SERC BULLETIN

SCIENCE & ENGINEERING RESEARCH COUNCIL

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IN THIS ISSUE

The Science and Engineering Research Council is one of five research councils funded through the Department of Education and Science. Its primary purpose is to sustain standards of education and research in the universities and polytechnics through the provision of grants and studentships and by the facilities which its own establishments provide for academic research.

Establishments of the Science and Engineering Research Council

SERC Central Office
Polaris House, North Star Avenue
Swindon SN2 1ET
Telephone (0793) 26222

SERC London Office
160 Great Portland Street
London W1N 6DT
Telephone 01-636 8955

Rutherford Appleton Laboratory (RAL)
Chilton, Didcot, Oxon OX11 0QX
Acting Director Dr P R Williams.
Telephone Abingdon (0235) 21900

Daresbury Laboratory
Daresbury, Warrington
Cheshire WA4 4AD
Director Professor L L Green
Telephone Warrington (0925) 603000

Royal Greenwich Observatory (RGO)
Herstmonceux Castle
Hailsham, East Sussex BN27 1RP
Director Professor A Boksenberg FRS
Telephone Herstmonceux (0323) 833171

Royal Observatory, Edinburgh (ROE)
Blackford Hill, Edinburgh EH9 3HJ
Astronomer Royal for Scotland and
Director Professor M S Longair
Telephone 031-667 3321

SERC *Annual Report* (available from HMSO Bookshops) gives a full statement of current Council policies together with appendices on grants, awards, membership of committees and financial expenditure. ***SERC Bulletin,*** which is normally published three times a year, summarises the Council's policies, programmes and reports.

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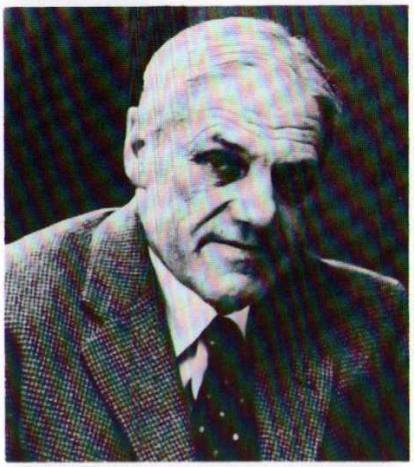
Front cover picture

A prototype sensor, the basis of a new generation of optical systems for monitoring a variety of functions in various industries and medical environments, under laboratory test at Liverpool University. ***See page 21.***

Sir Richard Woolley OBE FRS (1906-1986)



Sir Richard Woolley

Sir Richard Woolley died on Christmas Eve 1986 at the age of 80, following a short period in hospital after breaking his hip in a fall. Sir Richard was Astronomer Royal and Director of the Royal Greenwich Observatory from 1956 to 1971, having previously been Chief Assistant from 1933 to 1937.

Sir Richard was responsible for transforming the RGO by giving it a substantial and active research role and so bringing it into the modern era of astrophysics. As a source of inspiration for British astronomers he instituted regular conferences at Herstmonceux attended by many famous foreign astronomers and also started a summer vacation course for university students. He gave great assistance to Sussex University in developing its Astronomy Centre.

Sir Richard played a very important part in the successful establishment of the Mount Stromlo Observatory, the Isaac Newton Telescope, the South African Astronomical Observatory and the setting up of the Anglo-Australian Telescope. All of these have formed the basis on which the resurgence of British, Australian and South African astronomy has been built.

While at the RGO, Sir Richard was involved not only with the official side of his work as Director but was keenly and actively involved in the Sports and Social Club. One of the last of his sporting achievements was to captain the Astronomer Royal's XI against the Rest of the World in an entertaining climax to his retirement conference.

Sir Richard is survived by his third wife, Sheila, to whom we express our condolences.

Professor A Boksenberg FRS
Director, Royal Greenwich Observatory

Cray X-MP/48 inaugurated

Secretary of State for Education and Science, the Rt Hon Kenneth Baker MP, inaugurated one of the most powerful computers in the UK in April. Located at the Atlas Centre at the Rutherford Appleton Laboratory, the Cray X-MP/ 48 will provide, through the five Research Councils, a new and major computing facility to Britain's academic community (see *SERC Bulletin* Volume 3 No 7, Spring 1987).

Use of the Cray will provide a considerable boost for UK scientists and engineers engaged in wide range of computer simulation problems including: aircraft design; the evolution of the galaxies; molecular reactions; the physics of liquids and solids; large-scale integrated circuit design; the circulation of the atmosphere and oceans; and the design and operation of new pharmaceutical products.

In such areas of science, the laws governing the behaviour of matter and materials are well known, but applying these laws to complex systems results in equations which require enormous computing power to solve. Modern supercomputers, like the Cray, make it possible to tackle problems which could not be approached with earlier computers.

These areas of science are spread across the boundaries of all the Research Councils, and many are relevant to the needs of industry. The exploitation of supercomputers is an area of growing importance, and without appropriate provision of equipment in this country British scientists would not be able to compete internationally, neither would they be able to produce the trained manpower that the UK needs for supercomputing applications in industry and in Government.

Council commentary

The Forward Look, 1988/89 to 1990/91

The largest item before Council at its February meeting was formulating its Forward Look - the plan of SERC's funding activity for the three years starting in April 1988. With the present speed of developments in many areas of science and engineering, a lead time of this duration means that the Council has to preserve sufficient flexibility in its planning to be able to accommodate new activities to which it accords high priority. Maintaining this flexibility is becoming increasingly difficult because of factors over which Council has no control, including the effects of exchange rate movements, and the margin between domestic cost increases and the budget indexation allowed by Government. An example in the second category arose just before the February Council meeting in the form of the announcement of the proposed university salaries settlement (see above).

Although the Council was able to approve plans within the guidelines for an impressive portfolio of Board programmes, there remain important areas of basic and strategic work which Council will not be able adequately to exploit. These new departures thus become 'bids' for the additional funds. Council has bid for funds for a number of items chosen from a much longer list.

The total allocation to SERC from the Government's Science Vote for 1987/88, announced in December 1986, was £350.252 million.

Changes to SERC's working procedures

The Council has approved a package of changes aimed at simplifying its procedures and releasing staff effort for application to some of the manpower intensive initiatives that have recently been launched.

Changes affect both research grants and studentships and will be implemented in October 1987 or as soon as reasonably possible, allowing sufficient notice to provide adjustments to the new procedures.

On the grants side, it is proposed to encourage academic departments to submit consolidated applications; a lower limit of £25,000 will be introduced for individual grant applications, but requests for Visiting Fellowships, overseas travel funds and facility time will continue to be allowed whatever the value. For studentships, the review of 'quota' allocations will be in alternate years and the CASE scheme will be further simplified.

A summary of the new procedures has been communicated to universities and polytechnics and full details will be published as soon as possible.

The Council has said it will review the position when the new arrangements have been in operation for three years.

International participation in SERC facilities

In line with the policy declared in its Corporate Plan, the Council is continuing to seek overseas collaborators to work on, and share the cost of, its central facilities. Recent developments include participation by Japan in the construction of an instrument for ISIS, the spallation neutron source at the Rutherford Appleton Laboratory; an extension of the agreement both with Sweden and the Dutch research organisation ZWO covering the synchrotron radiation source at the Daresbury Laboratory; and discussions are in progress for the participation of Canada in the James Clerk Maxwell telescope in Hawaii.

The LINK scheme

The recently announced LINK scheme aims to involve industrial concerns and academic researchers in the development of research in the so-called 'strategic' areas of science and engineering, ie subjects that can be foreseen as being of future economic importance. An example is 'molecular electronics', which aims to exploit the electronic behaviour of certain materials at the molecular level. Individual programmes under the LINK scheme will be jointly funded by public money (from Government departments and through Research Councils' research grants) and by industry, either as single firms or, more usually, as consortia. SERC will be heavily involved and it is envisaged that expenditure through research grants might build up to about £20 million a year by 1991-92. The Council has confirmed its wish to participate fully in this important national initiative.

Information technology

In a review of its activities in IT (information technology) in December 1986, the Council received presentations from Professor E A Ash and Mr R W Brander (past and present chairmen of SERC's Information Engineering Committee) and from Sir Austin Bide (chairman of the 'IT86' Committee, whose report on future national action in IT was published in November 1986.)

SERC's past activities in IT pre-dated the launch of the 'Alvey' programme of research and development and have done much to establish a healthy academic research capability in the subject. On the training side, too, there has been a marked increase in activity: the annual number of one-year advanced course studentships awarded by the Information Engineering Committee has gone up from about 200 to about 1200, the major growth being in 'conversion' courses for graduates in other disciplines.

Looking to the future, the Council believes it important that the momentum that has been engendered in academic research should be maintained to ensure a continuous supply of exploitable research results and to help establish a national teaching capability. The Council welcomed the call in the IT86 report for more concentration on the application of IT and believes that SERC has a positive role to play. It will be important also to ensure the continuing vitality of the on-going research base.

Research grants restored

The Secretary of State for Education and Science, Mr Kenneth Baker, announced in the House of Commons on 1 April that he was making an additional £15 million available to the Advisory Board for the Research Councils. This extra funding is being shared between the Research Councils to help compensate for the recent increase in salaries, including those for academic staff supported by SERC. The share allocated to SERC is to be £7.5 million. As a result of the academic salary settlement, SERC's research grant bill will rise by some £8 million in 1987-88 above the sums provided in the Council's budget (salaries accounting for about 60% of the annual grant expenditure) and in later years the shortfall was expected to be more than £10 million a year, or something like one-tenth of SERC's annual grant expenditure. Faced with these difficulties, the Council at its meeting on 18 March had seen no alternative but to cancel round 3 (April 1987) of the current session as a general grants round. However, following the Secretary of State's welcome announcement, the research grant round was restored, with an extended closing date. In addition, the Secretary of State said he would look favourably upon the provision of money to cover the shortfall in future years.

Quarks, transputers and computational physics

The Inmos transputer represents a radical new development in the search for more cost-effective computing power. Professor Anthony Hey gives an account of a possible role for the transputer in solving the problem of quark confinement, and reports on the construction of powerful reconfigurable transputer arrays at Southampton University being carried out under the European Community's ESPRIT programme, and related research support by both SERC's Particle Physics Committee and Physics Committee.

Within the next decade, in all important computationally-intensive areas of research, such as those identified by the Forty Committee, the field-leaders will undoubtedly be those who can most effectively combine physics insight with access to huge computing resources. It will not be enough to be merely ingenious and be content with access to a VAX or a few hours per week on a Cray or Cyber supercomputer. Research at the frontier will be done by scientists who are both innovative and creative, and who have at their disposal the equivalent power of a supercomputer dedicated to their research programme.

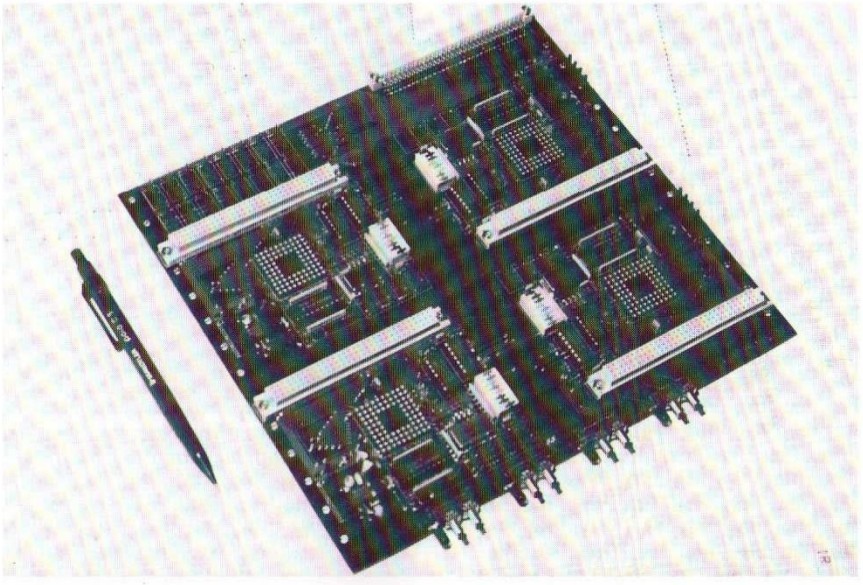
Particle physicists seeking to understand the complex nonlinear field equations of quantum chromodynamics (QCD) are a case in point. The problem of how the theory keeps quarks locked inside so-called elementary particles and forbids them to exist in isolation is clearly not one that can be attacked using perturbation theory. Numerical simulation of QCD using various Monte Carlo techniques can, however, allow us to explore genuinely non-perturbative aspects of the theory. There is therefore the real hope that one day in the not too distant future we may be able to calculate and predict particle masses and matrix elements. Over the past few years many groups in Europe and the USA have been able to beg, borrow or steal large amounts of supercomputer time for such calculations. These calculations are still in their infancy but it is already clear that physicists without access to competitive computing power will be excluded from these exciting developments.

Given that today's supercomputers have a price-tag of ten million dollars or more, how can individual groups afford this kind of computing power? Many people now believe that the answer lies with novel computer architectures involving the concurrent operation of many processing 'nodes'. An early example of such a 'parallel' computer is the ICL DAP, a 64x64 array of single-bit processors purchased with a £90,000 SERC grant by Professor Wallace's group at Edinburgh University, and used to great effect by them. Another early example is the Cosmic Cube, developed at Caltech by Fox and Seitz, which consists of up to 128 processors configured at the corners of a hypercube. Descendants of these machines are now commercially available. In addition to these more-or-less commercial ventures, physicists both at Columbia University in the USA and in a nation-wide Italian collaboration are designing and building 'parallel' machines with which to attack QCD. Even IBM is developing its own QCD machine, the GF-11, for use at its Yorktown Heights Laboratory. How can such machines hope to compete with commercial supercomputers? The answer is that although the processing power of one of the individual nodes of these machines is relatively feeble, the nodes are replicated many times. Then, provided that the particular application program can be effectively divided up among the many nodes of the machine, such parallel computers can provide supercomputer performance for a fraction of the price of a commercial supercomputer.

Where does the transputer figure in all this? The transputer is unique in that, on a single chip, there is not only a very fast 32-bit microprocessor and 2 kilobytes of fast static RAM, but also four high-speed communication links. These links enable transputers to be easily connected together without any extra glue chips to handle the communication protocol. Furthermore, with the transputer comes a novel programming language called Occam. This language has been designed for use with multiprocessor systems, and communication 'channels' are an explicit part of the language and can be mapped directly on to the hardware links connecting different transputers. These two features — the on-chip links and the Occam language — together with the high-speed RISC (reduced instruction set computer) processor which allows rapid switching between processes, make the transputer an ideal building-block for large concurrent systems.

At Southampton, the Physics and the Electronics and Computer Science Departments are partners in a multi-million pound ESPRIT collaboration called the Reconfigurable Transputer Project (RTP). The goal is to design and build reconfigurable transputer arrays capable of floating-point performance in the gigaflop range. It is reconfigurable in the sense that each of the four links from each transputer can be connected in the network most suitable for the particular application by merely setting a software-controlled switch. Moreover, for this machine, Inmos have developed an enhanced floating-point version of the transputer, the T800 which is superior in performance to a VAX minicomputer.

The Physics group at Southampton is involved in developing algorithms and methodologies for parallelising many different types of physical problems. Until the RTP machine comes along in a year or so, the applications group are gaining experience on a 17-transputer Meiko Computer Surface purchased with funds from the Particle Physics



Four intercommuncating transputers which will form part of a multi-computer network

Committee, and from an array of transputers with floating-point co-processors built at Southampton with a grant from the Physics Committee. Many applications are now up and running on these transputer arrays, including various lattice gauge theories, a mathematical model of the retina, a liquid crystal simulation, the 'travelling salesman' problem via simulated annealing, and several multi-tasking demonstration programs. The liquid crystal simulation has now been run to completion and attained around 80% efficiency when distributed over a system of 17 transputers. For the particular mix of integer and floating-point arithmetic in the code, this corresponds to a performance equivalent to around 30 VAX 11/780s. This clearly demonstrates the potential of such tranputer arrays for providing cost-effective computing power since the 17 transputer system costs much less than one VAX machine!

The future for this type of parallel computing and for the Inmos transputer now looks bright. Fortran, C and Pascal are now available for the transputer and should reduce the hurdle of porting standard software to such arrays. The high energy physics group at Southampton is currently collaborating with Meiko Limited to demonstrate the utility of using transputer arrays as a 'Fortran farm' to generate the many high statistic simulations required in modern particle physics experiments at CERN and DESY. We are looking forward to the arrival of the RTP machine from the ESPRIT project which we hope will contain more than 500 floating-point transputers. This should finally convince the sceptics that parallel computing and the transputer have a major role to play in enabling British university computational groups to be internationally competitive.

Professor A J G Hey
Physics Department
Southampton University

Professor Hey was awarded a five-year SERC Information Technology Senior Fellowship in 1986.

Meiko Computing Surface being used by particle physicists at Southampton University.

Congratulations to...

Lord Flowers, Vice-Chancellor of London University and former Chairman of the Science Research Council (1967-73), has been awarded the Glazebrook Medal and Prize for his leadership in the support of scientific and technological research over many years.

Sir Sam Edwards, of the Cavendish Laboratory, Cambridge University, and former Chairman of the Science Research Council (1973-77), has been awarded the Guthrie Medal and Prize for his many outstanding contributions to theoretical solid state physics.

Dr Roger Heckingbottom, Head of the Materials Division at British Telecom's Research Laboratories and a member of SERC's Materials Committee, has been appointed Honorary Professor in the Departments of Physics and Materials Science and Mechanical Engineering at University College, Cardiff, to work in particular on molecular beam epitaxy of semiconductors.

Brian Hadley, head of Photolabs at the Royal Observatory, Edinburgh, has been elected a Fellow of the British Institute of Professional Photography, for scientific photography in support of astronomical research.

And to newly elected Fellows of the Royal Society:

Dr A J Kirby (Reader in Organic Chemistry at Cambridge University), member of the Organic Chemistry Subcommittee;

Professor R Loudon (Professor of Physics at Essex University), member of the Atomic and Molecular Physics Subcommittee; and

Professor P N Robson OBE, FEng (Professor of Electronic and Electrical Engineering at Sheffield University), member of the Solid State Devices Subcommittee and the SERC-DTI JOERS Assessment Committee.

Major new grants

Approval has been received from the Department of Education and Science for:

- a grant of £812,200 to Warwick University (Professor E H C Parker) for research in low-dimensional phenomena in silicon;
- the installation of accelerator modules from the folded tandem accelerator at Oxford into the Nuclear Structure Facility at Daresbury at a cost of £1,145,000;
- a revised capital sanction for the construction of an along-track scanning radiometer (to measure the temperature of the world's oceans) that will be carried by the European Space Agency's first remote-sensing satellite in 1989.

In addition, the Council has approved:

SCIENCE BOARD

- a grant of £483,200 over four years to Cambridge University (Professors Sir Sam Edwards and V Heine, Dr R C Ball *et al*) for research into the theory of condensed matter;
- a grant of £700,400 to Oxford University (Dr R J Nicholls and Dr P J Walker): growth of heterojunctions in semiconductors using metallo-organic chemical vapour deposition;
- a grant of £762,600 over four years to Nottingham University (Professor L J Challis *et al*) for research into phonon interactions in low-dimensional structures;

NUCLEAR PHYSICS

- a grant of £415,000 over two years to Oxford University (Dr N A Jelley) for experimental research in nuclear structure physics;

ASTRONOMY AND PLANETARY SCIENCE

- a grant of £402,000 over four years to Cambridge University (Dr J E Baldwin, R J Warner and Dr D C Mackay) for the construction of an optical synthesis telescope.

LEP: news from the OPAL experiment

With the first electron-positron collisions in the CERN LEP machine now only two years away, work in preparing the experiments is in full swing. Detectors for OPAL, one of three experiments with UK support, are arriving at CERN, and there is heavy demand for test beams to measure the performance of the first production units. Increasing emphasis is also being placed on preparation of software for rapid collection and analysis of data from the first e^+e^- events in Spring 1989.

There are more than 250 physicists and engineers working on OPAL, drawn from 22 institutes in eight countries (see *SERC Bulletin* Volume 2 No 12, Autumn 1984). UK participation includes groups from Birmingham, Cambridge and Manchester Universities, from Queen Mary College and University College/ Birkbeck, London, and from the Rutherford Appleton Laboratory (RAL). This report, by Dr C N P Gee of RAL, concentrates on developments in areas for which these UK groups have special responsibility.

The Cambridge and QMC groups, together with RAL Electronics Group, have successfully completed the development of readout for the Vertex Detector, a high-precision cylindrical drift chamber. With the final modular electronics, the design precision of 50 μm per point was reached under a variety of conditions, and coordinate precisions better than 30 μm were achieved with one gas mixture. This detector will be capable of measuring the lifetimes of short-lived particles down to 10^{-13} seconds.

The same groups are responsible for the fast track trigger, which performs the complex task of identifying tracks originating from e^+e^- collisions and discriminating against backgrounds. One of the particular strengths of OPAL is that the central drift chambers provide fast information on track coordinates. When combined with the very high speed logic in the trigger, this enables a decision on whether to record an event to be taken within the 22.5 microsecond interval between bunch crossings. Thus data from every bunch crossing in the LEP machine can be examined until an interesting event is identified. A prototype section of the trigger processor has now been tested in a beam, and performed well over a wide range of background conditions.

The first calorimeter nearing completion. The lead glass blocks, weighing 17 kg, are supported in brass cans only 0.5 mm thick. (Photo CERN)

Another notable feature of OPAL is the lead glass electromagnetic calorimetry, which provides excellent detection and high precision energy measurement of electrons and photons. A group from Tokyo is constructing the barrel part of the lead glass detector, and this is sealed at the ends by four D-shaped modules, which are the responsibility of the Cambridge, QMC and RAL groups. The end caps must operate in the 0.4 Tesla magnetic field inside OPAL, and they required the development, with industry, of a new device to detect light from the glass. The resulting devices (vacuum photo triodes) are equipped with a specially developed low-noise amplifier designed at RAL. The end cap passed an important milestone in November 1986, when the first D-shaped module reached its design performance in an electron beam.

Muon detectors, forming the outermost layers of the experiment, are being developed by the Birmingham and Manchester groups. They will help to shed light on a variety of physics problems including the study of heavy quarks, whose decay products frequently include a muon.

Chambers of the barrel muon detector measure 10.4 by 1.2 metres, and weigh 250 kg. Of the total of 112 chambers, 86 have already been built at Manchester and shipped to CERN, and delivery there will be completed this year, well ahead of schedule. Prototypes of the end cap muon chambers have been tested in a beam at CERN, and full sized prototypes are now under construction at RAL and Birmingham.

A number of electron-positron processes emit secondary particles forwards close to the beam, and these can escape from the main body of the OPAL detector. These forward particles are intercepted by the forward detector, five of whose six components are being built by the University College/Birkbeck group. Prototypes of all but one of the parts have recently been tested at CERN, and production of the final version of the first is underway at UCL.

A network of 100 VME-based microprocessors, up to 12 MicroVaxes and a powerful Vax 8700 computer will be used to collect and process the OPAL event data. The Vax 8700 processor arrived in March. Groups from the UK institutes are responsible for development and coordination of the on-line Vax hardware and software and for a substantial part of the off-line analysis chain. A prototype version of the data collection software is running and has been used to collect cosmic ray data from sectors of the OPAL jet chamber. The OPAL Monte Carlo program now provides an intricate description of the experiment, and work on the event reconstruction program is well advanced.

Dr C N P Gee
Rutherford Appleton Laboratory

First light on the James Clerk Maxwell Telescope

On 3 December 1986, the first radio signals were received by the James Clerk Maxwell Telescope (JCMT) at the Mauna Kea Observatory on Hawaii. A few days later, observations were made of spectral lines of carbon monoxide in the Orion Nebula. These were exciting developments, writes Ron Newport of Rutherford Appleton Laboratory, both for astronomers in the UK and the Netherlands who will soon be able to start using the telescope; and for RAL staff who have been heavily involved in the design, development, construction and commissioning phases of the project since 1980 (see *SERC Bulletin* Volume 3 No 6, Autumn 1986.)

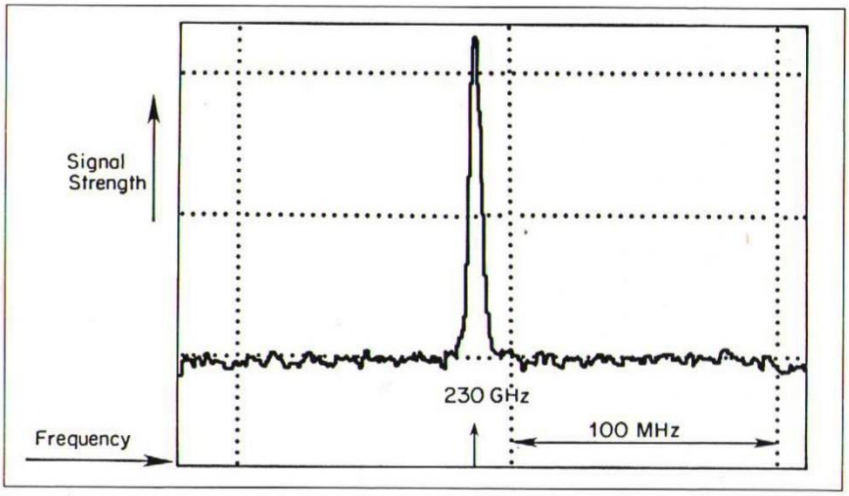
To test the new telescope it was first pointed at the Moon with a receiver tuned to a frequency of 230 GHz (which is approximately a thousand times higher than the frequencies used for TV and FM radio transmissions). A strong signal was received. This was as expected since all 'warm' objects emit signals at these high frequencies and for an object as close as the Moon they are easily detected by the sensitive detectors used by astronomers. The telescope was then pointed at the planets Jupiter and Mars, and again strong signals were detected. Later, signals were detected at 270 and 340 GHz from Jupiter and Mars, using a continuum receiver. These events marked the end of the first phases of the commissioning, in which engineering tests of the telescope and its drive systems were carried out, and the reflecting surface (consisting of 276 individual panels) was measured and adjusted to the correct paraboloidal shape.

When the sensitivity of the telescope was tested on far more distant objects, spectral lines were observed from carbon monoxide in the Orion Nebula at 230 and 345 GHz. Further measurements of the telescope's reflecting surface followed, to increase its accuracy.

Tracking and pointing tests continue until completion of the commissioning, ready for the formal opening of the telescope by His Royal Highness the Duke of Edinburgh on 27 April, and its transfer to the Royal Observatory, Edinburgh for operation.

Astronomical observations are scheduled to start on 1 July. The James Clerk Maxwell Telescope will be the world's largest instrument capable of observing efficiently at frequencies above 300 GHz. It will give astronomers an opportunity to study a relatively unexplored part of the electromagnetic spectrum in which star formation and the microwave background radiation are but two of the exciting fields of interest.

Dr R W Newport
Rutherford Appleton Laboratory



Spectral line from carbon monoxide in the Orion Nebula, observed on 11 December 1986.

Lunar sample loan programme

The British National Space Centre, acting on behalf of SERC, has five lunar sample packages which it lends to educational institutions for short periods.

There are two types of lunar sample material:

Lunar thin sections: these consist of 12 polished thin sections suitable for viewing in transmitted or reflected light. A standard petrographic microscope, using polarised light, is needed to examine this material.

Background notes are provided which describe the thin sections, relate them to the suite of rocks and soils they represent, and attempt to fit them into a broad picture of their relationship with the Moon, what we have learned of it, and what unsolved problems remain.

Encapsulated disc: these are designed specifically for schools and consist of a disc of clear plastic, six inches in diameter, one inch thick, containing a ½-1 gramme sample of each of the following soil types:

- lunar breccia (a broken surface soil type);
- a lunar basalt (solidified volcanic matter);
- a lunar anorthosite (an igneous rock composed of calcium, aluminium, silicon and oxygen);
- a sample of the Moon's orange glassy soil;
- a sample of lunar Mare soil; and
- a sample of lunar Highland soil.

A meteorite encapsulated disc package is also available.

A low-powered microscope (x10) may be used to provide a greater resolution of the samples, but it is not essential.

The lunar samples can be borrowed by any educational institution for a week or two if the institution can satisfy the security arrangements set down by NASA, the most important requirement being that the lunar samples have to be kept in a secure storage cabinet equipped with a combination padlock separate from all other valuables. On some occasions the samples can be borrowed for longer periods if the samples are to be used as part of an exhibition or display.

For further details on the security arrangements and the availability of the lunar packages, contact:

Mrs Lorraine Dicken
Space Science Programme Board Secretariat
British National Space Centre
SERC Central Office, Swindon,
ext 2418.

A new era in infrared astronomy

A unique infrared camera constructed at Edinburgh and delivered recently to the UK Infrared Telescope in Hawaii heralds the start of a new type of infrared observation that will open up a wide range of fundamental observations. It is described here by Dr Ian McLean of the Royal Observatory, Edinburgh.

Over the past three to five years, a dramatic and exciting change has been occurring in ground-based infrared astronomy world-wide. Detector technology which was previously classified or semi-classified for security reasons has now become available for scientific and other applications. The new infrared detectors are solid-state arrays having upwards of one thousand detector elements or pixels. It is not an exaggeration to say that these new detectors offer an immense potential for the growth of astronomy. Study of the infrared region of the electromagnetic spectrum has long been recognised as a key regime, fundamental to our understanding of star formation and all its ramifications, applicable to an immense range of objects, from planetary systems to primeval galaxies. That study has been inhibited by the difficulties of detecting and measuring infrared radiation from astronomical objects, but now, at last, efficient imaging and spectroscopy are possible and the instrumentation no longer needs to be designed around single element detectors.

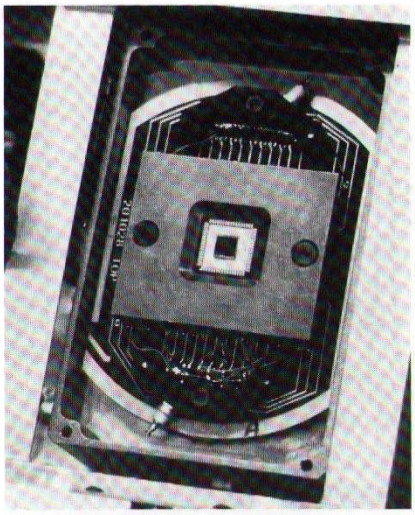


Figure 1: The SBRC 62 × 58 InSb array in situ in the UKIRT infrared camera (IRCAM).

Of course these are early days. Infrared array detectors employ low band-gap semiconductor alloys, such as indium antimonide or cadmium mercury telluride, and the fabrication technology is still a delicate process. The number of detector elements in the new arrays is still rather small compared to the number in silicon imaging devices. Moreover, these arrays must be 'hybridised' to silicon devices to provide efficient low-noise readout schemes. The situation on the availability, cost and quality of the new arrays is akin to the status of silicon charge coupled devices (CCDs) in the early to mid 1970s. Today, all major optical observatories possess silicon CCD cameras. Because there has never been an imaging capability for infrared astronomy, however, the impact of these new arrays will be all the more staggering.

To respond to the demand of the astronomical community and to help provide a stimulus to manufacturers, the Royal Observatory, Edinburgh (ROE), undertook a major initiative some years ago to build astronomical instrumentation incorporating infrared detector arrays. Following a survey of the UK astronomical community, and on the recommendation of the UK Infrared Telescope Users Committee, first priority was given to an imaging system.

The wavelength range of 1 to 5 microns (1 micron is 10^{-6} metre) was selected partly because of the immense scientific potential of this waveband and partly because of the constraints of what appeared to be technically feasible.

ROE's role began in late 1982 with a survey of potential vendors by the author. Interest among manufacturers in both the UK and the USA was high. Initial investments centred on a 1 × 32 array of indium antimonide and then moved to 62 × 58 arrays of the same material. Current interest lies with the development of large arrays of cadmium mercury telluride and with long-wavelength sensitive arrays of extrinsic silicon.

IRCAM

A satisfactory 'first product' was delivered to the UK Infrared Telescope

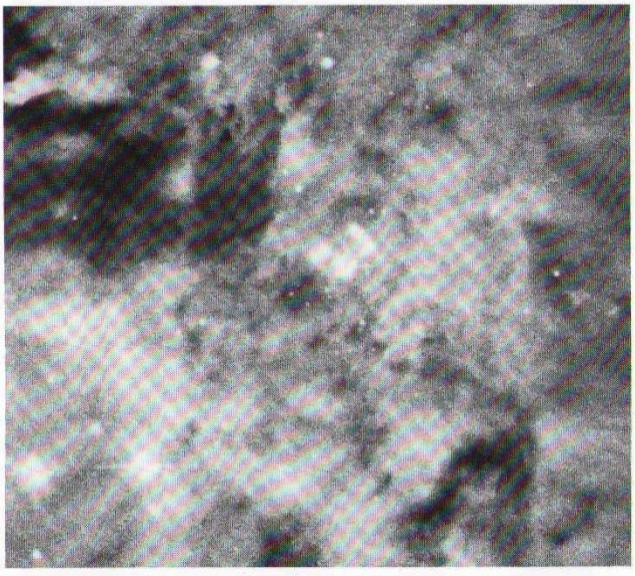


Figure 2: The central region of the Orion Nebula, as recorded by an optical photograph in blue light. Dust absorbs the optical radiation from stars within the nebula. (Photo: AAT).

Figure 3: The same region as seen by IRCAM at 2.2 microns in the infrared. At this wavelength the observation penetrates deep into the nebula, picking up many previously invisible stars. (Photo: ROE).

in Hawaii in September 1986 in the form of an infrared camera known as IRCAM 1.

Currently, the detector employed in IRCAM 1 is a 62 × 58 (3,596 pixels) array of photovoltaic indium antimonide diodes manufactured for us by a Californian company. Each detector (0.0762 × 0.0762mm) is ion-implanted into the indium antimonide substrate which is then turned over, thinned to about 20 microns and illuminated from the back. All the detectors integrate on the image scene simultaneously and store charge locally using (mainly) the junction capacitance of the diode itself. To read out the infrared signal from each detector the array is hybridised to a matching silicon array of field-effect transistor switches and decoders by 'bump-bonding' the two arrays together using a matrix of indium contact bumps. Figure 1 shows the detector *in situ* in IRCAM 1.

Although this form of detector has some shortcomings, it has the advantage of covering the entire 1 to 5 micron region of the near-infrared spectrum with greater than 60% quantum efficiency throughout. This wavelength region includes the five major atmospheric 'windows' for that part of the spectrum and contains many important astrophysical emission lines such as the Brackett series of atomic hydrogen, vibrational states of molecular hydrogen, the so-called 'dust' emission features associated with interstellar polycyclic aromatic hydrocarbons, and the 3.1 micron absorption band due to ice.

Mosaics like photographs

The 62 × 58 array in IRCAM 1 has already produced fascinating and original infrared images. For example, figure 3 shows what appears to be an optical photograph of a nebulous star cluster. But this is not an optical image at all: it is an infrared view (at a wavelength of 2.2 microns) of the famous Orion Nebula which, in an optical photograph like that given as figure 2, usually appears as a bright, opaque cloud of gas and dust. Infrared radiation penetrates the dust screen and allows us to 'see' directly the magnificent star cluster embedded within. Since the Orion cloud is the nearest region of active star formation to the solar system, it is crucially important to our understanding of the star formation process in general and hence of the formation of planetary systems and even of whole galaxies like our own.

It may soon be feasible to make observations which probe back in time to the formation of the first galaxies; such objects, being extremely distant, have large Doppler shifts to the red due to their enormous speed of recession and thus much of their energy appears to be emitted in the infrared.

IRCAM is beginning to make a completely new range of fundamental investigations possible.

Dr Ian S McLean
Royal Observatory, Edinburgh

Secretary of State meets the stars

Mr Kenneth Baker, Secretary of State for Education and Science, paid a three-hour visit to the Royal Observatory, Edinburgh, on 13 March. It was his first close encounter with astronomy in SERC. He took a keen interest in all the work of the Observatory, ranging from instrumentation being built for infrared and submillimetre observations in Hawaii, to some of the many early astronomical books and manuscripts in the Crawford Library. He is seen here with Professor Malcolm Longair, Director of ROE, pointing out a detail on a night sky photograph taken in Australia with the UK Schmidt Telescope. Also in the picture are Dr Bob Stobie (Deputy Director), Dr David Morgan (Head of UKST Unit) and Mr Rob Smith (DES).

ASTRO-C in orbit

The Japanese ASTRO-C satellite (see *SERC Bulletin* Volume 3 No 7, Spring 1987) was successfully launched on 5 February from the Kagoshima Space Centre in Japan and, by 26 February, was already sending back observations of a supernova — one of the exciting astronomical events in almost 400 years.

The satellite (renamed GINGA, the Japanese for Galaxy, once it was in orbit) carries three experiments. One of these, the Large Area Counter (LAC), is a joint project between Leicester University, the Rutherford Appleton Laboratory, the Japanese Institute of Space and Astronautical Science and the University of Nagoya. It is the first Anglo-Japanese collaborative space venture.

Weighing more than 100 kg and with a sensitive area of 0.5 m^2, the LAC is studying cosmic X-ray sources. Hundreds of these most powerful of X-ray sources, discovered using earlier satellites such as Ariel 5 and EXOSAT, have been identified as binary star systems and quasar-like galaxies. By its sensitivity, the LAC will enable these X-ray signals to be monitored with greater precision than ever before, so revealing important new information on the nature of the emitting objects.

GINGA is now orbiting the Earth at a mean altitude of 560 km, with an orbital period of 100 minutes. Power was switched on to the experiments earlier than planned so that it could scan the supernova.

This supernova — an exploding star — is in the Large Magellanic Cloud, one of the galaxies closest to our own, and is the brightest such event visible to the naked eye since 1604. Its arrival will make great advances in star studies and the LAC's observations may add an invaluable dimension.

It is hoped that observations from GINGA will continue for up to five years.

Spatial spread of a rabies epidemic in England

During the past few hundred years, continental Europe has been swept repeatedly by rabies epidemics not unlike the plague epidemics of the middle ages. Rabies, a viral infection of the central nervous system, is transmitted by direct contact. Only about four people die of the disease in Europe each year but the disease is much more common among animals: in 1980 in France alone, 314 cases in domestic animals and about 1280 in wild animals were reported. The present European epidemic seems to have started around the Polish-German border about 1940 and since then it has moved westward at around 30 to 60 km a year. The epidemic has now almost reached the north coast of France in spite of the strong measures taken to halt its spread. It seems increasingly possible that rabies will be reintroduced into England through the illegal importation of some infected but not yet rabid animal. The main carrier of the rabies virus is the red fox and, with the high urban and rural fox population, and the large number of domestic dogs and cats in England, the disease would spread particularly rapidly. Professor James Murray of Oxford University describes how it is possible to plot the course of such an epidemic.

We can get a lot of practical information about the spatial spread of rabies by using realistic mathematical models. Such models can be used to carry out 'experiments' on how fast the epidemic will travel, to determine the number of rabid foxes at any given time and to examine the effects of various possible control strategies. In this article I shall try and give some idea about how such models are set up and I shall briefly describe some of the results of an experiment in which rabies was 'introduced' on the south coast of England. The model can also be used to estimate the width in kilometres of a rabies 'break', analogous to a fire break.

The spatial spread of rabies is a complex process and a model which incorporated all of the known facts would be of little practical use. There is thus strong motivation for studying a comparatively simple model which captures the essential features of fox ecology, the disease and its spread, and for which real parameter values can be determined. Results from our model indicate key processes and highlight questions that must be answered by any model which purports to describe the spread of rabies. When the results from this model were compared with data from continental Europe, they turned out to be surprisingly good. Even with the relative ecological simplicity of the model, the mathematical realisation is not trivial; the numerical simulations of the nonlinear partial differential equations, under the practical conditions which obtain in England, took several hours of computer time on a Cray in the Los Alamos National Laboratory in New Mexico.

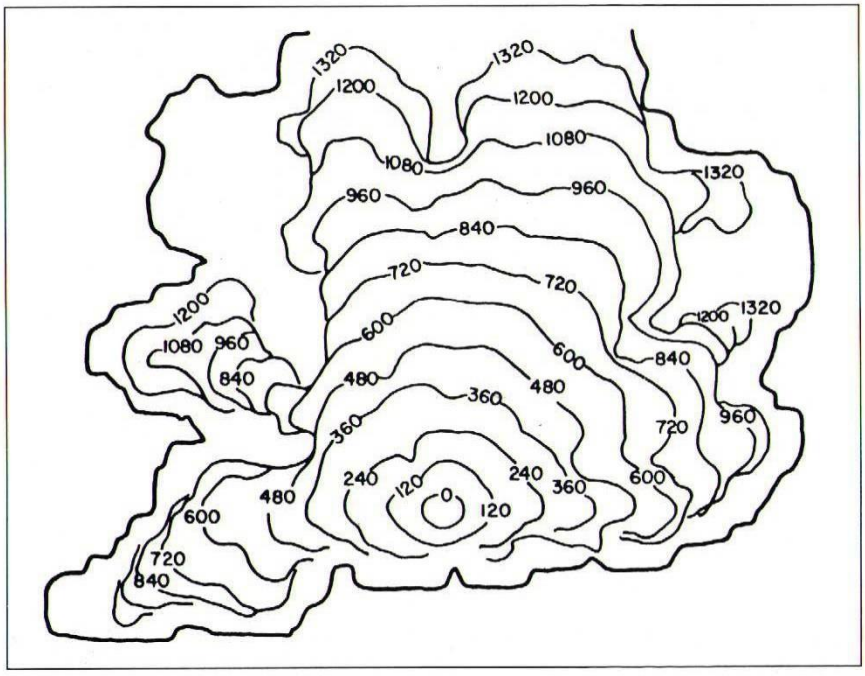


Figure 1: The position of the epidemic wave front every 120 days as predicted by the model with the fox densities appropriate to England.

In the model, the fox population is divided into three groups: susceptible foxes; infected foxes, which are not yet infectious; and infectious, that is rabid, foxes.

During the infected period, the animal seems to act quite normally. The rabid stage lasts from 1 to 10 days. If the virus enters the spinal chord the rabid fox is generally paralysed, whereas if it enters the central nervous system the rabid animal exhibits the typical aggressive symptons associated with the disease; it is the so-called 'furious rabies'. About half of the rabid foxes get the 'furious' form.

The model is based on known facts and the following assumptions about fox behaviour, which are particularly relevant.

- In the absence of rabies, the size of the fox population is controlled by the number of foxes which can be sustained by the habitat. Although this varies markedly in England, a typical density is around 4 foxes/km^2, which is much higher than on the continent.
- Rabies is transmitted by direct contact, usually by biting, and susceptible foxes become infected at an average per capita rate proportional to the rabid population.
- The average incubation time is about 28 days, although there are documented cases of more than six months. (The current UK six-month quarantine requirement is certainly not too long.)
- Rabid foxes almost always die; the average life expectancy of a rabid fox is roughly five days.
- Foxes with 'furious rabies' become aggressive, lose their strong sense of territorial behaviour and wander randomly. We assumed that this random wandering is the principal means of spreading the disease.

The model consists of three equations which relate the rate of change of each fox population — the susceptible, the infected and the rabid — in terms of the various contributions to its loss or gain based on the above assumptions. The mathematics quantifies the various contributions in the equations.

Graphical results, such as illustrated, were obtained from the numerical simulation of the equations with parameters relevant to the English scene.

From the simulations, the speed of propagation of an epidemic wave front is about 100 km a year as compared with 30

to 60 km a year on the continent. The model simulation also indicates periodic outbreaks after the passage of the main epidemic. In fact the disease seems to die out after the first wave with the susceptible fox density recovering in what looks like a healthy manner and with very few rabid foxes. It is easy to imagine the complacency this would cause.

The variable density of the susceptible fox population causes considerable distortion of the epidemic wave. Figure 1 shows the progression of the front of the rabies epidemic every 120 days from an initial introduction of the disease near Southampton.

It can be shown mathematically that an epidemic will die out if there are insufficient *susceptibles* to propagate the disease. So a possible means of containing the epidemic, or rather of stopping it from moving into uninfected regions, is to create a rabies 'break' which halts that progressing epidemic wave. Such a break is, very simply, a region where the susceptible fox density has been reduced to a level where the disease cannot survive. The susceptible fox population can be reduced by culling or, what is much better, by vaccination (chicken heads, infused with vaccine and left around for the foxes to eat, seem to be particularly effective). The latter technique is strategically much better because, if indiscriminate killing was used, there would be more territory available for the young to colonise. Should they be infected, this would enhance the spatial spread. On the other hand if the territory was occupied by vaccinated foxes it would inhibit the spread of young, and hence the disease.

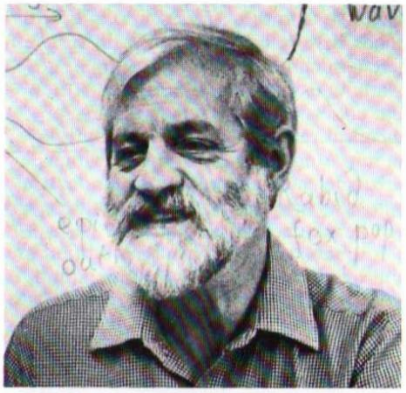
The disease spreads because of the random wanderings of rabid foxes. So the crucial question in the creation of a rabies break is how wide it should be.

What these models provide is a quantitative width of such a break in terms of the various parameters of the model. A width of about 20 km is typical for a fox population of 0.4 foxes/km^2 in the break.

The simulations give the period of the recurring outbreaks and their distance apart. For England it turns out that roughly 1500 to 2100 days after the disease first appeared in the south, the area appears to be effectively free of rabies. Figure 2 shows how a pocket of the disease would spread and propagate from an infection started near Southampton.

The model studied was relatively simple. It does however incorporate many of the salient features of the spatial spread of rabies among foxes. In the Centre for Mathematical Biology in Oxford, we hope to investigate model modifications which incorporate the effect of fox immunity, vaccination, spatial movement of the young and so on. The simulations of the present model equations agree pretty well with the observed behaviour of the spread of rabies in Europe, so the results we have obtained for England are probably not too unrealistic.

Professor J D Murray FRS
Director, Centre for Mathematical Biology
Oxford University



Professor James Murray

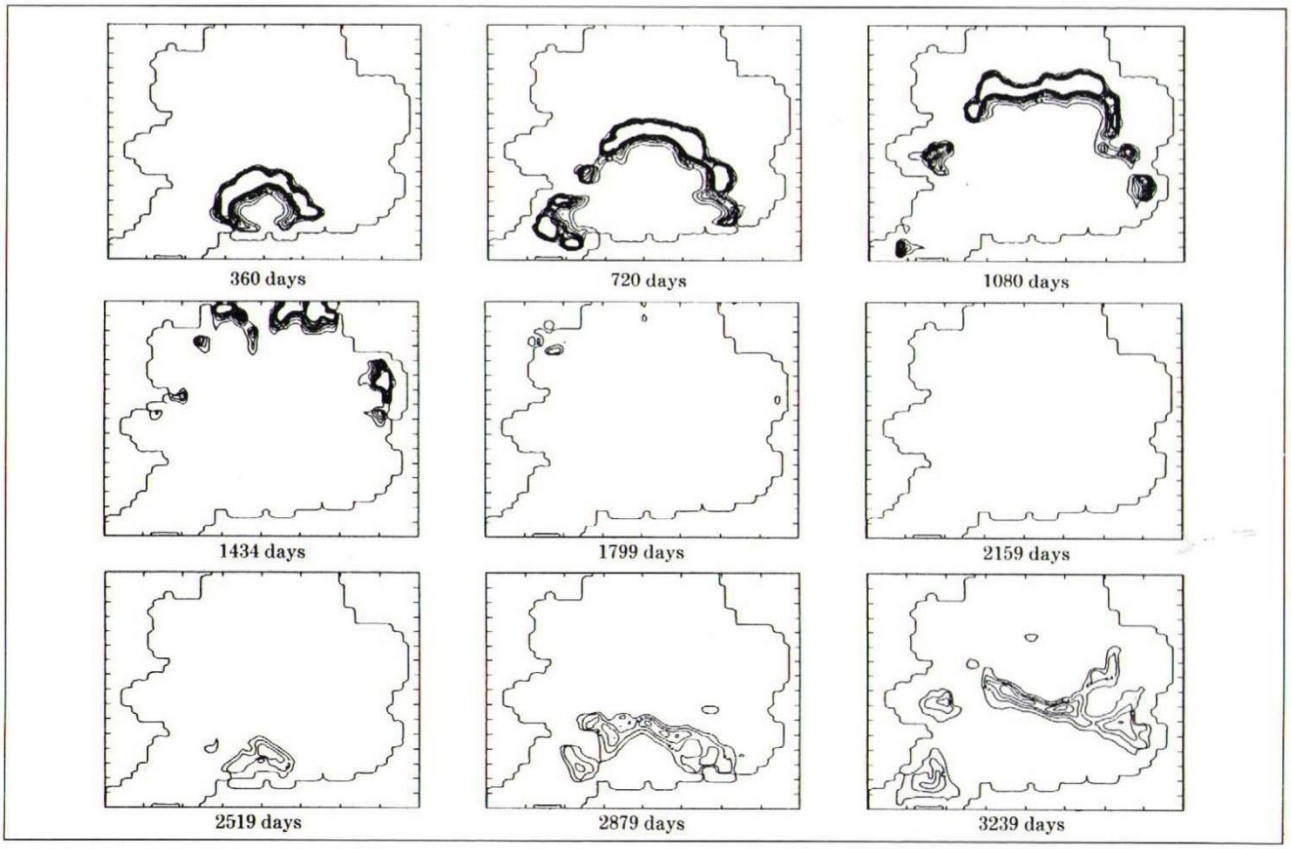


Figure 2: Simulated movement of the epidemic if a localised density of rabid foxes was initially introduced at Southampton and allowed to spread. Contour plots of the rabid fox densities are given at a sequence of times, as the wave moves outward from its source. Note how few rabid foxes there are in the region behind the front. Note also the reappearance of another epidemic wave of lower intensity, which starts about seven years after the initial outbreak.

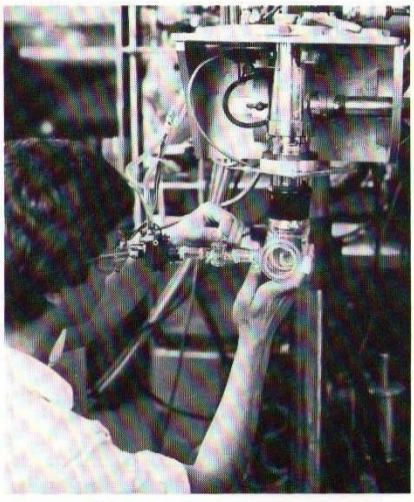
Reaction pathways in organometallic chemistry

At Nottingham University, infrared spectroscopy is being applied in unusual ways to identify intermediates in chemical reactions of relevance to catalysis and to unravel the complex behaviour of these short-lived molecules. The work is described here by Dr Martyn Poliakoff and Professor Jim Turner.

British chemists have for many years been at the forefront of organometallic chemistry, synthesising compounds with bonds between carbon and transition metals such as iron or chromium. These compounds have fascinating structures and undergo a bewildering variety of chemical reactions. Many of them play an important part as catalysts, which persuade chemical reactions of industrial importance to proceed under milder, and hence cheaper, conditions. But, before such reactions can be modified or improved, one must try to understand how the reactions occur.

The outcome of every chemical reaction is determined by its sequence of *reaction intermediates*, the unstable, transient, elusive substances which are born at the outset of the reaction, flourish and decay in brief and rapid succession, until out of their transformation a stable end-product appears.

For nearly twenty years we have been attempting to learn something of the nature and behaviour of intermediates in organometallic reactions. With the help of SERC support, skilled research students and technical staff, and widespread collaboration, we are still devising new ways of doing it. Each advance in technique has forced our apparatus to grow more complex but has enabled us to probe reactions in ever greater detail.



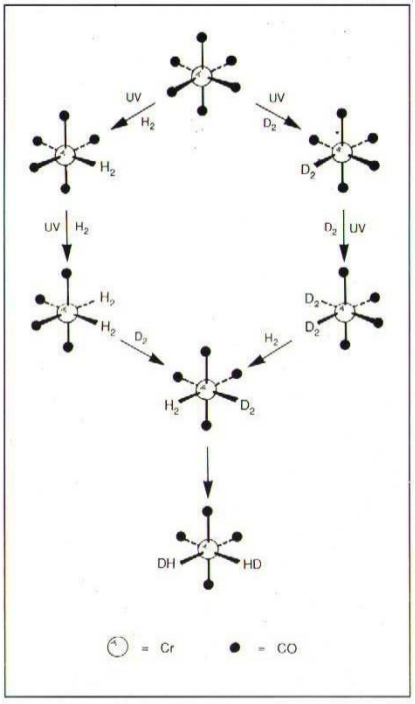
SERC-supported student, Stephen Firth, preparing the low temperature equipment for a matrix isolation experiment.

Matrix isolation: a molecular deep freeze

The most fundamental trick in the armoury is drastically lowering the reaction temperature. This extends the life of even the most reactive intermediate, and can stabilise them completely. The most powerful method of establishing the molecular structures of organometallic intermediates is infrared (IR) spectroscopy, which determines the pattern of IR wavelengths absorbed by a sample. The classic combination of spectroscopy and low temperatures is called *matrix isolation*, a technique pioneered in the early 1950s by Pimentel at Berkeley and by Porter in England.

Matrix isolation has been used by us since 1968. The technique involves mixing the reactants with an inert gas, and spraying the gaseous mixture on to a plate cooled to only a few degrees above absolute zero, where it freezes instantly. The reactant molecules thus find themselves trapped in a solid inert matrix. By irradiating the matrix with ultraviolet (UV) light, or allowing it to warm up slightly, the molecules can be made to react with each other or decompose; but the resulting intermediates are stabilised by the frozen matrix and isolated from further reaction partners. The IR spectrum of the matrix, and the way it changes during such reactions, can often be decoded into quite detailed information about the structure, bonding and reactions of the trapped molecules.

Scheme 1 gives an example of chemistry in a frozen matrix. For some years, synthetic chemists had postulated the existence of iron tetracarbonyl, $Fe(CO)_4$ as an intermediate in many reactions but it had never been observed. It was finally trapped by UV irradiation of the relatively unreactive molecule $Fe(CO)_5$ in an argon matrix at −253°C. $Fe(CO)_4$ was identified by IR spectroscopy, which

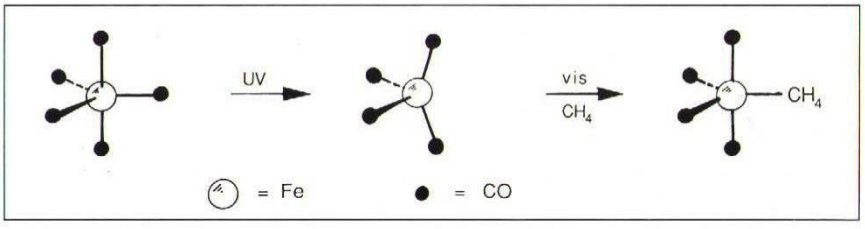


Scheme 2: Chemistry in liquefied xenon

was sufficiently precise to give an estimate of the bond angles. When excited by visible light, $Fe(CO)_4$ turned out to be highly reactive even combining with methane, CH_4, when it was added to the matrix.

Liquefied xenon: slowing reactions down

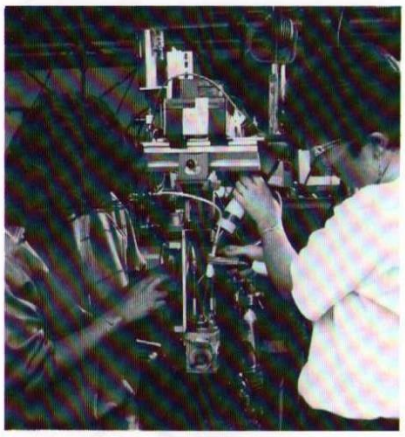
In 1979, Dr Bill Maier, of the US National Laboratory at Los Alamos, spent a year at Nottingham as an SERC Visiting Fellow. He brought with him a novel cryochemical technique for conducting chemistry and spectroscopy in cold *liquefied xenon*. This exotic, tricky solvent combines great chemical inertness with unrivalled spectroscopic



Scheme 1: Chemistry in a frozen matrix

transparency, and has opened up a whole new field of study.

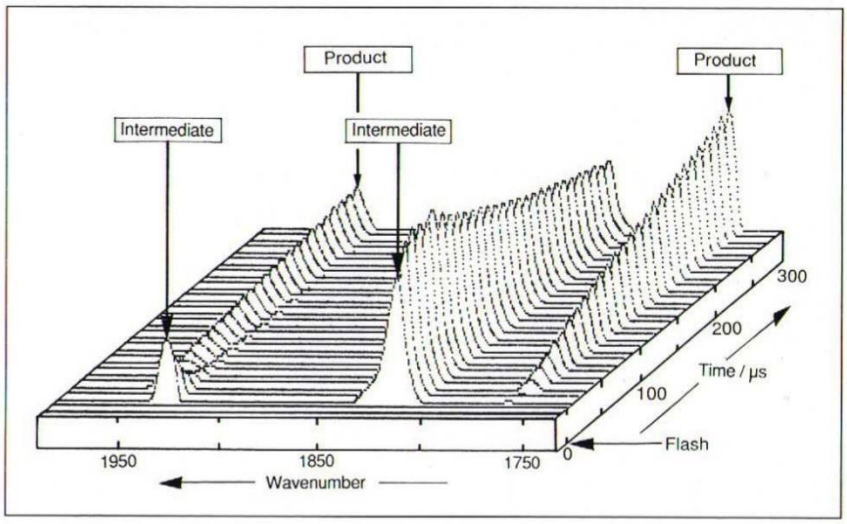
Scheme 2 gives an example of the intermediates which can be made in liquefied xenon and studied in true solution rather than in frozen matrices. Many catalytic processes involve hydrogen, H_2, reacting with compounds containing metals but the intermediates in such reactions are usually very reactive. The low temperature (−100°C) of liquefied xenon increases the lifetime of some intermediates, allowing them to be detected by IR spectroscopy. The intermediates, shown in scheme 2, present intriguing problems of chemical bonding because the H_2 molecule is attached to the metal without rupturing the bond between the two H atoms. Even at low temperatures, the intermediates undergo some reactions; for example, the unexpected exchange reaction with deuterium, D_2, a heavy isotope of hydrogen, with the resulting formation of hydrogen deuteride, HD.



Rita Upmacis and Sarah Jackson, two CASE students, who have studied the reactions of hydrogen with organometallic compounds in liquefied xenon.

Time-resolved IR: intermediates at room temperature

Our most recent technique is *time-resolved IR spectroscopy*. This technique is used to study reaction intermediates at room temperature. Without the stability conferred by cooling, intermediates may last less than a millisecond but this is time enough for IR spectroscopy to record them. The starting solution is decomposed into photochemical intermediates by a flash from a UV lamp or laser, lasting about a microsecond. Over the next few microseconds, as the unstable products decay or react further, an IR laser and fast-acting IR detector record the resulting lightning swings of IR absorption. By repeating the experiment many times, each time tuning the IR laser to a different wave-number, a complete spectroscopic history of the fleeting molecules and their reactions can be pieced together.



Time-resolved IR spectra of the reaction shown in Scheme 3.

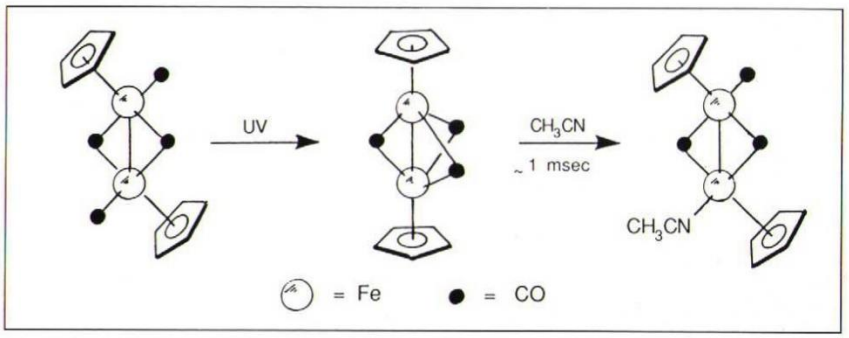
Time-resolved IR has been particularly useful for studying compounds containing two metal atoms, because a solid matrix can often alter the reactions of these relatively large molecules. Frequently, it is important to know whether, in solution, the intermediates contain one metal atom or two. Such a compound is cyclopentadienyliron-dicarbonyl dimer, $[(C_5H_5)Fe(CO)_2]_2$, which has recently been shown to have interesting catalytic behaviour. The figure shows a set of time-resolved IR spectra from a reaction of this molecule with methyl cyanide, CH_3CN. The spectra reveal that the intermediates are formed instantaneously by the UV flash but that the product appears more slowly. A more detailed interpretation of the spectra shows that the principal intermediate in this reaction contains two iron atoms and that the bond between the atoms remains intact throughout the reaction (see scheme 3).

Conclusions

Each of the three techniques (matrix isolation, liquefied xenon and time-resolved IR) makes a different contribution to the identification of reaction intermediates. Together, they illustrate the power of infrared spectroscopy as a tool for unravelling the intricate pathways of organometallic chemistry.

CASE students, Andrew Dixon and Michael Hodges, conducting a time-resolved IR experiment.

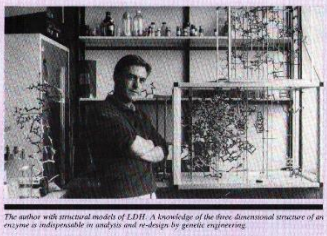
Dr M Poliakoff
Professor J J Turner
Department of Chemistry
Nottingham University



Scheme 3: A reaction followed by time-resolved IR

Protein engineering on lactate dehydrogenase

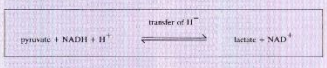
The use of modern nucleotide chemistry to synthesise parts of genes and so direct amino acid substitutions in proteins has supplied a new, precise and reliable way of altering their covalent structure. This method, called site-directed mutagenesis (SDM), has removed an enormous barrier to understanding the relationship between the structure and the behaviour of proteins and, in addition, has allowed us to modify their properties, in a rational way, to suit industrial purposes. In short, the protein chemist is no longer limited to what Nature supplies, supplemented by a few 'hit and miss' chemical modifications, but can modify or design proteins at will. From this technical achievement a new field of science is rapidly emerging; it has been termed 'protein engineering'. As an illustration of the potential of protein engineering, Dr Anthony Clarke of Bristol University describes the progress made by applying it to the study of the enzyme lactate dehydrogenase (LDH).



The author with structural models of LDH. A knowledge of the three dimensional structure of an enzyme is indispensable in analysis and re-design by genetic engineering.

Structual rearrangements in the enzyme during catalysis

Much of the interest in LDH revolves around two of its properties. First, it requires a coenzyme (NADH) to achieve the catalytic conversion:



Secondly, both reaction kinetics and X-ray crystallographic studies show that a change in the structure of the enzyme is an important element of catalysis. Figure 1 shows the major difference in structure between the free enzyme and the enzyme-coenzyme-substrate complex. This gives an overall 'before-and-after' picture of a rearrangement but does not reveal whether all of the changes occur simultaneously and concertedly or in stages and independently. In other words, local defined kinetic information is needed to relate motion and catalytic function.

Our original attempts to provide this for mammalian LDH relied on using chemical modifications to introduce reporter groups at defined sites. While this approach showed that substrate-induced structural changes occur at different points in the catalytic cycle, the range of chemically introduced reporters was rapidly exhausted and so we turned to the genetic methods of modification and to the structurally and kinetically similar LDH from a high temperature bacterium. SDM was used to take out the three tryptophan residues in the native bacterial LDH and create mutants containing only one tryptophan at a good reporting position. This process, perhaps surprisingly, has in no case disrupted the catalytic function of the enzyme, and single-tryptophan fluorescence is now used routinely to correlate local movements with stages in catalysis.

Transition-state stabilisation

An inspection of the two extreme LDH X-ray structures suggests that the substrate-induced loop closure has two chemical consequences:
(1) it pushes the nicotinamide group of the coenzyme into an oily pocket (thus stabilising the neutral NADH in preference to the charged NAD^+); and
(2) it shifts a 'loop' arginine residue (109) by 8 Å, from a position in the solvent to one in the active site within hydrogen-bonding distance of the carbonyl oxygen of pyruvate (see figure 2).

To examine the role of this mobile and basic residue, it was replaced by the neutral glutamine. In contrast to the non-intrusive tryptophan mutations, this is an example of the substitution of a conserved residue (in all 22 known LDHs), intended to cause a functional disruption of the enzyme which can then be interpreted. In the event the mutant enzyme loses only 2 kcals of binding energy for the ground state pyruvate molecule, but for its transition state must lose at least 6 kcals: the transfer of H from NADH to substrate, rather than loop closure, now being the slowest process in pyruvate oxidation (see figure 3). The entry of the positively charged arginine-109 into the active site as the loop falls stabilises the negative charge developed on the carbonyl group of the pyruvate-lactate transition state by at least 4 kcals (see figure 2).

Bonding and substrate recognition

Figure 2 shows that the carboxylate group of the bound substrate is held by the guanidinium group of arginine-171. On changing this residue, which makes a two-point interaction with the carboxylate, to a lysine (which can only form a single bond) 6 kcals of substrate-binding energy is lost. The strength of the guanidinium-carboxylate interaction, which contains both an ionic and a hydrogen-bond component, is an important consideration in designing tight binding pockets for carboxylic acids. The arginine-171 residue is also important in binding specificity; the lysine mutant is unable to bind pyruvate in preference to other keto-acid substrates with larger alkyl groups. The strong orienting effect of an arginine-171-carboxylate bond allows the enzyme to discriminate between keto-acids by forcing the alkyl group into a recognition cleft (formed by residues thr-102, arg-109 and gln-246).

Communication between effector-site and active site

One of the few differences between mammalian and bacterial LDHs is that the latter only binds substrates tightly when fructose-1,6-bisphosphate (FBP) is attached to the enzyme. In many bacteria this regulation acts as a switch between the production of lactate and of other industrially important catabolites, for example ethanol. Engineering the effector-regulation in LDH offers the opportunity of modifying the enzyme's response to FBP and of controlling the fermentative output of certain bacteria.

The regulatory FBP-site is formed at the end of two structural 'rods' (an α-helix (α) and an extended chain (β), see figure 1). The other ends of the rods are 20 Å away and form the substrate-binding site. Removing a single basic residue (arginine-173 -> glutamine) stops the acidic FBP making contact with one of these rods and completely blocks the activation signal. As the mutation has no other effect on catalysis and still allows FBP to bind, we conclude that activation occurs by the ability of FBP to optimise the arrangement of the rods for substrate binding.

General measurement of the local flexibility of a protein

One of our general and encouraging observations on mutant LDHs is that amino acid substitutions have only local effects and do not disrupt the structure and behaviour of the whole protein. Large proteins like LDH (molecular weight 134,000) are stabilised by an extensive network of intramolecular bonds and disruption of only one or two will usually have less influence than in a small protein which has fewer bonds to determine its overall structure. In this sense, it is desirable when building new properties on to a protein to choose a structurally stable scaffold.

Yet, as we have shown, proteins are mobile structures and a knowledge of the principles that underly industrially desirable properties, such as resistance to high temperatures, to extremes of pH, and to organic solvents, requires an understanding of structural movement. Nuclear magnetic resonance cannot usually be applied to large proteins so, for these, an alternative method of mapping flexibility and changes of structure has been developed. Protein engineering enables the construction of single-tryptophan versions of any protein and these can be used to map the flexibility of specific parts of the structure by measuring the rotational correlation-time or the lifetime distribution of the indole fluorescence.

The first of these measurements yields information on the extent and rate of the group's motion and the second on the number and range of environments it occupies. An initial survey of four sites in LDH using these methods has shown that the inserted tryptophans respond predictably to the local protein environment, the temperature and the binding of ligands. At present, we are extending this method to mapping local 'melting-points' from which thermal denaturation is triggered, and to plotting pathways of protein folding and subunit assembly in LDH. It is the lack of correct protein-folding that still limits the production of many physiologically active and therapeutically useful human proteins in bacteria on a large scale.

Dr A R Clarke
Department of Biochemistry
Bristol University

Figure 1: The LDH subunit

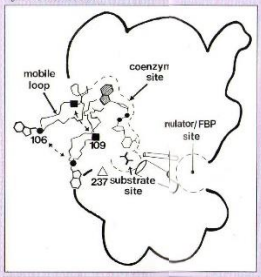
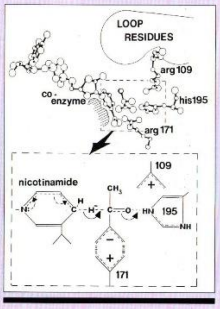


Figure 2: The site structure and chemistry



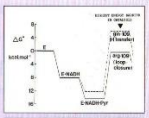
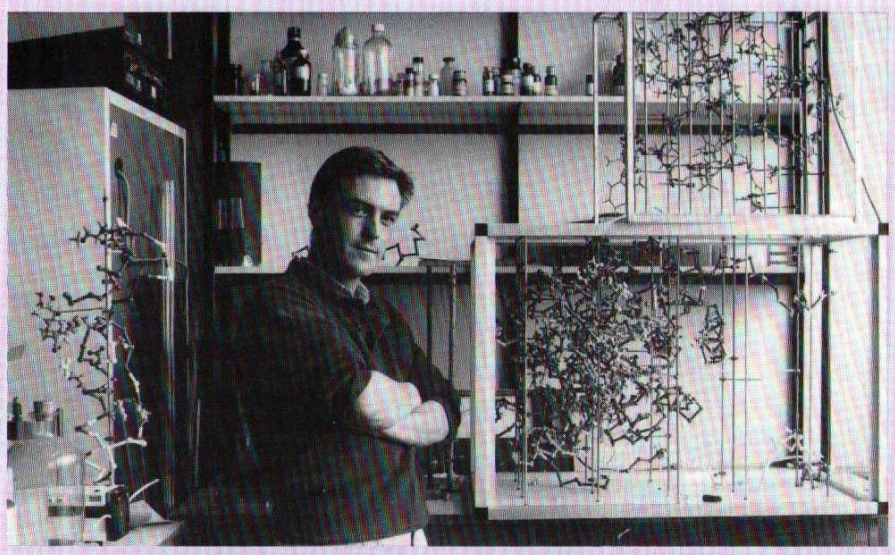


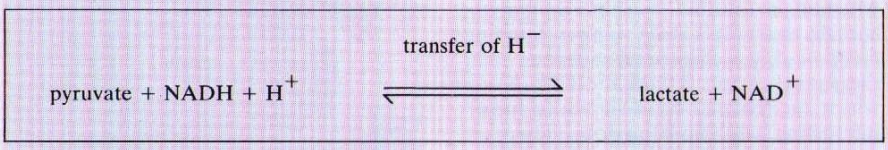
Figure 3: An energy profile of pyruvate reduction; arginine-109 allowing more rapid catalysis



The author with structural models of LDH. A knowledge of the three dimensional structure of an enzyme is indispensable in analysis and re-design by genetic engineering.

Structual rearrangements in the enzyme during catalysis

Much of the interest in LDH revolves around two of its properties. First, it requires a coenzyme (NADH) to achieve the catalytic conversion:



Secondly, both reaction kinetics and X-ray crystallographic studies show that a change in the structure of the enzyme is an important element of catalysis. Figure 1 shows the major difference in structure between the free enzyme and the enzyme-coenzyme-substrate complex. This gives an overall 'before-and-after' picture of a rearrangement but does not reveal whether all of the changes occur simultaneously and concertedly or in stages and independently. In other words, local defined kinetic information is needed to relate motion and catalytic function.

Our original attempts to provide this for mammalian LDH relied on using chemical modifications to introduce reporter groups at defined sites. While this approach showed that substrate-induced structural changes occur at different points in the catalytic cycle, the range of chemically introduced reporters was rapidly exhausted and so we turned to the genetic methods of modification and to the structurally and kinetically similar LDH from a high-temperature bacterium. SDM was used to take out the three tryptophan residues in the native bacterial LDH and create mutants containing only one tryptophan at a good reporting position. This process, perhaps surprisingly, has in no case disrupted the catalytic function of the enzyme, and single-tryptophan fluorescence is now used routinely to correlate local movements with stages in catalysis.

Transition-state stabilisation

An inspection of the two extreme LDH X-ray structures suggests that the substrate-induced loop closure has two chemical consequences:
(1) it pushes the nicotinamide group of the coenzyme into an oily pocket (thus stabilising the neutral NADH in preference to the charged NAD^+); and
(2) it shifts a 'loop' arginine residue (109) by 8 Å, from a position in the solvent to one in the active site within hydrogen-bonding distance of the carbonyl oxygen of pyruvate (see figure 2).

To examine the role of this mobile and basic residue, it was replaced by the neutral glutamine. In contrast to the non-intrusive tryptophan mutations, this is an example of the substitution of a conserved residue (in all 22 known LDHs), intended to cause a functional disruption of the enzyme which can then be interpreted. In the event the mutant enzyme loses only 2 kcals of binding energy for the ground state pyruvate molecule, but for its transition state must lose at least 6 kcals; the transfer of H^- from NADH to substrate, rather than loop closure, now being the slowest process in pyruvate oxidation (see figure 3). The entry of the positively charged arginine-109 into the active site as the

Protein engineering on lactate dehydrogenase

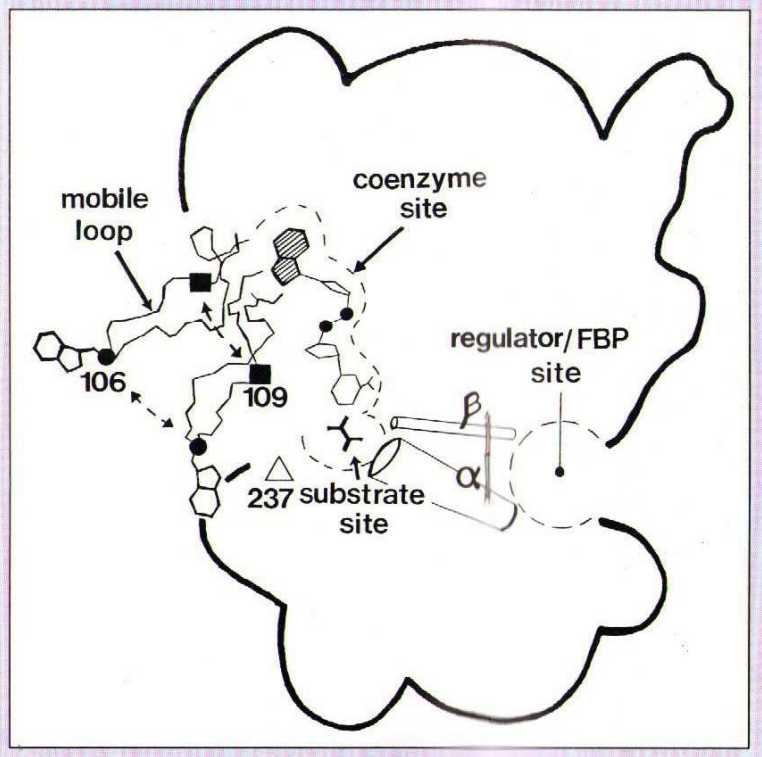
The use of modern nucleotide chemistry to synthesise parts of genes and so direct amino acid substitutions in proteins has supplied the only precise and reliable way of altering their covalent structure. This method, called site-directed mutagenesis (SDM), has removed an enormous barrier to understanding the relationship between the structure and the behaviour of proteins and, in addition, has allowed us to modify their properties, in a rational way, to suit industrial purposes. In short, the protein chemist is no longer limited to what Nature supplies, supplemented by a few 'hit and miss' chemical modifications, but can modify or design proteins at will. From this technical achievement a new field of science is rapidly emerging; it has been termed 'protein engineering'. As an illustration of the potential of protein engineering, Dr Anthony Clarke of Bristol University describes the progress made by applying it to the study of the enzyme lactate dehydrogenase (LDH).

loop falls stabilises the negative charge developed on the carbonyl group of the pyruvate-lactate transition state by at least 4 kcals (see figure 2).

Bonding and substrate recognition

Figure 2 shows that the carboxylate group of the bound substrate is held by the guanidinium group of arginine-171. On changing this residue, which makes a two-point interaction with the carboxylate, to a lysine (which can only form a single bond) 6 kcals of substrate-binding energy is lost. The strength of the guanidinium-carboxylate interaction, which contains both an ionic and a hydrogen-bond component, is an important consideration in designing tight binding pockets for carboxylic acids. The arginine-171 residue is also important in binding specificity; the lysine mutant is unable to bind pyruvate in preference to other keto-acid substrates with larger alkyl groups. The strong orienting effect of an arginine-171-carboxylate bond allows the enzyme

Figure 1: The LDH subunit



to discriminate between keto-acids by forcing the alkyl group into a recognition cleft (formed by residues thr-102, arg-109 and gln-246).

Communication between effector-site and active site

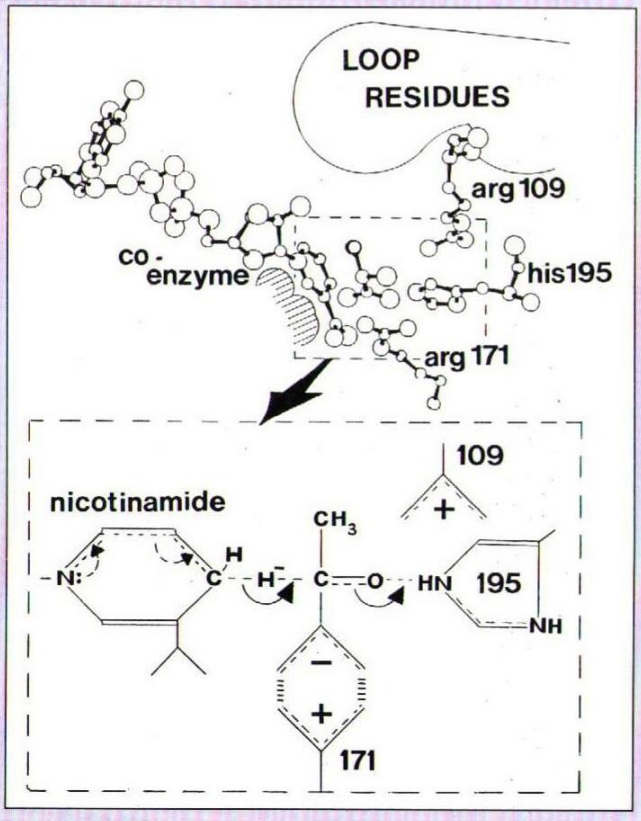
One of the few differences between mammalian and bacterial LDHs is that the latter only binds substrates tightly when fructose-1,6-bisphosphate (FBP) is attached to the enzyme. In many bacteria this regulation acts as a switch between the production of lactate and of other industrially important catabolities, for example ethanol. Engineering the effector-regulation in LDH offers the opportunity of modifying the enzyme's response to FBP and of controlling the fermentative output of certain bacteria.

The regulatory FBP-site is formed at the end of two structural 'rods' (an α-helix (α) and an extended chain (β), see figure 1). The other ends of the rods are 20 Å away and form the substrate-binding site. Removing a single basic residue (arginine-173 -> glutamine) stops the acidic FBP making contact with one of these rods and completely blocks the activation signal. As the mutation has no other effect on catalysis and still allows FBP to bind, we conclude that activation occurs by the ability of FBP to optimise the arrangement of the rods for substrate binding.

General measurement of the local flexibility of a protein

One of our general and encouraging

Figure 2: Active site structure and chemistry



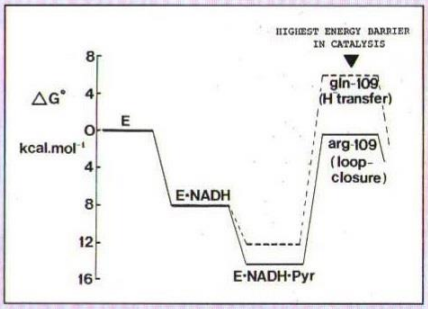


Figure 3: An energy profile of pyruvate reduction; arginine-109 allowing more rapid catalysis

observations on mutant LDHs is that amino acid substitutions have only local effects and do not disrupt the structure and behaviour of the whole protein. Large proteins like LDH (molecular weight 134,000) are stabilised by an extensive network of intramolecular bonds and disruption of only one or two will usually have less influence than in a small protein which has fewer bonds to determine its overall structure. In this sense, it is desirable when building new properties on to a protein to choose a structurally stable scaffold.

Yet, as we have shown, proteins are mobile structures and a knowledge of the principles that underly industrially desirable properties, such as resistance to high temperatures, to extremes of pH, and to organic solvents, requires an understanding of structural movement. Nuclear magnetic resonance cannot usually be applied to large proteins so, for these, an alternative method of mapping flexibility and changes of structure has been developed. Protein engineering enables the construction of single-tryptophan versions of any protein and these can be used to map the flexibility of specific parts of the structure by measuring the rotational correlation-time or the lifetime distribution of the indole fluorescence.

The first of these measurements yields information on the extent and rate of the group's motion and the second on the number and range of environments it occupies. An initial survey of four sites in LDH using these methods has shown that the inserted tryptophans respond predictably to the local protein environment, the temperature and the binding of ligands. At present, we are extending this method to mapping local 'melting-points' from which thermal denaturation is triggered, and to plotting pathways of protein folding and subunit assembly in LDH. It is the lack of correct protein-folding that still limits the production of many physiologically active and therapeutically useful human proteins in bacteria on a large scale.

Dr A R Clarke
Department of Biochemistry
Bristol University

Biochemical engineering transforms protein processing

Proteins are important food components, industrial enzyme catalysts and diagnostic agents based on antibodies and enzymes. Treatment by human protein therapy is already life saving in some medical conditions and, as a result of advances in biotechnology, it may soon be more widely useful. Given the importance of proteins in terms of health and commerce, write Dr Michael Hoare and Professor Peter Dunnill of University College London, the study of protein processing has been a major research theme in the Biochemical Engineering Group at UCL, and in recent years the work has been supported by a special rolling grant from the Biotechnology Directorate.

Biochemical engineering, which had its beginnings in the 1950s, is creating a process engineering foundation for the biological industries comparable to that provided to the chemical industries for much longer by chemical engineering. A prime concern of biochemical engineering is whether seemingly delicate macromolecules such as proteins can be handled in conventional process engineering equipment or require specialised and more expensive devices. Many of the proteins of interest are roughly spherical in shape with few cross-links between the folded chains of their constituent amino-acids. It might be expected therefore that proteins would be damaged by the substantial shear forces in operations, such as pumping, mixing and continuous-flow centrifugation. Early attempts to scale up laboratory isolation of enzymes and non-catalytic proteins often yielded far less undamaged product. However, our studies have shown that shear alone is not the cause.

We have found that a typical enzymic protein, such as alcohol dehydrogenase, is able to withstand the very high shear rate of 26,000 sec^{-1} in a laminar shear test device for more than an hour with no loss of catalytic activity — a good measure of maintenance of structure. Under turbulent flow conditions in a stirred tank, the same enzyme remains fully active after 12 hours of intense mixing corresponding to a Reynolds number of 10^6. But this striking robustness is only preserved in the absence of any gas—liquid interfaces. If these are present, damage is rapid and substantial. It has long been known that globular proteins unfold at gas—liquid interfaces but usually the total damage is small because the unfolded molecules accumulate at the interface and so protect the bulk of the protein in solution. However, intense mixing strips the damaged molecules away from the interface and they are replaced by other protein molecules, which in turn will be damaged.

These observations in test systems suggested that conventional industrial equipment could be used directly or modified to handle water-soluble globular proteins, if it could be operated to exclude gas—liquid interfaces. This has proved to be the case. For example, studies of a variety of industrial pumps showed that damage can be prevented for up to one thousand passes at least, a number only rarely exceeded in biotechnology applications. In using ultrafiltration membranes for the separation of proteins, particularly high shear fields are an intrinsic consequence of the need to sweep the upstream membrane surface with fluid to prevent build-up of a protein layer and reduction in liquid flux. Serious damage to processed protein is often reported and attributed to shear-induced effects. But it seems evident that a major cause of reported low yields during industrial

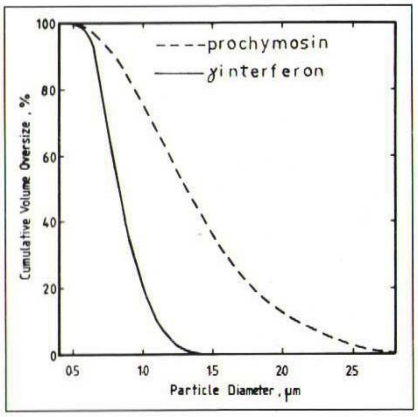


Figure 2: Particle properties of protein inclusion bodies arising from the synthesis in the bacterium, E coli, *of recombinant calf prochymosin and γ-interferon.*

Figure 1: Electron micrographs of thin sections of bacteria genetically engineered to produce a high concentration of just one protein foreign to the cell. The newly synthesised protein is present as an insoluble inclusion body which shows up as a dark mass in the centre of the cells.

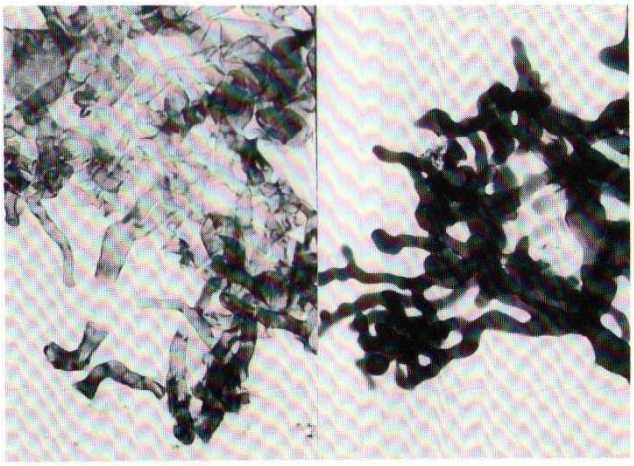


Figure 3: The fungal microorganism Rhizopus nigricans *before (right) and after (left) disruption in a high pressure industrial homogeniser to release the membrane-bound enzyme complex which 11α-hydroxylates the steroid progesterone.*

membrane separation and other operations is air trapped in the fluid flow, which is easily caused in setting up industrial process equipment. Our studies have shown that even here careful process design and operation can prevent measurable losses. (We showed in an earlier study that the long processing time for industrial-scale batch recovery of proteins allows degradative enzymes to cause substantial loss of yield, but this source of damage can be greatly reduced by continuous processing techniques which have low residence times).

Membrane-associated proteins

Protein molecules, which are several nanometres in diameter, can evidently evade shear damage within the larger 'packages' of fluid which external mixing does not disturb, but what of larger assemblages containing globular protein molecules? Recently, we have studied enzymes associated with biological membranes because many of the highly selective reactions that industry would like to catalyse, such as steroid hydroxylations, are brought about in nature by enzymes embedded in bilayers of lipid membrane. These membranes often occur in cells as onion skin-like structures. They have dimensions approaching those of the cell — that is, several micrometres, or a thousand times the size of a protein molecule. When a microbial cell is mechanically disrupted to release the contents, the relatively large membrane vesicles are broken up by the shear fields which are applied and they form microsomes — microspheres of membrane a fraction of a micrometre in diameter. Major losses of activity can occur during the formation of microsomes because reactions catalysed by membrane-associated enzymes typically require intimate interaction of several neighbouring proteins, and this organisation is readily disturbed or destroyed. Once the size reduction is complete, the microsomes are again small enough to resist further mechanical damage. We have been using size-analysis instruments based on centrifugal sedimentation, conductivity and photon-correlation spectroscopy to examine the nature of the particles formed during cell rupture. The intention of this work is to devise improved methods of rupture using mechanical and non-mechanical techniques that will cause less damage during microsome formation.

Precipitation

One of the most widely used techniques for recovering globular proteins of all kinds from solution is precipitation. Proteins form fine, highly hydrated, precipitate particles with a density typically only 30 to 50 kg m^{-3} above that of the aqueous medium. Therefore their recovery on a large scale — usually by industrial centrifugation — is not straightforward. Anything that can be done to increase particle size will be valuable, and increasing their effective density also will be important. Protein precipitate particles have mean sizes in the range 1 to 10 micrometres so that by the standards of individual protein molecules they are relatively large. As our other studies would suggest, they are highly sensitive to shear fields both during formation and in subsequent handling. At the precipitation stages this calls for careful reactor design.

We have also developed an in-line acoustic conditioning technique, in collaboration with the Edinburgh Protein Fractionation Centre, that can substantially increase the size and density of particles and also improve their resistance to shear-induced break-up. To improve performance further it has been necessary to work with centrifuge manufacturers to reduce the level of shear-induced attrition of protein precipitates which occurs in the entry region of continuous liquid flow machines. Centrifuges are reliable and effective but capital costs are high and, in favourable instances where membrane fouling is not severe, we have shown that pilot-scale ultrafiltration-based methods can concentrate precipitates to 350 kg m^{-3} protein — a level previously only possible on the industrial scale using centrifuges.

The impact of genetic engineering

Because proteins are the biological substances specified directly by genes, the dramatic advances in 'genetic engineering' are having a particularly strong impact on protein and enzyme technology. It is now possible using these techniques to produce an enzyme or protein not normally synthesised by a microorganism at a level of up to 30 per cent of the cell's total protein. For example, prochymosin (the precursor of calf rennin) and human γ-interferon may be produced in this way in bacteria. Natural rennin is in short supply for cheese making and γ-interferon has promise in cancer therapy. However, production using genetic engineering is not straightforward. The manner of synthesis and its artificiality are often reflected in the formation of partially folded protein chains which are interlocked in an insoluble mass, termed an inclusion body (figure 1). The insolubility of the inclusion bodies usefully protects the desired product from protein degrading enzymes, but after disrupting the bacteria, the separation of the bodies from debris and any remaining whole cells has required detailed measurements of their relative sizes (figure 2) and densities. With this information, it is possible to separate the inclusion bodies into a purified form by centrifugation in industrial machines.

The themes of shear sensitivity and particle characterisation which are important in protein processing also run through other studies at UCL — for example, of industrially important mycelial microorganisms and immobilised enzyme catalysts. In this way, a common core of biochemical engineering concepts and methods provides the basis of efficient production of a wide range of useful substances. Each study requires a linkage of engineering with biological science that is characteristic of biotechnology.

Dr M Hoare and Professor P Dunnill F Eng
Department of Chemical and Biochemical Engineering
University College London

Research at University College London on advanced high-speed industrial centrifuges allows more efficient recovery of proteinaceous materials.

Complex buckling of textile fabrics

The study of textile materials is a branch of applied mechanics which was late in starting. There are two main reasons for this: first, there are the complexities of the problem, with a typical piece of textile fabric being a structure containing around 100 million fibres and suffering large, non-linear deformations. Furthermore, there is the fact that experience combined with trial-and-error is an acceptable procedure for making shirts, but not for building bridges. However, the needs are now changing due to the vastly increased range of choice, the use of textiles in demanding engineering applications, and social and educational factors. Dr Amirbayat, Professor Hearle and Dr Leech of the University of Manchester Institute of Science and Technology describe their work.

Analysis of the mechanics of fabrics, which has developed over the last 40 years, divides into two parts. Micromechanics aims at predicting the anisotropic stress-strain relations of the two-dimensional sheet from a knowledge of the yarn properties and the geometry of interlacing. Macromechanics is concerned with the overall deformation of the fabric under given boundary conditions, and it is in this area that our research has been supported by Materials Committee grants from 1980 to 1986. We have been motivated by a desire to understand the mechanics of fabrics in use.

Fabric buckling

In mechanical engineering, buckling is the start of failure and so applied mechanics has traditionally dealt with criteria for the occurrence of buckling, but not with what happens once buckling starts. But in textile materials, buckling is the beginning of success. A sleeve, a trouser leg, a skirt, a curtain must buckle to be of any use, and it is important that the buckling occurs in comfortable, graceful folds.

The buckling patterns are three-dimensional and so involve double curvature. The ability to take up smoothly changing forms of double curvature is a feature which differentiates textile materials from most other sheet materials, as illustrated in figure 1. Paper can be as flexible as a textile fabric in uniaxial bending, but the smallest curvature in one direction makes bending impossible in a perpendicular direction (which is useful in printed sheets). If paper is forced into three-dimensional buckling, it forms sharp points or line discontinuities, not rounded folds. Paper garments are harsh, noisy, and unattractive. Even if strength is sacrificed, as in tissue papers, the geometric form shows sharp points, though the limpness makes them feel soft. The only other sheet materials which allow extensive double curvature are rubber sheets with very low modulus, but these are unsuitable for textile uses for other reasons.

Buckling with double curvature is important in the way that different consumers see and feel textiles. Drape and handle are thus major factors in marketing for the manufacturer. In engineering uses of textile fabrics, the ability to take up complicated shapes is important in forming composites, and the avoidance of sharp creasing is necessary in coated fabrics used for air- or cable-supported buildings and in inflated structures.

About 25 years ago, research led to three developments: a drapemeter, which gave a measure of drapeability; a correlation between subjective and objective assessment; and an empirical association of the drape coefficient with bending and shear stiffness. But then progress stopped, and it is only the recent research which has uncovered the basic mechanics of the effects. The crucial advances have been: the recognition that double curvature, even on a geometrically uniform spherical surface, cannot be treated as a tessellated deformation of uniform strain; and the identification of the simplest unit of deformation within the multiple folds found in a practical buckling situation.

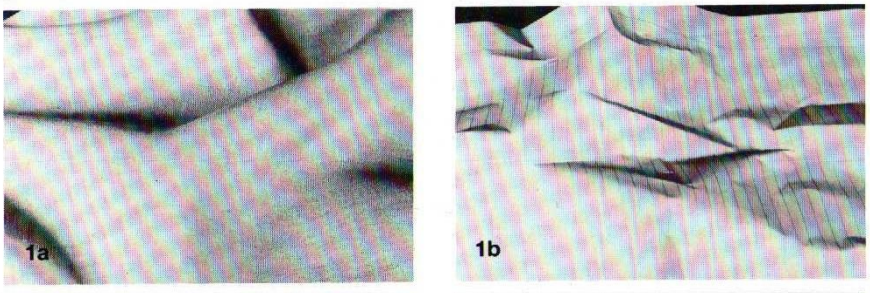


Figure 1: (a) Textile fabric showing multiple three-fold buckling. (b) Paper showing sharp points and lines.

Mechanics of double curvature

Deforming a planar sheet into a spherical surface is the converse of drawing a map of the world on a flat sheet of paper, and, like map projections, requires either change of area or shear, unless there is a loss of continuity (openings in the map or tucks in the fabric). Out-of-plane bending, unless it is uniaxial, is necessarily associated with in-plane strain. In the limit, for an infinitesimal area, the in-plane strain vanishes; but it increases with increase in area at a given curvature. It is because paper cannot accommodate large in-plane strains that it will not take up extensive double curvature, even though it has low bending stiffness. Instead, the double curvature zone tends to zero area, of infinite curvature but zero in-plane strain.

Three-fold buckling

Examination of a complex buckling pattern, such as inside the elbow on a sleeve, shows that it is made up of a collection of places in which three folds come together. The natural three-fold forms are asymmetric and join on to one another, occasionally merging into a single four-fold form. Nevertheless this suggests that the basic problem to be studied first is the buckling of a circular sheet pushed inwards at three equally spaced locations, as shown in figure 2.

An exact treatment would require determination of the coordinates of the three-dimensional surface which would minimise the energy (or alternatively a solution of the equations of force and moment equilibrium). However, simple experiments indicate that the geometry can be closely approximated by a division into two zones: an inner zone

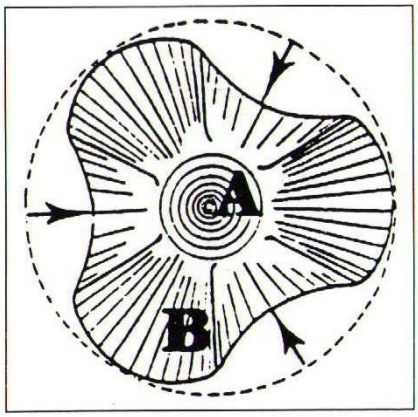
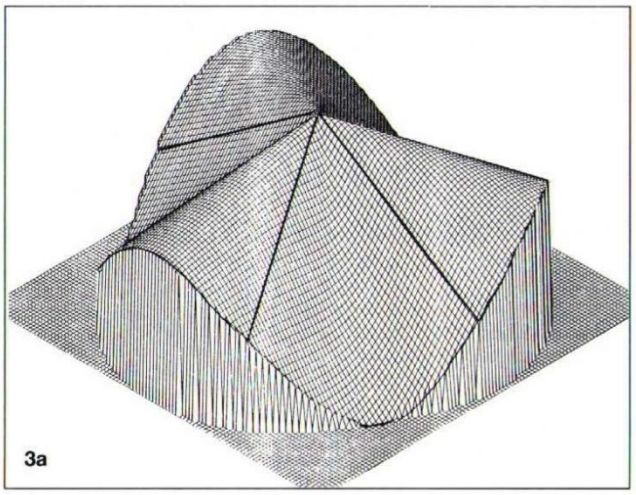


Figure 2: Idealised form of three-fold buckling, with doubly curved central dome A, and outer folds of single curvature B.



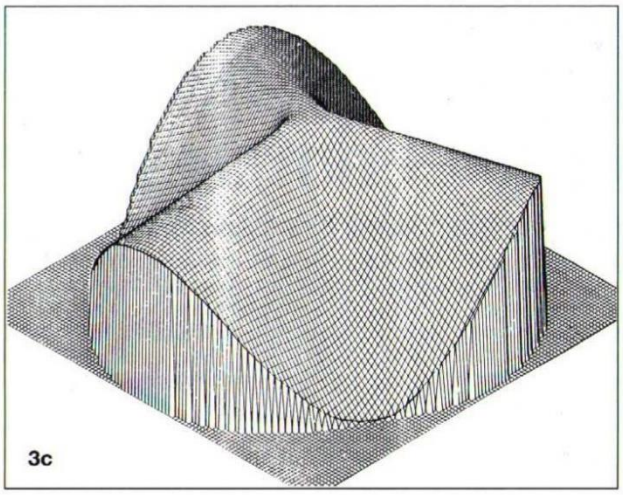


Figure 3: Computed surfaces:
(a) Portions of cones which make up outer zone, meeting at a point; the lines show inflection between convex and concave portions.
(b) Central zone, which replaces the region around the point.
(c) Resultant surface.

with double curvature; and an outer zone of folds of single curvature. The outer zone can be represented by portions of cones, which would come together in a point as in figure 3 (a), with a geometry explicitly defined by the magnitude of the inward displacement. The central zone shown in figure 3 (b) is defined by equations which ensure a smooth fit to the outer zone and contain three variable parameters, fixed by energy minimisation, which also gives the radius of the inner zone. The numerical computation scheme must include the following energy terms: bending energy of each zone, potential energy of each zone, and in-plane (membrane) energy of central zone. The results of a typical calculation which gives the final form shown in figure 3 (c) are given in figure 4. For the particular material properties selected, the double curvature dome occupies 5% of the total area. As the properties change, this area alters.

Closer to reality

The first analysis and computer program was limited to an isotropic Hookean material, but it does serve to demonstrate the essential physics of the problem. The research has therefore been supplemented by the development of a test instrument which enables the contours of the deformed surface and the energy of deformation to be determined. This is one way of getting closer to reality with nonlinear anisotropic textile materials, and of checking the theory with simple materials.

Progress has also been made in the later stages of the research in modifying the computer programs to deal with anistropic, nonlinear mechanical responses, and with asymmetric folding. Finally, an approach has been made towards dealing with a multiple buckling situation. If a large sheet is pushed inwards, the strain energies will be least when there is a single large buckle, but gravitational energy will be least when there are many small buckles. Thus it is necessary to compute the density of buckles which is the best compromise and leads to a stable local minimum energy.

Detailed advances are important, but we would identify our main achievement in this research as taking a textile problem, which was not understood in terms of mechanics, and formulating it in a way which makes the essential features clear. Like most good research, it opens up many opportunities: for more rigorous and more widely applicable analysis, and for investigations of ways of incorporating the ideas into engineering design procedures and thus influencing industrial practice.

J Amirbayat, J W S Hearle and C M Leech
Departments of Textiles and Mechanical Engineering
University of Manchester Institute of Science and Technology

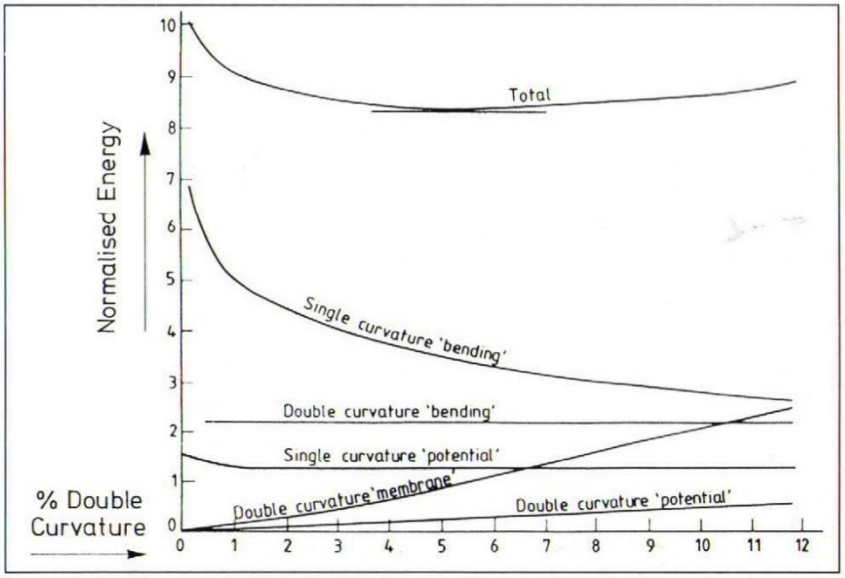


Figure 4: Variation of energy with percentage of total area in double curvature zone, for a 10% inward movement of a circular sheet of plane weave (5 cm diameter).

Equipment facilities for engineering research

SERC's Process Engineering Committee and Machines and Power Committee have over the last year added several items to the list of portable research apparatus available for use by SERC research grant holders. All items listed are available for short-term use in the grant holder's department for work to support current SERC grants. However, availability does vary. Some assistance can be given to set up the equipment, but it will be up to the user to run the apparatus.

Imacon camera (Hadland Photonics 790)

This high-speed image converter camera can produce up to 16 images on one Polaroid print. The speed range is in steps between 1×10^4 and 2×10^6 frames per second (fps) or, for streak work, 10 to 1000 nS/mm. (An article describing the camera more fully appeared in *SERC Bulletin* Volume 3 No 6, Autumn 1986.)

Cinemax image intensifier (Hadland Photonics)

Manufactured for use primarily with the Hadland Photonics Hi-speed cine camera, this image intensifier can also be used with a Fastax or with the Imacon camera above (the camera is not included). It is suitable for enhancing the brightness of dim self-luminous events, with a gain of approx 250 for white light. Resolution is 20 line pairs/mm. The Cinemax is mainly used on combustion research.

Image analyser (Oxford Framestore Applications)

This apparatus can be used with the Imacon camera, the two videos described below, and with any image input. Four video frames can be stored in 64 grey levels for further manipulation. Image processing software allows averaging, measurement, contrast enhancement and subtraction, as well as particle size and fringe pattern analysis. Output can be stored using disc, video or dot printers.

Laser velocimeter (Polytech L2F)

The L2F provides twin focus time-of-flight measurement of seeded particles in fluid flow in the range of 0.5 to 3000 m/s. The apparatus includes multi-channel analysis of velocity, which can be synchronised to measure between rotating blades. The measurement volume is very small and can be within fluid boundary layers.

High-speed video (NAC 200)

The NAC 200 has a fixed operating speed of 200 fps using a single camera and synchronised strobe light. It records on to standard VHS tape to NTSC (American) standard, and features include slow speed forward and reverse playback and excellent still frame picture. The maximum recording time is 30 minutes.

Ultra high-speed video (Kodak Ektapro 1000)

For even faster recording, this video provides operating speeds from 30 to 1000 fps at full aspect ratio via two synchronised cameras and a strobe flash, and speeds up to 6000 fps with narrow aspect ratio pictures. Features include a fixed playback speed of 30 fps and still frame picture. The maximum recording time is 30 seconds at 1000 fps.

Differential scanning calorimeter (Stanton Redcroft HT DSC1500)

Quantitative thermal analysis of small samples with respect to a reference can be obtained using controlled rate of temperature change up to 1500°C. This item is used to obtain mechanical and thermal properties, the chemical reactivity and characterisation of materials.

View of moving sand grains using the Kodak Ektapro.

Droplet and particle size analyser (Malvern 2604 Lc - extended range)

The analysis of particle sizes from 0.5 to 1800 μm is determined by laser diffraction. The subject can be in the form of transient, pulsed or continuous sprays or as a powder in suspension. The analyser uses a central processor and a colour graphics plotter.

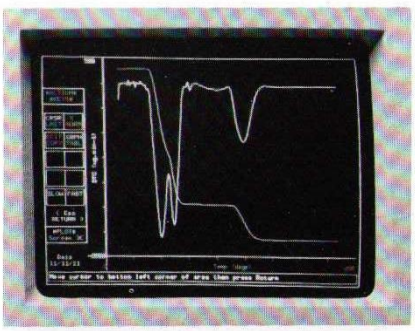
Autosizer IIc (Malvern PCS 45)

Submicron particles in suspension are analysed by laser scattering. This model measures size distribution, molecular weight and diffusion coefficient of particles in the range 0.003 to 3 μm, molecular weights of 10^3 to 10^{14}. The autosizer uses a central processor and a printer output.

Thermal analyser (AGA Thermovision 780)

This unit, previously available via the former Polymer Engineering Directorate, is a flexible infrared measuring system to study thermally or spatially fixed or moving objects. The temperature range possible is between 20 and 1600°C with thermal sensitivity of 0.1°C at 30°C. Five lenses (3.5 to 40°) are available. Images are recorded on to Polaroid or 35mm film and thermal information can also be recorded, processed or analysed using either analogue or digital techniques.

For technical advice on the suitability and availability of these items, and for application forms, please contact Pete Goodyer at Rutherford Appleton Laboratory, telephone Abingdon (0235) 21900 ext 6272. Priority use of the Cinemax image intensifier, the laser velocimeter and the high-speed video will be given to those people holding grants administered by the Machines and Power Committee. On all other items, priority will be given to those holding grants from the Process Engineering Committee.



Typical DTC vs temperature output from the Stanton Redcroft calorimeter.

Optical fibre instrumentation spin-off from power switchgear research

Power switchgear research funded by SERC has yielded valuable spin-offs in optical fibre instrumentation systems. The continuing research at Liverpool University is serving as a useful catalyst for the interaction between industries having complementary interests in the manufacture and utilisation of such systems, writes Dr Gordon Jones of Liverpool University.

Although power circuit breakers form a crucial link in the protection of power systems, their condition monitoring and control have until now been limited on account of the inherent difficulties imposed by the hostile environment of the circuit interrupter on conventional electronic instrumentation. This limitation is due to the strong magnetic fields produced by high fault current flow (> 63 kA rms), electromagnetic interference produced by the current interruption process, high voltage transients due to the network response to current interruption (> 420 kV), chemical aggressiveness (due to temporary decomposition of the insulant gas, SF_6, during arcing) and the severe mechanical stresses imposed by high accelerations during switch operation.

Research performed at Liverpool University in collaboration with NEI Reyrolle and GEC and funded by SERC demonstrated the feasibility of using optical fibre-based systems within the environment of commercial circuit breakers for monitoring optical spectra during arcing. This work had two major spin offs. First, it led to new possibilities for the spectral monitoring of plasmas in material processing. The industrial implications of this aspect are being examined through experimental work at Liverpool University.

Secondly, the work has formed the basis of a new generation of optical monitoring sytems for a variety of parameters in manufacturing and process industries which include pressure, temperature, displacement etc. This aspect of the research is based upon new concepts relating to the evolution of sophisticated forms of multiwavelength optical modulation and is being sponsored by SERC, BICC and NEI. The technique is proving to be extremely flexible and enables the monitoring of a variety of physical parameters using common instrumentation. These new concepts are attracting wide industrial interest because they are adjustable for both coarse and fine measurements and adaptable for a range of signal transmission distances. To date, operation over a total transmission distance of at least 9 km has been shown to be feasible, with displacement sensitivities of considerably less than 1 μm.

The sensor systems are not only for use for circuit-breaker monitoring but are also being extended to other applications such as plasma processing systems and medical research in special environments both of which, like the switchgear application, are subject to serious electromagnetic difficulties. First generation sensor systems have already been engineered and demonstration projects and field trials are being implemented. The first such system (figure 1) has been installed in conjunction with BICC for monitoring at the chemical plant of A D Plastics Dentsply, Blackpool, where a potentially explosive hazard exists. A second upgraded system has been installed for assessment at the short circuit test station of NEI Reyrolle, again in collaboration with BICC, for circuit-breaker testing and development.

Sensors for medical applications are being assessed by Liverpool University Department of Medicine. Such field trials are regarded as essential for the transfer of the new technology to the commercial sector and for ensuring its acceptability by the industrial community.

Dr G R Jones
Department of Electrical Engineering and Electronics
Liverpool University

Figure 1: Prototype sensor under laboratory test.

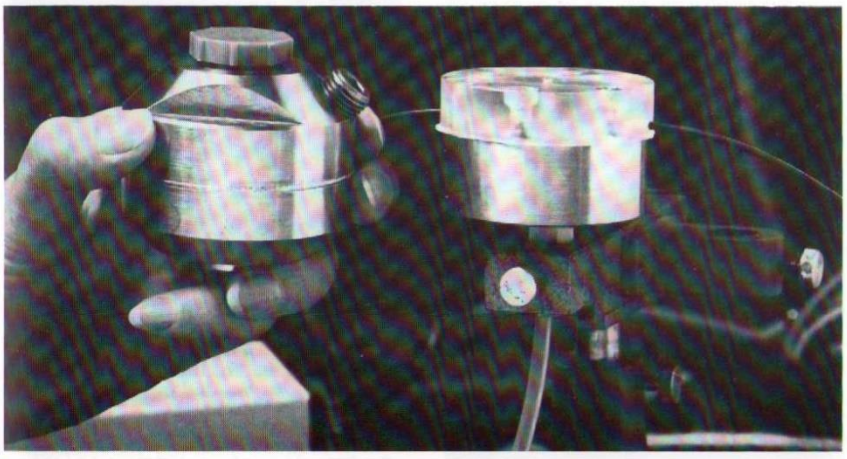


Figure 2: A conventional sensor (left) and an opticalty adapted sensor.

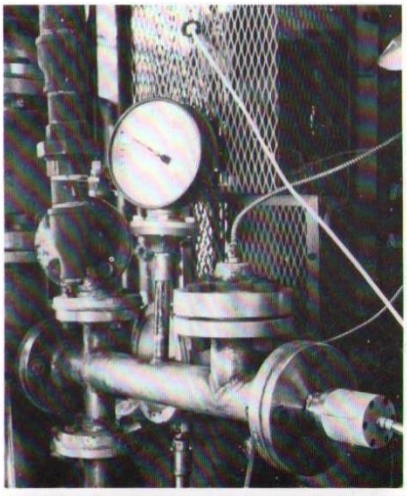


Figure 3: Assembly for the optical monitoring pressure, temperature and shaft rotation on a chemical plant.

Fatigue testing of wood for aerogenerator blades

The large-scale generation of electricity by wind turbines is no longer the environmentalist's dream. Substantial wind farms, and single aerogenerators of up to 5 MW capacity, are in operation in countries such as Denmark and the USA. In the UK James Howden and Co Ltd and the Wind Energy Group have developed prototypes and subsequently set up wind farms in California. In each case the aerogenerator blades are constructed from laminated wood which offers specific strength, stiffness and cost advantages over denser materials such as steel, aluminium alloys and composites. The fatigue properties of wood and wood laminates have in the past been sparsely documented, and work in the School of Materials Science at Bath University is intended to expand the available data base for the fatigue life of wood. It is described here by Dr Martin Ansell.

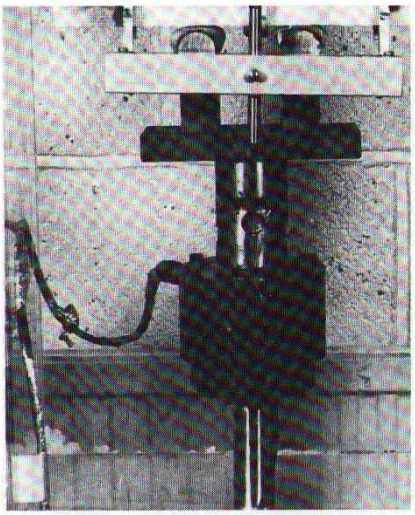


Figure 1: Wooden beam subjected to repeated fatigue loads in a humidity-controlled environmental chamber.

Early work in the 1940s on the fatigue properties of wood was based on deflection-controlled fatigue experiments in flexure. Fatigue testing at Bath is load-controlled using a half-tonne capacity servohydraulics fatigue frame. Wood is a viscoelastic material that will creep during a fatigue test and so load control is essential for simulating constant wind and gravitational loads experienced by a rotating blade.

Wood samples are subjected to repeated and reversed cyclic loads (figure 1), in an environmentally conditioned chamber where the moisture content of the wood, which critically affects its properties, can be controlled. The load cell is situated below the specimen and the control signal in analogue form can be supplied by a signal generator from the control panel, or by a digitised signal from a Macintosh microcomputer through a digital-to-analogue converter. The beam centre point deflection can be measured with an LVDT displacement transducer to allow real-time analysis of changes in the sample compliance, calculated by the computer via an A-to-D converter.

The effect of moisture content on the fatigue life of wood is demonstrated in figure 2 for Khaya ivorensis, an African mahogany used in the manufacture of aerogenerator blades. Although the fatigue life of wood is variable at a given cyclic stress level, there are clear trends which show that high moisture content reduces fatigue life. In practice, wooden blades have a moisture content of no more than 10% and they are protected from the environment by a glass-reinforced plastic skin. Sets of fatigue data for laminates at 10% moisture content are combined to produce constant life-lines, essential for the design of wooden blades.

Unlike metals, wood is stronger in tension than in compression. It has thus been an important objective of the programme to determine microcellular failure mechanisms for wood by inspecting cellular damage on the compression face of cyclically loaded beams. After 500 cycles of fatigue load at 75% of the ultimate flexural strength, longitudinal cells of Sitka spruce are examined (figure 3) by optical microscopy of sledge-microtomed wood sections. Clear evidence of compression damage can be seen, crossing the cell walls in the form of microscopic shear planes which are accentuated by polarised light. Horizontal zones of such microfailures are termed compression creases and after 10^5 cycles (figure 4) extensive cell rupture has occurred which can be seen by eye on the sample surface as a fine line. As the fatigue test continues the compression crease develops progressively deeper towards the neutral axis of the beam. Such damage in Khaya, although present, is

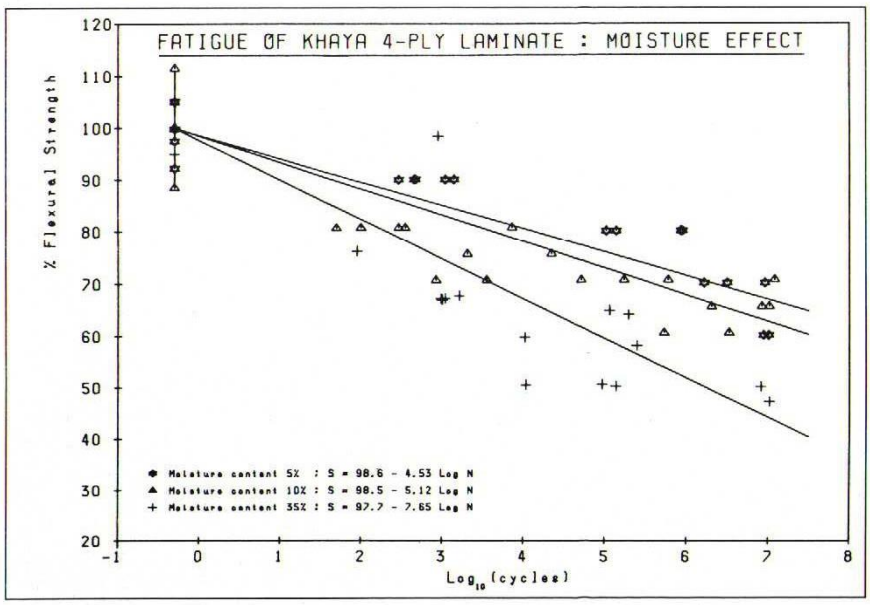


Figure 2: Fatigue life characterisitcs for Khaya ivorensis laminate at moisture contents of 5%, 10% and 35%.

Figure 3: Fine microscopic cell wall creases in a radial longitudinal section of Sitka spruce after 500 cycles of load at 75% of the ultimate flexural strength.

much more difficult to observe because of the more open microstructure of hardwoods.

The Materials Committee-funded programme has now been supplemented by a substantial grant from the Department of Energy under its generic materials evaluation programme for wind energy. Uniaxial tension/compression fatigue loads can be applied to wood using two 20-tonne capacity servohydraulic machines. The fatigue programmes have been carried out in collaboration with Composite Technology Ltd, designers and fabricators of wooden laminated aerogenerator blades.

Dr Martin P Ansell

School of Materials Science
Bath University

Figure 4: Extensive cell wall rupture after 10^5 cycles. Crossed circles are cell wall pits viewed under polarised light.

Creep properties of softwood

A group at the Polytechnic of the South Bank under Dr D G Hunt, supported by a Materials Committee grant, have been investigating the creep properties of softwood in changing climatic conditions. Dr Hunt describes the work.

If a wooden part is under-designed, it usually shows up as excessive deflection rather than actual fracture. Part of this deflection is instantaneous, or elastic, and part is time-dependent, or creep. The creep deflection can be anything from 25% to 80% of the total over a long period, depending on the conditions and the quality of the material. The conditions that affect creep are loading, temperature and moisture. Detailed studies of wood creep under constant conditions have been made over the years by various laboratories, and these have been incorporated in the design standards.However, wood is a hygroscopic material, and it is well known that during changing humidity conditions wood can creep considerably more than in either high or low constant-humidity conditions. Because of the practical difficulties, this changing-humidity phenomenon, known as mechano-sorptive creep, has not been studied enough in the past to provide design guidance.

The experiments are performed in two purpose-built environmental chambers. The first chamber houses a number of specialised testing machines for exploratory measurements. Any interesting results are then studied in a more routine manner on 12 identical bending-creep machines in the second chamber.

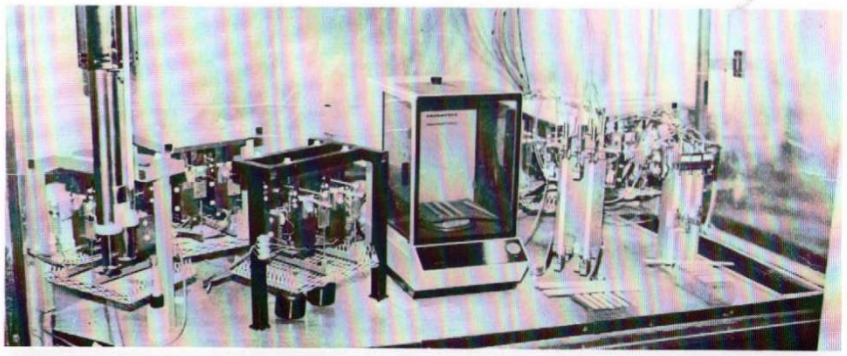
A special study has been made of correlations of the mechano-sorptive creep susceptibility with some other materials properties, susceptibility being determined from the slopes of deflection versus moisture-contents graphs. It was found that a wood sample that was resistant to mechano-sorptive creep also had a characteristically small angle between the main load-bearing microfibrils and the grain direction (measurable by X-rays). It also had a low elastic or instantaneous deflection and characteristic dimensional movements with moisture changes. The intention of these correlations was to find a simple 'fingerprinting' technique in order to grade material for resistance to creep without doing any actual creep tests on it.

The ability to sort susceptible from resistant pieces of wood, by means of instantaneous elastic deflection, means that a standard stress-grading machine, without any modifications, can sort timber for resistance to excessive deflections in service as well as for resistance to fracture, as at present. Timber stress-grading machines involve passing members along a continuous line through rollers that apply a small bend and automatically compute the resulting compliance — a parameter that has been found to correlate well with fracture strength.

The correlations that were found also allow the matching of test pieces by simple pre-tests, thus reducing one of the main obstacles to research in this field; namely the large variation of properties within a sample and the consequent difficulty of drawing conclusions. Other observations that will allow the simplification of testing programmes are the general similarity of response in bending and tension and some that point the way towards the development of accelerated creep-testing methods.

Dr D G Hunt

Department of Mechanical and Production Engineering
South Bank Polytechnic



Inside one of the environmental chambers at the South Bank Polytechnic, showing bending machines, hygrometer, balance and zero-load movement apparatus.

Teaching Company Programmes at Strathclyde

The Department of Design, Manufacture and Engineering Management at Strathclyde University has had a long-standing involvement with the Teaching Company Scheme. Its initial programme, at Anderson Strathclyde (Motherwell), was the first in Scotland when it began in 1977, and since that time the department has had a succession of programmes, with Rolls-Royce Ltd (Glasgow); NEI Peebles (Edinburgh); James Howden (Glasgow); IBM (Greenock) and Cummins Engines (Shotts). Programmes continue to run at four of these, and are described here by Professor D S Ross of Strathclyde University.

Anderson Strathclyde

Anderson Strathclyde manufactures mining machinery, which involves a high level of specialism in electro-mechanical-hydraulic design, coupled with high quality precision engineering. Before the Teaching Company Programme with Strathclyde, Anderson's was starting to use advanced manufacturing technology in the form of magnetic tape-controlled machine tools. Design was carried out in the traditional manner, on the drawing board. With the creation of a Teaching Company Programme, and a well considered capital expenditure budget, the company was able to assess the potential for changes in its design office practices and in its manufacturing methods.

A national and international survey of available CAD/CAM facilities by an associate led to a decision by the Teaching Company Directorate to install a Computervision system in the university department, and this was used by company and departmental staff. Within a year, the company had purchased a full system and had trained a nucleus of design staff in its operation.

On the manufacturing front, other Teaching Company Associates were investigating materials handling techniques for large steel castings, gear manufacture and numerically controlled machining. For the latter, a proposal was drawn up for what must be among the first of the flexible manufacturing systems (FMS) installed in the UK.

This FMS, with an investment of some £6.5 million, was designed for the manufacture of the large, steel prismatic components which make up units of the company's products. Throughout the entire period, from the start to the hand-over of the system to the company, the Teaching Company Associates and the university staff were involved with the company staff in a variety of ways. The experience gained by all parties was considerable. With the need to minimise tooling costs for such a large system, consisting of six large machining centres each with tool magazines carrying 100 tools, a programme of rationalisation in design, and design for production was initiated, with a Teaching Company Associate leading the drive. This process has continued.

Another area of interest, pursued by two Teaching Company Associates in succession, is the application of computers to the test procedures for mechanical, electrical and hydraulic systems. This important project has led to the selection and initial testing of a data acquisition and control system for the test facilities in the company.

In the CAD/CAM area, an associate is completing his work on a project entitled *CNC machine instructions generation using CAD-created data,* with specific application to the products being produced on the flexible manufacturing system line.

IBM United Kingdom Ltd

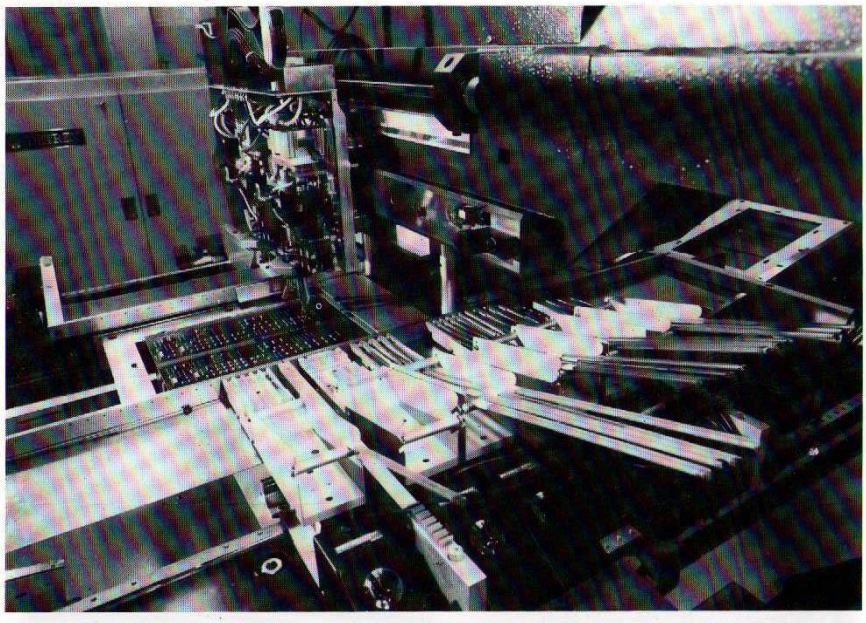
At IBM United Kingdom Limited (Greenock), two programmes are under way. On the main programme, seven Teaching Company Associates have been involved to date. Their project areas are quite diverse, as there are many areas within the company from which to choose.

One of these has been in the development of flexible circuits. The Teaching Company Associate involved in this was a school teacher (of chemistry) who wished to change her career. Her graduate background in chemistry was ideally suited to the work which she ultimately carried out to a successful conclusion with IBM staff collaboration.

A second Teaching Company Associate was involved in the production processes applied to surface-mounted components. He assisted with the development of the techniques, and the installation, commissioning and staff training associated with a computer-controlled automated production line.

Another associate was involved with stress testing of printed circuit boards, and with the application of thermal imaging for quality control purposes.

Environmental testing forms the basis of one current project, in which the associate is seeking to identify control system requirements and hardware appropriate to the company needs. Chemical safety and process control is being handled by an associate who was previously an industrial chemist, and who is now working closely with the company staff in developing and



Surface mounting of components is performed automatically by this special purpose machine, part of a major installation at IBM (Greenock) developed with Teaching Company involvement.

installing procedures associated with an automated processing line. Computer simulation of manufacturing processes is the subject of study for the sixth associate, while the seventh is involved in an investigation into the use of expert systems in manufacture.

James Howden

The programme at James Howden (Glasgow) has two associates, one of whom is working on project planning and control applied to a large FMS installation in the company. This programme includes the selection of appropriate computer software and developing its application to the installation of the FMS.

The second associate is involved with the development of software to monitor the overall performance of the FMS and this includes hardware aspects such as tooling for the Scharmann machine tools.

Cummins Engine Company

At Cummins Engine Company (Shotts) there are three associates in post. The company has embarked on the installation of an advanced FMS which will utilise some 27 machines, robots and after-handling devices for a family of diesel engine parts covering a range of engines. The whole programme is thus directed towards the design, installation and integration of the system. One associate is therefore working on computer simulation of the complete system, using ISTEL software and IBM hardware, which are available both at the company and in the university department. This associate required initial training in the use of the system by ISTEL, and she is now working alongside the company staff developing the simulation model.

The second associate is tackling the tooling technology needs, and the tool-management requirements, while the third associate is dealing with the system interfacing and computer linking aspects. Two further associates will be introduced to become involved with the commissioning and integration of the eight manufacturing cells which comprise the FMS.

Apart from these continuing programmes, two others have been completed, one at **Rolls-Royce Ltd** (Glasgow), where the associates were involved with the company staff in preparing a feasibility proposal for an FMS for small turned parts; and the second at **NEI Power Distribution Transformers** (Edinburgh), where the associate successfully introduced new manufacturing processes and materials handling practices, the savings accruing to the company greatly exceeding their investment in the Scheme.

There have been very positive benefits to the university staff as a result of their involvement with these programmes. The highly practical basis of the experience gained has been applied to new lecture material and case study examples. A new SERC-supported research programme on *Modular simulation models for FMS* has been developed. Furthermore, the staff feel they have been privileged to be involved with the introduction of the latest technology.

These examples of Teaching Company programmes show the great variety of opportunties that exist for associates, companies and academic staff to become involved in a productive and challenging scheme that has benefits for all participants.

Professor D S Ross

Department of Design, Manufacture and Engineering Management
Strathclyde University

European Community Stimulation Programme

The objective of the Stimulation Programme is to foster high-quality collaborative research in basic science between laboratories in Member States of the European Community. Following an experimental phase, it has now operated for two years. Some fields of activity have been identified for attention under the programme but it remains open to high quality proposals in all areas of science and engineering.

The programme supports three types of project:

- *laboratory twinning* which assists groups of researchers working in similar or complementary areas to collaborate, and hence to reach a higher level of achievement, with grants covering travel, subsistence and additional expenses of joint work;
- *operations contracts* which support teams of researchers in different Member States who agree to work together on a specific project having a practical objective;
- *research grants* which aim to encourage mobility among both young and experienced researchers in Member States by assisting the costs of transfer to another laboratory.

Funding is at a level of approximately 15 million ECU a year (1 ECU is about £0.7). The amount of support given by the Commission to each selected proposal varies according to the method of support required. The EC aims to cover 100% of the expenditure needed for the collaboration. The programme is scheduled to continue to 1988 but will be subsumed with the 1987-91 Framework Programme and extended to 1991.

Research proposals are assessed by referees and selection is by the Committee for the European Development of Science and Technology (CODEST), whose members are distinguished scientists from Member States. There are no closing dates. Applications may be submitted at any time and are considered at the next appropriate CODEST meeting.

Rutherford Appleton Laboratory (RAL) and Daresbury Laboratory (DL) have secured the following funding to cover their parts of approved stimulation programmes:

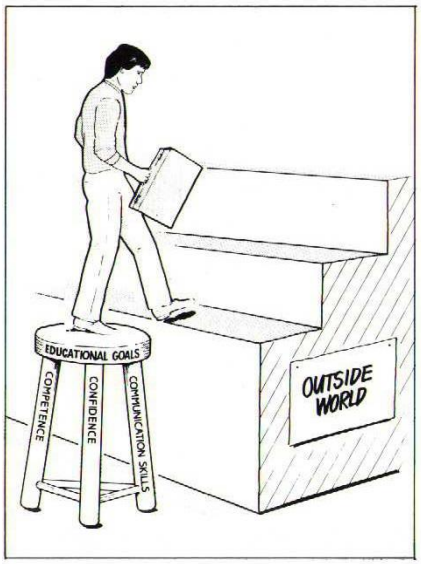
£120,000	A muon spin resonance facility on ISIS (RAL, Munich, Parma and Saclay)
£23,000	Study of climate transients (RAL, Kiel and Palaiseau)
£17,000	Computational and theoretical study of the charge-transfer reaction in collisions of multi-electron atoms and ions (DL and University of Bordeaux)
£16,500	Development of the European Suppression Shield Array (DL, Liverpool, Manchester, Bonn, Cologne, Copenhagen and Milan Universities, NRC Demokritas Athens and KFA Julich)
£15,000	Multilayer film development for the extreme vacuum ultraviolet and soft X-ray regions (DL, Aberdeen University and FOM Amsterdam)
£2,000	Study of high power interferometers for the detection of gravitational radiation (RAL, Glasgow and Paris Universities, Max Planck Institute and INFN Pisa)

UK academic groups have also been successful in participating in the Stimulation Programme. Out of 289 projects supported through the programme since 1985, 139 have involved UK laboratories, the majority of which are in the academic sector.

Making education work

Any request from a university or polytechnic to SERC for recognition of a new MSc course in engineering, for the award of SERC studentships, is likely to be met with the question, "Does it combine academic excellence with industrial relevance?" These two criteria are, however, essentially subjective and can be interpreted in a variety of ways, so meeting them becomes a real challenge. Should the institution concerned go for a highly specialised course serving only a narrow sector of industry? Or should it provide a broad programme to enable specialist engineers and scientists to convert their skills in order to meet a shortage of expertise in another sector? In recent years one measure of an institution's success in meeting the criterion of 'industrial relevance' has been the number of its graduates whose first appointments are taken up in UK industry. Nevertheless, Professor Chengi Kuo and Dr Peter Sayer, who are responsible for the MSc course in Marine Technology at Strathclyde University, argue that a satisfactory interpretation of both criteria is urgently needed for the benefit of everyone concerned, because of the increasingly keen competition for studentships.

When the Marine Technology Centre was created at Strathclyde University in 1975 through the initiative of SERC, it was decided to give equal emphasis to both postgraduate training and research, and so one of the first tasks we faced was establishing our educational goals. For the one-year postgraduate course leading to an MSc in Marine Technology we chose to remain loyal to our own brand of educational philosophy which holds that a graduate must possess three interrelated qualities of *competence, confidence* and *communication skills* in proper balance. Since marine technology is a truly multidisciplinary subject calling for knowledge and understanding of both technical and non-technical topics, this degree programme seeks to develop these qualities by means of both team work and individual project study.



The three interrelated qualities that graduates must develop in proper balance.

During the first six months of the course the students are grouped into 'consultancy teams' to make a full examination of key aspects of an off-shore project such as the development of a marginal field with limited oil reserves in the North Sea. As part of their work schedule the teams submit written progress reports every two weeks. In addition, in order to increase experience and develop confidence, each team member must take it in turn to make a concise oral presentation on the position to date and is expected to meet subsequent questioning with convincing answers in order to improve their confidence and ability to communicate effectively.

The reports cover working sessions on issues that range from defining the problems to be tackled and devising a strategy to meet them, to assessing the market and evaluating the financial aspects. Teaching sessions and seminars presented by people from industry are directed solely at backing up the groups' own study activities. The subjects range from the behaviour of floating vehicles in hostile seaways and the preparation of a business plan for field developments to training in report writing and in how to get the best out of industrial visits.

Towards the end of the sixth month a written report is submitted by the group as a whole outlining its findings together with an application for a grant to do research proposed on a particular topic already identified as needing further attention. The climax of the group work period is the formal presentation of this report to a panel of experts from industry and its defence in the face of their searching questions. Performance in the group project is assessed in the context of a team but individual understanding of the key topics is also evaluated by means of short written examinations.

During the second six months each student concentrates on a single topic selected from problems encountered in practice, and this project work leads to the submission of a thesis. This is the point at which the work of the MSc students becomes directly linked with the activities of the major research programme in progress at Strathclyde's Marine Technology Centre. The aim of this phase of the training is to develop the students' ability to tackle an actual industrial problem systematically from the beginning right through the intermediate stages to a valid solution. Not surprisingly, the students are encouraged to think broadly before selecting the particular issue on which to concentrate. In the event, some of their theses compare very well with progress reports from PhD students, while their projects have often provided ready 'test beds' for new ideas and some have been the seed corn for new research projects.

What does all this mean? This is a degree programme in Marine Technology but the approach adopted is applicable to any engineering course. By ensuring that graduates have confidence and communication skills alongside professional competence, there is no doubt that SERC's criteria are being met in full.

Professor Chengi Kuo
Dr P Sayer
Marine Technology Centre
Strathclyde University

Some new publications from SERC

ACME Directorate
Copies of the *ACME Directorate annual report 1985-86* are available from Mrs G Ford, SERC Central Office, Swindon, ext 2250 or 2475.

Machines and power
Copies of the *Machines and Power Committee annual report 1985-86* are available from Mrs M Wilkes, SERC Central Office, Swindon, ext 2116.

Nuclear physics
Copies of the *Nuclear Structure Committee* and *Particle Physics Committee Annual reports 1985-86* are available from SERC Central Office, Mrs T A Douse, ext 2223, and Mr P Bussey, ext 2325, respectively.

Molecular sensors
Copies of *Molecular sensors,* an introduction to the new SERC research initiative, are available from Mr R D Coster, SERC Central Office, ext 2263.

Synchrotron Radiation Facility
Copies of the *Synchrotron Radiation Facility Committee annual report 1985-86* are available from Mr A P Brown, SERC Central Office, ext 2217.

Studentship numbers 1986-87

1986 report

The continuing importance attached by the Council to postgraduate training was reflected in the number of awards made available in 1986. The Boards and specialist Directorates allocated 4945 studentships (compared with 4869 in 1985), of which 1705 lay within the field of information technology.

By 1 November 1986, a record total of 4814 awards had been taken up. The demand for 'appeals' awards was little changed this year, with 649 eligible applications being received compared with 642 in 1985. As was the case last year, only four first class honours candidates failed to secure an award. In the area of information technology, demand for studentships remained buoyant and consequently the Information Technology Directorate decided to offer more awards than had been provisionally allocated.

Applications for Cooperative Awards in Science and Engineering (CASE) continued to fall short of the Council's targets. However the removal of a closing date for CASE nominations, announced in 1986, has to date resulted in about 160 successful applications being received since the main awarding exercise of last August. This later take-up has helped to close the gap on CASE and is reflected in part in Table 1 which compares the take-up of studentships at 1 November 1986 with Boards' targets.

Overall, the provision of awards is in reasonable balance with demand.

Plans for 1987

The Council plans to make 4912 postgraduate studentships available for the 1987 round. This is marginally less than last year's total allocation of 4945 awards. Most areas of Council have held or increased their provision of research studentships compared with last year and in particular the Biotechnology Directorate's provision has been increased by about 50% to 90 research studentships. Science Board has increased its provision by 21 research studentships while maintaining its support of advanced course awards. The overall level of support for information technology remains unchanged with some redistribution between standard research and CASE studentships.

However the Engineering Board, taking account of the pattern of demand for its awards in 1986, has increased its support of advanced courses by 43 studentships (about 8%) while reducing its provision of research studentships by just under 130 awards (about 20%).

Table 2 sets out the distribution of studentships to be made in 1987.

Table 1: Distribution of 1986 awards taken up by 1 November 1986

(1986 targets agreed by Boards in brackets)

	APS	Engineering	IT	NP	Science	Biotech-nology	TOTAL
Research Studentships							
Standard	74(72)	307(379)	307(300)	59(55)	894(871)	28(27)	1669(1704)
CASE	3(7)	227(288)	153(130)	5 (7)	417(470)	31(34)	836(936)
Instant	1(3)	17(20)	8(10)	1(2)	65(70)	--(--)	92(105)
Total RS	**78(82)**	**551(687)**	**468(440)**	**65(64)**	**1376(1411)**	**59(61)**	**2597(2745)**
Advanced Course Studentships							
Standard	22(21)	496(471)	319(300)	--(--)	300(310)	29(30)	1166(1132)
Instant	1(1)	46(50)	40(50)	--(--)	19(21)	--(--)	106(122)
Conversion	--(--)	--(--)	916(915)	--(--)	--(--)	--(--)	916(915)
Total ACS	**23(22)**	**542(521)**	**1275(1265)**	**--(--)**	**319(331)**	**29(30)**	**2188(2169)**
Awards tenable overseas	**--(2)**	**17(20)**	**3(--)**	**--(--)**	**6(6)**	**--(--)**	**29(31)***
TOTAL	**101(106)**	**1110(1228)**	**1746(1705)**	**65(64)**	**1701(1748)**	**88(91)**	**4814(4945)***

*These figures also include three overseas awards provided on behalf of other Research Councils in consequence of SERC's responsibility to NATO.

NB Information Technology embraces both awards funded under the Alvey programme and those provided by the Engineering Board's Information Engineering Committee.

Table 2 : Allocations decided by Boards for 1987

	APS	Engineering	IT	NP	Science	Biotech-nology	TOTAL
Research Studentships							
Standard	72	310	275	55	939	40	1691
CASE	6	230	150	7	423	50	866
Instant	3	19	10	2	70	--	104
Advanced Course Studentships							
Standard	21	510	300	--	313	30	1174
Instant	1	54	50	--	21	--	126
Conversion courses (IT only)	--	--	915	--	--	--	915
Awards tenable overseas	3	19	5	--	6	--	36*
TOTAL	**106**	**1142**	**1705**	**64**	**1772**	**120**	**4912***

*Includes overseas awards for provision outside the Council's field in consequence of SERC's responsibilities to NATO.

Third Alvey Vision Conference

The Third Alvey Vision Conference (AVC87) will be held in Cambridge from 15 to 17 September. Its prime function is to provide a forum for the presentation and discussion of technical reports of Alvey-funded work in computer vision and image interpretation. In addition, there will be papers in these fields from other sources, as in previous years. The conference will be chaired by Professor John Frisby of the AI Vision Research Unit at Sheffield University.

Registrations and general enquiries should be addressed to the AVC87 Conference Secretary:

Ms Kate Crennell
Rutherford Appleton Laboratory
Telephone Abingdon (0235) 21900
ext 6397; direct line (0235) 446397;
electronic mail KMC @ UK.AC.RL.VJ.

The SABRE auroral radar system

The Sweden and Britain Radar-aurora Experiment (SABRE), described here by Professor Tudor Jones of Leicester University, is a bistatic phased array radar constructed jointly by the Max Planck Institut fur Aeronomie, Lindau, West Germany, and Leicester University.

The radars are located at Wick in Scotland and Uppsala in Sweden and the Uppsala Ionospheric Observatory assists in operating the latter station. The amplitude and Doppler frequency shifts of the signals backscattered from the E-region radar aurora are measured. By combining the data from the two stations, the magnitude and direction of the current flow, and hence the electric field vector, can be determined. The viewing area of the two radars is approximately 200,000 km^2. This region corresponds to the plasmapause boundary where the effects of important magnetospheric-ionospheric coupling processes can be observed. The spatial and temporal resolutions of the measurements are 20 × 20 km and 20 sec respectively.

The radar system

Each radar has a 50 kW pulse transmitter and frequencies of 153.2 and 142.6 MHz are radiated from Wick and Uppsala respectively. The backscatter returns are received on a phased array consisting of 16 stacks of 4, 8 element Yagi antennas. These are connected to a Butler matrix which enables eight beam directions to be monitored simultaneously. The Doppler velocity of the backscatter returns is measured for each range cell. The Wick radar can also be operated in a multipulse mode which allows detailed spectral information to be obtained. An interferometer is being constructed at Wick so that the height of the backscattering irregularities can be determined.

The radar at Wick is controlled from Leicester using a communications link over the public telephone network. This link also enables data to be retrieved from Wick each day for processing at Leicester.

The analysis facility

The data are first examined to ascertain the level of auroral activity by means of a 'range time intensity' (RTI) plot.

For selected times, the data from Wick and Uppsala are merged to obtain the vector velocity from the two line-of-sight velocities. This information is displayed graphically in the form of a latitude-longitude map containing a series of vectors corresponding to each resolution cell as illustrated in the figure. Summary data are held on disk and can be accessed by external users over the JANET link. Requests for detailed analysis of particular time intervals can be made via JANET.

Scientific objectives

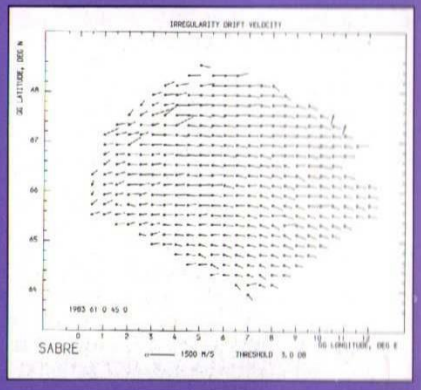
The initial objective of SABRE was to examine the behaviour of the radar aurora at sub-auroral latitudes. It has however been employed in a wide variety of magnetosphere and ionosphere studies. These include investigations of the polar convection current flows and their dependence on magnetic activity, pulsation events (Pc5, Pi2), comparison with measurements of electric field from EISCAT (the European Incoherent Scatter project) and the investigation of ion-acoustic turbulance. Correlation with satellite measurements of electric fields (VIKING, HILAT) and of reconnection events (AMPTE) have also been undertaken.

Many research groups, both in the UK and abroad, have used the SABRE data and, as a result, an extensive SABRE literature now exists.

Future objectives

The construction of the SABRE radar marked a major advance in the application of the coherent radar technique for auroral zone studies in the UK. Plans are now well advanced for the development of a new 1 GHz coherent radar which will employ some of the existing EISCAT facilities and a new transmitter located in Finland. This project, COSCAT, is a joint venture between Leicester University, the University of Oulu, Finland, and the Max Planck Institut fur Aeronomie, West Germany. There is still a need for a VHF radar to undertake observations in the Polar Cap and to support UK EISCAT activities. Attention is therefore being given to the design of a transportable VHF system which could be moved to various locations on a campaign basis. The success of SABRE has clearly established the coherent radar technique as one of the most powerful and cost effective tools for studying both the geophysics and plasma physics of the high latitude ionosphere.

Professor T B Jones
Department of Physics
Leicester University



SABRE data displayed as a map, indicating the vector drift velocities in each range cell.

The SABRE receiving antennas at Wick.