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Kurchatov synchrotron radiation source: Status report

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Abstract

Project parameters of the big storage ring are practically reached. At the project energy of 2.5 GeV stored current reached 72 mA. Three SR beamlines are installed on the bending magnets of the small storage ring with an electron energy of 450 MeV. Three experimental stations are installed in VUV experimental hall. Three front ends of X-ray beamline are installed on the big storage ring. One X-ray beamline is out of biological shielding of the big ring. Construction of the big experimental hall is almost completed. A status report on the first part of the active proposals is given. © 2000 Elsevier Science B.V. All rights reserved.

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Keywords: Synchrotron radiation; Storage ring; Beamline; X-rays

1. Introduction

1.1. Storage rings

Kurchatov Synchrotron Radiation Source (KSRS) is the first dedicated synchrotron radiation facility in Russia. Budker Institute of Nuclear Physics (BINP) constructed it. Commissioning of the rings has been carried out by the joint efforts of BINP and Russian Research Centre Kurchatov Institute. The facility includes two storage rings: 450 MeV SIBERIA-1 and 2.5 GeV SIBERIA-2 and is intended for experiments in the 0.1–2000 Å range of SR wavelengths. The detailed description of KSRS with planned experimental station was given in Refs. [1,2].

Large progress was achieved in increasing SIBERIA-2 stored current during the last year. Now the maximum current at injection energy is 129 mA in multibunch mode and 59 mA in single bunch mode. The maximum current at 2.5 GeV is 72 mA. Description of SIBERIA 1 and SIBERIA 2 machines operation is given in Refs. [3–5].

2. An ionization detector of synchrotron beam spatial parameters

An ionization Beam Cross-section Image Detector (BCID) is developed [6–9]. The detector measures the shape, the size, the profile, the position and the angle of an SR beam without any influence on it. BCID can be installed into a separate vacuum chamber with Be windows. For better sensitivity the chamber can be filled with Ar or Xe under a pressure of about 10^{-4} Torr. BCID

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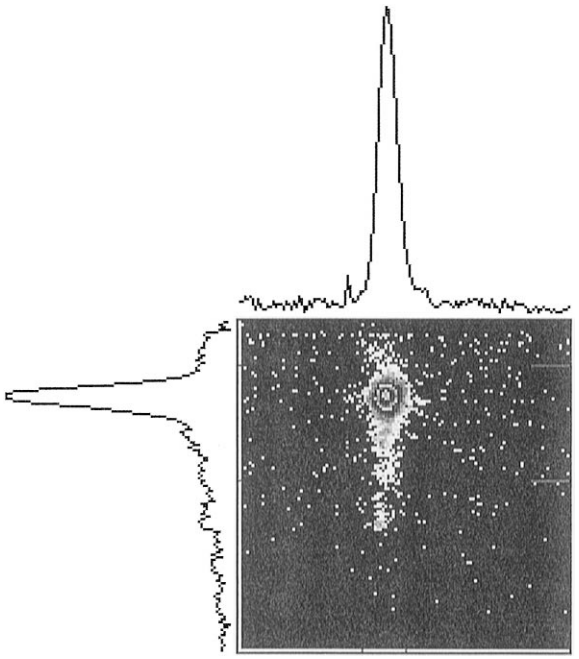

Fig. 1. Image of a cross-section and corresponding profiles of the monochromatized and focused SR beam of MAX - 2 storage ring. Ionization detector.

registers electrons or ions created by the investigated beam in residual gas. Extractor electric field draws out ions through the narrow slit into the analyzer. The analyzer electric field transforms the energy distribution of ions created by extractor electric field into two-dimensional distribution. Then there is an open image converter tube (ICT) that is made of two microchannel plates. The image of the real-beam cross-section is formed on outer luminescence screen of ICT. This image is registered by a CCD camera, presented on a TV monitor and processed by a computer.

The detector was checked on white SR beams of the storage rings DCI (LURE, Orsey, France) and KSRS (RRC KI, Moscow, Russia). These experiments showed high sensitivity, good resolution and clear images of the beam cross-sections. A summation of the large amount of TV frames was used. This method increases signal/noise ratio. Uncertainty of some microns was achieved for SR beam gravity center while the size of the beam was about 2 mm. On the storage ring MAX-2 (MAX-lab, Lund, Sweden) a monochromatized SR was measured (Fig. 1). The FWHM in that case was about 0.5 mm.

2.1. VUV experimental hall

Three beamlines are available to transfer synchrotron radiation with a critical energy of 200 eV from bending magnet of the small ring to experimental stations. All stations are in the final stage of commissioning and were tested by an SR beam. Let us review these stations.

2.2. Photoemission station (Fig. 2)

The station consists of high-resolution ultra-high-vacuum monochromator for the spectral region from 4 to 100 eV and operation vacuum of 10E-8 Pa and the spectrometer. The monochromator has two optical schemes: normal incidence scheme with a 3 m spherical grating with resolution better than 0.1 nm (with 1200 l/mm) and grazing incidence scheme. Both schemes used the same exit slit and the electron beam itself was used as the entrance slit. The photoemission spectrometer allows one to perform the following: to use the ion beam for cleaning the surface of samples and substrates; to produce films of practically any substance; to check the contents of samples and films by using the Auger spectroscopy method; to measure the films resistance; to study the samples and films by using the photoemission spectroscopy method; to investigate the samples and films by EELS and Auger spectroscopy methods; to investigate the surface structure of samples by low electron energy diffraction (LEED) method; to measure optical reflectivity of samples; to measure the luminescence spectra of samples; to carry out the investigation within the temperature range from 2 to 1300 K. The spectrometer has a special module for production of thin films by ion plasma sputtering. The energy analyzer is a 15–255 GAR model of the Perkin-Elmer Company.

3. General purpose station for optical investigations of solids in VUV Region. (Fig. 3)

The special interest for the investigation lies in the novel materials such as HTSC, fullerenes, etc.

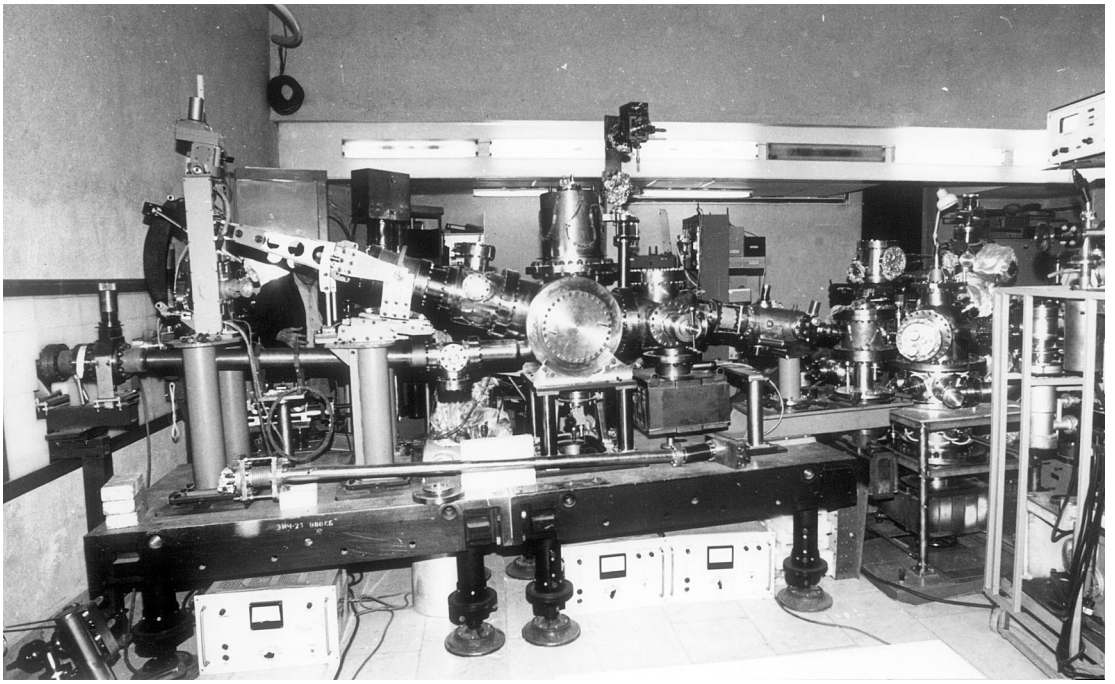

Fig. 2. Photo emission station in experimental hall of the Kurchatov small storage ring.

The station contains a monochromator and an experimental chamber. The primary monochromator contains two optical schemes united in the single vacuum chamber, and can deliver the monochromatized SR in the wide range of energies – from 4 up to 200 eV. The low-energy (4–40 eV) scheme is the Seya–Namioka monochromator with a resolution of about 10E4. The high-energy scheme (30–200 eV) is the grazing incidence monochromator with a resolution of more than 100. The experimental chamber includes a chamber for the sample preparation and a high-vacuum sluice. The vacuum in the main chamber will be better than 10^{-7} Pa. For the various optical measurements the station can be equipped with a secondary monochromator with the resolution 10E4 operating in the visible range. For the analysis of the chemical composition of the samples surface the Auger spectrometer with an electron gun is provided. At present, the general tests of the monochromator are finished. These tests contain measurements of the spectral efficiency in the visible part of SR, the calibration of the monochromator in the visible region using a mercury lamp and a HeNe laser, the vacuum tests of the monochromator and the vacuum chamber.

4. Station for optical spectroscopy of solids in VUV region (Fig. 4)

The essential information on the band structure of many insulators such as the band-gap width, thresholds of exciton and defect creation, thresholds of inelastic electron–electron scattering that results in the luminescence yield increase, etc. can be obtained from the optical measurements in VUV region. The experience concerning the operation of VUV spectroscopy stations has shown that the Wadsworth monochromator scheme is preferable due to high throughput and resolution required for the reflectivity and luminescence quantum yield measurements.

UHV monochromator for VUV region (4–40 eV) constructed by Moscow State University contains the following main optical parts: a collimating

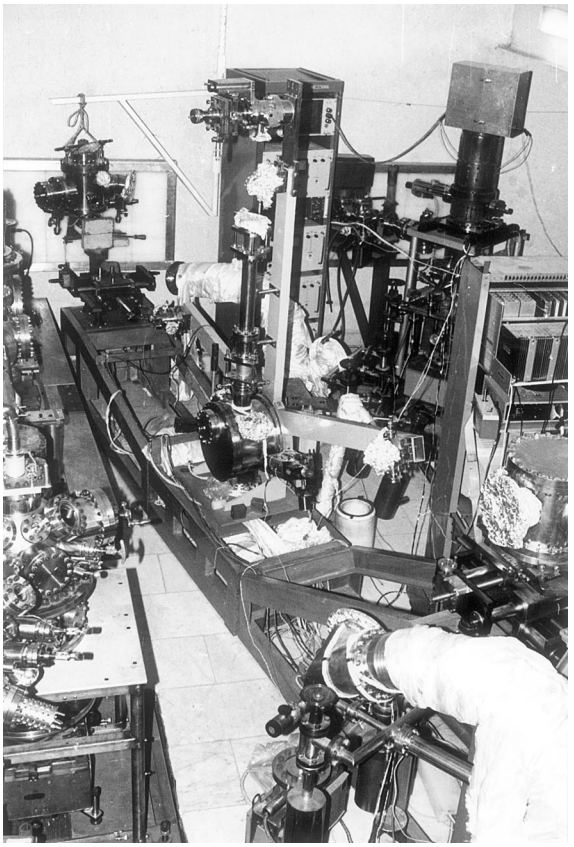

Fig. 3. General purpose station for optical investigations of solids in VUV region in the experimental hall of the Kurchatov small storage ring.

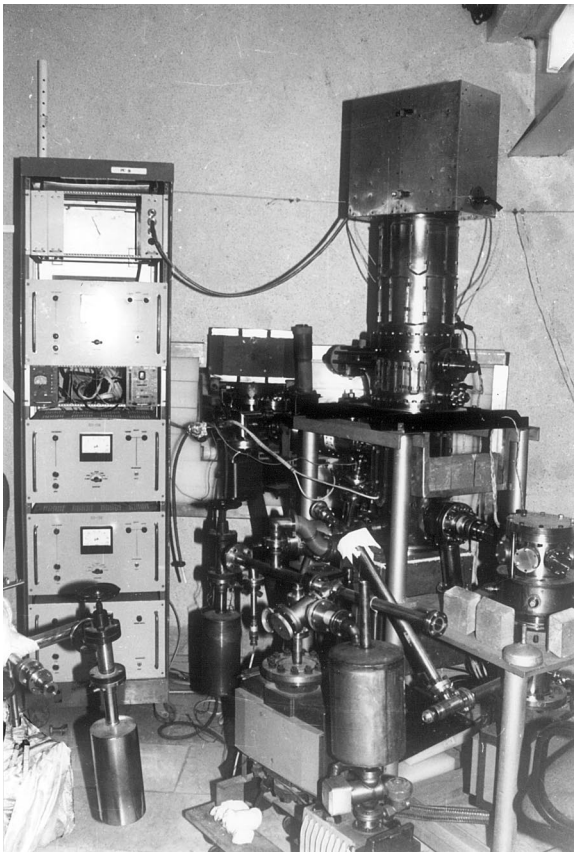

Fig. 4. Station for optical spectroscopy of solids in VUV region in experimental hall of the Kurchatov small storage ring.

primary toroidal mirror, a 1 m radius concave grating, an exit slit and an exit focusing mirror. Both mirrors are oriented under the angles of incidence close to the Brewster's angle; therefore the radiation impinging onto the sample is highly polarized.

The sample chamber comprises vertically movable holder for three samples that allows sample changing in high vacuum. The cryostat temperature range extends from 80 up to 500 K. The sample chamber housing is equipped with a set of windows for the simultaneous measurements of the reflectivity and luminescence quantum yield. Secondary Seya–Namioka monochromator is used for the luminescence spectra recording and for the separation of the emission bands when the luminescence quantum yield is measured. The secondary monochromator can be turned around its entrance shoulder for the analysis of polarized luminescence.

4.1. X-rays experimental hall

The construction of the X-ray experimental hall 1200 m∗m is practically completed. The floor of the hall and the biological shielding is covered by the natural marble. (Fig. 5). Three beamline front-ends for SR from bending magnet of the big storage ring are mounted. Each front-end includes the water-cooled collimators, pumping, removable scintillation screen and three Be foils with a total thickness of 600 μm. The Ionization Detector of Synchrotron Beam Spatial Parameters mentioned above equips

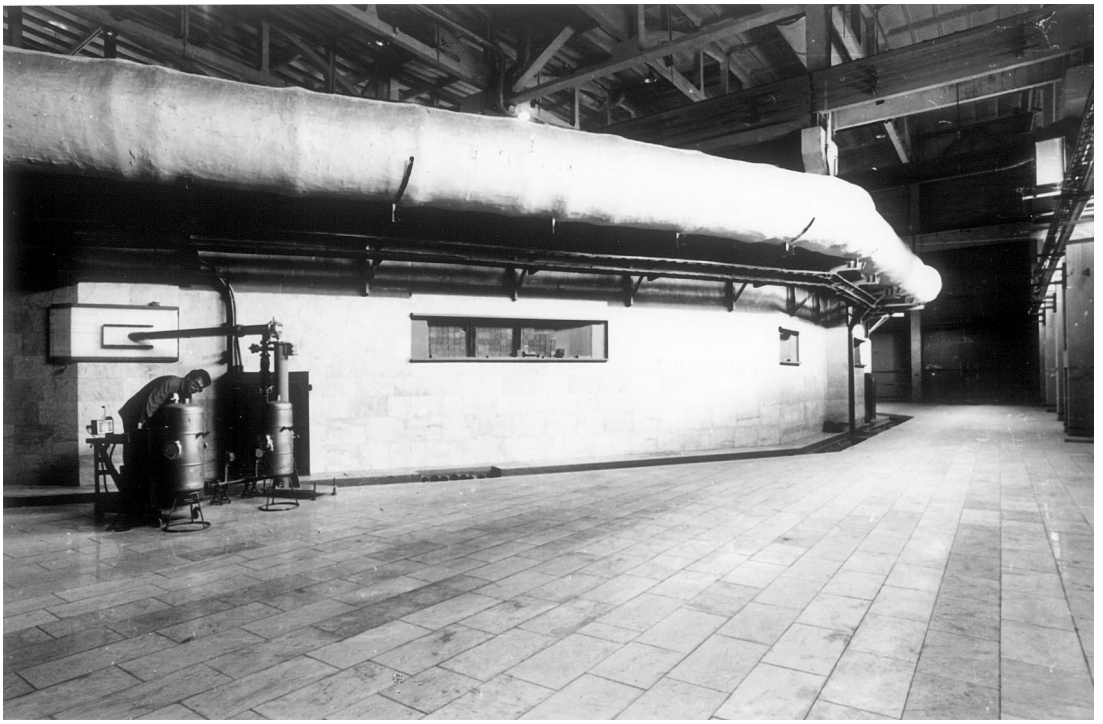

Fig. 5. X-ray experimental hall of 1200m∗m around the Kurchatov big storage ring. The floor of the hall and the biological shielding is covered by natural marble.

one of the front-ends (Fig. 6). We plan to complete the installation of the first four SR beamlines and to begin regular experiments with SR from the big storage ring at the beginning of 1999. The next five stations will be installed on these four beamlines: deep X-ray lithography station, medical diagnostic station, station for the investigation of the chemical shifts of X-ray emission lines, photoelectron diffraction spectrometer.

4.2. Deep X-ray lithography

The first experiment at KSRS on the Deep X-ray Lithography (DXRL) was carried out in 1996 when storage ring parameters were rather low [10]. The attainment of the projected level of the stored electron current in 1998 makes it possible to carry out the full-scale experiments on the DXRL. In the framework of KSRS Microtechnology Program and according to the European Network "MICROSYNC" the complete set of the beam-line for DXRL was installed on its full length (15 m). The designing of more advanced vacuum chamber, scanner and its actuator system is under way.

4.3. Medical diagnostic station for combined investigation

We plan to create a medical diagnostic station for combined investigation at Kurchatov Synchrotron Radiation Source. This station will include usual absorption radiography, refraction introscopy and small-angle scattering. Refraction introscopy is based on the influence of local refraction coefficient on the beam direction. To reveal this deviation it is necessary to use optical schemes with high angular resolution. With the help of refraction introscopy it became possible to investigate the inner structure of the samples having low absorption which is quite impossible with the help of usual

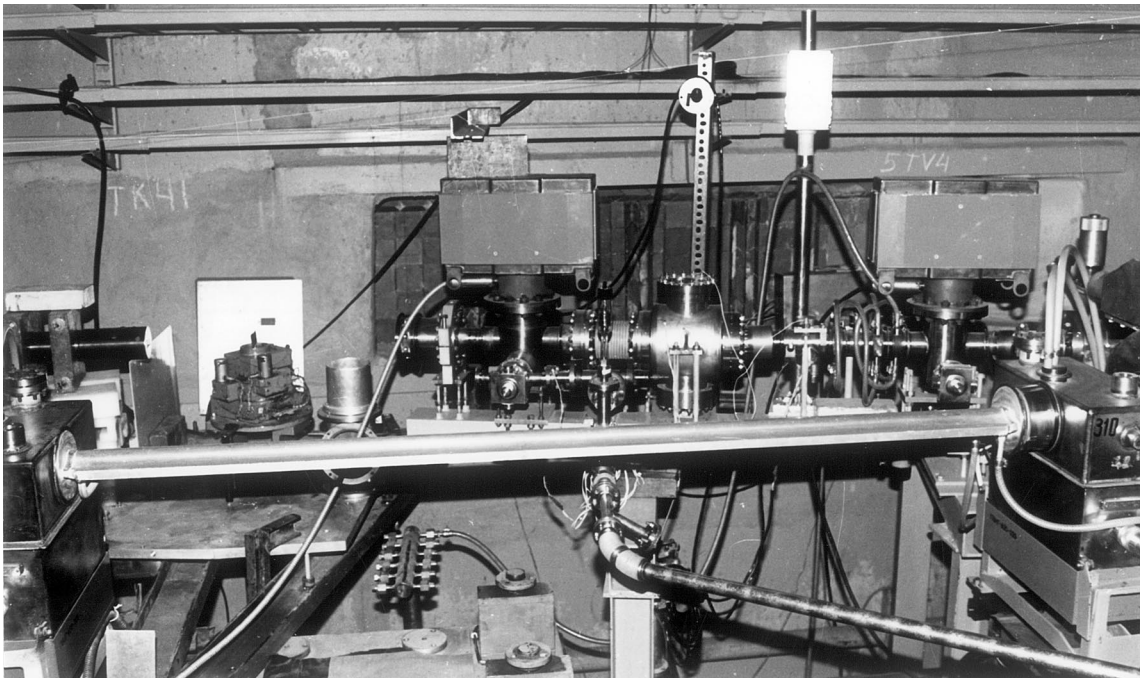

Fig. 6. One of the SR beamline front-ends mounted from bending magnet of the Kurchatov big storage ring.

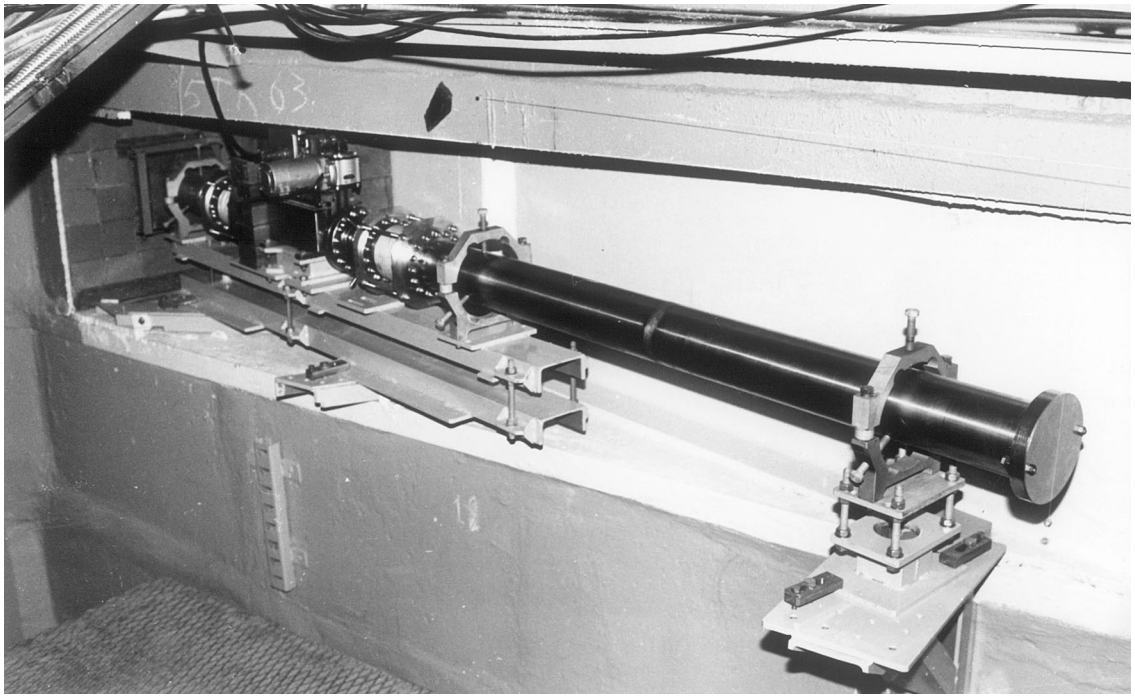

Fig. 7. One of the central parts of a beamline going through biological shielding of the Kurchatov big storage ring.

radiography. Investigation of the biological samples was carried out with the help of X-rays [11]. Paper [12] shows that a resolution of up to 1 μm can be achieved with the help of SR and measuring time of order 1 s. Together with inner structure measuring it is possible to get local refraction coefficient (refraction densimetry). The high angle resolution is the base for the investigation of medical and biological objects by small angle method. This method gives information about the structure on a submicro level. Nowadays some experiments on different SR collimating and focusing schemes are in progress (Fig. 7).

5. Polarized tagged photons

In the beginning of 1998, the PTP facility status to study photo nuclear reactions at intermediate energies was the following: the beam test with the coordinate sensitive gamma-ray detector was successively done to check the alignment one of the front-end flange of the storage ring; the principal PTP elements are completed for installation. Among them: the Si micro-strip detector for the tagging system with a coordinate resolution of 0.6 mm, an efficiency of 100%, an energy resolution of 6 MeV; the laser system to get back scattered gamma rays with an energy of up to 200 MeV, flux 10 MHz; the total photo absorption detector as a beam monitor with BaF2 crystals; the cleaning magnet, the coordinate gamma beam monitors, etc. At the beginning of operation, the PTP facility is planned to be used for calibrations of nuclear detectors.

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