

Wilhelm Röntgen - one hundred years after his discovery of X-rays, this radiation remains the main weapon of medical diagnosis, while the even older techniques of photographic film remain the avenue of choice for recording the X-ray images.

production of a Compendium of Scientific Linacs which gives pertinent details for 176 "scientific linacs" distributed over 3 continents that are in operation, under construction, or proposed.

Linac 96 was superbly organized by a team under Conference Chairman Helmut Haseroth. The meeting brought together over 300 scientists from 16 countries for 40 invited papers and 230 poster presentations. From the initial welcome, through sessions and dinners in castles, to an interesting tour of CERN, the organizers ensured that everyone enjoyed a memorable mix of science and Swiss hospitality.

From Gerald McMichael (Argonne)

Minidose X-rays

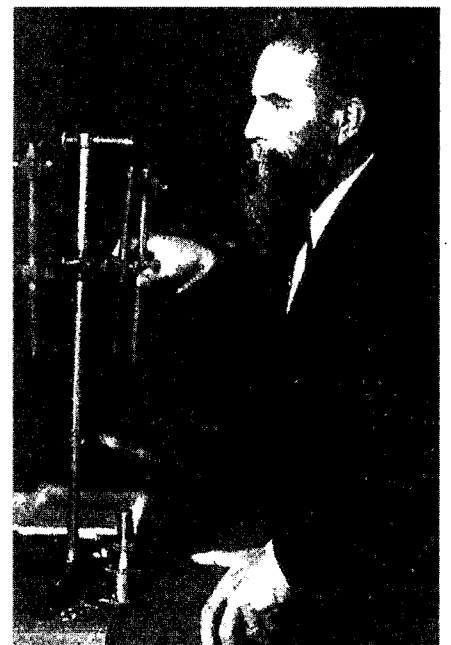
One hundred years after their discovery, X-rays remain the main weapon of medical diagnosis, while photographic film, invented more than a century ago, remains the medium of choice for recording the X-ray images. But if X-rays are administered indiscriminately, the accumulated dose can become dangerous. Now electronic detection techniques enable X-ray information to be recorded digitally and offer important advantages. The radiation dose needed can be as little as one per cent of that of conventional film radiography - such doses becoming comparable to natural background sources, so that X-rays can be taken for effectively 'zero dose'. Such digital information can also be processed to obtain different views, say of the chest and the spine, from the same recorded data without the

need for separate exposures. Despite these advantages, an ingenious system of digital readout for X-ray radiography developed by specialists in Novosibirsk, Russia, and used at several hospitals has yet to make an impact on the market. Entrenched in outdated technology and with relatively high X-ray doses nevertheless legal, major industrial suppliers are dragging their heels.

On 8 November 1895, Wilhelm Conrad Röntgen embarked on a physics experiment which was to change the course of science. Investigating invisible radiation such as ultra-violet rays, he covered a cathode-ray tube with black paper and darkened his tiny laboratory. With the glow from the cathode ray-tube masked, Röntgen was startled to see a fluorescent screen across the room light up. He had discovered X-rays.

In January 1896, newspapers across the world were carrying the story of Röntgen's dramatic new discovery, illustrated with skeletal photographs of people's hands. That same year, dentists began taking X-ray pictures of teeth, while doctors quickly realized how the new radiation enabled them to examine broken bones. It was a breakthrough in medical diagnosis - for the first time doctors were able to see inside the body without any need for invasive surgery.

But there were backlash effects. Ignorant of the dangers of radiation, research workers burned or otherwise injured themselves. As well as the operators, patients too ran risks, although these took longer to identify. A 1994 report by the United Nations Scientific Committee on the Effects of Atomic Radiation pointed out that high X-ray doses led to an



increase in primary cancers, particularly of the thyroid. X-rays are dangerous and have to be treated with respect.

What are the alternatives? Some half a century after Röntgen's discovery, other radiography techniques emerged. Radioactive substances can be administered and their distribution through the body or a particular organ followed by monitoring the emitted radiation. Rather than using film, the 'camera' for recording these images is usually an array of scintillating material, such as sodium iodide crystals, with photomultipliers amplifying the tiny light signals. However this technique, like X-rays, gives only a two-dimensional projection of a three-dimensional image, with no direct depth information, and the accuracy of about 0.5 cm is inadequate for many radiological needs.

In 1972, Godfrey Hounsfield at EMI made a new breakthrough which solved the problem of depth. In his

Georges Charpak - radiography with less radiation.



computer-assisted tomography (CT) scanner, a narrow fan of X-rays rotates around the patient's body, with the image recorded by an arc of high pressure gas detectors in which the X-rays produce tiny sparks. From this information, a two dimensional picture is reconstructed of each 'slice' of the patient's body. While CT scans now provide an important diagnostic tool, CT is relatively heavy diagnostic artillery. Conventional X-ray pictures, using photographic film, remain the front-line of medical diagnosis.

For medical work, alternative routes have opened up using digital imaging, however in many cases film has remained the initial recording medium, the film image being subsequently digitized by laser scanners or TV cameras. However film can be dispensed with by using photodiodes or photoluminescent screens. Such techniques are promising but have yet to make a major impact.

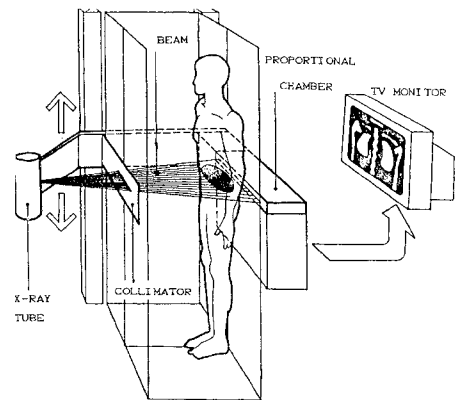
Röntgen's discovery was a classic example of 'spinoff' from pure sci-

ence. The Würzburg physicist had not been intending to find a new tool for medical diagnosis. Instead, his primary goal had been fundamental physics, and here he also succeeded, being awarded in 1901 the first-ever Nobel Prize for Physics. Röntgen's discovery was a major turning point in physics. On hearing the news, J.J. Thomson at the Cavendish Laboratory in Cambridge mobilized his research forces, a young New Zealand student called Ernest Rutherford being ordered to drop his investigations in radio telegraphy and turn to X-rays instead.

In the early 20th century, Rutherford became the Moses of subatomic physics. His epic 1911 discovery of the atomic nucleus led in turn to the study of subnuclear physics and the world of elementary particles, the smallest possible constituents of matter. To watch the behaviour of these tiny fragments, physicists used ingenious cloud or bubble chambers in which particle interactions showed up as a network of tracks, like aeroplane vapour trails in the sky.

Millions of these tracks were photographed. Physics laboratories employed teams of scanners to patiently scrutinize these films for signs of anything unusual. It was a very labour-intensive way of doing research. In the mid-1960s the Polish-born French physicist Georges Charpak set himself the task of finding a way of revealing particle tracks without always having to photograph them. When a high energy particle passes through a gas, it leaves behind it a trail of broken atoms, or 'ionization'. If a high voltage is applied, this ionization literally causes sparks to fly, and such 'spark chambers' were first developed in the early 1960s as another way of seeing particle tracks.

The Novosibirsk X-ray camera consists of a single fan-like array of wires pointing towards the X-ray source, delineated by a narrow horizontal slit. The source, slit and camera then move vertically, building up a matrix exposure. This mechanical scan takes about 8 seconds.

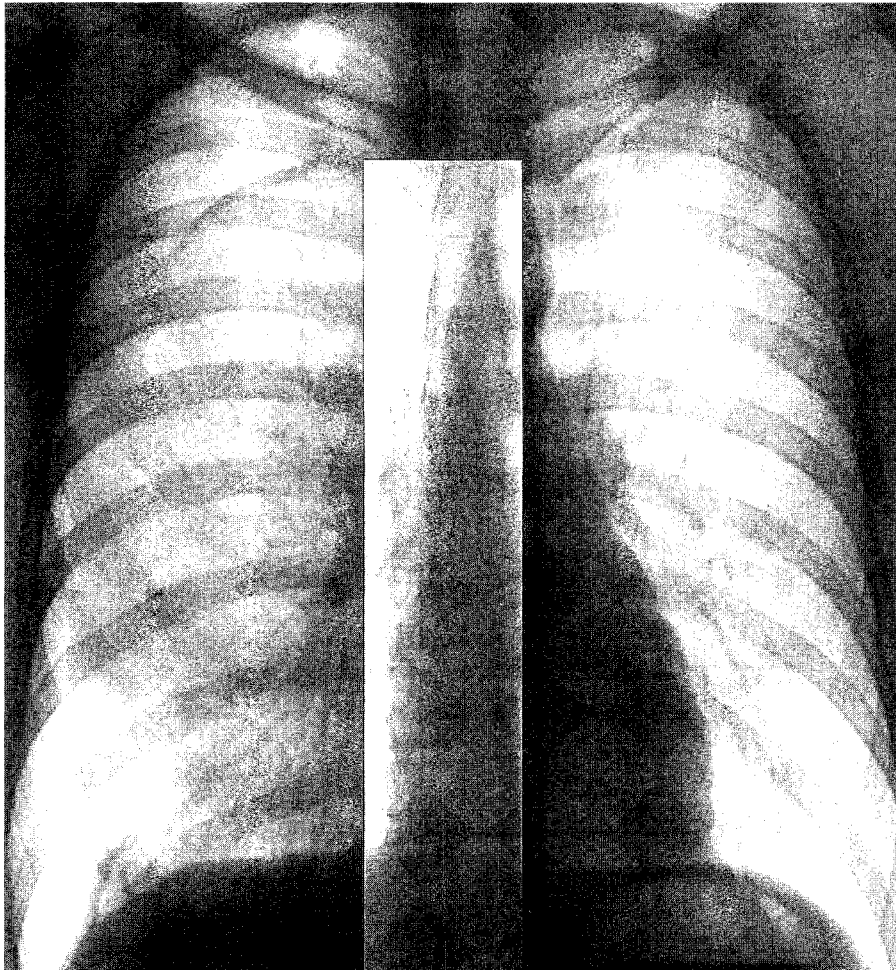


But Charpak was convinced that ionization could be exploited in a more subtle way.

In 1908, Ernest Rutherford and Hans Geiger had developed a high tension device called a 'proportional tube', a long metallic cylinder which acts as a cathode, surrounding a central anode wire. When a particle passes through such a tube, it rips electrons from the atoms of gas in the tube. These electrons are pulled towards the wire anode, producing still more electrons in their wake. This electron 'avalanche' produces a signal, showing that a particle has passed through. In principle an array of such tubes could be used as a particle detector, but with the tube diameter of a few centimetres, little precision was possible, while arrays of such tubes would quickly become unmanageable.

Charpak's brilliant 1968 idea was to use instead an array of parallel anode wires a few millimetres apart sandwiched between two cathode planes - the multiwire proportional chamber, or MWPC. Ionization electrons are produced as high energy particles pass through the chamber, but in this case the geometry of the wires and the stronger electric fields make the ionization electrons react faster and

An X-ray digital readout system developed at Novosibirsk can provide different views from the same exposure data. Here an image of the chest and lungs are separated from a view of the spinal column.



move more uniformly, giving reliable and rapid readout. Charpak's chambers soon became the workhorse detector for particle physics, eventually replacing the bubble chamber. But Charpak was convinced that his new detector could be put to other uses. Here was another development in fundamental physics which was ripe for spinoff.

An ionization 'hit' on the nearest MWPC wire shows where a particle has passed. But such a signal from a single wire only gives one-dimensional information. To build up a full picture, physicists also have to know how far along the wire the hit

has occurred.

For high energy particles, this is done by mounting the MWPCs in layers, successive layers having their sense wires running in alternate directions, giving the x- and y-coordinates of the 'hit' signal. However low energy particles, such as those produced from X-rays, find it difficult to penetrate more than one chamber and another method is needed to build up a full picture.

Ripping electrons from atoms leaves behind large positive ions built around the atomic nuclei. These too move in an electric field, but in the opposite direction to the electrons.

The work at CERN showed that the signals from these positive ions can help pinpoint where the ionizing particles have passed. Readout methods pioneered by Victor Perez-Mendez at Berkeley opened up new avenues for X-ray work, but did not attain the sensitivity needed for medical diagnostics.

Instrumentation specialists at the Budker Institute for Nuclear Research in Novosibirsk, Russia, have successfully twinned the MWPC with a classic Röntgen source, finally dispensing with the need for photographic film. The Novosibirsk X-ray camera consists of a single fan-like array of wires pointing towards the X-ray source, delineated by a 0.5 mm horizontal slit. To reduce parallax errors, individual anode wires in the camera point towards the focus of the X-ray tube. The source, slit and camera then move vertically, building up a matrix exposure. The mechanical scan takes about 8 seconds, but as the exposure time for each horizontal slice is only 12 milliseconds, slight movements of the patient do not seriously disturb the quality of the image.

The first installation at Moscow's Centre for Maternity and Child Health Protection was initially used to examine 1500 pregnant women, with an individual dose of 40 millirem compared to 1700 with a conventional X-ray - just 2.35% of the dose! From measurements of pelvis and infant head size, specialists were able to develop a quantitative way of evaluating the potential success of the birth and ascertain at an early stage if recourse to Caesarean section would be called for.

Several years ago, a team from London's University College made a quantitative examination of the

performance of the Novosibirsk system, concluding that the digital method provided substantially better results in all cases except for high-contrast objects smaller than 1 millimetre across, where the electronic system was limited by the spacing of its anode wires.

With film, the wide range of transmitted X-ray intensities means that an image may contain information which is not visually perceptible. A chest X-ray 'sees' the spine as well as the lungs, but the different X-ray intensities are not matched to the performance of the film, and lung and spine images normally require separate exposures. However with digital readout, different X-ray intensities can be 'windowed' to reveal different kinds of image from the same data. A single X-ray scan using the Novosibirsk technique can reveal separate images of the lungs and the spine without the need for separate exposures.

Cost is no handicap although the installations are still relatively unsophisticated. The Novosibirsk facility costs \$100,000 without X-ray tube and power supply, while a commercially-available X-ray unit with three separate radiation stations costs some \$250,000. Systems have been supplied to several Russian hospitals. Charpak has taken a paternal interest in the idea and has introduced it to a Paris hospital.

Despite the obvious advantages of the system, major suppliers of X-ray equipment, protected by current dose legislation, see no need to discard the technology they currently use. But as Charpak points out 'We are still petrified by the radiation from the 1986 Chernobyl disaster, but in a Parisian hospital, children with problems of the spine or dislocations

receive much more radiation from a hundred X-ray examinations over a two-year period than did the children of Chernobyl. This is tolerated because it is for the good of the patient. But in more than half the cases, the Siberian system could have done the job for ten times less dose.'

Collision crossroads

The remarkable consistency of the current 'Standard Model' picture of particle physics requires that whatever the mechanism responsible for mass generation is, it has to occur at an energy scale of less than about 1 TeV - within the range of the next generation of accelerators.

In addition to this underlying puzzle of the origin of mass, there are other compelling questions. For example, the observed matter-antimatter asymmetry of the universe is not understood. Also, astrophysical observations suggest that between 90 and 99% of the matter that makes up the universe is invisible. There are a number of possible candidates for this "dark matter", but none have been proven experimentally to exist.

Avenues for attacking these problems were explored in the "Future High Energy Colliders" Symposium held in October at the Institute for Theoretical Physics (ITP) in Santa Barbara, one of three symposia hosted by the ITP and supported by its sponsor, the National Science Foundation, as part of a five-month programme on "New Ideas for Particle Accelerators". The programme and symposia were organized and coordinated by Zohreh Parsa of Brookhaven.

The primary tools for high energy physics research are particle beam colliders, and their design and construction are motivated and constrained by: forefront physics questions; the available technology needed to build and operate these machines and the capabilities to detect and analyse the collisions; and, last but not least, the cost and the availability of funding.

US high energy physics is at a crossroads where its future depends on participation in foreign projects, upgrading and utilizing existing facilities, and new construction initiatives. While some of the underlying physics motivations and technical issues had been addressed at earlier workshops, the Santa Barbara symposium's specific aim was to begin the process of reaching a consensus on how to attain a vision of the future.

The most urgent open physics question is to understand where the masses of Standard Model particles come from. The simplest possibility, the "higgs mechanism" predicts a fundamental particle called the higgs scalar. Finding it or whatever new physics is actually responsible for mass generation originally motivated the US Superconducting Supercollider (SSC) and remains the primary goal of the next generation of colliders, led by the LHC at CERN.

The current energy frontier is delimited by Fermilab's Tevatron proton-antiproton collider, CERN's LEP electron-positron collider, and the SLC electron-positron collider at the Stanford Linear Accelerator Center (SLAC). The proton-antiproton and electron-positron collision routes complementary information. LEP's 1996 energy upgrade almost doubled the energy ceiling in electron-positron collisions.