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A b s t r a c t

The selective X-ray imaging method of the patient's circulatory system at the absorption edges of elements, which uses the synchrotron radiation, is considered. It is shown that for application of the suggested method, at reasonable doses of irradiation, it is sufficient to create the mean weight concentration of a X-ray contrast element (for example iodine) in the blood at a level of 0.1-1%. The first results obtained with test objects and an alive rabbit at the Br K-absorption edge are presented. The advantages of the described method are analysed compared to the traditional X-ray imaging of the patient's blood vessels, and the future perspectives of its application are evaluated.

Electron storage rings designed for high energy physics turned out to be very powerful sources of X-ray synchrotron radiation (SR) arising from the motion of electrons in a magnetic field. In contrast to the radiation of X-ray tubes, the SR has a continuous spectrum and is concentrated within small angle near the plane of an electron orbit. The SR intensity in the X-ray range is several orders of magnitude higher than the radiation intensity of the most powerful X-ray tubes /1/.

The essential advantages of the SR over the radiation of X-ray tubes as well as the highly developed procedures of data acquisition, storage and displaying in a form convenient for a researcher, which are being currently used in elementary particle physics, enables one to hope to raise the conventional methods of X-ray medical diagnostics on a qualitatively new level. The present paper is devoted to the possibility to study the pathology in the circulatory system and different organs of the human body, which are capable of storage, in appreciable concentrations ($\gtrsim 0.1\%$), X-ray contrast compounds (for example iodine) by the selective X-ray exposure at the absorption edges of elements.

At present, the angiography methods, the radiographic study of blood vessels, are sufficiently developed in medicine. The main idea of angiography is to introduce a high-concentrated contrast substance (with 30-50% of iodine in it) as close as possible to the point under study. The contrast substance, up to 60-80 ml, is injected into this point with a catheter inserted into one of the large blood vessels. After injection a fast exposure of a series of roentgenograms is carried out. In practice, the angiographic study is a specific surgical operation performed under X-ray monitoring. The below described meth-

od makes it possible to avoid the surgical injection of a contrast substance into the region under examination and requires a low mean concentration ($\leq 1\%$) of it in the blood to be only created.

It is well known that the dependence of the X-ray absorption coefficient μ on a radiation wavelength at definite wavelengths changes discontinuously - there are the "jumps" at the absorption edges (Fig.1).The greatest jump occurs at the K-absorption edge.Separation of the high-intensity radiation with a definite wavelength from the SR beam with the use of a monochromator permits to exposure selectively X-ray patterns below (p.A in Fig.1) and above (p.B) the K-absorption edge of the element under study. When the radiation passes through the body's part containing this element, the intensity of the passed radiation decreases drastically due to a jump-like change of μ at the absorption edge if the wavelength is switched on from point A to point B. During the wavelength transition from point A to point B, the change of X-ray absorption in the remaining chemical components of the body is negligibly small. In view of this, the difference picture (obtained by subtracting the roentgenogram taken above the K-absorption edge from the roentgenogram taken below the edge) contains information on the distribution of the element in question only. If I_A and I_B are the intensities of the radiation passed through the body at some point of the image at wavelengths λ_A and λ_B respectively, then the quantity

$$\xi = \ln\left(\frac{I_A}{I_B}\right) = \ln\left(\frac{I_B+\Delta I}{I_B}\right) \simeq \frac{\Delta I}{I_B} \simeq c\cdot d\cdot\rho\cdot\Delta\mu \qquad (1)$$

is proportional to $c\cdot d$ of the element under study, where: c is the concentration, ρ is the blood density; d is the blood

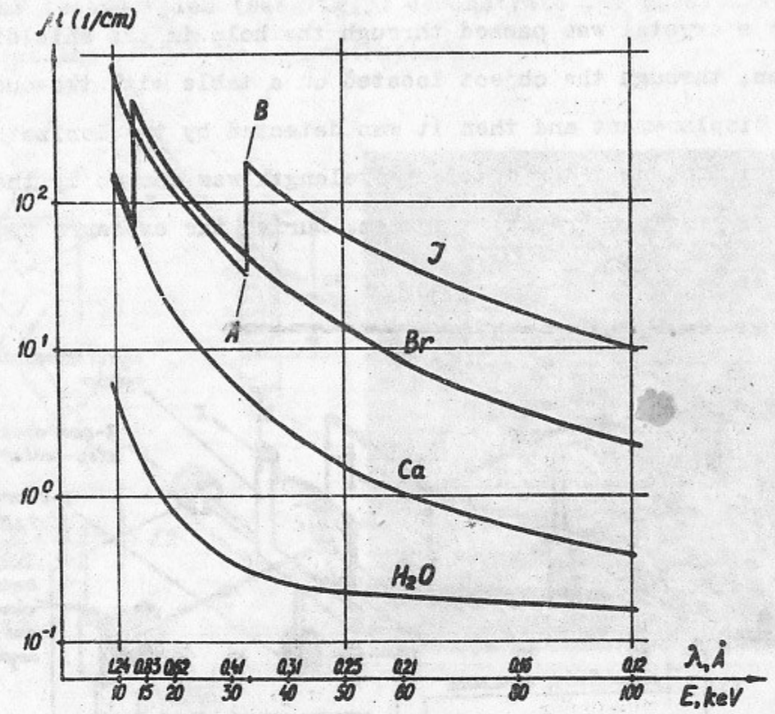

Fig.1. The dependence of the linear X-ray absorption coefficient on a wavelength (the energy of X-ray quanta) for some substances.

vessel diameter; $\Delta\mu = \mu_B - \mu_A$ is the difference between the mass coefficients at the absorption edge. With the use of X-ray imaging when the radiation is detected with the help of ionization or proportional chambers of a large dynamic range ($\geq 10^4$), a significantly higher effective sensitivity to the concentrations being detected can be expected over the existing angiography methods.

The method has been tested at the VEPP-3 storage ring at the Br K-absorption edge with the SR from the bending magnet, the X-ray pictures have being taken at two wavelengths. The

experiment scheme is shown in Fig.2. The SR beam monochromatized by a crystal was passed through the hole in the shielding screen, through the object located on a table with two-coordinate displacement and then it was detected by the ionization chamber. The needed radiation wavelength was chosen by the crystal precision rotation system. During the exposure process

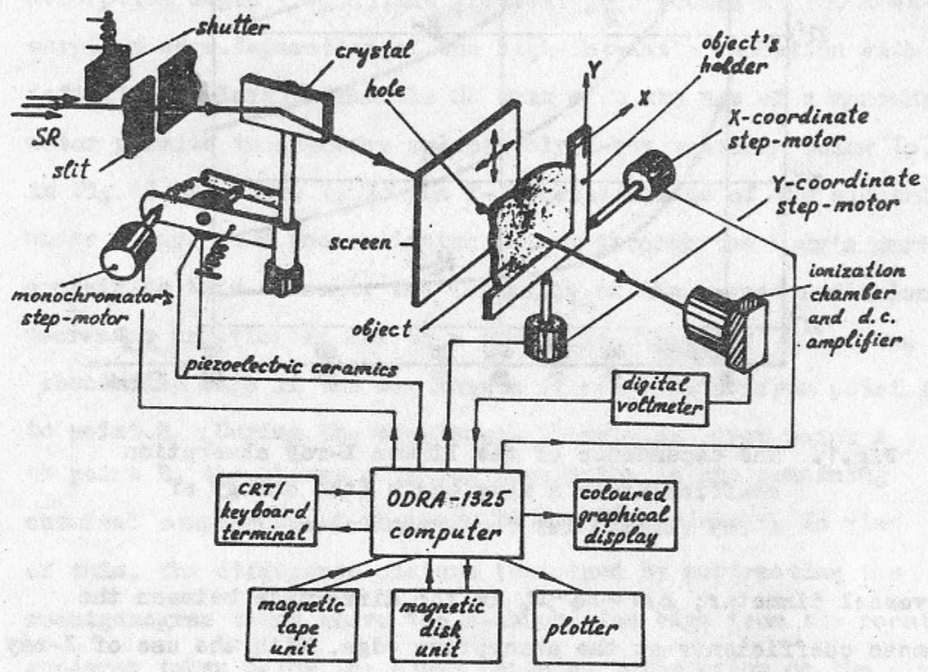

Fig.2. The scheme for radiation exposure at the absorption edges of the elements under study.

the object was scanned in two coordinates relative to the hole. The picture under detection consisted of 100 x 100 points; the intensity was measured for two wavelengths at each point of scanning. The experiment was completely automatized with the help of the ODRA-1325 computer.

The experiments at the Br K-absorption edge carried out with the test samples (see Fig.3) demonstrate the possibility to detect the $\sim 10^{-3}$ Br concentrations.

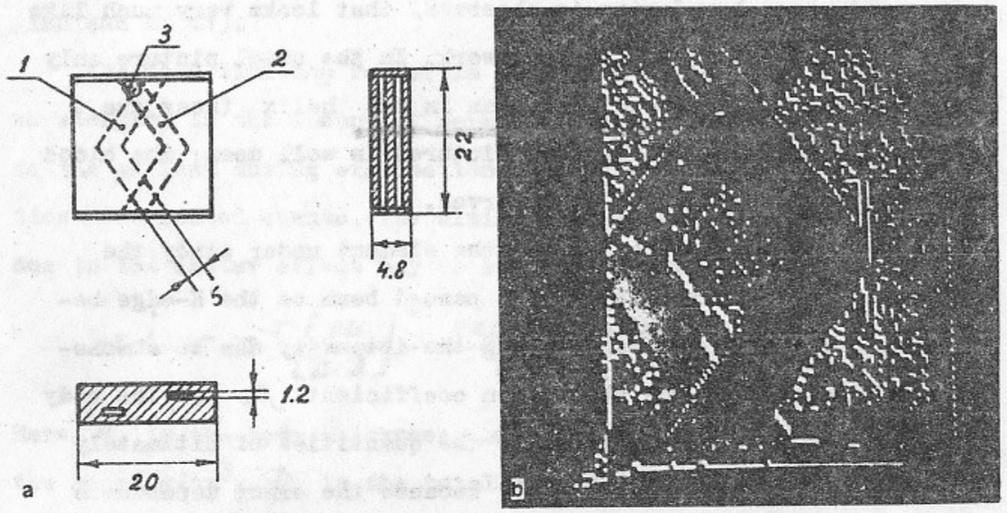

Fig.3. The scheme (a) and the difference picture (b) of the test sample. Channels 1 and 2 in plexiglass are filled with Br solutions with 10^{-3} and 10^{-2} concentrations, respectively; 3 - air bubble in channel 2.

The other object examined at the Br K-absorption edge was a part of the helix of an alive rabbit. The Br concentration in the rabbit's blood was artificially created by the fractional injection of the potassium bromide solution through a catheter into the vein of a hindleg; the rabbit was intravenously narcotized. 14 ml of the 10% KBR solution was introduced; the estimated Br concentration in the rabbit's blood was $2 \cdot 10^{-3}$. The sections for exposure were chosen to be 10 x 10 mm^2 in size, spatial resolution was 0.1 x 0.1 mm^2. Fig.4 demonstrates the

usual (for one λ) and difference (the distribution of ξ) pictures of the chosen section. Two blood vessels are clearly observed in the upper and middle parts of the difference picture. In the lower part of the picture the wide bed with indistinct space boundaries is observed, that looks very much like the branched small capillary network. In the usual picture only the collagenic increased thickness in the helix (near the upper vessel in the difference picture) is well seen; the blood vessels are not practically observed.

With low concentrations of the element under study the decrease in the intensity of the passed beam at the K-edge becomes comparable with increasing the intensity due to a monotonous decrease of the absorption coefficient μ_o of the body (the object). This effect limits the quantities of ultimately detectable concentrations C^*, because the exact dependence

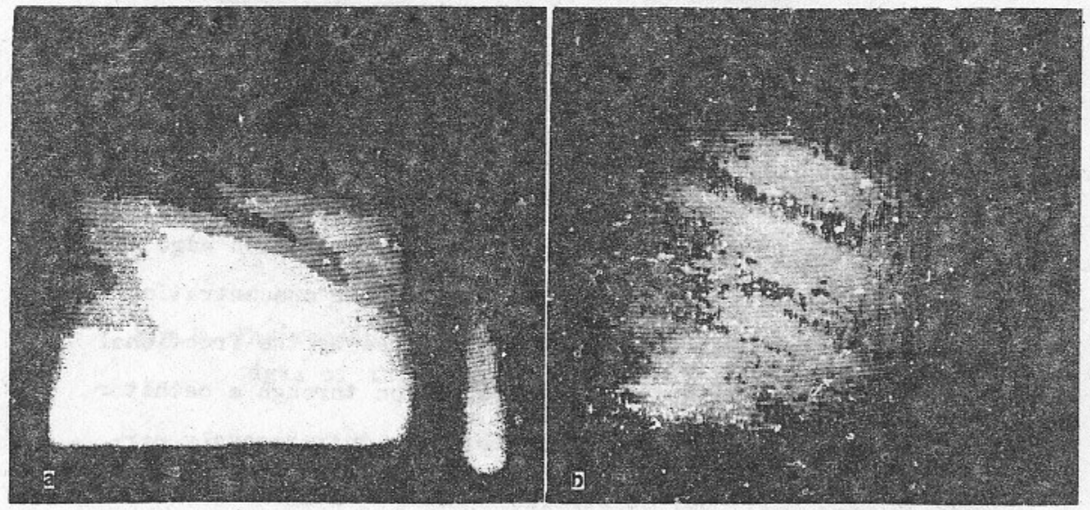

Fig.4. The conventional (a) and difference (b) pictures of a part of the rabbit's helix taken at the Br K-absorption edge.

$\mu_o(\lambda)$ in the human body is unknown. This limitation can be essentially weakened by additional X-ray exposure at the third wavelength $\lambda_c = \lambda_A + \Delta\lambda$, where $\Delta\lambda = \lambda_A - \lambda_B$. In this case, the quantity proportional to concentration will be $\xi = \ln[I_A^2/(I_B \cdot I_c)]$ instead of (1).

The main limiting factor in radiation exposure with three wavelengths is the amount of permissible absorbed dose delivered to the patient during examination, and hence the finite statistics of detected quanta. The ultimately detectable concentration due to the latter effect may be estimated as follows:

$$C^* d = 6 \cdot 10^{-5} \cdot \left[\frac{\mu_o}{D \cdot \lambda}\right]^{1/2} \cdot \frac{\exp(0.5 \cdot \mu_o \cdot \rho_o \cdot A)}{6 \cdot \rho \cdot \Delta\mu} \quad . \qquad (2)$$

Here A is the body thickness, cm; ρ_o is the mean density of the body, g/cm^3; D is the total absorbed dose (for three roentgenograms) on the surface of the human body's part under irradiation, R; 6 is the spatial resolution of the roentgenogram, cm; d in cm; λ in Å; μ_o and $\Delta\mu$ in cm^2/g; ρ in g/cm^3.

To examine different organs of the human body, it is necessary to use hard X-ray radiation with a quantum energy of ≥30 keV. The SR of the needed intensity with such quantum energy can be generated, for example, by a superconducting wiggler installed at the storage ring VEPP-3 /3/. Let us evaluate the possibilities of the method for studying the patient's blood system at the I K-absorption edge (λ = 0.3739 A; $\Delta\mu$ = 30.1 cm^2/g; μ_o = = 0.325 cm^2/g; $\rho_o \approx \rho \approx 1$ g/cm^3) with the help of X-ray exposure for three wavelengths. The spatial resolution of roentgenograms is taken to be equal to 1 x 1 mm^2. In this case, the ultimately detectable concentrations of I in the blood versus the thickness A of the body's part under examination, the total dose of

irradiation on the body's surface and the diameter of the blood vessels under study can be estimated with the help of Fig.5. If the number of quanta N is larger than a definite level c^*d, this implies the possibility to detect the concentration c^* in the blood vessels of diameter d.

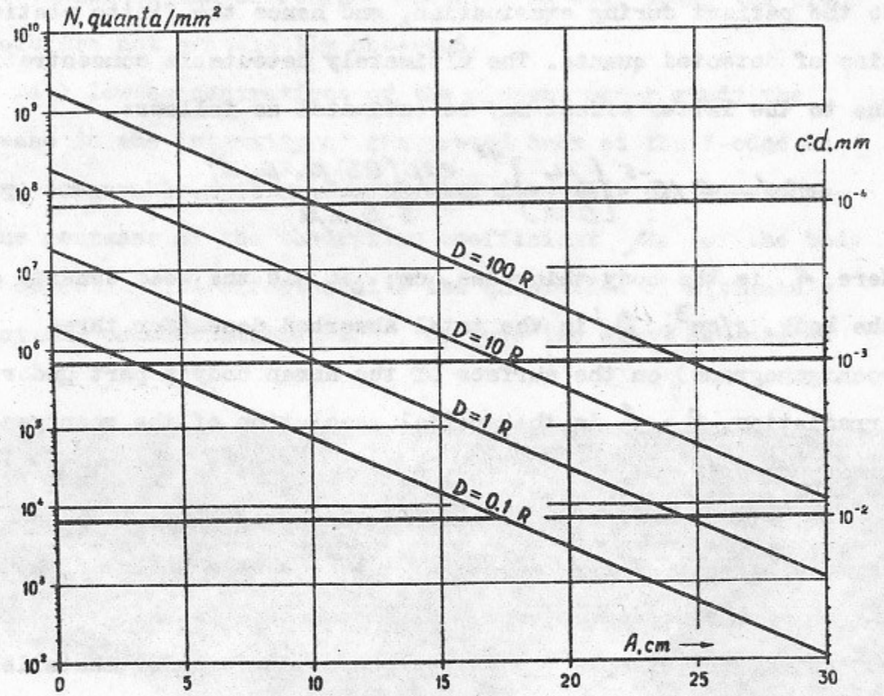

Fig.5. The number of quanta N (the coordinate axis to the left) per point of one image, which were passed through some body's part of thickness A at different total doses of irradiation D. The levels of the product (the coordinate axis to the right) of the ultimately detectable iodine concentration c^* by a diameter d of the blood vessels under examination.

The reference data /4/ on radiation sensitivity of the patient's different organs show that in practice, the absorbed

20 R dose does not lead to their visible alterations. If the dose, D = 20 R, is taken as a permissible one, then in studying the thorax ($A \simeq 25$ cm) we have $c^* \cdot d = 2.4 \cdot 10^{-3}$ mm. Thus, for the 1 mm vessel diameter the iodine concentration $c^* \simeq 2.4 \cdot 10^{-3}$ can be expected to be detected. For the vessels of 5 mm diameter the detectable concentration will be $c^* \simeq 4.8 \cdot 10^{-4}$, respectively. In studying the thiner parts of the body the quantity c^* decreases essensially. For example, for a hand (A = 4 cm) the quantity c^* is equal to about $8 \cdot 10^{-5}$ at the same dose and blood vessels of 1 mm diameter. Without going into details of injecting maximum possible concentrations of iodine into the blood, we would like to note that, according to conventional angiography methods, up to 80 ml of the high-concentrated contrast substance is introduced ($\simeq$ 50% iodine). This corresponds to the mean concentration of I in the blood, $\simeq 8 \cdot 10^{-3}$, and appreciably exceeds the above estimates. With the selective X-ray exposure at absorption edges it is sufficient to create the mean concentration of I in the blood, that can be realized, for example, by a slow injection of contrast substances into a vein, regardless the location under examination.

It is worth noting also that it is possible to synchronize the radiation exposure with different phases of cardiac contractions, and hence to study the heart and large blood vessels at different stages of blood filling.

It is necessary to mention feasible difficulties which can be encountered in the selective X-ray exposure of the human body's parts. First, a large number of capillaries on the path of the X-ray beam can worsen the degree of contrastness of the blood vessels under study. Second, detection of all blood vessels in the region under investigation (unlike the conventional

angiography where only the vessels being analysed are contrasted) can complicate significantly the picture under observation. If the image is too complicated for its clear interpretation, then the definite part of the body should be exposured in several projections and the difference pictures should be additionally analysed. An experimental study needs to be done to solve these questions.

The estimations and first experimental data demonstrate the applicability of the selective X-ray exposure method for a study of the patient's circulatory system and its essential advantages over conventional angiography methods.

References

1. G.N.Kulipanov, A.N.Skrinsky. Application of Synchrotron Radiation: Status and Prospects. Uspekhi Fiz. Nauk, vol.122, 369 (1977).
2. Angiography Manual, edited by I.Kh.Rabkin, Moscow, "Medicine", 1977.
3. L.M.Barkov et al. A proposal to install a superconducting wiggler magnet on the storage ring VEPP-3 for generation of the synchrotron radiation. Nuclear Instruments and Methods, 152, 23 (1978).
4. I.A.Pereslegin, Yu.Kh.Sarkisyan. Clinical Radiology. Moscow, "Medicine", 1973.

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