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CONCEPT DESIGN OF THE CCU SKIF–NSU EXPERIMENTAL STATION 1-7 "BASIC METHODS OF SYNCHROTRON DIAGNOSTICS FOR EDUCATIONAL, RESEARCH, AND INNOVATIVE ACTIVITIES OF STUDENTS"

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We present a concept design of the CCU SKIF–NSU Experimental Station 1-7 "Basic methods of synchrotron diagnostics for educational, research, and innovative activities of students" for improving the efficiency of the educational process and helping the NSU students to solve research problems using the capabilities of a modern synchrotron radiation source. Several research methods are planned to be jointly implemented at the Experimental Station 1-7: powder and single-crystal X-ray diffraction, X-ray absorption spectroscopy, and X-ray fluorescence analysis. This research complex will not only allow solving a wide range of scientific problems in various fields of science such as physics, biology, chemistry, geology, archeology and medicine, but will also become an essential element of the practical education of scientific and technical stuff for the synchrotron research.

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INTRODUCTION

It is assumed that the coming years after the launching of the 4+ generation synchrotron radiation source CCU Siberian Circular Photon Source SKIF (CCU SCPS SKIF) in the Novosibirsk Region should witness the emergence of a scientific community of Russian and foreign researchers who would widely employ new and largely unique experimental possibilities to solve urgent problems in various fields of science and technology. The synchrotron radiation source is intended to become an experimental base for the training and retraining of scientific and engineering stuff in collaboration with interested educational institutions. The Novosibirsk State University (NSU) is one of the key universities training personnel for the CCU SKIF. Thanks to its close scientific cooperation with RAS institutes, NSU can train specialists in the synchrotron research methods for various fields (physicists, biologists, chemists, geologists, archaeologists, physicians, etc.).

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From this viewpoint, a special educational station as part of CCU SKIF can become a unique material and technical basis for the training of highly qualified specialists using synchrotron radiation in their work, ensuring the operation of all stations of the research complex, and participating in the program for the modernization of the CCU SKIF infrastructure that is aimed, among other things, at the foundation of experimental stations of the second and subsequent lines. Therefore, developing a concept of the interaction between NSU and CCU SKIF and creating joint educational programs is an urgent task.

REVIEW OF EDUCATIONAL PROGRAMS OF INTERNATIONAL SYNCHROTRON CENTERS

The idea that the infrastructure of international synchrotron centers can be broadly used for the realization of targeted educational programs is repeatedly discussed in the professional community [1-5]. Each of the synchrotron radiation (SR) sources has its own experience in solving this issue. One of the most successful approaches to the training of novice users is the organization of synchrotron workshops and “schools”. The most well-known examples include the Higher European Research Course for Users of Large Experimental Systems (HERCULES) in Europe, the “Cheiron” school in Japan, and the National School on Neutron and X-Ray Scattering in the USA. These well-established events are aimed at the training of university students, postdoctoral students, and scientists interested in SR research. The main purpose of such schools is to train participants to work at collectively used synchrotron and neutron facilities. Besides lecture courses, the Schools offer the participants practical training with real experimental facilities. Some institutions utilize the possibilities of audio and video streaming technologies and online training programs to teach the potential users remotely. The latter approach was especially in demand during the COVID-19 pandemic in 2020-2022. The interested students could join the online video broadcast with lectures on synchrotron methods.

Note that the educational activity of synchrotron research centers was discussed in a special issue of the Synchrotron Radiation News (2013) journal *Focus on Synchrotron Education Initiatives* (edited by Antonio Lanzirotti, University of Chicago) [1]. Two articles of this issue were devoted to the targeted programs of involving high-school and university students and their teachers in the scientific research using the modern equipment of synchrotron centers. The first article romantically entitled *Inquiry for Inspiration* [2] describes the *Students on the Beamlines Program* that has been conducted at the Canadian Light Source (CLS) since 2006. The program is funded by the National Science and Engineering Research Council of Canada. As part of this event, small groups of high school students from different schools conduct a synchrotron experiment according to a pre-planned and formulated program. The groups compete with each other, and the winner is announced at the end of the year. The work of a group at the synchrotron source usually takes three days. On the first day, the members of a group are getting used to the new location, get acquainted with the equipment of the synchrotron facility, and examine the experiment procedure. The program assumes that adults (teachers, scientists, other professionals) act as consultants and experts, while the students develop the experiment strategy. This means that students are responsible for decision-making (experts can only give advice) and the direction of work. The experiment is carried out on the second day, and the third day is devoted to the analysis and interpretation of the results. The internship program ends up by the presentation of the report.

In another similar program [3] developed on the basis of an American SR source (National Synchrotron Light Source, NSLS) and entitled *Introducing Synchrotrons into the Classroom* (InSynC), a competition of scientific proposals for synchrotron research is organized for teachers and their students. Before proposals can be submitted, the teachers attend a three-day training workshop where they are instructed about how synchrotron facilities work, presented with a basic overview of the physics behind synchrotron methods and examples of research conducted. The participants get an opportunity to actually do some training experiments at the beamlines to see how data are collected, processed, and interpreted. After the workshop, the teachers and students plan the future experiment and a write a proposal for the synchrotron experiment. The proposals are reviewed by leading SR specialists with an experience of teaching at the universities. In addition to the standard criteria for scientific merit and the stated experimental plan, the proposals are also evaluated in terms of the project's potential educational impact. The winners of the competition are allocated beam time to implement their ideas. The groups with insufficient scores are met personally with beamline scientists to analyze their proposals and the reasons of low scores.

The staff of the SR source in Australia (Australian Synchrotron, AS), realizing the importance of attracting young personnel, also conduct training for university students (physicists, chemists, biologists, mathematicians) as well as tours for school students [4]. Though most of the tours are intended for high-school students, there is also a primary school group experience. After learning the possibilities of SR, young people are more likely to choose a job related to scientific research.

A one-week interdisciplinary course *Integrated Design of a Synchrotron Beamline* (Ecole Centrale Paris) was developed in France to train engineers. In this course, no knowledge about accelerators or SR physics is required. It is important that the students understand that even their technical background is sufficient to contribute to the SR source development. In this course, students are divided into groups, each developing a virtual design one of the key components of the SR station. The students can consult the remote experts from France, USA, and Japan. During the course, the students learn to work in a team, better understand their scientific potential, and see the connection between individual disciplines on specific examples.

HERCULES (Higher European Research Course for Users of Large Experimental Systems. A research course for the users of "megascience" facilities, is a five-week course coordinated by the Université Grenoble Alpes (UGA) and the Institut polytechnique de Grenoble (Grenoble INP). This unique school in Europe provides training for students, postdoctoral and senior scientists from European and non-European universities and laboratories using a variety of methods and scientific possibilities in the field of neutrons and SR research of condensed matter studies (biology, chemistry, physics, materials science, geosciences, industrial applications). The school includes specialized lectures, practicals, tutorials, and visits of large European synchrotron facilities. During the COVID-19 pandemic in 2022, the school was organized entirely online in Grenoble, including remote workshops and tutorials for participants in the same volumes as usual (about 40% of the course) as well as virtual visits to the megascience facilities and a poster session. The program of practical and educational sessions in Grenoble included 3-4 half-day practical sessions in the European Synchrotron Radiation Facility (ECCU), which were conducted online through various experimental channels, and 3-4 training courses of the same duration in ILL, ECCU, CNRS, CEA and/or IBS [7].

The Diamond Light Source conducts annual courses on macromolecular crystallography and presents review workshops for young physicists every two years. The proposals submitted for the courses are reviewed in terms of their quality and the probability of using the source capabilities in the applicant's future work. The classes for physicists begin with two days of lectures. During the next two days, the Diamond staff demonstrates to the students experimental techniques at ten different stations. On the last day, the scientists demonstrate SR possibilities to the students on the example of their works [6].

As part of an educational program at the MAX IV source in Sweden, cross-cutting groups were organized at research stations. The program is intended for university courses, training workshops or any other educational process. To participate in this program, students submit a proposal with the indicated goal of learning and expectations from the experimental activities in MAX IV. During a year, the proposals are reviewed and selected in the course of two rounds [10].

The CCU SSTRC (Siberian Synchrotron and Terahertz Radiation Center, Budker Institute of Nuclear Physics) in Novosibirsk hold regular schools for young scientists, including lectures by SR specialists, excursions, and acquaintance with CCU SSTRC stations. The center has considerable experience in carrying out the SR research work.

The RÅCIRI International Summer School is a joint initiative by Sweden, Russia and Germany embedded in the collaborative frameworks of the Russian-German Ioffe-Röntgen-Institute (IRI) and the Swedish-German Röntgen-Ångström-Cluster (RÅC) association. The School was founded in 2013 and since then has been held annually; the venue is determined by the partner countries Sweden–Germany–Russia. The Summer School program encompasses current scientific topics and challenges in the field of materials science closely related to the analytical potential of current and future research infrastructures of megascience facilities in the Baltic Sea region. World-famous scholars and experts from these fields are invited as lecturers and tutors to provide an environment for intergenerational interaction and dialogue. All students are trained according to the School program at special poster sessions, science slams, educational workshops, and cultural activities [11]. Also worth mentioning is the German-Russian Travelling Seminar that has been held since 2008 for undergraduate and graduate students. Its goal is to get the young scientists acquainted with modern approaches to the synthesis of nanomaterials and the methods of their physical and chemical analysis using synchrotron radiation and neutron sources. The seminar is organized by the Federal Ministry of Education and Research of Germany (Bundesministerium für Bildung und Forschung) and the Ural Branch of the Russian Academy of Sciences, and all the events over the past years have been supervised by Prof. Andreas Magerl (University of Erlangen-Nürnberg) and Academician Andrey Rempel (Institute of Metal Physics, Urals Branch of RAS, Ekaterinburg).

Thus, there are various formats of educational programs held at international SR sources: they include short-term thematic schools-conferences, mid-term advanced training courses, internships at the station (solving scientific or educational problems), work on graduation and postgraduate projects on the station equipment.

The NSU and CCU SKIF are currently working on the project CCU SKIF–NSU Station 1-7 “Basic methods of synchrotron diagnostics for educational, research, and innovative activities of students”.

GENERAL CONCEPT OF NSU EDUCATIONAL PROGRAMS AT THE CCU SKIF–NSU STATION 1-7

Since the Station 1-7 is intended to become the main center for the practical training of scientific and engineering personnel for the synchrotron research, it is to encompass the basic set of physical SR methods. This set includes powder -ray diffractometry (including the possibility of obtaining the function of radial distribution of atoms); single-crystal X-ray diffraction analysis; X-ray fluorescence analysis; X-ray absorption spectroscopy.

The world experience of educational programs based on SR sources includes a variety of forms of educational and scientific initiatives ranging from small seminars to highly specialized experiments on the SR equipment. The international experience has proved the effectiveness of teaching students and attracting new users. Therefore, three categories of scientific and educational programs are planned to be implemented at Station 1-7: (1) activities within the NSU educational process, including workshops and laboratory works by undergraduate/specialist/master's students, qualification works, and research projects of graduate students and postgraduate students; (2) additional education: schools, advanced training courses, thematic conferences; (3) internships for solving scientific and educational tasks using the station experimental resources.

1. Educational programs within the NSU educational process. Deep integration into the educational process, conducting training sessions with groups of students of different levels, and different profiles of training assume pursuing a variety of educational tasks, demonstrations of clear easy-to-remember experiments, performing laboratory, course, and graduation works on various topics. The Station should be widely involved in the educational process by means of various workshops for the students with different backgrounds and training profiles. The workshop programs should be directly related to the necessary basic training and knowledge of theoretical foundations of the methods.

The workshops will be based on laboratory works demonstrating fundamental possibilities of the station techniques:

- powder X-ray diffraction (phase analysis of multicomponent systems, first and second order phase transitions, melting and crystallization phenomena, etc.; crystal structure refinement; structural study of polycrystalline objects; studying the short-range order in crystalline, nanocrystalline, and amorphous objects);
- single-crystal X-ray diffraction (solving crystal structures, obtaining electron density distribution, solving structures with long-range order violations, macromolecular systems, etc.);
- fluorescence analysis (elemental mapping, determination of minimal detection limits for different experimental modes);
- X-ray spectroscopy, X-ray absorption spectroscopy (determining local atomic environments, determining electronic state of atoms);

- combined application of several methods, including in *in situ* and *operando* modes.

A separate category of laboratory activities will be special workshops for training specialists in specific fields. For example, the following studies will be available for bachelors in physics to demonstrate various effects of X-ray interaction with matter:

- attenuation of X-rays in matter in a wide range of photon energies (Moseley's law);
- measurement of the X-ray fluorescence quantum yield;
- secondary processes accompanying photoabsorption (electrical conductivity jumps in semiconductors, optical luminescence, etc.);
- irreversible radiation-induced changes.

For engineering physics specialties, the operation principles of X-ray optical instruments and detectors will be demonstrated:

- focusing properties of curved crystals;
- various modes of gas detector operation (ionization chamber–proportional counter–Geiger counter);
- comparative analysis of quantitative characteristics of different X-ray scintillators (quantum efficiency in different ranges, decay period, dead time).

Laboratory works for chemists, biologists, and geologists will show the capabilities of synchrotron methods on the examples of interest for these fields:

- determining phase compositions of the synthesized samples by powder X-ray diffraction;
- solving a compound's structure using a single-crystal X-ray diffraction experiment;
- determining the chemical composition of a sample using fluorescence analysis;
- determining the local structure of amorphous/nanodispersed systems by EXAFS (Extended X-ray Absorption Fine Structure) and RDF (radial distribution function) methods.

Along with gaining experience in experiment conduction, the students should master practical skills in using the software for processing the obtained data. The students are assumed to work in a classroom (perhaps in a virtual computer class) equipped with the appropriate software. Tutorials will be created for mastering known software products and those designed especially for the CCU SKIF stations; trainings to work with various crystallographic and diffraction databases and in specialized programs to analyze the results of powder and single-crystal XRD data; the opportunity for the students to participate in such work should be provided.

In addition to getting acquainted with the methods implemented at the Station, the NSU students will have the opportunity of conducting their own experiments as part of laboratory works and diploma/postgraduate works. It is planned that the students will create and install their our own modules, e.g. to study the processes of mechanochemical [6-8] and hydrothermal [9-11] synthesis.

2. Additional education, schools, advanced training courses, thematic conferences. It is planned to conduct training programs on Station 1-7 focused on the SR theory and the SR interaction with matter, on the application of physical SR methods to study the electronic and atomic structure of solids. Such programs can be conducted in the form of specialized schools, seminars, courses, and in the form of advanced training courses with IRAT NSU (Institute for Retraining and Advanced Training of NSU) certificates issued. The interested people for such programs can be teachers from the Novosibirsk region, Russia, and other countries whishing to improve their qualification in the chosen field. As a result, new users for the CCU SKIF will be attracted. Specialized schools/conferences devoted to narrower fields of research are also possible.

3. Excursions and internships for solving scientific and educational tasks using the station experimental resources. The internships at the NSU station are intended to help accomplish scientific tasks and educational activities. Educational activities (workshops, teaching experiments in physics, laboratory works) are of interest to a wide range of educational institutions. First of all, this work can be conducted with school and gymnasium students in order to popularize science among youngsters, demonstration experiments and tours at the CCU SKIF. By means of the internships, students and university teachers, scientific workers will be involved in various educational initiatives and will be able to conduct SR research experiments. It is assumed that the applicants will submit a proposal indicating the educational (scientific) goal and expectations from the requested activity: what new knowledge and skills the SR work will add to the existing course/program/ research; what specific results and knowledge the participants will receive from the internships. The proposals should be reviewed and selected by experts in the corresponding fields to evaluate if the current experimental and methodological capabilities of the Station correspond to those required and to estimate the scientific and educational merit of the proposals.

EXPERIMENTAL APPROACHES AND SCIENTIFIC PROBLEMS

There are specific requirements for the planned station compared to other stations of the first stage of the CCU SKIF, which provide the possibility of conducting unique experiments, but are usually focused on some single basic physical method or on a relatively narrow range of problems. Station 1-7 should provide a universal possibility of conducting various spectral, diffraction and other experiments, flexibility, and a maximum simplicity when switching between different experimental modes. These important requirements are due to the educational role of Station 1-7.

In addition to training activities, the experimental station allows solving a wide range of research and engineering problems. Its concept assumes the study of synthetic and natural objects by a range of structural and spectral experimental techniques. The range of current experimental problems includes the study of phase and chemical composition, local and electronic structure, and structural transformations of various substances and materials: catalysts, minerals, functional and structural materials, energy generation and energy saving materials, construction industry, pigments, proteins, pharmacy materials.

Some studies of atomic and electronic structure require more than one research method: a sample should be characterized comprehensively by various X-ray methods both in standard conditions (*ex situ*) and in the conditions of external influences (*in situ*) such as temperature, pressure, etc. While the difficulties of *ex situ* studies, utilizing a combination of different methods, is mainly related to organizational issues (work of a group of scientists at SR two stations, need for additional equipment and its adjustment to the workstation), the difficulties of *in situ* studies are due to the need of fixing the state of the system at a certain moment when monitoring the dynamics of the process. From this viewpoint, the use of several methods in one experimental cycle can provide unique and reliable information both on the features of the studied process and on the system as a whole.

TECHNICAL PARAMETERS OF THE STATION

A joint use of spectral and diffraction methods is planned at the station. According to the requirements to the X-ray absorption spectroscopy method, the energy spectrum should be continuous in the maximum available energy range. The lower energy limit is determined by the transmission function of the front-end window, and the upper limit is determined by the monochromator's operation range. When using silicon crystals as a monochromator, the energy resolution $\Delta E_{\mathrm{FWHM}}/E$ is $\sim 10^{-4}$, which is sufficient for X-ray diffraction and X-ray absorption spectroscopy experiments. There are currently no requirements for the radiation focusing, but the subsequent development of the station implies the use of mirrors for the collimation, high harmonics suppression, and radiation focusing. Based on expediency considerations, the beam size limit from above was taken equal to 10 mm at 30 m from the source. Also, the equipment and the control system should be user-friendly so that the radiation parameters (energy, geometry) could be adjusted with a minimal participation of the station stuff. The system of experiment control should exclude emergency operation modes.

Fig. 1 shows the scheme of the main optical elements of the station.

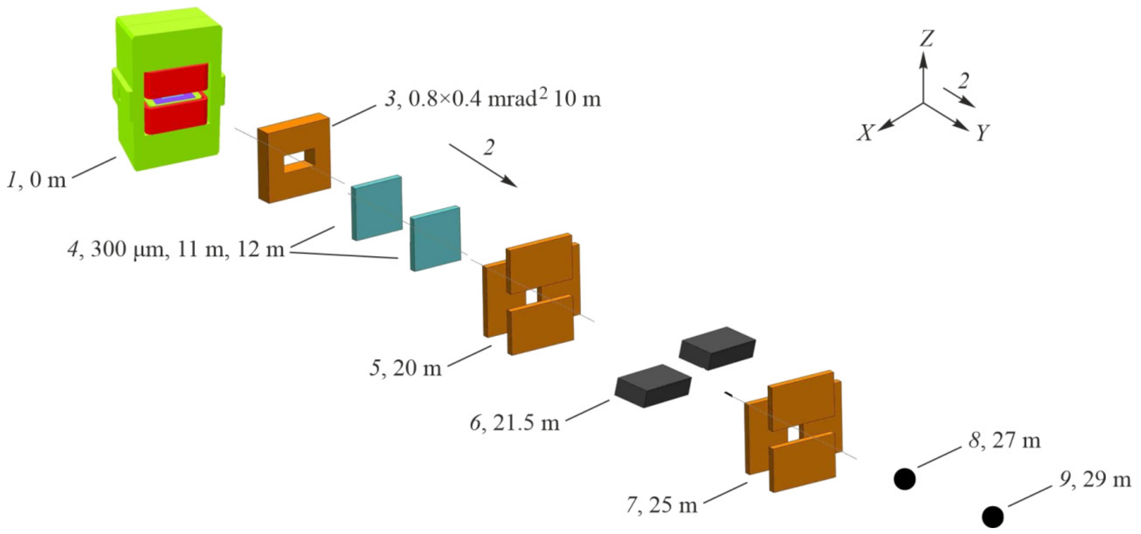

Fig. 1. Scheme of Station 1-7 optical elements and the coordinate system used in this work: high-field deflecting BPC_BM magnet (*1*); synchrotron radiation (SR) beam (*2*); fixed mask (*3*); Be windows (*4*); WB slits (*5*); channel-cut DCM (*6*); monochromator beam slits (*7*); 1-7 XAS (*8*); 1-7 XRD (*9*).

The radiation source the station is a high-field rotary magnet with the basic storage ring magnetic structure [12] and parameters listed in the Table 1. The source parameters were calculated using the SPECTRA 11.1.2 package [13]. The ray tracing was carried out using the XRT 1.4.0 package [14].

The source provides a continuous spectrum and a photon flux sufficient for the employed methods in the energy range of 3500-35000 eV or the wavelength range of 0.35-3.5 Å (Fig. 2). A channel-cut "butterfly" monochromator with the possibility of changing the crystal is proposed to ensure the necessary degree of monochromatization in the ranges of 3500-20000 eV (Si ⟨111⟩) and 15000-35000 eV (Si ⟨311⟩).

The front-end is designed to safely transport X-rays from the storage ring to Station 1-7 and to separate the storage ring vacuum and the channel vacuum. Vacuum separation is performed by two groups of beryllium windows with a total thickness of 600 μm.

The first front-end element is a fixed mask receiving unused radiation from the deflection magnet with a total power of up to 500 W. Fig. 3 shows the angular power distribution after passing through the mask and the beryllium windows.

The WB slits (red rectangle in Fig. 3) are located at 20 m from the source just behind the biosecurity wall. The WB slits are designed for a maximum thermal load of 72 W (~10 W power with a 0.2×0.2 mrad^2 aperture).

The vertical channel-cut monochromator is located at 21.5 m from the source. This construction ensures higher stability of energy scanning than two independent crystals.

TABLE 1. Parameters of the Station SR Source

Parameter	Value
β_x / β_y, m	0.252 / 7.77
η_x, m	0.003
Magnetic field, T	1.95-2.05
Critical photon energy, keV	12.27
Power density in the orbit plane, W/mrad	93.4
Full power, W	587
Source size horizontal / vertical, μm	14.14 / 24.14

Note: β_x, β_y are the horizontal and vertical β-functions, η_x is the horizontal dispersion.

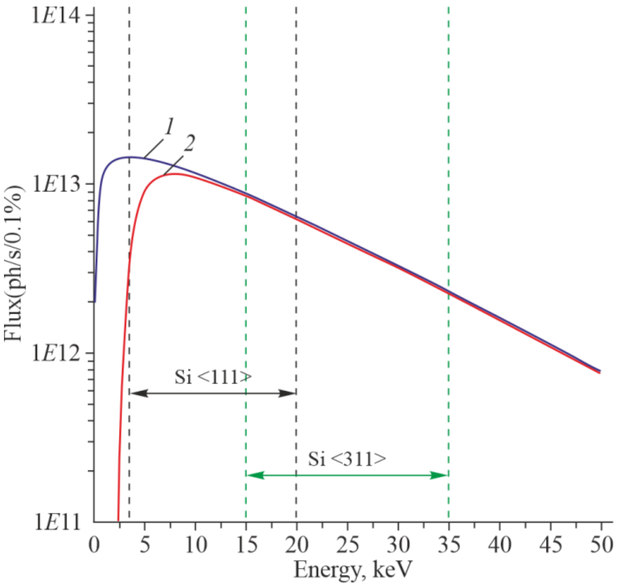

Fig. 2. Photon flux passing through the WB slits (0.8×0.4 mrad^2) (*1,* blue line). The same photon flux after taking into account the absorption in beryllium front-end windows (600 μm total thickness) (*2,* red line). Operating ranges of the channel-cut DCM with Si ⟨111⟩ and ⟨311⟩ crystals are shown in black and green, respectively (see the electronic version).

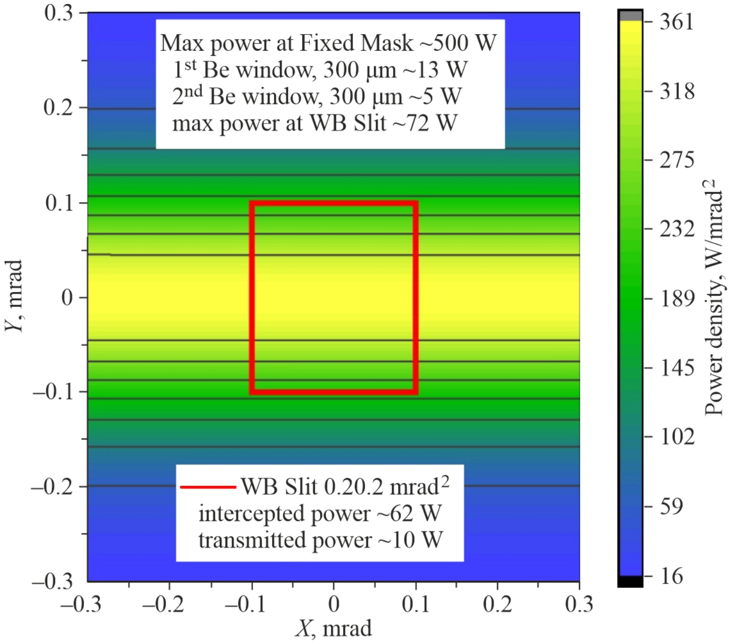

Fig. 3. Angular distribution of the radiation power after passing the fixed mask. The red rectangle shows the WB slits with an aperture of 0.2×0.2 mrad^2.

Since the crystals are rigidly fixed relative to each other, the beam position changes with energy. Fig. 4 shows the position of the maximum of the emitted monochromatic radiation as a function of energy for Si ⟨111⟩ and Si ⟨311⟩ crystals for the distance 8 mm between the reflecting crystal faces. The maximum shifts during the scanning in the range of 1000 eV

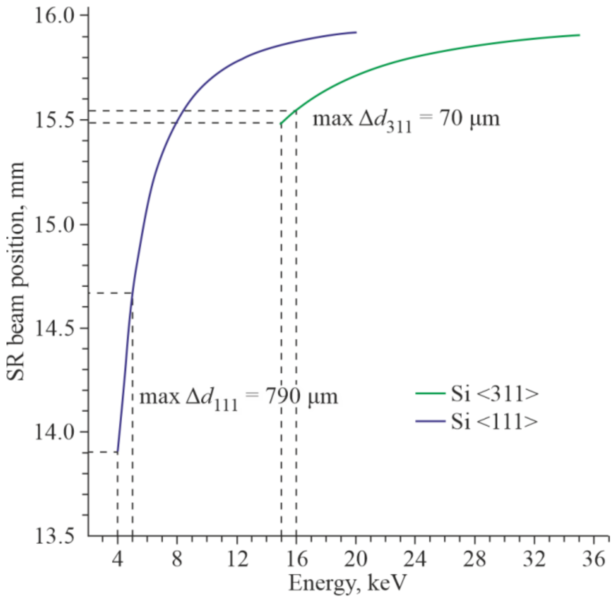

Fig. 4. Position of the SR beam maximum after the monochromator as a function of energy.

(the order of magnitude corresponding to the average EXAFS spectrum) are also shown. These shifts must be taken into account in energy adjustments.

Quite low thermal load on the first monochromator crystal is quite moderate (~10 W) and the maximum power density not exceeding 0.3 W/mm^2 (Fig. 5) allow using indirect water cooling of crystals.

Since the beam is not additionally collimated, the monochromator transmission function (resolution energy) will depend strongly on the photon energy. Fig. 6 shows how the photon flux changes for a given energy resolution of the final

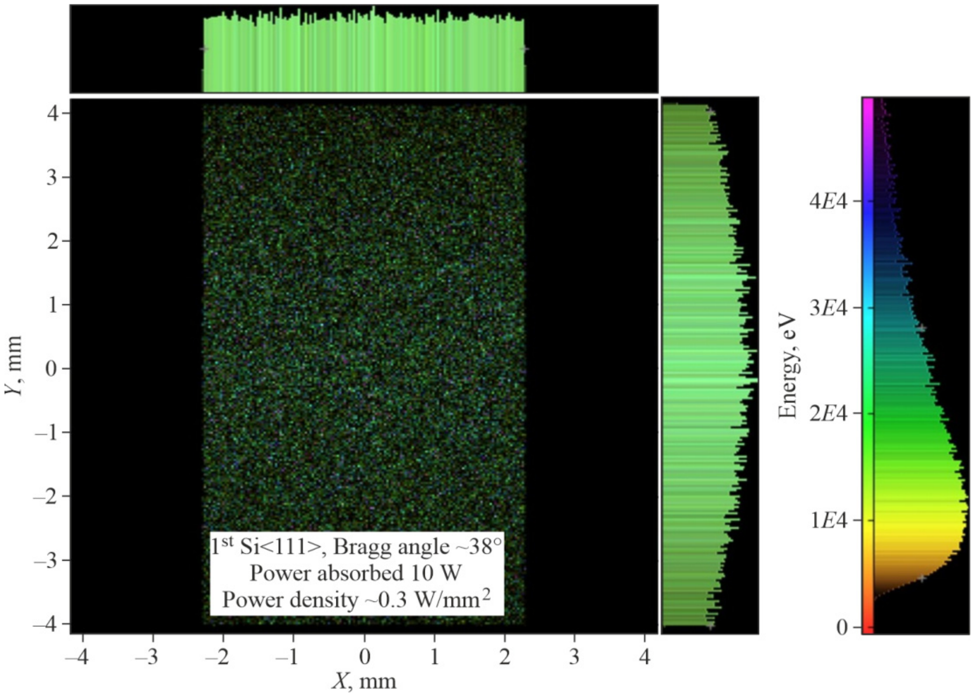

Fig. 5. Power distribution and energy spectrum of absorbed photons for the first Si ⟨111⟩ crystal (the Bragg angle of the crystal corresponds to an energy of 3.5 keV).

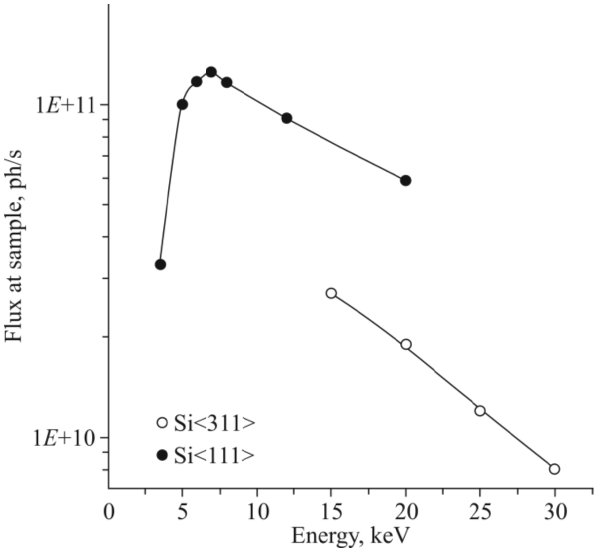

Fig. 6. Photon flux on the sample (29 m) at a spectral width of $\Delta E/E = 3\cdot10^{-4}$. The lines are drawn for clarity.

photon beam ($\Delta E/E = 3\cdot10^{-4}$) controlled by the slits from 3500 eV to 20000 eV for Si ⟨111⟩ and from 15000 eV to 35000 eV for Si ⟨311⟩.

The experimental site will be divided into two sections: X-ray absorption spectroscopy (XAS, 27 m) and X-ray diffraction (XRD 29 m).

The first section will be equipped with three ionization chambers operating in transmission mode and with a semiconductor drifted germanium detector for measuring the fluorescence output. For the radiation spectrum utilized at the station, the measurements can be conducted for the edges from Z 19 (potassium K-edge) to Z 55 (cesium K-edge) and from Z 46 (palladium L-edge) to Z 92 (uranium L-edge).

The diffraction station will be equipped with a single-crystal diffractometer with an area semiconductor detector for hybrid photon counting. The diffractometer will be also equipped with a fast (~1 ms) shutter and a video microscope to position small (~10 μm) samples. Based on simple geometric considerations (Fig. 7*a*), the following corrections will contribute to the reflection broadening and the accuracy of determining their positions in the experiment with an area detector: size of the detector pixel (p, $2\theta_\text{p}$); correction for the non-orthogonal position of the detector with respect to the scattered radiation (sl, $2\theta_{sl}$); longitudinal (w, $2\theta_w$) and transverse (h, $2\theta_h$) sizes of the sample; divergence of the scattered radiation (δ). The convolution of all these contributions into the Gaussian profile gives the following expression for the total correction:

$$\Delta 2\theta_\text{tot} = (2\theta_p^2 + 2\theta_{sl}^2 + 2\theta_w^2 + 2\theta_h^2 + \delta^2)^{0.5}. \quad (1)$$

The planned diffraction system will allows varying the sample–detector distance from 25 mm to 375 mm. As a result, the experiments can be carried out up to 35 Å^{-1} (sample–detector distance: 25 mm, energy: 35 keV). Fig. 7*b* shows the estimated instrumental contribution to the reflection broadening according to (1) for the sample–detector distance 375 mm, sample size 0.1 mm, beam size 0.1 mm, detector size 170 mm, detector pixel size 0.172 mm, radiation energy 12.4 keV and 35 keV (the contribution of divergence can be neglected for these parameters). The maximum possible resolution in this scanning mode for a weakly diverging beam will be $\Delta d/d \simeq 1.2\cdot10^{-4}$ for a distance of 375 mm (an energy of 12.4 keV). The diffractometer is also equipped with a κ-goniometer to conduct a standard single-crystal experiment with the following characteristics: rotation around the ω axis from –90° to +90°, rotation around the ϕ axis from –360° to +360°, rotation around the χ axis from –72° to +72°, and rotation around the θ axis from –100° to +25°; the minimum step of positioning along the axes is 0.0001°.

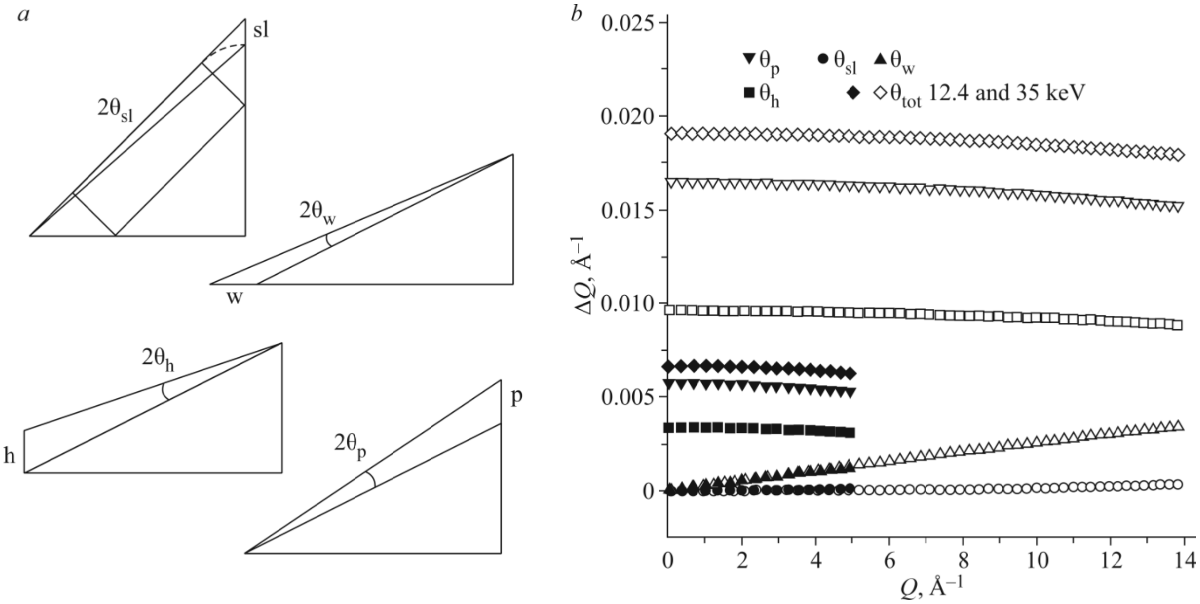

Fig. 7. Estimation of various contributions to the reflection broadening based on simple geometric considerations for a planar area detector (*a*); individual contributions to the reflection broadening and total correction over the entire range of scattering vectors for a given geometry (*b*).

Additional continuous-flow cryostats or heaters may be required for *in situ* studies. It will also make possible the experiments with protein crystals and other organic macromolecular systems. The use of hard radiation (stronger than 20 keV) allows conducting experiments in closed cells (temperature chambers, reactors, etc.)

CONCLUSIONS

The analysis of the world-wide and the Russian experience of educational programs based on synchrotron radiation sources reveals numerous forms of educational and scientific initiatives. These initiatives have proved their effectiveness in the teaching of students, attraction of new users, and popularization of science. This work presents a concept of NSU–CCU SKIF scientific and educational programs: (1) activities within the NSU educational process, including workshops and laboratory works by students; (2) additional education: schools, advanced training courses, thematic conferences; (3) internships for solving scientific and educational tasks using the station experimental resources. The CCU SKIF–NSU Station 1-7 “Basic methods of synchrotron diagnostics for educational, research, and innovative activities of students” is to become a foundation for the cooperation between NSU and CCU SKIF in the field of education. It is planned that the CCU SKIF–NSU Station 1-7 will be put into operation in 2025 immediately after launching the accelerator complex and the first-stage experimental stations. The characteristics distinguish this station are its universal character, flexibility in the conduction of studies, availability of various informative methods. The structure of the station and the implemented methods will help to solve problems from various fields of science and to acquire practical skills for conducting experiments and mastering the appropriate software for students of various specialties, as well as to prepare high-quality term-and qualifying projects. The developed station is characterized by the universal character and the possibility of conducting research with a number of diffraction and spectral methods, including powder and single-crystal X-ray diffraction, X-ray absorption spectroscopy, and X-ray fluorescence analysis. Station 1-7 should become a site for practical training of scientific and engineering personnel for the synchrotron research in various fields of science: physics, biology, chemistry, geology, archeology, medicine.

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CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interests.

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