IV. NOVEL DEVELOPMENT AND CONSTRUCTION OF EQUIPMENT FOR THE SPECTROMETER COMPLEX OF THE IBR-2 FACILITY

1. Cryogenic neutron moderators

In 2016, a new device (diaphragm) was successfully tested on the laboratory test stand to measure the flow rate of gaseous helium in the pneumatic pipeline of the cold moderator.

A device for nitrogen-free charging of frozen pellets into the CM202 chamber has been developed and tested (**Fig. 1-IV-1**). The main advantage of this device is that in the process of loading of frozen pellets into the dosing machine, liquid nitrogen does not get into the pneumatic pipeline. This will make it possible to avoid problems related to the freezing of liquid nitrogen in the pipeline, namely, in the heat exchanger of the cold moderator.

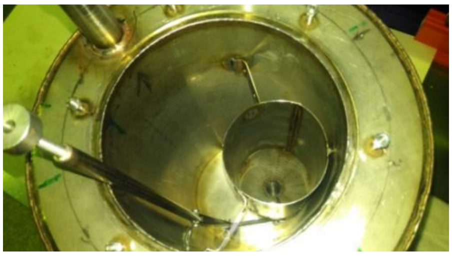


Fig. 1-IV-1. *A device for nitrogen-free charging of frozen pellets into the CM202 chamber.*

An experimental comparison has been made of the cold neutron yield and radiation resistance of aromatic hydrocarbon triphenylmethane with those of mesitylene and m-xylene, already being used in the pelletized cold neutron moderator in the direction of IBR-2 beamlines № 7, 8, 10 and 11.

The comparison of the cold neutron yield from the surface of the materials under investigation has been carried out by experimentally studying the evolution of vibrational states as a function of temperature (**Fig. 1-IV-2**) on the DIN-2PI inelastic neutron scattering spectrometer. It can be seen from the figure that the intensity (yield) of scattered cold neutrons from the surface of the capsule with mesitylene and m-xylene is almost 2 times higher than the intensity of the triphenylmethane sample.

The comparison of radiation resistance has been done by comparing the yield of radiolytic hydrogen from the materials under irradiation on the radiation research facility (IBR-2 beamline 3) up to radiation doses corresponding to the real reactor experiment doses during the operation of the cold pelletized moderator at a reactor power of 2 MW.

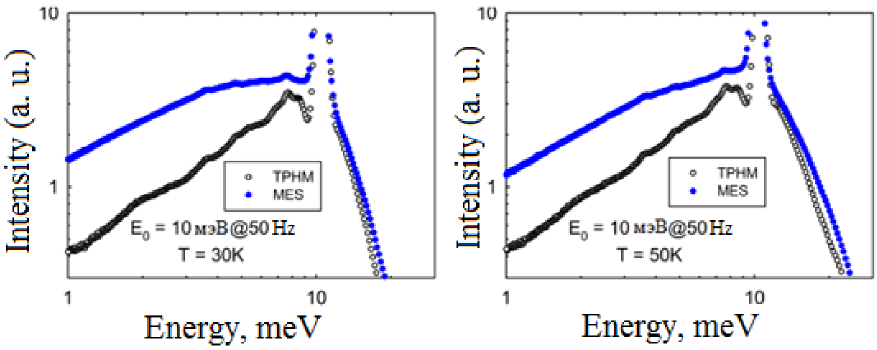


Fig.1-IV- 2. *Evolution of vibrational states as a function of temperature (for 30 and 50 K) for an incident neutron energy of 10 meV (TPHM - powdered triphenylmethane, MES - solid frozen mesitylene mixed with m-xylene).*

Figure 1-IV-3 presents a diagram of the yield of radiolytic gaseous hydrogen from aromatic hydrocarbons under irradiation to a fluence of ~10^{18}n·cm^{-2} (dose ~180 mGy). One can see that the hydrogen yield in the case of triphenylmethane, regardless of the form (whether it be powder or solid pellets) 9 times lower than the yield of hydrogen from a mixture of mesitylene and m-xylene, which points to a significantly higher radiation resistance of triphenylmethane as compared with the above-mentioned mixture.

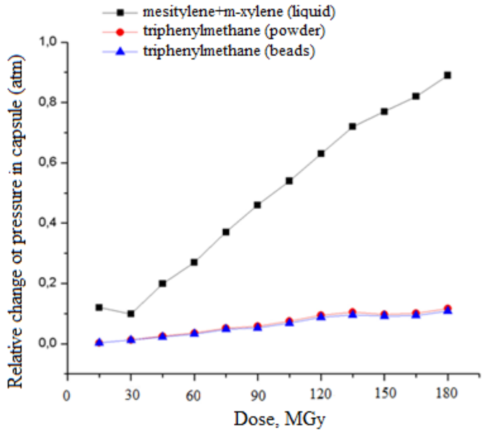


Fig.1- IV-3. *Relative change of pressure in the capsule as a function of the absorbed dose for the mixture of mesitylene with m-xylene and triphenylmethane in the form of powder and solid pellets.*

From these data we can make a preliminary conclusion that the neutron-physical properties of triphenylmethane make it possible to consider it as a material for a cold neutron pelletized moderator at IBR-2. To draw final conclusions, it is necessary to carry out a number of additional experiments on inelastic neutron scattering on the NERA spectrometer (IBR-2), neutron transmission on the IREN accelerator, pneumatic transport of triphenylmethane pellets, etc.

2. Radiation research facility

In 2016, the following activities were performed on the radiation research facility at IBR-2:

- in cooperation with FLNR a design specification was developed for a spectrometer of heavy nucleus fission products (VEGA – Velocity-Energy Guide-based Array) allowing the identification of primary (unmoderated) fission fragments by mass and energy in the experiments studying the rare modes of heavy nuclei fission;
- in collaboration with the Laboratory of Magnetic Sensors of the Lviv Polytechnic National University a study on the radiation resistance of magnetic sensors (3D Hall sensors) was carried out in the framework of the ITER international project (**Fig. 1-IV-4**);

Fig.1-IV-4. *Samples of magnetic sensors under study.*

- in collaboration with DLNP JINR the experiments on the irradiation of samples of silicon scintillators were conducted to study their electrical properties under irradiation;

- in collaboration with VBLHEP JINR we carried out preliminary studies on the nature of radiation defects in topaz samples after irradiation.

3. Calculations and simulation of spectrometers

During the period of 2016 the development of special mathematical models and related programs for simulating full reflectometric and GISANS experiments on samples, including multilayer rough samples and magnetic scattering has generally been completed. Various modifications of the kinematic approximation have been developed taking into account the penetration depth, refraction and renormalization of the 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.

Below are the results of the simulation of two virtual full reflectometric experiments (diffraction from gold columns on a silicon substrate (**Fig. 1-IV-5**)) in the modified kinematic approximation.

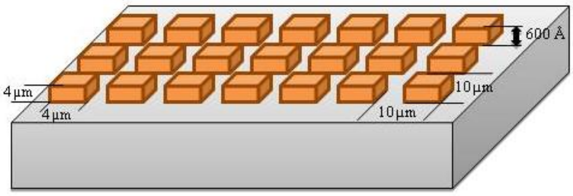


Fig. 1-IV-5. *System of gold columns on a silicon substrate [1] (column height – 600 Å, column width – 4×4 µm, spacing in the horizontal plane – 10×10µm).*

The results of the simulation of the system presented in **Fig. 1-IV-5** for a full reflectometric experiment are shown in **Fig. 1-IV-6**.

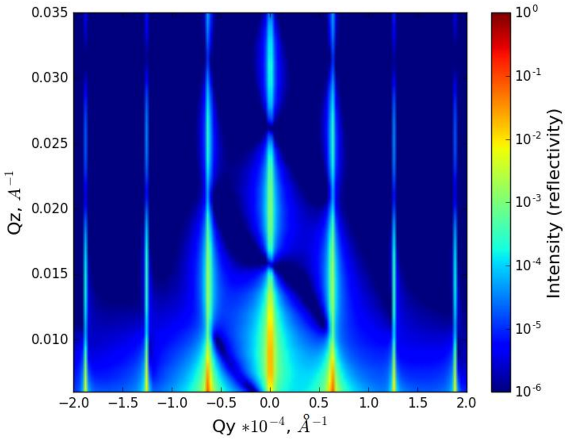


Fig. 1-IV-6. *Simulation of a full reflectometric experiment in the modified kinematic approximation of the system of gold columns on a silicon substrate.*

The results of the simulation of specular reflection of the system shown in **Fig. 1-IV-5** using four methods are presented in **Fig. 1-IV-7**:

- Parratt method, dynamic theory (the most accurate method);
- Born approximation;
- kinematic approximation with consideration of refraction from the columns;

- 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.

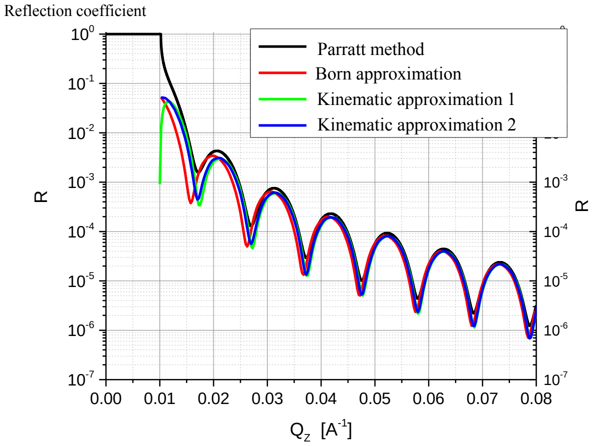


Fig. 1-IV-7. *Simulation of specular reflection for the system presented in* ***Fig. 1-IV-5*** *using various methods.*

This is a very common situation when domains observed in multilayer magnetic structures are not ordered, but randomly oriented and randomly distributed in size. In [2], in particular, the analysis of the polarized neutron scattering from a multilayer lamellar iron-chromium system was performed. The magnetic iron layers were assumed to be divided into random domains, with the size distribution of the domains in the neighboring layers being identical, and the magnetization of the domains corresponding to the antiferromagnetic ordering in the adjacent layers. In the simulation, we chose the parameters of the structure similar to those used in [2]: the thickness of each iron layer was chosen to be 90 Å with a 10-Å thick chromium layer being between the iron layers, and the domain size distribution was described by an exponential function.

The result of simulation of the full experiment with magnetic roughness described by the exponential correlation function is shown in **Fig. 1-IV-8**.

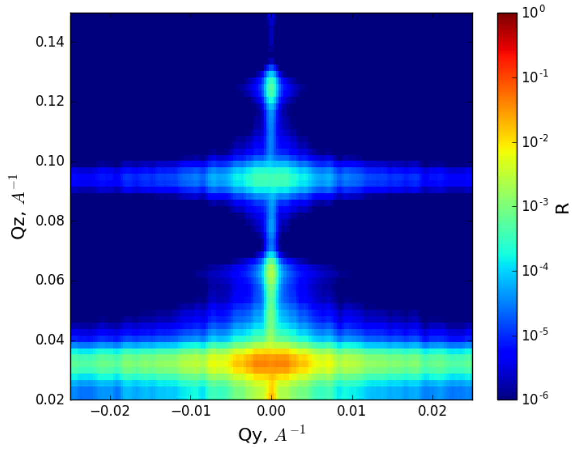


Fig. 1-IV-8. *Simulation of iron-chromium multilayer magnetic structures in the modified kinematic approximation.*

The simulation results in the modified kinematic approximation qualitatively are almost identical to the results published in [2] for such a system. What is more, this concerns both the measurements and the DWBA simulation.

4. Cryogenics

The following major activities were carried out in 2016 in the framework of the project “Development of PTH sample environment system for the DN-12 diffractometer at the IBR-2 facility”:

- a cryostat for a superconducting magnet with HTSC current leads and a cryostat for a high-pressure cell were manufactured (**Fig. 1-IV-9 (a)**);
- a machine for HTSC tape winding was manufactured (**Fig. 1-IV-9(b)**);
- magnet windings were produced;
- thermal measurements were carried out for both cryostats with a prototype of the magnet in a vertical position with a zero current (**Fig. 1-IV-(c)**);
- equipment and materials required for final assembling and commissioning of the PTH system were purchased.

(a) 

(b) 

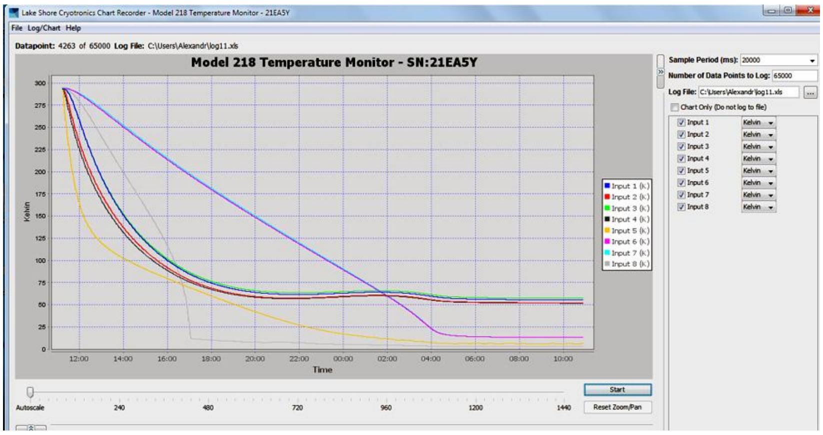
(c) 

Fig. 1-IV-9. (a)*A cryostat for a superconducting magnet with HTSC current leads, with a cryostat for a high-pressure cell inserted into its shaft, in the mode of operating cryocoolers;* ***(b)*** *Manufacturing of magnet windings on a special machine;* ***(c)*** *Graphs of temperature in various parts of the cryostat versus time (temperature of magnet prototype – Input 6, 7; temperature of warm ends of HTSC current leads – Input 1, 3; sample temperature – Input 8).*

The achieved terminal temperatures of the magnet prototype (13 K), warm ends of HTSC current leads (55-57 K), and sample (2.8 K) correspond to the design values.

5. Upgrade of control systems, actuators and sample temperature control systems on the IBR-2 spectrometers

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. Below are a few examples of these devices.

On the YuMO spectrometer 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. A platform with a detector mounted on the position adjustment mechanism is shown in **Fig. 1-IV-10**.

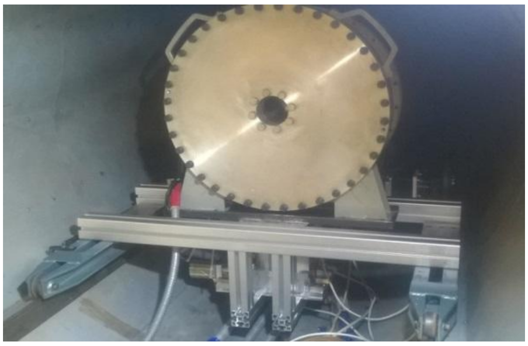


Fig. 1-IV-10. *A platform with a detector mounted on the position adjustment mechanism for moving in the horizontal and vertical directions.*

The control systems of experimental setups have been upgraded on the HRFD and FSS spectrometers (**Fig. 1-IV-11**). They have become more technological, easy-to-operate and provide:

- connection of up to 5 devices via RS485 interface;
- control over 4 relay signals on the status of the setup;
- connection of additional 3 devices via a USB interface.

The interface converters have been replaced in the control systems as well.

Fig. 1-IV-11. *The control system of the setup status on the basis of AC4 (USB-RS485) and AC3-M (RS485-RS232) interface converters on the FSS diffractometer.*

A control system of the Fourier-chopper on the FSS spectrometer has been put into operation. The chopper on beamline 9 of the IBR-2 reactor has been moved to the ring corridor. It has been tested with a standard control system and speed sensor on the basis of a reed switch and magnet. It has been shown that the parameters of the sensor during the operation under high radiation conditions of the ring corridor do not worsen as compared to its operating characteristics in the restricted area.

6. Detectors and electronics

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. 1-IV-12**.

Fig. 1-IV-12. *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.

At present, the assembling of the detector mechanical units is underway. The digital data acquisition and accumulation electronics are based on the previously developed unified MPD modules.

In 2016, the spectrometer based on a recoil proton telescope, which had been developed in FLNP (see Annual Report 2015) was adjusted and put into trial operation in 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)^{3}He 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. The photo of the spectrometer is shown in **Fig. 1-IV-13**.

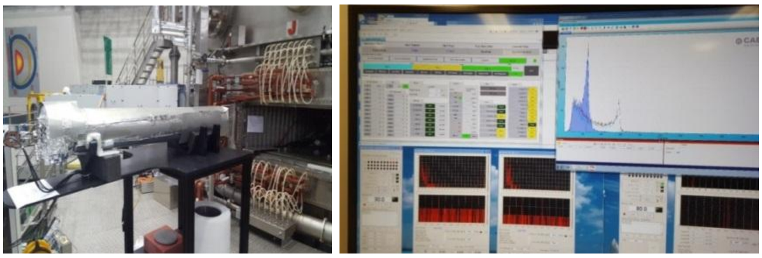


Fig. 1-IV-13. *Spectrometer on the basis of a proton recoil telescope at the KSTAR nuclear fusion reactor.*

Further development of these activities is proposed with the purpose of improving the energy resolution and enabling the operation in a wide range of neutron energies.

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. 1-IV-14**. A similar detector has been put into service on the RTD diffractometer.

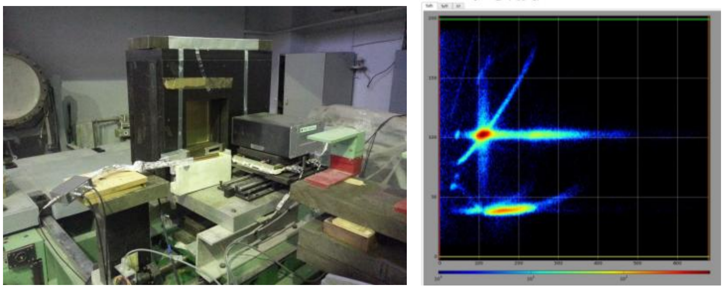


Fig. 1-IV-14. *2D PSD on the REMUR spectrometer (left) and measurement results (right).*

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. 1-IV-15**). These activities have been performed in the framework of the collaborative work on the ESS project (Lund, Sweden).

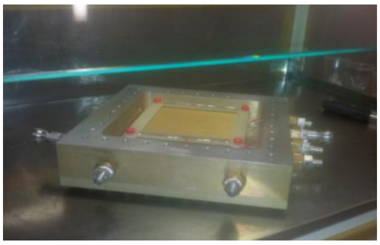


Fig. 1-IV-15. *A prototype of PSD with a 10B converter.*

In 2015, we completed the manufacturing and commissioning of scintillation counters of the fourth section of the ASTRA detector on the FSD diffractometer. 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. 1-IV-16**. A technical project for the detector system has been developed.

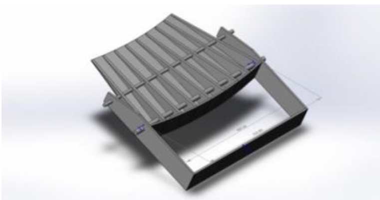


Fig. 1-IV-16. *A 3D model of one of the planes of the new “Astra” detector.*

The research and optimization of the scintillation detector on the FSD spectrometer have been carried out. High-voltage power sources have been replaced on FSD and HRFD. For acquisition and accumulation of data from two lithium-glass scintillation detectors of the FSS spectrometer the detector electronics modules received from GKSS (Germany) have been adjusted. In addition, a 32-channel discriminator module and controller MPD-32 have been manufactured and adjusted (**Fig. 1-IV-17**).

Fig. 1-IV-17. *Electronics of high-voltage power supply of detectors (top crate), modules of detector electronics and data acquisition electronics (bottom crate).*

Methodological work has been carried out on the investigation of possibilities of using multichannel digitizers to acquire data from position-sensitive neutron detectors. At the requests of the researchers measurements of the neutron beam profiles on the 5, 9 and 13 beamlines of the IBR-2 reactor have been performed using a PSD.

7. Software and computer infrastructure

In 2016, in the framework of development of the software package Sonix+ the following activities were done:

- Modules to support new devices on the spectrometers were developed and put into service:
  - new Fourier chopper (HRFD);
  - new sample temperature control systems (HRFD, RTD, DN-6 and REMUR);
  - magnetometer and power sources (REMUR).
- The FSD spectrometer was put under control of OS Windows 7.
- A standard version of the user interface was installed on the DN-6 and DN-12 spectrometers.
- At the requests of the experimenters we carried out work on improving the user interface, position adjustment program and some process execution modules.
- Conversion of Python-based programs from Python 2.6 to Python 3 started.
- A new, more reliable and secure version of WebSonix was prepared.

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 is 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.

References

[1] Metting Christopher Jason. (2011). Characterization and modeling of off-specular neutron scattering for analysis of two dimensionally ordered structures, Dissertation submitted to the Faculty of the Graduate School of the University of Maryland, College Park in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

*drum.lib.umd.edu/bitstream/1903/12439/1/**Metting**_umd_0117E_12778.pdf*

[2] Lauter H., Lauter-Pasyuk V., Toperverg B. et al. // J. Magn. Magn. Mat. 2003. V. 258–259. p. 338.