5.3 Medical Beamline

The application of the synchrotron X-ray beams for medical purpose becomes an important part of the synchrotron radiation use and opened an opportunity for best medical diagnosis and treatment. Actually all the modern synchrotron radiation sources are accompany by the satellite medical center. The highlights for medical therapy and diagnosis by use of synchrotron radiation of CANDLE synchrotron light source include

- Angiography
- Bronchography
- Mammography
- Computed Tomography
- Diffraction Enhanced Imaging Microangiography
- Microbeam Radiation Therapy

To cover this wide area of the medical applications for the radiation therapy and treatment, the two beam lines, one from wiggler and one from bend magnet, can be delivered to medical center as an extension of the end stations at the experimental hall of the CANDLE light source. In this section the wiggler beamline specification and technique to be used is presented.
The 2 T magnetic field wiggler beamline from CANDLE has a critical photon energy of about 12 KeV, the spectrum of which is extended up to 100 keV with sufficient photon flux and cover the photon energy of 33.17 KeV – the iodine K-edge energy. The full length of the beamline is about 140 m. The X-ray beam produced by the wiggler magnet passes out of the experimental hall surrounding storage ring and enters a satellite laboratory. The parameters of the wiggler source is presented in table 5.3.1

Table 5.3.1 The Beamline Source

Critical photon energy (keV)	11.88 keV
Magnetic field (T)	1.98 T
Electron beam spot size ($\mu m \times \mu m$)	314.2×20.18 (H×V)
Electron beam divergence ($\mu rad \times \mu rad$)	32.4×4.16 (H×V)
Total power emitted (kW)	29.9
Flux at critical photon energy (ph/s*0.1%bw)	$6.5 \cdot 10^{15}$

Different experiments can be performed at the end station located in the main experimental hall of the CANDLE and the end stations. Medical wiggler beamline will produce a high flux of hard X-Rays and sequentially serve three experimental stations for medical applications:

- Experimental Hutch 1 (EH1) - microbeam radiation therapy,
- Experimental Hutch 2 (EH2) - computed tomography
- Experimental Hutch 3 (EH3) - coronary angiography / bronchography

Microbeam radiation therapy (MRT) is directed towards clinical applications. Theory and the rationale of pre-clinical experiments of MRT are based on dose-volume relationships that shape tissue complications after ionising irradiation. In general, the smaller the irradiated macroscopic tissue volumes, the higher the threshold absorbed doses for damage to normal tissues. Present-day clinical applications of this principle include stereotaxic radiosurgery and conformal radiotherapy, using photon beams collimated in millimeters.

Computed tomography (CT) is widely used in clinical practice and produces images of high diagnostic quality. Nevertheless there are some difficulties related to the use of conventional sources for CT. In particular beam hardening, where higher energy photons have a higher probability of traversing a large tissue thickness than do lower energy photons, is a troublesome problem in image reconstruction. Synchrotron radiation has some obvious advantages in that monochromatic beams will not beam harden whilst the tunability of the beam permits K edge subtraction imaging.

Coronary angiography / bronchography. The high brilliance and tunability of CANDLE x-ray beams can dramatically improve the speed, clarity and safety of diagnostic tools, such as coronary angiography and computed axial tomogarphy scans.

The coronary ***angiography*** is an X-ray procedure in which coronary vessels are made visible through the injection of iodine as a contrast medium. Two x-ray beams, one tuned to an energy readily absorbed by the iodine and one at the slightly lower energy, are used to record two images simultaneously. When the computer subtracts one image from the other, the contrast of view of the arteries is enhanced 150 000 times over that of bone or flesh. This extreme sensitivity allows the use of much lower iodine concentrations and lower X-ray doses, compared to conventional angiography. With such low iodine level, the contrast agent can be safely introduced through an arm vein. And by using the high brilliance of CANDLE x-ray beams, an image can be formed in milliseconds, fast enough to make "snap shots" and "movies" of the living, beating heart and nearby arteries. Monochromatic x-rays of sufficient intensity to visualize coronary arteries of 1 mm in diameter with an extremely low iodine mass density of 1 mg/cm^2 are only provided by synchrotron radiation.

The same technique can be applied for the imaging of lungs and respiratory passages- ***bronchography***. The patient inhales a gas mixture of xenon (80%) and oxygen (20%). The inspired volume is limited to the anatomic dead space, which includes the small bronchi but not the alveoli, and therefore virtually no xenon is absorbed. Moreover, this protocol limits overlap problems caused by xenon in the alveoli or in vascular structures. The patient then holds his/her breath for several seconds whilst dual energy imaging is performed in a manner very similar to that used for line scan coronary angiography. The only difference is that the energies are chosen to bracket the xenon K edge at 34.56keV. The technique could be particularly valuable in the early diagnosis of lung cancer, which is the leading cause of cancer. It is calculated that K edge subtraction imaging using inhaled Xenon as a contrast agent could detect tumors that are significantly smaller than the 1cm limit of conventional techniques.

The monochromator for angiography (bronchography) is based (Fig.5.3.1) on the use of a cylindrically bent Si-crystal in a vertically focusing Laue geometry **[1].** The white beam is diffracted by the thin crystal and a water-cooled beam splitter, located downstream from the crystal, divides the incoming beam into two beams with energies above and below the iodine K-edge. The parameters of the monochromator are presented in Table 5.3.2.

Table 5.3.1 Monochoromator characteristics.

Optical elements	Si-bent Laue crystal	Fixed-exit monochromator
Distance from source	145m	140m
Usage	Angiography	Computed tomography
Spectral range	17-51 keV	15-80keV
Max beam size at patient	300x10 mm^2(HxV) (aperture limited)	
Expected flux	$1.1 \cdot 10^{15}$ph/s, 0.1%bw, 0.350A, 33keV	

Fig. 5.3.2 presents the results of the computer simulation of dual energy quasi-monochromatic synchrotron radiation beam formation (the energy range 33170 ± 250 eV) after the monochromator that is obtained via the Si (111) Laue diffraction (Fig. 5.3.2a). The photon beam image at focus location after the beam stopper (2 mm vertical size) is shown in Fig. 5.3.2b and finally the photon beam image at the detector is given in Fig. 5.3.2c.

The monochromator parameters - radius of curvature, thickness, and diffraction asymmetry factor – will be further optimized to obtain a maximal intensity of the diffraction radiation with the minimum size in a vertical direction. Accordingly will be adjusted the horizontal and vertical apertures of the beam before and after a crystal, distance between the patient and the detector, and distance between two rulers of the detection system.

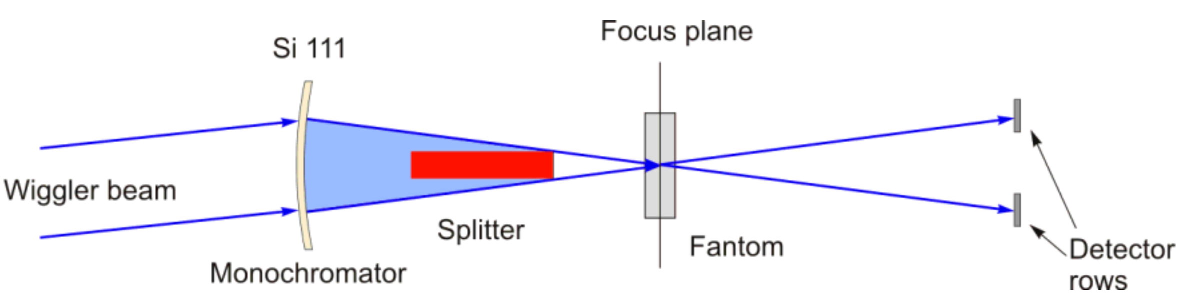
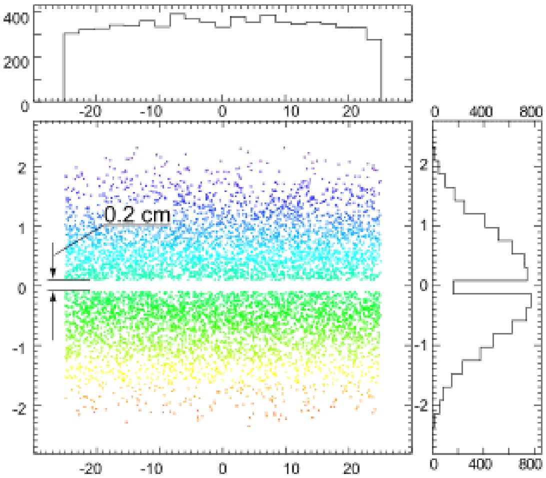
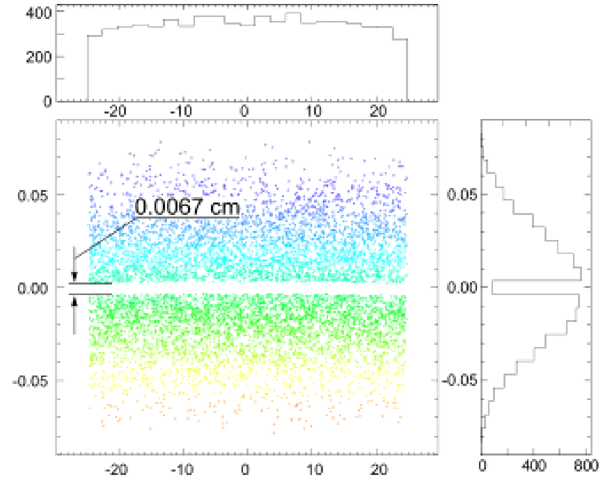


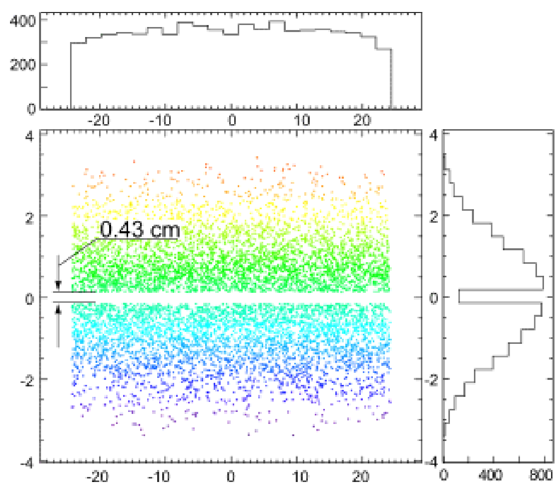
Fig. 5.3.1 Experimental layout for the angiography/bronchography at the medical wiggler beamline of CANDLE.



a)



b)



c)

Fig. 3.5.2 Result of the computer simulation of a quasi-monochromatic SR beam (energy range 33170 ± 250 eV) obtained via the Si (111) Laue diffraction monochromator. Beam image a) at 15cm after monochromator, b) at focus location after the beam stopper, c) in place of detector.

The apparatus associated with end station for coronary angiography and bronchography (EH3) include:

- In house design and production goniometer and crystal monochromator with bender,
- Special chair for patient,
- Radiation detecting system-high purity germanium detector associated with high dynamic range electronics (864 strips distributed over two rows with detection pitch of 350 micrometers)