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# Synchrotron radiation and free electron laser activities in Novosibirsk

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**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, 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 the Budker INP, is given.

## 1. Introduction

At present the Siberian Synchrotron Radiation Centre (SSRC), which was established on the basis of the Budker INP laboratories, is a major site for synchrotron radiation (SR) and free electron laser (FEL) research 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.

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## 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 (0.7 GeV energy) is a major facility used in synchrotron radiation research in the VUV and soft X-ray ranges ($\lambda = 5 \times 10^3$–2 Å) at the Siberian Synchrotron Radiation Centre. The basic parameters of VEPP-2M as a SR source are given in Table 1.

There are two special rooms 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) is extracted to one of them, having a 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 at the second room whose total area is 48 m$^2$. The station for positron beam parameter measurements (beamline 5P) is housed in a separate room.

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

At present, the VEPP-3 storage ring is the 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


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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 seven beamlines, six of which transmit 5 mrad of radiation and the remaining two are capable to transmit 8 mrad. Beamline 10 extracts radiation from the 1.8 T bending magnet through a 30 μm thick Be foil into the super-high-vacuum beamline with differential pumping.

The layout of the VEPP-3 facility with the SR experimental area is given in Fig. 2 and the arrangement of the SR experimental stations is shown in Fig. 3.

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

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 six experimental stations positioned on 4 SR beamlines. The works were conducted at an energy of 4.6–5.1 GeV and a storage ring current up to 30 mA.

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

| | | |
|---|---|---|
| Energy, MeV | 700 | |
| Circumference, m | 17.88 | |
| Kind of particles | $e^- e^+$ | |
| Operating mode | single- or multi-bunch | |
| Emittance, cm·rad | $4.6 \times 10^{-5}$ | |
| Stored current, mA: | | |
| Total | 300 (150 $e^-$ and 150 $e^+$) | |
| Single-bunch | 200 ($e^-$ or $e^+$) | |
| Multi-bunch | 300 ($e^-$ or $e^+$) | |
| Lifetime, h | 1–2 | |
| Magnetic field in bending magnets, T | 1.91 | |
| Revolution period, ns | 59.6 | |
| Bunch length $2\sigma_s$, cm | 8 | |
| Insertion devices: | superconducting wiggler | |
| Number of poles | $5 = 3(H_0) + 2(H_0/2)$ | |
| Pole length, cm | 12 | |
| Magnetic field $H_0$ on the orbit, T | 7.5 | |
| Transverse beam dimensions at irradiation points at the coupling coefficient $\kappa$: | | |
| $\kappa = 0.1 / \kappa = 1$ | $2\sigma_x$, mm | $2\sigma_z$, mm |
| Bending magnet | 2.7/1.9 | 0.17/1.2 |
| Wiggler | 1.0/0.7 | 0.03/0.2 |
| Total SR power, kW | 7.5 (with the wiggler) | |
| Critical radiation wavelength, Å: | | |
| From bending magnet | 19.9 | |
| From wiggler | 5.1 | |
| Number of beamlines: | 9 | |
| From bending magnet | 6 (2 $e^-$, 4 $e^+$) | |
| From wiggler | 3 (2 $e^-$, 1 $e^+$) | |
| Mode of operation for SR works | parasitic/dedicated | |

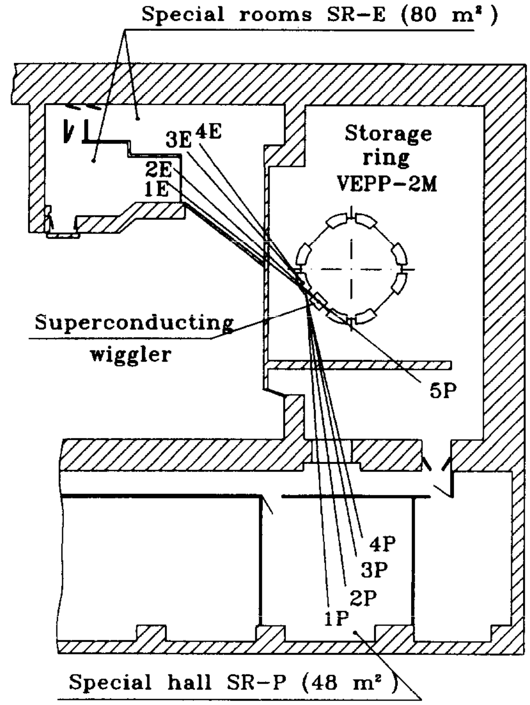


Fig. 1. Layout of the VEPP-2M facility.

In the recent years a 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 a 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.

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 in 1995. Most of the SR experiments will be carried out in parallel with high energy physics experiments. Some of the SR experiments which need special operational modes will be performed during the runs intended for SR works.

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

| Beamline (emitting particles) | Irradiation point | Angle of beamline axis to straight section axis (deg) | Total angular aperture of beamline (mrad) | Total SR power in beamline (E = 700 MeV; $I_{e^-}$, $I_{e^+}$ = 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 |
| 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 (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 gas photodesorption (in operation) |
| 5P ($e^+$) | wiggler | 0 | 5.6 | 9.0 | positron beam parameters measurements (in operation) |

## 3. SR research in Budker INP

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

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

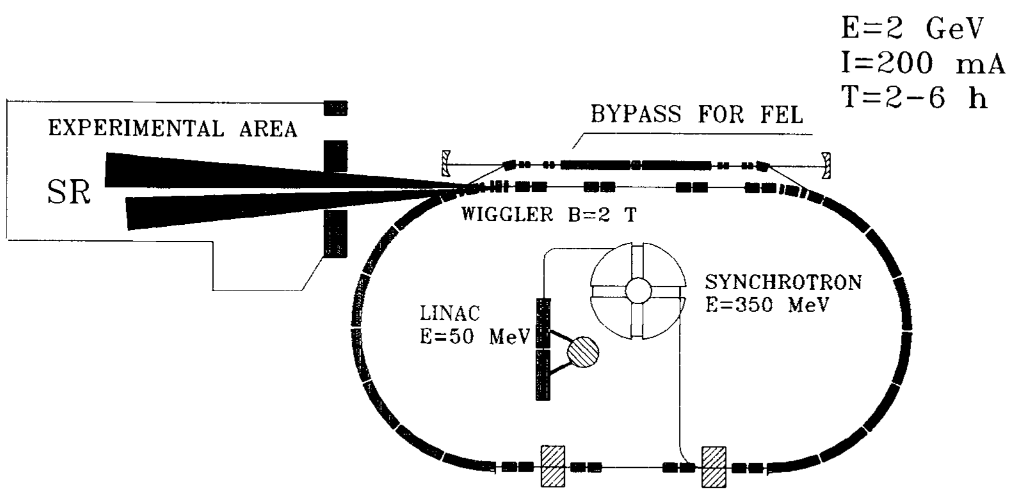


Fig. 2. Layout of the VEPP-3 facility.

Table 3
Basic parameters of the VEPP-3 storage ring

| | |
|---|---|
| Maximum energy, GeV | 2.0 |
| Circumference length, m | 74.4 |
| Operational mode | one- or two-bunch |
| Emittance, cm · rad | $2.7 \times 10^{-5}$ |
| Current, mA | 250 |
| Lifetime, h | 3–4 |
| Number of wiggler poles | 3 |
| Magnetic field in the wiggler, T | 2.0 |
| Magnetic field in the bending magnet, T | 1.7 |
| Electron beam dimensions, mm: | |
| Vertical | 0.06 |
| Horizontal | 0.9 |
| Revolution period, ns | 250 |
| Bunch length, $2\sigma_s$, cm | 30 |
| Critical wavelength, Å: | |
| From the wiggler at $E = 2.0$ GeV | 2.3 |
| From the bending magnet at $E = 2.0$ GeV | 2.6 |
| From the bending magnet at $E = 1.2$ GeV | 12.0 |
| 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<br>b) Anomalous scattering |
| 3 | wiggler | X-ray fluorescence element analysis |
| 4 | wiggler | Subtraction angiography |
| 5 | wiggler | a) X-ray microscopy and microtomography<br>b) Time resolved diffractometry<br>c) Macromolecular crystallography<br>d) Inelastic scattering<br>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 |

concerning the annual number of SSRC publications. Needless to say, the subjects of these papers are noted for 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 contracted muscles, as well as the phase transitions under superhigh pressures are studied. With 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 Baikal lake water and sediments, element analysis of aerosols, microelement analysis of 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 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 the X-ray lithography technology, regular micropore filters with high – up to 50% – transparency, with a given

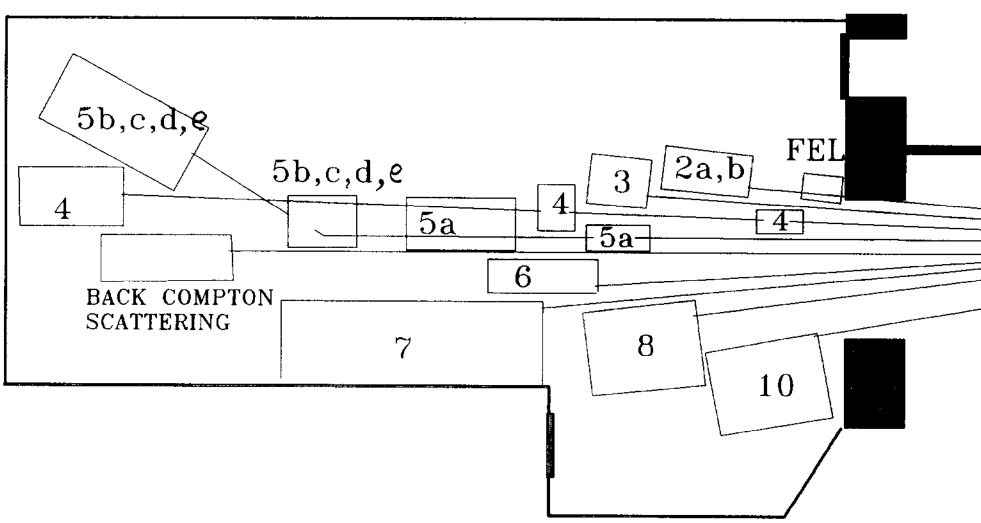


Fig. 3. Arrangement of the SR experimental stations at the VEPP-3 storage ring.

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

| | |
|---|---|
| Maximum energy, GeV | 6 |
| Circumference length, m | 366 |
| Operational mode | single- and multi-bunch |
| Emittance, cm · rad | $4 \times 10^{-5}$ |
| Maximum current, mA: | |
| Single-bunch | 50 |
| Multi-bunch | 100 |
| Lifetime, h | 6–20 |
| Magnetic field in the bending magnet, T | 1 |
| Revolution period, μs | 1.2 |
| Bunch length, $2\sigma_s$, cm | 4 |
| Critical wavelength, Å: | |
| From the bending magnet | 0.51 |
| From the seven-pole wiggler | 0.4 |
| Number of SR beamlines | 14 |

Table 6
List of SSRC experimental stations

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

arrangement and a size of 0.2–0.4 μm diameter pores in a 2–10 μm thick lavsan film were manufactured. X-ray lithography was also applied for manufacturing 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 stations. Besides, teams from other cites from the institutes of the Russian Academy of Sciences, universities and high education schools, and 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 teams in 1986–87 was caused by a fire at the Institute, that happened in August of 1985. The second decrease after 1990 was due to the change in the political and economic situation in the countries of Eastern Europe and in the republics of the former Soviet Union. As a consequence, ten teams from the former German Demo-

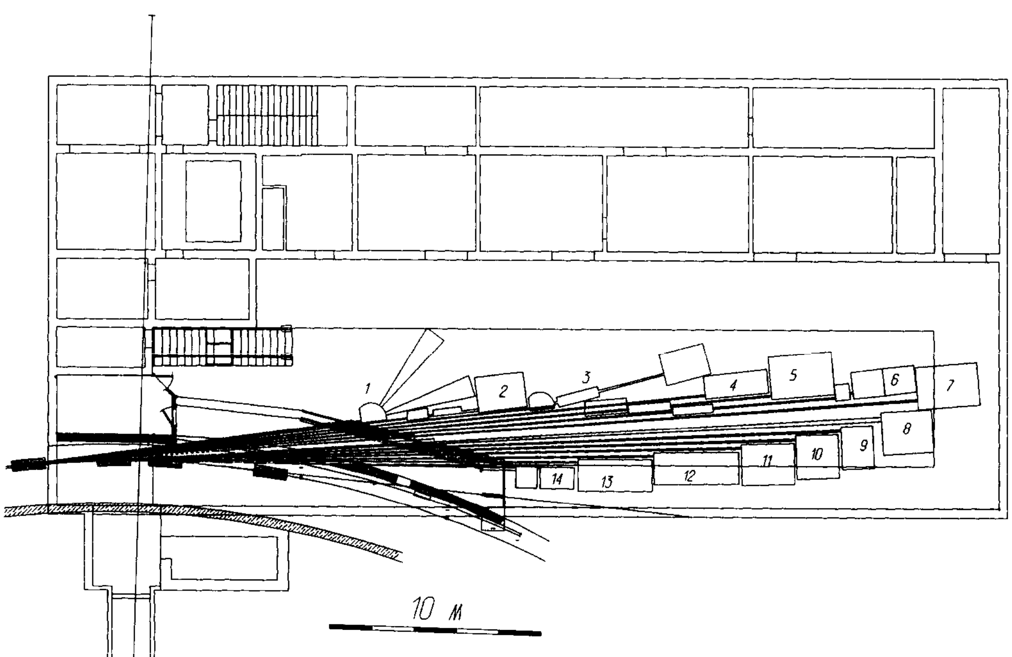


Fig. 4. Arrangement of the VEPP-4M SR experimental stations.

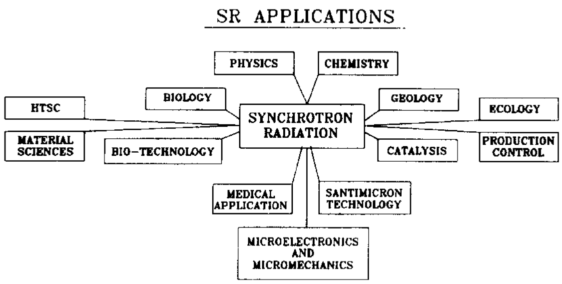


Fig. 5. SR applications in SSRC.

cratic Republic, six teams from the former Czechoslovakia, three groups from Hungary, as well as the teams from Armenia, Azerbaijan, Estonia, Latvia and Ukraine stopped working. A drastic reduction of funds for science in Russia and increased prices of flight tickets and hotel accommodation decreased the number of teams from cities of the European part of Russia. In 1994 only 64 teams have worked at the SSRC, including 12 from foreign countries (England, USA, Germany, Korea, 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 the 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 program 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. The layout of these magnets makes it possible to construct, from 8 magnets, a compact 600 MeV storage ring for submicron lithography ($\lambda \sim 8$ Å), composed of either 16 magnets: the 1.2 GeV storage ring for LIGA-technology to manufacture micromechanics elements ($\lambda \sim 2$ Å); or 24 magnets: the 2.4 GeV storage ring for angiography ($\lambda \sim 0.5$ 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);

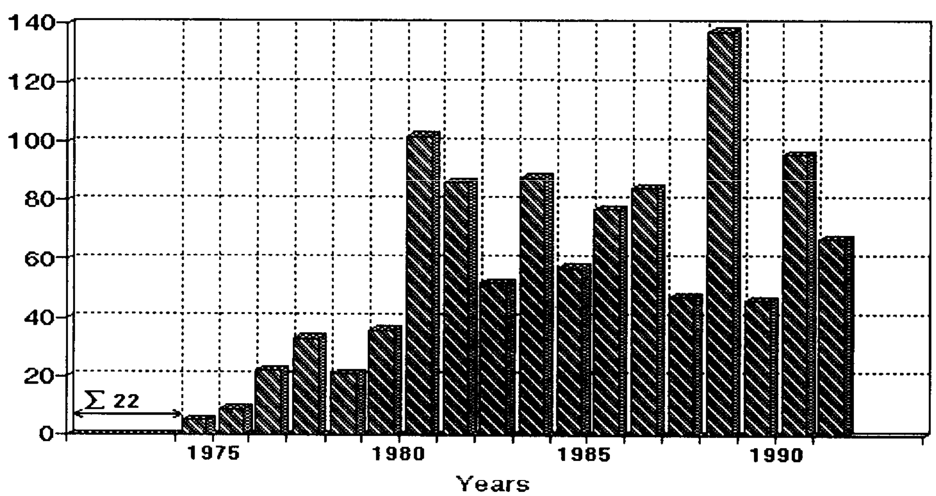


Fig. 6. The annual number of SSRC publications.

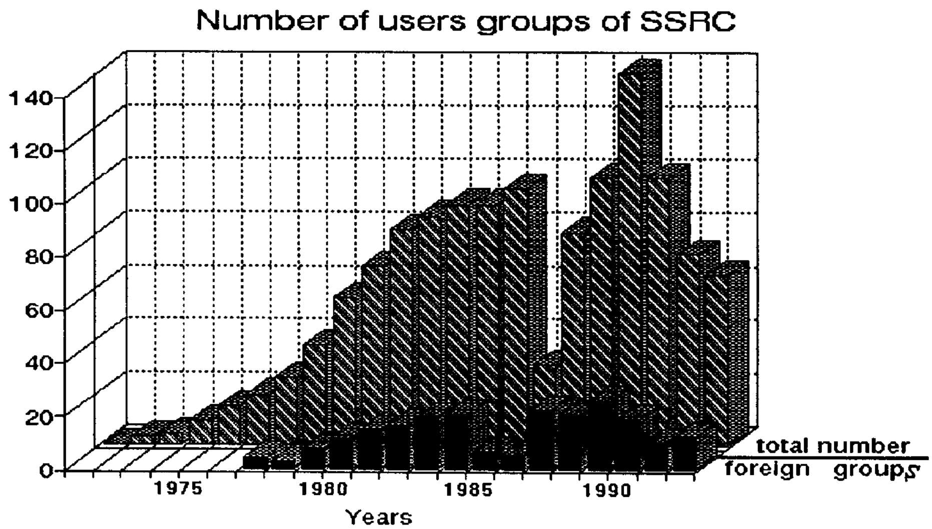


Fig. 7. Variations in the number of users teams in SSRC.

- 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 world's first superconducting 20-pole wiggler, installed at the VEPP-3 storage ring in 1979, enabled an increase of the brightness of the source at $\lambda \sim 1$ 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 it possible to generate, at a 0.7 GeV energy, 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, the only source of quasimonochromatic undulator radiation with circular polarization. Besides, 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 intensely used at many SR centres around the world.

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

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

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

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·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 $2\sigma_s$ (cm) | 60 | 4 | 4 |
| Lifetime (h), Touschek | 5 | 10 | 10 |
| Type of filling | $e^-$ | $e^-$ | $e^-$ |
| Number of beamlines | 7 | 39 | 39 |
| Insertion devices | | | |
| number | 1 (SCW) | 2 (SCW) | 2 (SCW) |
| | | 5 (W) | 5 (U) |
| | | 2 (U) | 2 (W) |

- 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 region (3–50 μm) at an average power of up to 100 kW on the basis of a new accelerator, the microtron-recuperator.

In 1988, a FEL, the optical klystron of the visible and UV range (0.7–0.24 μm), was commissioned at the VEPP-3 bypass. So far this is the shortest-wavelength FEL in the world (Fig. 8). On this device, experiments with an intracavity Fabry–Perot etalon have been performed and oscillation with a line width of $2\times10^{-6}$ has been obtained. The experiments on oscillation in the optical klystron in the confocal optical cavity are completed. This is of significance for the creation of long optical cavities for a powerful FEL. In addition, experiments have been performed concerning the interference of radiation from two undulators separated by an 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.

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 new physical results on generation within the 0.24–0.05 μm region (Fig. 8). The American side funds this project within the frames of the "Medical FEL Program", and also, possibly, within the frames of the International Centre of Science and Technology.

The second trend of FEL activities deals with the creation of the Centre of Photochemical Researches in Novosibirsk. At the end of 1992, the Decree of the Presid-

Table 9
Superconducting insertion devices in INP

| | Year | $E$ (GeV) | $B_{max}$ (kG) | $\lambda_0$ (cm) | $N_p$ | $L$ (cm) | $g$ (cm) | $A_z$ (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 | 6.0 | 1.28 | 4.6 |
| Total length (cm) | 60 | 60.8 | 160 | 100 | 100 |
| Number of periods | 6 | 9 | 22 | 78 | 22 |
| Field amplitude (kG) | 3–0 | 7 | 6.4 | 4.3–2–0 | 16–0 |
| Gap (cm) | 1.1–2 | 1.1 | 1.43 | 0.5–0.8–3.5 | 0.5–3.5 |
| Years | 1979–1980 | 1981–1982 | 1984–1985 | 1994 | 1994 |

ium 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 a 3–50 μm FEL at an average power of up to 100 kW will be housed [4].

The distinguishing features of this FEL are:

- The use of a race-track microtron-recuperator as a source of electrons; the electrons in it accelerate to the required energy, while the used electrons decelerate. 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 ($\sim$ 100 A) and mean (0.1–1 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 photoinjector, the stand for vacuum tests, the stand for magnetic measurements, and an injector with a thermocathode. Under favorable, largely financial, conditions, the device is scheduled to be available to 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.

At this moment the joint Russian–US proposal "JEDI-ALT" is being prepared.

The major aim of the Russian–US cooperation within the JEDI-ALT frame might be, in the not too distant

Table 11
Electromagnetic insertion devices in INP

| | Year | E (GeV) | $B_{max}$ (kG) | $\lambda$ (Å) | $\lambda_u$ (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 | 15–30 | 3 | 3 | 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) | $\sim$ 100 | 130.8 | 133.3 | 181.6 |
| Number of periods | 1 | 11 | 5 | 7 |
| Field amplitude (kG) | 80 | $\leq$ 6.5 | 10 | 10 |
| Gap (cm) | 3.0 | 3.2 | 3.2 | 3.2 |
| Wave length | | | | |
| $\lambda_c$ (Å) | $\sim$ 0.9 | 11.2 | 7.28 | 7.28 |
| $\lambda_{FUND}$ (Å) | | 56–1305 | | |
| Undulator factor, $K$ | 230 | 6.68 | 22.4 | 22.4 |
| Maximal horizontal spread $(2K/\gamma)$ (mrad) | $2 \times 74$ | 4.27 | 14.3 | 14.3 |

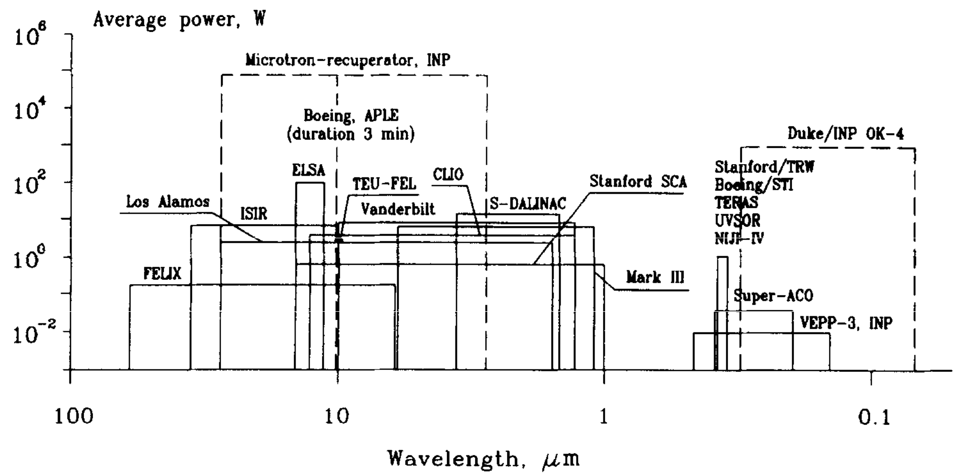


Fig. 8. Status of FELs in the world.

future, the completion of the creation of a FEL at an average power of 100 kW and its testing in Novosibirsk, with the participation of 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 at 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 at 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 at an average power of 1 kW. This FEL could be constructed on the basis of a dedicated storage ring having strong-field superconducting magnets.

## 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-80, 82, 84, 86, 88, 90 conferences were published either as collected books [5–7], or as special issues of Nuclear Instruments and Methods in Physics Research [8].

Since 1977, these conferences were attended by foreign scientists, the representatives, practically, of all the leading SR centres the world around. Starting in 1982, there were 20–50 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 three monographs [9].

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 "US–Russian Workshop on JEDI-ALT" was 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 experimental equipment needed;
- to exchange the experimental culture effectively between experimental teams from various institutes and institutions;
- to arrange the training not only for some students and post-graduate students, but also for teams from the other SR Centres;
- to arrange a fruitful cooperation between science and industry;
- to use international cooperations effectively.

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Synchrotron Radiation Diffractometry (Nauka, Novosibirsk, 1989) 144 pp.