. A change in liquid mixture relative viscosity against a relative radiation absorbed dose (reactor MW-hr), where: circle – experiment, square – approximation (right).

Over the past year the main technological systems of the cryogenic moderator have been fully developed and modernized. In all IBR-2 cycles in a cold moderator mode for physics experiments the

CM-202 has demonstrated stable and trouble-free operation. The moderator control system allows the technicians to control the moderator key parameters (fan shaft rotation speed (gas blower), helium flow rate and temperature, vacuum in pipelines, movement of beads when loading the pipeline) during operation. The characteristics of CM-202 monitoring instruments meet in general the design requirements and make it possible to ensure the operation and maintenance of the moderator in a regular mode. A report on the start-up of CM-202 and its commissioning documentation have been prepared.

We have developed a program and started experiments on irradiation of both the spent liquid and fresh liquid solutions of mesitylene and m-xylene doped with inhibitors of radiolysis of aromatic hydrocarbons on beam 3 of IBR-2. First experiments have showed that the addition of inhibitors may increase the cycle duration up to 9-9.5 days on one loading. These results should be verified for a solid phase of the solution. These investigations are conducted in cooperation with the Chemical Faculty of the Moscow State University.

The design of a cryogenic test stand to study loading, transport and discharging of beads has begun for CM-201—a future cold moderator in the direction of beams 4-6.

Calculation and simulation of spectrometers.

In 2013, special VITESS modules that allow simulation and calculation of neutron time focusing for time-of-flight spectrometers on pulsed neutron sources continued to be improved. Here, the time focusing surface may be approximated by a plane/planes, cylinder/cylinders and sphere/spheres. For the FSD spectrometer the simulation of the ASTRA detector (7 surfaces, **Fig. 43**) with time focusing was performed. The simulation was done for ideal and approximated (modification of a cylindrical surface) time-focusing surfaces. The comparison of the obtained results shows practically no shift in the position of both diffraction peaks. However, a small broadening of the diffraction peak for the approximated surface can be observed. **Figure 44** illustrates an example of simulation of the 4th time-focusing surface of the ASTRA detector (covered angles– 89.0-84.031 degrees; sample dimensions – 0.1 mm × 0.1 mm; d-spacing of Bragg scatterer – 10 Å). All other surfaces of the detector yield similar results. An experimental check showed that the suggested approximation of time-focusing surfaces is feasible for practical realization.

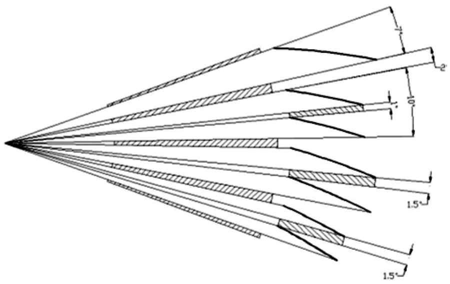

Fig. 43. ASTRA detector in a horizontal plane

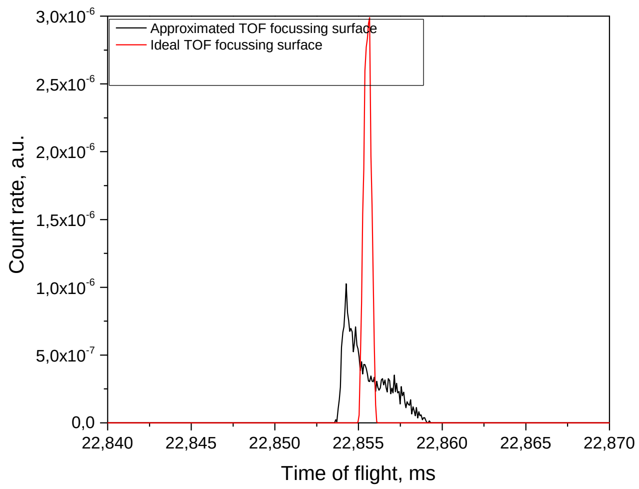

Fig. 44. Example of simulation of the 4th surface.

Using the VITESS software the Monte Carlo calculations have been performed for the project of a new neutron guide for the REFLEX spectrometer with a total length of about 30 m, 1 cm wide and 8 cm high. A special feature of this neutron guide is its small width (1 cm) and considerable height (8 cm). The neutron guide will have a curved part (about 16 m), which will make it possible to reduce the fast-neutron and gamma-ray background at a sample position, and a straight part that will ensure uniform irradiation of samples. The neutron guide is planned to be coated with ^{58}Ni.

In the middle of 2013 we started work on the application of the Reverse Monte Carlo (RMC) method to reconstruct a 3D structure of glasses (or other disordered systems) using neutron diffraction data. An RMC_POT program was used in the calculations. Also, a special program was developed, which allows one to determine coordination of glass atoms using Voronoi networks. This program reads the data obtained by means of the RMC_POT program, and calculates coordination numbers. In particular, for a three-element system FeYB nine coordination numbers are determined. If necessary, two options can be used in the calculations, namely: to build a Voronoi network with regard for ionic radii of particles and to discard the particles for which the Voronoi surface area is less than a specified level. An example of a reconstructed 3D structure from diffraction data for FeYB glass with the help of the RMC_POT program is given in **Fig. 45**.

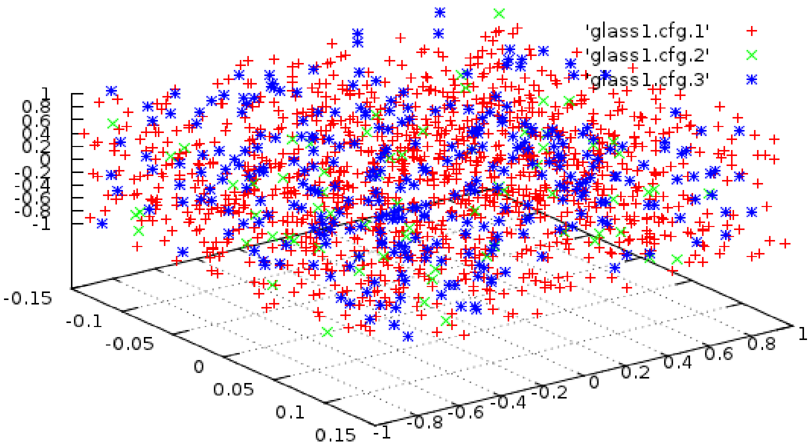

Fig. 45. Example of a reconstructed structure of FeYB glass (Fe atoms – red, Y atoms – green, B atoms – blue).

Development and production of equipment for new and modernized spectrometers.

The work continued on the construction of a new high-resolution Fourier diffractometer on beam 13 of the IBR-2 reactor on the basis of the units of the FSS spectrometer (Fourier Stress Spectrometer), which had been used for a long time in the GKSS Research Centre (Geesthacht, Germany). In accordance with a concluded contract with PNPI the FSS spectrometer equipment packaged in containers has been transported to Dubna. At present, the equipment is being checked and a design study of its layout and installation on IBR-2 beam 13 is in progress. On the same beam the infrastructure for testing spectrometer equipment is under construction.

Fig. 46. Ring-shaped helium backscattering detector on the RTD diffractometer.

A ring-shaped helium backscattering detector along with 8-channel analog electronics and multichannel data accumulation electronics (MPD) has been developed and produced for the **RTD diffractometer** (DN-2) intended for real time studies of transient processes. The detector system has been adjusted and tested at a test stand, and then installed on IBR-2 beam 6a (**Fig. 46**) where the first stage of tests has been carried out. After the background shielding is manufactured and installed, physical characteristics of the detector will be measured and it will be put into service in a regular mode. A 2D position-sensitive detector on RTD operates with a PC-built-in data acquisition and accumulation electronics module De-Li-DAQ1. In the near future it will be replaced with a NIM-standard De-Li-DAQ2 module with a count rate of up to 10^6 events/s.

An adjustable neutron beam diaphragm capable of linear movement along horizontal and vertical axes has been developed and manufactured (**Fig. 47**). It is mounted on an exit flange of the RTD neutron guide. The diaphragm dimensions are 20×105 mm^2; 1.1-mm-thick pyrolytic boron nitride is used as a neutron absorption material. FL57STH51 stepper motors are employed to control the diaphragm; a four-channel control unit of the motors is connected through a CAN/USB converter to a control computer.

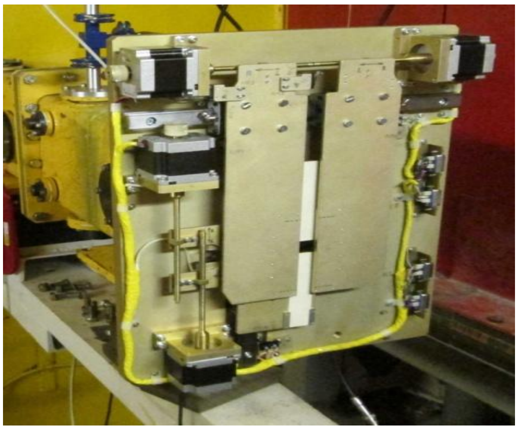

Fig. 47. Adjustable neutron beam diaphragm for the RTD diffractometer.

The modernization of the detector system, which consists of two detector rings each comprising 16 gas detectors has been completed for the DN-12 diffractometer for investigations of micro-samples at high pressures. New detectors SNM-31 are installed in collimators and are in a common protective housing. Each detector has its independent output, which is connected to a separate preamplifier input. New detector and control electronics provide amplification and selection of signals, as well as control (from a computer) over detection thresholds and high voltage on the counters. Data acquisition and accumulation are performed by a 32-channel MPD electronic unit developed in FLNP. The software of DN-12 is similar to that of the DN-6 diffractometer.

The analog electronics of two ring-shaped 8-channel detectors of the YuMO small-angle neutron scattering spectrometer have been completely replaced. The detectors have been tested at the test stand and put into operation. A new MPD-32-based data accumulation system has been introduced.

Modernization of sample environment and control systems on IBR-2 spectrometers. Cryogenics.

At present, sample environment and control systems have been modernized on 10 spectrometers out of 13. Key features of the new systems are:

- development of all systems according to a unified scheme;
- spectrometer control systems are realized as an independent module connected to a PC through a USB interface;
- control system can be brought to a sample via an optical USB extender;
- unification of the system basic elements (sensors, motors, movement controllers, temperature controllers, etc.) and their interfaces;
- focus on the use of industrial equipment.

As an example a block diagram of the YuMO spectrometer control system after modernization is given in **Fig. 48**.

In 2013 using the same scheme the automation systems for the ***Fourier diffractometers***: ***HRFD*** (6 control channels) and ***FSD*** (12 channels) were modernized, and a new system was developed and constructed for the ***GRAINS*** spectrometer (26 channels). A 19-inch crate 3U high with stepper motor controllers (their number is equal to the number of control channels) is placed near a sample. A USB-RS485 OWEN AC4 adapter for communication between PC and stepper motor controllers is accommodated in a similar crate near PC. Each controller has its own address in RS485 line. A simultaneous movement of stepper motors can be specified by a control program and this option is limited only by the power source used.

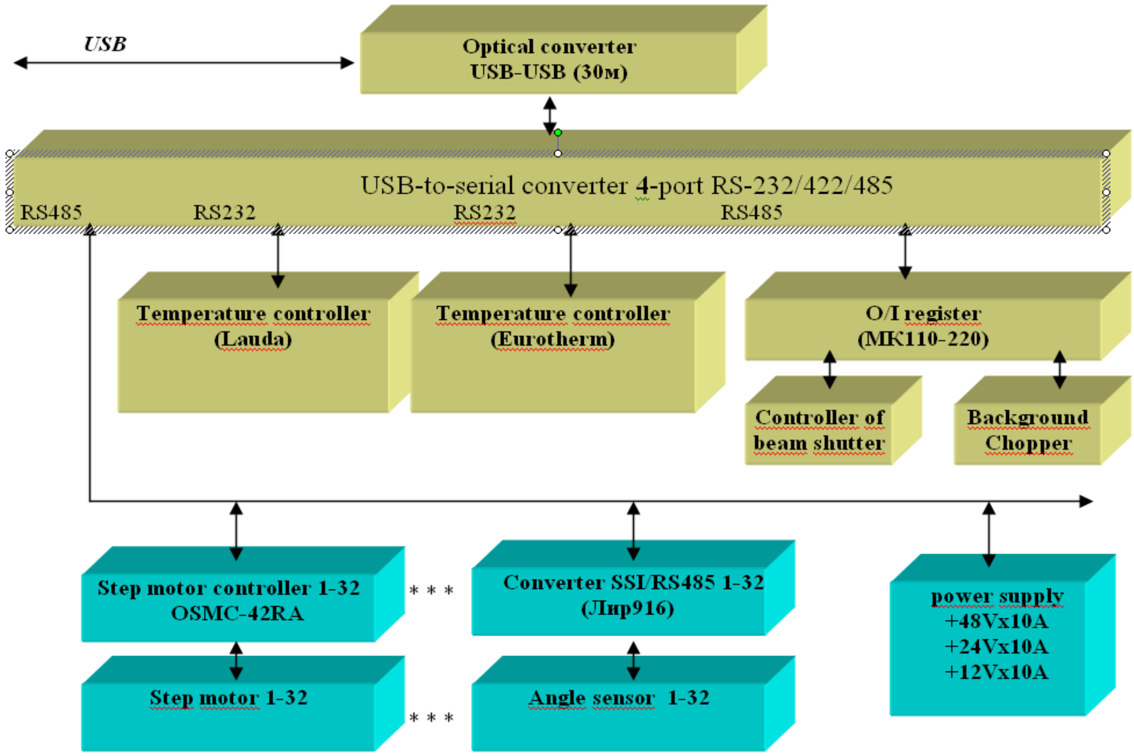

Fig. **48**. Block diagram of the YuMO spectrometer control system.

A set of remote terminal units controls the state of a shutter and beam chopper and using OSM-42RA-3U controllers operates goniometers and Huber scanners (**Fig. 49**), diaphragms, polarizers, collimators and other devices. Up to 8 devices of this kind can be connected using RS 232/422/485 interfaces.

A new 6-position sample-changing device is now available at the HRFD spectrometer.

A **horizontal cryostat** for cooling high-pressure cells with a sample (**Fig. 50**) has been developed, manufactured and installed at the DN-6 diffractometer. A minimum temperature of 4 K was achieved on the sample cell.

Fig. 49. Goniometer and Huber scanner at the FSD diffractometer.

Fig. 50. Horizontal cryostat for the DN-6 diffractometer.

On the NERA spectrometer the modernization of a shaft cryostat is in progress.

Detectors.

A test scintillation detector on the basis of an ND screen with wavelength-shifting fiber readout has been developed and manufactured. Its characteristics have been studied on beam 9 of the IBR-2 reactor and a time-of-flight neutron spectrum has been obtained (**Fig. 51**).

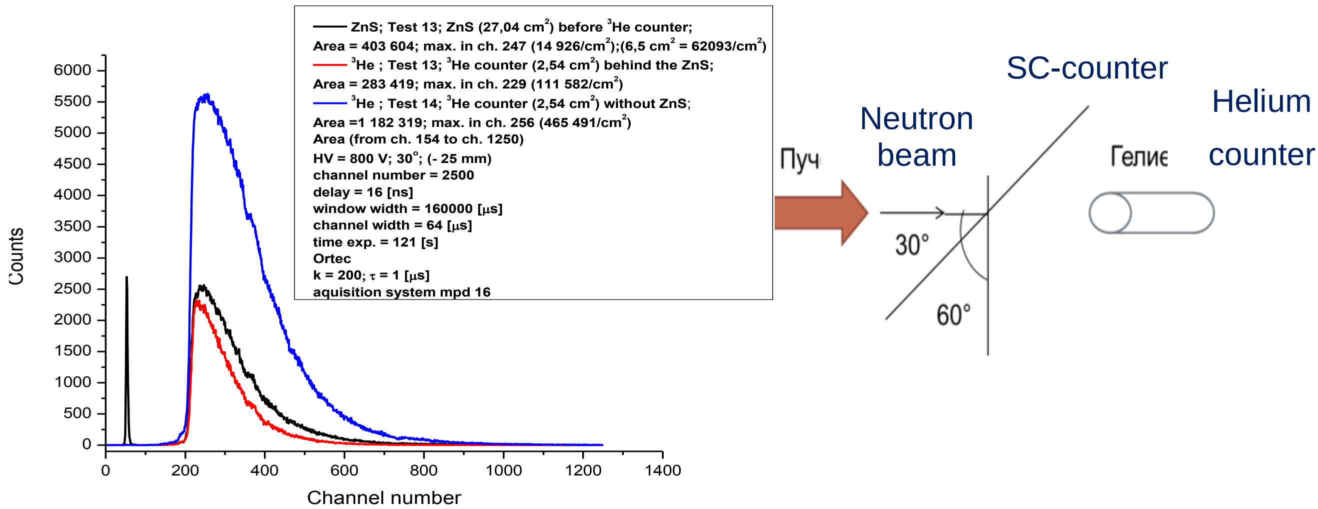

Fig. 51. Time-of-flight neutron spectrum of the test ND-screen-based detector. Spectrum from the test detector is in black, from an SNM-17 counter placed in front of the detector – in blue and from an SNM-17 counter immediately behind the detector – in red. Time channel width is 64 μs. The detector is installed at an angle of 30 degrees to a neutron beam.

In the 2nd quarter of 2013 a prototype of a scintillation counter of the ASTRA detector for the FSD diffractometer was manufactured and tested at a test stand with a source. During the autumn IBR-2 operation cycles we carried out comparison tests of "new" and "old" counters (**Fig. 52**) which produced good results for low-resolution TOF-spectra (**Fig. 53**). The construction of a section consisting of four scintillation counters of the detector ASTRA is in progress.

Fig. 52. A new counter of the ASTRA detector during the comparison tests.

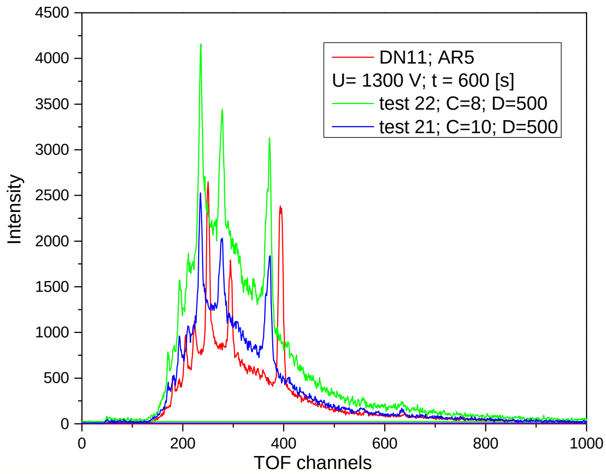

Fig. 53. General view of TOF-spectra (low resolution) of ASTRA detector section R5 (red – only one out of 4 elements was switched on) and of a new ZnS element (blue, green, two spectra were obtained at different thresholds).

Measurements of a profile of neutron beam №10 have been carried out. Measurements of profiles of beams №7a-1, №7a-2, №7-b have been repeated after adjustment of the neutron guide. In cooperation with the employees of the Nuclear Physics Department we have conducted simultaneous measurements of profiles of beams №6a, №6b, №10, №11, №12 using a thermal neutron monitor and evaluated their intensity with the help of a uranium chamber.

A 2D PSD with an active area of 200×200 mm^2 has been manufactured and installed at the REFLEX spectrometer. Design documentation for a 2D PSD has been developed for horizontal channel №3 of the IR-8 reactor in the NRC "Kurchatov Institute". The drawings have been forwarded to the NPO "Atom" for production of the housing and other mechanical units of the detector. Work is now underway toward the construction of a new 2D thermal neutron position-sensitive monitor for measuring IBR-2 beam profiles. The technical specification of the monitor has been agreed with the concerned FLNP Departments of Nuclear Physics (NP) and Neutron Investigations of Condensed Matter (NICM).

Data acquisition electronics.

Seven sets of digital and analog MPD-32 units for data acquisition and accumulation systems for the IBR-2 spectrometers have been manufactured and adjusted. The DAQ systems assembled from these units have been put into operation on the RTD, YuMO, DN-12 spectrometers mentioned earlier, and also the systems for the FSD and HRFD diffractometers have been completed and are in the adjustment stage. Firmware software for digital filtration of input signals from scintillation detectors has been developed for MPD-16 and MPD-32 units. It is with these units that the tests of a "List Mode"-analyzer for accumulation of "raw" data in the list mode and the debugging of data processing programs for plotting high-resolution spectra are in progress. The measurements are carried out in parallel with the old system of RTOF-analyzers using two 90°-modules of the ASTRA detector or back-scattering (BS) detector and with the "List Mode"-analyzer using all modules of the ASTRA and BS detectors. **Fig. 54** illustrates high-resolution spectra obtained using DSP and "List Mode" -analyzers. It can be seen that the spectra are identical, but there are some differences in absolute values of intensity and background. We try to find the reasons for these differences in the investigations now under way.

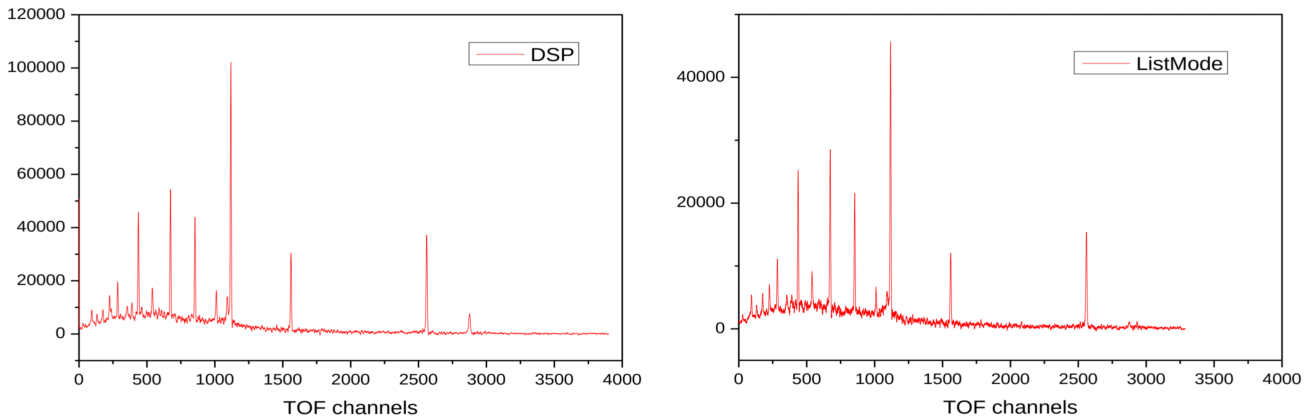

Fig. 54. High-resolution spectra obtained using DSP and "List Mode" -analyzers.

A new data acquisition and accumulation unit De-Li-DAQ2 for 1D and 2D position-sensitive detectors (**Fig. 55**) has been constructed and adjusted and the development of its software is nearing completion. The unit has a 1GB built-in histogram memory and a high-speed interface providing fiber-optic communication with a PC. The unit can operate in two modes: histogram mode (on-line sorting and accumulation of spectra in the internal memory) and list mode (accumulation of raw data immediately on a computer disk). The real count rate (with consideration for data transfer and recording to a PC) is no less than 10^6 events/s.

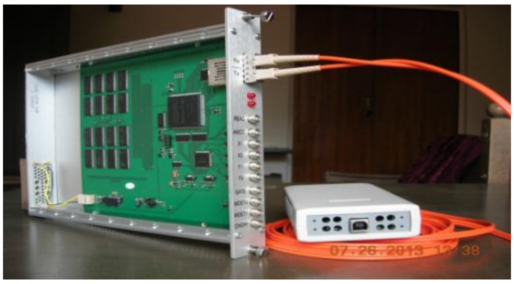

Fig. 55. De-Li-DAQ2 unit for data acquisition and accumulation from PSD.

Reactor-start couplers with optical isolation have been manufactured and installed on six IBR-2 spectrometers. Also, preventive maintenance on the IBR-2 spectrometers, as well as routine modernization and repair of electronic equipment were done.

Software.

In 2013, in accordance with the plan the Sonix+ software package developed in FLNP was installed in full on the DN-6, SKAT, DN-12 spectrometers and only for the available equipment on RTD and GRAINS (the package will be installed further as new devices become available). On the HRFD diffractometer because of the tight schedule of the user program the replacement of VME system and installation of Sonix+ proceed in-between the measurements, which somewhat slows down the pace of work.

The activities on the development of the Sonix+ software package included:

- development of a new universal graphical user interface (GUI) on the basis of PyQt and matplotlib (introduced on the YuMO, NERA-PR, SKAT, REMUR spectrometers), an example is given in **Fig. 56**;
- improvement of an operation library for reflectometers (REMUR, REFLEX, GRAINS);
- improvement of programs for visualization (SpectraViewer) and adjustment (ICE) on demand of the users.

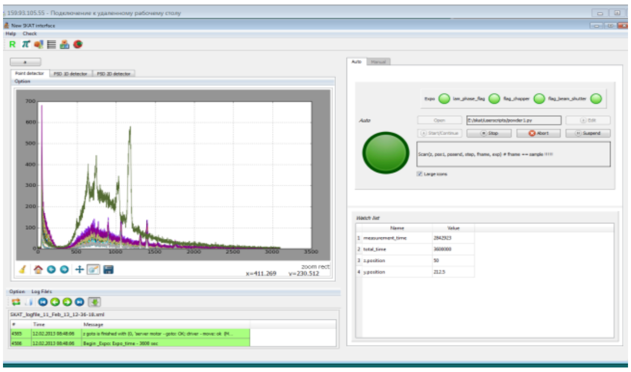

Fig. 56. New GUI using the SKAT spectrometer as an example (top).

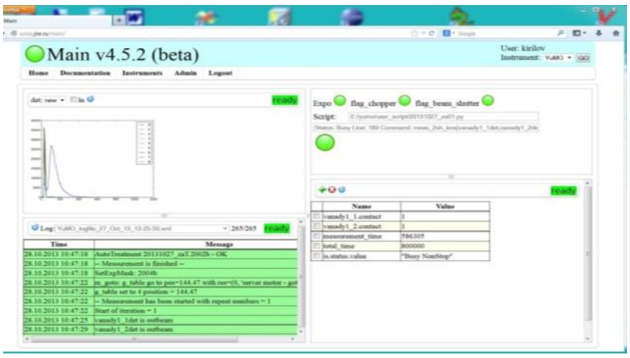

Fig. 57. Main page of WebSonix using the YuMO spectrometer as an example (left).

Over the past year a new significantly improved version of the system for remote monitoring of parameters and control of spectrometers (WebSonix) has been prepared, which is now in trial operation on the SKAT and YuMO spectrometers (**Fig. 57**).

Local area network.

In 2013, the FLNP network service installed and configured a Supermicro DP SSG-6047R-E1R24N file server (**Fig. 58**) with the following technical characteristics:

processor – 2x Intel(R) Xeon(R) CPU E5-2637 0 @ 3.00 GHz;
RAM – 32 GByte;
hard disks – 2x 500 GByte and 24x 3 TByte.

A free distributed **Freebsd 9.1** was chosen as an operating system as it proved to be the most fault-tolerant and high-performance OS among the users. Its important feature is the support of ZFS file system, which allows the implementation of a software RAID array using a host bus adapter. It is a journaling file system, which uses a snapshot technology making it possible to create a point-in-time image of a database, thus increasing the probability of recovering the lost data. The file system can tolerate the loss of up to 2 disks.

Fig. 58. New file server.

The disk array is implemented on 24 Hitachi HUA72303 disks using ZFS file system. Its storage capacity is 58 TByte. It can be accessed via such protocols as **cifs**, **smb**, **nfs**, and **scp**. At present, the server is in trial operation.

The creation of a WiFi network has been completed in the FLNP main buildings: 42, 42a, 117 (tower) and 117 (IBR-2 experimental halls), 119. D-link DW-360AP and Ubiquiti UniFi AP are used as network access points. At present, 21 wireless Internet access points are available in the Laboratory.