ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И. Будкера СО РАН

V.N.Korchuganov, G.N.Kulipanov,
N.A.Mezentsev, A.D.Oreshkov,
V.E.Panchenko, V.F.Pindyurin,
A.N.Skrinsky, M.A.Sheromov,
N.A.Vinokurov, K.V.Zolotarev

SYNCHROTRON RADIATION AND FREE ELECTRON LASER ACTIVITIES IN NOVOSIBIRSK

BudkerINP 94-34

НОВОСИБИРСК

Budker Institute of Nuclear Physics

V.N.Korchuganov, G.N.Kulipanov, N.A.Mezentsev,
A.D.Oreshkov, V.E.Panchenko, V.F.Pindyurin,
A.N.Skrinsky, M.A.Sheromov,
N.A.Vinokurov and K.V.Zolotarev

SYNCHROTRON RADIATION AND FREE ELECTRON LASER ACTIVITIES IN NOVOSIBIRSK

BudkerINP 94-34

NOVOSIBIRSK
1994

Synchrotron radiation and free electron laser activities in Novosibirsk

V.N.Korchuganov, G.N.Kulipanov, N.A.Mezentsev,
A.D.Oreshkov, V.E.Panchenko, V.F.Pindyurin,
A.N.Skrinsky, M.A.Sheromov,
N.A.Vinokurov and K.V.Zolotarev

Budker Institute of Nuclear Physics
630090, Novosibirsk, Russia

ABSTRACT

In the last decade the Siberian SR Centre has implemented a wide program of SR and FEL research in cooperation with various research centres and institutions in Russia and abroad. The report illustrates this program, including joint experiments with the use of SR and FEL sources available at the Budker Institute of Nuclear Physics (INP), the implementation of new joint projects in Novosibirsk and in the other centres, as well as the delivery of equipment to foreign countries, designed and manufactured at the Budker INP or in collaboration with Russian industry.

Some technical information on the storage rings - SR sources, wigglers, undulators and free electron lasers which are being constructed, used or developed at Budker INP is given.

1 Introduction

At present the Siberian Synchrotron Radiation Centre (SSRC), which was established on the basis of the Budker Institute of Nuclear Physics (INP) laboratories, is a major site for synchrotron radiation (SR) and free electron laser (FEL) researches in Russia. The general lines of the SSRC scientific program are:

- the performance of experiments and the development of new technologies, using synchrotron radiation from the Budker INP SR sources—the VEPP-2M, VEPP-3 and VEPP-4M storage rings;
- the development of experimental equipment for SR research (beamlines, optics, monochromators, detectors);
- the development of storage rings—dedicated SR sources, the development of devices for SR generation—wigglers and undulators;
- *the development of free electron lasers.*

SSRC has no budget source of funding and performs its experimental and research programs at the expense of:

- the Russian State scientific-technical program "Synchrotron radiation";
- purposeful funding of FEL works;
- grants of Russian scientific and technological funds;
- contracts with various institutions in Russia and abroad;
- international cooperation.

2 SR sources of Budker INP

There are three storage rings available as synchrotron radiation sources in the Budker INP — VEPP-2M, VEPP-3 and VEPP-4M.

The VEPP-2M electron-positron storage ring is a major facility used in synchrotron radiation research in the VUV and soft X-ray ranges ($\lambda = 5\cdot10^3 \div 2$ Å) at the Siberian Synchrotron Radiation Centre. The basic parameters of VEPP-2M as a SR source are given in Table 1.

Table 1: Basic parameters of the VEPP-2M storage ring

1. Energy, MeV	700
2. Circumference, m	17.88
3. *Kind of particles*	e^-, e^+
4. Operation mode	single- or multi-bunch
5. Emittance, cm·rad	$4.6\cdot10^{-5}$
6. Stored current, mA:	
total	300 (150 e^- and 150 e^+)
single-bunch	200 (e^- or e^+)
multi-bunch	300 (e^- or e^+)
7. Lifetime, h	$1\div2$
8. Magnetic field in bending magnets, T	1.91
9. Revolution period, ns	59.6
10.Bunch length $2\cdot\sigma_s$, cm	8
11.Insertion devices:	superconducting wiggler
number of poles	$5 = 3(H_o) + 2(H_o/2)$
pole length, cm	12
magnetic field H_0 on the orbit, T	7.5
12. Transverse beam dimensions at irradiation points at the coupling coefficient κ:	

$\frac{\kappa=0.1}{\kappa=1}$	$2\cdot\sigma_x$, mm	$2\cdot\sigma_z$, mm
bending magnet	$\frac{2.7}{1.9}$	$\frac{0.17}{1.2}$
wiggler	$\frac{1.0}{0.7}$	$\frac{0.03}{0.2}$

13. Total SR power, kW	7.5 (with the wiggler)
14. Critical radiation wavelength, Å:	
from bending magnet	19.9
from wiggler	5.1
15. Number of beamlines:	9
from bending magnet	6 (2 - e^- , 4 -e^+)
from wiggler	3 (2 - e^- , 1 - e^+)
16. Mode of operation for SR works	parasitic/dedicated

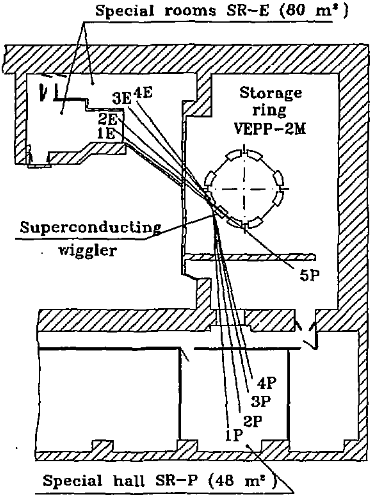

Fig. 1. Layout of the VEPP-2M facility.

There are two special rooms and hall available for SR works. Their location, as well as the directions of SR beamlines are shown in Fig. 1. The radiation from a superconducting wiggler (beamlines 1E and 2E) and from a bending magnet (beamlines 3E and 4E) are extracted to the special rooms, having the 80 m^2 total area, along the direction of the electron motion. In the direction of the positron motion, the radiation from a bending magnet (beamlines 1P to 4P) arrives to the special hall whose total area is 48 m^2. The station for positron beam parameters measurements (beamline 5P) is housed in a separate room.

The SR beamlines and experimental stations (with indication of their current status) are listed in Table 2.

At present, the VEPP-3 storage ring is a main source of synchrotron radiation in the X-ray range. Synchrotron radiation is extracted from a dedicated 3-pole wiggler, with a field of 2 T on the orbit, mounted in the straight section of the storage ring. The magnetic fields are approximately equal at all three poles. Synchrotron radiation is extracted from the storage ring vacuum chamber through Be foils whose total thickness is 0.8 mm. These foils separate the storage ring vacuum from the vacuum of the beamlines to the experimental stations. The total horizontal angle of the wiggler radiation is 120 mrad. This radiation fan is divided by 8 beamlines, six of which transmit 5 mrad of radiation and the remaining two being capable to transmit 8 mrad. Beamline 9 extracts radiation from the 1.7 T bending magnet

Table 2: SR beamlines and experimental stations of the VEPP-2M

Beamline (emitting particles)	Irradiation point	Angle of beamline axis to straight section, axis, °	Total angular aperture of beamline, mrad	Total SR power in beamline (E=700 MeV; Ie^-, Ie^+ = 150 mA), W	Experimental station (current status)
1E (e^-)	wiggler	−0.7	7.3	11.8 (from one irradiation point)	Out of use
2E (e^-)	wiggler	0	7.3	11.8 (from one irradiation point)	X-ray lithography (beamline assembling, preparation of the station)
3E (e^-)	bending magnet	5	16.1	6.7	Photoelectron spectroscopy for chemical analysis (in operation)
4E (e^-)	bending magnet	10	19.5	8.1	in reserve

Table 2: SR beamlines and experimental stations of the VEPP-2M (continuation)

Beamline (emitting particles)	Irradiation point	Angle of beamline axis to straight section axis, °	Total angular aperture of beamline, mrad	Total SR power in beamline ($E = 700$ MeV; $Ie^-, Ie^+ =$ 150 mA), W	Experimental station (current status)
1P (e^+)	bending magnet	4	17.5	7.2	Photoelectron spectroscopy II (beamline assembling, station design)
2P (e^+)	bending magnet	7	15.4	6.4	Time-resolved luminescence (beamline asembling, preparation of the station)
3P (e^+)	bending magnet	10	17	7.0	Soft X-ray metrology (station commissioning)
4P (e^+)	bending magnet	12.5	19	7.9	Stimulated photodesorption (in operation)
5P (e^+)	wiggler	0	5.6	9.0	Positron beam parameters measurements (in operation)

through a 30 μm thick Be foil into the super high vacuum beamline with differential pumping.

Layout of the VEPP-3 facility with SR experimental area is given in Figure 2 and an arrangement of the SR experimental stations is shown in Figure 3.

Synchrotron radiation works on the VEPP-3 are being performed at an energy of 2.0 GeV and at a maximum current within 250÷100 mA. The X-ray lithography station has the operational mode of its own at 1.2 GeV. The basic parameters of the VEPP-3 as a SR source, as well as SR beamlines and experimental stations are listed in Table 3 and Table 4, respectively.

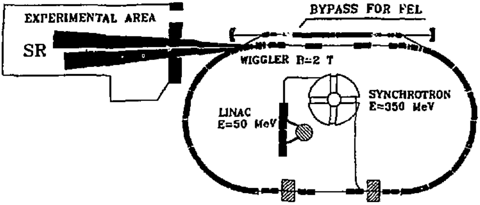

Fig 2. Layout of the VEPP-3 facility.

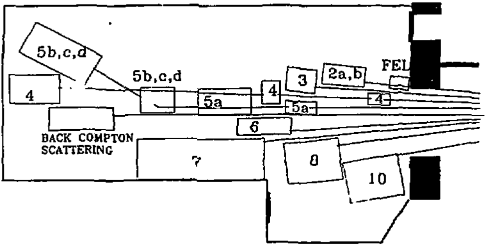

Fig. 3. Arrangement of the SR experimental stations
at the VEPP-3 storage ring.

In 1983-85 SR investigations at the VEPP-4 storage ring were performed in a special bunker of 35 m^2 area. The bunker housed 6 experimental stations positioned on 4 SR beamlines. The works were conducted at an energy of $4.6 \div 5.1$ GeV and a storage ring current up to 30 mA.

Table 3: Basic parameters of the VEPP-3 storage ring

1. Maximum energy, GeV	2.0
2. Circumference, m	74.4
3. Operation mode	one- or two-bunch
4. Emittance, cm·rad	$2.7 \cdot 10^{-5}$
5. Current, mA	250
6. Lifetime, h	$3 \div 4$
7. Number of wiggler poles	3
8. Magnetic field in the wiggler, T	2.0
9. Magnetic field in the bending magnet, T	1.7
10. Electron beam dimensions σ, mm:	
in vertical	0.06
in horizontal	0.9
11. Critical wavelength, Å	
from the wiggler at $E = 2.0$ GeV	2.3
from the bending magnet at $E = 2.0$ GeV	2.7
from the bending magnet at $E = 1.2$ GeV	12.6
12. Number of SR beamlines:	
from the wiggler	8
from the bending magnet	1

Table 4: SR beamlines and experimental stations of the VEPP-3

Beamline	Radiation point	Experimental station
2	wiggler	a) Laue diffractometry b) Anomalous scattering
3	wiggler	X-ray fluorescence element analysis
4	wiggler	Subtraction angiography
5	wiggler	a) X-ray microscopy and microtomography b) Time-resolved diffractometry c) Macromolecular crystallography d) Inelastic scattering e) Small-angle diffractometry
6	wiggler	Time resolved spectroscopy
7	wiggler	X-ray topography and diffractometry
8	wiggler	EXAFS-spectroscopy
10	bending magnet	X-ray lithography

In the recent years the project for updating the VEPP-4M storage ring has been implemented. This project envisaged, in particular, the replacement of two periodicity components in the middle of each semi-ring by equivalent insertion devices consisting of C-shaped bending magnets and lenses. The design of these magnets enabled us to easily arrange the radiation extraction from them using special vacuum chamber of the storage ring at this location. Due to the increase in the magnetic field in the C-shaped magnets, their length was shortened, thus making it possible to arrange 1.8 m long straight sections to place dedicated generators—wigglers and undulators. In one of the straight sections, an 1.5 T electromagnetic seven-pole wiggler is suggested to be positioned.

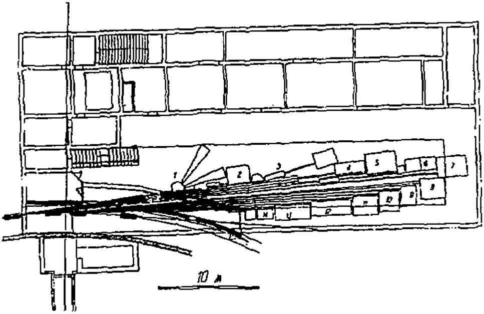

Fig. 4. Arrangement of the VEPP-4M SR experimental stations.

Near the tunnel for the VEPP-4M northern semi-ring, the construction of the radiation-protected bunker (total area 1200 m^2) comes to completion. About 20 experimental stations, the SR beamlines and special laboratory rooms for experimental teams will be housed in this bunker (see Fig. 4). The basic parameters of the VEPP-4M as a source of synchrotron radiation are listed in Table 5. Experimental works with SR beams in the new bunker are expected to start by the end of 1994. Most of SR experiments will be carried out in parallel with high energy physics experiments. Some of SR experiments which need special operational modes will be performed during the runs intended for SR works.

Table 5: Basic parameters of the VEPP-4M storage ring

1. Maximum energy, GeV	6
2. Circumference, m	366
3. Operation mode	single- and multi-bunch
4. Emittance, cm·rad	$1.2 \cdot 10^{-4}$
5. Maximum current, mA	
single-bunch	40
multi-bunch	80
6. Lifetime, h	4÷6
7. Magnetic field in the bending magnet, T	1
8. Revolution period, μs	1.2
9. Bunch length, $2 \cdot \sigma_s$, cm	5
10. Critical wavelength, Å	
from the bending magnet	0.51
from the seven-pole wiggler	0.4
11. Number of SR beamlines	14

3 SR research in Budker INP

The SSRC activities cover a wide spectrum of scientific and technological problems (Fig. 5).

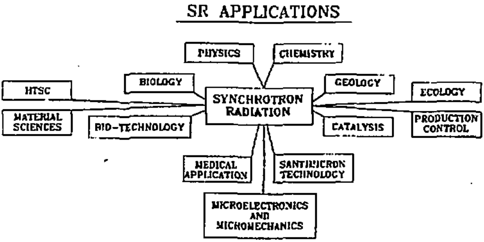

Fig. 5. SR applications in SSRC.

Table 6: The list of SSRC experimental stations

X-ray lithography
Photoelectron spectroscopy
Stimulated photodesorption
Time-resolved luminescence
Hard and soft X-ray metrology
Optical klystron
Compton back scattering
Laue diffractometry
Anomalous scattering
X-ray fluorescence element analysis
Digital subtraction angiography
X-ray microscopy and microtomography
Time-resolved powder diffractometry
Macromolecular crystallography
Time-resolved X-ray-induced luminescence
Small angle scattering
Topography and diffractometry
EXAFS-spectroscopy
LIGA-technology

Nineteen experimental stations, which now operate at the VEPP-2M and VEPP-3, are listed in Table 6. SSRC works were presented in over 1100 publications, in Russian and foreign journals [1]. Fig. 6 gives information concerning the annual number of SSRC publications. Needless to say, the subjects of these papers are noted for by great diversity. In works that apply X-ray diffraction methods, the structural changes in metals in the process of their destructions, in solids during chemical reactions and in the contracted muscle, as well as the phase transitions under superhigh pressures are studied. Due to EXAFS-spectroscopy, the structure of amorphous semiconductors and metal glasses, the active centres in proteins and various catalysts are examined. Among applications of X-ray fluorescence element analysis are a *search for new ore deposits*, analysis of marine water and sediments, element analysis of aerosols, microelement analysis of water, medicines, blood, and so on. Synchrotron radiation allows one to examine the structure of the surface layers of materials of submicron thickness, to take microtomograms with

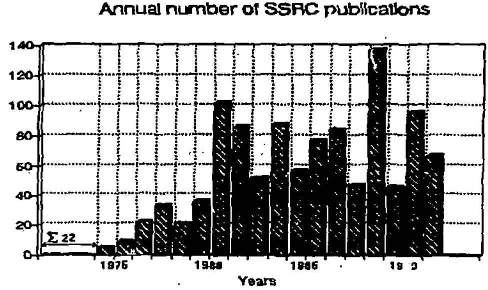

Fig. 6. The annual number of SSRC publications.

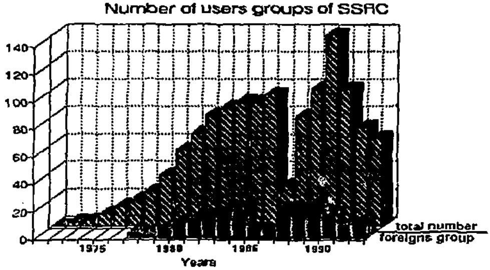

Fig. 7. Variations in the number of users teams in SSRC.

two microns spatial resolution (for example, of lymphatic nodes), to measure the concentrations of elements in fluid inclusions in minerals, to measure the distribution of various elements along the human hair, and so forth. Using

Table 7: The list of collaboration agreements between SSRC and foreign laboratories.

1. Daresbury Lab (SERC United Kingdom)	1977	Generation and utilization of SR
2. LBL, SLAC, University of Wisconsin (DoE USA)	1980	SR beam production insertion devices, compact SR sources, development of SR experimental equipment
3. CAT, BARC, Inter-University Consortium (DST India)	1987	SRS design and development, SRS utilization
4. FEL lab Duke University (NC USA)	1992	Free electron lasers
5. POSTECH (Korea)	1992	Accelerator design, beam lines, insertion devices, SR experiments
6.IHEP Academia Sinica (China)	1992	Scientific exchange and Joint Research and development in the field of SR
7.Laboratory BESSY (Germany)	1993	Development, design and construction of BESSY-II
8. APS ANL (USA)	1993	Area synchrotron radiation instrumentation

the X-ray lithography technology, regular micropore filters with high — up to 50% — transparency, with given arrangement and size of 0.2÷0.4 μm diam pores in a 2÷10 μm thick lavsan film were manufactured. And the X-ray lithography was applied for manufacturing the field-effect transistors with 0.25 μm gate length.

The staff of the experimental teams involved in SSRC works is mainly from Novosibirsk institutes of the Siberian Division of the Russian Academy of Sciences. These teams are usually the hosts of the experimental sta-

tions. Besides, the teams from other cites from the institutes of the Russian Academy of Sciences, universities and high education schools, technological institutes of industry both from Russia and abroad are involved in SR works. Fig. 7 illustrates the dynamics of changing the number of the experimental teams since 1973, for two decades. The decreased number of the teams in 1986–87 was caused by the fire at the Institute, that happened in August of 1985. The second decrease after 1990 was due to the change in political and economic situation in the countries of Eastern Europe and in the republics of the former Soviet Union. As a consequence, 10 teams from the former German Democratic Republic, 6 teams from the former Czechoslovakia, 3 groups from Hungary, as well as the teams from Armenia, Azerbaijan, Estonia, Latvia and Ukraine stopped to work. A drastic reduction of funds for science in Russia and the increased prices of flight tickets and hotel accommodation decreased the number of teams from cities of the European part of Russia. In 1993, as small as 64 teams have worked at the SSRC, including 12 from foreign countries (2 from England, 3 from Germany, 3 from Korea, 1 from India).

The list of agreements on scientific cooperation between SSRC and foreign laboratories is given in Table 7, with the field of cooperation indicated.

4 Development of dedicated SR sources

In the last decade, SSRC has executed contracts on the design and manufacture of dedicated SR sources [2] — *the electron storage rings SIBERIA-1,* TNK (ZELENOGRAD) and SIBERIA-2 (their parameters are listed in Table 8). Since 1983 the SIBERIA-1 storage ring operates at the Kurchatov Institute (Moscow). As for SIBERIA-2, this storage ring is fully assembled at the Kurchatov Institute. The difficulties with funding for two last years has somewhat delayed its assemblage and commissioning. However, we hope to have the electron beam in SIBERIA-2 by the end of 1994.

The TNK storage ring, intended for the technological Microelectronics Centre in Zelenograd, is also ready for the assembly, but its components are still stored at Novosibirsk. The works on the creation of this centre were ceased due to the lack of funds.

The same reason also stopped *the SSRC programs on the creation of* compact SR sources on the basis of superconducting magnets [3]. This program has envisaged the modulus principles when designing technological storage rings whose key component is magnets of one and the same type, namely short rectangular magnets with a 6 T homogeneous magnetic field.

Table 8: The parameters of the dedicated SR sources: SIBERIA-1, TNK (ZELENOGRAD) and SIBERIA-2

Name	"Siberia-1"	"Zelenograd"	"Siberia-2"
Status	Operates	Constr.	Constr.-1994
Energy (GeV)	0.45	1.5	2.5
Emittance ($nm \cdot rad$)	880	27	78
Critical wavelength (Å)	61-BM,21-W	8-BM	1.75-BM
Stored current (mA)			
total	360	300	300
single bunch	360	100	100
SR power (kW)	4	~ 30	200
RF frequency (MHz)	34.5	181.3	181.4
Bunch length $2 \cdot \sigma_s$ (cm)	60	4	4
Lifetime (h)			
touchek	5	10	10
vacuum			
Type of filling	e^-	e^-	e^-
Number of beamlines	7	39	39
Insertion devices			
number	1 (W)	2 (SCW) 5 (W) 2 (U)	2 (SCW) 5 (U) 2 (W)

The design of these magnets makes it possible to construct, from 8 magnets, a compact 600 MeV storage ring for submicron lithography (λ ~8 Å), composed of either 16 magnets — the 1.2 GeV storage ring for LIGA-technology to manufacture micromechanics elements (λ ~2 Å), or 24 ones — the 2.4 GeV storage ring for angiography (λ ~0.5 Å). A mixed magnetic structure, which comprises conventional 1.6 T and superconducting 6 T magnets positioned in minimum betatron functions, opens up new possibilities. Such a structure ensures low emittance of the beam, high brightness and a wide spectral range suitable for various kinds of experiments.

The SSRC international cooperation on the creation of dedicated SR sources has covered:

- the development of the conceptual project of a SR source for LIGA-technology, for KfK (Karlsruhe, Germany);
- the design of the components of the magnetic system for the synchrotron-injector and the main storage ring BESSY-2 (Berlin, Germany);

- the participation in the projects for new SR sources SLC (PSI, Switzerland) and DIAMOND (Daresbury, England), which are based on the Novosibirsk idea of a mixed magnetic structure and the Novosibirsk design of a superconducting magnet [3].

5 Development of insertion devices

The INP has designed and manufactured a great deal of dedicated SR generators — wigglers and undulators — on the basis of superconducting magnets (Table 9), permanent magnets (Table 10) and conventional electromagnets (Table 11). The first in the world superconducting 20-pole wiggler, installed at the VEPP-3 storage ring in 1979, enables to increase the brightness of the source at λ ~1 Å by a factor of 200. The superconducting wiggler with a record field of 8 T, mounted at the VEPP-2M storage ring in 1982, made

Table 9: Superconducting insertion devices in INP

	Year	E (GeV)	B_{max} (kGs)	λ_0 (cm)	N_p	L (cm)	g (cm)	Az (cm)
Wiggler VEPP-3	*1979*	*2.1*	*34*	*9*	*20*	*90*		
Helical undulator VEPP-2M	1984	0.65	4.7	2.4	16	25	1.8	
Wiggler VEPP-2M	1984	0.65	80		5	60		
Wiggler Siberia-1	1985	0.45	58		3	35		
Wiggler TNK (2)	1993	1.6	80		3		3.5	2.0
Wiggler PLS (Pohang)	1994	2	75		3		4.8	2.4

Table 10. Permanent magnet insertion devices in INP

Parameter	OK-1 SmCo	OK-2 SmCo	OK-3 SmCo	U-4 SmCo	W-4 SmCo
period (cm)	*10*	*6.5*	*6.9*	*1.28*	*4.6*
total length) (cm)	60	60	160	100	100
number of periods	6	9	22	78	22
field amplitude (kGs)	3÷0	7	6.4	4.3÷2÷0	16÷0
gap (cm)	1.1÷2	1.1	1.3	0.5÷0.8÷3.5	0.5÷3.5
years	1979–1980	1981–1982	1984–1985	1994	1994

it possible to generate, at a 0.7 GeV energy, the intense 5 Å synchrotron radiation. *In 1983, the helical undulator was installed at the VEPP-2M storage* ring, which was, for a long period of time, a single in the world source of quasimonochromatic undulator radiation with circular polarization. Besides,

Table 11: Electromagnetic insertion devices in INP

	Year	E (GeV)	B_{max} (kGs)	λ (Å)	λ_u (cm)	g (cm)	N_u	L_u (cm)
Helical undulator VEPP-2M	1980	0.7	2.1	100	2.5	1.8	10	25
Wiggler VEPP-4M	1985	5.5	16	0.4	22	2.2	5	110
Wiggler VEPP-3	1986	2.0	22	2.1	70	3	1	70
Undulator OK VEPP-3	1987	0.34	5.6	2400÷7200	10	2.2	68	680
Wiggler VEPP-4	1993	3÷6.5	15		20	38	7	128
Undulator TNK (2)	1992	1.6	6.5	100÷1500	11	3.2	12	130
Wiggler TNK (4)	1992	1.6	10	8÷40	24	3.2	8	210

Table 12: Insertion devices for TNK (1.6 GeV)

Parameter	Superconducting wiggler	Wiggler-undulator	Lithography wiggler	Lithography wiggler
period (cm)	31	11	24	24
total length (cm)	~100	130.8	133.3	181.6
number of periods	1	11	5	7
field amplitude (kGs)	80	≤6.5	10	10
gap (cm)	3.0	3.2	3.2	3.2
Wavelength λ_c (Å) λ_{FUND} (Å)	~0.9	11.2 56÷1305	7.28	7.28
Undulator factor, K	230	6.68	22.4	22.4
Maximal horizontal spread ($2K/\gamma$) (mrad)	2×74	4.27	14.3	14.3

the INP scientists were the first who invented, designed and built undulators on the basis of Sm-Co permanent magnets with the use of iron poles for the concentration of the magnetic flux in the longitudinal direction. They were installed at VEPP-3 in 1979–1981. Known as "hybrid", undulators of this type are in intense use at many SR centres all around the world.

Special insertion devices were developed and constructed also for the dedicated storage rings, manufactured in INP, for example, for TNK (Table 12).

In the recent years the SSRC is a participant of the development and manufacture of wigglers for the centres abroad:

- a superconducting 7.5 T field wiggler for PLS (University in Pohang, Korea);
- a prototype of the wiggler for the production of circular polarized radiation on APS (ANL, USA), which will be tested at the NSLS (BNL, USA) in 1994.

6 Free electron laser development at the Budker INP

In the last decade FEL investigations are being carried out in two directions:

- FEL experiments in the visible and UV ranges on the VEPP-3 bypass;
- the creation of a powerful FEL in the IR range (3–50 μm) with an average power of up to 100 kW on the basis of a new accelerator—microtron-recuperator.

In 1989, a FEL - the optical klystron of the visible and UV range ($0.7 \div 0.24$ μm) was commissioned at the VEPP-3 bypass. So far this is the shortest-wavelength FEL throughout the world (Fig.8). On this device, experiments with the intracavity Fabry-Perot etalon have been performed and the oscillation with line width $2 \cdot 10^{-6}$ has been obtained. The experiments on oscillation of the optical klystron in the confocal optical cavity is completed. This is of significance for the creation of long optical cavities of powerful FEL. In addition, the experiments have been performed concerning the interference of radiation from two undulators separated by the achromatic bend with a view to simulate the "electron radiation extraction" from a high power FEL. The works on the VEPP-3 bypass are expected to be accomplished in 1994.

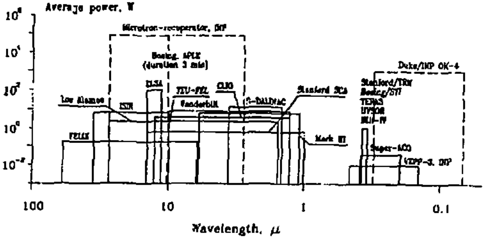

Fig. 8. Status of creating FEL in the world.

In collaboration with the Duke University (USA), we prepared the "Short wavelength FEL development and application project". The project envisages FEL transportation from the VEPP-3 bypass to the Duke University and its installation at the dedicated Duke electron storage ring for obtaining of new physical results on generation within the 0.24÷0.05 μm range (Fig.8). The American side funds this project within the frames of "Medical FEL program", and also, possibly, within the frames of the International Centre of Science and Technology.

The second direction of FEL activities deals with the creation of the Centre of Photochemical Researches in Novosibirsk. In the end of 1992, the Decree of the Presidium of the Siberian Division of the Russian Academy of Sciences on the foundation of this Centre on the basis of the Institute of Chemical Kinetics and Combustion and the Budker INP was signed. For the Centre, one of the buildings of the Institute of Chemical Kinetics was allotted, where 3÷50 μm FEL with an average power of up to 100 kW will be housed.

The distinguishing features of this FEL are:

- The use of a race-track microtron-recuperator as a source of electrons; the electrons in it are accelerated to the required energy, while the used electrons are decelerated. This is useful to increase the efficiency of the device and to drastically reduce radiation hazard, and, what is especially significant, to eliminate the induced radioactivity.

- A comparatively low frequency (180 MHz) of the RF system provides high peak (~100 A) and mean (0.1 to 1 A) electron currents.
- Electromagnetic undulators make it possible to tune the radiation wavelength without the variation in the electron energy.
- "Electron radiation extraction" reduces significantly the power inside the optical cavity, and hence the heat problems of mirrors, thereby allowing a relatively simple optical cavity to be used.

At present, designing the basic units of this device has come to completion. At several plants, RF generators and cavities, some components of the vacuum system, power supply sources for electromagnets and the other components of the FEL are being fabricated. A number of stands for FEL tests are ready for exploitation. These are the stands for testing RF cavities and a photo injector, the stand for vacuum tests, the stand for magnetic measurements,and an injector with thermocathode. Under favorable, largely financial, conditions, the device is scheduled for exploiting by users in 1997.

The Budker Institute of Nuclear Physics is extremely interested in the participation of foreign institutions in this program and in its partial funding. Our colleagues are welcomed to participate in:

- the creation of a powerful FEL on the basis of an accelerator- recuperator, at the INP;
- the preparation of the program and in the future experiments at the International Centre of Photochemical Research.

In July of 1993, the Russian-US Workshop on FEL power beaming to satellites (including geostationary ones) for the satellite information network was held. The meeting was attended by the representatives of the INP, the Institute of Chemical Kinetics and Combustion (Novosibirsk), OKB "Raduga", OKB "Granat", OKB "Astrofizika" from the Russian side and those of NASA, Navy laboratory in China Lake, Duke University, Los Alamos National Laboratory and Boeing Company from the American side. The workshop made a decision to prepare the joint project "FEL power beaming" on the basis of the FEL which is being designed at the Budker INP [4] and the USA program SELENA [5].

Besides, for the ARPA agency the joint Russian-US proposal "Applications of Defense Laser Technology to the remediation of toxic and hazardous wastes" was prepared. The proposal was prepared by the Institute of Chemical Kinetics, Duke University, the State North Carolina University and some other USA institutions.

The major result of the Russian-US cooperation in the field of FEL might be, in not too distant future, the completion of the creation of the FEL at an average power of 100 kW and its testing in Novosibirsk, with the participation of the Russian and American partners, in order to check the main principles underlying the project and to demonstrate the serviceability of the FEL.

The more distant result of this cooperation might be the creation, by Russian and American partners, of FELs with higher average power (200÷1000 kW).

In addition to the VEPP-3 bypass and FEL works for the Photochemistry Centre, the INP considers the project of a compact FEL with an average power of 1 W within 1÷50 μm . This project is suggested to implement jointly with CAT (Indor, India). Also considered is the project of a free electron laser of visible and UV ranges with an average power of 1 kW. This FEL could be constructed on the basis of a dedicated storage ring having strong-field superconducting magnets. This project is assumed to be implemented in the framework of the cooperation between Russia, on one side, and France (CEA-LURE) and Netherlands (NIKHEF).

7 Conclusion

The Siberian Synchrotron Radiation Centre held regularly the All-Union conferences on Utilization of synchrotron radiation (SR-75, 77, 78, 80, 82, 84, 86, 88 in Novosibirsk, and SR-90 in Moscow). The proceedings of the SR-82,84,86,88,90 conferences were published either as collected books [6,7,8], or as special issues of Nuclear Instruments and Methods in Physics Research, Section A [9].

Since 1977, these conferences were attended by foreign scientists, the representatives, practically, of all the leading SR centres the world around. Starting with 1982, there were 20 through 50 foreign participants in each.

On the basis of SSRC, three All-Union schools took place: EXAFS-spectroscopy (1984), X-ray fluorescence element analysis using synchrotron radiation (1985), Synchrotron radiation — new possibilities of X-ray diffraction (1987). The results of these schools were published in 3 monographs [10].

The recent years (especially, 1991 and 1992) were particularly unfavorable for the arrangement of conferences and schools. Nevertheless, in 1993 two small international conferences were held on the basis of SSRC: "US-Russian Workshop on FEL Power Beaming", covering the problems of power beaming to satellites using FEL, and "Siberian HAZE-2" concerning the application of synchrotron radiation and FEL to element analysis of aerosols. In July of 1994, the National conference SR'94 is scheduled to be held.

The analysis of the SSRC activities shows that this kind of management allows one:

- to exploit effectively the unique expensive facilities - SR sources;
- to unite the efforts of many institutes and institutions in the development of the needed experimental equipment;
- to exchange effectively by experimental culture between experimental teams from various institutes and institutions;
- to arrange the training not only for some students and post-graduate students, but for teams from the other SR Centres;
- to arrange the fruitful cooperation between science and industry;
- to use effectively the international cooperation.

References

1. Synchrotron radiation in the INP of the Siberian Division of the USSR Academy of Sciences (bibliography): Part 1 (1986), Part 2 (1988), Part 3 (1990).
2. G.N.Kulipanov. Project of SR sources including research and development for insertion devices in the USSR. NIM, Sec.A, 1981, vol.303, No.3, pp.435-448.
3. G.N.Kulipanov, N.A.Mezentsev, et al. Development of superconducting compact storage rings for technical purposes in the USSR (invited). Rev.Sci.Instrum. 63(1) 1992, pp.731-736.
4. N.G.Gavrilov, E.I.Gorniker, et al. Project of a race-track microtron-recuperator for free electron laser. IEEE J. Quant. Electron, 1991, v.27, No.12, pp.2626-2628.
5. J.Rather. "NASA's perspective on laser power beaming", Proceedings of OE LASE'92, SPIE Conference, 1628.
6. Report on SR works in the INP of the Siberian Division of the USSR Academy of Sciences. Novosibirsk, 1981, 198 p.

7. *Proceedings of the 5th National Conf.* on SR Utilization: SR-82. Novosibirsk, 1982, 472 p.

8. Proceedings of the 6th National Conf. on SR Utilization: SR-84. Novosibirsk, 1984, 350 p.

9. Proceedings of the National Conf. on SR Utilization (Publ. in NIM): *7th, SR-86* - Nucl. *Instrum.* and *Meth.*, 1987, vol. A261, No.1/2; 8th, SR-88 - Nucl. Instrum. and Meth., 1989, vol. A282, No.2/3; 9th, SR-90 - Nucl. Instrum. and Meth., 1991, vol. A308, No.1/2.

10. *Collected books:*
    X-ray method for study of amorphous body structure: EXAFS Spectroscopy/Inst. of Catalysis. Novosibirsk: Nauka, 1988. 306 p.
    Synchrotron radiation in geochemistry: Sci. work collection / Inst. of Geology & Geophysics. Novosibirsk: Nauka, 1989, 151 p.
    Synchrotron radiation diffractometry. Novosibirsk: Nauka, 1989, 144 p.

V.N.Korchuganov, G.N.Kulipanov,
N.A.Mezentsev, A.D.Oreshkov, V.E.Panchenko,
V.F.Pindyurin, A.N.Skrinsky, M.A.Sheromov,
N.A.Vinokurov and K.V.Zolotarev

Synchrotron radiation and
free electron laser activities
in Novosibirsk

В.Н.Корчуганов, Г.Н.Кулипанов,
Н.А.Мезенцев, А.Д.Орешков, В.Е.Панченко,
В.Ф.Пиндюрин, А.Н.Скринский, М.А.Шеромов,
Н.А.Винокуров, К.В.Золотарев

Синхронное излучение и лазеры на свободных
электронах в Новосибирске

BudkerINP 94-34

Ответственный за выпуск С.Г. Попов
Работа поступила 12 апреля 1994 г.

Сдано в набор 12.04. 1994 г.
Подписано в печать 19 апреля 1994 г.
Формат бумаги 60×90 1/16 Объем 1,7 печ.л., 1,4 уч.-изд.л.
Тираж 250 экз. Бесплатно. Заказ N 34

Обработано на IBM PC и отпечатано на
ротапринте ИЯФ им. Г.И. Будкера СО РАН,
Новосибирск, 630090, пр. академика Лаврентьева, 11.