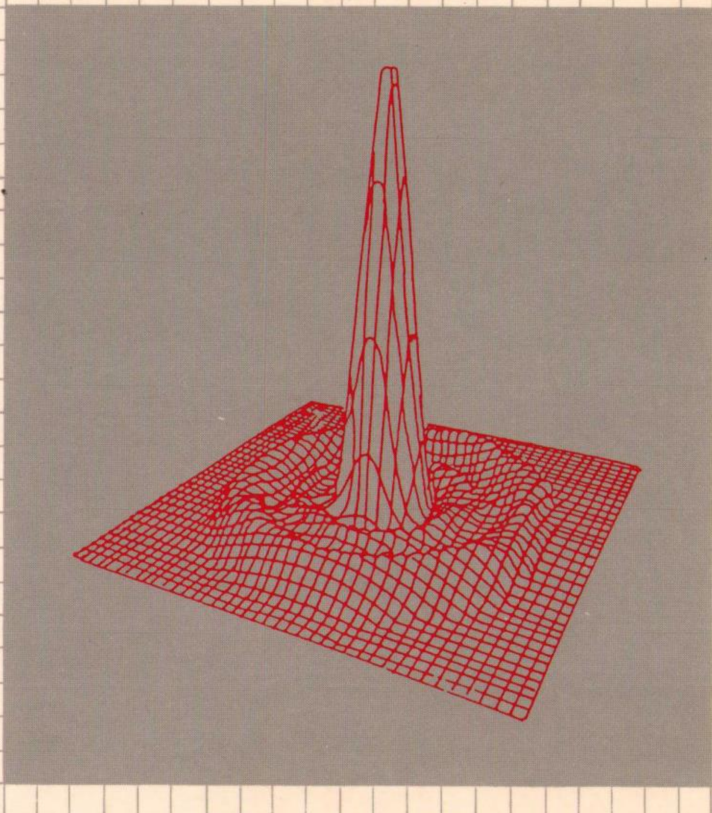
DIGITAL RADIOGRAPHY



Rutherford Appleton Laboratory

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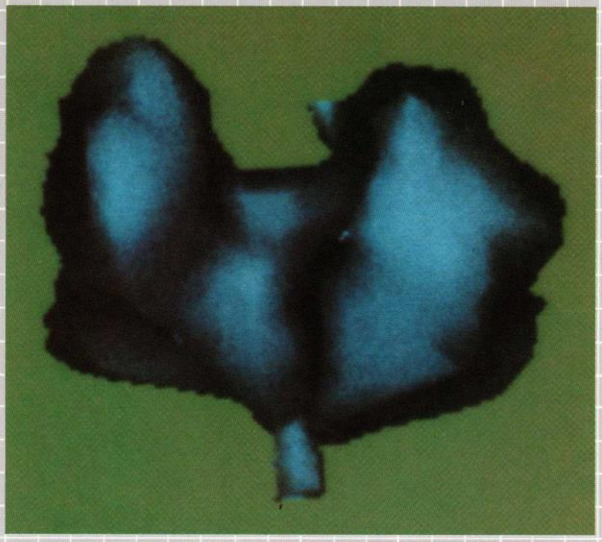
The multiwire proportional counter

(Developed to meet the exacting demands of high energy physics research)
is finding exciting new applications in

- Medical physics
- Materials science
- Engineering
- Chemistry/biochemistry

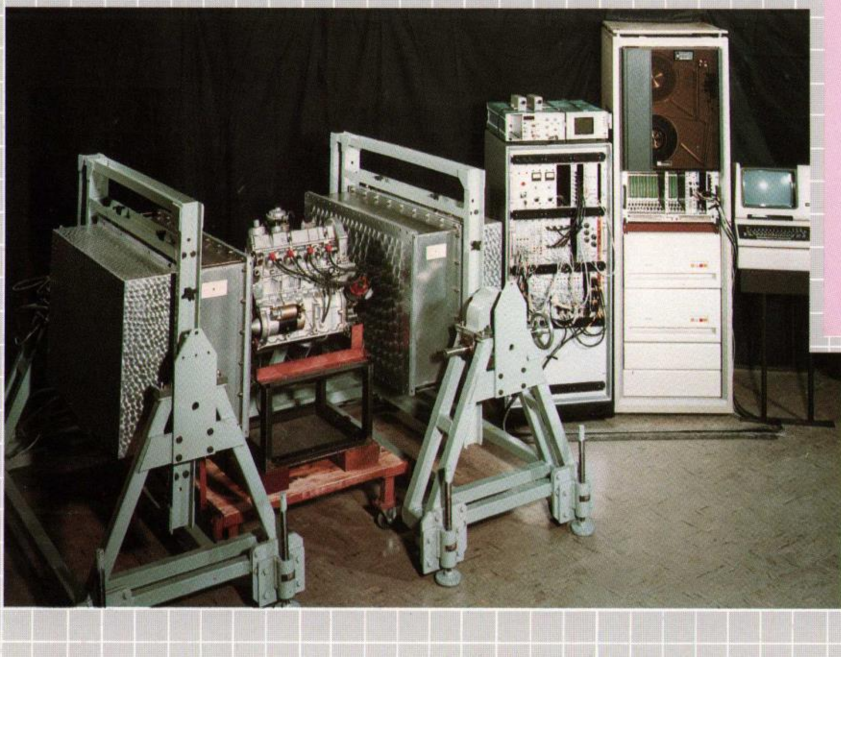


Positron camera image of human thyroids

Positron emission tomography

is a new research technique for imaging physiological functions in the living human body

The multiwire proportional counter positron camera has the unique ability of producing images in 3-dimensions

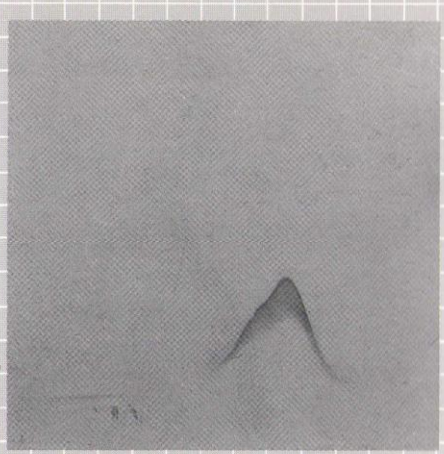


Blood flow in the human foot

The positron camera is also proving useful in the study of oil flows in working internal combustion engines

Autoradiography

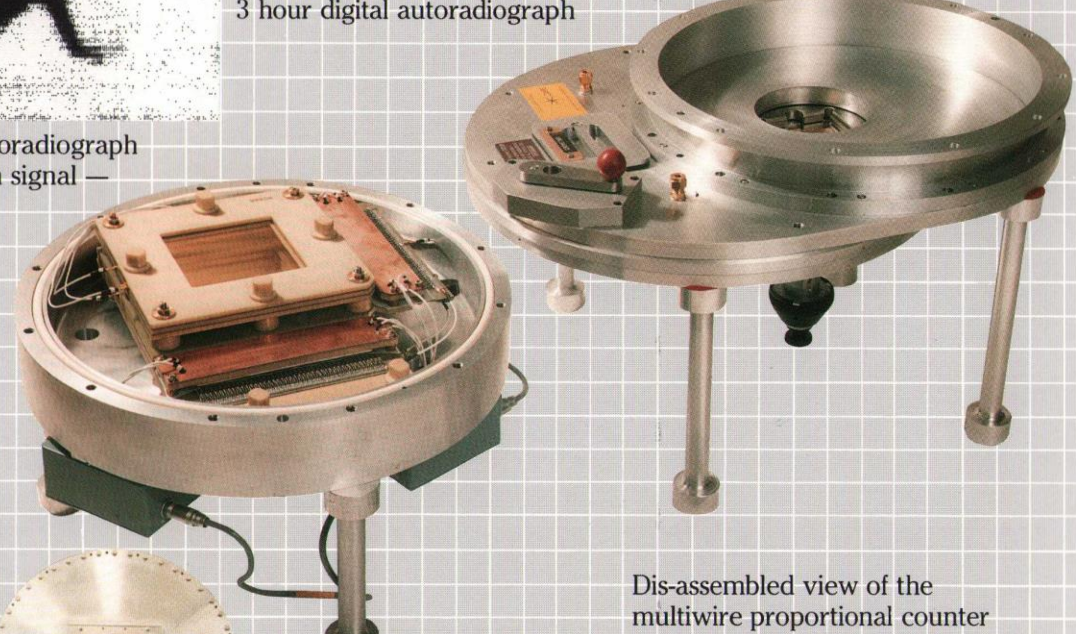
Tritium labelled immuno-electrophoretograms



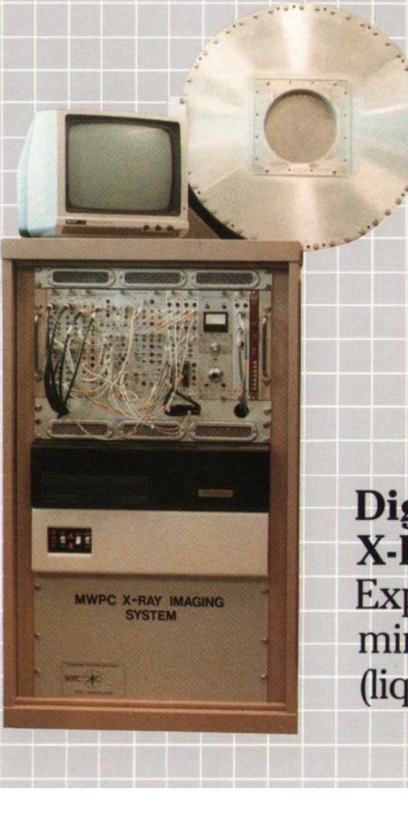
6 week film autoradiograph

3 hour digital autoradiograph

24 hour digital autoradiograph
(note weak protein signal —
invisible on film)



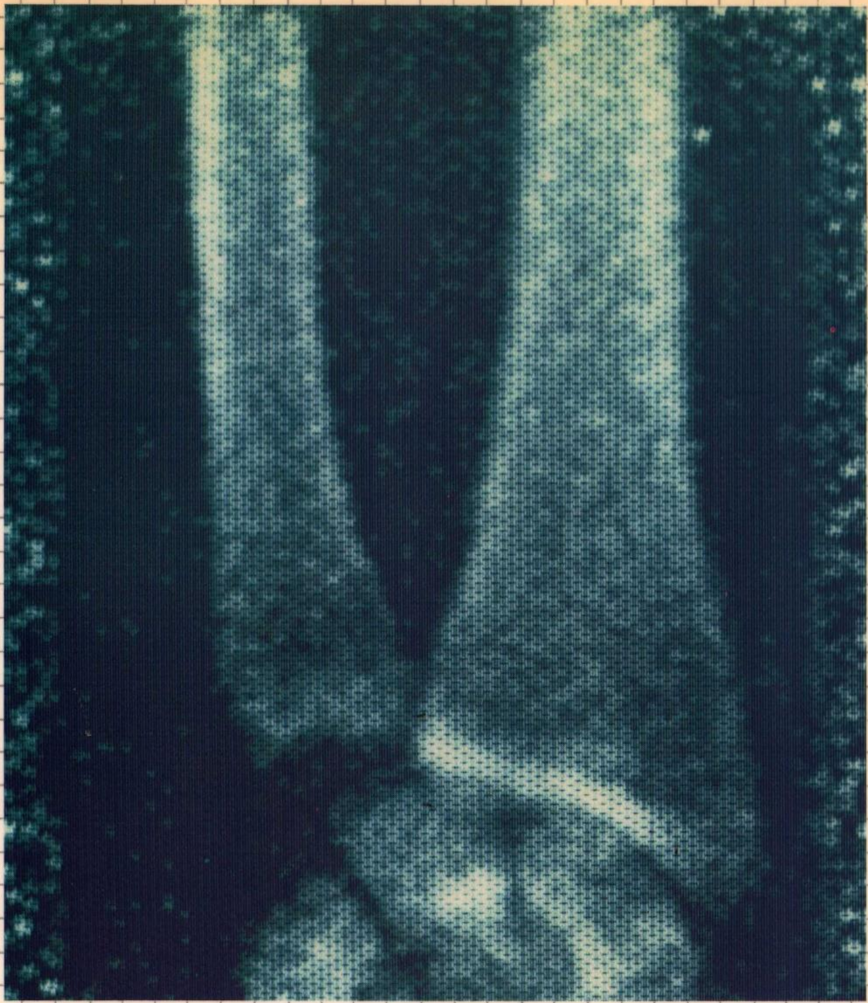
Dis-assembled view of the multiwire proportional counter which produced the digital autoradiographs



In addition to requiring dramatically shorter exposures, the digital autoradiographs contain quantitative information

Digital X-Ray imaging system for X-Ray diffraction

Exposure times can be reduced from hours to minutes in structure studies of organic materials (liquid crystals for example)



Bone density map of the human wrist (obtained by digital radiography)

Digital X-Ray imaging offers the advantages of

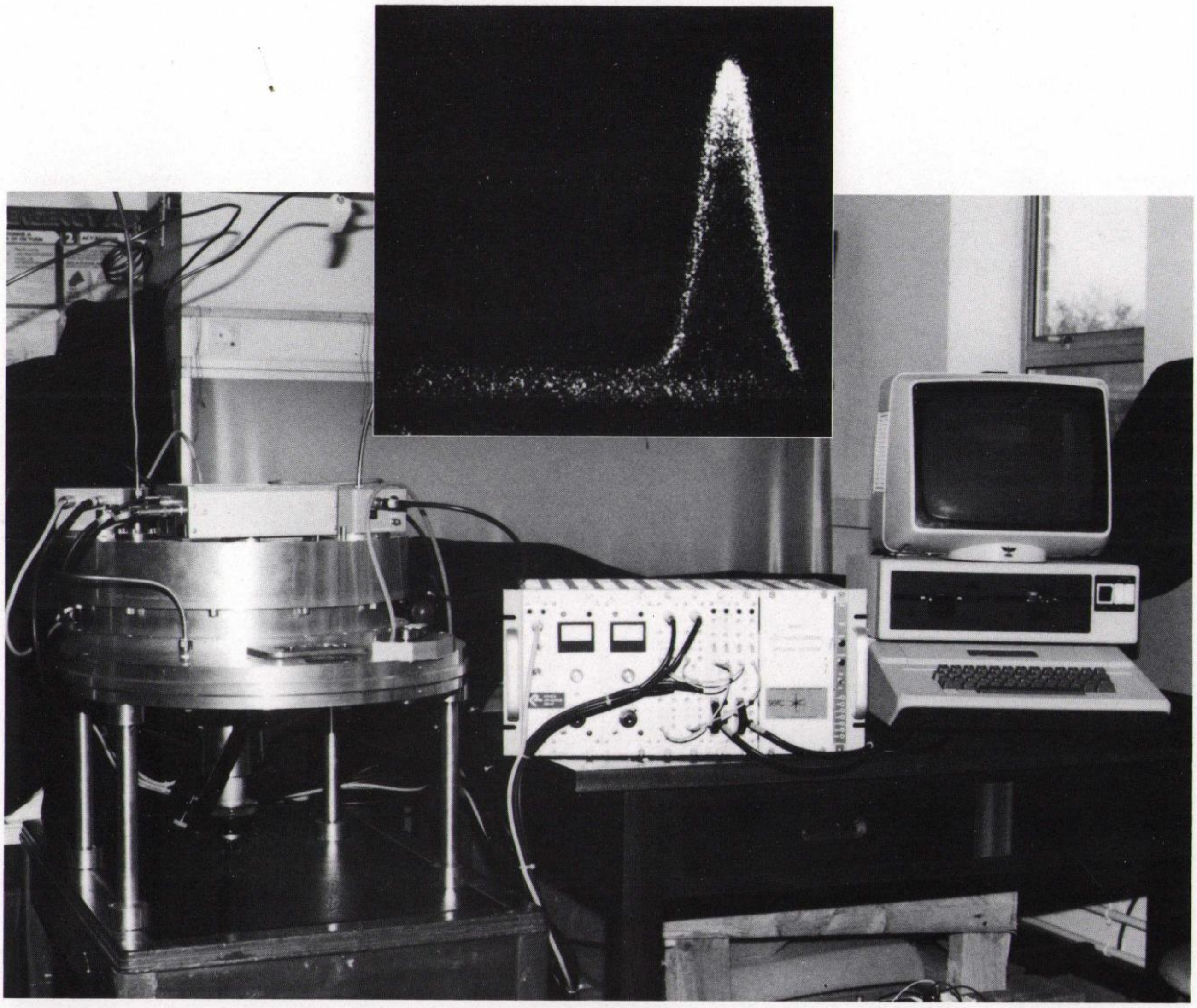
- High sensitivity — low dose
- Wide dynamic range
- Low background
- No film — data direct to computer
- Digital image processing

Rutherford Appleton Laboratory has built and commissioned complete systems for universities (departments of chemistry, medicine, biochemistry, engineering physics), Medical Research Council units and hospitals

BETA AUTORADIOGRAPHY

Electrophoresis with radio-labelled immuno-specific binding agents followed by autoradiography using sensitive silver halide emulsions is one of the favoured methods of identifying picogram quantities of biologically active proteins. Tritium is the radio-label of choice but the low sensitivity of emulsion to tritium results in unacceptably long exposures of about 1 month. The MWPC, imaging digitally into a microcomputer radically changes this situation producing images in exposure periods of around 1 hour with spatial resolution of 0.5mm. In addition to yielding the requisite spatial information quickly, the MWPC also gives the novel capability of quantifying the amount of protein present.

The illustration shows the system developed at Rutherford Appleton Laboratory which is now in routine use for immunological research at the Department of Medicine at Birmingham University. The inset shows a typical image obtained by the MWPC in about 1 hour's exposure from a 2-d radioimmunoelectrophoretogram of albumin into tritium labelled anti-albumin. This device incorporates a recent improvement to the basic MWPC design. Known as the Multi-Step Avalanche detector it provides the full 0.5mm spatial resolution without the wire artefacts typical of the basic MWPC.

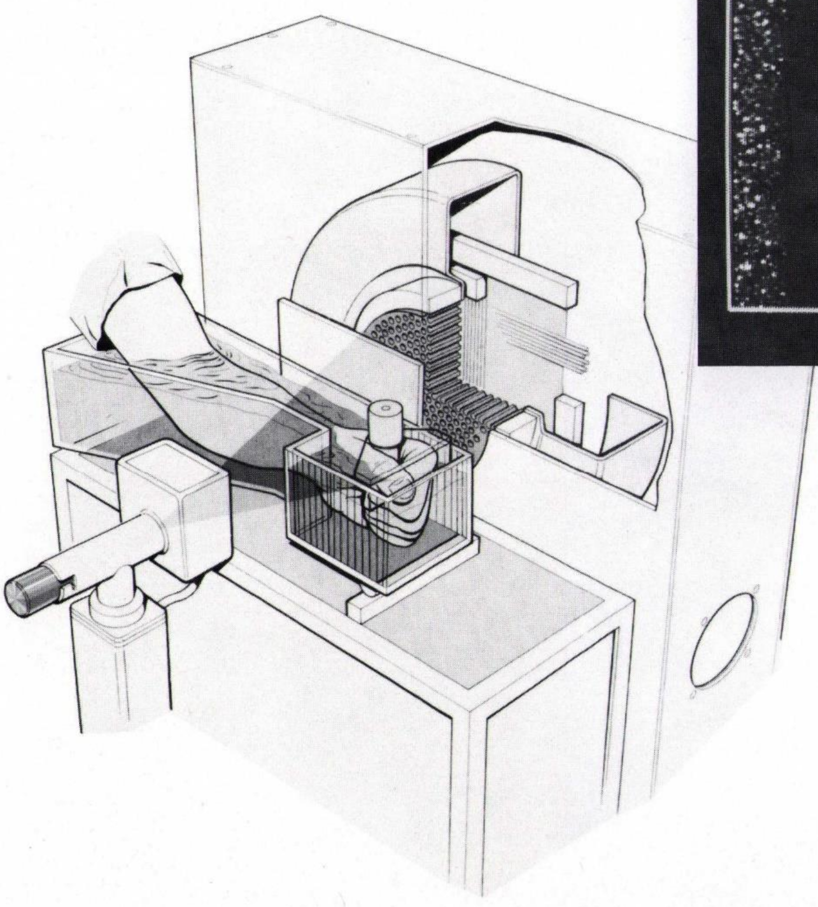


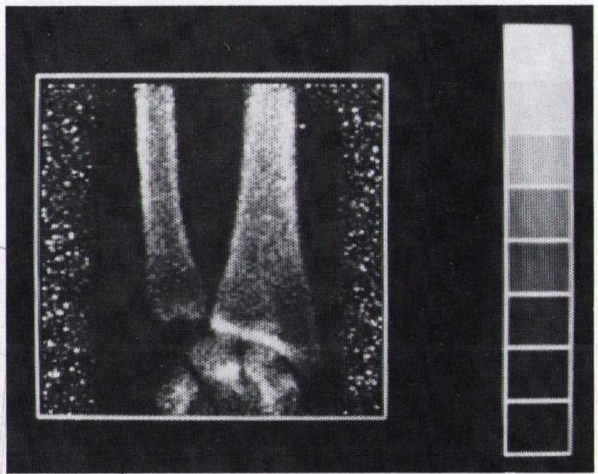
BONE MINERAL ABSORPTIOMETRY

The digital X-ray imaging made possible by the MWPC is particularly valuable in applications such as Bone Mineral Measurement using X-ray absorption. In this technique of clinical research it is important to be able to measure locally, and accurately the amount of the major bone-forming minerals present in the living tissue. The MWPC has been shown to be capable of doing this with an accuracy of 2% and a submillimeter spatial resolution. This level of performance has been found more than adequate to support a long term clinical research programme into conditions such as osteoporosis and osteomalacia in which, as a result of ageing, or consequent upon short bowel surgery, the bones of a patient waste away through a process of demineralisation.

The illustration shows schematically the principles of operation of the system which has been installed at the MRC Mineral Metabolism Unit at Leeds General Infirmary since 1979, X-rays from a ^{153}Gd radioactive source illuminate the patient's arm and the xenon-filled MWPC through a water bath (to eliminate the absorption of the soft tissue in the arm) and a rotating collimator (to eliminate scattered x-rays). The computer normalises the image to a blank exposure and calculates the logarithm of the image so giving a "mass" image (inset) in which the brighter regions represent the areas of highest bone density.

This system has recently been converted into scanning tomographic device capable of giving 3-d images of bones in difficult (but important) sites in the living body.





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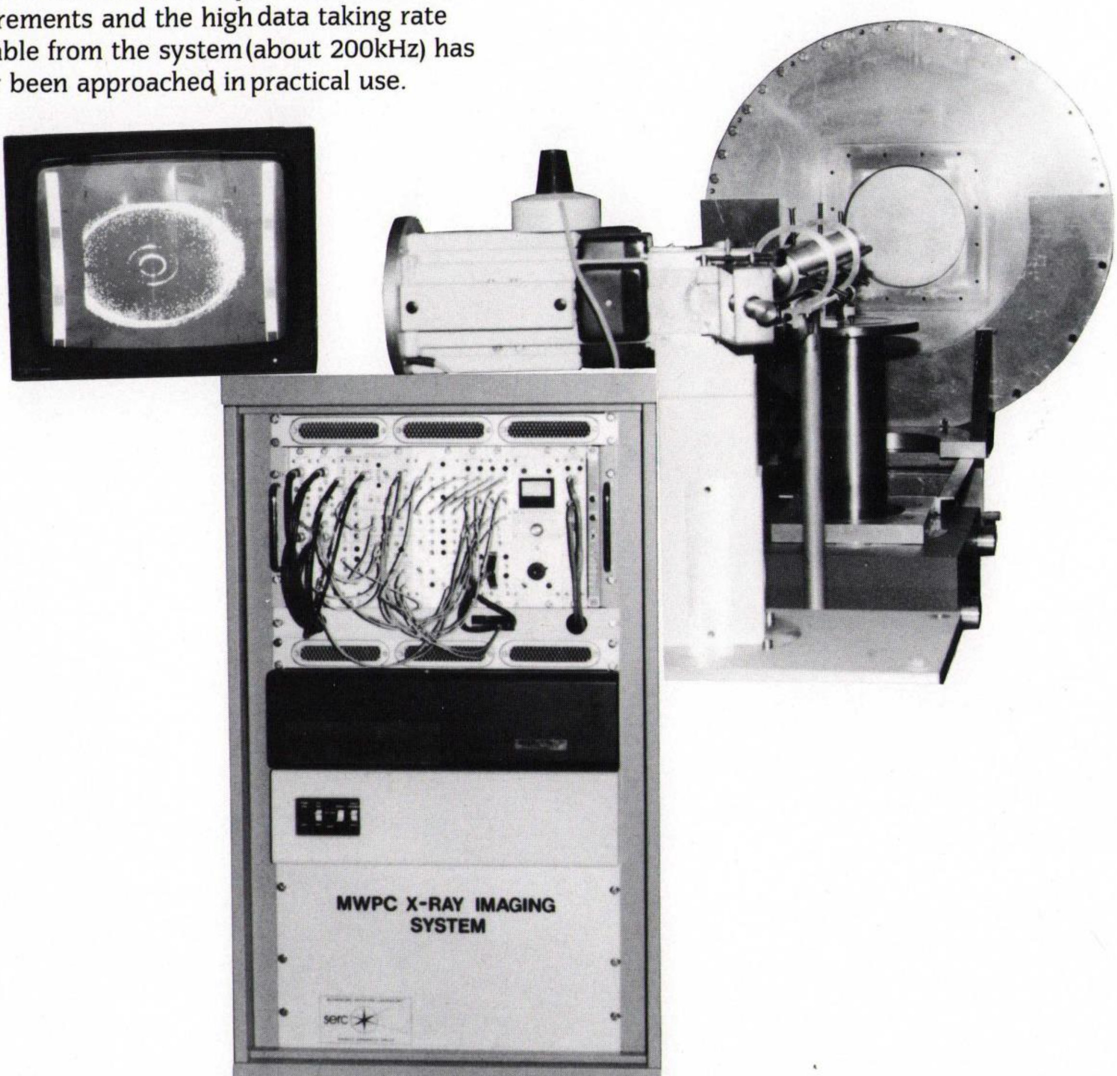
DIGITAL X-RAY DIFFRACTION

X-ray diffraction still remains the principle method of analysis of the structure of materials. Unfortunately, the low sensitivity of X-ray emulsion to soft X-rays combined with the weak scattering power of organic materials has made structural analysis of biological materials painfully slow and has severely limited productivity. The xenon-filled MWPC dramatically improves this situation by yielding a useful "count" for 8 out of 10 X-rays hitting the detector and reducing exposure times from hours to minutes or less. At Rutherford Appleton Laboratory we have supplied three large MWPC's (200mm × 200mm) for this application to Daresbury Laboratory, Exeter University and Bristol University. The spatial resolution of around 0.5mm is more than adequate for the current requirements and the high data taking rate available from the system (about 200kHz) has never been approached in practical use.

The illustration shows the most recent system installed in the Department of Chemistry at Bristol University where it is used to study liquid crystals and polynuclear ions. The inset shows the X-ray diffraction pattern produced in the MWPC system by a partially aligned liquid crystal sample after an exposure of 8 minutes. In this latest system we have implemented facilities not hitherto available in X-ray imaging such as fast framing (for X-ray movies) and electronic signal averaging (for the recovery of weak signals buried in scatter from a substrate).



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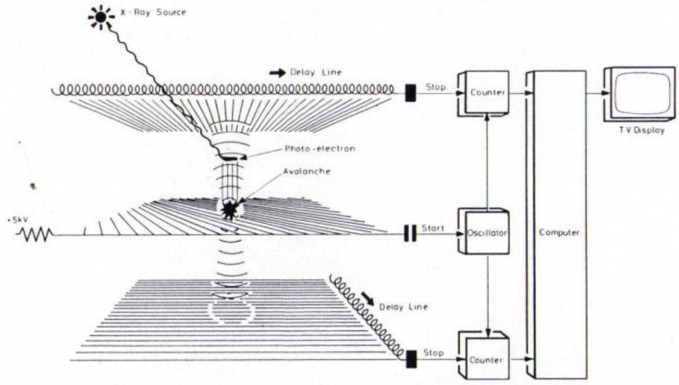
THE MULTIWIRE PROPORTIONAL COUNTER

The MultiWire Proportional Counter (MWPC) is a device capable of imaging X-rays and other nuclear radiations electronically and sending the image direct to a digital computer, thus replacing, in many applications, the traditional silver halide emulsion. Suitably adapted it can also image high energy gamma radiation of the type used in nuclear medicine thus replacing scintillator/ photomultiplier detector systems.

The MWPC is the latest in a long line of gas-filled radiation detectors which stetches back 60 years to the original "Geiger Counter" with which Geiger and Marsden first observed nuclear fission. The ever growing technological demands of Nuclear and High Energy Physics led to the development of a gas counter in which a large number of fine wires (less than the diameter of a human hair) are stretched in parallel arrays on frames in an enclosure containing a suitable gas. When high electric potential of several thousand volts is applied to the wire planes the system is capable not only of recording the impact of a particle of nuclear radiation but also of measuring the position of the impact with sub-millimeter accuracy.



When High Energy Physicists first installed MWPC's on their experiments in the early 1970's they obtained a dramatic increase in the speed and accuracy of their imaging of fundamental particle scattering events. Particles of sub-nuclear radiation could now be tracked to sub-millimeter accuracy over areas of tens of square meters with sub-microsecond timing accuracy. In addition to these advantages the technology was found to be very flexible and relatively cheap to implement. The consequence of these facts is that the MWPC in its various guises forms the main imaging element in virtually all current High Energy and Nuclear Physics experiments.

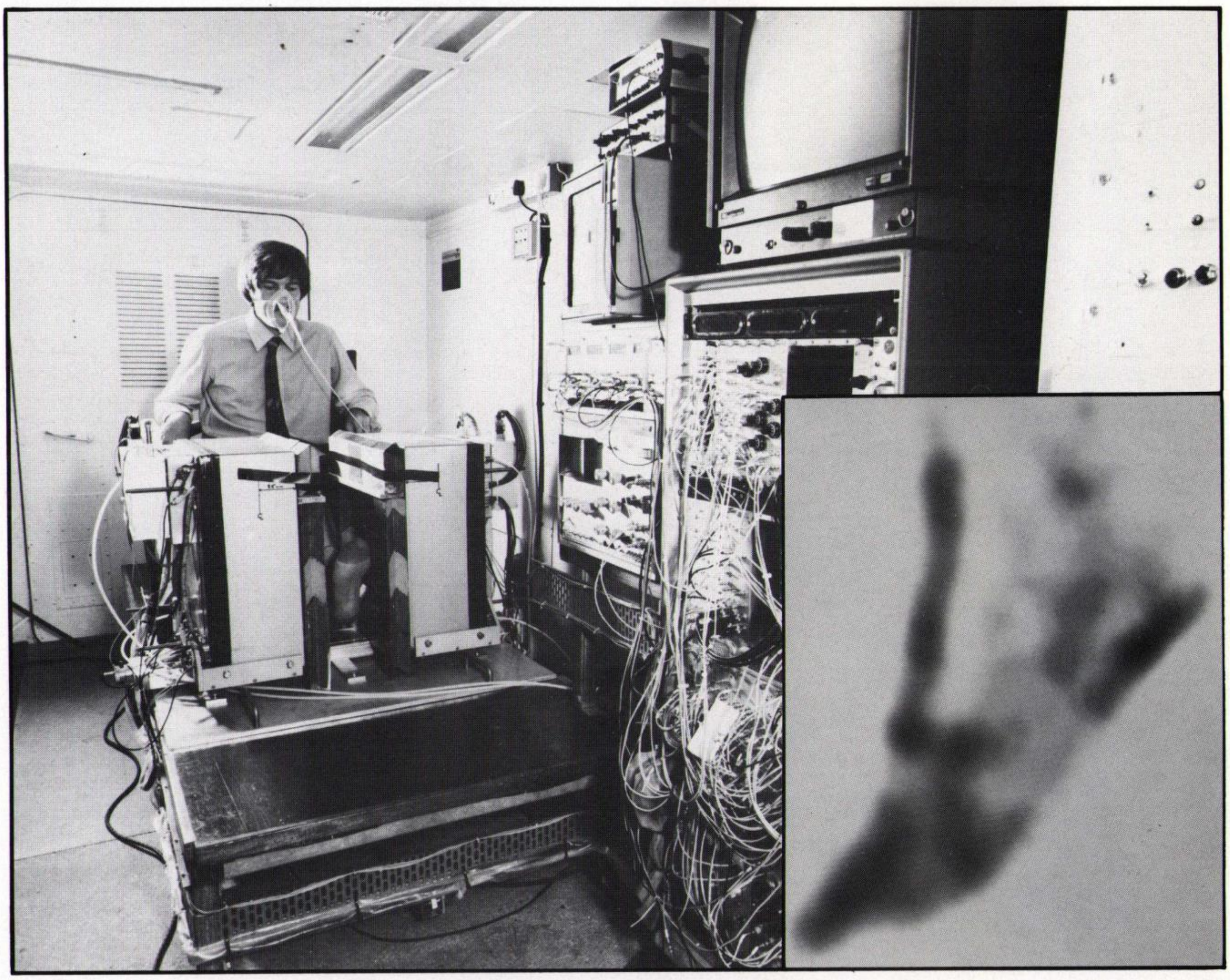
The potential for the development of the MWPC as an "electronic X-ray film" was early perceived by many workers. However, the high cost of the essential readout electronics and the associated computing power made the case very difficult to make at that time. The micro-electronic revolution of the 1970's dramatically changed this situation until today the computing power is the cheapest element in the total cost of a system.

The figure shows the main structural and operational principles of an X-ray imaging MWPC. We see three parallel planes of wires, a central plane of very fine wires held at a potential of 5000V sandwiched between two (earthy) cathode planes of coarser wires stretched at right angles to each other. Ionisation released by an X-ray conversion in the xenon gas of the detector is powerfully amplified by the high electric field around the anode wires. The mutually orthogonal cathode arrays project out the resulting electrostatic induction pulse and communicate it to the artificial delay line to which each is coupled. The X and Y coordinates of the X-ray impact are thus finally evaluated by measuring the relative delays in the arrival of the pulses at the ends of the delay lines. The time delays are converted to digital form by Time to Digital Converters and transmitted to the host computer in which a two-dimensional array representing the MWPC area is incremented at the appropriate address for each impact. After an exposure the image data is stored on magnetic media for subsequent digital processing.

POSITRON EMISSION TOMOGRAPHY

When fitted with lead foil cathodes the MWPC can image 0.5MeV gamma rays with an efficiency approaching 10% and a spatial resolution approaching 5mm. This performance makes it attractive for application in Positron Emission Tomography (PET). This Nuclear Medical imaging technique uses the "back to back" decay gammas of positronium to build up a quantitative image of the presence of a biologically active compound labelled with a positron emitting isotope within the living human body. Commercially available systems use expensive scintillator/photomultiplier devices to obtain a thin axial slice image of the human body. The cheap large area capability of MWPC technology opens the way to viable imaging over substantial volumes (e.g. axial slices 15cm deep) of tissue with genuinely 3-d representation.

The illustration shows the Rutherford Appleton Laboratory's Mark I MWPC Positron Camera operating at The MRC Cyclotron Unit, Hammersmith Hospital. The subject is inhaling $C^{15}O_2$ which, because of the short half-life of ^{15}O allows one to image blood flow. The insert shows the image of the subject's foot generated by the Positron Camera with the blood flow in anterior tibial artery and the active foot muscles clearly visualised. It is this ability to image and measure physiological function within the living body which is responsible for the great current research interest in PET.



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Radiograph of a small Holly leaf made with a multiwire proportional counter and a source of 5.9 keV X-Rays.

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