No. 4, JULY-AUGUST 1997
ISSN 0869-7078

SCIENCE IN RUSSIA

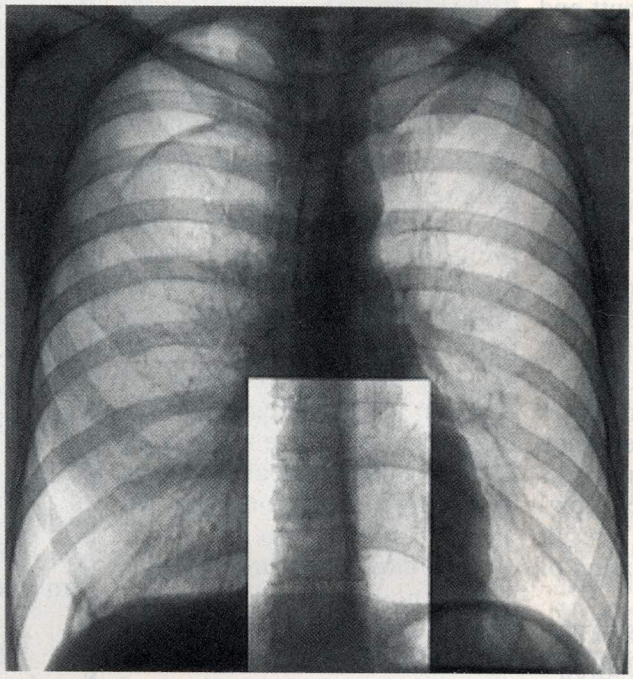
Russian Academy of Sciences Presidium and Ministry of Science and Technology of the Russian Federation

THIS FAMILIAR-UNFAMILIAR CARBON

INTELLECTUAL ANTS?

SPITZBERGEN: MESSAGES FROM THE 17th CENTURY

X-RAYS MADE SAFER



X-ray picture of lungs with vertebral (one can see right-side pneumothorax).

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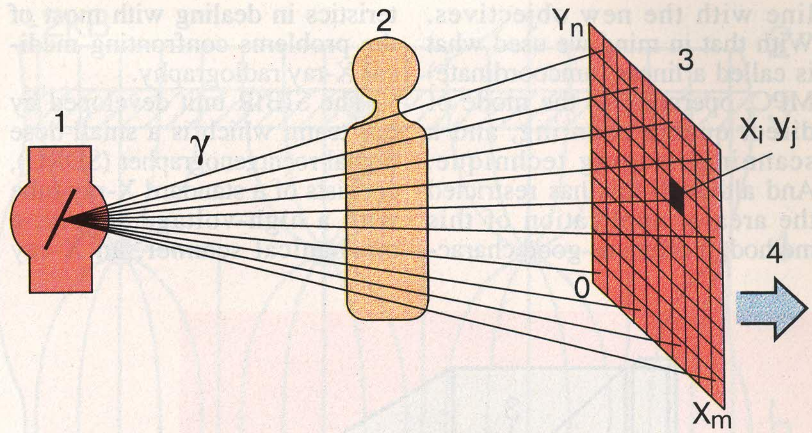
On December 29, 1895, German physicist Prof. Wilhelm Konrad von Röentgen, the Würtzburg University Rector, made science history by announcing his discovery of a new kind of radiation, which he called X-rays (because of their unknown nature). A year later the new radiation began to be used for medical diagnostics. Today X-ray radiography is a common medical tool used in clinics and hospitals all over the world. And the basic mechanism of X-ray radiography remains unchanged, just as it was a hundred years ago. X-rays are generated by X-ray cathode tubes, and on the receiving end there is either a photographic plate, or film, or a fluorescent screen. As for the X-ray tube, it seems to be meeting with no objections, something which can hardly be said of the receiver, or the X-ray detector.

Films used for X-ray photographs—having high sensitivity and good spatial resolution—also have some serious drawbacks. The main of these is what we call low efficiency (which results in exposing the patient to large doses of radiation), a narrow dynamic range of measurements (which precludes simultaneous investigation of soft and dense body tissues), the impossibility of having a direct link



Digital roentgenography with two-dimensional detector: 1. X-ray tube; 2. Patient; 3. Detector; 4. Data transmission to computer.

with a computer and of obtaining an X-ray picture right after an examination and without wasting time on film development. That being so, there have been numerous attempts over the past few decades to improve the technical parameters of X-ray detectors most of which boiled down to trying to improve viewing screens and X-ray photographic materials.

An important breakthrough was made in the early 1970s. The advent of computer tomography (body-section radiography) opened up new possibilities of obtaining and digitalizing X-ray radiography data. But with all its advantages, the new technique has not done away with the traditional projection roentgenography.

A basically new and more perfect device that has emerged on the scene is what we call the NMR (Nuclear Magnetic Resonance) tomograph. But any really broad use of these devices is precluded by their considerable cost and complexity. In the meantime tangible progress in the field of mathematical image processing in computer tomography has led to the development of what we call digital roentgenography in which a digitalized image can be put into computer memory for processing, storage and visualization. The technique involves some "indirect" imaging methods by means of digitalizing and X-ray, or TV image or the input from X-ray electron-optical converters. But none of the above techniques has been able to resolve the basic problems inherent in the X-ray screen-film systems. What is more, the process of digitalizing the image involves unavoidable data losses.

One should mention at this point that the quality of digital imaging can be substantially improved by using an X-ray direct registration technique with the detector having a direct link with the computer. Such a detector, capable of "piecemeal" recording of X-ray quanta, consists of a two-dimensional surface divided into X_m and Y_n cells. Every incoming quantum is ascribed to one specific cell and added up to the earlier "arrivals". In practice, however, it proves to be a very tall order building such a detector of the size required for X-ray radiography (40 × 40 cm) which has to have high efficiency, rapid response, good spatial resolution and which can be put on-line with a computer. In addition, using a two-dimensional detector one has to use collimators (slit devices for obtaining a beam of radiation of limited cross section), which cut off X-rays scattered in the body of a patient affecting the image.

The aforesaid problem has been resolved unexpectedly and the solution came from a very different field of science: high-energy physics. This field of basic research requires still better and better detectors for the registration and investigation of elementary particles. The appropriate nuclear physics techniques have been rapidly developing over the past few decades and the prospect of putting them to good medical uses, so to speak, appeared to be a very practical proposition. Back in 1981 scientists at the Institute of Nuclear Physics of the Siberian Branch of the Russian Academy tried using for X-ray radiography a multi-purpose proportional camera (MPC) developed by a Swiss scientist, Prof. J. Sharpaq, in the 1970s (the invention won him a Nobel Prize in 1992). But the device had to be modified in line with the new objectives. With that in mind we used what is called a linear (unicoordinate) MPC, operating in the mode of direct quanta counting, and a scanning imaging technique. And although this has restricted the area of application of this method, it offers us good characteristics in dealing with most of the problems confronting medical X-ray radiography.

The SIBIR unit developed by our team, which is a small-dose digital roentgenographer (SDRU), consists of a standard X-ray tube with a high-voltage supply, a mechanical scanner, an X-ray detector and a system of registration and control. The horizontal radiation pattern is measured by a camera, and the vertical by the mechanical scanner. The X-ray tube, the slit collimator and the camera move during the examination evenly and simultaneously in a vertical plane. The collimator, with a slit of 0.5-2 mm, forms a flat and fan-like beam of X-rays. After passing through the body of a patient the beam enters the intake aperture of the camera.

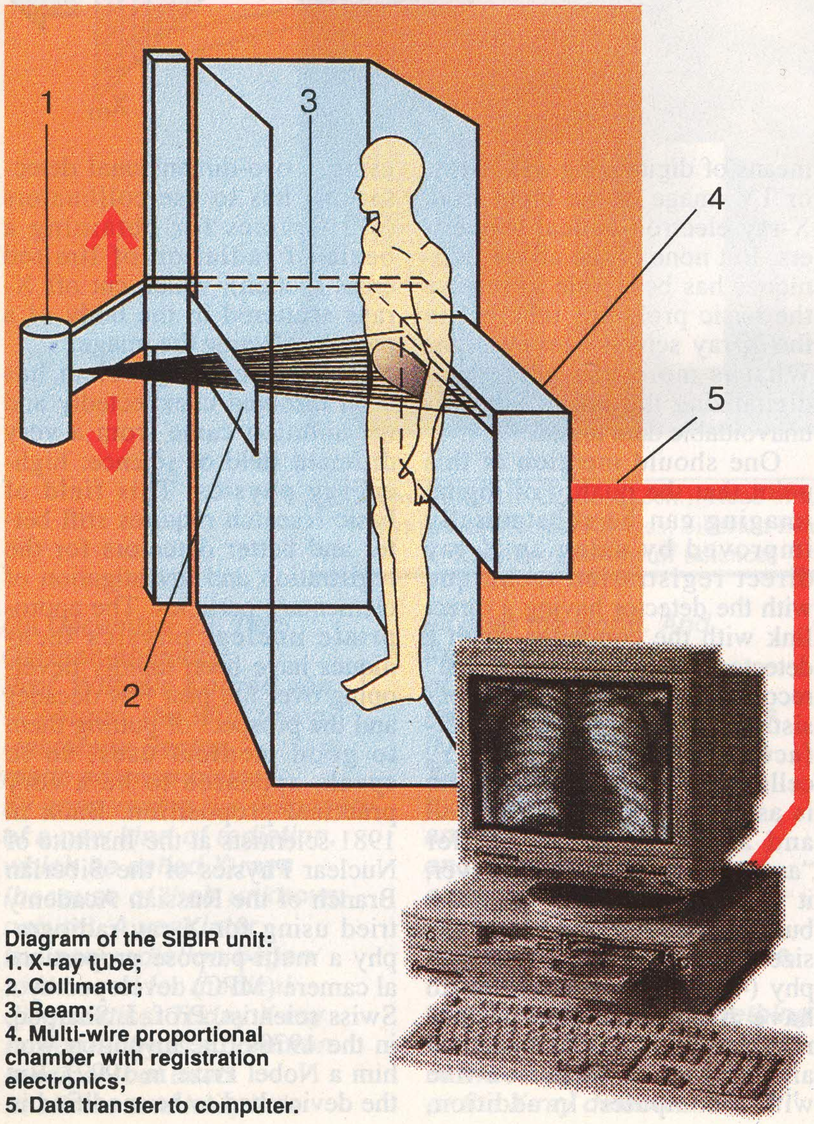
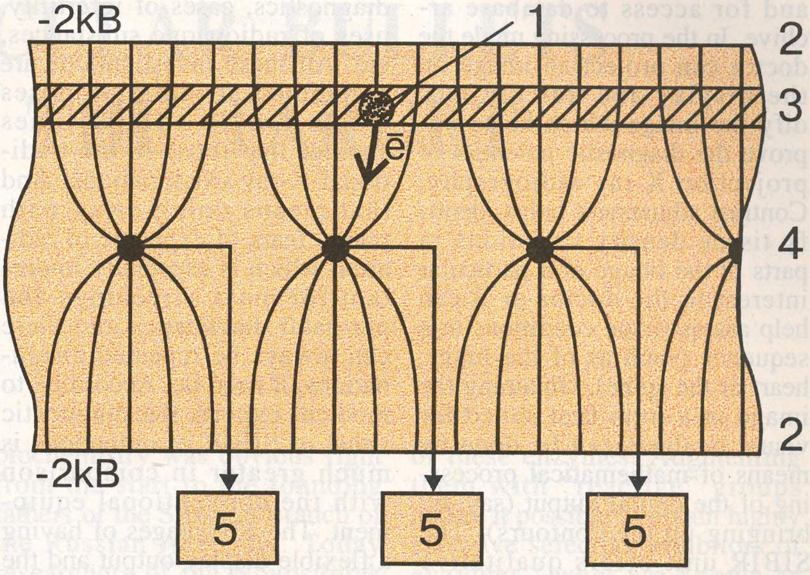


Diagram of the SIBIR unit:
1. X-ray tube;
2. Collimator;
3. Beam;
4. Multi-wire proportional chamber with registration electronics;
5. Data transfer to computer.

The MPC of the unit is a system of three wire surfaces—two cathode ones and one anode, located in between them. Negative voltage is supplied to the cathodes and anode wires, 10 mcm in diameter, are targeted at the focus of the X-ray tube. Attached to each of them is an amplifier-discriminator. The camera is placed in an air-tight vessel filled with a working gas mixture of 80 percent of xenon and 20 percent carbon dioxide at a pressure of 3atm. When an X-ray quantum is absorbed by a heavy xenon atom, the primary ionization is "drifting" along the lines of force of the electrical field and its components enter the high-tension area around a thin cathode wire. Thereupon impact ionization takes place, a charge is applied to the wire and the amplifier-discriminator is actuated. The electron multiplication factor amounts to several thousands thanks to which the signal from the anode wire is quite sufficient for a direct quanta-counting mode, although it amounts to about 10^{-13} coulombs. Nevertheless it exceeds the sensitivity threshold of the



Camera layout (view of detector from the side of X-ray tube):
1. Point of quantum conversion (primary ionization);
2. Cathode;
3. Input aperture;
4. Anode wires;
5. Amplifier-discriminator.

amplifier-discriminator only upon quantum registration, while "ignoring" the background. The signal from the anode wire is proportional to primary ionization.

The input electronics contain 640 pulse counters attached to the discriminators. Thus the aforesaid camera and its electronics can be regarded as an assembly of 640 autonomous X-ray quanta detectors with a channel width of 0.6 mm. Input data stored in the counters during a "one-stroke" exposure (the time in which the scanner shifts by 0.5 mm in the vertical direction), is fed into computer memory after which the next "stroke" begins. At the end of an examination we get a digital image in the memory—a matrix of 640 by 640 digits, which describes the radiation distribution after passage through the body of a patient. What we call a formalized image appears on the display 20 seconds after the scanning is over.

The SIBIR unit boasts some truly unique characteristics with every elements of the matrix recording data about an area of the body organ being investigated measuring 0.5 by 0.5 mm. The size of the vertical display (320 mm) can be scaled down, or scaled up. The capacity of every element amounts to 65,536 registered quanta and contrast sensitivity is one percent. That means that the unit can detect aluminium foil which is 0.1 mm thick. Its dynamic range is 130, which amounts to a 5 percent decrease in sensitivity (0.5 mm of aluminium) which can be seen in a homogeneous and direct X-ray flux or the one weakened by 130 times. The surface dose of irradiation of a patient for a lung X-ray is 3-5 mR, which is close to the weekly background value. From 1,000 to 4,000 images can be stored on a hard disc of one Gbt.

The input aperture of the camera, which is a slit of 1-2 mm, practically rules out the registration of radiation scattered in the patient's body. Direct quanta count at the zero camera background and its rapid response (of about 600 cycles per channel) ensures a broader dynamic range of registration as compared with other methods, which means that the doctor can observe on one and the same X-ray photograph tissues with higher or lower density. The zero background of the camera and the filtering out of scattered radiation ensures excellent contrast resolution which helps detect even minor tissue density variations. And even despite a relatively long time of recording an image (about 8 sec), its sharpness is not affected by any slight movements of the patient, since exposure time per scanning stroke is only 12 m sec.

SIBIR is computer-controlled and supplied with software for a doctor and a lab assistant, an X-ray room database and a program for automatic control of the unit. The lab assistant program provides for taking several pictures, examining them on the display, storing them on a computer disc and for access to database archive. In the processing mode the doctor can project an image on the display and quickly modify the image which helps improve the diagnostic potential of projection X-ray radiography. Contrast adjustment helps identify tissue density variations in parts of the image of a particular interest to the doctor or it can help assess tissue conditions in a sequence (such as of the lungs, heart or the spine). Obtaining the image in a form best suited for visual analysis can be done by means of mathematical processing of the digital output (say, by bringing up the contours). The SIBIR unit offers qualitative diagnostic information, such as measuring distances between lesions of one and the same body organ, or measuring the size of an organ or of pathological neoplasms. An examiner can determine the relative density in any point of the image or measure mean density in any section thereof. The doctor program also embraces some what we call service programs such as scaling up the image on the display, its inversion and putting on the display several images at the same time (such as direct and lateral projections or picture taken at different times). If need be, the doctor can resort to special diagnostic programs.

To put the long story short, SIBIR is designed for a broad spectrum of X-ray examinations of patients. This includes inspection of the chest, including routine medical checks, the locomotor system, including the spine and the head, pre-natal diagnostics, cases of infertility, uses of radiopaque substances, etc. All these investigations are conducted at radiation doses which are 30 to 100 times smaller that those in the traditional X-ray examinations. And that means doing away with public fears of exposure to radiation which is especially important for mass screenings and pre-natal diagnostics and there can always be repeated examinations, if need be. According to medical experts the diagnostic value of SIBIR examinations is much greater in comparison with the conventional equipment. The advantages of having a flexible display output and the possibility of varying observation conditions combined with high contrast resolution, a broad dynamic range and the possibility of digital image processing make it possible for the examining doctor to detect pathologies at much earlier stages than ever before. The archive database is easily accessible, "fire-proof" and does not require special storage facilities. Images can be transmitted by computer and telephone links to specialists for consultation. The doctor-roentgenologist can compare incoming new images with previous ones projected from a second computer.

The "throughput" of SIBIR is 10-15 patients per hour. High quality prints of X-ray images can be obtained using the ALDEN 9315 CTP thermoprinter which offers a range of 256 shades of grey. Doing away with expensive photographic film, SIBIR can cut down operating expenses by nearly 15,000 dollars a year at an average "workload" of 20 patients a day.

The first unit of this type was put into operation at the Institute of Nuclear Physics of the Siberian Branch of the Russian Academy in 1984 and was handed over there and then to the All-Union Health Center of Mother and Child in Moscow. Six years later we dispatched to that center a second unit for patient examination in a horizontal position. After due modernization five new SIBIRs with the aforesaid parameters were produced from 1994 to 1996 and installed in medical centers in Moscow, Novosibirsk, Krasnoyarsk and Paris.

In 1995 SIBIR was put through official medical tests at the Bakulev Cardio-Vascular Surgery Center of the Russian Medical Academy. Parallel tests were conducted at the All-Russia Research and Testing Institute of Medical Equipment of Russia's Ministry of Health. The Committee for New Medical Technology of that Ministry had created SIBIR for commercial production and hospital use. Preparations for launching its commercial production are now under way at the NAUCHPRIBOR Manufacturing Association in the Central Russian city of Oryol. ■