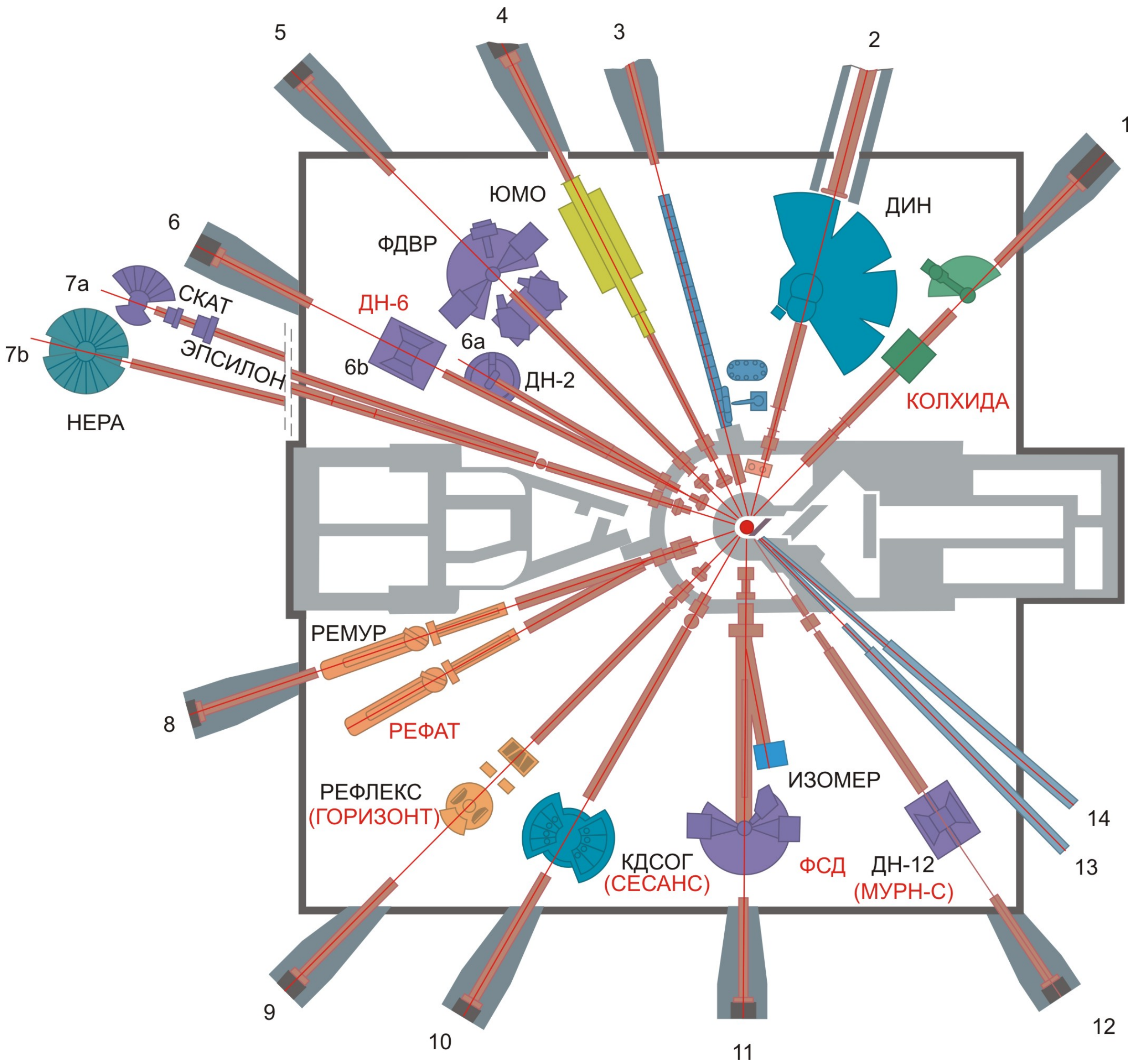
Proposals for IBR-2M spectrometer complex development program



Frank Laboratory of Neutron Physics

Scientific and Experimental Division of Condensed Matter Neutron Investigations

Proposals
for IBR-2M spectrometer complex development program

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CONTENTS

1. INTRODUCTION

The IBR-2 reactor was commissioned in February 1984. The IBR-2 service life expires in 2006. In 2007 a second stage of IBR-2 modernization starts (Table 1), as a result of which the new IBR-2M reactor is actually to be created. The basic parameters of the reactor, the total thermal neutron flux (10^{16} n/cm^{2}s) and the thermal neutron pulse duration (~400 μs), will virtually remain unchanged in the course of modernization. An essentially new feature is to be the existence of several cold moderators around the IBR-2M active zone. This fact is taken into account in plans for modernization of the spectrometer complex to be carried out during a long shutdown of the reactor for redevelopment in 2007 – 2010 (Table 1).

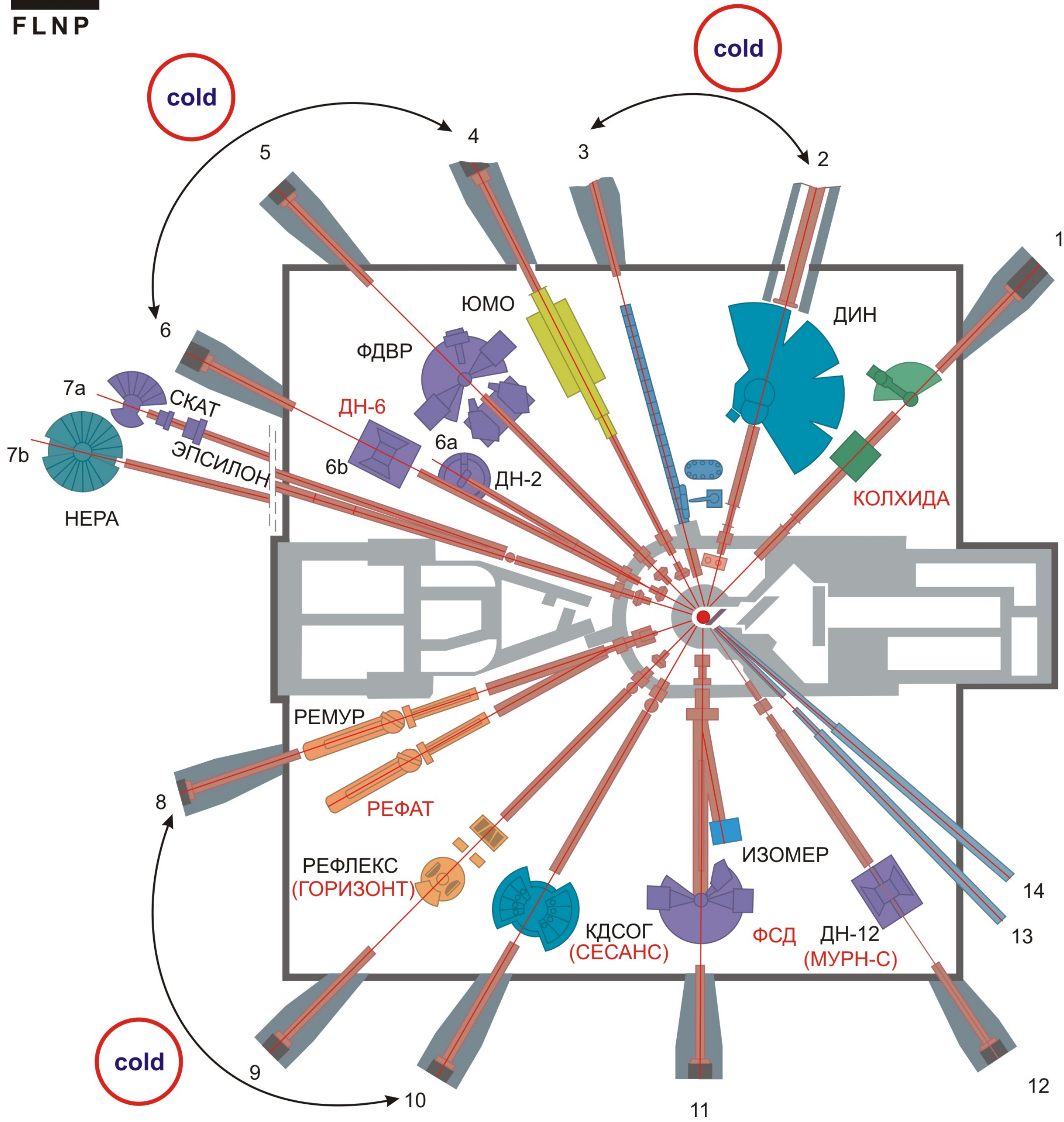
In the course of 20 years of IBR-2 operation a unique spectrometer complex has been created on the IBR-2 beam-lines and extended experience has been acquired in the field of condensed matter investigations by neutron scattering. Today at IBR-2, 6 diffractometers, 3 inelastic neutron scattering spectrometers, 2 polarized neutron reflectometers, and 1 small-angle neutron scattering instrument are operating (Fig. 1). The existing prevalence of diffractometers reflects exceptionally successful development of this technique at IBR-2, which is due to several reasons. First, it is diffractometry that development of experimental techniques for solid matter investigations started from. In 1962 in Dubna the world's first time-of-flight diffractometer at a pulsed neutron source was built. In FLNP many ideas lying in the basis of neutron diffractometry procedures that found applications and received further development in other neutron centers were suggested. The new stage of time-of-flight diffractometry development is connected with building Fourier diffractometers, first in 1984 at the VVR-M reactor in PNPI, RAS (the town of Gatchina), then in 1992 at the IBR-2 reactor. The construction of the high-resolution Fourier diffractometer (HRFD) has shown that at a pulsed neutron source with a long pulse (like IBR-2) there can be obtained structural results of an equal or even higher quality as at today's neutron sources with a narrow pulse. The success of HRFD facilitated the construction at IBR-2 of another Fourier diffractometer (FSD) optimized for internal stress investigations with which prototype tests and first experiments were carried out in 2003. With diffractometers operating at IBR-2 it is possible to solve quite a large variety of problems (structural investigations of mono- and polycrystals, determination of the magnetic structure, study of the impact of high pressures on the atomic or magnetic structure, texture analysis, carrying out real-time experiments, etc.) and correspondingly, such extended possibilities of the diffractometers attract scientists from other institutions of Russia and JINR member-states. At the same time, in the last years there is growing the number of experimental proposals from chemists, biologists, materials scientists, geophysicists. So, the SKAT and EPSILON spectrometer complex is oriented, to a large extent, to earth sciences. The growing demand for neutron method applications in materials and engineering sciences facilitated the appearance of the FSD diffractometer.

The only IBR-2 small-angle neutron scattering (SANS) instrument YUMO is evidently overused – the number of proposals for experiment on the instrument equals about 2/3 of proposals for experiments on 6 diffractometers (Fig. 2). Overused is also the reflectometer REMUR. It should be remembered that as a rule, polarized neutron experiments take a long time and therefore, actual demand for REMUR time is two or three times higher than it is presently available. The necessity to increase the number of SANS instruments and reflectometers is also dictated by the general picture of distribution of the instruments at reactors in Russian neutron centers (Table 2).

IBR-2

FLNP

Предварительная схема экспериментального зала ИБР-2 после 2010 года



Спектрометры ИБР-2:

Дифракция:	**КОЛХИДА, ФДВР, ДН-2, ДН-12 (ДН-6), СКАТ – ЭПСИЛОН, ФСД**
Малоуловое рассеяние:	**ЮМО, МУРН-С**
Рефлектометрия:	**РЕМУР, РЕФАТ, РЕФЛЕКС (ГОРИЗОНТ)**
Неупругое рассеяние:	**ДИН, НЕРА, КДСОГ (СЕСАНС)**
Ядерная физика:	**ИЗОМЕР, КОЛХИДА**

Fig. 1.

ПРЕДЛОЖЕНИЯ НА ЭКСПЕРИМЕНТ 2004-2005

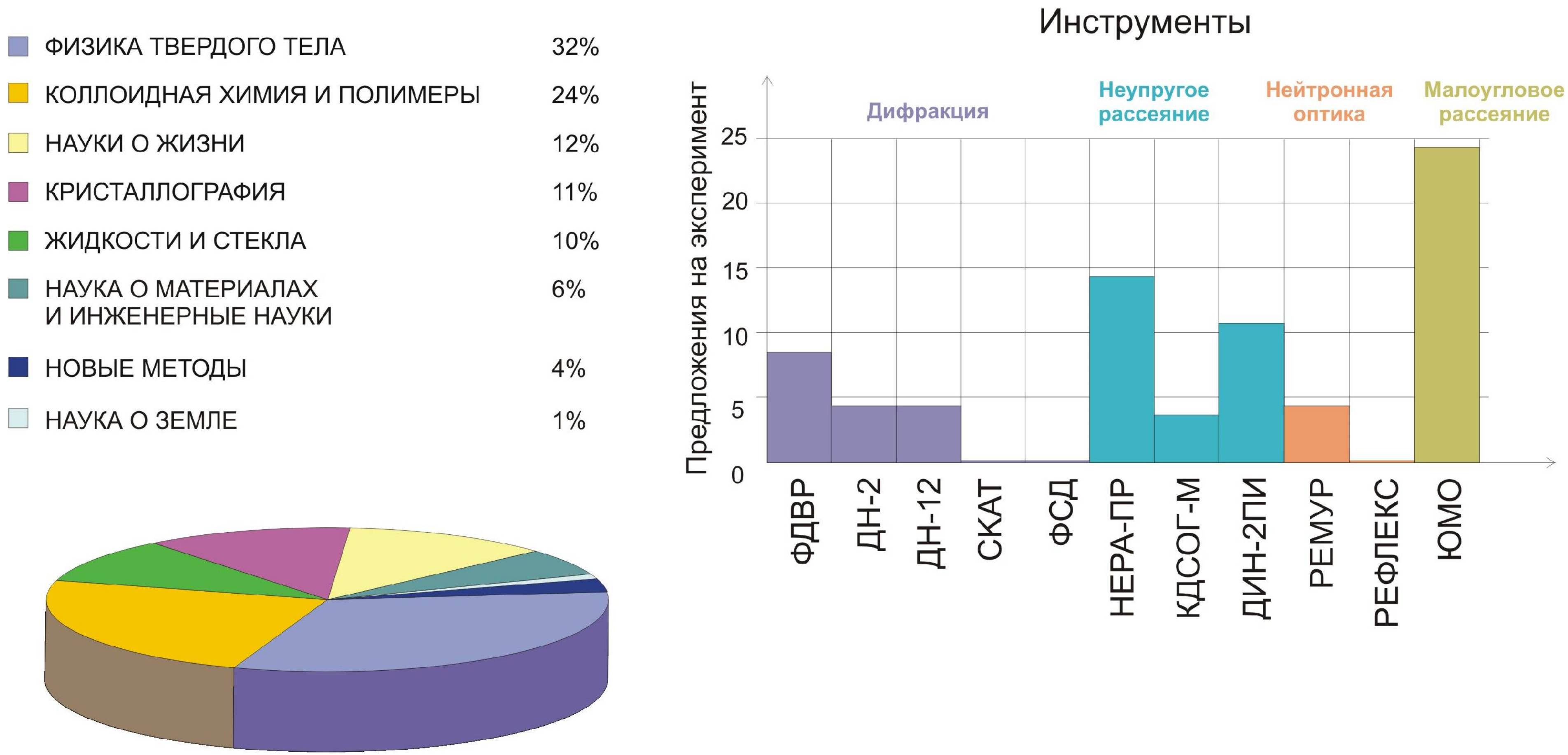


Рис. 2.

Table 1. IBR-2 modernization schedule (stage II)

№	Activity	2007	2008	2009	2010
1.	Active zone unloading				
2.*	Used equipment dismantling				
2.1	Reactor jacket				
2.2	MR-3				
2.3	Control and safety systems (CSS)				
3.	New equipment assembling				
3.1	Jacket				
3.2	MR-3				
3.3	CSS				
4.	Physical startup				
5.	Power startup				
6.	Operation for physical experiment				

Table 2. Quantitative data about neutron spectrometers at high-flux reactors in Russia

Spectrometer type	IBR-2, FLNP JINR Dubna	VVR-M, PINP Gatchina	IR-8, RRC"KI" Moscow	IVV-2M, Yekaterinburg
Total number of spectrometers	12	8	4	5
Diffractometers	6	3	2	4
Small-angle scattering spectrometers	1	2	1	1
Inelastic scattering spectrometers	3	1	1	-
Reflectometers	1	-	-	-
Polarized neutron spectrometers	1	2	-	-
Number of experiments conducted per year. Experiments conducted by external users.	~150 ~110	~50 ~15	~35 ~10	~50 -

As it is seen from Table 2 reactors in Russia are mainly equipped with diffractometers and inelastic scattering spectrometers. At the same time, modern investigations of condensed matter are more and more often connected with studies of the chemistry or physics of polymers, colloid dispersions, and biological objects where typical are long-period or disordered structures. This results in increasing demand for use of cold neutrons and experimental techniques like small-angle scattering and reflectometry.

Development of small-angle scattering and reflectometry is quite adequate for the IBR-2 reactor that has a high total neutron flux and, at the same time, a long pulse. Therefore, to increase the effectiveness of IBR-2 operation it would be only natural to have equivalent numbers of channels occupied by SANS instruments, reflectometers, and diffractometers. Since late 1999 at IBR-2 a cryogenic moderator situated on the side of channels 4, 5, 6 has been tested. Experiments on YUMO, HRFD, and DN-2 have demonstrated that operation with a cryogenic moderator considerably increases the effectiveness of all three spectrometers. It has also been found that for the YUMO small-angle neutron scattering instrument most favorable is the moderator operation mode at ~30 K while for the diffractometers HRFD and DN-2 optimal is operation at 60 - 80 K. Thus, it has appeared necessary to create a combined moderator ensuring a high neutron flux both in the thermal and cold regions of the spectrum. In the course of reactor modernization it is planned to engineer a principally new complex of moderators whose parameters are adjusted depending on proposals for particular spectrometers.

In the course of compiling proposals for the development of the IBR-2M spectrometer complex rapid development of synchrotron radiation sources in the last years, which forces neutron community to pay attention to realization of the brightest possibilities of neutron scattering, was taken into consideration. In this connection obvious is the growing role of methods employing polarized neutrons and accordingly, it is necessary to build instruments with polarized neutrons, both reflectometers and diffractometers.

This book contains proposals for development and modernization of the existing and for creation of the new spectrometers at the reactor IBR-2M. In the main, the proposals are prepared by members of the Condensed Matter Division. Two instruments, on channel 1 and 11B, and the complex for neutron activation analysis are being created and developed by physicists of the Nuclear Physics Division. Reactor channel 3 is used by Nuclear Safety and Radiation Investigations Department for irradiation programs and radiation investigations.

Scientific supervisor
Frank Laboratory of Neutron Physics V.L.Aksenov

List of projects

I. Existing spectrometers

1. High-resolution Fourier diffractometer HRFD
2. Fourier stress diffractometer FSD
3. Diffractometer DN-2.
4. EPSILON-MDS and SKAT diffractometer complex
5. Small angle neutron scattering spectrometer YUMO
6. Inelastic neutron scattering spectrometer NERA
7. Inelastic neutron scattering spectrometer DIN-2PI
8. Polarized neutron spectrometer REMUR
9. Spectrometer with a polarized target KOLKHIDA

II. New spectrometers

10. Neutron spectrometer for real-time experiments
11. Spectrometer DN-6 for microsample investigations
12. High-flux small-angle neutron scattering spectrometer MURN-S
13. Polarized neutron reflectometer with atomic resolution REFAT
14. Polarized neutron spectrometer with vertical scattering plane
15. Spin-echo spectrometer of small-angle neutron scattering SESANS

III. General-purpose projects

16. Moderator complex at IBR-2M
17. Spectrometer equipment
18. Gas-filled position-sensitive neutron detectors.
19. ZnS(Ag) scintillator-based position-sensitive scintillation detectors
20. Portable cryogenic systems
21. Development of IBR-2 spectrometer data acquisition systems and computing infrastructure in FLNP

Summary table of projects for IBR-2M spectrometer complex construction

Spectrometer projects are divided into two categories: A – development and modernization, B – new project. The category C includes general-purpose projects.

A. Development of existing spectrometers

1. High-resolution Fourier diffractometer HRFD
Project leader: A.M.Balagurov

Backscattering detector	190	2010	Complete set
PSD, Δx=0.3 cm, *l*=30 cm	25	2007	FLNP manufacturing
Refrigerator, T_{min}=3 K	45	2006	Purchase
Correlation analysis electronics	40	2009	FLNP manufacturing

Total: 300 KUSD

2. Fourier stress diffractometer FSD
Project leader: G.D.Bokuchava

ASTRA detectors	100	2009	Complete set
Radial collimators for ASTRA detectors	50	2007	Order
Correlation analysis electronics	30	2007	FLNP manufacturing
Neutron beam monitor	2	2007	FLNP manufacturing
Experiment control software development	18	2008	Order

Total: 200 KUSD

3. Diffractometer DN-2
Project leader: A.I.Beskrovnyi

Ring detector and supporting electronics	150	2010	Purchase
Chopper electronics	4	2007	Purchase
Neutron beam chopper	3	2007	Purchase
Head part of neutron guide	20	2008	Purchase
Neutron guide modernization	50	2008	Purchase
Refrigerator, T_{min}=3 K	45	2007	Purchase
Thermostat	8	2006	Purchase
High-temperature furnace	10	2009	Purchase
Electronics/software modernization	30	2009	Order

Total: 320 KUSD

4. EPSILON-MDS and SKAT diffractometer complex

Project leaders*:* A. Frischbutter (Potsdam, Germany, K. Ullemeyer*,* (Freiburg, Germany)

Neutron guide	400	2007-2010	Purchase
Loading machine with a system of temperature variation	150	2010	Purchase and manufacturing
Ultrasonic pulse generator	10	2007	Purchase
Acoustic signal preprocessor	16	2007	Purchase
Chopper electronics	4	2007	Purchase

Total: 580 KUSD

5. Small-angle neutron scattering spectrometer YUMO
Project leader: V.I.Gordelii

PSD (second)	280	2010	Complete set
Chopper	45	2009	Purchase
Detectors and collimation system	80	2007	Purchase/ manufacturing
Electronic and computing equipment	35	2010	Purchase
Sample environment	155	2010	Purchase

Total: 595 KUSD

6. Inelastic scattering spectrometer NERA
Project leader: I.Natkaniec

7b neutron guide modernization: 1 – complete neutron guide replacement, 2 – replacement of argon inflated head section of neutron guide (12 m) and installing of supermirror beam concentrator in front of sample (10 m)	450 150	2010 2010	Purchase of complete set
Renewal of spectrometer evacuating and sample environment equipment	50	before 2010	Equipment purchase
Detector system renewal	50	before 2010	Purchase and FLNP manufacturing
New electronics for neutron energy analyzers	30	2010	FLNP manufacturing

Total: 580 (280) KUSD

7. Inelastic scattering spectrometer DIN-2PI
Project leader: A.V.Puchkov (Obninsk)

Cold moderator	500	2010	FLNP manufactured
Neutron guide	120	2010	Purchased/ partially manufactured in FLNP
Installing of additional section of second flight path, equipment with detectors and electronics	250	2010	Manufactured by SRC RF-PPEI
Small angle scattering interval extension	50	2008	Manufactured by SRC RF-PPEI
Refrigerator, T_{min}=7 K	25	2006	Purchase

Total: 945 KUSD

8. Polarized neutron spectrometer REMUR
Project leader: A.V.Petrenko

Collimators	3	2007	FLNP manufactured
Shielding for detectors	15	2007	FLNP manufactured
Position-sensitive detector	6	2007	FLNP finishing
Polarization analyzer	90	2010	Purchase
Materials	35	2010	Purchase
Equipment	25	2010	Purchase
Chopper	10	2010	FLNP manufacturing
Control and acquisition system	10	2007	FLNP developed
Nonmagnetic goniometer for cryostat	11	2007	Purchase
Power supply for cryomagnet	15	2007	Purchase
Insert in cryostat for work at T=0.3 K	20	2007	FLNP manufactured
Insert in cryostat for work at T=600 K	10	2010	FLNP manufactured
Cryogenerator for magnetic measurements at T=10÷400 K	40	2007	Purchase
System for hydrogen saturation of samples	5	2007	FLNP manufactured
Finishing of rotating platform	10	2007	FLNP manufactured
Finishing of servicing platforms	5	2007	FLNP manufactured
Focusing neutron guide	80	2010	Purchase

Total: 390 KUSD

9. KOLKHIDA – spectrometer with a polarized target
Project leader: M.I.Tsulaia

Vacuum pumps	75	2007	complete set
Measuring device of superlow temperatures with a temperature sensor	10	2007	complete set
Superconducting solenoid power supply	10	2007	complete set
Multislit polarizer	20	2007	Purchase
PSD L ≈ 50cm, ΔX ≈ 0.5cm	30	2008	FLNP manufactured
Remote-controlled goniometric device	10	2010	Manufacturing
Refrigerator, T_{min}=3 K	45	2009	Purchase
Monochromator Cu_2MnAl_3	10	2010	Purchase

Total: 210 KUSD

B. New spectrometer projects

10. Neutron spectrometer for real-time analysis of processes
Project leader: G.M.Mironova

Drum-like chopper	15	2010	Manufacturing
Supermirror neutron guide	125	2008	Purchase
Detector system	100	2008	Manufacturing
Sample environment systems	60	2010	Purchase

Total: 300 KUSD

11. Spectrometer for microsample investigations DN6
Project leader: B.N.Savenko.

Detector block (32 pieces.)	160	2010
Neutron beam chopper	3	2007
Electronic control system of neutron beam chopper	3	2007
Neutron guide casing and head part modernization	50	2008
Data acquisition system	20	2009

Total: 236 KUSD

12. Small-angle neutron scattering instrument MURN-S
Project leader: V.I.Gordelii.

Neutron guide	120	2009	Complete set
Chopper	55	2010	Purchase
Detectors	560	2010	Purchase
Electronics	55	2010	Purchase
Sample environment	95	2010	Purchase,manufacturing

Total: 885 KUSD

13. REFAT – polarized neutron reflectometer with atomic resolution
Project leader: Yu.V.Nikitenko

Chopper design debugging	2	FLNP
Evacuated neutron guide	8	FLNP
Neutron guide	100	PINP
Neutron polarizer	15	PINP
Diaphragm (2pieces)	10	FLNP
3-axis goniometer	30	Purchase
Electromagnet with power supply	20	Purchase
Polarization analyzer, 10 cm×70 cm	100	PINP
Linear PSD 10 cm×70 cm with resolution 3 mm	100	Purchase
Spin-flippers (gradient and current foil-type)	2+20=22	FLNP
Electronic equipment and software	25	FLNP
Preliminary design	10	FLNP
Shielding, collimators	30	FLNP
Design effort	8	FLNP

Total: 480 KUSD

14. Polarized neutron spectrometer with vertical scattering plane.
Project leader: V.I.Bodnarchuk

Optics (neutron guide, bender-polarizer, deflecting mirrors, analyzer)	150	2010	Purchase (PINP)
2D-PSD	40	2010	Purchase and manufacturing
Sample environment	100	2010	Purchase and manufacturing
Electronics and software	30	2010	FLNP manufacturing
Additional equipment	30	2010	Purchase and manufacturing

Total: 350 KUSD

15. SESANS – spin-echo spectrometer of small-angle neutron scattering
Project leader: Yu.V.Nikitenko

Phase-sensitive system: Electromagnet EL (4pcs) Electromagnet E (2 pcs) Polarization rotator (3 pcs) Power supply for electromagnets (2 pcs) Generator for 1-3 MHz	 80 20 10 15 25	 FLNP manufactured FLNP manufactured FLNP manufactured Purchase Purchase
Polarizer	15	PINP manufactured
Polarization analyzer	70	PINP manufactured
Position-sensitive detector	70	Purchase
Neutron guide	80	PINP manufactured
Platform (2 pcs)	15	FLNP manufactured
Electronics and software	20	FLNP manufactured
Shielding	20	Purchase
Total:	440 KUSD	

The total cost of spectrometer projects 1 – 14 is **7,096** KUSD of which the cost of spectrometer modernization (projects 1 – 8) is 4,105 KUSD and the cost of new spectrometer creation (projects 9 – 14) is 2,991 KUSD.

C. General-purpose projects

16. Moderator complex at IBR-2M reactor
Project leaders: E.P.Shabalin,V.D.Ananiev

Project of moderator complex and in-process lines	400	2007	Complete set (NIKIET,GSPI)
Investigation of cryogenic moderators and in-process lines	100	2007	In FLNP together with GSPI and NIKIET
Purchase of coolant circulators and auxiliary equipment	200	2007	Purchase
Manufacturing of cryogenic moderators	500	2009	Order
Helium pipeline: designing, manufacturing, assembling	150	2009	Order, assembling in FLNP
Total	1350 KUSD		

17. Spectrometer equipment upgrading at IBR-2M reactor

Projectleader: V.G.Simkin

Equipment	Model	Firm	Cost	Number of pieces	Total cost
Close-cycle refrigerator, 3 K	SHI-3	Janis, USA	55	1	55
Single-step close-cycle refrigerator, 77°K	AL200	Cryomech, USA	24	2	48
Temperature control	900S	Evrotherm, UK	1.5	3	4.5
Silicon diode	ДТ470	Lake Shore, USA	0.5	5	2.5
Temperature calibrator	CZ125	Omega, UK	0.5	1	0.5
Heating element	62M36A5X	Watlow, USA	0.05	10	0.5
Turbo-molecular pump		Leybold	8	2	16
Forevacuum pump	2НВР-9ОД	Russia	1.7	1	1.7
Forevacuum pump	2НВР-9ДМ	Russia	0.7	1	0.7
Vacuum gauge with low- and high-pressure lamps	L8350301	Varian, USA	4	5	20
Vacuum armature (vacuum lines, valves, headers, oiling)		Leubold, Germany	10		10
Goniometer Huber with refrigerator to 4°K	DISPLEX202N	Huber, Germany	62	1	62
Translational displacement table		Micromech	3	4	12
Rotary table		Micromech	3	1	3
Sapphire and diamond anvils		Russia	10	1	10
Cryomagnet 7 T	7THL	Janis, USA	85	1	85
Nitrogen tank		Russia	45	1	45
Helium devuar		Russia	4	3	12
High-clean gases	He, ^{3}He, CO, Ar	Russia			2
Multi-purpose polarizer		Gatchina, Russia	15	1	15
Disk chopper control system	Vector	CTDL, Germany	10	5	50

Total 455.4 KUSD

18. Position-sensitive gas-filled neutron detectors

Project leader: A.V.Belushkin

№	List of works	Cost	Times	Executor
1.	"Detector infrastructure" (clean rooms, technological equipment, gases, test benches)	40	2007-2010	FLNP manufacturing, purchase
2.	2D PSD system designing, manufacturing, testing (225x225 mm², 2.0 mm), scattered beam	70	2007-2008	FLNP manufacturing
3.	2D PSD system designing, manufacturing, testing (130x70 mm, 2.0 mm), incident beam	70	2007-2008	FLNP manufacturing
4.	Development of new DAQ-electronics and software for MWPC detectors with delay lines	25	2007-2008	FLNP manufacturing, regular electronics purchase
5.	Designing, manufacturing, testing of 2D PSD with individual readout and of DAQ electronics	80	2008-2009	FLNP manufacturing, regular electronics purchase

Total 285 KUSD

19. ZnS(Ag) scintillator-based position-sensitive scintillation detectors
Project leader: E.S.Kuzmin

Expense items	Cost	Period
Equipment and materials	20	2006
Exterior organization services	25	2007 – 2008
Bonus fund	10	2007 – 2008

Total 55 KUSD

Name	Firm	Cost per unit	Number	Sum
Photomultiplier matrix H9500	Hamamatsu	5350 USD	2	11000 USD
Electronic components	-	-	-	7000 USD
Engineering materials	-	-	-	2000 USD

Services	Cost
Mechanical structure engineering	5000 USD
Mechanical structure manufacturing	5000 USD
Electronics development	8000 USD
Electronics manufacturing	7000 USD

20. Portable cryogenic systems
Project leader: A.N.Chernikov

№	Name	Producer	Sum (KUSD)	Schedule time	Notes

1	Cryostand:			2007	
	- cryocooler PT410	Cryomech	40	2008	
	- temperature measuring device (model 370)	Lake Shore	10	2007	
	- thermometers	Lake Shore	6	2008	
	- evacuating equipment	Varian	10	2007	
	- experimental cryostat with control panel		30	2007	Designing and manufacturing
	- He3	Russia	13	2007	
	materials	Russia	5	2008	
2	Redecoration of room for cryostand		4	2008	
3	^{3}He-circulation cryostat for 0.4–3 K	Russia	50	2009	Designing and manufacturing
4	Cryostat for operation with superconducting magnets	Russia	60	2010	Designing and manufacturing

Total 228 KUSD

21. Development of IBR-2 spectrometer data acquisition systems and computing infrastructure in FLNP

Project leader: V.I.Prikhodko

№	Activity	Cost	Schedule times	Executor
1.	Engineering and manufacturing of development samples of new electronic blocks and testing benches	60	2007-2010	FLNP manufacture, accessories purchase
2.	Development, debugging, and optimization of DAQ-software	30	2007-2010	FLNP manufacture, purchase and updating of support software products
3.	Equipping of workplaces for engineers and programmers (purchase and updating of PC, CAD/CAE–systems, measuring and monitoring instruments, etc.)	40	2007-2010	Purchase
4.	Modernization of power supply systems and upgrading of computers of IBR-2 spectrometers	15	2007-2010	Purchase
5.	Modernization of control systems of choppers, executive mechanisms, and sample environment systems	40	2007-2010	FLNP manufacture, purchase
6.	Manufacturing of new data acquisition systems (hard-and software) in agreement with spectrometer development projects	-	2009-2010	FLNP manufacture
7.	Renewal of exhausted-resource special-purpose servers and	50	2008-2010	Purchase

	workstations, disks, subsystems			
8.	LAN architecture modernization, operational systems renewal	20	2007-2010	Purchase, FLNP manufacture
9.	Laying of backup communication lines and modernization of communication equipment	30	2009-2010	Purchase, FLNP manufacture
10.	Renewal of LAN exhausted-resource peripheral equipment (printers, copiers, and projection equipment)	40	2007-2010	Purchase

Total 295 KUSD

High Resolution Fourier Diffractometer

Project leader: A.M.Balagurov.

The 1992-year-created high resolution Fourier diffractometer HRFD is a unique instrument for carrying out neutron diffraction experiments requiring the interplanar spacing resolution on the level of 0.001. In the course of its operation on the HRFD there have been conducted numerous experiments of precise structural analysis of powders, investigation of phase transitions in powders and single crystals, measurement of residual internal stresses in bulk samples and a broad circle of HRFD users from Russia and other countries has formed. With a view to extending the possibilities of HRFD, improving its parameters and making it ready for operation at the new reactor IBR-2M some of HRFD units have to be modernized and the diffractometer should be equipped with additional devices of external conditions on the sample.

1. Status and research program

The high resolution neutron diffractometer is a complex and expensive instrument, which is why precise neutron diffraction experiments with high resolution (on the level $\Delta d/d \approx 0.002$ or higher) are only being conducted in a few most advanced neutron laboratories in the world. In Russia it may be done at FLNP JINR (Dubna) and PNPI (Gatchina) only. Moreover, the high resolution Fourier diffractometer (HRFD) at the IBR-2 reactor is one of three or four neutron diffraction instruments in the world where it is possible to do experiments requiring the resolution $\Delta d/d \approx 0.001$ or higher. The performance of the initial HRFD version is described in [**1**]. During the 1992 to 2004 period of HRFD operation some diffractometer components were replaced, the detector system was changed and the electronics for data acquisition and experiment control was radically changed. The HRFD lay-out is shown in **Fig.1**.

Today, the special purpose of HRFD is **precise structural analysis of powders** with an average unit cell volume of up to ~500 Å^3. The characteristic examples are investigations of mercury-based high temperature superconductors with different concentrations of oxygen or fluorine in the basal plane [**2, 3**] and of doped manganites with a colossal magnetoresistance [**4, 5**]. HRFD is also used to perform **analysis of single crystals** when its d_{hkl} unique resolution is needed, e.g., to study phase separation in the crystals $La_2CuO_{4+\delta}$ due to low-temperature diffusion of extra oxygen [**6**].

In addition to structural experiments, an essential part of HRFD schedule (up to 40%) is dedicated to applied research related to **measurements of residual stresses in bulk industrial components**. To realize this part of the program, special equipment was purchased. The measuring procedure of residual stresses in bulk samples with the HRFD is described in [**7**]. It is believed that as soon as the special-purpose diffractometer FSD is put into operation, all or most of internal stress experiments will go over to FSD.

2. HRFD operation at a cold neutron source

The HRFD is currently located at IBR-2 channel 5 on the side of which it is planned to install a cold moderator. A widely accepted opinion is that a high resolution diffractometer for powders should operate on a warm or even hot neutron beam. In fact it is true for a steady state reactor, i.e., for constant wavelength diffractometers, and, to a limited extent, for TOF diffractometers dedicated to the measurement of diffraction peak intensities at very small d_{hkl}. High resolution TOF diffractometers designed to analyze complex structures (with a unit cell volume over 200 Å^3) are advantageous to be used with sources **whose temperature is of the order of 100 K** like HRPD (ISIS) for example.

The test experiments with a cold source conducted in 1994 and 1999 showed that for relatively complex structures the best result is undoubtedly obtained if cold neutrons are used. In the wavelength range 4 – 10 Å the cold compared to comb-like moderator gives a 5 to 10 times gain. This makes it possible to register peaks at larger d_{hkl}, which is often a principal factor in the study of magnetic structures. Since the primary beam on the HRFD is formed with the help of a mirror neutron guide, **the cold moderator may be not large, namely, 150x150 cm^2**.

The HRFD specific feature is operation in the scanning mode sweeping the chopper rotation frequency (frequency sweep). The HRFD operation experience shows that optimum sweeps are 2-hour ones and the number of them is as a rule 3 to 10, i.e., the time of experiment is from 6 to 20 hours. This means that HRFD operation on a cold source will be only possible if **the time of stable operation of the source is not less than one day**.

3. Proposed HRFD diffractometer modernization

HRFD modernization aims at **increasing the intensity**, **reducing the background level**, **improving Fourier analysis parameters** and providing the diffractometer with additional devices for assigning external conditions on the sample. According to estimates these will about double the number of the conducted experiments, noticeably increase the precision of the obtained structural information, and essentially extend the diffractometer possibilities for conducting experiments over a wide range of temperatures and pressures.

3.1. Diffractometer intensity increase and background level decrease

Today the HRFD detector system consists of three detectors, two of which are at the scattering angle ±152°and the third is at 90°. The first two are mainly used for investigations of the structure of powders, the third is mainly used for internal stress measurements. The detecting element is Li-glass-based scintillators. From the present-day viewpoint the HRFD detectors have two disadvantages: a high sensitivity to γ-background and an insufficiently large solid angle. The disadvantages can be removed by introducing ZnS(Ag)-based scintillators and combined electronic-geometric focusing. To extend the d_{hkl} working range, HRFD must be equipped with a good position-sensitive detector to work at small and average scattering angles in the low resolution mode. The existence of such PSD will make it possible to accumulate information in the 3 Å to 20 Å range in parallel with high resolution spectra in the d_{hkl} range to 3 Å, which is often essential for structure solution.

3.2. Improvement of Fourier analysis parameters

The quality of Fourier analysis is influenced by a number of factors. One of the main ones is the degree to which the Fourier chopper follows the specified rotation frequency distribution law, which depends on the accuracy and stability of control systems operation. Important factors are also the intensity modulation depth of the chopper transmitted neutron beam and operation stability of systems forming the pick-up signals. Today, at the end of the 7-year period of HRFD operation some diffractometer components (chopper disk, control system) are close to exhausting their resource. Some of the other components could be replaced by better quality ones.

3.3. Creation of external conditions on the sample

At present to meet the purpose, the HRFD has a helium refrigerator (T ≥ 10 K), a furnace (T ≤ 600°C) and a high-pressure cell (for up to 6 kbar). To widen the spectrum of the conducted experiments it is necessary to purchase a helium refrigerator that will make it possible to reduce the temperature down to 3 K and continue work on putting into operation a high-pressure cell for pressures up to 10 – 12 kbar.

4. Required resources, cost and schedule times of HRFD modernization

In view to keeping the HRFD intensity on the world level, the solid angle of the detector system must be increased **~5 times**, i.e., achieve ~0.8 sr. This can be done on the basis of principles developed in the course of creation of a ZnS(Ag)-scintillator-based detector for the FSD. The cost of components together with expenditures for manufacturing a ZnS-detector with an area of 600 cm^2 (1 module) is 15,000$. A complete set enabling to have a solid angle of 0.8 steradian consists of 12 modules. Thus, the resulting cost of the new detector system is 180,000$. The detector could be manufactured by members of the FLNP detector group.

For work at small and average scattering angles a PSD with a resolution of ~0.3 cm and a length of about 30 cm is necessary to be purchased or manufactured. In both cases the estimated cost is around 25,000$.

The cost of detectors together with expenditures for HRFD components to be renewed and equipment for creating external conditions on the sample is summarized in **Table 1**.

Works on the project are to be carried out by specialists of the HRFD Group of the Diffraction Division.

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Table 1. The cost (in USD) and desirable dates of production (purchase) of some of the HRFD components in the framework of the modernization project.

Backscattering detector	190,000	2010	Complete set
PSD, Δx=0.3 cm, *l*=30 cm	25,000	2007	Purchase or production at FLNP
Refrigerator, T_{min}=3 K	45,000	2007	Purchase
New version of correlation analysis electronics	40,000	2008	Production at FLNP

Total: **300,000 USD**

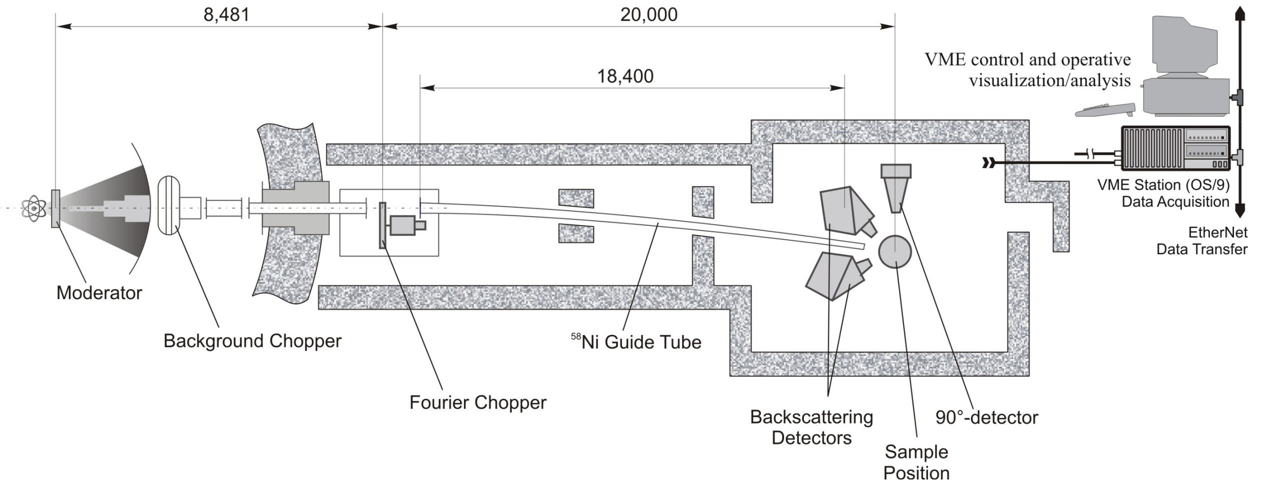

Fig.1. The HRFD layout. The chopper for elimination of neutrons between the main power pulses of the reactor (background chopper) is situated in the ring corridor and the fast Fourier chopper is immediately behind the wall of the ring corridor. The neutron beam on the sample is formed by a bent focusing neutron guide tube. Around the sample position there are installed the main wide-aperture detectors and detectors working in the low-resolution mode (low resolution detectors). Signals from the detectors are fed to correlation electronics.

Fourier Stress Diffractometer

Project leader: G.D. Bokuchava

In 1999 at the IBR-2 reactor in FLNP JINR the creation of the special-purpose Fourier diffractometer for internal stress measurements FSD started. In 2002 the first physical experiments were conducted. In spite of the fact that the construction of the FSD has not been completed yet, numerous experiments to measure residual internal stresses in industrial products, study elastic properties of novel composite materials and investigation of the experimental method itself are currently being carried out. To complete the construction of the FSD, extend its possibilities, improve its parameters and make it ready for work at the new IBR-2M reactor, it is necessary to complete the detector system, carry out the modernization of some of FSD units and equip it with additional devices for creation of special conditions on the sample.

1. Status and research program

The investigation of internal mechanical stresses in materials is of fundamental as well as of applied importance. The method of stress investigation using neutron diffraction appeared about 10 years ago and since then it has become widely applied thanks to a number of essential advantages over conventional methods. The most important advantage is that neutrons penetrate the material to a depth of 2-3 cm in steel and to 10 cm in aluminum. The advantages of neutron diffraction are so substantial that almost in all advanced neutron centers in the world there have been built diffractometers for internal stress investigations during the past few years.

The FSD belongs to the class of **high resolution diffractometers**. The high resolution neutron diffractometer is a complex and expensive instrument, which is why experiments with resolution on the level $\Delta d/d \approx 0.002$ or higher are only being conducted in a few most advanced neutron laboratories in the world. In Russia it may be FLNP JINR (Dubna) and PINP (Gatchina). The performance attributes and a description of the FSD are in [**1, 2**]. During the period of FSD operation actual possibilities of the diffractometer to solve certain problems have been revealed and the main directions of research have been identified. These are connected with the achieved resolution and intensity and accessible range of interplanar spacings d_{hkl}.

The basic part of problems is related to the **determination of the residual stress tensor in industrial samples and units**. The most frequent source of stresses is various technological processes. The research is of interest for manufacturers from the viewpoint of creating optimal properties of materials used and optimization of technological processes of production. The results help create optimal residual stress states in the different cross sections of the detail and consequently, improve its performance characteristics and life time. Typical in the field are investigations of residual stresses in the Zr/stainless steel adapter **[3]** and in the perforator striker **[4]** used in nuclear power industry.

Another important group of problems is **studies of residual stresses and elastic properties in advanced materials**, such as composite or gradient materials as well as different types of steel. Within the scope of these problems investigations of coexistence of different phases in a material and their joint impact on the elastic properties and residual stresses in the material are conducted. The research is important for the creation of materials with physical-chemical and elastic properties specified in advance. As a result, there appear possibilities to create new materials with predictable properties and behavior. Typical examples are studies of residual stresses and elastic properties in novel composite and gradient materials like W/Cu, WC/Co, Al_2O_3/Al. **[5, 6, 7]**.

2. FSD operation at the modernized reactor IBR-2M

At present the FSD diffractometer is installed on IBR-2 11A beam-line. The specific features of the investigated samples and of the experimental procedure for investigation of internal mechanical stresses result in that the observed diffraction peaks are mainly concentrated in the region $d_{hkl} \approx 1.5 - 3,5$ Å. This is why it is optimal to use **thermal neutrons and comb-like water moderator** to carry out such experiments.

The characteristic property of the FSD is the position of the 11A beam-line. On the way of the channel there is part of the moving reflector jacket. In addition, in the new IBR-2M reactor the active zone will be smaller than in the IBR-2, which means that the neutron guide of the beam will not view the active zone. This fact calls for creation of an orthogonal comb-like water moderator of complicated-configuration.

Since in the FSD the primary beam is formed by a mirror neutron guide, the water moderator can be not large, namely 150x150 cm^2.

3. FSD completion and further development

The development of the FSD is in the direction **of increasing the diffractometer intensity**, **background reduction, improving of the Fourier analysis parameters** and equipment of the diffractometer with additional devices of external conditions on the sample. According to estimates the solution of the problems will make it possible to **increase the number of the conducted experiments 10 times**, raise noticeably the precision of the obtained information, and essentially extend the possibilities of the diffractometer as to performing experiments over a wider range of temperatures and external conditions.

3.1. Diffractometer intensity improvement and background reduction

Today's FSD detector system consists of three detectors, two of which are at the scattering angles ±90° and the third is at 141°. The first two are the ASTRA-type detectors mainly used for internal stress measurements, the third is a backscattering detector mainly used in investigations of the structure of powders.

The traditionally employed detector systems have two disadvantages: an increased sensitivity to the γ-background and an insufficiently large solid angle. With the help of ZnS(Ag)-based scintillators it has become possible to remove the sensitivity to the γ-background in the ASTRA detectors. The second disadvantage – a small solid angle, is planned to be removed in the final version of the detector system (**Fig.1**) which is to consist of ASTRA detectors each containing 7 independent elements, i.e., the ones with separate electron signal outputs. Combined electron and time focusing of the diffracted beam will make it possible to **increase the solid angle to 0.29 sr in each ASTRA detector**. To date there has been installed three such elements in each ASTRA detector.

In addition, to carry out internal stress investigations, it is necessary to be able to single out a measured volume with a characteristic dimension of several cubic millimeters (gauge volume) in the investigated sample. To meet the purpose, there is a system of slits in the FSD. **The use of radial collimators** will not only allow the separation of the necessary volume inside the sample, but also will reduce the background and increase the employed solid angle of the detector.

3.2. Fourier analysis parameter improvement

The quality of correlation Fourier analysis is influenced by a number of factors. One of the main is how exactly the Fourier chopper follows the specified rotation frequency distribution law, which depends on the accuracy and stability of control system operation. Important factors are also the chopper-transmitted beam intensity modulation depth and the stability of the pick-up signal formation system. In the course of FSD operation some of the systems (chopper disk, control system) have nearly exhausted their resource. Some other FSD elements could also be replaced by a better quality ones.

3.3. Experiment control system improvement

Today the experiment control system NICS **[8]** includes VME server software with an OS-9 real-time operation system and interface programs initiated at SUN working stations. The VME server software allows users to execute control through a system of interface program commands initiated at SUN working stations in the FLNP domain. The user is able to control the system from any X-terminal or computer linked to the FLNP network. Unfortunately the possibilities of the OS-9 system are rather limited and therefore it seems necessary to **develop software under OS Windows**. This will simplify control of the experiment, reduce the time spent to write control programs and perform adjustment works as well as improve experimental data viewing.

In addition, the creation of **a system for monitoring and video survey of the sample** and sample environment will allow better control of the experiment and will reduce the sample positioning time.

4. Required resources, cost and schedule times of FSD completion

To complete the creation of the FSD electronic system and raise the FSD intensity to the world level, **ten modules of ASTRA detectors must be produced and installed**. The cost of components together with that of production of a ZnS-detector (ASTRA) with an area of 600 cm^2 (1 module) is 10,000$. The cost of completion of the detector system is thus 100,000$. The detector can be manufactured by the FLNP detector group. To achieve maximum performance parameters of the detector system, **radial collimators** with an estimated cost of 50,000$ need to be manufactured and installed. The cost of the FSD components to be manufactured or renewed and of sample environment equipment is reflected in the following table:

ASTRA detectors	100,000	2007	Complete set
Manufacturing of radial collimators for ASTRA detectors	50,000	2007	Order
New correlation analysis electronics	30,000	2007	Manufactured in FLNP
Neutron beam monitor	2,000	2007	Manufactured in FLNP
Experiment control software development	18,000	2007	Order

Total 200,000 USD

The project is to be executed by specialists of the HRFD Group of the Diffraction Sector.

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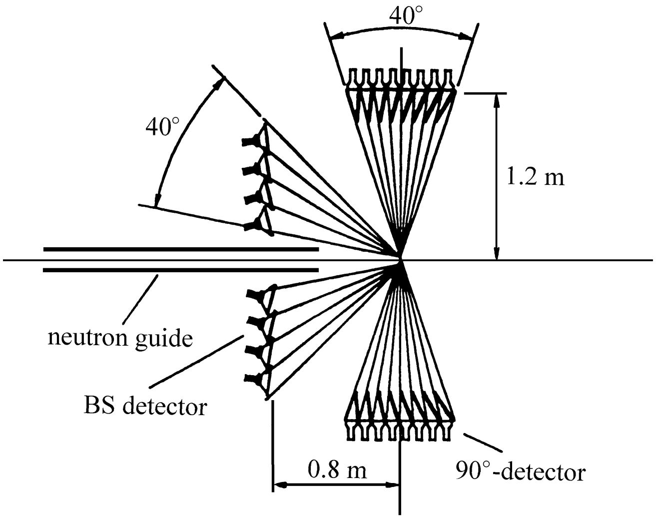

Fig. 1. The detector system of the Fourier diffractometer FSD. BS – BackScattering detectors ±141°. The 90° etector is the ASTRA detector system (left and right wings).

DN-2 Diffractometer

Project leader: A.I.Beskrovnyi

The Diffractometer DN-2 is one of the instruments that have been operating since the IBR-2 startup. The main directions of research with the diffractometer are determined by its interplanar spacing resolution (~0.01) and high neutron flux on the sample (~10^7 n/cm^2/sec). During the last time numerous experiments of investigation of powders, single crystals and biologic membranes to determine their atomic and magnetic structures and to study their kinetics and phase transition peculiarities have been performed with the diffractometer. To extend the possibilities of the diffractometer, improve its parameters and prepare it for work at the new reactor IBR-2M, some of the diffractometer components have to be modernized and additional sample environment equipment have to be introduced.

1. Status and research program

To the advantages of the DN-2 diffractometer there belongs its high luminosity (on the order of 10^7 n/cm^2/sec) and a wide accessible wavelength range (from 1 to 20 Å). The diffractometer employs three types of detector systems:

- Eight neutron counters CHM-17 at the scattering angles from 30 to 174°,
- Linear one-coordinate PSD with a 50 cm resistive wire and a spatial resolution of 5 mm,
- Two-coordinate PSD on delay lines with a sensitive area of 260x140 mm^2 and a coordinate resolution of 2.0 mm that is possible to be positioned at a wide variety of scattering angles (from 2 to 160 °) at a distance from a sample of 0.2 to 1.5 m.

The interval of accessible wavelengths together with the possibility of neutrons registration at the scattering angles 2° to 174° allows covering of the measured interplanar spacing range 0.7 to 60 Å.

The diffractometer equipment used includes a three-axis goniometer, close cycle refrigerator, high temperature furnace and a high-pressure toroidal cell. The parameters of the diffractometer and of the employed equipment make it possible to study [1-20]:

1. crystalline structures over a wide temperature range of 7 K to 1000 K,
2. magnetic structures,
3. phase transitions,
4. processes in the real time mode such as:
   a) solid phase chemical reactions,
   b) crystallization,
   c) hydration – dehydration,
   d) phase transitions.
5. diffuse scattering in imperfect crystals,
6. domain structures,
7. superstructure reflexes of low intensity (~0.1-0.01% of the main peak intensity) in modulated structures,
8. low-dimensional structures with a large elementary cell,
9. incommensurate modulated magnetic structures,
10. structures at high pressures.

2. Operation with a cold neutron moderator

It is planned to install a cold moderator on IBR-2M channel 6. Test experiments with a cold moderator model carried out in 1994 and 1999 showed that over the wavelength interval 4 – 10 Å the gain is from 5 to 10 times compare to the comb moderator. For complex structures with an elementary cell volume of ~300 Å^3 and larger, the main observed diffraction peaks are concentrated in the region $d_{hkl} \approx 2.5 - 10$ Å, which means that operation with a cold moderator allows registration of diffraction peaks with large d_{hkl} with good statistics over an acceptable period of time. This is especially important in the field of magnetic structure studies. The cold moderator is also essential for long-period structure studies. These are, for example, investigations of the structure and kinetics of lipid membranes with a period of 20 to 100 Å.

The measuring time of one diffraction spectrum on the DN-2 is, as a rule, from 2 to 20 hours. It means that DN-2 operation with a cold moderator will be only possible if the latter works stably for a period of not less than a day. The optimal temperature of the moderator is around 100 K.

3. Proposed DN-2 modernization

For further successful use of the DN-2, development of its experimental possibilities (including improvement of parameters), preparation of the diffractometer for work at the new reactor IBR-2M it is necessary to replace some elements of the diffractometer and equip it with new sample environment instruments.

3.1. Diffractometer intensity improvement and background reduction

The DN-2 detector system of six CHM-17 counters and one-coordinate PSD located at different scattering angles provides for a one-run measurement of spectra over an interplanar spacing interval of 1 to 60 Å. However, the solid angle of the CHM-17 counters is very small. To increase the intensity in measurements of powders with small or large elementary cells, two axial geometry multi-ring detectors at small and back-scattering angles need to be installed. This will increase the solid angle in ~200 times.

An increase in the intensity is possible by using evacuated neutron guide (it is filled with argon at present). The intensity will be also increased by replacing the head part of the neutron guide and by locating an additional neutron-guide section closer to the moderator. In view to reducing the background it is planned to install a neutron beam chopper with a vertical rotation axis in the ring corridor.

3.2. Sample environment equipment

The equipment used in the diffractometer includes a three-axis goniometer, close-cycle refrigerator for 7 – 300 K, high temperature furnace for up to 800 K and a high-pressure toroidal cell for up to 7 GPa at room temperature. To extend the DN-2 experimental possibilities, it is planned to develop and build an evacuated furnace (up to 1300 K). It is also necessary to buy a refrigerator with a minimum working temperature of 3 K and a thermostat for investigations of biologic samples over the temperature range 0 - 100ºC.

3.3. DN-2 electronics and software development

The electronic equipment, data acquisition systems and computer-aided control of the diffractometer are realized in VME standard. It is planned to introduce internet technology-based software of diffractometer control which enables remote control of the experiment and of experimental data analysis.

4. Required resources, cost and schedule times of modernization

The ring detector proposed for the project has been developed in FLNP (a prototype is successfully operating at YuMO). The detector can be produced at a plant and the supporting electronics – in the FLNP CM Division. The estimated total cost of two sets is about 50,000$. The electronic equipment of neutron beam chopper control costs 3,500$. The evacuated mirror neutron guide is to be designed and constructed at PINP, Gatchina. The cost of equipment for the proposed modernization of the DN-2 is summarized in Table 1.

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Table 1.

Ring detector and supporting electronics	150,000	2010	Purchase
Chopper electronics	4,000	2007	Purchase
Neutron beam chopper	3,000	2007	Purchase
Mirror neutron guide	20,000	2008	Purchase

Neutron guide casing and head part modernization	50,000	2008	Purchase
Refrigerator, T_{min}=3 K	45,000	2007	Purchase
Thermostat	8,000	2007	Purchase
High-temperature furnace	10,000	2009	Purchase
Measuring module electronics/software modernization	30,000	2009	FLNP

Total: 320 th. dol. USA

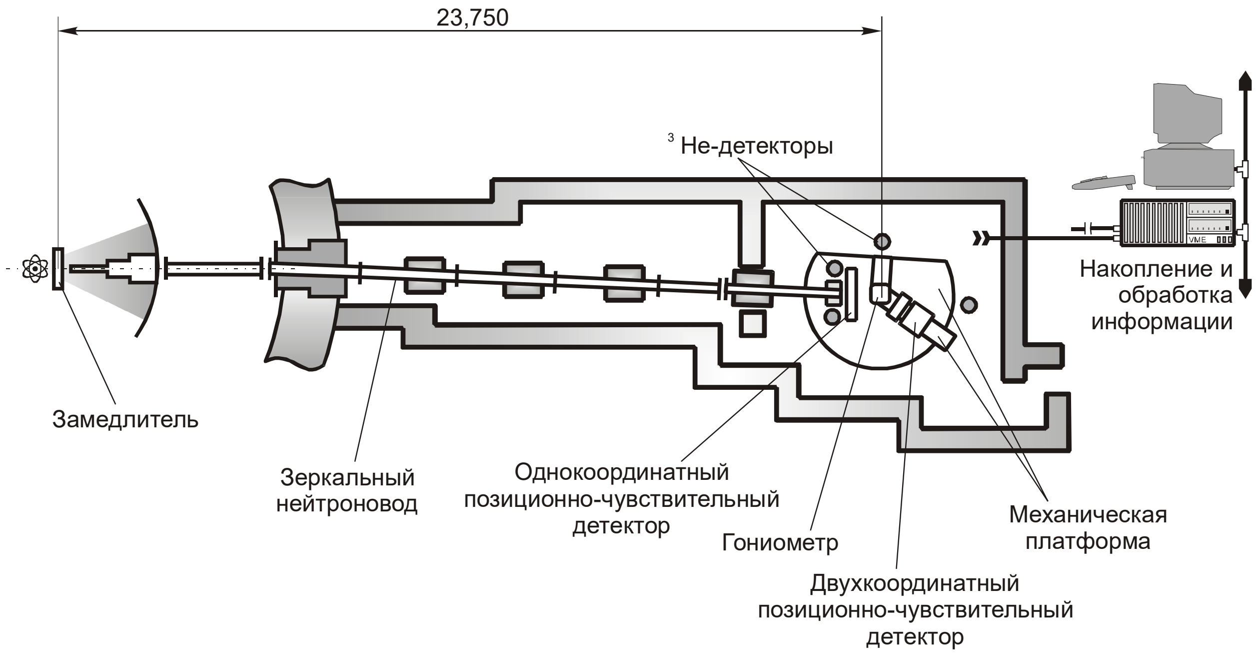

Fig. 1. The DN-2 diffractometer layout

EPSILON-MDS and SKAT diffractometer complex on channel 7A

Project leaders: A. Frischbutter (Potsdam, Germany, K. Ullemeyer, (Freiburg, Germany)

Channel 7A has a long flight path (100 m) and as a result, good time-of-flight resolution. The straight neutron guide, that is 92 m long (evacuated section – 76 m, Ar-filled section – 18 m) and is covered with Ni, yields a neutron flux of about 10^6 n/cm^2/s. A large cross section of 50x170 mm^2 allows using two instruments simultaneously. The diffractometer EPSILON-MDS is for investigations of internal stresses and microstrains, on the SKAT diffractometer experiments to investigate preferred orientations of crystal grains in polycrystal (crystallographic textures) are mainly carried out. With both spectrometers it is possible to investigate materials containing low-symmetry phases, which is an important advantage in the field of geologic materials research. The spectrometers' operation is supported by the German Ministry of Science and Education. The directions the research program for the EPSILON-MDS and SKAT diffractometers focuses on together with proposals for their modernization are discussed below.

1. EPSILON-MDS diffractometer for internal stress measurements in geologic samples: target setting and research program

The process of originating and development of earthquake sources in the different layers of the earth lithosphere cannot be completely understood and described without creating precise physical models of the geologic medium [1]. In doing so attention must be paid to the fact that the earth lithosphere consists of various-size blocks forming a hierarchic system. The blocks are heat-, movement- and physico-chemical bond-saturated to different extents [2]. They are influenced permanent vibrations on a wide geometric scale at a great variety of frequencies: from thermal vibrations of molecules to earthquakes or continental plate shifts. Externally supplied energy may lead to that some domains of the hierarchic system achieve instability and release excess energy as elastic waves.

In this connection there arises a problem of investigation of instability phenomena in rocks experiencing high temperatures and pressures, including the phase (polymorphous) transition.

The physical mechanism of such processes can be modeled and investigated in laboratory experiments. This allows carrying out repeated experiments at known and controlled parameters, which is necessary for obtaining reproducible results and investigation of process patterns at specified parameters. At the same time, however, laboratory experiments do not account for the variety of natural processes. Therefore, the laboratory results need field data-based verification. The question of the scale and type of the process initiating mechanical instability resulting in avalanche growth of formation breakings and as a consequence, in earthquakes remains open [3].

The second problem of immense practical importance is safe disposal of highly toxic radioactive and chemical wastes. One of the advanced technologies is their burial in rock salt fields characterized by their high plasticity, i.e. the capability to "heal" cracks. There is little known, however, about the kinetics of microprocesses that may take place in such rocks if the temperature increases under the action of radioactivity, for example. The question of open cracks or some physical mechanisms of transport that may arise in this case and enable filtration of underground solutions, including those containing ecologically hazardous components, remains open.

To perform investigations to solve the problems there is created the EPSILON-MDS instrument [4, 5] that allows simultaneous registration of neutron diffraction spectra, load induced macroscopic sample deformation, and acoustic emission spectra. Neutron diffraction makes it possible to measure crystalline lattice deformation and strains in the lattice at changing thermodynamic parameters [6-8] while measuring of acoustic emission yields information about arising breaks in interatomic bonds on the scale of microcracks and cracks. In this way, the process of preparation of micro damage can be observed in a complex experiment over a wide scale range.

1.1. Technical description of basic units.

The diffractometer EPSILON-MDS located on channel 7A of the IBR-2 reactor has a multidetector system, which presently consists of 9 radial collimators and 78 detectors. Channel 7A has a long flight path (100 m) making it possible to achieve good spectral resolution. The 92-m straight neutron guide gives a neutron flux on the sample of 10^6 n/cm^2/s.

The diffractometer is equipped with the uniaxial compression system EXSTRESS for *in-situ* experiments of cylindrical samples (30 mm in diameter and 60 mm high); the external stress is up to 150 MPa. Around the diffractometer there is a special cabin to keep stable the temperature of the sample increasing essentially the quality of the obtained data especially during long-time experiments and making it possible to compare the data obtained during different IBR-2 sessions. The temperature in the cabin (20 ± 0.15)°C is kept by the Eurotherm system. In addition, the diffractometer has an independent device to measure macroscopic deformation of the sample – laser extensiometer.

It is planned to carry out the modernization of the EPSILON-MDS with the aim of carrying out experiments to investigate stress and strain in geomaterials at raised temperatures and mechanical loads in combination with the possibilities provided by ultrasonic equipment allowing real time measurements of the velocity of elastic waves in the sample as well as of frequency, energy and spatial characteristics of acoustic emission events occurring in the sample in the course of the experiment [9,10].

2. **SKAT diffractometer for investigation of crystallographic structure of rocks: target setting and research program**

The use of neutron diffraction texture analysis with SKAT [11] in combination with other physical methods is needed to solve fundamental and applied problems in geology and geophysics [12,13]. The most urgent problems and targets are:

- Study of the origin, evolution, composition, structure, and properties of substances in the lithosphere at different thermodynamic parameters [14].
- Study of the relationship between crystallographic and form textures and physical properties of rocks (elastic, piezoelectric, magnetic, thermal, etc.) at different thermodynamic parameters [15-17].
- Study of metamorphic, geodynamic, and evolution processes in the lithosphere based on the data about the texture of deep and near-surface rocks [18-20].
- Development of the theory and experimental technique of paleotectonic strain and stresses basing on the crystallographic texture data [13].

2.1. Technical description

The SKAT diffractometer detector system of 19 detectors is arranged on a 2 m diameter installation ring axially symmetric with respect to the neutron beam. The scattering angle is equal for all detectors ($2\theta = 90°$). The investigated sample is placed in the center of the ring and rotates about the horizontal axis at 45° to the incident neutron beam in the goniometer that holds the equipment weight up to 30 kg. The SKAT spectrometer has a number of advantages over other instruments:

* Diffraction peaks corresponding to a particular value of d_{hkl} are registered by all detectors in identical situations (time channels) on all the spectra obtained from the measured sample. It is therefore not necessary to introduce corrections for the scattering angle and wavelength into calculations;
* Since the angular range of the detectors is 180°, a single rotation of the sample is sufficient to measure a complete pole figure, which reduces the time of the experiment 2 times;

* Positioning of the sample in the center of the detector ring makes it possible to surround it with various external action devices like heaters, high pressure cells, magnetic or electric field generating ones, etc.

3. Proposed modernization

3.1. New neutron guide

The neutron guide currently employed on beam 7A was built in FLNP in the mid-eighties of the last century, i.e. has operated for over 20 years and is now outdated. Geologic samples often contain minerals with a large elementary cell. On the flight path of beam 7A the IBR-2 reactor allows having wavelengths to 8 Å, or d_{hkl} = 5.6 Å, at the scattering angle $2\Theta = 90°$. In practice, however, it is not possible to register diffraction peaks at $\lambda > 5$ Å due to the fact that the neutron guide has a low efficiency in the long wavelength region. In view to increasing the total neutron flux of the neutron guide and improving the spectral distribution of the primary beam the existing neutron guide ought to be replaced by a new one during the reactor shutdown for modernization. In addition, a cold neutron source on beam 8 can be installed in such a way that it will be partly viewed by the new neutron guide, which will optimize the spectral distribution.

3.2. EPSILON-MDS sample environment improvement

Today, to conduct real time deformation experiments with EPSILON-MDS a single-axis compression system is used. In future, it is necessary to replace it by a system that will allow creating a wider range of conditions on the sample nonhydrostatic) to model actual processes occurring at different depths in the earth. In addition, there are plans of combined use of loading and ultrasonic equipment for the registration of acoustic emissions and measurement of elastic wave velocities in the sample, including at high temperatures.

3.3. SKAT diffractometer modernization

The SKAT is a comparatively new instrument and modernization proposals are therefore reduced to creation of a device for sample rotation around a vertical axis.

4. Required resources, cost and schedule times

Table. The cost (in USD) and desired schedule times of manufacturing (purchase) of some of EPSILON and SKAT components within the framework of the modernization project.

Neutron guide	400	2007-2010	purchase
Loading machine with a system of temperature variation	150	2010	purchase and manufacture
Ultrasonic pulse generator	10	2007	purchase
Acoustic signal preprocessor	16	2007	purchase
Chopper electronics	4	2007	purchase

Total: 580 th.dol. US

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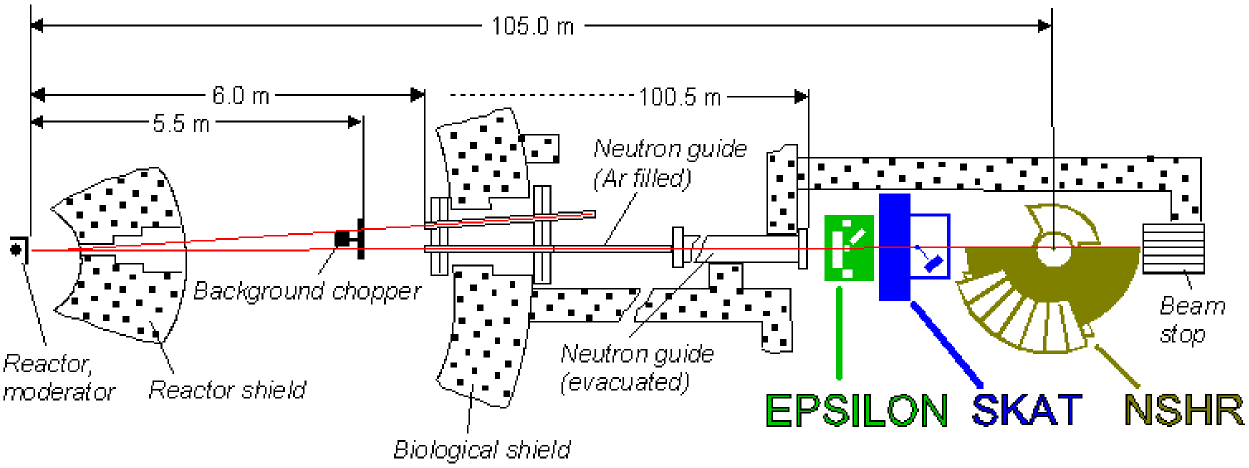

Fig. 1. The EPSILON and SKAT layout. The chopper for eliminating neutrons between the main power pulses from the reactor (background chopper) is situated in the ring corridor.

YUMO small angle neutron scattering spectrometer

Project leader: A.I.Kuklin

The project is aimed at modernization and development of the small angle neutron scattering spectrometer operating on IBR-2 beam 4. The project makes provisions for continued use of the existing components of the spectrometer without any decrease in their operation time for the experiment. The realization of the project will make it possible to qualitatively change the character of the obtained data (by changing the type of the detector), extend the range of accessible scattering vectors, increase experimental data acquisition rate, and improve resolution and background conditions. The existing number of users will become essentially larger thanks to the modernization.

1. Status and research program

Small angle neutron scattering is being widely applied for investigations of the subatomic structure of substances as an efficient method for the solution of fundamental as well as important technological problems. With the YUMO spectrometer investigations in condensed matter physics, physics and chemistry of disperse systems, aggregates of surface-active substances, biophysics and biology [1, 2], polymeric materials [3, 4], metallurgy [5], materials science [6], etc., are being conducted. An important peculiarity of small angle scattering is that it allows analysis of the structure of disordered systems. This technique is often the only way to obtain information about the structure of systems with chaotic or partially ordered distributions of scattering density inhomogeneities in a range of 10 - 10000 Å. It allows investigation of the disperse structure of alloys, powders, glasses (phase separation mechanism, size and extent of particle polydispersion), polymer structure peculiarities in the different aggregation states, weight and geometric characteristics of biological molecules and their complexes, submolecular biological structures such as biological membranes and viruses. An essential difference between coherent neutron scattering lengths of hydrogen and deuterium together with the possibility of specific deuteration of macromolecules and submolecular structures makes small angle neutron scattering indispensable in investigations of biological and colloid objects as well as of polymers and liquid crystals.

2. YuMO operation with a cold neutron source

Almost all present-day small-angle scattering spectrometers operate at a cold neutron source. This is chiefly due to the necessity of covering a wide interval of momentum transfer Q with a minimum possible value of Q. The specific feature of the YUMO geometry is direct visibility of the reactor active core. This allows having (without a neutron guide) a high neutron flux on the sample with the help of a comb-like moderator at room temperature [11]. The most suitable opportunity for YUMO is, however, a moderator enabling a high flux in both thermal and cold regions of the neutron spectrum. An optimal size of the moderator is 200x200 mm.

3. Proposed YUMO modernization

The spectrometer parameters to be improved through modernization are the range of accessible scattering vectors $Q_{min} - Q_{max}$, experimental data acquisition rate, detectors type, resolution, and the background conditions.

1) **The Q range** will be increased by means of changing detectors, excluding the non-evacuated flight path, improving neutron beam collimation. Two position sensitive scattering detectors (PSD)

and one straight beam detector are to be installed. The first PSD is to be situated in the first position (2 m from the sample) and the second PSD is to be able to take positions at a distance from 5 to 12 m from the sample. The realization of the two-detector system requires changing the collimation system, electronic equipment (data acquisition system) and implies qualitative changes in the software. In addition, joint analysis of the experimental data from the different detectors demands improvement of the existing technical approach. The proposed changes are based on technical [7] and scientific achievements [8] and on the existing software [9, 10] reducing considerably the corresponding expenditures.

2) **An increase in the experimental data acquisition rate** will be achieved by means of simultaneous registration of the scattered neutrons with several detectors arranged in such a way that they should cover the entire required (accessible) interval of scattering vectors, by increasing the efficiency and working area of the detectors as well as by improving background conditions.

3) Since in the YUMO the resolution function is mainly determined by the geometrical contribution (the pulse width contribution is small), **its decrease** will become possible by means of improving the position resolution of the detector and of the corresponding collimator.

4) The possibility of measurements of samples with small scattering cross sections will be provided by means of decreasing essentially the background with the help of the new chopper and the new collimation system as well as by using advanced detectors and detector electronics.

5) **The sample environment** will be extended to enable investigations over a wider range of external conditions on the sample. This, in the first place, concerns the possibility of carrying out rheological investigations, investigations under pressure, under the action of external magnetic fields, experiments with a rotating sample and over an extended temperature interval.

4. Required resources, cost and schedule times of YuMO modernization

Table 1. The cost (in USD) and desired schedule times of manufacturing (purchase) of some of YuMO components within the framework of the modernization project.
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PSD (second)	280,000	2010	Complete set
Chopper	45,000	2009	Purchase/ manufacturing in FLNP
Detectors and collimation system	80,000	2007	Purchase/ manufacturing
Electronic and Computing equipment	35,000	2010	Purchase
Sample environment	155,000	2010	Purchase/ manufacturing

Total: **595,000**

The work on the Project will be carried out by the YuMO group.

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Table 2. The main parameters of the existing and modernized YuMO instruments.

Parameters	Before modernization	After modernization
Flux on sample	10^7 - $4x10^7$ n/(s cm^2)	10^7 - $4x10^7$ n/(s cm^2)
Wavelength range	0.5 Å to 8 Å	0.5 Å to 14 Å
Q-interval	$8x10^{-3}$ – 0.5 $Å^{-1}$ *	$4x10^{-3}$ – 1 $Å^{-1}$ @
Investigated object size range	10 - 500 Å	8 - 1500 Å
Measured scattering cross section	0.01 cm^{-1}	0.002 cm^{-1}
Calibration (normalization) system	V standard during experiment	V, H_2O, graphite
Collimation type	Axial	Axial
Detector system	2 scattered neutron detectors 1 straight beam detector	2 PSD of scattered neutrons, straight beam detector, monitor
Automatic sample control	14 samples in a special box	24 samples in a thermostat box
Temperature range	from –20°C to +130°C	from –270°C to +1000°C
ΔQ/Q resolution	5 - 20%	2 - 8%
Controlled parameters	Starts, temperature, V-standard, sample position	Starts, temperature, evacuation, V-standard, sample position, detector position, monitor, chopper, reactor power

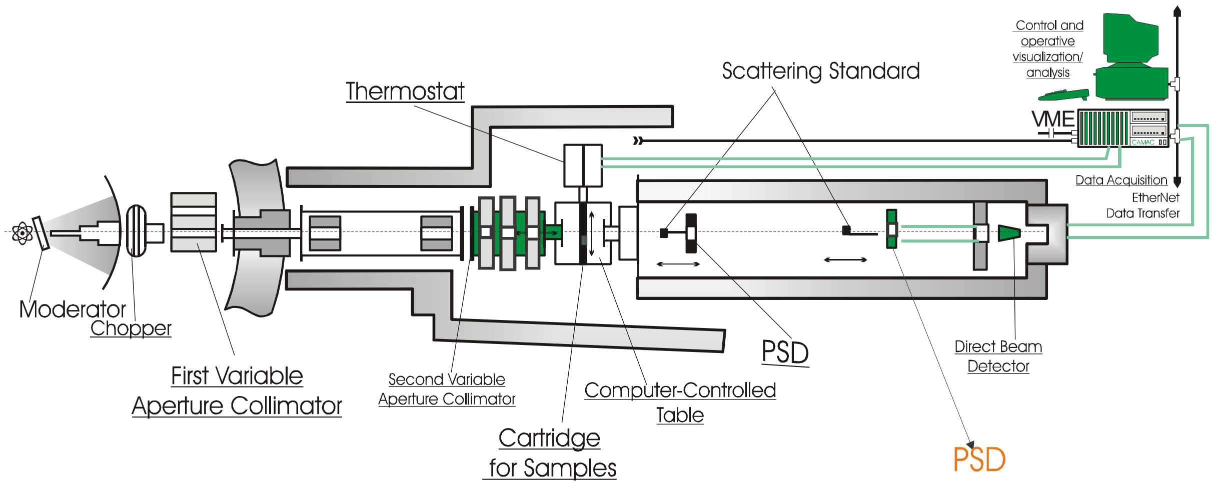

Fig. 1. The YUMO spectrometer lay-out. The names of the YUMO components to be modernized are underlined.

Backscattering spectrometer NERA for simultaneous investigations of atomic structure and dynamics

Project leader: I.Natkaniec

The backscattering geometry technique, in which irradiation of the investigated sample with a "white" beam from a pulsed source is used, provides a unique possibility of simultaneous investigation of neutron diffraction and neutron inelastic scattering. It is thus possible to investigate simultaneously the structure and the dynamics of the sample in dependence on the external conditions on the sample. The experiments carried out in FLNP in the 1970s show that the method is especially convenient for investigations of polymorphism and phase transitions in liquid-crystalline materials as a function of temperature and pressure.

1. Status and research program

The spectrometer NERA was designed and constructed at the IBR-2 in 1986-92 [1] by a collaboration of G.Newodnicanski Nuclear Physics Institute in Krakow and Frank Laboratory of Neutron Physics. Since startup in 1993 the NERA is employed in the user mode for inelastic neutron scattering and neutron diffraction investigations in the field of molecular dynamics and phase transitions. Every year about 15 proposals for experiment are realized resulting in about 10 articles in research journals and about 20 reports at international conferences.

NERA-aided investigations of current importance are reflected in the list of literature for the years 2003-2004. [2-21]. In the last 5 years investigations of biologically active materials have been the main field of NERA research [2,11,12,18,19,20,22]. Neutron spectroscopy enables very precise verification of quantum mechanical calculations of the structure, dynamics and electronic properties of molecules in such materials. With a similar aim urea [4] and methanol [23] as examples of compounds with hydrogen bonds were investigated. Works to investigate phase transitions and dynamics of methyl groups in methyl benzol compounds [14,15], which resulted in the choice of mesitylene-based solutions as a neutron moderator for the cold neutron source at the IBR-2, must be also mentioned.

3. Proposed modernization

The spectrometers NERA at IBR-2 and TOSCA at the pulsed neutron source ISIS are still best instruments of the world level for neutron spectroscopy of hydrogen-containing materials. Competitive instruments are being created at new high flux neutron sources in the USA and Japan. In the course of NERA operation at IBR-2 the cost of spectrometer operation, renewal of detectors and electronics modernization amounting to 10-15 th. USD was paid from annual Polish dues to JINR. In the period from IBR-2 shutdown to IBR-2M startup more substantial modernization of neutron guide 7B, which is one of the NERA basic components determining the neutron flux on the sample, must be carried out, which is quite costly. An optimal solution is complete replacement of the existing mirror neutron guide, which was built using technologies of the 1970's, whose resource is exhausted. Today's technologies of building evacuated mirror neutron guides allow having a ~10 times higher output neutron flux. In the NERA case, optimal is a "ballistic" neutron guide employing the idea of neutron capture from a maximally large accessible area of the source surface, transport of the neutron flux at a large distance over a large cross section mirror neutron guide, and concentrating of the beam on the sample with the help of a conic supermirror section. With limited financing, the neutron flux in the NERA spectrometer can be increased by replacing the argon inflated head section and introducing a supermirror concentrator behind the evacuated section of the existing neutron guide (fig. 1).

4. Required resources, cost and schedule times of modernization

Table 1. The cost (in USD) and desired schedule times of manufacturing (purchase) of some NERA components under modernization project.

7b neutron guide modernization: 1 – complete neutron guide replacement 2 – replacement of argon inflated head section of neutron guide (12 m) and installing of supermirror beam concentrator in front of sample (10 m)	 450,000 150,000	 before 2010 before 2010	Complete set purchase Neutron guide section purchase
Renewal of spectrometer evacuating and sample environment equipment	50,000	before 2010	Equipment purchase
Detector system renewal	50,000	before 2010	Purchase and manufac-turing in FLNP
New electronics block of neutron energy analyzers positioning	30,000	before 2010	FLNP manufacturing

Total: 1 – neutron guide replacement 580,000 USD
2 – neutron guide modernization 280,000 USD

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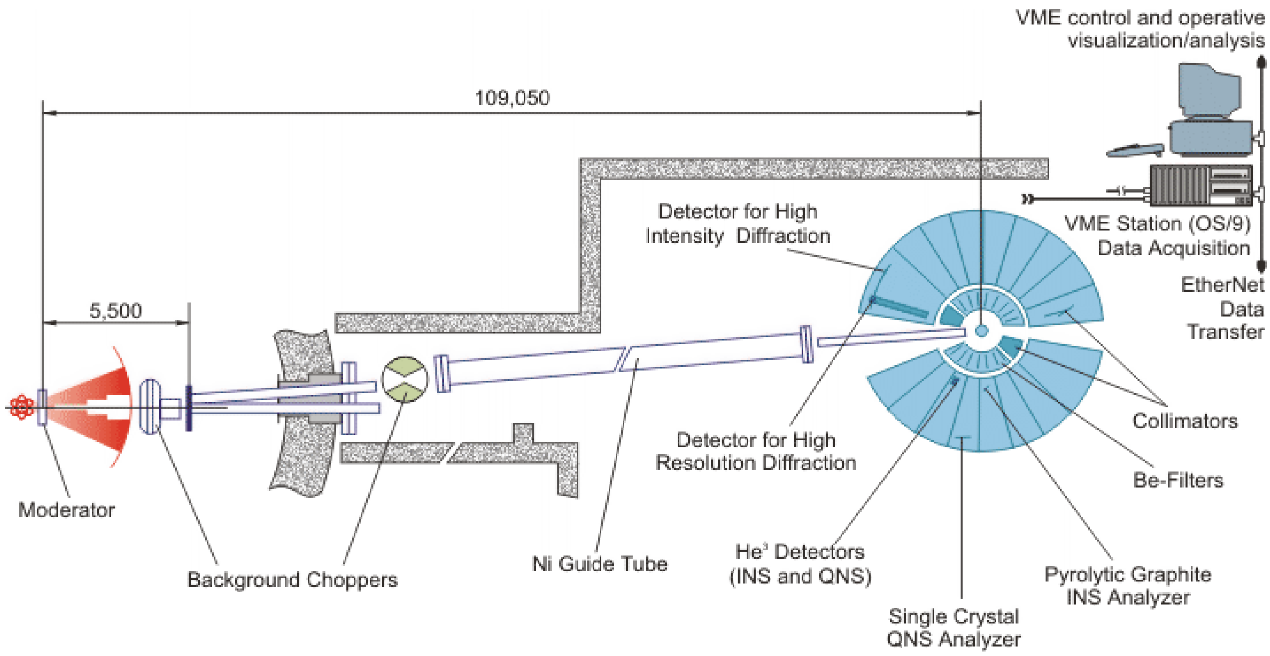

Fig. 1. The scheme of the neutron guide and the NERA spectrometer at IBR-2 channel 7b.

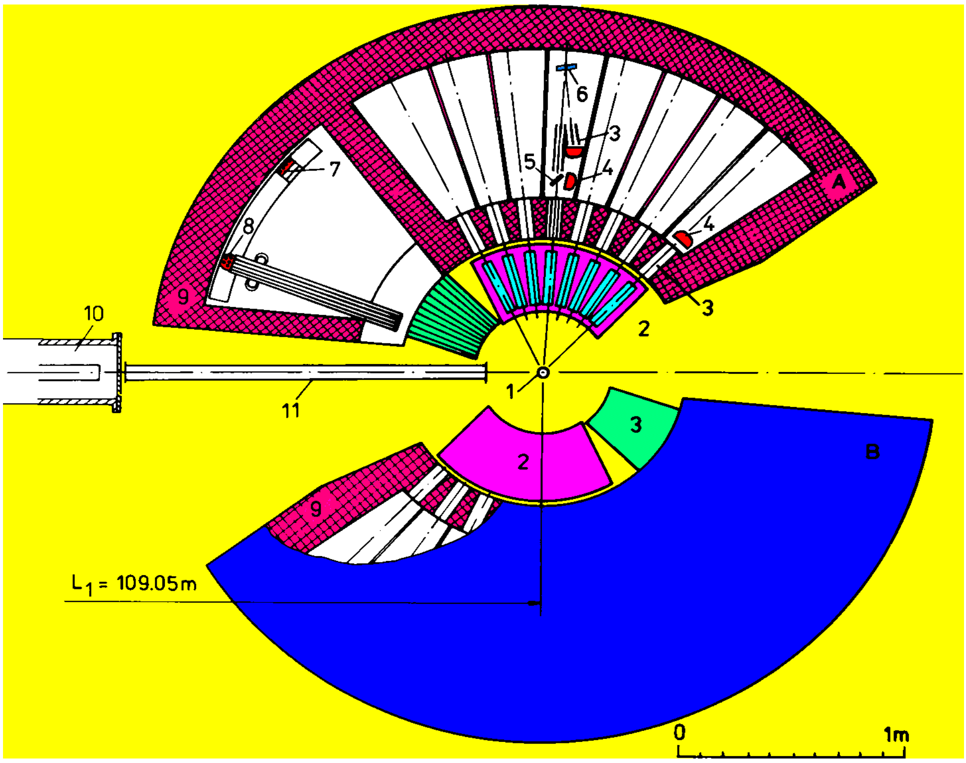

Fig. 2. The scheme of basic NERA elements.

1 - sample, 2 - Be-filters, 3 - collimators, 4 - ^{3}He detectors (INS and QNS), 5 - PG analysers (INS), 6- single crystal analysers (QNS), 7 – detectors for high intensity diffraction, 8 – detectors for high resolution diffraction, 9 - spectrometer shielding, 10 - Ni-coated mirror neutron guide in a vacuum tube, 11 - vacuum neutron guide.

Inelastic scattering spectrometer DIN-2PI

Project leader: A.V.Puchkov.

1. Status and research program

The inelastic scattering spectrometer DIN-2PI installed and operating on IBR-2 channel 2 since 1985 has a classical direct geometry configuration with a 20 m flight path in front of the sample and a 7 m flight path behind the sample. The DIN-2PI has a ^{3}He-counters-based detector system covering the scattering angle interval 3º-134º and a system of rotating collimators arranged in the ring corridor of the reactor to suppress the background. The sample housing cell shaped as a 1200 mm diameter cylinder 800 mm high allows using a wide variety of sample environment systems. The general scheme of the spectrometer is shown in Fig.1 and its technical characteristics are described in [1].

Today, the optimum operation mode of the spectrometer is for experiments with the primary neutron energy ~(2-20) meV. It provides satisfactory resolution of elastic or inelastic scattering (~5%) and a reasonable measuring time allowing us to have the necessary statistical accuracy of the experimental data. The long-time experience of DIN-2PI operation for the experiment has shown that one of the main advantages of the spectrometer is low background and «purity» of the obtained experimental data because of the absence of side effects causing distortion of the scattered neutron spectra.

The configuration of DIN-type spectrometers is optimal for obtaining information about the scattering pattern (or the dynamic function of scattering) over a wide range of the dynamic variables Q and ε for solids as well as liquids. The traditional directions of research, which are being conducted with and developed for the spectrometer, are:

1. Investigations of liquid metals (Na, Ga, Pb, K) and liquid metal systems with admixtures (K-O, Pb-K, Na-Pb melts) [2-3].
2. Investigations of ionic hydrate or hydrophobic solutions [4], including pure aqueous dispersions of carbon particles (fullerenes, schungite, soot).
3. Investigations of quantum liquids in the «bulk» state [5] and in the limited geometry conditions [6].
4. Investigations of multicomponent and amorphous systems, including solid solutions, metal oxides or hydrides, superionic conductors, and triple admixture systems [7-8].
5. Investigations of reactor materials over a wide temperature range to solve problems in the field of safety of nuclear power facilities.

On the DIN-2PI there can be realized, as an auxiliary one, the time-of-flight diffraction mode which can be used in particular, to obtain the structural data about the melts K, Na, Pb, Pb-K, Na-Pb, Li-N).

3. Proposed DIN-2PI modernization

The main DIN-2PI disadvantage today is low neutron intensity in the energy range of several meV. In this parameter it yields an order of magnitude to foreign analogs (IN6 (ILL), V-3 (BNSC), FOCUS (PSI)) whereas the IBR-2 is currently the highest intensity pulsed source of thermal neutrons in the world. The reason lies in the absence in the DIN-2PI configuration of a cold moderator and a mirror neutron guide, which are indispensable attributes of such instruments in the West. The solution of the two problems is the most important stages of modernization of the DIN-2PI spectrometer determining the entire future of the instrument.

3.1. Cold moderator

The experiments conducted with the cold moderator model installed on IBR-2 channels 4, 5, 6 at the moderator temperature 50-70 K show that the intensity gain in the neutron wavelength interval ~ (4-6) Å is about a factor of 10. It is just the wavelength interval that is most frequently used in experiments with DIN-2PI. However, to be able to work at higher neutron energies (15-20 meV), it is desirable that the cold moderator could be either removed from the beam or be filled with room-temperature water. An important DIN-2PI advantage is that changes in the characteristics of the neutron spectrum emitted from the moderator due to a change in the moderating substance during the reactor cycle are not essential for the normal operation of the spectrometer.

3.2. Mirror neutron guide

Until recently it has been considered that the use of a mirror neutron guide (MNG) in the DIN-2PI scheme is not effective for the three reasons:

- large natural divergence of the employed beam (~ 0.01 rad); in the case of natural nickel such critical scattering angle is only achieved for neutron wavelengths > 6 Å;
- large distance from the moderator surface to the site where MNG can be physically installed (~ 6 m);
- about equal dimensions of the source area and the neutron guide cross section (200x200 mm^2).

At the same time, recent years' development and introduction into practice of multilayer supermirrors for MNG providing a double and more critical scattering angle have made it possible as well as necessary to reconsider the situation with MNGs for DIN-2PI. The performed estimates show that using a ~12 m MNG (transition from 200x200 mm^2 to 100x100 mm^2 cross section) it is possible to have a 5-10 times intensity gain in the neutron wavelength interval of interest. In addition, a converging MNG will allow the use of significantly smaller samples, which is also very important in the case of the DIN-2PI spectrometer.

3.3. Additional scattering angles

For the reason of strength properties, in the original version of the DIN-2PI spectrometer the second evacuated flight path was to have a few sections arranged in such a way that they should cover the entire scattering angle interval from 3 to 160°. For a number of reasons connected with anticipated erection of some equipment on the neighboring channel 3, two of the sections have not been installed.

It is proposed to install additional detectors to cover the scattering angles 50-70° and 90-110°. This will make it possible to conduct experiments over the entire interval of dynamic variables corresponding to the scattering angles 3-160°. This is extremely important for the solution of a wide spectrum of problems related with reconstruction of the scattering law S(Q,ω) and measurements of the dispersion curves of polycrystalline materials the study of which with a time-of-flight spectrometer has a number of advantages. To install additional detectors, essential alterations to the structure of the evacuated neutron guides and biological shielding of the second flight path must be made.

3.4. Small angle scattering interval

The number of problems solved with the DIN-2PI can be made essentially larger if the scattering angles 1-3° are employed. This is most essential when diffraction experiments, for which the interval of Q ~ (0.1-0.5) $Å^{-1}$ is a highly informative region, are conducted. It is possible to extend the small angle scattering interval if minor modifications to the structure of the spectrometer are made in the area of the direct beam output. Preliminary estimates show that the use of the scattering angles on the order of ~ 1° can be expected in future.

3.5. Sample environment

At present the regular sample environment provides us with the temperature interval from 1.5 K to 1200 K. However, for the solution of a number of problems in particular, those the nuclear industry is facing, it is necessary to extend the interval to higher temperatures. In the current year, the thermostat TS3000 is to be commissioned, which will open wide possibilities for carrying out a great number of investigations of practical importance that are yet not feasible to carry out with the neutron method at temperatures up to 3000 K.

The presently existing MAX ORANGE cryostat-based cryogenic equipment employs liquid helium to reach the temperatures 4 -300 K. It seems expedient to purchase a close-cycle refrigerator that does not require liquid helium to create temperatures in the range.

4. Estimated cost of proposed measures

Cold moderator	500,000	2010	FLNP manufactured
Mirror neutron guide	120,000	2010	Purchased/ partially manufactured in FLNP
Installing of additional section of second flight path, equipment with detectors and electronics	250,000	2010	Manufactured and installed by PhEI
Small angle scattering interval extension	50,000	2008	Manufactured and installed by PhEI
Refrigerator, T_{min}=70 K	25,000	2007	Purchase

Total: 945,000 USD

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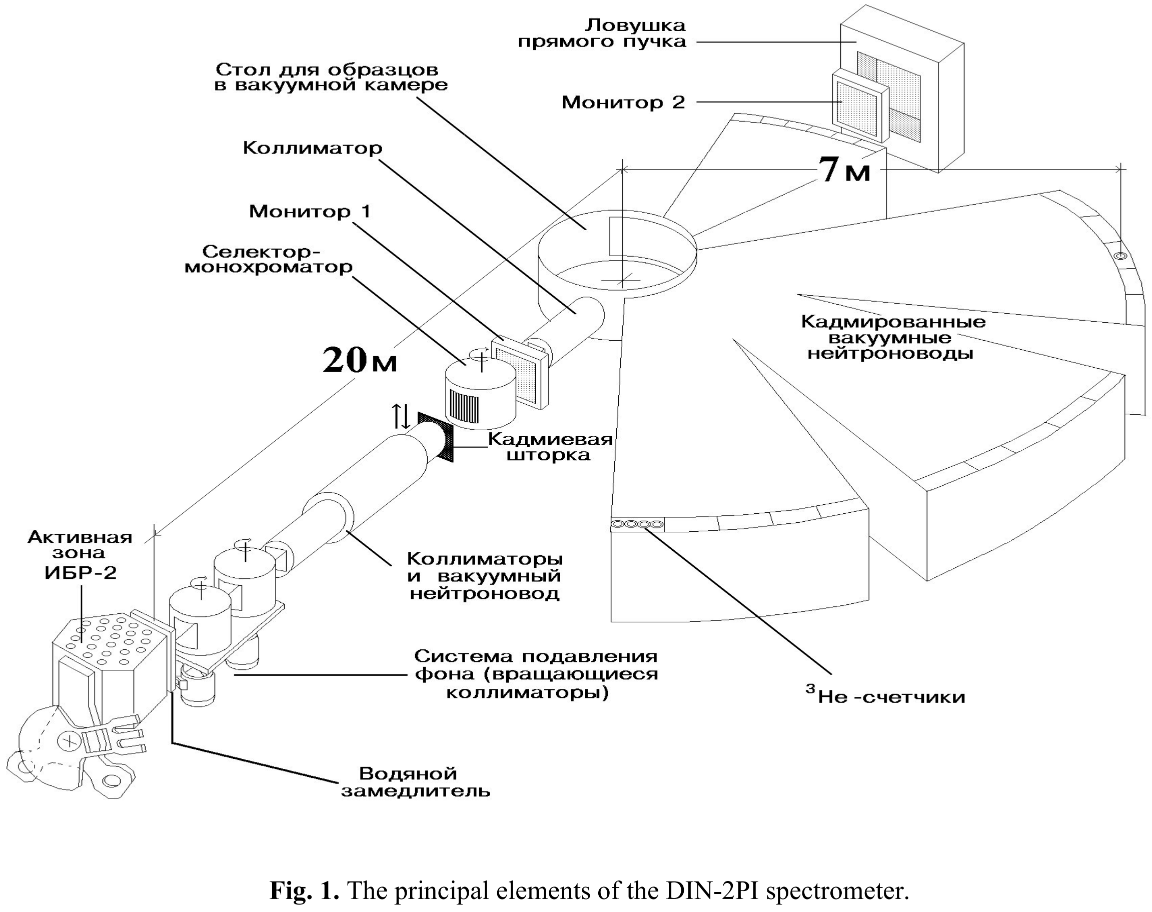

Fig. 1. The principal elements of the DIN-2PI spectrometer.

Polarized neutron spectrometer REMUR

Project leader: A.V.Petrenko

The REMUR spectrometer created in 2002 is a unique instrument for carrying out experiments in the field of polarized neutron reflectometry and small-angle scattering. During the time of REMUR operation numerous investigations of multilayer magnetic films, multilayer polymeric films and of superconducting films have been conducted and a broad circle of REMUR users from Russia and other countries have formed. To extend the REMUR capabilities, improve parameters and prepare REMUR for work at the new reactor IBR-2M with a cold moderator, it is necessary to update some spectrometer components and install additional devices of external conditions on the sample.

1. Status and research program

The REMUR spectrometer is a polarized neutron reflectometer with a possibility of measuring polarized neutron small-angle scattering.

The REMUR has two measuring modes:

1) The reflectometry mode (reflection at small glancing angles) allows investigation of neutron reflection from layered structures at the glancing angle 3÷10 mrad, has a spatial resolution on the order of 10÷100 nm and measures spatial nuclear and magnetic profiles to a depth of about 1 μm. The spectrometer in the reflectometry mode can operate in the regime of single reflection from polarizer 2 (higher intensity) and in the regime of double reflection, i.e., successive reflection from polarizers 1 and 2 (higher polarization).
2) The small-angle mode (reflection at large glancing angles, small-angle scattering in bulk samples) allows investigation of neutron reflection at the glancing angle 5÷20° and has a spatial resolution of 0.2÷1 nm. In the small-angle mode the beam is polarized with the help of a multi-slit polarizer.

The functional scheme of the spectrometer is in Fig. 1. The technical characteristics of the spectrometer are described in [1]. The RENUR main purpose is neutron reflectometry investigations of the magnetic properties of surfaces and thin films and investigations of the diffuse scattering of polarized neutrons with complete polarization analysis. Typical examples are the investigations of the structure of the multilayer films $^{56}Fe/^{57}Fe$ [2], of the magnetic field distribution in the superconductor $Yba_2Cu_3O_7$ [3], and of Fe/Cr multilayer films with giant magnetic resistance [4]. Non-magnetic samples are also investigated with the spectrometer. Typical are investigations of self-organizing multilayer polymeric films by measuring diffuse neutron scattering [5].

2. REMUR operation at a cold neutron source

The REMUR spectrometer is situated on IBR-2 channel 8. On the channel a cold moderator is to be installed. This will essentially raise the efficiency of spectrometer operation because the spectrometer intensity is proportional to λ^2, where λ is the working neutron wavelength, in the reflectometry mode and is proportional to λ^3 in the small-angle scattering mode.

The REMUR operation experience shows that a typical measuring time of one spectrum is 5÷6 hours. To carry out complete polarization analysis it is necessary to measure five spectra. So, **the time of stable operation of the cold source must be not less than one day.**

The cold moderator is also to satisfy the requirements:

1) The most important wavelength interval is 2÷20 Å.
2) The wavelength corresponds to the spectrum maximum 4 Å.

3) The employed wavelength interval is 1÷25 Å.
4) The dimensions are:
   A) 200 mm (width) x 235 mm (height) — maximum
   B) 150 x 180 mm^2 — minimum permissible
5) The center of the moderator is to remain at the present-day height or can be raised with respect to the present-day position. **No downward displacement of the moderator center with respect to the present-day position is allowed.**
6) The shape of the moderator is to satisfy the maximum integral neutron flux condition.
7) The maximum allowed thermal neutron pulse duration is 400 μs.
8) The allowed intensity instability is 1 % in 5 hours.
9) The frequency of breaks in the operation is every 3÷5 days.

It is also desirable that the moderator will work effectively at room temperature. A possible solution is to divide the moderator into two, cold and warm, parts with respect to the height or situate the cold and warm moderators one over the other by shifting them over the height of the moderator (without moving them away from the reactor).

3. Proposed REMUR modernization

The tasks are:
1) Reduce the background of fast neutrons and γ-rays and increase the neutron flux in the reflectometry mode by installing a focusing neutron guide;
2) Create the new to replace the existing background chopper;
3) Create the new to replace the existing polarizers;
4) Replace the outdated equipment;
5) Provide measurements in a cryostat with a field of H=3 T by means of creating a nonmagnetic goniometer for the cryostat;
6) Provide measurements with a field flowing out of the sample surface by means of installing a cryogenerator;
7) Extend the temperature interval to 0.3 K ÷ 600 C with the help of special inserts in the cryostat;
8) Complete the creation of the block of reflectometry detectors;
9) Replace one-coordinate PSD of the reflectometry mode with a two coordinate one with a working area of 200x200 mm^2;
10) Create and introduce into the spectrometer scheme a neutron polarization analyzer with a working cross section of 200x200 mm^2;
11) Update the spectrometer software.

The cost of the REMUR components to be renewed is indicated in **Table 1.** The REMUR after-modernization general scheme is in the figure of the project **«Polarized neutron reflectometer with atomic resolution (REFAT)»** (beam 8a).

4. Required resources, cost and schedule times of REMUR modernization

1. FLNP Experimental Workshops FLNP – 10 000 standard hours.
2. JINR Experimental Workshops – 15 000 standard hours.
3. FLNP Design Bureau – 1 500 standard hours.
4. Cost of materials and manufacturing works – 56 th.USD per year.
5. Staff members on the project – 5 persons (staff members of the Scientific and Experimental Division of Neutron Investigations of Condensed Matter, FLNP).

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Table 1.

Collimators	3	2007	FLNP manufactured
Shielding block of reflectometric mode detectors	15 000 st.hours	2007	FLNP or EW JINR manufactured
Position-sensitive detector	6	2007	FLNP finishing
Polarization analyzer	90	2010	Purchase
Materials	35	2010	Purchase
Equipment	25	2010	Purchase
Devices	10	2010	FLNP manufactured
Control and acquisition system	10	2007	FLNP developed
Nonmagnetic goniometer for cryostat	11	2007	Purchase
Power supply for cryomagnet	15	2007	Purchase
Insert in cryostat for work at T=0.3 K	20	2007	FLNP manufactured
Insert in cryostat for work at T=600 K	10	2010	FLNP manufactured
Cryogenerator for magnetic measurements at T=10÷400 K	40	2007	Purchase
System for hydrogen saturation of samples	5	2007	FLNP manufactured
Finishing of rotating platform	10	2007	FLNP manufactured
Finishing of servicing platforms for cryostat and experimental house	5	2007	FLNP manufactured
Focusing neutron guide	80	2010	Purchase

Total: 375 th.dol. US + 15 000 st.hours

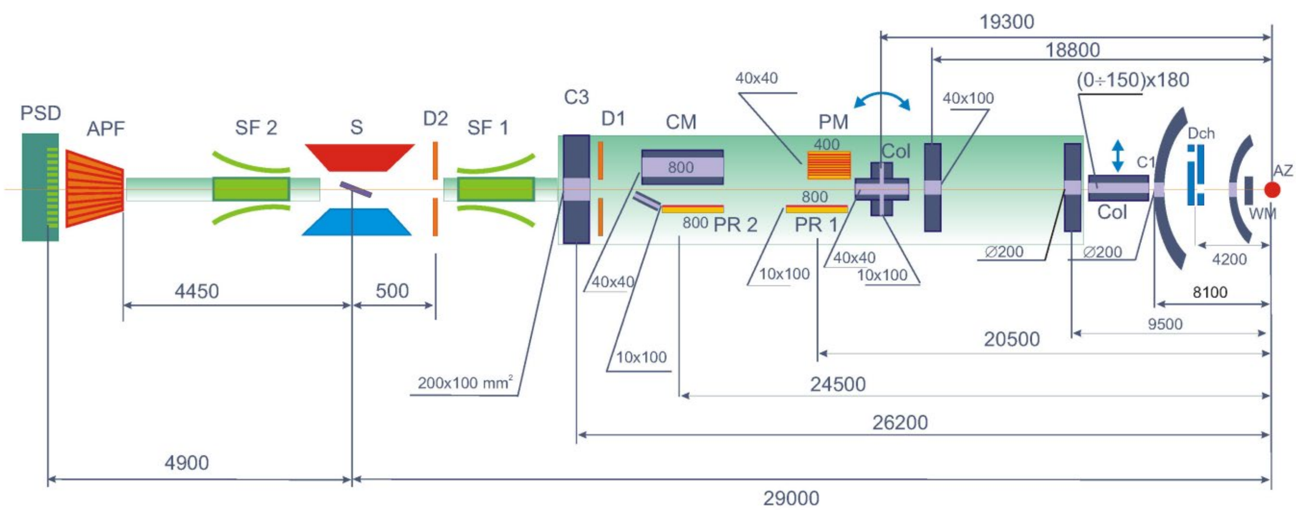

Fig. 1. The REMUR spectrometer lay-out.

D_{ch} – double-disc chopper
PR1, PR2 – reflectometry mode polarizers
PM – small-angle scattering mode polarizer
D1, D2 – controlled diaphragms
SF 1, SF 2 – spin-flippers
APF – multislit polarization analyzer
S – sample position

KOLKHIDA – a spectrometer with a polarized target

Project leader: M.I.Tsulaya.

On IBR-2 channel 1 works to complete the construction of the experimental facility KOLKHIDA comprising a polarized neutron spectrometer and a polarized nuclear target are being carried out. The first stage has been completed: the polarized spectrometer is put into operation, its parameters are investigated, and first experiments to investigate the single crystal Bi_2CuO_4 are conducted. The facility KOLKHIDA is dedicated to investigations of the interaction of polarized neutrons with polarized nuclei and of the magnetic structure and properties of crystals using diffraction of polarized neutrons. To extend the capability of the KOLKHIDA, improve the parameters of the facility and make it ready for operation at the new IBR-2M reactor, modernization of some elements and installation of additional devices are necessary.

1. Status and research program

The KOLKHIDA spectrometer makes it possible to carry out investigations in nuclear physics as well as in condensed matter physics. Initially, the facility was designed to operate at a steady state nuclear reactor [1], but later it was adapted to operation at a pulsed reactor. The facility includes:

1. Spectrometer of monochromatic polarized neutrons (Fig. 1). Neutrons get polarized in the course of diffraction from a Co-Fe single crystal. The energy of polarized neutrons varies from 0.06 eV to 2.0 eV and the polarization $P_n = 0.98$.
2. The ^3He in ^4He dilution cryostat with a superconducting solenoid to produce polarized nuclei.

The technical parameters of the polarized neutron spectrometer, an element of the KOLKHIDA, are described in [2]. Polarization of nuclei in the $^3He/^4He$ dilution cryostat is accomplished by either the method of «brute force» or the method of dynamic pumping. The sample in the cryostat is cooled to 24 mK and is kept in the magnetic field H=6 T, the field homogeneity being $\Delta H/H = 10^{-4}$.

The research program for the facility includes, in the first place, investigations of nuclear pseudomagnetism demonstrating itself in the interaction of polarized neutrons with polarized nuclei. In the process neutron spin rotation about the polarization axis of nuclei is observed. Of special interest is observation of the so-called paramagnetic resonance that connects the conventional magnetic field with the pseudomagnetic one as well as study of an effect in the region of the neutron resonance. In the region a change in the neutron spin rotation direction is expected, though not investigated experimentally.

Another research direction is observation of the parity violation effect when polarized neutrons interact with polarized nuclei. To date the effect has practically not been studied yet.

It is also planned to carry out neutron diffraction investigations of magnetic properties of crystals. Test measurements of a Bi_2CuO_4 single crystal measuring 5x5x7 mm were conducted. The polarized neutron beam with $\lambda = 1.15$ Å and a maximum intensity of 430 n/cm^{2}sec was used. In the experiment the diffraction reflections (100) and (200) with an interplanar spacing of d=8.51 Å and d=4.25 Å, respectively, were measured. The conducted measurements show that diffraction experiments to study single crystals can be successfully performed with KOLKHIDA.

When polarized thermal neutrons with λ=1.15 Å as those that have a maximum intensity and registration of neutrons scattered on the sample over the angle range $2\Theta = 5^\circ \div 90^\circ$ are used, the interplanar spacing region accessible for observation lies between 0.8 and 12 Å.

2. Required resources, cost and schedule times of modernization

For normal operation of the ^3He / ^4He dilution cryostat with a superconducting magnet it is necessary:

1. Replace outdated vacuum pumps for ^3He circulation with new ones with better parameters.
2. Purchase a PC-controlled stabilized power supply for the superconducting solenoid.
3. Purchase a device for measuring superlow temperatures with a graduate temperature sensor.
4. Install the monochromator Cu_2MnAl_3.

One of the most important parameters of an instrument is intensity. The intensity of the polarized neutron spectrometer can be increased several times by replacing the single crystals CoFe (polarizer and analyzer) with better neutron polarizers, e.g., the Geisler alloy Cu_2MnAl_3, so that the spectrometer could be used to perform neutron diffraction. In a more radical way (several orders of magnitude) the intensity will increase if a multislit. polarizer and analyzer are used. In this case, the sample is placed in a specular reflected beam of polarized neutrons. In such geometry it is possible to do experiments with single crystal as wells as powder samples.

Diffraction experiments to be conducted need:

1. A one-coordinate PSD ($l \approx 50$cm, spatial resolution $\Delta x \approx 0{,}5$cm) with the corresponding and a 128 K data acquisition system;
2. A remote-controlled goniometric head for single crystal sample positioning;
3. A multislit polarizer.

The cost of components and equipment to do modernization and desirable times of their deliveries are indicated in Table 1.

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Table 1. The cost of components and equipment (in KUSD) for KOLKHIDA modernization and desirable delivery times.

Name	Cost	Time	Notes
^{3}He circulation vacuum pumps	75	2007	complete set
Measuring device of superlow temperatures with a temperature sensor	10	2007	complete set
Superconducting solenoid power supply	10	2007	complete set
Multislit polarizer	20	2007	purchase
PSD: $l \approx 50$cm, $\Delta x \approx 0.5$cm	30	2007	Purchased or FLNP manufactured
Remote-controlled goniometric device	10	2010	Designing and manufacturing
Refrigerator, T_{min}=3 K	45	2009	purchase
Monochromator Cu_2MnAl_3	10	2010	purchase
TOTAL:	**210**		

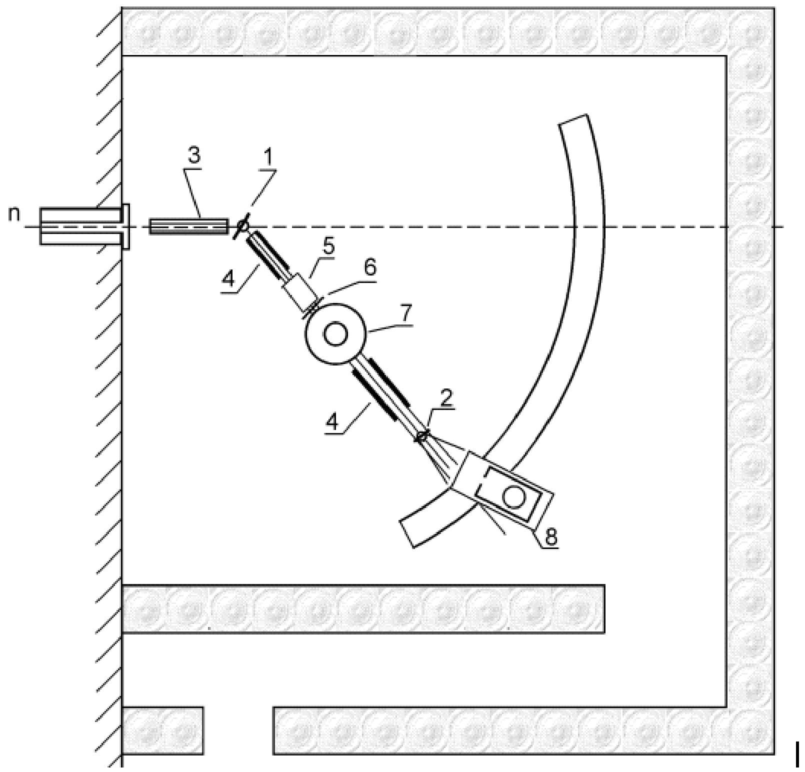

Fig. 1. The general scheme of the spectrometer: 1 – crystal-polarizer; 2 – crystal-analyzer; 3 – Soller collimator; 4 – lead magnetic fields; 5 – spin-flipper; 6 – shim; 7 – cryostat; 8 – detector.

Neutron spectrometer for experiments in real time

Project leader: G.M.Mironova

In the mid 1980's in FLNP at IBR-2 the real time neutron scattering technique was developed. With a special arrangement of the detector-sample system on the DN-2 diffractometer the neutron spectra with sufficient statistics can be measured at an exposition of several seconds to a minute simultaneously over the angle interval from –179 to +179° and the interval of incident wavelengths on the sample 1 – 25 Å. The method allows study of the mechanism and kinetics of equilibrium and non-equilibrium phase transitions and chemical reactions in condensed matter. Fundamental results concerning the processes of melting and solidification, oxygen diffusion in HTSC ceramics, glass crystallization, oxidation of metals, hydration-dehydration of polymers, lipids, binding phase transitions in iron, etc. have been obtained [1-7]. The aim of the project is to construct a special-purpose spectrometer with record parameters for real-time investigations of irreversible transitional processes in condensed matter at the reactor IBR-2M.

1. Target setting and research program

Real-time scattering (RTS) is a study of non-equilibrium states in condensed matter by registration of the scattered or transmitted radiation. The unique parameters of the pulsed neutron source IBR-2: record neutron flux, low pulse repetition rate, and low background between pulses, allow having record RTS parameters: an exposition of about one pulse duration (providing a microsecond resolution [2]), any scattering angle, including direct beam transmission, incident spectrum wavelength range 1 – 25 Å (on the 20 m flight path), and transformed radiation registration (gamma-rays, etc.). In the general case of investigation of single crystals, oriented or low-dimensional objects it is possible to separate eight variables: azimuth and polar angles of sample and detector orientation, velocities of the incident and scattered beams, sample-to-detector distance, and type of the scattered radiation. The temperature, gaseous environment of the sample and other kinds of external action on the sample (continual or pulsed) are additional coordinates of the so-called Multi-Dimensional Real-Time Neutron Scattering. The fundamental moments of the proposed method have been approved. A series of experiments with orientation effects, sample condition changes (temperature, gaseous environment, mechanical interactions) have been performed. The small-angle and large-angle scattering spectra were measured during the time of one pulse to show a real possibility of carrying out kinetic experiments with a resolution of tens of microseconds. The project aims at construction on the IBR-2M of a specialized instrument with record parameters dedicated to real-time studies of transitional processes in condensed matter – a real-time spectrometer (further referred to as RTS).

2. RTS components description

2.1. *RTS composition*

The instrument is to consist of a stationary version of the DN-2 diffractometer-based model that proved itself, additional dedicated equipment to perform procedures connected with orienting of the sample and detector as well as of sample environment devices. The RTS schematic diagram is shown in **Fig. 1**. The diffractometer comprises:

- a chopper in the ring corridor;
- a mirror neutron guide in the reactor shielding;
- a supermirror neutron guide;
- adjustable diaphragms for neutron beam formation on the sample;
- a diffractometer platform;
- a table for sample environment devices, including goniometer;
- a detector system for registration of diffraction and SANS spectra;
- a neutron beam monitor;
- electronic equipment for measurement automation, including electronic equipment for experiment control and data acquisition.

Below is a brief description of some SRV basic components.

2.2. *The chopper in the ring corridor*.

The drum-like chopper is to eliminate recycled neutrons. The chopper currently operating at DN-12 can be used as a basis for the structure

2.3. The s*upermirror neutron guide.*

The guide serves to have a maximum increase of the neutron flux on the sample. The neutron guide is to be made using advanced technologies to provide a maximum increase of the critical reflection angle up to $5 \cdot 10^{-3}\lambda$ rad. The critical wavelength (determined by the radius of curvature) can be chosen to be around 2 Å.

2.4. *The detector system.*

The detector system is an RTS key element whose parameters determine the capabilities of the spectrometer. The structure of the detector system must be in agreement with modern trends of creation of detectors with a large solid angle. As a basis there can be used the developed ZnS-element-based detectors. A minimum detector system must consist of three blocks: a small-angle detector to allow the registration of neutrons in the interval 0° - 5°, medium-angle scattering detectors (30° - 90°), and large-angle scattering detectors (150° - 179°).

2.5. *Sample environment systems.*

A real-time experiment is, as a rule, performed using a sample that experiences the action of some external factors like temperature, humidity, etc. Therefore, the availability of either one or another device for creation of external conditions on the sample determines the conducted investigation. A minimum version of the equipment must comprise: a furnace for 20 – 1500°C, a furnace for 20 – 900°C with a hermetic volume to be filled with a mixture of gases, hermetic cells with a humidity level determined by saturated solutions of salts over the temperature range of 20 – 100°C.

3. RTS operation at a cold neutron source

An indispensable condition of successful realization of the RTS research program dedicated to studies of transitional processes is the installation of the spectrometer on the channel with a cold neutron source. The 1994 and 1999 experiments show that a cold moderator improves considerably the quality of the obtained information due to an order of magnitude increase of the effective resolution [8]. The registration with RTS of diffraction peaks at large d_{hkl} is decisive for the study of processes of many types.

A specific characteristic of the real-time regime is the necessity to have good stability of the neutron beam intensity over time. As a result, successful RTS operation with a cold neutron source will be only possible if **the time of stable operation of the source is not less than five hours**.

4. Required resources, cost and times of RTS creation

An optimal version of RTS creation is the use of the infrastructure of the HRFD or DN-2 diffractometers situated on beams 5 and 6A, respectively. In this case the cost of RTS construction will practically equal the cost of manufacturing of RTS basic components (**Table 1**). Work on the project is to be carried out by the HRFD group.

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Table 1. The cost (in USD) and desirable time of manufacturing (purchase) of some SRV components.

Drum-like chopper	15,000	2010	Manufacturing
Supermirror neutron guide	125,000	2008	Purchase
Detector system	100,000	2008	Manufacturing
Sample environment devices	150,000	2010	Purchase

Total: 390,000 USD

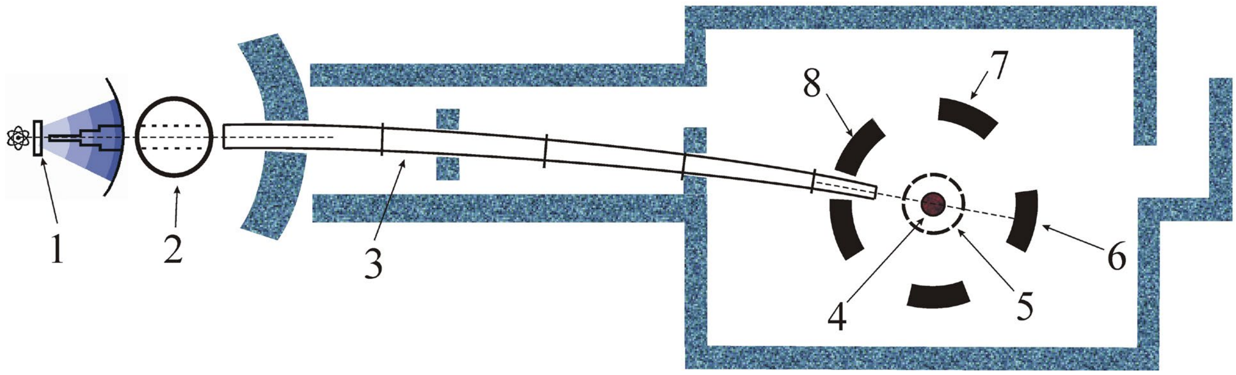

Fig. 1. The RTS functional scheme: 1 – moderator, 2 – drum-like chopper, 3 – curved neutron guide, 4, 5 – sample and sample environment, 6, 7, 8 – detector blocks.

Spectrometer DN-6 for microsample investigations

Project leader: B.N.Savenko

The new technique was developed for condensed matter studies by means of neutron scattering at high pressure and the specialized spectrometer DN-12 for investigations of microsamples was designed at the IBR-2 reactor together with RRC "Kurchatov Institute". The spectrometer makes it possible to carry out investigations at a pressure of up to 7 GPa. During the period of spectrometer operation there was acquired considerable experience in the field of designing, development and modernization of the spectrometer as well as of the development of neutron scattering at high pressures. The new spectrometer DN-6 on channel 6B is a direct development of the existing spectrometer DN-12, and is aimed at a considerable increase of intensity. The new spectrometer will allow us to extend essentially the pressure range, i.e., to deal with problems that have not been possible to solve at IBR-2 so far.

1. Status and research program

Today neutron scattering experiments using high-pressure cells are only being carried out in a few most advanced laboratories of the world. This is because of the fact that to obtain the experimental data appropriate for analysis one needs a high-flux neutron source and expensive detector systems. Until recently, as a rule, application of neutron methods has been restricted within the pressure interval 1-2 GPa, which involves the use of relatively large samples in cells of the cylinder-piston type. The development of the method of neutron investigations at high pressures employing the technique of sapphire/diamond anvils in combination with low-background neutron diffractometry has allowed us to extend the pressure range of the experiments to several tens of GPa. At present, the DN-12 spectrometer [1] is mainly used to carry out investigations of the atomic and magnetic structures of condensed matter at high pressures, 0 – 7 GPa, and low temperatures, 10 – 300 K. A typical example is investigations of alloy manganites with a colossal magnetoresistance effect [2, 3] and of other magnetic compounds such as MnAs and $FeBO_3$ [4, 5] at high pressures. In addition, on the spectrometer DN-12 inelastic scattering experiments to investigate the dynamics of condensed matter are conducted [6].

Further development of the high-pressure technique to extend the interval of pressures to 20-30 GPa requires an increase of neutron flux on the sample in order to reduce the volume of the investigated samples. Channel 12 is one of the lowest intensity channels at the IBR-2, which does not make it possible to work with a cold moderator imposing severe restrictions on investigations of magnetic structures under pressure.

IBR-2 channel 6B has a thermal neutron flux five times higher than that of channel 12. A cold moderator installed on the channel will essentially extend the possibility of investigations of the magnetic structure of crystals at high pressure. An optimal combination of the intense neutron beam of channel 6B, mirror neutron guide and a unique multidetector system of the DN-6 spectrometer will make it possible to perform experiments at up to 20-30 GPa using new high-pressure cells made of natural diamond or mussonite and samples of a super-small volume of 0.01 – 0.1 mm^3. The main elements of the new spectrometer DN-6 ate shown in Fig. 1.

1.1. Spectrometer intensity

The intensity of the neutron beam in channel 6B is ~5 times higher than that in channel 12. To increase intensity, two ZnS-scintillator-based detector rings (each consisting of 16 independent detector blocks) are to be created. This will reduce the experiment time ~ 5-10 times compared with the present-day level.

1.2. Background improvement

It is planned to install a neutron beam chopper. The device operating on IBR-2 channel 12 serves as a neutron chopper prototype. The neutron guide of channel 6B will be modernized: the neutron guide casing and head part are to be replaced.

1.3. Sample environment

In view to creating various conditions on the sample a helium refrigerator ($T \geq 8$ K) and high-pressure cells of different designs will be used. To extend the pressure range, new pressure cells with anvils made of sapphire, diamond or novel ultrastrong materials (like mussonite) are being designed and manufactured. A cooled beryllium filter will make it possible to measure inelastic incoherent neutron scattering, which is necessary for investigations of the dynamics of atoms in crystals.

2. DN-6 operation with a cold neutron source

At present, the DN-12 is on IBR-2 channel 12 where a cold moderator is not to be installed. Construction of the DN-6 on channel 6B where a cold moderator is to be installed will allow an ~5 to 10 times increase of the intensity of the incident cold neutron beam over the wavelength range 4 – 13 Å, which will essentially improve the quality of the measured diffraction data on magnetic crystals and extend the range of problems in the field of investigation of magnetic structures at high pressure.

3. Required resources, cost and times of DN-6 creation.

The cost of components and of production of a ZnS-detector (1 module) is 5,000$. A complete set of 32 modules costs 160,000$. The detector can be produced by the FLNP JINR detector group. The modernization of the 6B channel neutron guide costs ~50,000$. The cost of detectors, new DN-6 components and of sample environment devices is summarized in **Table 1**.

The work on the project is to be carried out by specialists of Group 3 of the Diffraction Sector (Head of Group – B.N.Savenko) specialist of RRC “Kurchatov Institute” (V.A.Somenkov’s Laboratory).

Table 1. The cost (in USD) and desirable times of manufacturing (purchase) of some DN-6 components under the new spectrometer project.

Name	*Cost*	*Manufacturing schedule times*
Detector block (32 pieces.)	160,000	2010
Neutron beam chopper	3,000	2007
Electronic control system of neutron beam chopper	3,000	2007.
Neutron guide casing and head part modernization	50,000	2008
Electronic module	20,000	2009

Total: **36,000** USD

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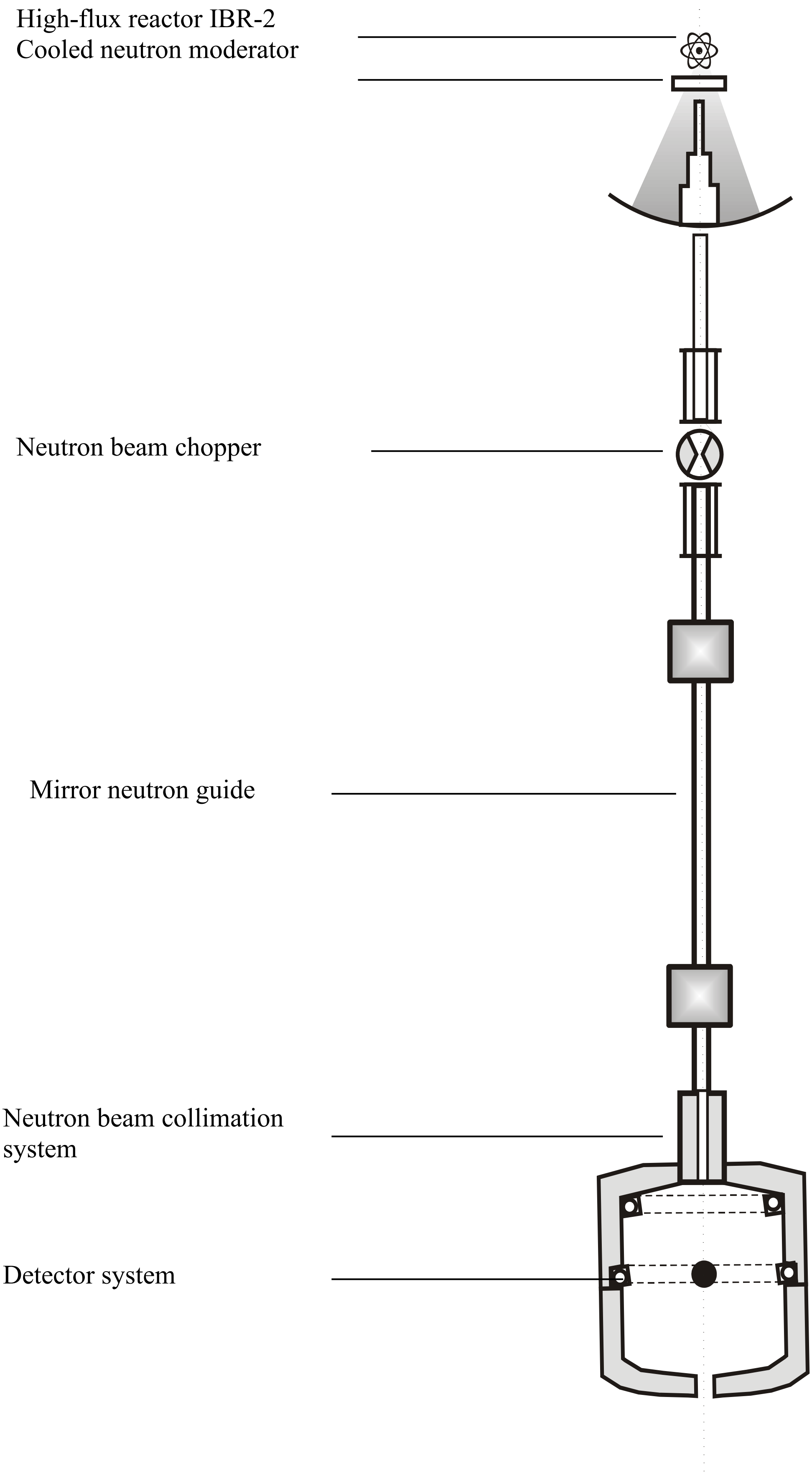

Fig. 1. The main elements of the DN-6 spectrometer.

Small angle neutron scattering spectrometer MURN-S

Scientific supervisor: V.I.Gordelii

The project suggests construction of an up-to-date high-flux small angle scattering facility on one of the IBR channels with a cold moderator. The characteristic features of the proposed facility are: a bent neutron guide, high neutron flux on the sample (from 10^7 to $4x10^7$ n/s/cm^2), wide momentum transfer range ($1x10^{-3}$ – 0.5 Å^{-1}, which agrees with a characteristic dimension of the studied objects varying from 10 to 6000 Å), and use of an up-to-date position sensitive neutron detector. The necessity of construction the facility is, in the first place, connected with a high demand for the use of the small-angle scattering method, which is, in turn, explained by a wide spectrum of problems being solved (from those in materials science to new problems in biology) as well as by the originality of the method.

1. Status and research program

The aim of the project is to create a new small-angle neutron scattering setup (MURN-S) with world-level parameters on one of the IBR-2 channels equipped with a cold moderator. Two main components of the setup are a bent neutron guide and a two-dimensional position sensitive detector of scattered neutrons. The MURN-S realizes in full measure the unique possibilities provided by the IBR-2 in the field of small-angle neutron scattering, including a wide scattering vector range (from 0.001 to 0.5 Å^{-1}), high speed of experimental data acquisition, high resolution, possibility to study anisotropic- or weak-scattering samples.

The streamlined small angle spectrometer YuMO and the MURN-S will be **complimentary**. High efficiency of their operation will be provided by reasonable distribution of experiments between them. Such strategy will make it not only possible to minimize YuMO modernization expenditures but will also reduce essentially the cost of the new setup MURN-S because of unification of some of their elements, software and sample environment.

Small angle neutron scattering, an effective technique for study of fundamental problems and solution of important technologic problems, is widely applied for investigation of subatomic structure of matter [1]. It is intensely used in condensed matter physics, physics and chemistry of disperse systems and aggregates of surface-active materials, biophysics and molecular biology, investigations of polymeric materials, metallurgy and other fields of science and technology. The most important characteristic of small-angle scattering is the possibility of analysis of the structure of disordered systems. For example, the method is often the only way to obtain direct structural information about systems with a chaotic or partially ordered distribution of size density inhomogeneities on the order of 10 – 10000 Å; the method allows investigation of disperse structures of powders, glasses (phase distribution mechanisms, size and degree of polydispersity of particles), structure peculiarities of polymers in different aggregate states, weight and geometric characteristics of biologic macromolecules and their complexes, submolecular biologic structures like biologic membranes or viruses. An essential difference between the lengths of neutron scattering on hydrogen and deuterium as well as the possibility of specific isotope substitution of molecules and submolecular structures makes small angle neutron scattering an indispensable tool for investigation of biologic, colloid objects and of polymers and liquid crystals.

A small-angle spectrometer is a much-favored effective instrument for investigation of condensed matter. As a rule, at world neutron sources there are 2 or more of them (LLB –PAXE, PAXY, ILL- D11, D22, D16, D17; GKSS –SANS-1, SANS-2; KFA – KWS 1, KWS 2; BENSC-V4; V12; KEK –SAN, WINK; JAERI – SANS-J, SANS-U; IPNS –SAD, SAND). This is due to a high demand for the small angle scattering. The situation at YUMO, IBR-2 is similar. In the last few years the demand for the small angle scattering time has exceeded the YuMO possibilities several times.

To prove the necessity: in the period from January to May, 2005 there were submitted 32 proposals for the experiment, i.e., for over 100 days of experimental time, while only 50 days are available. The list of institutions collaborating or interested in collaboration includes Moscow State University, Belozerskii Institute; Institute of Bioorganic Chemistry in Moscow; Enikopolov Institute of Synthetic and Polymeric Materials in Moscow; Institute of Protein in Puschino; Faculty of Pharmacy Comenius University, Bratislava, Slovakia; University of Bayreuth, Germany; Leipzig University, Germany University of Utrecht, Netherlands; Institute of Macromolecular Chemistry, Czech Republic; LLB, Saclay, France; IBI-2, Forshungszentrum Julich, Germany; National Institute of Materials Physics, Romania.

The MURN-S will be mainly dedicated to solution of problems that are beyond the possibilities of the YuMO, namely, to investigations of small cross section samples (weak contrast), large characteristic inhomogeneities and their high anisotropy.

2. Operation of the new instrument with a cold neutron source

In fact, practically all of the small angle spectrometers in the world operate with a cold neutron source. This is, in the first place, due to the necessity of having a maximally wide range of Q vectors at as minimum Q as possible. The dimensions of the cold moderator are determined by the dimensions of the neutron guide and are equal to 200x200 mm. It is required that the moderator works in a stable way for one day.

3. The new small angle scattering spectrometer

Realization of the project to construct a modern small angle neutron scattering setup will make it possible to take full advantage of the possibilities provided by the IBR-2. It is quite urgent today in connection with putting into operation of a cold moderator. No risk is anticipated because there exists world and Russian experience of construction similar instruments [2, 3]. The setup under design includes (Fig.1): 1, 2 – reactor and moderator; 3 - chopper; 4 – bent mirror neutron guide; 5 – collimating system, 6 – sample site enabling positioning of the corresponding modern sample environment equipment (goniometer, magnet, thermostat, etc.); 7 – evacuated tube; 8 – two-dimensional PSD measuring 64x64 cm^2 or 100x100 cm^2, which makes it possible to investigate anisotropic scattering samples, widen the range of accessible scattering vectors and increase the data acquisition rate; 9 – cabin with electronics and computer equipment. In addition, it is planned to use a two-detector system in view to becoming a world leader in momentum transfer dynamic range. The proposed setup has the parameters summarized in Table 1.

Table 1. The main parameters of the MURN-S spectrometer.

Parameter	Value
Flux on sample (thermal neutrons)	10^7 - $4x10^7$ n/s/cm^2
Wavelength range	0.5 Å to 20Å
Q-range	$1x10^{-3}$ – 0.5 $Å^{-1}$
Investigated object dimension range	10 - 6000 Å
Measured cross section (lower limit in absolute units)	0.001 cm^{-1}
Calibration system (normalization)	V, H_2O, graphite
Detector system	1 cm-resolution PSD
Temperature range	from 4 K to +1000°C
Momentum transfer resolution	1-20%

In addition, the setup is to have low background conditions, which allows investigation of weakly scattering objects with a minimum scattering cross section of 10^{-3} cm^{-1} and a modern sample environment.

4. Required resources, cost and schedule times of MURN-S construction

Table 2. The cost (in USD) and desirable times of manufacture (purchase) of some of the MURN-S components under the MURN construction project.

Neutron guide	120,000	2009	complete set, purchase
Chopper	55,000	2010	purchase or FLNP manufacturing
Detectors	560,000	2010	purchase, manufacturing
Electronics	55,000	2010	purchase
Sample environment	95,000	2010	purchase, manufacturing
Total:	**885,000**		

Work on the project is to be carried out by specialists of the YuMO Group and the Spectrometer Complex Division.

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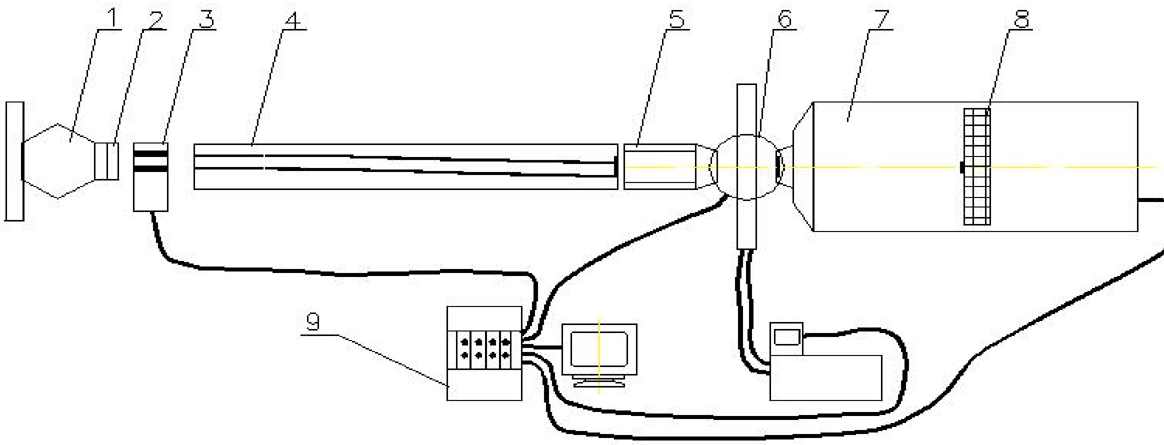

Fig. 1. General view of the small angle spectrometer MURN-S.

REFAT – polarized neutron reflectometer with atomic resolution

Project leader: Yu.V.Nikitenko

The reflectometer of polarized neutrons with atomic resolution will make possible investigations of the nuclear and magnetic structure of near-surface layers in substances and of interfaces in layered nanostructures with a resolution as high as 1 Å. Investigations with such resolution are important for synthesis of new layered nanostructures with perfect interfaces and studies of phenomena arising on the interface of magnetic, superconducting or other media in the case of short range interaction between them.

1. Target setting and research program

Today in microelectronics layered magnetic structures are widely used as memory elements, information playback and recording heads, sensors in measuring devices of temperature, magnetic field, pressure, etc. It is a well-established fact that magnetic, electric, superconducting and especially, frequency properties of layered structures are determined by the structure and spatial dimensions of the interface. In the last years certain progress has been achieved in synthesis of layered nanostructures with perfect interfaces. For example, using the methods of molecular epitaxy and magnetron dispersion it is now possible to produce Fe/V layered structures with the repetition period 50 Å and the number of layer pairs 20 where the mean square spatial deviation of the interface is 3 Å, which corresponds to two monolayers. However, it is often insufficient because many phenomena in layered structures (coexistence of magnetism and superconductivity, giant magnetic resistance, magnetic ordering, etc.) have a linear dimension of interaction of 1÷10 Å. This requires determination of the magnetic nuclear profile deep in the nanostructure with a resolution of $\delta_z \approx 1$ Å. To investigate the magnetic nuclear structure with such resolution (atomic resolution), it is natural to use polarized neutrons with the maximum wave vector $k_{max} \approx 1/(2\delta_z) = 0.5$ Å^{-1}. Also, the spectrometer allows carrying out investigations of magnetic nuclear structures in the plane of the interface by measuring diffuse scattering on disordered clusters (domains) and of diffraction reflection from the lattice. The spectrometer (reflectometer) of polarized neutrons will be used to investigate the phenomenon of coexistence between magnetism and superconductivity in periodic structures and the bilayers “ferromagnetic (paramagnetic) – superconductor”, formation of magnetic and nuclear clusters in the vicinity of the interface “ferromagnetic – nonferromagnetic”, magnetic ordering in the structure “ferromagnetic – nonferromagnetic (antiferromagnetic) – ferromagnetic”, changes in magnetic ordering near the interface “ferromagnetic – nonferromagnetic” as a function of layers thickness and temperature, etc.

2. Description of main components

The neutron polarization technique starts being effective beginning from neutron wavelengths ~1.5 Å. The two-disk chopper on IBR-2 beam 8 effectively suppresses the fast neutron background beginning from the wavelength 2 Å. This determines the desirable average neutron wavelength in the spectrum, $\lambda_{av} = 3$ Å, and the necessity to use a cold neutron moderator. For $\lambda_{av} = 3$ Å and $(\delta k/k)_{max} = 0.03$ we obtain the maximum neutron glancing angle on the investigated structure $\theta_z \approx 0.22$ rad and its mean square deviation $\delta\theta_{z,max} = 6.6$ mrad. To have such large $\delta\theta_{z,max}$, a neutron guide must be used. It is proposed to install the reflectometer REFAT on beam “b” of channel 8. The figure shows the scheme of channel 8 with beams “a” and “b”. On beam “a” there is a reflectometer where the glancing angles 3÷20 mrad are realized and structures are investigated with a resolution of ~2 nm. The reflectometer is actually the operating spectrometer REMUR. To increase the spectrometer intensity, it is additionally equipped with a 20 m neutron guide (whose walls are situated in a horizontal way) and a 20 cm×20 cm two-dimensional PSD.

Beam “b” needs a 24 m four-wall neutron guide with the distance between the vertical walls a = 4.5 cm (λ_{ch} = 2.0 Å). The neutron guide forms a neutron beam with $\delta\theta_z$ = 6.6 mrad on the sample at a distance of 2 m from the neutron guide exit. The neutron guide axis is at an angle of 40 mrad to that of the channel, which and the curvature of the neutron guide ensure a distance between beams “a” and “b” at a sample position of 1.5 m. At the exit of the neutron guide there is the neutron polarizer P3 made as a stack of 5 cm×5 cm cross section supermirrors. The neutron beam is collimated with the diaphragms D3 and D4. Between the diaphragms there is situated the gradient radiofrequency neutron flipper FL3 operating at $\lambda > 1.5$ Å. The investigated sample is at site S2, the flipper FL4 (current foil) for $\lambda < 20$ Å is behind the sample. Next go the wide-aperture polarization analyzer AP2 and the neutron position sensitive detector PSD2. Since the detector has a large size (50 cm) and can be displaced within the limits of 1.5÷5 m from the sample, investigations of magnetic nuclear lattices with lattice parameters within the limits of 10÷1000 Å in the plane of the interface or disordered structures with the correlation lengths L_x and L_y within the limits of 10÷1000 Å.

3. Requirements imposed on cold moderator

The moderator size should be about 20 cm×20 cm. The maximum of the neutron spectrum must be shifted towards the wavelength 3 Å.

4. Required resources, cost, schedule times of project realization

The spectrometer can be constructed by specialists of FLNP and other JINR Divisions in collaboration with PINP (Gatchina) and the REMUR Group of Condensed Matter Division, FLNP. The cost of separate elements is summarized in the Table.

Table The cost (in KUSD) of the spectrometer components.

Chopper design debugging	2	FLNP, 2008
Evacuated neutron guide	8	FLNP, 2008
Neutron guide	100	PINP, 2007
Neutron polarizer	15	PINP, 2009
Diaphragm (2pieces)	10	FLNP, 2010
3-axis goniometer	30	Purchase, 2011
Electromagnet with power supply	20	Purchase, 2011
Polarization analyzer, 25 cm×25 cm	100	PINP, 2011
Two-dimensional PSD 50cm×50cm with resolution 2mm	100	Purchase, 2012
Spin-flippers (gradient and current foil-type)	2+20=22	FLNP, 2010
Electronic equipment and software	25	FLNP, 2010
Preliminary design	10	FLNP, 2007
Shielding, collimators	30	FLNP, 2009
Design effort	8	FLNP, 2008
Total:	**480 KUSD**	

Schedule times:

2006÷2007: Preliminary design

2008÷2010: Manufacturing, purchase, accommodation in channel 8b

2011÷2012: Tests on the neutron beam and putting into operation

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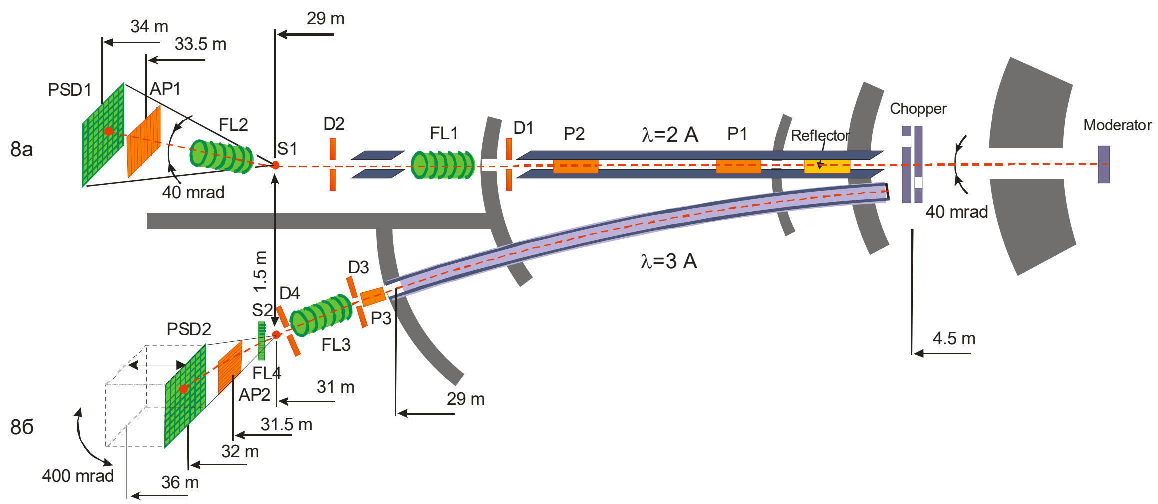

Fig. 1. The scheme of the spectrometer REFAT.

Polarized neutron spectrometer with vertical scattering plane

Project leader: V.I. Bodnarchuk

The polarized neutron reflectometer REFLEX was put into operation in the mid-1990s and is dedicated to investigations in the physics of surface phenomena. In the REFLEX the geometry with a horizontal reflecting plane (reflecting surface of the sample is situated vertically) is realized. The geometry was chosen based on simplicity of realization, and experiments with the reflectometer are oriented to studies of metallic films in the main. The choice was quite justified at the time of designing the instrument because metallic films were then of particular scientific interest. For example, one of the problems for the spectrometer REFLEX was to study the magnetic field penetration depth in superconducting films. However, rapid development of life sciences brings forward a whole set of problems that in principle, can be solved with the help of the thermal neutron reflectometry. As a rule, biologic objects are liquid solutions. To study their surface properties, one needs a vertical scattering plane. Taking into account the fact that another reflectometer of polarized neutrons at IBR-2 – REMUR with a vertical scattering plane, has undergone successful modernization it makes sense to rebuild the REFLEX so that there is realized a reflectometer with a vertical scattering plane for studies of liquid sample surfaces on the same reactor channel.

1. Target setting and research program

Insufficient financing at the time of REFLEX construction in the mid-1990s resulted in that the period from designing to commissioning lengthened. This is why with respect to many parameters the spectrometer loses the competition with analogous instruments, including the updated reflectometer REMUR. In particular, an overlong flight path leads to unjustified intensity losses on the sample, FeCo films used as polarizing mirrors produce lower polarization of the beam than supermirrors, and the neutron beam travels through the air rather a long way, which also results in intensity losses. The collimation system of the spectrometer made of polyethylene needs being replaced as it worsens background conditions. In addition, full replacement of the experiment automation system, data acquisition electronics, and software is needed and the spectrometer needs to be equipped with a position-sensitive detector. Such upgrading requires considerable financing. In the circumstances and having a new operating reflectometer of polarized neutrons (REMUR) with a horizontal scattering plane at the IBR-2 it is not unreasonable to speak about construction of another reflectometer (in place of the REFLEX) with a principally new property allowing one to extend the spectrum of scientific problems possible to be solved with reflectometry technique. This new property assumes replacing of the existing horizontal scattering plane by a vertical one.

Below are some topical scientific directions the problems in which can be solved with the help of reflectometry with a vertical scattering plane:

- investigation of the structure of thin films (mono-layers) formed by lipid molecules of Stratum Corneum (upper layer of skin) on the surface of water, determination of their lateral and lamellar structure as a function of surface pressure.
- investigation of the influence of disaccharides on the structure of phospholipid and lipid/protein mono-layers in the course of dehydration with subsequent hydration, study of physical and chemical regularities of bioprotection properties of disaccharides.
- investigation of the structure of lipid/protein mono-layers as a function of surface pressure.
- investigation of the structure of block copolymers on a liquid surface.
- investigation of ferroliquids.

2. Description of main components

To create a reflectometer of polarized neutrons with a vertical scattering plane the following components are necessary.

A) The optic system of the new reflectometer is to include a NiMo/Ti supermirror-based neutron guide immediately behind the moderator in the ring corridor, **bender-polarizer (FeCoV/TiZr supermirror)**; **deflecting mirrors (NiMo/Ti supermirrors)** to organize a vertical scattering plane with a possibility to install both polarizing and nonpolarizing mirrors; wide angle analyzer of polarization.

B) The detector system must include a two-dimensional PSD and a monodetector.

C) The sample block. A sample-positioning table on a shock-absorber platform and a sample holder allowing positioning of liquid samples must be designed and constructed. The table must permit positioning of additional equipment around the sample, including electromagnets, cryostats, power supplies, ovens, etc.

D) Electronics and software. It is necessary to develop data acquisition electronics and the corresponding software.

E) Additional equipment. It is necessary to design, manufacture or purchase new additional equipment, including electromagnets, spin-flippers, heaters, spin-rotators, positioning devices, current sources, etc.

3. Requirements imposed on cold moderator.

The specific feature of the reflectometry consists in the reflection of the neutron beam from a smooth surface at a small glancing angle ($\sim10^{-2}\div10^{-3}$ rad). As a result, the investigation-accessible range of momentum transfers has an upper limit of $Q\sim10^{-1}$ Å^{-1}. However, if biologic objects are studied, the most informative region of the scattered neutron spectrum lies in the area of small momentum transfers ($Q\sim10^{-4}\div10^{-3}$ Å^{-1}) and it is therefore desirable to have as many cold neutrons as possible in the incident neutron spectrum. In addition, an increase of the portion of cold neutrons in the spectrum increases essentially the efficiency of the instrument. For specified resolution and momentum transfer values transition to colder neutrons allows increasing of the angle of reflection from the sample and using of large diaphragms in the detector. Therefore, the spectrometer under design must be installed on a beam with a cold neutron source. Reflectometry uses narrow beams with a cross section of several millimeters in the scattering plane with the other dimension being dependent on the size of the source. Taking into account the size of the beam shutter hole in channel 9 (100x200mm^2) where the REFLEX is situated today, the distance from the moderator surface to the beam shutter hole (~2 m) and assuming the horizontal dimension of the beam to be ~ 100mm, it can be said that the dimensions of the cold moderator must be within the limits of 100÷400mm in the horizontal cross section.

4. Required resources, cost and schedule times of modernization.

The cost (in KUSD) of the components of the updated reflectometer REFLEX is presented in the Table.

Cold moderator	300	2010	FLNP-NIKIET
Optics (neutron guide, bender-polarizer, deflecting mirrors, analyzer)	150	2010	Purchase (PINP)
2D-PSD, He^3-monodetector	40	2010	Purchase and FLNP manufacturing

Sample environment	100	2010	Purchase and FLNP manufacturing
Up-to-date electronics and software	30	2010	FLNP manufacturing
Additional equipment	30	2010	Purchase and FLNP manufacturing

Total: **650 KUSD**

The project is to be executed by specialists of the Neutron Optics Sector of the Condensed Matter Division, FLNP in collaboration with PINP (Gatchina) and ILL (Grenoble, France) specialists.

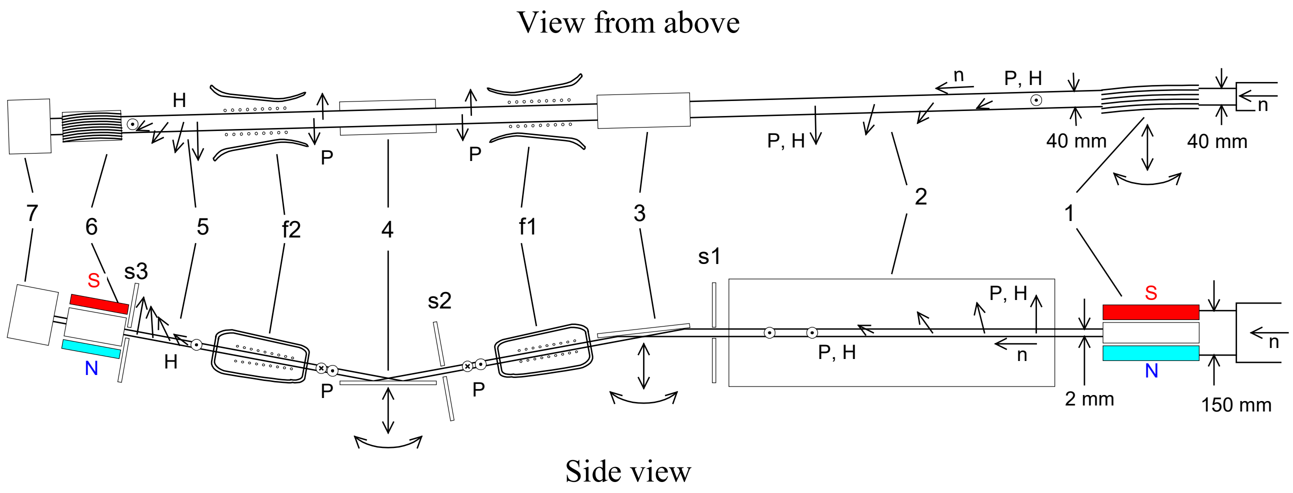

Fig. 1. The lay-out of the spectrometer of polarized neutrons REFLEX with a vertical scattering plane.
1 – FeCoV/TiZr supermirror-based neutron beam bender-polarizer; 2 – region of adiabatic turn of the leading magnetic field H and neutron beam polarization P; 3 –NiMo/Ti supermirror-based deflecting mirror; 4 – sample block; 5 – region of adiabatic turn of the leading magnetic field H and neutron beam polarization P; 6 –FeCoV/TiZr supermirror-based multichannel polarization analyzer; 7 –position sensitive neutron detector; s1, s2, s3 – beam forming slits; f1, f2 – radiofrequency flippers

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SESANS – spin-echo spectrometer of small-angle neutron scattering

Project leader: Yu.V.Nikitenko

Realization of the SESANS project will make possible investigations of nuclear structure over the correlation length interval L_c = 1 nm ÷ 100 μm and of low frequency dynamics over the correlation time interval τ_c = 0.1 ps ÷ 10 ms that were earlier beyond the reach of layered structures and continuous materials. The spectrometer SESANS will allow the investigation of large-scale objects and slow processes typical of biology, polymer science, colloid chemistry and some other sciences.

1. Target setting and research program

Today, interest in nanostructure analysis, i.e., study of the structure of synthetic or biologic polymers, colloids, porous materials, as well as in fundamental research in the region of nanodimensions is growing. In the last two decades small angle scattering (SANS) of cold neutrons with the wavelength 4÷10 Å has proved to be one of the most informative techniques. This is due to high penetration depth of neutrons, possibility of handling the local density of the scattering amplitude through isotopic substitution or solution composition, and minimum radiation damage to the investigated object. With the help of SANS there were obtained new data in structural biology (on distribution of proteins in ribosomes and internal structure of viruses) and in polymer science (on polymer chains conformation in amorphous and crystalline states, confirmation of predictions about phase diagrams of polymeric solutions and membranes). At present, almost every neutron centre has SANS instruments covering the scattering vector interval $Q = 10^{-3}÷1$ Å^{-1}, which means that the upper limit of the correlation length $L_c \sim 10^3$ Å.

Investigations on the microlevel ($L_c > 10^2$ nm, $\tau_c > 10^{-9}$ sec) of structure and dynamics are also extremely important particularly in materials science (ceramics, fiberglass), in fundamental physics (phase transitions, superconductivity), in the physics of polymers (phase separation and critical phenomena), in colloid chemistry (colloid crystals), etc. The linear dimensions and oscillation frequency of macromolecules in soft materials (polymers, biomaterials, gels, etc.) are r = 1 nm ÷ 100 μm and f = 1 kHz ÷1 THz ($\tau_c = 10^{-3}÷10^{-12}$ sec), respectively. The necessity of studying the structural organization of the material and low-frequency dynamics on the meso- or microlevel calls for developing of the neutron scattering technique covering an ultra-small range of the scattering vector $Q = 10^{-6}÷10^{-3}$ Å^{-1} (USANS technique). The conventional USANS technique is a double-crystal diffractometer (DCD). USANS spectrometry was developed in 1970÷1980 and is presently used in the USA, Austria, Germany, Japan, and Russia. To date, the DCD–based USANS spectrometer has been improved through adaptation of the Bonse-Hart technique employing triple Bragg scattering. The DCD-based USANS spectrometer, however, has an essential disadvantage due to that high resolution in it is achieved owing to a high level of monochromatization and collimation of the incident neutron beam and collimation of the reflected beam. In other words, precise selection of the initial and final values of the neutron wave vector is done. As a result, the intensity of the spectrometer appears to be not very high, which leads to heavy use of the experimental time. Free of said disadvantage is a small-angle spectrometer based on the spin-echo technique (SESANS). In the SESANS the momentum transfer is only selected. Therefore, the resolution in input and output neutron wave vectors can be quite bad (10%). As a result, in the spectrometer a high intensity and a high resolution are simultaneously realized. Today, spin-echo spectrometers are being constructed or operate in ILL (Grenoble, France), CEA-CNRS (Saclay, France), FJ GmbH (Julich, Germany), ANL (Argonne, USA), HMI (Berlin, Germany, IRI (Delft, Netherlands) and other neutron centres.

2. Description of main components

The spectrometer SESANS is to be installed on IBR-2 channel 10. On the channel there are two neutron beam choppers: a disk and a drum-like one at a distance of 5 m and 8.8 m from the moderator, respectively. With the disk chopper reducing the background 20 times the low background wavelength interval is 2÷15 Å, with the drum chopper that reduces the background 100 times, which is important for investigations of weakly scattering samples, it is 2÷9 Å. In free spaces on the way of the beam behind the beam shutter situated at 2.6 m from the moderator neutron guides (straight and bent) are installed. The polarization sensitive section of the SESANS-spin-echo instrument (SEI) is at 25÷35 m from the moderator.

The figure shows the SEI lay-out. Functionally the SEI consists of a neutron polarizer, π/2-rotator of polarization, first spin-precessor, sample positioning site, π-rotator of polarization, second spin-precessor, second π/2- (or -π/2-) rotator of polarization, polarization analyzer, and a neutron detector. Polarization rotators, spin-precessors and compensating coils form a phase-sensitive system (PSS). In the discussed PSS there are polarization rotators in the form of a current leaf formed by a wire with current and three types of spin precessors. Different type spin-precessors allow realization of various possibilities by being operated together or separately. Spin precessors 1 and 2 employ the phenomenon of precession in a zero magnetic field. A spin-precessor in a zero magnetic field consists of two electromagnets (EL1 and EL2 form the first spin precessor, EL3 and EL4 form the second one) between the poles of which wideband spin-flippers are situated. The poles of the electromagnets are made as a parallelogram with the angle θ_0 and can rotate with the step $\Delta\theta_0 = 3\times10^{-5}$ rad. As the poles rotate at an angle of $\pi/2-\theta_0$ the space between the poles takes a rectangular form. In this, precessor 1 is realized. For any other angular situation of the poles the space between them has the form of a parallelogram. In this way, precessor 2 is realized. Structurally, all of the PSS elements situated in front of the sample are on one platform and those behind the sample are on the second one. The second platform rotates around the sample position at the angle θ. This allows carrying out measurements of the excitation dynamics of the sample for known values of energy transfer E and wave vector transfer Q (the law of neutron scattering on the sample S(E,Q)):

$$K_f^2-K_i^2 = \alpha E,\ Q = (K_f^2 + K_i^2 - 2 K_iK_f\cos (\theta))^{1/2},\ (L_1/K_i+ L_2/K_f) = \beta T_{TOF} \qquad (1)$$

where K_i, K_f are the initial and final wave vectors, L_1 and L_2 are moderator-to-sample and sample-to-detector flight paths, respectively, T_{TOF} is the time of flight. Precessors 3 in the form of layered magnetic structures are biased with the electromagnets E1 and E2 and are for measuring the momentum transfer in the direction perpendicular to the incident beam. The total PSS length is 8m.

3. Requirements imposed on cold moderator

The area of the moderator must be as maximum as possible, i.e., 20 cm×20 cm. The temperature of the moderator must be as minimal as possible to obtain a spectrum with an average neutron wavelength as large as possible.

4. Required resources, cost, and schedule times of project realization

The Table shows the spectrometer components and their cost (in KUSD).

Phase-sensitive system: Electromagnet EL (4pcs)	80	FLNP manufactured, 2009

Electromagnet E (2 pcs) Polarization rotator (3 pcs) Power supply for electromagnets (2 pcs) Generator for 1-3 MHz	20 10 15 25	FLNP manufactured, 2009 FLNP manufactured, 2009 Purchase, 2008 Purchase, 2008
Polarizer	15	PINP manufactured, 2010
Polarization analyzer	70	PINP manufactured, 2010
Position-sensitive detector	70	Purchase, 2011
Neutron guide	80	PINP manufactured, 2010
Platform (2 pcs)	15	FLNP manufactured, 2009
Electronics and software	20	FLNP manufactured, 2009
Shielding	20	Purchase, 2010
Total:	**440**	

Schedule times of spectrometer construction:

2005÷2006: Preliminary design development
2006÷2008: Development and manufacturing of phase-sensitive system
2007÷2010: Purchase of neutron guide, polarizer, polarization analyzer, and neutron detector
2010: Assembling of components on neutron beam
2011: Adjustment and on-beam test measurements

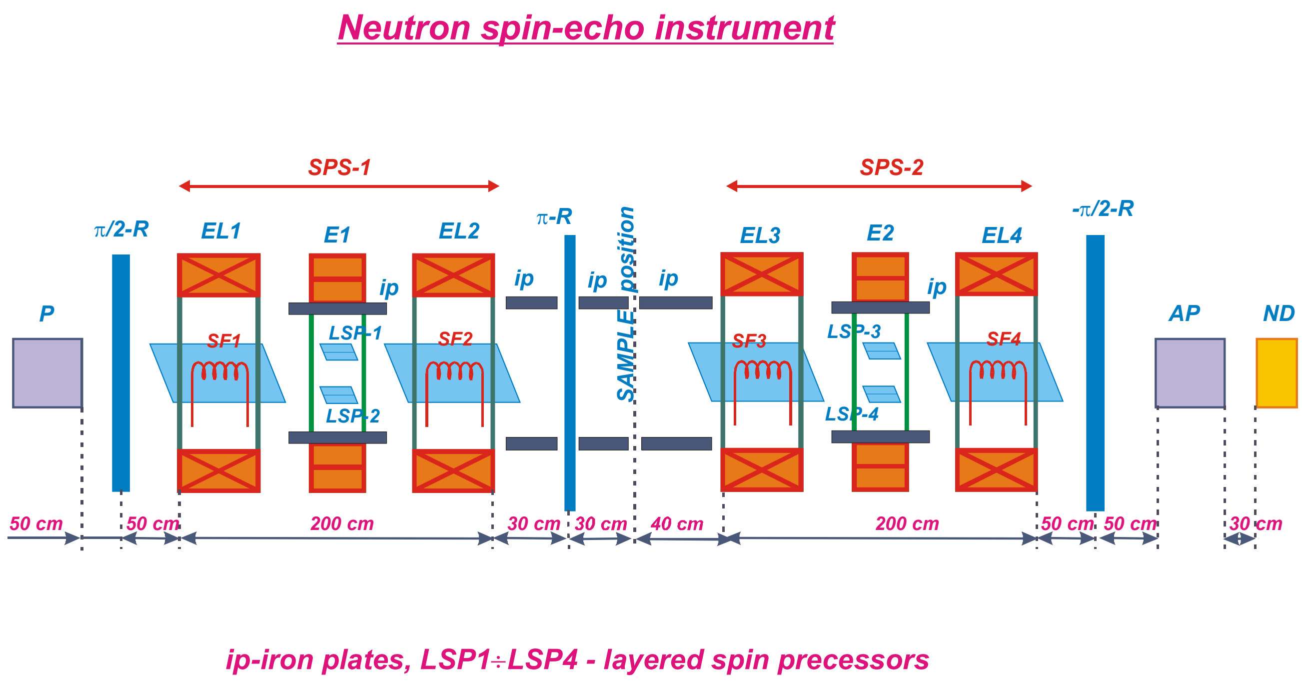

Fig. 1. The polarization-sensitive system of the spin-echo small-angle neutron scattering spectrometer.

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Moderator complex at IBR-2M

Project scientific leaders: E.P.Shabalin, V.D.Ananiev

In view to providing effective operation of some types of neutron spectrometers dedicated to experiments in the field of condensed matter physics neutrons with large wavelength (~ 4 – 10 Å) are needed. Such neutrons are generated in "cold" (cryogenic) neutron moderators. At the IBR-2M reactor three cold neutron moderators that will generate neutrons with the wavelength over 4 Å are to be installed. This will greatly improve conditions for carrying out experiments to study long-period structures, solutions of polymers and biologic molecules, multi-layer films, diffuse motion in liquids, etc.

1. Moderator complex at IBR-2M

To date, FLNP has acquired rich experience in the field of creation and operation of methane-based cold moderators [1-5]. Such moderators, however, do not meet in full the requirements of experiments with cold neutrons. The main reason is that it is necessary to raise periodically (several times a day) the moderator temperature to remove excess hydrogen that can damage the moderator chamber [5,6]. The investigations carried out in FLNP [7-15] made it possible to create a new-type cryogenic moderator on the basis of aromatic hydrocarbons that can operate continuously for several days.

The new complex of neutron moderators at IBR-2M is to include warm and cryogenic neutron moderators (Fig. 1). For the purpose of most effective accommodation of the moderators and choice of materials and their thickness calculations aimed at optimizations of the entire moderator complex were carried out.

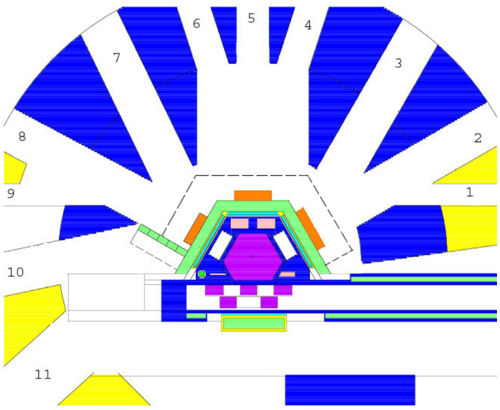

Fig. 1. The horizontal cross section of the IBR-2M reactor with a moderator complex. The numbers of the neutron beam-lines are indicated.

Calculations to compare cold neutron leakage from IBR-2M moderators taking into account the conditions imposed on their use show that aromatic hydrocarbon-based moderators are more effective than methane-based ones. The calculation results for one of the moderators are illustrated in Fig. 2.

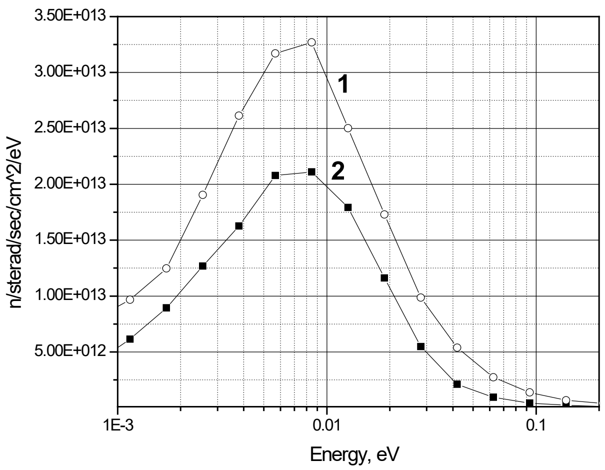

Fig. 2. A comparison of neutron spectra from methane- and mesitylene-based moderators at moderator parameters optimal for IBR-2M: 1- mesitylene at 20 K and 5 cm thick premoderator, 2 – methane at 60 K and 9 cm thick premoderator.

With a cold moderator the number of neutrons with the energy < 0.005 eV (neutron wavelength > 4 Å) increases ~10 times in comparison with that from a comb water moderator at room temperature.

2. Functional diagram of cold moderator and helium cooling system

A good-enough solution of the problem of moderator filling up is solid balls made of a mixture of mesitylene and pseudocumene or m-xelene. Such mixture in the frozen state has an amorphous structure, which is important both for increasing the cold neutron output and producing regular homogeneous balls. The balls are conveyed into the moderator chamber by a flow of cold helium at T = 20 – 22 K. The helium also cools the balls in the course of regular operation. As the time expires, i.e. mesitylene burnup starts affecting the cold neutron output; spent balls are replaced with the new ones.

The functional scheme of helium cooling of the cold moderator is depicted in Fig. 4. The moderator cooling circuit is a two-contour one. In the primary contour, which accommodates the chamber, helium is circulated by a special circulator (e.g.,, BNHeP-25 of Barber-Nicols make). Each moderator has its own contour with a circulator and a ball supply tract. In the secondary contour the cooling source is a refrigerating helium facility RHF-500 or CHF-700 with a capacity of 500 and 700 W at 15 K, respectively. At IBR-2M it is planned to install three cold moderators with three primary and two secondary contours. At present a facility for mass production of the balls and technology of their delivery to moderator chambers are being developed.

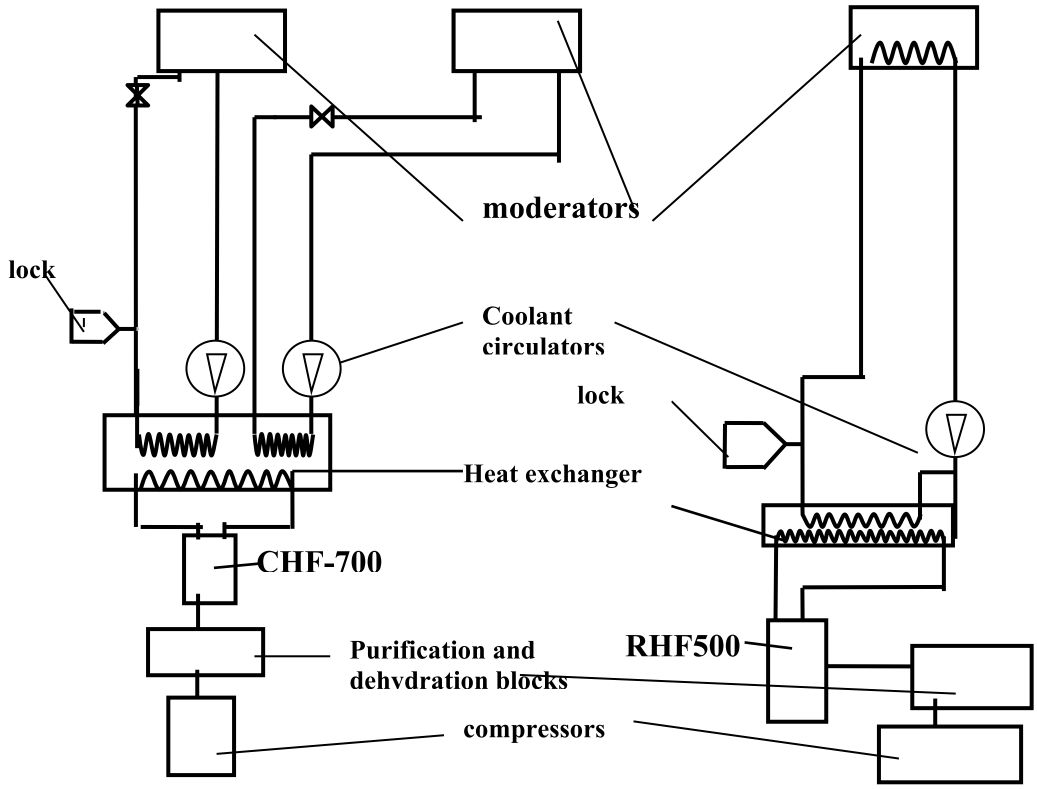

Fig. 3. The scheme of the cold moderator helium cooling system.

4. Required resources, cost (in USD) and schedule times of moderator complex construction

Project of moderator complex and in-process lines	400	2007	Complete set (NIKIET, GSPI)
Investigation of cryogenic moderators and in-process lines	100	2007	In FLNP together with GSPI and NIKIET
Purchase of coolant circulators and auxiliary equipment	200	2007	Purchase
Manufacturing of cryogenic moderators	500	2009	Order
Helium pipeline: designing, manufacturing, assembling	150	2009	Order, assembling in FLNP

TOTAL 1350 th.USD

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Spectrometer equipment upgrading at IBR-2M reactor

Project leader: V.G.Simkin.

The project "Sample Environment" executed in FLNP in 1995-1998 with financial support of Russia, Germany and Poland resulted in the main in equipping of the IBR-2 spectrometers with regular, then modern equipment. Recent advances in experimental technologies open new possibilities of investigations in extreme, with respect to some parameters, conditions: high pressures, low temperatures, strong magnetic fields. Realization of the new possibilities and providing conditions for effective operation of the existing instrumental suit are the main objectives of the present project. The project will be executed in the following main directions: low and high temperatures, high pressures, strong magnetic fields, goniometric equipment, and evacuating equipment.

1. Low and high temperatures

At present (the year 2006) IBR-2 spectrometer-aided low temperature measurements are carried out with the help of helium cryostats (Orange-100 – 1 cryostat., Orange -50 – 2 cryostats.) and close-cycle refrigerators (CT1 – 2 refrigerators., RGD – 5 refrigerators). Cryostats allow reaching the temperature 1.5 K by evacuating over-helium vapor with special pumps. Operation of cryostats requires liquid nitrogen and helium. Close-cycle refrigerators, which do not need any refrigerating medium, are easier, safer and more convenient in operation for experiments. The lower temperature limit achievable with refrigerators existing in the Laboratory is 7 – 10 K. Modern refrigerators, which employ pulsed tubes, have the lower limit $T \approx 3$ K and suffer much smaller vibrations than CT1 or RGD. Single-stage close-cycle refrigerators, which have a simpler design and are less expensive, allow cooling of beryllium filters in inelastic scattering spectrometers without a refrigerating medium (liquid nitrogen).

In order to obtain high temperatures up to 1000°C, gas- (rare gas-) filled vacuum ovens, whose operation requires additional equipment, must be purchased.

2. High pressures

Measurements of microsamples at high pressures (up to ~70 kbar) are conducted in specially designed (JINR - KI) cells with sapphire anvils that become destroyed after several cycles of pressure-cooling-heating. Essentially higher pressures (up to ~300 kbar) can be reached in cells with diamond anvils. Carrying out of the experiments requires having a set of cells and renewal of anvils in stock.

3. Magnetic fields

At present, experiments in strong magnetic fields at IBR-2 are carried out with polarized neutron spectrometers. There, superconducting magnets situated in helium cryostats of the Orange type are used. The magnetic field limit is 3 – 4 T. In view to extending the range of investigations in the direction it is necessary to buy a modern cryomagnet for 6 – 7 T.

5. Goniometric equipment

Diffraction investigations of single crystals at IBR-2 are mainly conducted with GKS-100 goniometric heads enabling operation of the existing close-cycle refrigerators. Modern goniometers compatible with modern refrigerators will make it possible to carry out such investigations in a more effective way and over a wider range of temperatures. In addition to full-circle goniometers it is necessary to have in stock precision rotary and translational movement goniometric tables.

Table 1. The cost and the list of the required equipment (in KUSD).

Equipment	Model	Firm	Cost	Number of pieces	Total cost
Close-cycle refrigerator, 3 K	SHI-3	Janis, USA	55	1	55
Single-step close-cycle refrigerator, 77°K	AL200	Cryomech, USA	24	2	48
Temperature control	900S	Evrotherm, UK	1.5	3	4.5
Silicon diode	ДТ470	Lake Shore, USA	0.5	5	2.5
Temperature calibrator	CZ125	Omega, UK	0.5	1	0.5
Heating element	62M36A5X	Watlow, USA	0.05	10	0.5
Turbo-molecular pump		Leybold	8	2	16
Forepump	2НВР-9ОД	Russia	1.7	1	1.7
Forepump	2НВР-9ДМ	Russia	0.7	1	0.7
Vacuum gauge with low- and high-pressure lamps	L8350301	Varian, USA	4	5	20
Vacuum armature (vacuum lines, valves, headers, oiling)		Leubold, Germany	10		10
Goniometer Huber with refrigerator to 4°K	DISPLEX202N	Huber, Germany	62	1	62
Translational displacement table		Micromech	3	4	12
Rotary table		Micromech	3	1	3
Sapphire and diamond anvils		Russia	10	1	10
Cryomagnet 7 T	7THL	Janis, USA	85	1	85
Nitrogen tank		Russia	45	1	45
Helium duar		Russia	4	3	12
High-clean gases	He, ^{3}He, CO, Ar	Russia			2
Multi-purpose polarizer		Gatchina, Russia	15	1	15
Disk chopper control system	Vector	CTDL, Germany	10	5	50

Total: 455,4

Position-sensitive gas-filled neutron detectors

Project leader: A.V.Belushkin

Many projects for the development of spectrometers at the IBR-2 reactor involve equipping of the spectrometer with a one- or two-dimensional position-sensitive detector (PSD). In the world there is a limited number of companies under neutron centers engaged in designing, manufacturing, and selling of position-sensitive detectors, including ORDELA (USA), DENEX (GKSS, Germany), D2L (ILL, France). At the same time today, there exists no mature market of neutron detectors, excluding standard proportional gas counters that are not position-sensitive and one-dimensional PSD with a resistance wire. In every particular case PSD construction is a subject of a special producer-customer agreement. According to ORDELA the estimated cost of such detectors is between 9000$ (neutron monitors) and 200000$ (two-dimensional muti-wire MWPC detector with an area of 650×650 mm²). As a rule, the cost does not include expenditures for electronics and software. Since FLNP has a capability to design and produce neutron PSDs with required characteristics, the necessity to start such production at FLNP seems obvious as this will bring essential fund saving.

1. Status of FLNP electronic system development

Today the Laboratory has an infrastructure for the development and production of detectors – clean room, gas and test desks. There are also developed and manufactured models of a one-dimensional (1D) position-sensitive detector [1] and a two-dimensional (2D) MWPC-based monitor [2] with delay-line-based information read-out. PC-integrated data acquisition electronics and software are developed. So, we speak about detector systems that include a detector itself, detector electronics, data registration and acquisition electronics, computer, and software [3]. It is actually a finished autonomous element of the neutron spectrometer that can be easily accommodated in any system of experiment control.

Figures 1 and **2**, respectively, show a MWPC-based one-dimensional (1D) PSD with delay-line information read-out made for the spectrometer REFLEX and the functional scheme of the corresponding electronics. The characteristics of the detector are summarized in **Table 1**.

Figure 3 shows a two-dimensional (2D) position-sensitive neutron monitor developed for the research reactor FRM-II (Germany), and **Table 2** summarizes the monitor characteristics.

Fig. 1 The one-dimensional PSD for the REFLEX spectrometer.

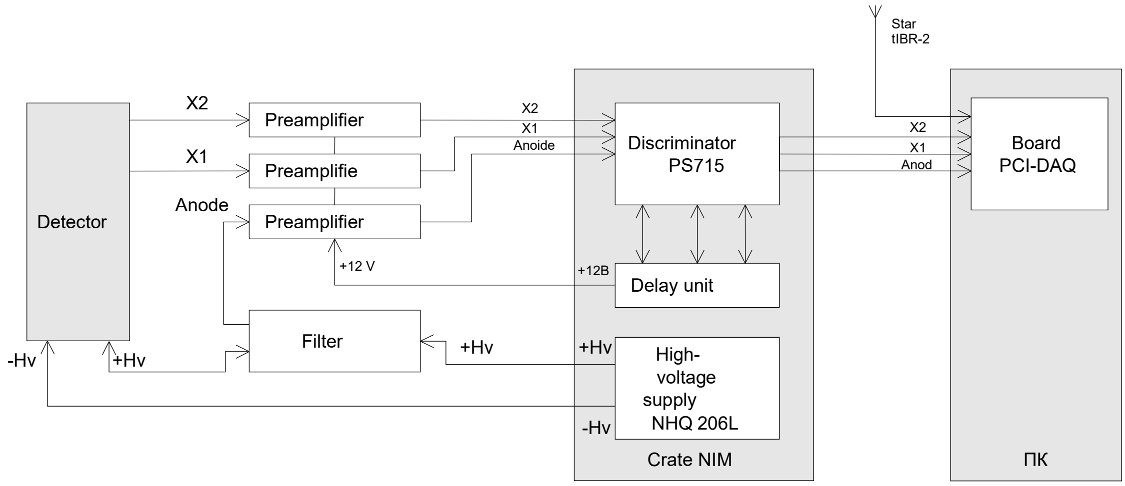

Fig. 2. Functional diagram of electronics

Table 1. The parameters of the 1D MWPC-based PSD with delay-line information read-out of the REFLEX spectrometer.

№	Parameter	Description
	Detector type	One-dimensional position-sensitive detector
	Working area	200x80 mm^2
	Effectiveness	40-45% (1 Å neutrons)
	Coordinate resolution	Not worse than 2 mm (determined by full width at half maximum (FWHM) in intensity distribution on detector at irradiation with beam with true size of not larger than 0.3 mm (FWHM))
	Load	Up to 100 kHz (maximum counting rate below which miscounts due to wrong addressing, dead time and electronics saturation do not exceed 10% of true counting rate)
	Stability	< 0.5%/24hr
	Channel homogeneity	< 10%
	Casing material	aluminum D16T
	Entrance window	aluminum, 7mm
	Gas mixture	4.0 atm ^3He + 2 atm CF_4
	Information read-out	Delay line

Fig. 3 The 2d monitor case.

Table 2. The parameters of the 2D position-sensitive neutron monitor for the research reactor FRM-II.

№	Parameter	Description
	Detector type	Two-dimensional MWPC-based position-sensitive detector
	Working area	100x100 mm^2
	Effectiveness	10^{-3}-10^{-6}% (for 1 Å neutrons depending on gas mixture composition)
	Coordinate resolution	4x4 mm^2
	Load (planned)	Up to 100 kHz
	Casing material	aluminum Д16Т
	Entrance window	Aluminum, 1 mm
	Working gas	N2 + CF4, total pressure= 1 atm
	Information read-out	Delay line

2. Proposals for engineering and production of detector systems and equipping of the IBR-2M spectrometers with them

The project sets the task of engineering, improvement of production technologies, and mastering of production of 1D and 2D neutron PSD that meet present-day requirements with respect to resolution and operation speed:

- Coordinate resolution on a level of 2 mm
- Counting rate on a level of 10^5-10^7 /(cm^2·s)
- Efficiency 40-80%.

2.1 Engineering of 2D neutron PDS with a delay-line readout

It is proposed to design a 2D PSD for measuring the spatial distribution of the neutron flux in the primary (at neutron-guide exit) and the scattered neutron beams. The following is chosen as initial parameters for development:

	incident beam	scattered beam
Neutron flux density (n/(cm^2s)	10^7	10^5
Sensitive area (mm^2)	130×70	225×225

Coordinate resolution (mm)	2.0	2.0.

Such parameters will be reached by improving the technology of winding signal wires of the anode and cathode plains of the detector, selecting the components of the gas mixture and by engineering new fast electronics.

2.2 Designing of 2D PSD with individual information readout

Preliminary prototyping has demonstrated an actual possibility to construct a large-size 2D PSD (500x500 mm^2) with individual information readout from each wire. For the purpose, it is necessary to design and build a new winding machine, design a detector case, develop data readout and acquisition electronics, multichannel detector electronics of signal readout and transformation, and electronics for event registration and coordinate determination (in binary and gray-scale variants) and for data acquisition.

2.3 Designing of new electronics and software for data registration and acquisition

For 1S and 2D PSD with delay-line information readout it is planned to design unified fast DAQ electronics based on logic matrices (FPGA) with an optic interface for PC data input. The predetermined registration rate is up to 1 mln.event/s, on-board histogram memory is 1 Gbyte. Event filtration and preliminary processing are executed on a hardware level in FPGA. From the viewpoint of hardware the electronics of 1D and 2D detectors is similar, the functional difference and parameters are programmed in FPGA. The DAQ boards are to be situated in the NIM crate together with detector electronics and the connection with PC is via a fiber-optic cable. Similar to those in the existing DAQ board there will be two operation modes – histogram and "listing" (raw data acquisition). The software for the DAQ board is to be integrated with the existing complex Sonix+.

For PSD with individual information readout there is to be engineered or purchased multichannel detector electronics for signal readout and transformation as well as electronics for event registration and coordinate determination (in binary and gray-scale variants) and for data acquisition. The PC interface is analogous to DAQ board interface for detectors with a delay line.

2.4 Equipping of IBR-2M spectrometers with detectors.

Under the Project it is planned to engineer detectors, manufacture model and test sample detectors and to develop the "detector infrastructure" (technological equipment, test benches, etc.). Equipping with detectors of particular instruments is to be carried out and financed in accordance with the corresponding projects of spectrometer designing and upgrading. The estimated cost of the detector systems is about 60 th.USD (1D) and 70 th.USD (2D). At present the Scientific and Experimental Condensed Matter Division (SECMD), FLNP is capable of producing two detectors a year (one-dimensional detectors analogous to that for the spectrometer REFLEX – up to three detectors a year).

3. Required resources, cost, and schedule times

The required resources, cost and schedule times of detector systems production are summarized in **Table 3**.

Table 3

№	List of works	Cost (th. $)	Times	Executor
6.	*"detector infrastructure" development(clean rooms, technological equipment, gases, test benches)*	40 (10th.$/year)	2007-2010	FLNP manufacturing, purchase
7.	*2D PSD system designing, manufacturing, testing (225x225 mm², 2.0 mm), scattered beam*	70	2007-2008	FLNP and EW JINR manufacturing,
8.	*2D PSD system designing, manufacturing, testing (130x70 mm, 2.0 mm), incident beam*	70	2007-2008	FLNP and EW JINR manufacturing
9.	*Development of new DAQ-electronics and software for MWPC detectors with delay lines*	25	2007-2008	FLNP manufacturing, regular electronics purchase
10.	*Designing, manufacturing, testing of 2D PSD with individual readout and of DAQ electronics*	80	2008-2009	FLNP and EW JINR manufacturing, regular electronics purchase

Total: 285 th $

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ZnS(Ag) scintillator-based position-sensitive scintillation detectors

Project leader: E.S.Kuzmin

Scintillation detectors of thermal neutrons have made a good showing when used as wide-aperture counters with geometric focusing. Till recently, however, most informative there have remained gas-filled position sensitive detectors because of a high cost of photomultipliers (~300 USD/channel). Today, with a new generation of photodetectors – photomultiplier matrices, with a record low cost per channel (~25 USD/channel) there has appeared a possibility of designing a new class of competitive devices with parameters meeting the requirements of a wide spectrum of problems, including high registration effectiveness, low gamma-sensitivity, registration of coordinates and neutron capture times.

1. Scintillation detector development status in FLNP

During the time of scintillation detector designing in FLNP (1998 –2005) on the basis of experimental investigations the following original systems have been designed and individual detectors as well as detector systems have been built:

- Prototypes of counters with geometric focusing for the FSD diffractometer built;
- A new-version geometric focusing detector system for FSD designed;
- The method of «rough» time focusing for moderate resolution diffractometry developed;
- The experimental module of the DN-6 diffractometer built;
- 24 working modules for the FSD diffractometer built;
- A multichannel module detector for superposition measurements designed;
- A 100-channel module detector for IMP, Ural Branch, RAS, built.

Rich acquired experience has allowed reaching high registration parameters: gamma-sensitivity of detectors is reduced to 10^{-7}, which is a good parameter for gas-filled detectors, electronic registration efficiency is increased to 99%, and counters of considerable extension (to 40 cm) show the existence of a count plateau of registration and long-term stability.

2. Proposal for engineering new-class detectors – module position-sensitive detectors of thermal neutrons

Position-sensitive gas-filled detectors used today are, as a rule, unique devices that require continual high-qualified servicing, and regular working-gas refilling. So, in addition to costly individual design, gas detectors have considerable operation cost. It is proposed to reduce the problem of engineering position-sensitive detectors to designing a unified module that is an independent device linked to a computer individually. In this case, assembling of a position-sensitive detector of optional form and size reduces to arranging such modules in space and modifying the data acquisition program.

Today's market of photodetectors offers special-purpose devices (Flat Panel type), dedicated to solution of such problems. A particularly attractive model with respect to the cost/quality criterion is offered by Hamamatsu Photonics. The photomultiplier matrix H9500 has the following geometric parameters:

• Pixel size	(2.8×2.8) mm
• Pixel arrangement step	3.04 mm
• Number of pixels	256 (matrix16×16)
• Photocathode effective area	49×49 mm
• External dimension	52×52 mm
• Packing density (effect.area./ ext.dimen.)	89%.

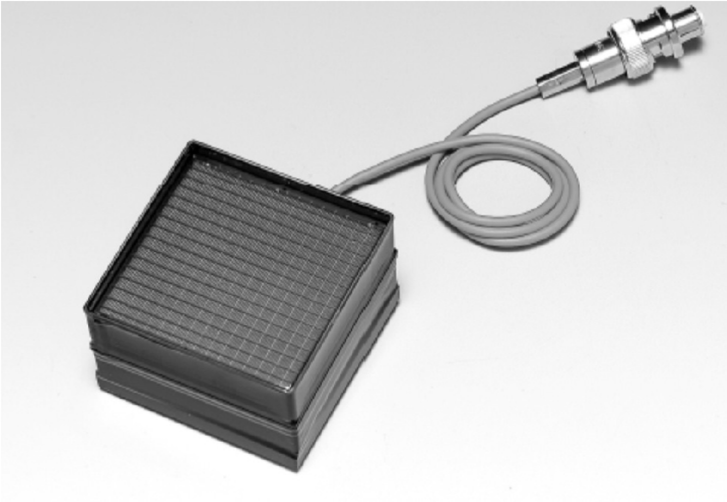

Fig. 1. The photomultiplier matrix H9500

Thus, when a detector is assembled of the modules, the total width of resulting «dead registration zones» equals the width of a single pixel. The proposed device is to consist of a matrix of photomultipliers accommodated immediately in the entrance window where the screen ND is situated. In the rear end of the module there is a high-voltage source, signal processing and computer linking electronics. The device is in a thin lightproof shell.

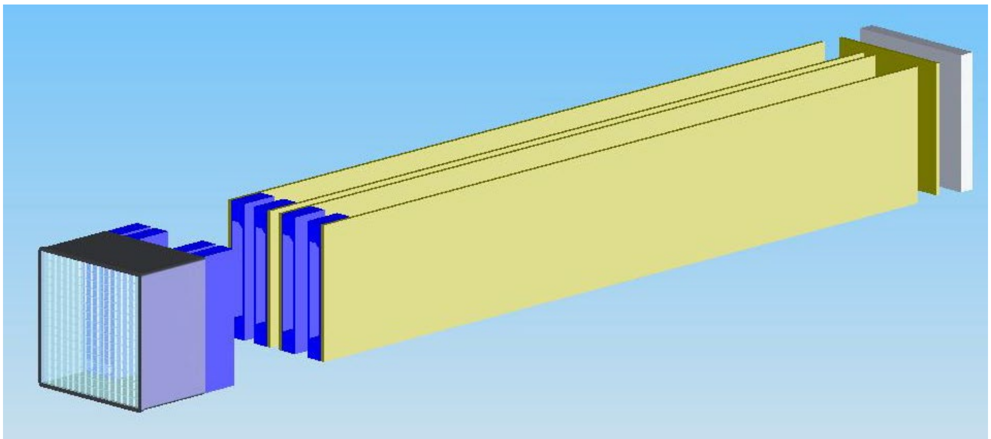

Fig. 2. The interior arrangement of the scintillation position-sensitive detector module. The module is accommodated inside a thin-wall metallic shell in the form of a parallelepiped. The entrance window of the module is a H9500 matrix and the rear end accommodates data transmission, signal synchronization and power-supply connectors. The major part of the module volume is occupied with electronic boards responsible for signal selection and coding.

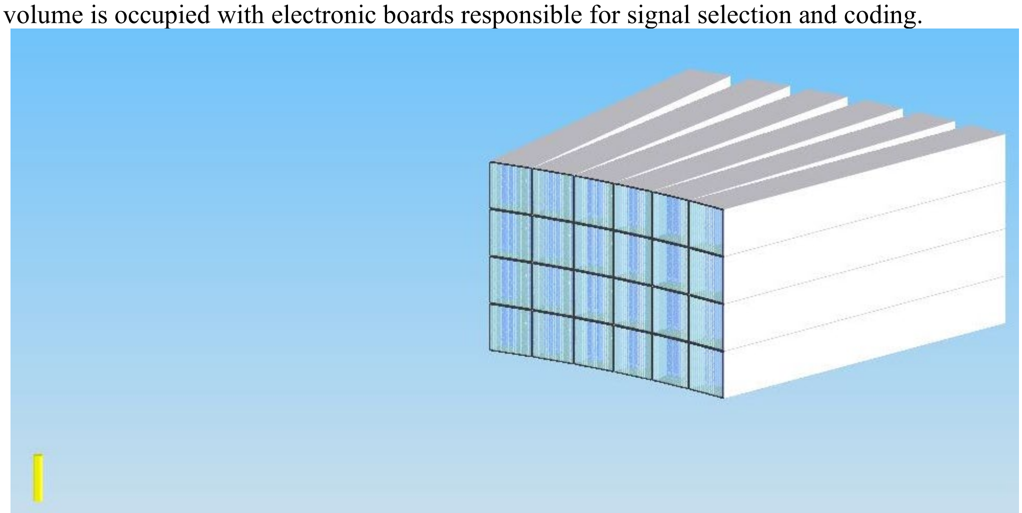

Fig.3. The ready-assembled position-sensitive detector.

In the initial stage it is proposed to create a device with a relatively low resolution – on a photodetector pixel size level. In such variant there are only registered events whose amplitude exceeds the specified threshold and that pass through a system of neutron signal selection. Depending on the optical scheme of screen-detector coupling one neutron capture event induces a signal on a different number of pixels on the screen, which affects the resolution of the device.

Anticipated characteristics of the module:

- Detector type — 2D + time
- Module sensitive area dimensions — 50×50 mm
- Coordinate resolution — 2.5 mm
- Data input into computer — USB/CAN;
- Maximum number of modules in detector — 96
- Registration efficiency (IBR-2 channels) — 40%
- Gamma sensitivity — 10^{-7}
- Maximum count/module speed — 10^5

3) Detector development prospects.

Provided the project is successfully realized, the design can be further developed, which will require much more complicate electronics but allow reaching a resolution on a level of tenths of a mm. In order to realize a promising variant of the device it is necessary to register the charge generated in each activated pixel and use software tools for precise recovery of the neutron capture coordinate. In this case the optical scheme of the device must be optimized with respect to geometric resolution criterion, and the data transmission volume increases by two orders of magnitude.

4) Required resources, cost and schedule times of development completion

The device can be engineered in the course of two years, in 2006 – 2007. The estimated cost of engineering is – 55 th.USD. The estimated cost of modules produced in the repetition work regime is 15 th.USD.

Cost of engineering

Expense items	Cost	Period
Equipment and materials	20000 USD	2007
Exterior organization services	25000 USD	2007 – 2008
Bonus fund	10000 USD	2007 – 2008

Total 55000 USD

1. Equipment and materials

Name	Firm	Cost per unit	Number	Sum
Photomultiplier matrix H9500	Hamamatsu	5350 USD	2	11000 USD
Electronic components	-	-	-	7000 USD
Engineering materials	-	-	-	2000 USD

2. Exterior organization services

Services	Cost
Mechanical structure engineering	5000 USD
Mechanical structure manufacturing	5000 USD
Electronics development	8000 USD
Electronics manufacturing	7000 USD

Work on the project is to be executed by members of the Scintillation Detector Group with commercial organizations intake.

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Portable cryogenic systems

Project leader: A.N.Chernikov

In the last decade progress in cryogenics is mainly in the direction of engineering pulsed-tube-based close-cycle refrigerators (PTR). Such refrigerators have a limiting temperature of 2.2 K and a refrigerating capacity of up to 1 W at 4.2 K corresponding to a liquid helium evaporating rate of up to 1.5 *l*/sec. The specific feature of refrigerators of the type is a very low noise and vibration level because their cold heads do not have a piston system. On the basis of such refrigerators there has appeared a technological possibility to produce cryostats for a variety of applications and a wide temperature range without liquid nitrogen or helium (cryogen free cryostats). In order to equip IBR-2 spectrometers with cryogenic devices FLNP has designed and manufactured a number of original "cryogen free" cryostats and cryostat-refrigerators in the last time. This project proposes dressing of a cryo-stand for designing and manufacturing of world-class portable autonomous cryostats of different types.

1. FLNP cryostat designing status

1.1. Shaft cryostat for 6–300 K.

The cryostat was designed and manufactured with participation of FLNP (**Fig. 1**) but it employs and old-type refrigerator (Gifford-McMahon) for the temperature range 6-300 K [1].

Fig 1. The close-cycle shaft cryostat on the basis of the two-step cryogenerator CoolPower 100T.

*1.2. Cryostat for 2.5–300 K with sample loading by positioning the sample on the cold platform of the head (**Fig. 2**).*

Fig. 2 The refrigerator-cryostat RC2.5-300.

In the course of the first IBR-2 cycle in 2006 on the spectrometer DIN-2PI a PT 405 refrigerator-based cryostat manufactured in FLNP was installed.

1.3. Superlow temperature cryostats:

1.3.1. Cryostat with ^{3}He circulation for 0.4–3 K (object of scheduled engineering).

1.3.2. Cryostat with a ^{3}He sorption refrigerator for 0.3–3 K.

The given cryostat was manufactured in FLNP for autonomous operation [2, 3]. However, it is technically implemented in a 4.2 K helium cryostat (**Fig. 3**). Work to produce such cryostats is being carried out by the firms Oxford Instruments [4] (HelioxAC-V) and Janis [5] (HE-3-CCR-SSV with an old-type refrigerator, the Gifford-McMahon one). Designing and manufacturing of such cryostats on the basis of PTR RP-052A (Sumitomo) are also being carried out with FLNP participation.

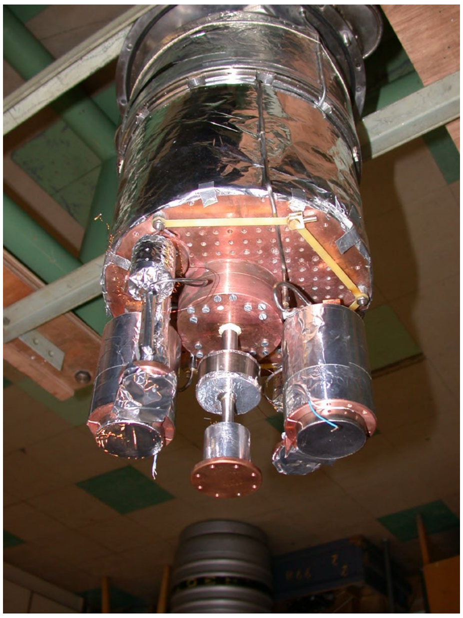

Fig. 3. The microrefrigerator with sorption pumping for temperatures down to 0.3 K.

1.3.3. ^{3}He-in-^{4}He dilution refrigerator with external circulation at 0.3 mmol/sec and final temperature down to 20 mK.

The work is carried out by the firm VeriCold (FRG) and is represented by the He7-System [6]. FLNP in collaboration with ITEP presents a project of an aligned target with a ^{3}He-in-^{4}He dilution refrigerator based on PTR PT405 (Cryomech) with external circulation of ^{3}He [7].
1.3.4. ^{3}He-in-^{4}He dilution refrigerator with sorption pumping for the final temperature down to 20 mK.
This project proposes construction of a development copy of the refrigerator for the first time in Russia.

All of the above-enumerated types are portable autonomous cryostats whose assembling or dismantling on IBR-2 spectrometers takes a short time. The FLNP cryostat engineering status is on the world level.

2. Proposal for development of FLNP cryogenic base

For successful fast designing and manufacturing of portable cryostats of the above-enumerated types for the IBR-2 spectrometers it is proposed to construct a cryostand in bldg. 119 and dress it with a pulsed tube-based refrigerator, ^{3}He circulation system, evacuating equipment, and measuring instruments.

The cost of the Project is specified in the Table and is estimated to be **228 KUSD.**

<u>*Schedule times:*</u>
2006÷2007: Development of a preliminary design of a cryostand. Equipment purchase.
2007÷2008: Manufacturing of cryostand components in accordance with preliminary design
2006÷2010: Designing and manufacturing of cryostats.

<u>*Required resources:*</u>

№	Name	Producer	Sum (KUSD)	Schedule time	Notes
1	<u>Cryostand:</u>			2007	
	- cryocooler PT410	Cryomech	40	2007	
	- temperature measuring device (model 370)	Lake Shore	10	2007	
	- thermometers	Lake Shore	6	2007	
	- evacuating equipment	Varian	10	2007	
	- experimental cryostat with control panel		30	2007	Designing and manufacturing
	- He3	Russia	13	2007	
	- materials	Russia	5	2007	
2	Redecoration of room for cryostand		4	2007	
3	^{3}He-circulation cryostat for 0.4–3 K.	Russia	50	2009	Designing and manufacturing
4	Cryostat for operation with superconducting magnets	Russia	60	2010	Designing and manufacturing

TOTAL 228 KUSD

Work on the project is to be carried out by members of Group No.2 "Automation and Sample Environment", FLNP with commercial organizations intake.

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Development of IBR-2 spectrometer data acquisition systems and computing infrastructure in FLNP

Project leader: V.I.Prikhodko

In the period of radical IBR-2 reactor modernization it is planned to build new and upgrade the existing neutron spectrometers. Therefore, in FLNP there has been elaborated a long-term program for development of the data acquisition system (DAQ) for the spectrometer complex and of the FLNP data processing infrastructure. This project describes the basic constituents of the program. The project aims at construction data acquisition and processing electronics and software corresponding to the world level of the FLNP spectrometers, which requires employment of advanced engineering standards, software products, and information technologies as well as of a unified approach to designing of such systems for all spectrometers. The research and designing work to be carried out under the project pursuit the goal.

1. Status and research program

Development of data acquisition systems and computing infrastructure is of key importance for successful realization of the program of scientific investigations in condensed matter at IBR-2. Measuring procedure perfection, increasing number of controlled parameters, increasing number and complication of detectors used in the experiment, higher requirements for precision and performance of recording systems, availability of remote control (from any point of the local computing system) of the spectrometer subsystems and of the experiment as a whole impose new requirements on experiment automation systems which cannot be satisfied in full measure by the existing hard- and software and the data processing infrastructure. The user mode of IBR-2 spectrometer operation imposes additional requirements on data acquisition systems: ease of familiarization and operation, handy graphical interface, Internet access to measurement results, etc.

The main problems that have to be solved in the course of creation of the new systems of data acquisition for neutron spectrometers are reliability, times of engineering and putting into operation, possibility of fast adaptation of the systems to changes in experimental requirements. Adaptability is of principal importance because it enables flexibility necessary for meeting the requirements (often unknown) of future experiments.

In the multilevel architecture of data acquisition systems only software support can be relatively easily modified. From the viewpoint of practice this means that digital signal processing must start as early as possible. It is just the approach that was used in construction the existing VME DAQ-systems at IBR-2 spectrometers. The digital data recording and acquisition systems of all spectrometers are in VME standard and present a limited in range but functionally complete set of identical (with respect to hardware) modules in which differences in parameters, functional possibilities, correction and preliminary processing procedures specific for a particular spectrometer are realized on the level of microprograms, electronic tables and unified control software complex SONIX.

The main body of the DAQ-system is in the processor module built on the basis of a high-end signal processor that implements intermediate memorization of primary data for each reactor cycle, data format transformation, computation of position codes in linear and two-dimensional PSD, time-of-flight correction (time focusing), addresses in histrogram memory as well as controls the parameters of the reactor and spectrometer and fulfils VME-system commands.

This very principal is to be used to create DAQ-systems for future spectrometers and experiments at the modernized reactor IBR-2. The main directions of the work are:

- PC integration into the VME-system of data acquisition in order to have a user-friendly interface under habitual Windows and effectively use the PC-oriented primary data processing and analysis software developed in FLNP and other neutron centers.
- Development of new software products.
- Integration of module PC into individual measuring and control subsystems and creation of mini-frame PC for control of spectrometers and data processing.
- Development of neutron experiment-specified electronic blocks with improved characteristics taking advantage of advances in engineering and manufacturing of electronic components, which allows:
  - Raise system performance to 10^6 event/s;
  - Increase histogram memory volume to 1 Gbyte;
  - Improve measurement precision and increase the number of recorded and controlled parameters;
  - Use more complicate algorithms of data filtration and preliminary processing etc.
- Galvanic junction of detector electronics.
- Basic upgrading of power supply systems.
- Reducing of in-house designing and orientation towards wide application of industrial standards and systems as well as commercial software products.
- Employing of new technologies of DAQ-system production, including, in the first place, mezzanine and net technologies.

The architecture of the new generation DAQ-systems is shown in Fig.1 At present, work is being carried out in all the enumerated directions, which, together with the existing data acquisition systems, is a good start in the direction towards realization of the discussed part of the project.

Another important direction under project is development of the computing infrastructure for the IBR-2 spectrometer complex (local-area network (LAN) and computing). As is known, the existing central file-server Enterprise 3000 of Sun Microsystem (two processors, Ultra Sparc 250 MHz, RAM – 250 Mbyte, HDD –200 Gbyte) is the only powerful calculator and provider of disk space for FLNP LAN users. The server has been in service for 8 years, which is inadmissibly long for computing machinery. This has resulted in support of the server hardware and software with low capacity disk memory, high operation cost, etc. In 2005 there was bought the new central server Sun Fire X4200 and a bulk storage device for 6.4 Tbyte to be installed in 2006, which will help solve the enumerated problems. The Enterprise 3000 is to be worn out in LAN to work with applications written for the old operation system.

Along with installing new servers and a bulk storage device, creation of the new FLNP LAN architecture and a transition to gigabyte speeds in the main LAN segments are planned (Fig. 2). At present the central LAN router Cisco 8510 is linked to the JINR network via two lines with a total capacity of 200 Mbyte/s. With continuously growing traffic and routing equipment load the connection does not provide users with stable high-performance service. Moving of the LAN main body to the newly purchased Cisco 3750 routers, installing of a 1 Gbyte/s interface in the router 8510 and a transition to high performance lines will make it possible to remove the existing difficulties, increase the reliability of network operation and ensure linking to JINR and other networks at gigabyte speed.

2. Proposal for modernization and development of data acquisition systems and computing infrastructure

Data acquisition systems and software for the new spectrometers will be created in correspondence with the architecture in Fig.1. 1. All the electronic blocks of the new DAQ-systems will not be logically connected with the existing nuclear electronics standards and the CAMAC, VME, NIM crates available will be only used as mechanical structures to house and supply power to the blocks. The blocks can be also accommodated immediately in the PC jacket. All the blocks will have a PC interface and be linked to it via high-speed communication lines (primarily optic).

It is planned to engineer a number of unified blocks for data acquisition from different type detectors:

- point (neutron counters, scintillation detectors);
- two-dimensional PSD with delay-line or individual read-out;
- one-dimensional PSD with delay line or resistance wire read-out.

The blocks will have various data acquisition regimes, including integral (monitoring counters), histogram (on-line sorting and acquisition of spectra in block's memory), and «listing» (raw data acquisition with further PC processing and sorting). All the functions and parameters of the blocks are programmable. Different versions of soft firmware (depending on the type and parameters of the detector, operation mode, and filtration and preliminary processing procedures) are recorded in blocks' logic matrices by a PC control program, which allows realization of the different functions and using of the blocks for data acquisition in different type spectrometers without any changes in the hardware.

In addition to the above indicated "typical" blocks, there will be designed some special-purpose blocks for particular applications, e.g., Fourier analyzer with real-time acquisition of a complete picture of events (recording of pick-up signal parameters and detector counting intensity with specified time discontinuity), block for acquisition of sets of histograms over short time intervals to carry out real-time studies of transitional processes in condensed matter, etc.

The data acquisition software is to be based on the improved version of the Sonix+ complex under Windows.

Individual subsystems of the spectrometers, position-sensitive detectors in the first place, can include their "own" PC that has in-built data acquisition electronics. In that way, several "subordinate" PCs can enter into the structure of the spectrometer with experiment control being executed by a central computer operating under Sonix+.

Partial modernization of data acquisition systems can be done in a simpler and less expensive way. The main point of it consists in replacing the processor in the VME crate with an external PC linked to the VME bus via a VME-PCI adapter. In that case, the PC takes over the task of the VME computer and the control complex Sonix is replaced with a Sonix+ one with a Windows instead of OS-9 operational system. This allows leaving the existing VME electronics without any changes and at the same time, makes it possible for user to work in the habitual user-friendly Windows environment rich in various software products. In addition, this makes the development of the Sonix complex considerably easier thanks, in the first place, to the possibility of employing new programming technologies. Favorable experience of the kind was acquired in the course of modernization of the spectrometers NERA-PR and REMUR where VME-PCI adapters and Sonix+ were installed.

The choice of the type of DAQ modernization for each spectrometer depends on the program for modernization of the spectrometer itself and on available financing. In any case it should be remembered that the spectrometers are to operate at the modernized reactor beginning from 2010 and that the technological decisions made should take into account the development tendencies in microelectronics and computer technologies, i.e., it must be the "systems of tomorrow".

In the projected period some modernization will undergo the control systems of the most conservative elements of the spectrometers – choppers, executive mechanisms and sample environment systems. It is also necessary to improve the systems of power supply of electronics and computer equipment in the experimental halls of the reactor. The easiest way is to install a continuous power supply source in each spectrometer.

Modernization and development of the net infrastructure aims at:

- increase of the actual net transmission capacity of major lines to 1 Gbyte/s;
- providing the mechanisms of control, analysis, and filtration of net traffic;

- organization of virtual subnets for users (or instruments) independently of their geographical situation;
- providing a guaranteed transmission bandwidth for the most important net applications (e.g., for particular spectrometers);
- providing reservation of the most critical elements of the net;
- organization of a special Intel server for centralized acquisition of the experimental data from the IBR-2 and other spectrometers.

The realization of the IBR-2 spectrometer complex project will result in creation of the new generation of unified data acquisition systems with characteristics on the world level. The chosen architecture of DAQ-systems fits well the net infrastructure and secures simplicity and low cost of their continuous modernization following computing and communication technology progress. There will also be solved a second vitally important for the Laboratory problem of development and maintenance on the world level of the computing infrastructure.

3. Required resources, cost and schedule times

Expenditures on data acquisition systems should, in the main, be made provision for in projects of creation or modernization of spectrometers. The present project asks financing for methodological investigations, manufacturing of development electronic blocks, construction of testing benches, equipment for working places of engineers and programmers, and development of the computing infrastructure of the Laboratory.

Table 1

№	Activity	Cost (th.$)	Schedule times	Executer
1.	Engineering and manufacturing of development samples of new electronic blocks and testing benches	60 (15 th/year)	2007-2010	FLNP manufacture, accessories purchase
2.	Development, debugging, and optimization of DAQ-software	30 (7 th/year)	2007-2010	FLNP manufacture, purchase and updating of support software products
3.	Equipping of workplaces for engineers and programmers (purchase and updating of PC, CAD/CAE–systems, measuring and monitoring instruments, etc.)	40 (10 th/year)	2007-2010	Purchase
4.	Modernization of power supply systems and upgrading of computers of IBR-2 spectrometers	15	2007-2010	Purchase
5.	Modernization of control systems of choppers, executive mechanisms, and sample environment systems	40 (10 th/year)	2007-2010	FLNP manufacture, purchase
6.	Manufacturing of new data acquisition systems (hard-and software) in agreement with spectrometer development projects	-	2009-2010	FLNP manufacture
7.	Renewal of exhausted-resource special-purpose servers and workstations, disks, subsystems	50	2008-2010	Purchase
8.	LAN architecture modernization, operational systems renewal	20	2007-2010	Purchase, FLNP manufacture
9.	Laying of backup communication lines and modernization of communication equipment	30	2009-2010	Purchase, FLNP manufacture
10.	Renewal of LAN exhausted-resource peripheral equipment (printers, copiers, and projection equipment)	40 (10 th/year)	2007-2010	Purchase

Total: 295 th. $

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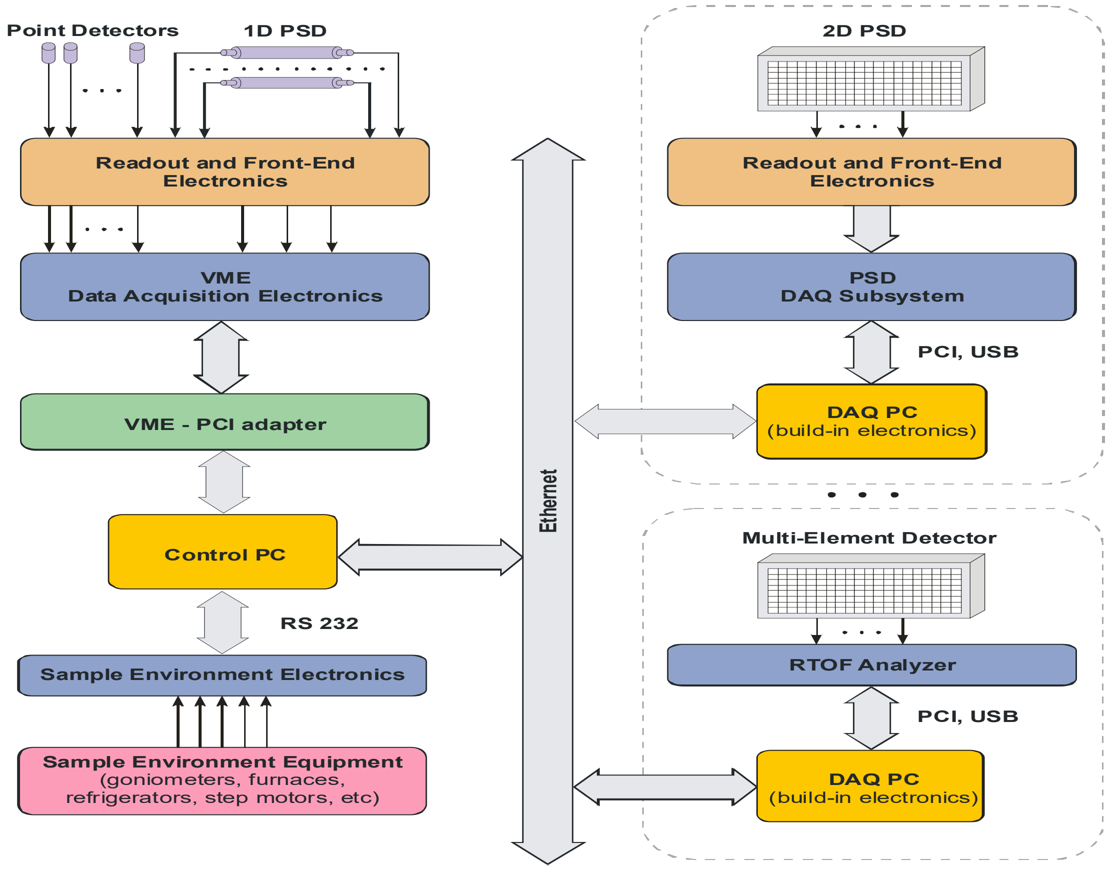

Fig. 1. The architecture of the new-generation data acquisition systems.

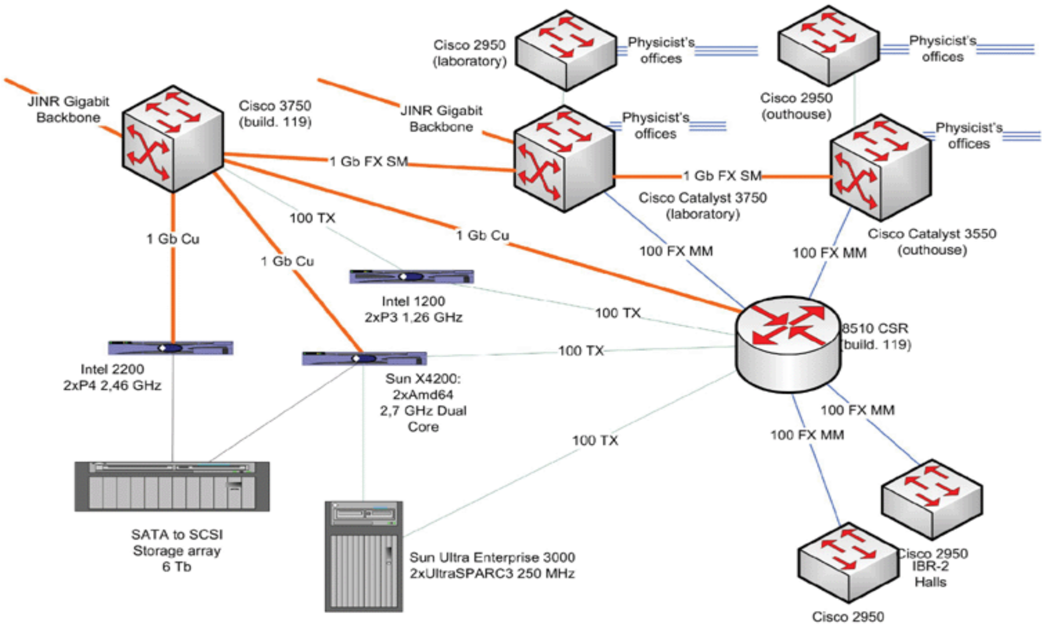

Fig. 2. The new LAN architecture in FLNP.