NOVEL DEVELOPMENT AND CONSTRUCTION OF EQUIPMENT FOR THE IBR-2 SPECTROMETERS’ COMPLEX

Development of the complex of neutron moderators.

In the first quarter of 2012 in the framework of the project aimed at the development of a complex of cold moderators the experiments on the simulation of loading mesitylene beads into a moderator chamber were carried out at various operating modes at a full-scale test stand. The automated system of acquisition and registration of data from sensors of the cold moderator monitoring system was modernized. In addition, the main technological systems and units of the cold moderator were upgraded.

The cold moderator operating mode, which determines the key maximum permissible physical parameters during its operation has been developed on the basis of the obtained results, and the start-up of the first cold aromatic hydrocarbon-based moderator CM-202 (**Fig. 26**) has been carried out on the modernized IBR-2M reactor.

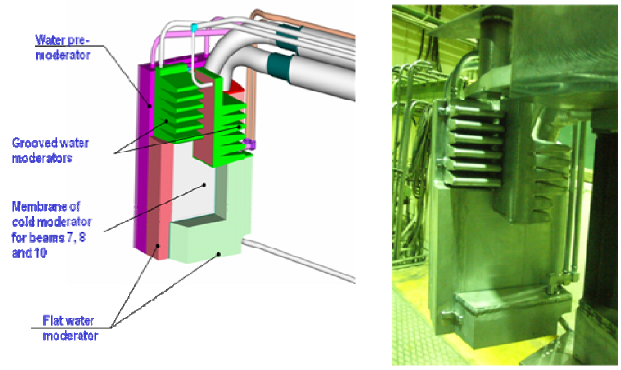


Fig. 26. A photo of the complex of neutron moderators CM-202 for beams № 7, 8, 10 and 11.

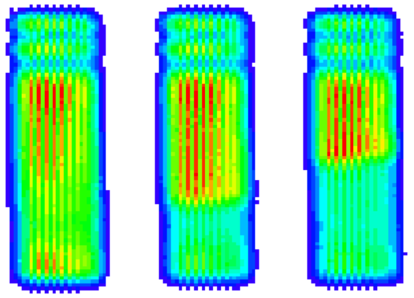


Fig. 27. Neutron images of a part of the complex of moderators CM-202 with a cryogenic moderator located in the bottom half at different bead filling levels: empty chamber (at the left), 2/3-filled (at the centre) and full chamber (at the right).

The key physical parameters of the CM-202 cold moderator while being loaded with frozen mesitylene beads were: 1) helium mass flow in the transport pipeline – 1.5 g/s, temperature – no less than 80 K; 2) maximum bead feed rate from the charging device to the transport pipeline did not exceed 8 pieces/s. The movement of beads through the pipeline was controlled by differential pressure sensors. A “pinhole-camera” method was used for monitoring the charging process by taking 2D neutron images of the moderator chamber (**Fig. 27**) by a two-coordinate PSD.

Upon filling the moderator chamber the reactor was brought to a power of 2 MW. The average temperature in the moderator chamber was 30 K. The measurements of neutron spectra have demonstrated that the long-wavelength neutron flux from the surface of the cold moderator has increased by a factor of up to 13 as compared to that from the surface of a water moderator (**Fig. 28**). Work is underway to determine the maximum operating time with one loading of the cold moderator.

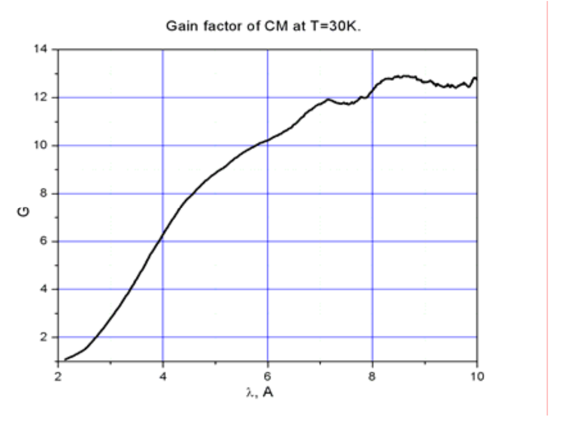


Fig. 28. The measured gain in the cold neutron flux when using the cold moderator.

Calculations and simulation of spectrometers.

In 2012, special VITESS modules that allow the simulation of the neutron spin behavior in arbitrary magnetic fields continued to be improved. Time dependences of magnetic fields for simulating spin-echo spectrometers with time-dependent (pulsed) magnetic fields (stationary fields are calculated by an external program) were added to the modules. A large number of simulations of parts of a new spin-echo spectrometer with rotating magnetic fields for the REFLEX beam of the IBR-2M reactor (in cooperation with V.Bodnarchuk and A.Rubtsov, FLNP NICM Department) were done in real magnetic fields calculated by the external program. A comparison with the first experiments (one spin-echo spectrometer arm) revealed good agreement between the experimental data and the data calculated using new VITESS modules. Further recommendations on engineering of units of a spin-echo spectrometer with rotating magnetic fields were developed on the basis of the performed simulations and calculations.

The first stage of a novel project – the immersion of VITESS modules in a magnetic field – has been fulfilled. A special library of VITESS subroutines that makes it possible to realize this task has been developed. At present, the module "polarizing mirror in a magnetic field" (**Fig. 29**) has been developed and tested, and is planned to be included into the next VITESS version. All the above-mentioned activities were carried out in collaboration with Prof. A.Ioffe (JCNS-Munich).

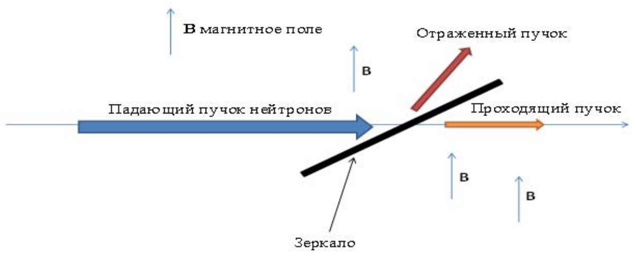
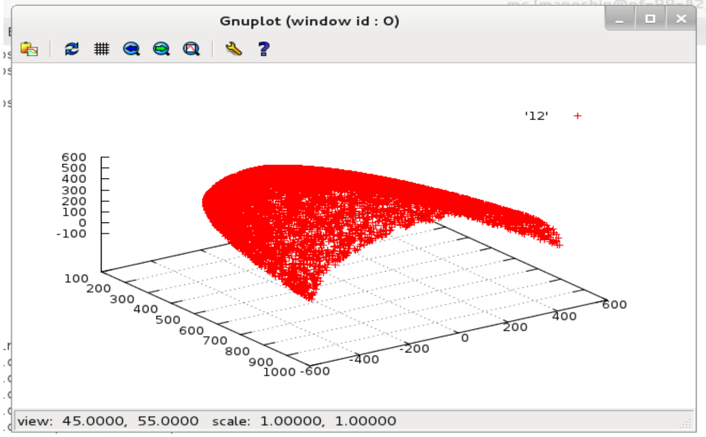


Fig. 29. Polarizing mirror in a magnetic field.

Four new VITESS modules have been developed for simulation and calculation of neutron time focusing for time-of-flight spectrometers on pulsed neutron sources. One of the modules makes it possible to calculate the time focusing surface for a given configuration of a time-of-flight spectrometer in a rectangular or polar coordinate system. Using other modules one can calculate approximating surfaces for the time focusing surface. An option is available to approximate by a plane/planes, cylinder/cylinders and sphere/spheres. These modules are in the testing stage. An example of building an ideal time-focusing surface is given in **Fig. 30**. In 2012, a module from the MCSTAS program for simulating a gas PSD was introduced and adapted for the VITESS package.



view: 45.0000, 55.0000 scale: 1.00000, 1.00000

Fig. 30. An example of building an ideal time-focusing surface for a simple ideal instrument with a Bragg scatterer for one fixed interplanar spacing.

Test beam and new Fourier diffractometer.

The work continued on the construction of a new high-resolution Fourier diffractometer on the basis of the units of the FSS spectrometer (GKSS, Geesthacht, Germany) on beam 13 of the IBR-2M reactor. In connection with the decision to create a new NIS spectrometer on beam 14 a draft layout of the instruments was corrected and a new arrangement of biological shielding of beams 13 and 14 was developed, drawings were made, shield elements were manufactured and assembled. Unfortunately, the problems connected with the transportation of the FSS equipment from St. Petersburg to Dubna have not been solved yet.

Cryogenics.

The work to design and construct a helium-3 purification facility (**Fig. 31**) has been completed. The facility is intended for purification and preparation of He^3 for re-use in neutron detectors. A gas He^3-containing mixture from the detectors is stored in the tanks of the facility, and then helium is separated from other gases using cryogenic and pumping-over systems. Next by means of a special cryogenic pump He^3 is compressed to a pressure of 80 bar, which is sufficient to fill new detectors. The facility has undergone pre-commissioning tests and has been put into operation.

Fig. 31. Helium-3 purification facility.

A feasibility study has been conducted to develop a pulse tube cold head under laboratory conditions. As a result a single-stage cold head connected to a Leybold RW4000 compressor has been made. The lowest temperature that can be reached at the cold head is 48 K. The cold head is used at the Department cryogenic stand.

The development of a horizontal cryostat for cooling high pressure cells with sapphire anvils (DN-6 diffractometer) has started.

Reconstruction of a neutron guide and modernization of the automation system of spectrometers on beam 7 of the IBR-2M reactor.

In 2012 on beam 7 of the IBR-2M reactor the construction and installation of an 80-m neutron guide for the NERA-PR spectrometer were completed **(Fig. 32**). The adjustment of optical elements was performed.

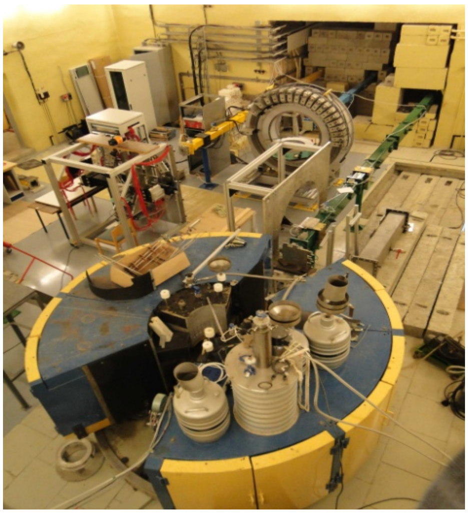


Fig. 32. Beam 7 in the IBR-2M experimental hall after reconstruction (EPSILON – yellow, SKAT – blue and NERA-PR – green; the detector system of NERA-PR is in the foreground).

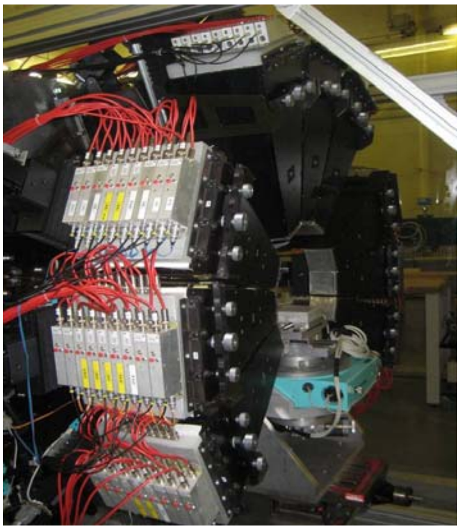


Fig. 33. Photo of detector collimators and goniometer (Huber) at the EPSILON spectrometer.

An adjustable diaphragm for neutron beam focusing has been manufactured. The diaphragm is controlled by stepper motors connected to PC via CAN/USB controller and converter. The modernization of a multi-counter detector for NERA-PR has been carried out as well. Amplitude spectra and counting characteristics of helium counters of the detector (36 rectangular counters, 24 SNM-17 and 4 monitor counters) have been obtained. On the basis of the characteristics measurement results the counters were grouped according to the gas amplification and working voltage, and the discriminating thresholds were determined for each counter.

A control system of detector collimators and goniometer (Huber) has been put into operation at the EPSILON spectrometer (**Fig. 33**). For the first time ball screws (BS) and stepper motors with controlled electromagnetic brakes were used in actuators of the FLNP spectrometers. Ball screws consist of a screw shaft, ball nut and a ball return mechanism and are usually used in situations in which high precision is necessary. They translate rotational motion to linear motion or vice versa with high accuracy and efficiency. A hardware-software system has been developed, which makes it possible to control the brakes using stepper motor controllers already employed at the IBR-2M spectrometers.

The total number of control channels for driving the actuators of the spectrometers on beam 7 has reached 72 (EPSILON – 32, SKAT – 4 and NERA-PR – 36 channels).The automation system of these instruments on beam 7 also monitors the status of choppers, shutters, and the readings of vacuum sensors and other elements of the spectrometers. At present, at the EPSILON and NERA-PR spectrometers new DAQ systems for point detectors have been installed; the adjustment work is nearing completion and test measurements are being made.

Sets of equipment for automation systems and data acquisition systems have been adjusted at a test-stand and are ready to be installed at the SKAT, GRAINS and DN-2 (RTD) spectrometers. Two polarizers and two diaphragms have been assembled and tested for GRAINS, and drawings of a beam collimation system for DN-2 have been developed. Among the actuators of the RTD spectrometer are:

- platform with a detector with a rotation angle varying from 0° to 180°. (1 control channel and 1 angular position sensor);
- goniometer Huber (1 control channel);
- goniometer GKS-100 (10 control channels including spare channels for connecting a neutron beam diaphragm and point detector collimators).

Detectors.

The project of creation of a gas ring-shaped multi-section detector for the DN-6 diffractometer has been completed. In 2012, the following main activities were conducted within the framework of the project:

– mechanical units for fastening and adjustment of the detector were developed and manufactured, and its background shield was mounted;

– 96-channel data acquisition and accumulation electronics were checked out and debugged;

– programs for testing the detector were written, data accumulation software was upgraded and a new program interface was developed;

– test trials of the detector were conducted on beam 6b with working gas mixtures at different pressures of He^3.

In November the measurements were conducted with the ring-shaped detector with background shielding with a working gas mixture (4.0 bar ^3He + 500 mbar of Ar + 30 mbar of CO_2). **Figure 34** illustrates the spectra of the samples under study. At present, the detector has been handed over to the physicists for further testing and working measurements.

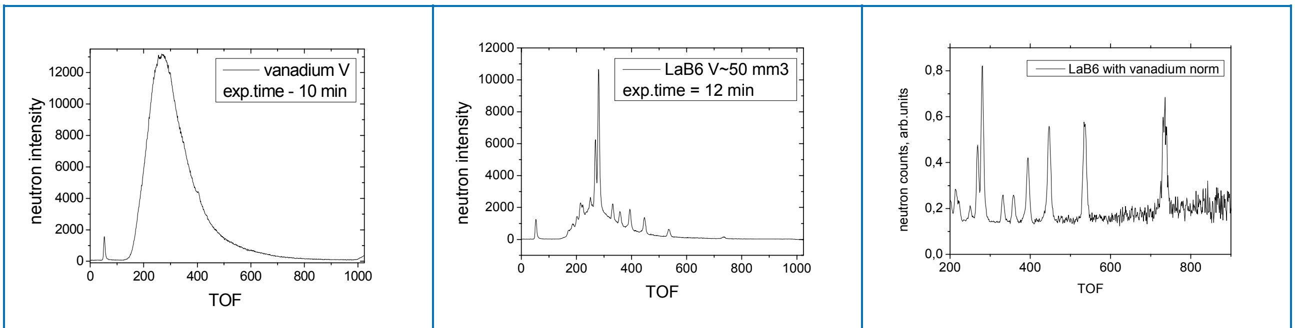


Fig. 34. Spectra of samples under study a) V, b) LaB_6, c) LaB_6 normalized to vanadium.

Inoperative position-sensitive detectors on HRFD and REFLEX have been replaced. Two detector systems that comprise 2D PSD, detector electronics, data acquisition and accumulation electronics as well as software have been made and transferred to the Nuclear Research Institute (NRI) in Řež (Czech Republic).

On the DN-2 (RTD) diffractometer a detector system with 2D PSD (active area of 225×225 mm^2) has been put into operation and a ring-shaped helium back-scattering detector (**Fig. 35**) has been manufactured, assembled, and tested on a test stand.

An ND-screen-based scintillation counter with light collection using wavelength shifting fibers has been made and tested The preparation for production of scintillation counters for the “Astra” detector has begun.

Fig. 35. Ring detector for DN-2.

A number of measures to upgrade the clean room have been taken; its area has increased to 10 m^2.

Neutron beam profiles have been measured on beams 2, 4, 6a, 6b, 7, 9, 11, 12 of the modernized IBR-2M reactor. The measurements were carried out in the beam extraction areas using a 2D thermal neutron PSD-monitor. An average intensity, coordinate and time distributions of neutron fluxes were measured for each beam.

Data acquisition systems.

In 2012, the introduction of a new generation of data acquisition and accumulation systems at the IBR-2M spectrometers continued. In accordance with the time schedule of this project approved at a joint meeting of the Scientific and Technical Councils of the SC and NICM departments, the major part of this work for all spectrometers should be completed in 2012-2013. This means that within the specified period either the DAQ systems will be put into operation or all electronic units, firmware and running-in test software will be manufactured and debugged, and the work on the Sonix+ software for particular spectrometers will be completed within the time limits agreed with the physicists.

In 2012, DAQ systems for point detectors were put into operation at the spectrometers NERA-PR, RTD (DN-2), EPSILON, SKAT, DN-6, REFLEX and FSD (for the development and debugging of the correlation analysis programs and for carrying out the instrument development studies). All the above-mentioned systems except for those of REFLEX and FSD consist of two types of units – one digital unit capable of registering and accumulating data from 1 to 240 point detector elements and several 32-channel analog units in which data acquisition, discrimination, transformation and transfer are performed using low-voltage differential signals (LVDS) from the detectors’ preamplifiers to the digital unit MPD-32. In the analog unit the transition from LEMO connectors to a flat cable is done as well. As an example, a block diagram of a 96-channel DAQ system for the ring detector of the DN-6 diffractometer is shown in **Fig. 36** and a photo of electronic modules of this system in a NIM crate is given in **Fig. 37**.

The MPD-16 modules, which combine printed-circuit boards with analog and digital electronics within a single frame, are installed at the REFLEX and FSD spectrometers. An MPD-16 module is intended for spectrometers with the number of detector elements being no more than 16. MPD-32 and MPD-16 modules are software compatible.

A test generator simulating the operation of data accumulation system is built in the MPD modules. This makes it possible to perform a quick test of the operability of the equipment before a reactor cycle as well as its independent adjustment without involving detector elements.

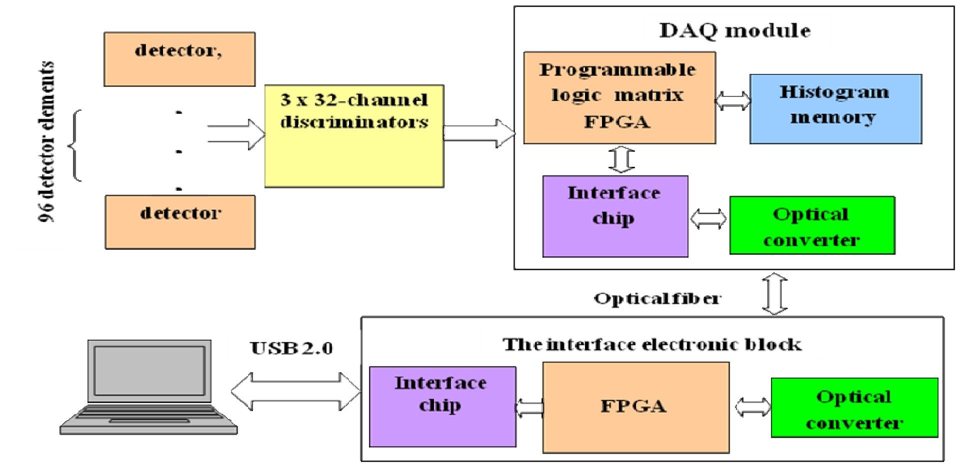


Fig. 36. Block diagram of the DAQ-system of the ring detector for DN-6.

Data transmission between DAQ electronics and USB 2.0 port is carried out via an interface unit using a serial fiber-optic communication line. Data transmission rate is 1.25 Gb/s, maximum distance from a computer – up to 100 m.

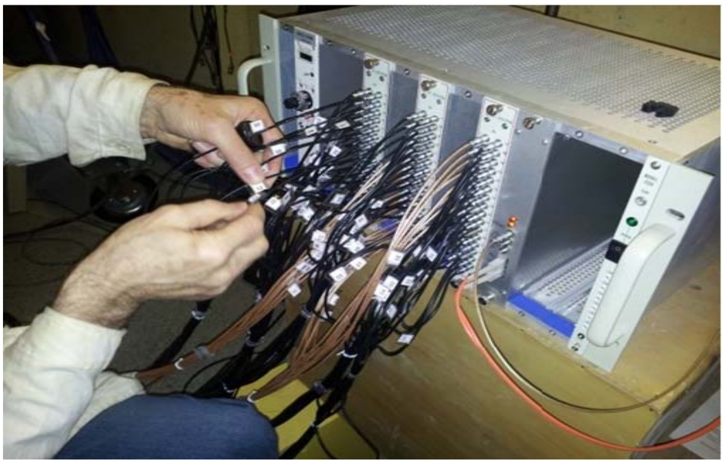


Fig. 37. Photo of MPD-32 electronic modules.

The electronics of the MPD modules are unified, and specific features of each spectrometer are considered when programming FPGA. The key parameters of MPD modules are as follows:

- time discretization frequency of all signals (detectors, reactor start, pick-up, etc.) – programmable (maximum of 62.5 MHz);
- maximum number of detector elements – 240;
- maximum count rate – $8\cdot10^6$ events/s;
- internal histogram memory – 64 Mbyte;
- maximum delay of registration start relative to a reactor burst – 0.268 s (programmable, time step – 16 ns); with the same accuracy the channel width for histogram memory and the width of a time window within which neutrons are registered, can be programmed.

On the FSD diffractometer the tests of a MPD-16-module-based “List Mode”-analyzer for accumulation of “raw” data in the list mode and the debugging of processing programs are in progress. It is expected that in the near future MPD electronics will replace the existing DSP electronics on all IBR-2M Fourier-diffractometers. **Figure 38** illustrates good agreement between the low-resolution spectra obtained using DSP- and MPD-analyzers.

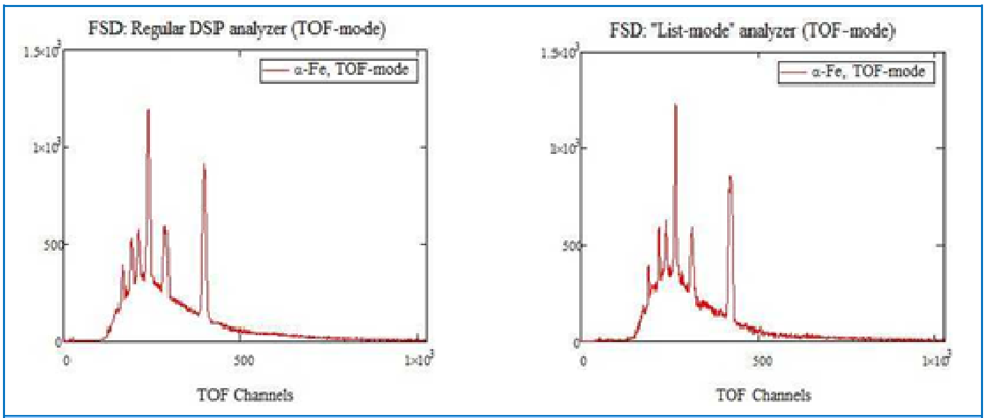


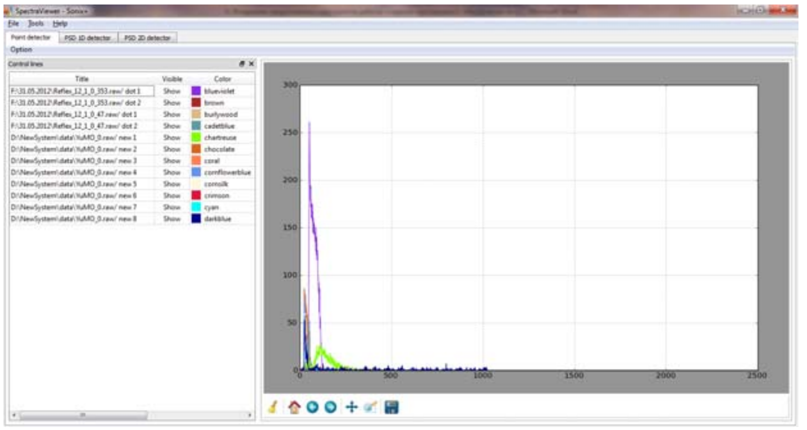
Fig. 38. Low-resolution spectra obtained with the FSD spectrometer.

Development of the Sonix+ software.

Sonix+ versions have been developed and put into trial operation on the spectrometers where new DAQ systems are installed. The complexity of this work lies in the fact that on many spectrometers the replacement of the detecting and data accumulation electronics proceeds along with the replacement of the control equipment of actuators of the spectrometers and of sample environment systems as well as along with the change-over from OS-9 to Windows. This demands certain efforts both from the physicists and engineers and eventually requires their joint work in testing the electronics and software during one-two reactor cycles.

Among other software-design activities the following should be mentioned:

- test program was prepared for testing a ring detector on the DN-6 spectrometer (the tests were successful and the detector with the DAQ system was put into operation).
- technology of designing program components and the technique of their use for creating systems of adjustment of the IBR-2M spectrometers were developed. Versions of adjustment programs were written for the YuMO, REMUR, REFLEX spectrometers. The adjustment program for YuMO was used to adjust a new drive of the ring-shaped collimator.
- work to improve the data visualization program continued. A new version of the SpectraViewer program for point detectors and PSD was developed on the basis of PyQT and Matplotlib. The program was implemented on the YuMO, REFLEX, NERA-PR, EPSILON, DIN-2PI spectrometers. The examples of the use of the SpectraViewer program are shown in **Figs. 39, 40** and **41**.
- initial version of the Journal program for automatic registration of measurements on spectrometers was developed. The program is being tested on the YuMO spectrometer.



Title	Visible	Color
F:\31.05.2012\Reflex_12_1_0_353.raw/ dot 1	Show	blueviolet
F:\31.05.2012\Reflex_12_1_0_353.raw/ dot 2	Show	brown
F:\31.05.2012\Reflex_12_1_0_47.raw/ dot 1	Show	burlywood
F:\31.05.2012\Reflex_12_1_0_47.raw/ dot 2	Show	cadetblue
D:\NewSystem\data\YuMO_0.raw/ new 1	Show	chartreuse
D:\NewSystem\data\YuMO_0.raw/ new 2	Show	chocolate
D:\NewSystem\data\YuMO_0.raw/ new 3	Show	coral
D:\NewSystem\data\YuMO_0.raw/ new 4	Show	cornflowerblue
D:\NewSystem\data\YuMO_0.raw/ new 5	Show	cornsilk
D:\NewSystem\data\YuMO_0.raw/ new 6	Show	crimson
D:\NewSystem\data\YuMO_0.raw/ new 7	Show	cyan
D:\NewSystem\data\YuMO_0.raw/ new 8	Show	darkblue

Fig. 39. Visualization of spectra from point detectors (YuMO spectrometer).

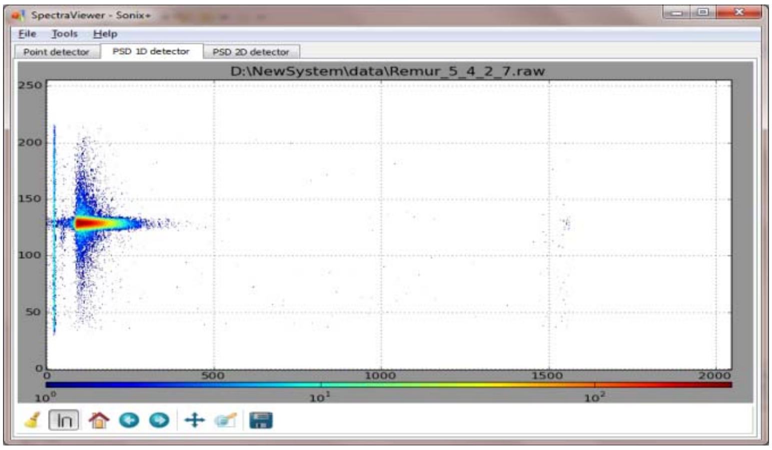


Fig. 40. Visualization of data from 1D PSD (REMUR spectrometer).

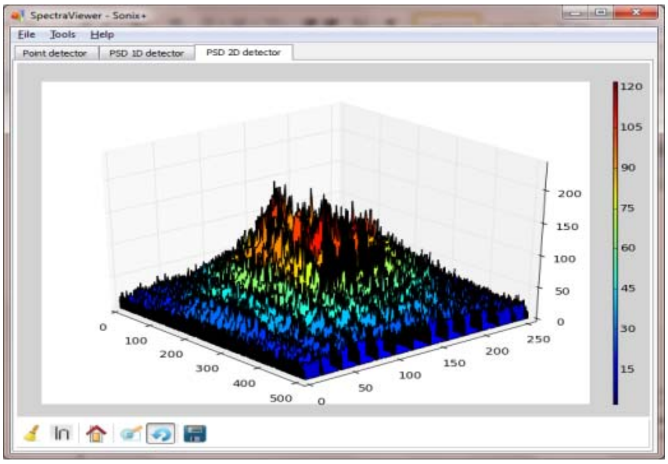


Fig. 41. Visualization of data from 2D PSD (YuMO).

Local area network.

The main task of the current year in the development of LAN ─ to provide the end-user with the rate of up to 1 Gb/s in the main network segments (bldg. 42, 42a, 43 (IREN), 44, 117, 119) ─ has been successfully fulfilled. A trouble-free operation of all network equipment has been maintained both on the IBR-2M spectrometers and in the offices of the Laboratory.

The work on the FLNP LAN modernization started in 2011, continued. The main reasons for the network modernization are:

- Change-over of the JINR Backbone to 10 Gbit/s.
- Modernization of the IBR-2 reactor and its spectrometers; construction of new instruments; tendency to the accumulation of raw data.
- Rapid increase in the efficiency and possibilities of personal computers.
- Higher requirements for information provision for users.
- Provision of access and shared use of network devices, data archives and software packages.
- Mass use of Internet.

The main objectives of the FLNP LAN modernization: **a)** localization of data flows and allocation of segments in a subnetwork to provide the maximum possible throughput of the communication equipment; **b)** to provide data transfer rates of up to 10 Gbit/s. Modernization stages:

- Replacement of the control switching equipment of level 3 and 2 in the main laboratory network segments (bldg. 42, bldg. 42a, IBR-2M, bldg. 119).
- Replacement of the server equipment and further network extension.

At present, the first stage has been mainly completed. A logic diagram of the modernized network as of December 1, 2012, is shown in **Fig. 42**. The following features of the new configuration of LAN should be mentioned:

- An increase in the amount of data coming from the IBR-2M reactor required to connect the IBR-2M segment directly to the FLNP switch to provide a throughput of up to 10 Gbit/s.
- An increase in the throughput by an order of magnitude for all segments of the network (from 100 Mbit/s to 1 Gbit/s and from 1 Gbit/s to 10 Gbit/s, respectively).
- A new SuperMicro 6047 server intended, first of all, for data storage was purchased and installed. The server disk memory capacity is 72 TB.

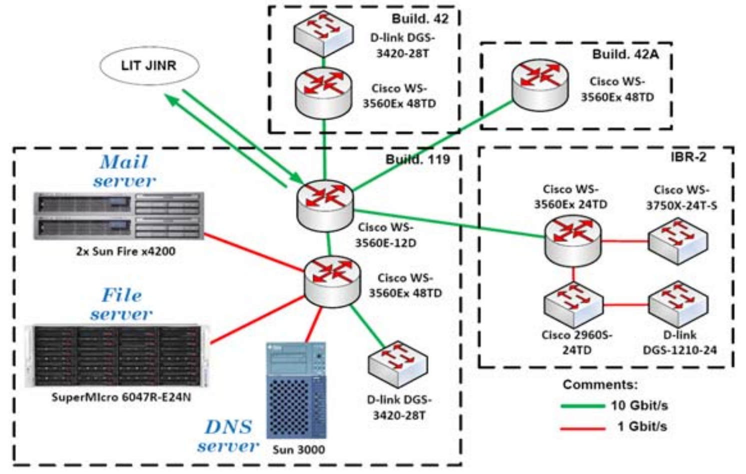


Fig. 42. Logic diagram of FLNP LAN (2012).