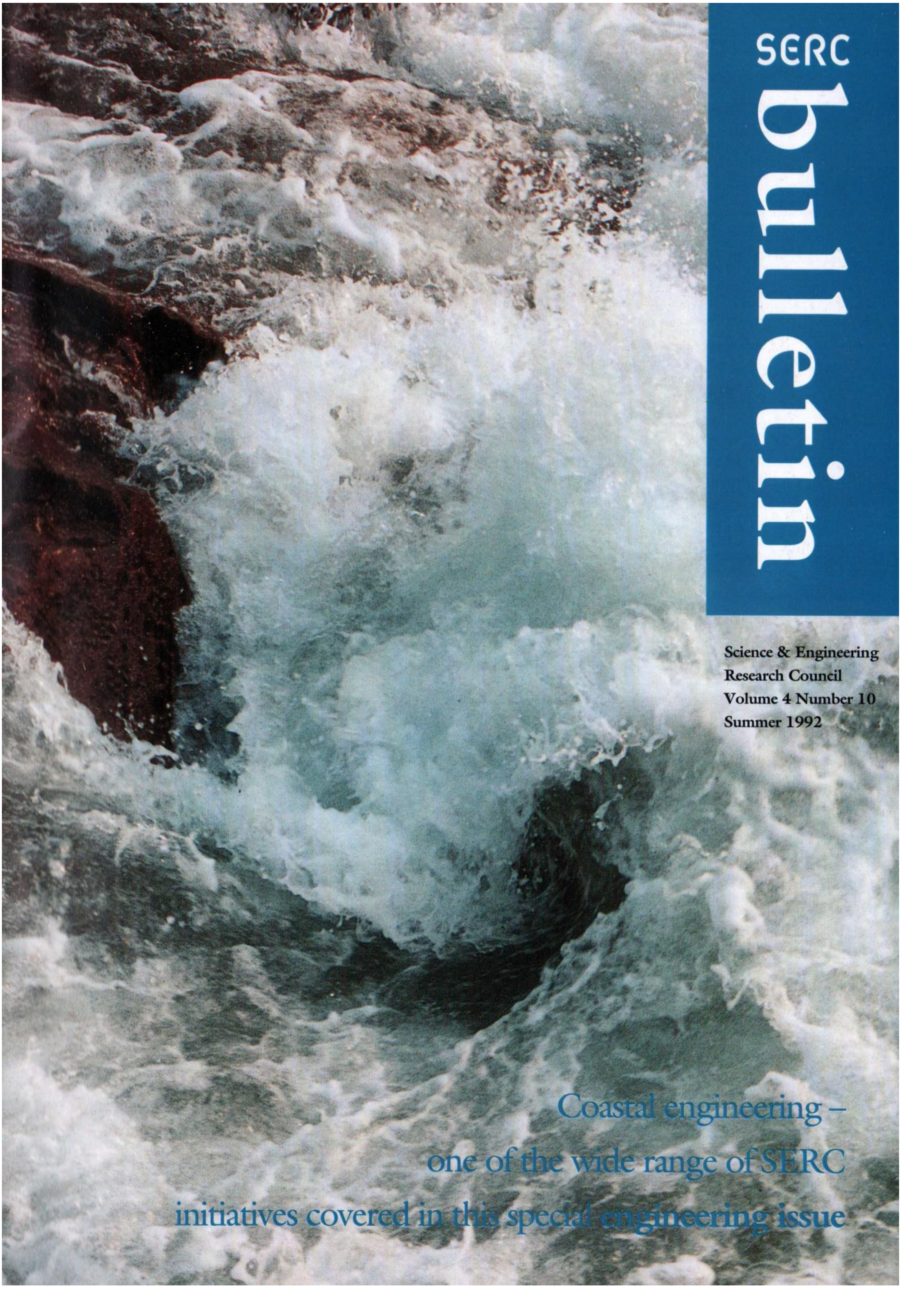

SERC bulletin

Science & Engineering Research Council
Volume 4 Number 10
Summer 1992

Coastal engineering –
one of the wide range of SERC
initiatives covered in this special engineering issue

SERC

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 research and training in the universities and polytechnics through the provision of grants and studentships and by the facilities which its own establishments provide for academic research.

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SERC *Annual Report* (available from PRU, SERC Swindon Office) gives a full statement of current Council policies and research highlights 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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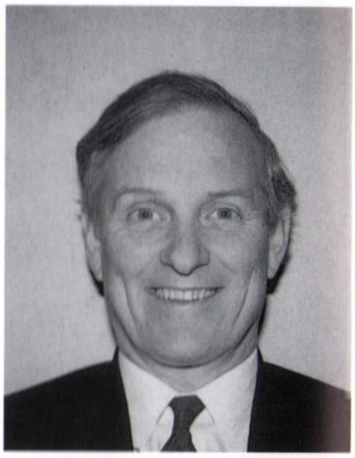
New Council Members

The Secretary of State for Education and Science appointed two new members to the Science and Engineering Research Council in September 1991. They are Dr S D Iversen of Merck Sharp & Dohme Research Laboratories and Dr K W Gray CBE of Thorn EMI plc.



Dr Kenneth Gray CBE

Dr Susan Iversen

Dr Susan Iversen joined Merck Sharp & Dohme Research Centre as Director of Behavioural Sciences in 1983, from the Department of Experimental Psychology, Cambridge, where her special interest, as Reader in Physiological Psychology, was in brain function and disorders of the brain. She continues to teach medical students in Cambridge, while researching new drugs for treating neurological and psychiatric illness. She is widely involved in scientific charities which support medical research and care of patients in the community.

Dr Iversen served on SERC's Animal Sciences and Psychology Subcommittee from 1983 to 1985.

Dr Kenneth Gray has been Technical Director of Thorn EMI since 1986 and has corporate responsibilities for research, development, engineering, environmental policy and manufacturing within the company.

Following a doctorate from the University of Wales in 1963, he spent several years in British Columbia and California doing research on magnetic resonance, semiconductor devices and satellite microwave radiometry. He joined the Royal Signals and Radar Establishment in Malvern in 1971 where he became manager of the defence and communications activities and, as Deputy Director, rose to the rank of Under Secretary.

Dr Gray has been on several Department of Trade and Industry and Ministry of Defence technical committees.

IN THIS ISSUE

Front cover picture

Breaking waves persistently erode and reshape unprotected coastline. (Photo: Mr Hewson, Polytechnic South West). **See page 4.**

Changes to the Dual Support System

From 1 August 1992 SERC will become responsible for meeting all the costs of the research it approves for support in higher education institutions apart from academic salaries, the institutions' central computing costs and premises costs. In the last Public Expenditure Survey, SERC received a transfer for the financial year 1992-93 of £26 million, rising to £88.4 million in 1994-95 when the process will be fully implemented. These amounts include funds for an increase in direct costs for certain items previously provided by institutions and an addition to cover indirect costs at a rate of 40% on the salaries of staff directly employed on grants.

Direct costs are those that can be unambiguously identified with a particular research project and where expenditure can be clearly audited as relating to that project. Indirect costs are defined as those central and department costs that underpin research activities but that cannot be readily assigned to a particular research project. These might include libraries and services such as administration, secretarial, minor consumables and so on. SERC is making changes to its research grant computerised processing systems and has been preparing its secretariats and peer review bodies for the change. The arrangements will be consistent with those of the other Research Councils.

Council commentary

February – March 1992

Patent law

SERC's Industrial Affairs Panel had considered an issue concerning the difference between patent law in the United States and in Europe and the Council endorsed the following statement to be passed to the Department of Trade and Industry who are the UK representatives in discussions on harmonising European patent law:

"SERC is concerned that a difference between European and USA patent laws places UK researchers at a disadvantage compared to their American counterparts and is thus potentially damaging to both academia and industry in the UK.

In the area of 'prior art' United States law permits a grace period of 12 months during which publication of an inventor's own papers cannot be cited as prior disclosure with regard to his patent applications. Under the European system publication is an immediate bar to patentability.

SERC takes the view that a significant period of grace is appropriate in order to prevent delays in either the publication of discoveries or the development of results. It is also clearly important to avoid any anomalies in the relevant laws. SERC urges that European and United States law in this area be brought into line."

EC research

The Council discussed the evolution of research supported by the European Commission under the successive Framework Programmes. The third of these (FP3) is now in operation although that part of it that impinges most on SERC's field of activity has been delayed because of differences of opinion between the Commission and the European Parliament. This part is 'Human Capital and Mobility', with a budget of about 500 million ecu, and the differences have centred on the proportion to be spent on funding fellows and other individual researchers' costs compared with support, equipment and facilities. Implementation is now expected during 1992.

Discussion is already under way on the content and size of the next programme, FP4, due to start in 1993 (overlapping two years with its predecessor). Again, some delay seems likely. Whether or not FP4 is larger than FP3, the volume of activity supported is already large enough that SERC must take account of it in formulating its own programmes. At the very least, duplications must be avoided. More detailed but very important aspects of the content of FP4 will be whether it moves towards 'basic' science as opposed to industrial programmes, and the extent to which it contains provision for the support of centralised facilities for scientific research. The Council has provided advice to Government on FP4 and will be following developments over the coming year.

EuroLEP

A judgement has recently been made under Swiss law concerning the dispute between CERN and the EuroLEP consortium, the group of contractors responsible for the construction of the LEP tunnel. An arbitration tribunal has ruled that CERN must pay EuroLEP a total of 107.9 million SF in settlement. CERN and the member states are currently considering how to honour this debt. However, SERC would resist any pressure to meet the debt through additional contributions from member states; if applied to the UK's CERN contribution, it would cost around £6.4 million and lead to a significant distortion of SERC expenditure.

Review of information science and engineering

A report of a panel under the chairmanship of Sir John Fairclough was presented to the Council in December. At that meeting Council decided that the report's recommendations should be reviewed by the appropriate Boards and Committees, including the Information Technology Advisory Board (ITAB), a joint SERC-Department of Trade and Industry body. At its March meeting Council discussed the responses from the various bodies and agreed to publish the report, *Review of information science and engineering in SERC* (see page 27).

New research grants

A grant of £1.7 million over four years to investigate the use of computational and mathematical tools in the process industries was awarded in February to Edinburgh University (Department of Chemical Engineering). Part funding by industry was envisaged towards the end of the research programme.

In March, Council approved the award of a revised grant to Dr J J Quenby of Imperial College of Science, Technology and Medicine, London, of just over £1.3 million over the four-year period of 1 August 1989 to 30 April 1995. This is to fund further work in the research for 'dark matter' in the Galaxy.

It also approved a £1.6 million four-year research grant for Professor Colin Gough and others at Birmingham University to fund their continued research into the underlying science and applications of superconducting materials.

Coastal engineering research

Attrition of Britain's coast by the sea is a ceaseless process and has led, over time, to substantial alterations in the outline of these islands. Despite the dangers of inhabiting coastal regions, the benefits were seen to outweigh the disadvantages, and lifestyles adapted as necessary. This is still true today and there is an increasing need for coastal land usage and hence the engineering capabilities to make this possible, writes Dr Paul Meakin of SERC's Water, Environmental and Coastal Engineering Group.

It has long been recognised that protection of land from the sea was desirable but, before the turn of the century, little could be achieved in the way of preventing severe damage to the coastal margins from flooding and erosion. These events, and consequent losses of crops and settlements, largely had to be endured and accepted for two main reasons: a lack of understanding of the sea's behaviour and insufficient engineering knowledge to build the required structures, defence or coast control, capable of withstanding repeated attack from the sea. Achieving success with man-made interventions in the coastal zone depends on harnessing engineering expertise with a sound knowledge of coastal processes — an ideal combination which has not always been achieved.

Coastal impact modelling

The importance of research into behaviour of the coastal zone has been fully recognised and in 1985 the then SERC Marine Technology Directorate set up a study to assess the current level of knowledge of coastal processes. In 1989 a report entitled *Coastal impact modelling — the way forward*, revealed that, although excellent in many areas, understanding of near-shore processes in certain key topics was inadequate. This deficit was attributed in part to incomplete coordination of effort and a lack of resources. In consequence, the ability of engineers to apply the latest techniques to coastal work was impaired.

Just how this shortfall in understanding of coastal processes and related engineering is to be overcome is described below, but first it is important to appreciate some of the difficulties faced by British coastal engineers. Britain's coast is some 17,000 km long; of this, more than 1,000 km are protected by some form of defensive structure, the value of which was estimated in 1984 at £4 billion. A third of the coastal structures were built before 1939 — and indeed much of their construction can be credited to Victorian engineers. Exposure to the harsh coastal environment inevitably accelerates deterioration of these defences and in the mid-1980s some £100 million a year was being spent on new works and maintenance of existing structures. Clearly, the sums of money which are being spent on coastal engineering projects are large and it follows that expenditure on research which leads to the saving of only a few percent of total cost would be justifiable. Experience has shown that research can lead to savings on individual schemes of up to 50% and, since it is most commonly public money that supports coastal work, economies of this scale are particularly welcome.

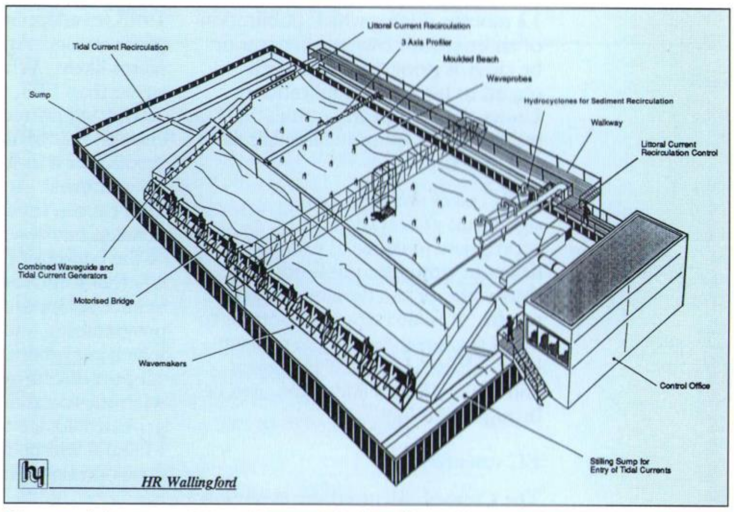
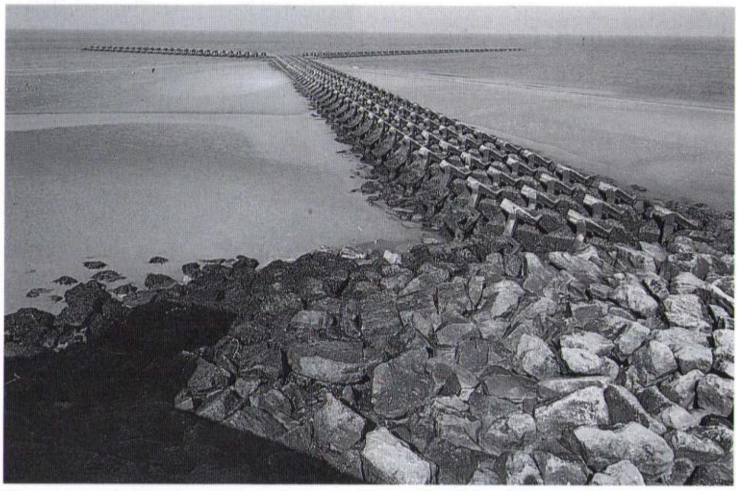


Diagram of the proposed Coastal Research,Facility which will act as a focus for the SERC-funded coastal engineering research programme. (Diagram: HR Wallingford)

Rising sea level

The problems arising from aging coastal structures (including defensive, beach control and outfalls) are being compounded by the threatened rise in mean sea level as a consequence of global warming. Furthermore, the Atlantic and North Sea are showing a marked increase in frequency of extreme events and a progressive rise in wave height, raising the likelihood of coastal flooding. As well as natural events forcing a reassessment of coastal engineering practice, ever more restrictive laws are placed on discharges to the sea, making changes in outfall design necessary. Public attention is focused currently on coastal events and in addition to flooding, of particular concern is the provision and preservation of amenities such as beaches and marinas, the disposal of pollutants and the inherent contamination risks to bathing waters and shell fisheries. New engineering methods are required to meet modern day challenges in both an economic and environmentally friendly manner.



Shore-connecting breakwater, New Brighton, Merseyside (Photo: Liverpool University).

Gaps in knowledge

Having identified gaps in current knowledge of coastal processes, the Coastal Impact Modelling Committee recommended that SERC should allocate substantial sums to support coastal engineering research, including finance for a coastal research facility which would be a focus for the programme. On the basis of these appeals, the Council's Engineering Board has made available funds to allow a £500,000 a year commitment in research grants over the next five years, plus a substantial contribution to the capital cost of an experimental coastal research facility. The programme of research in coastal engineering has been endorsed by reports from the Institution of Civil Engineers and the Coordinating Committee on Marine Science and Technology. Success has been achieved in securing the collaboration of the Ministry of Agriculture, Fisheries and Food and an interface with research funded by the National Rivers Authority will be maintained.

The *Coastal impact modelling* report concentrated on modelling of processes within nearshore waters. This work will form the core of the SERC research programme, probably broadening to include geotechnical and structural topics. The research requirements can be subdivided into areas of waves, currents, sediment transport and pollutant dispersion. These processes will be examined in the following coastal regions: surf zone, near shore, estuarial and inter-structure physical regions. Within this programme, the priorities are the study of the interaction of waves and currents with marine sediments and modelling pollutant behaviour within estuarial waters.

Encouraging innovation

The determination of the Council to ensure this programme of coastal engineering research has the maximum benefit to the UK as a whole is exemplified by the wide-ranging research topics. It is the aim of the programme to produce high quality data relevant to all areas of coastal engineering where deficiencies have been recognised and where benefits can be obtained. The major benefits will be the production of enhanced numerical models with improved confidence margins, the evolution of novel and improved sea defences and coastal protection, more accurate prediction of sediment movement and a greater understanding of effluent behaviour and dispersion. Furthermore, research under this programme will encourage engineering innovation and ensure the training of manpower necessary to compete in world markets.

Because of the complex nature of the research programme, several approaches to the work are envisaged. These can be categorised as theoretical development, two-dimensional laboratory flume tests, three-dimensional wave basin studies, and full-scale field measurement. Since there is currently no suitable wave basin facility available, SERC considered proposals from a number of potential hosts, finally deciding that the coastal research facility would be constructed by HR Wallingford in Oxfordshire. The coastal research facility is due to enter service in mid 1993 and will have dimensions of 54 x 27m and a still-water depth of 0.3 to 0.8m. A novel feature of this facility will be the capacity to generate random waves in a directional sea state at the same time that longshore and tidal currents are flowing. Various bathymetries can be modelled at a scale of 1:20, allowing replication of an 800m stretch of beach. A comprehensive array of equipment and instrumentation, including a bed profiler, sediment recirculation apparatus, laser anemometers, current meters and video systems, will be fitted as standard, with the possibility of additions as required for certain projects.

The importance of coastal engineering to the economy and prosperity of Britain cannot be denied and this coordinated programme of research funded by SERC will be instrumental in maintaining the UK as a world-leader in this field of engineering. The programme as a whole will be overseen by a management committee and further information can be obtained from the Coordinator, David Fiddes, telephone Chippenham (0249) 445004.

Dr P J Meakin
Secretary, Water, Environmental and Coastal Engineering Group
Environmental Civil Engineering Committee
SERC Swindon Office
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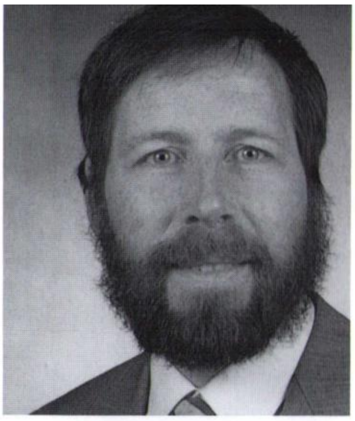
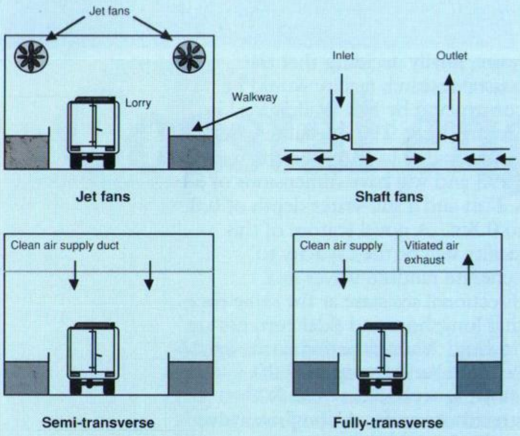


Professor Alan Vardy

Safe operation of vehicle tunnels

Methods of tunnel ventilation



All early tunnels and mines were ventilated naturally and most short tunnels are still ventilated in this way. That is, fresh air replaces stagnant or vitiated air as a consequence of normal operation. With railway tunnels, the trains can be thought of as huge displacement pumps that drive air through a tunnel. Road vehicles are similarly able to induce quite large air flows, thus helping to empty the tunnel of pollutants released from their exhausts. Natural ventilation is least effective when vehicles are stationary. In this case, buoyancy forces are all that is available. Polluted air is usually warmer than supplied air (recall conditions inside packed underground trains) so it tends to rise and migrate to the nearest portal or shaft. Designers can sometimes take advantage of this effect by locating (cool) fresh air supply ducts at roadway level.

In a **longitudinal** ventilation system, air flows are induced along a tunnel by fans which may be mounted either on the roof of the tunnel or in specially constructed shafts.

In a **semi-transverse** ventilation system, air is supplied continuously along the tunnel from an adjacent duct. This reduces average velocities along the main tunnel, but it necessitates the provision of a second 'tunnel' alongside the first.

In a **fully-transverse** ventilation system, air is supplied and removed from the tunnel laterally. In this case, there are two additional ducts alongside the main tunnel.

Few civil engineering projects have captured public attention as widely as the Channel Tunnel. The breakthrough of the service tunnel on 1 December 1990 provided great media excitement and reports of subsequent progress and setbacks appear regularly. Tales of disputes between the operator and the contractor sometimes overshadow the magnitude of the achievement, but most of us are aware that the link will probably be in operation some time in 1993. And most of us have asked, 'Will it be safe?'

The safe operation of vehicle tunnels is the subject of Alan Vardy's Royal Society/SERC Industrial Fellowship at Mott MacDonald in Croydon. Although Mott MacDonald have made a big contribution to the design of the Channel Tunnel, the fellowship is more broadly based than any particular tunnel, however large. Its purpose is to identify ways in which both road and rail tunnels can be operated more safely and to assist in the development of suitable procedures for use during an emergency such as a fire. Professor Vardy describes some of the problems and procedures he is studying.

Routine operation

In routine operation, the purpose of ventilation systems is to keep pollution concentrations below acceptable levels. The greater the rate of pollution, the greater the necessary air supply. Gale force winds are unacceptable so there is an upper limit to the length of tunnel that can be ventilated longitudinally (see box). Longer tunnels must either have intermediate ventilation shafts or be ventilated transversely, and this is reflected in their cost. One benefit of continuing reductions in emission levels from vehicle exhausts will be savings in construction and operating costs of road tunnels. Nearly all rail tunnels are ventilated longitudinally (although a semi-transverse system will be used in the Channel Tunnel).

Response to an incident

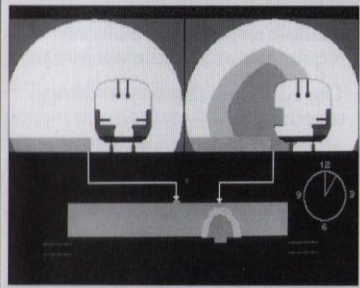
No matter how well routine operating procedures are planned and carried out, it is possible for accidents to occur and, in extreme cases, fire could develop. The risk of serious fire is very small indeed: there has never been a death from this cause in a road or rail tunnel in Britain. The King's Cross fire in 1987 involved major loss of life, but it was not a tunnel fire. This is not a case of splitting hairs; owners of department stores could have much to learn from King's Cross, but neither the cause nor the consequential events were directly relevant to tunnels. The worst ever tunnel fire in Britain involved a train of petrol tankers. It occurred in the Summit Tunnel near Manchester in 1984 and remained dangerous for five days. Conditions became uncontrollable when a pressure relief valve vented about four hours after the fire started. No-one was injured, but it is easy to see why hazardous goods such as this are not permitted in the Channel Tunnel and the London Underground.

The emphasis on fire risk has changed dramatically over the past 20 years. Previously, ventilation systems were designed primarily for routine ventilation and then modified to suit emergency needs. Today, it is almost the other way round. The capacity of the fans is commonly determined by their requirements in an emergency. Alternatively, as in the Channel Tunnel, a completely separate set of fans may be provided for use in emergencies.

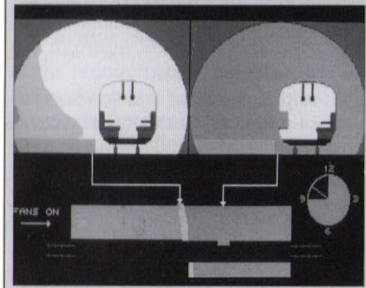
Whatever the system, its effectiveness depends crucially on the speed with which well planned and rehearsed procedures can be brought into operation. Usually, even big fires begin slowly and do not become life threatening for many minutes. The use of these minutes is the main focus of the Industrial Fellowship.

Consider a typical scenario in a standard road tunnel. A driver is distracted and collides with the tunnel wall. The car slews across the road and is struck by a coach which is struck in turn by a tanker. In the control room (which might be

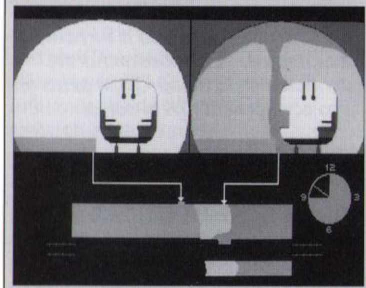
Models of smoke movement



Shortly after outbreak of fire



Just before fans are switched on



Shortly after fans are switched on.

CFD predictions of smoke spread. Each figure shows conditions at two locations, a plan view of the station and a clock.

The main threat from most fires is not fire itself, but smoke. In buildings, ventilation systems are not capable of overcoming buoyancy forces of hot smoke. Physical barriers (doors) are needed to arrest its progress. The same strategy is under investigation in the Washington Metro using inflatable air bags, but the usual approach is to install powerful fans.

Computational fluid dynamics (CFD) analyses are capable of simulating the development of a fire, either with complex models of the combustion process or with simpler heat release models, depending on the level of realism required. They are well suited to simulating conditions local to a fire, but less suitable for simulating complete tunnel networks. Computer memory limitations tend to favour the use of one-dimensional models in the far-field, perhaps supplemented by two-dimensional or stratified one-dimensional models in intermediate regions.

Whichever method is used, the purpose of such simulations is not to analyse individual incidents (except retrospectively as with Harwell's simulation of the King's Cross disaster) but rather to facilitate the design process or, increasingly, to train operating personnel and the emergency services. These three figures are part of a training video for staff in an underground station.

several miles away) the incident is observed on closed circuit TV monitors after a passenger from the coach raises the alarm on an emergency telephone. The car is on fire.

The controller is responsible for informing the fire, police and ambulance services. She is also responsible for directing approaching traffic and for providing a safe haven for everyone in the tunnel, no matter how close to the incident they may be. In our hypothetical case, all this must be achieved on the basis of information from the coach passenger and from TV monitors, which (hopefully) are not yet obscured by smoke.

It is easy to see that the procedures to be followed must be pre-planned. The controller cannot be expected to make key decisions on the basis of almost certainly inadequate information. Priorities must be determined in advance with the objective of minimising the risk of loss of life, either before or after the arrival of the emergency services. The Industrial Fellowship is concerned with coordination between different aspects of the response and with ensuring compatibility between day-to-day practices and necessary behaviour in an emergency. Well prepared staff should do the right thing instinctively.

Pre-planned procedures can be more difficult to develop than they seem. For example, what is the best ventilation strategy for a specific (assumed) fire? Remarkably, this question is unresolved. Clearly different answers are possible for different situations — one-way or two-way traffic, longitudinal or transverse ventilation and so on — but there is no international agreement on the best strategy even for well defined cases. Some argue that air velocities should be kept small to reduce the spread of smoke (the main threat to life). Others argue that a clean air route should be maintained between the incident and an entrance/exit to provide a means of escape and a means of access for the emergency services. This question is being considered in the Fellowship through computational fluid dynamics (CFD) analysis (see box) in conjunction with a network analysis of far-field flows.

So are tunnels safe?

Tunnels cannot be safe in an absolute sense. Neither is crossing a road or even walking downstairs. However, their track record is exceptionally good. There are fewer accidents per mile in tunnels than on open roads (perhaps because drivers concentrate better). The risk of fire is no greater than on the open road or track, but the consequences could be far greater so operators and designers pay great attention to the risk. To all intents and purposes, the answer for the Channel Tunnel and all new tunnels must surely be, 'Yes, very safe'. For existing tunnels with little or no ventilation equipment or control systems, a more cautious answer would be given if they did not already have such a fine record. As it is, the answer must be, 'Yes, they are safe, but there is scope for making them even safer.' In most cases, this requires expenditure of thought rather than vast sums of money.

Professor Alan Vardy
Department of Civil Engineering
Dundee University

International conference

One direct outcome of the Industrial Fellowship is an international conference on Safety in Road and Rail Tunnels to be held in Basel, Switzerland, 23-25 November 1992. The conference will provide a forum for interaction between academics, tunnel operators, designers and the emergency services. Abstracts have been received from about 20 countries and some 50 papers will be presented in a very full three-day programme. The main sessions will be:

- Design standards
- Fire development
- Risk assessment and reliability
- Tunnel and vehicle design
- Operation
- Response to incidents
- Training and review

Quality assurance in academic research

Quality Assurance (QA) is now widely accepted by industry as an essential and beneficial management tool, but so far it has seen little application in academic research. This article, by Dr Colin Taylor and Dr James Brownjohn of Bristol University, describes the QA experience gained in the Earthquake Engineering Research Centre (EERC) at Bristol, which houses the SERC Earthquake Simulator.

What is QA?

QA is a management philosophy. Its central tenet is that every activity should be carried out to the appropriate level of quality. This is most readily achieved and demonstrated though a formalised and documented management system, the Quality Assurance System. This is a management tool which, if properly designed and used, helps its users to be more effective and efficient.

The essence of QA is simply:

- plan what you do
- do what you plan
- document what you have done
- review what you have done so that you can do it as well or better next time.

The EERC Quality Assurance System

The EERC quality system was initially designed to support commercial testing on the Earthquake Simulator (figure 1). It complies with various standards, including BS5750 and BS5882. The system is adaptable and aims to serve the user, rather than the user serve it. It is project-specific since only particular elements of the system need be applied depending on a project's QA requirements. A full commercial test for the nuclear industry, for example, would require the highest level of QA. In contrast, a simple research test may only require the most rudimentary QA.

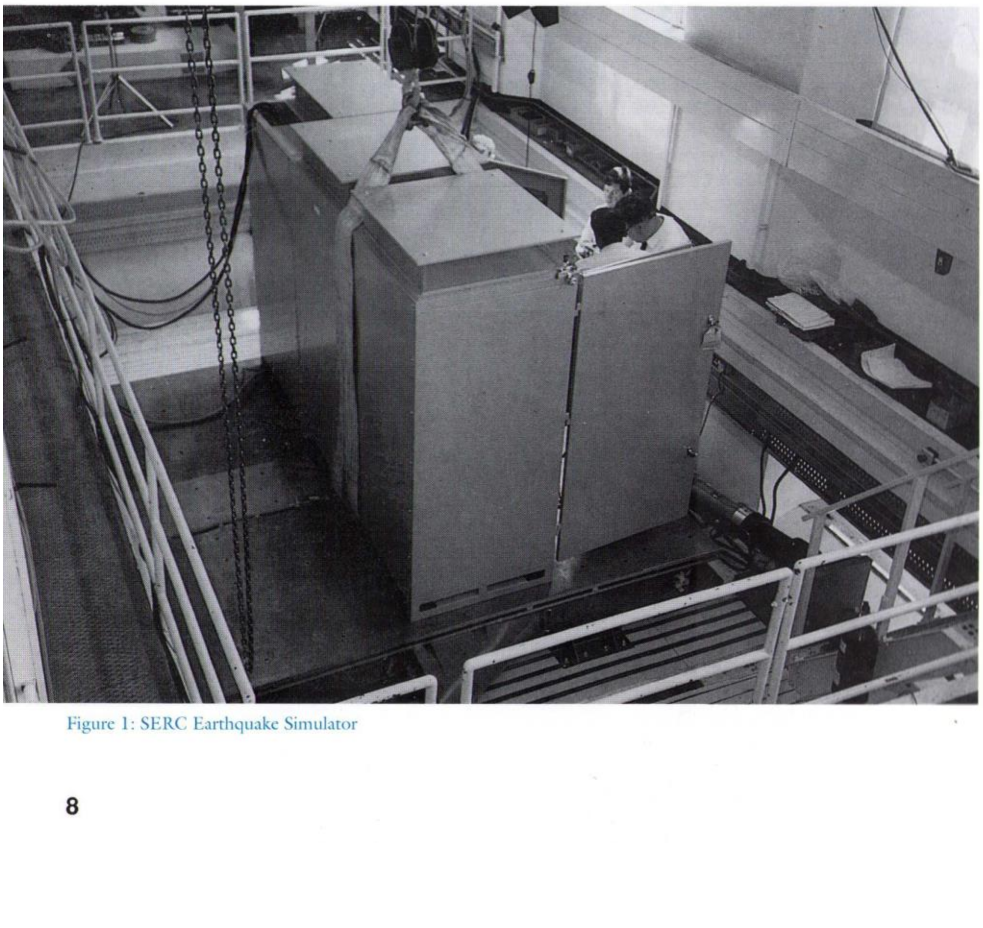


Figure 1: SERC Earthquake Simulator

The EERC quality system brings together:

- organisational and administrative activities
- writing and updating of quality system documentation
- the systems for project management
- the processes for auditing and reviewing the quality system
- the identification, implementation and verification of measures to rectify deficiencies
- the systems for operating and maintaining facilities, and
- the systems for management and preservation of records and documents.

Figure 2 shows the hierarchy of the EERC quality system documentation, which is formally maintained. The documents are divided into General QA systems and Project-Specific QA systems.

General QA Systems

The top-level document is the Quality System Manual. This defines the QA system as a whole, including its philosophy and scope, general organisation, staff responsibilities and the range of facilities and equipment available, but it provides minimal procedural detail.

Standard Procedures provide the procedural detail for quality system organisation, project management, hardware and computing.

Technical Instructions give specific and detailed instructions (use of data acquisition systems, cranes etc). They may refer to and supplement manuals supplied with hardware or software.

Quality Instructions provide information and mandatory instructions on QA matters which have not yet been incorporated into the quality system documentation.

Project-Specific QA Systems

For each project, a Quality Plan is written. This defines which parts of the QA system (Standard Procedures and Technical Instructions) are to be applied to the project. It identifies the aim and scope of the project, staff responsibilities, reporting requirements and generally translates the overall quality system policies to the particular project. A Research Quality Plan is an extended form of a commercial project Quality Plan, as discussed later.

A Test Method Statement is prepared, covering each experimental or analytical activity in the project. It includes a clear statement of the test objectives and detailed descriptions of the test procedures.

For an academic research project (figure 3), the Research Project Specification takes the place of a commercial client's project specification. It is a clear statement of the requirements and objectives of the research and would be written by the researcher (supervisor or student) in the first part of the programme.

Academic research is highly conditional and iterative. The EERC quality system recognises this by extending the quality plan to include a Research Project Plan. This acts as a flexible link between the Research Project Specification and the Test Method Statements, allowing feedback from results to influence the direction of the research programme.

The Research Project Plan includes 'hold points' in the research programme. Here, the plan and objectives are reviewed, so that the plan can be refined and become more detailed as the need to change the scope and activities of the research is identified. Even though the objectives and methods may change, the focus of the research will be the same and there will be documented strategy and detailed plans at all times.

Benefits of QA

Initially, QA may seem to be a paper pushing exercise of little value. We had such a view when first confronted with the task of developing the QA system for the Earthquake Engineering Research Centre. However, the smooth and effective running of the first few commercial tests on the Earthquake Simulator convinced us otherwise. Complex tests which would probably have taken several weeks to complete in a normal academic mode were instead finished in a few days. In addition, the reliability and accuracy of the acquired data were easily demonstrable.

Some other benefits of QA seen in the EERC include:

- accumulated experience and knowledge in the EERC is retained when researchers leave
- the learning process for new researchers is accelerated
- research projects are managed and supervised more efficiently, leaving academic staff more time for research
- equipment is properly maintained, calibrated and documented
- quality assured research is more attractive to industry (and possibly Research Councils?).

Verdict

Quality Assurance of academic research is not to be entered into lightly. To be successful, all researchers, from the highest level of management downwards, must be intimately involved. The initial costs are significant, but are greatly outweighed by the long term benefits. In our view, QA *is* worth the effort.

Dr Colin Taylor and Dr James Brownjohn
Earthquake Engineering Research Centre
Bristol University

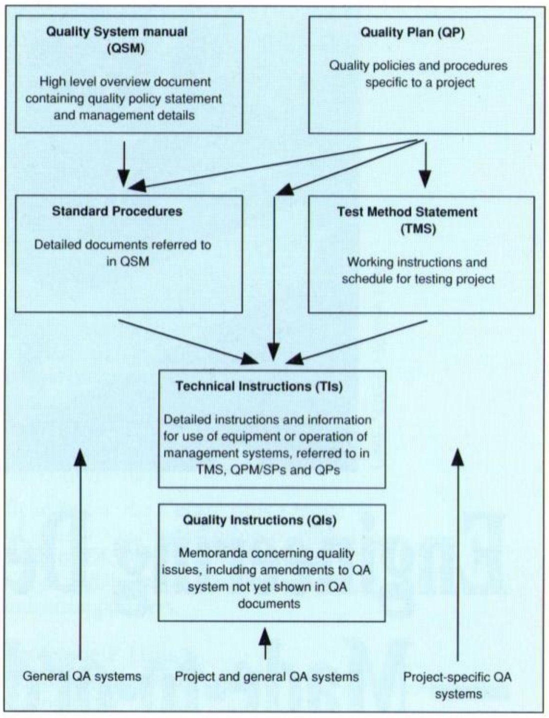


Figure 2: Hierarchy of quality system documentation

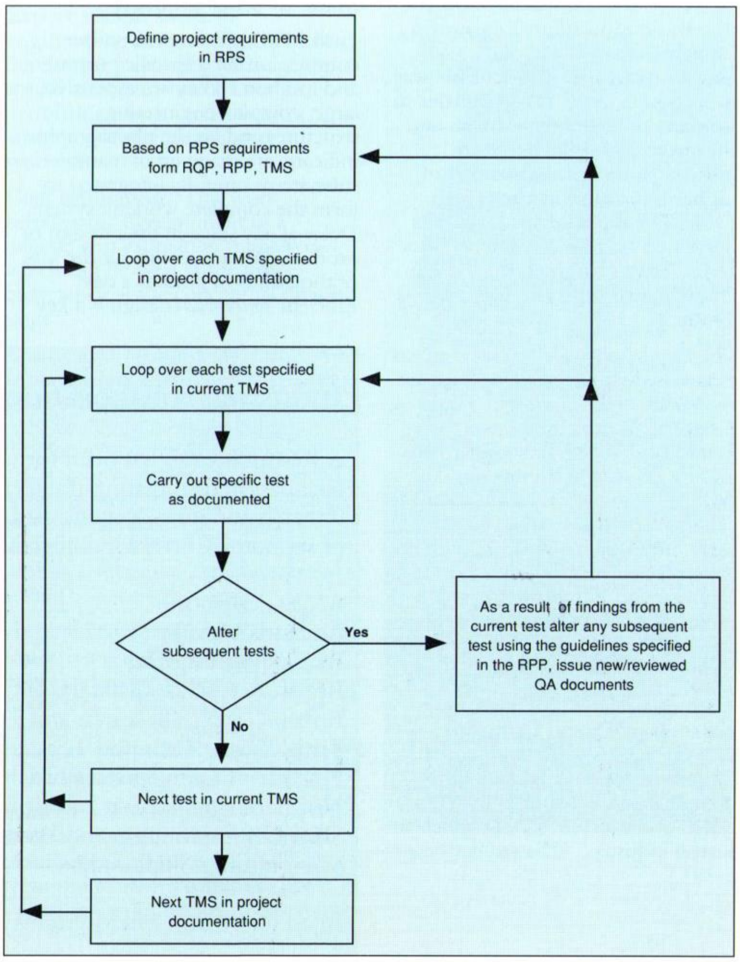


Figure 3: Management of research project documentation

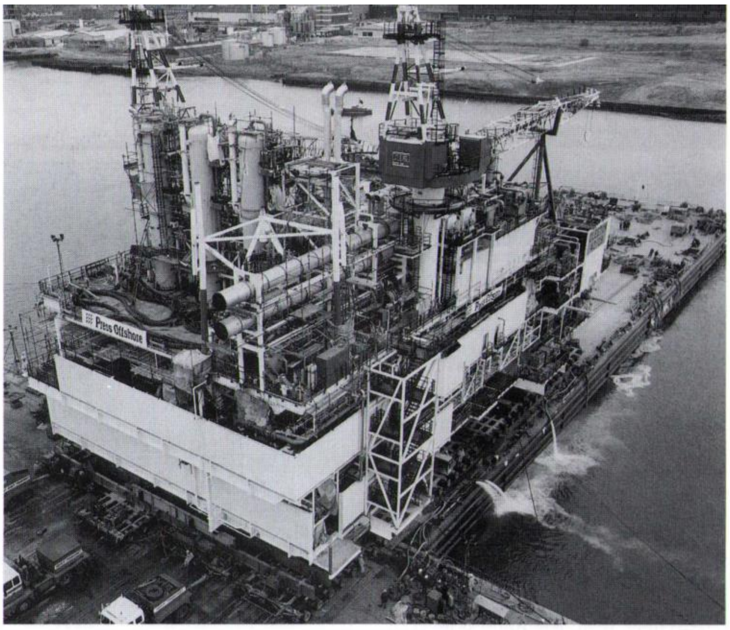


Photo: AMEC Offshore Ltd

Engineering Design Centre — Made-to-order products

SERC awarded a major grant for the foundation of an Engineering Design Centre (EDC) at Newcastle in July 1990. This was in recognition of its capabilities in fundamental design research and the successful links between industry and the institutions of higher education in the North East. The work of the Centre is described here by Professor Peter Hills, SERC Engineering Design Coordinator with the Design Council.

The Engineering Design Centre was established at Newcastle upon Tyne University, in collaboration with Newcastle Polytechnic and Sunderland Polytechnic. The SERC grant is £864,000 over a period of four years, and has been substantially enhanced by contributions from major industrial companies, together with a recent contract with the local Training and Enterprise Council (TEC) to facilitate the transfer of research findings into industry in the form of training materials.

The main objective of the Engineering Design Centre at Newcastle is to understand and exploit the role of engineering design in producing high quality 'made-to-order' (MTO) products in British industry.

Made-to-order products

Each MTO product is a unique commission for a specific purpose and location. They are expensive, large, complex engineering structures and, as the photographs indicate, are made up of many subsystems carefully integrated to form the complete working system. Delay at any stage in their design or production can account for the loss of thousands of pounds a day. Efficient *conceptual* design is a key element in the design process, allowing alternatives to be generated and compared. Sound and objective methods to select the best concept are crucial. This is followed by the *embodiment* stage at which the design takes shape. In *detail* design the resulting subsystems and components are then analysed, their dimensions obtained and their performances predicted. In the best practice, large parts of these later stages are accompanied concurrently with design for production, assembly and disposal. All this is repaid by substantial cost savings during the life cycle of such products.

The engineering design of MTO products is a broad-based activity. Because of the nature of the design process, its combination of creativity, empiricism, theory, practice, and all the wide variety of influencing factors and diversity of applications, it is necessary to apply the latest enabling technologies in an advanced computing environment. Good engineering design dictates the manufacturing system. Design for function and simultaneous design for production must be facilitated by compatible supporting technologies, and by intelligent design management, to maximise concurrency and shorten the lead time from concept to product.

Objectives

The achievement of the Newcastle EDC's objective entails:

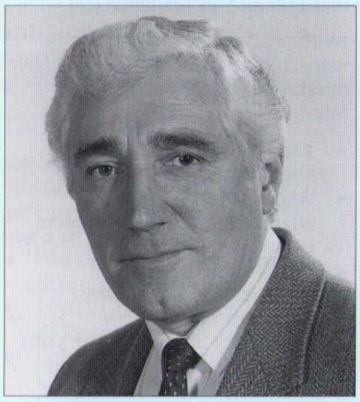
- Fundamental research in areas of engineering design which represent key generic elements of the design process for MTO products.

Industrial collaboration

A Research Club has been formed to allow industrial partners to take part in formulating the Centre's overall policy and its research and development. It has proved to be a notable source of support. Current membership comprises:

AMEC Offshore
Amerada Hess Ltd
BP Engineering Ltd
British Aerospace (Military Aircraft) Ltd
British Gas plc (Research and Technology Division)
British Steel (Technical Teesside Laboratories)
Northern Ocean Services Ltd
Northern Engineering Industries plc
Shell UK Exploration and Production
Swan Hunter Shipbuilders

In addition, Sun Microsystems fund a fellowship with the EDC



Bill Hills

Further information

For further information on the work of the Centre, please contact:
Bill Hills, Director
Engineering Design Centre
Newcastle upon Tyne University
Armstrong Building
Newcastle upon Tyne
NEl 7RU
Telephone 091-222 8554.

- Creation of a design environment in which effective data exchange supports fully integrated design and production.
- Development of enabling technologies for the design of specific MTO applications.
- Establishment of mechanisms which ensure the dissemination to industry of the results of research and the knowledge gained.

Research output

Research results are disseminated through journals, conferences, seminars and workshops, by input to existing courses, by special short courses and demonstrations, and by new methodologies and software. Special programmes to ensure that Research Club members' designers are updated with the latest methods and enabling technologies are regularly held.

Current research projects

Long, detailed and continuing discussions with manufacturers of MTO products have identified areas of design research which will enhance their competitiveness. The Centre employs advanced computing technology to develop new techniques for the synthesis and analysis of engineering design. The Centre's R and D programme is directly concerned with the interests and needs of the MTO industry. It is currently working on a core programme of research projects:

Computer based design data exchange conforming to the proposed ISO STEP standard. This models various life cycle activities such as product planning, design, construction, operation and decommissioning, using the ISO standard STEP (Standard for the Exchange of Product model data) and the efficient transfer of data between these activities.

Multiple criteria decision making for made-to-order projects. This is the research of procedures to select the best design solution given multiple conflicting goals.

Feature description in the design of MTO products. This work investigates methods and strategies for manipulating or generating feature descriptions.

Expert system shells in engineering design. This work is developing a system to manage the spatial arrangements of a design, permitting easy interaction with analysis software to enhance synthesis.

Cost estimating. This work involves the development of a generic cost estimating framework which can be used at the pre-contract or at the conceptual design stage.

Elastic and ultimate state design tools for large stiffened shell and plate structures. Powerful user-friendly design tools are being developed which will automatically select appropriate finite elements and meshing arrangement so that, for the first time, designers can rapidly design, analyse, re-design and re-analyse a structural configuration to within a specified accuracy.

An integrated approach to innovation in the design of engineering structures. This aims to develop a design and classification system for the assessment of innovative structures and materials at the design stage.

Materials selection and development for made-to-order products. This research, deriving from the work of Professor Mike Ashby at Cambridge, is to develop a system of communication between materials scientists and design engineers for the development and use of new materials in complex products.

Design for safety. A method for the integration of safety assessment procedures into the overall design decision-making process is being researched and implemented. Apart from its obvious direct benefits it will bring decision making on safety into the early stages of the design process.

Strategies for improved hydrodynamic design. This is researching systems which allow the designer to analyse the hydrodynamic and structural integrity of novel marine designs at the concept stage.

In addition, the Centre runs a range of industrially funded projects, with a value of £450,000, which are carried out in collaboration with individual industrial partners.

Professor P Hills
SERC Engineering Design Coordinator
The Design Council

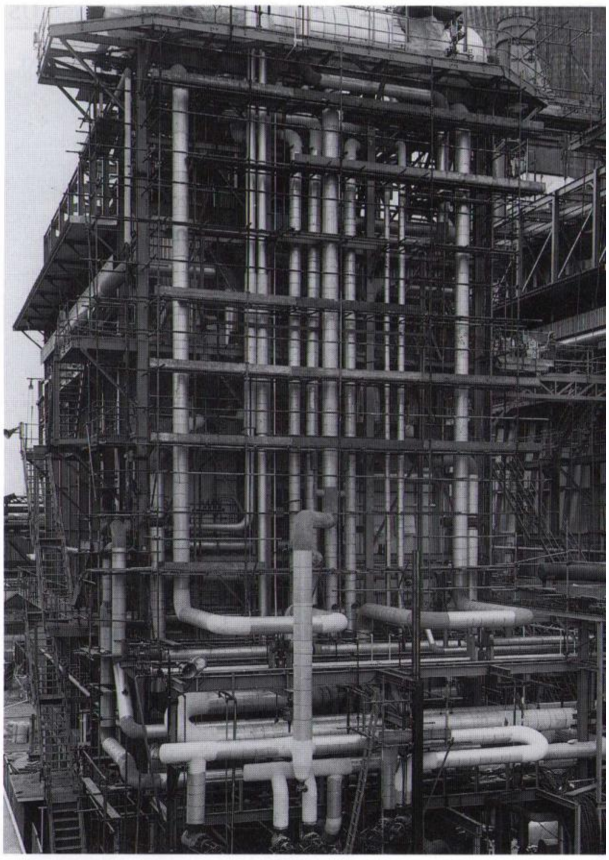
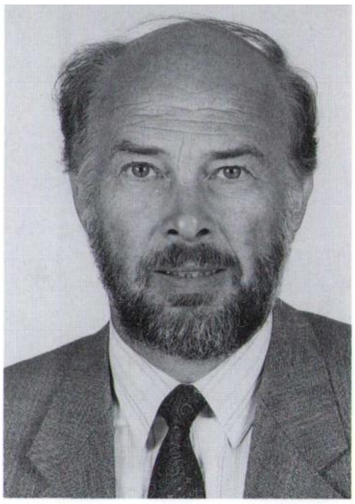


Photo: ICI Billingham



John Parnaby — 'the Parnaby Report' started the ball rolling.

New pilot scheme for engineering doctorates

* *The engineering doctorate: an SERC working party report* (1991).

In March 1992 SERC announced the funding of a pilot scheme at three centres to provide broadly based and industrially oriented doctoral level training. Thirty research engineers are expected to enrol in October for this new degree which incorporates the features from top German and US technical universities and has attracted the enthusiastic support of British industry, writes Dr Richard Liwicki, Secretary of SERC's Engineering Board Education and Training Committee.

The supply of well trained engineers, capable of applying their knowledge in a business environment in a disciplined, innovative and penetrating way is a very important element in the achievement of competitiveness of UK engineering businesses.

Over the past decade there has been increasing evidence to suggest that large sectors of engineering industry would welcome a more vocationally oriented doctorate in engineering to meet this need. In response, SERC asked Dr John Parnaby CBE FEng (Managing Director of Lucas Applied Technology) to chair a working party to look at the Doctorate in Engineering. The resulting report* confirmed the requirement from industry for broader based doctoral-level graduates.

Ray Leonard, UMIST.

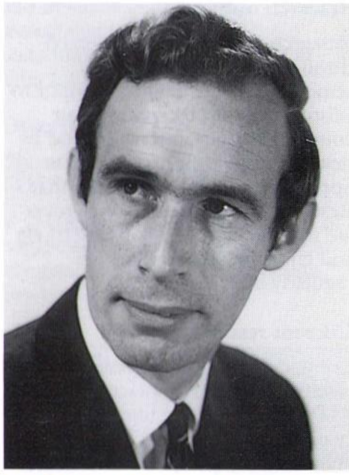
The Doctor of Engineering degree

The training which the Parnaby Working Party proposed incorporates the industrial relevance, team leadership and application of the best German *Dr Ing* degrees, and the concept of a taught component within the degree as found in many US universities.

The core of the degree is to be the solution of one or more significant and challenging engineering problems within an industrial context. Thus the solution of the problems will have to take factors such as financial constraints, timescales and personnel management into account; depending upon the nature of the project, research engineers are likely to spend a large proportion of their time at their collaborating firm's premises. To support the research engineers, packages of course work will be individually tailored to their needs, and will include courses in business studies as well as specialist technical subjects. Other broadening exercises will be available in, for example, communication skills and foreign languages. The taught component will be assessed and form an integral part of the degree. Supervision of the research engineer will be joint between an industrial manager and an academic.

By the end of the programme of work, the doctorate holder will have developed competencies in the following areas:

- Expert knowledge of an engineering area
- Appreciation of industrial engineering and development culture
- Project and programme management skills against realistic timescales
- Teamwork and leadership skills
- Communication — oral and written, technical and non-technical
- Technical organisational skills
- Financial engineering project planning and control
- The ability to apply skills and knowledge to new and unusual situations
- The ability to seek optimal, viable solutions to multi-faceted engineering problems and to search out relevant information sources
- The evaluation of the environmental impact of the industry and how to minimise it.



David Llewellyn, University College of Swansea.

These competencies will be ensured by projects being designed jointly by the academics and the cooperating company (with, when recruited, the candidate), with agreed objectives, deliverables and timescales and regular monitoring against these targets.

The extra work which this degree will entail is recognised by SERC which will provide the research engineers with support for up to four years. Furthermore, to ensure that the best industrially oriented graduates are recruited to the scheme, a much enhanced stipend will be provided which, together with an industrial top-up, will be equivalent to the net salary of a graduate recruited by industry.

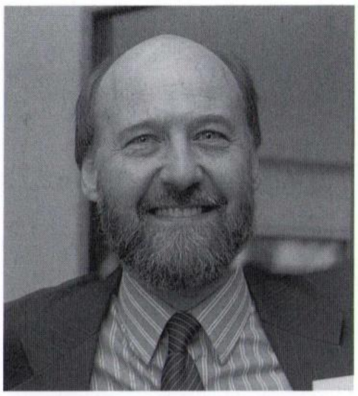
The pilot scheme

Selected from strong competition, SERC is funding three centres on a pilot basis. These centres will be based at:

- Warwick University: Warwick Manufacturing Group
- UMIST/Manchester University: all Engineering Departments
- University College Swansea/ University of Wales College of Cardiff/North East Wales Institute: Department of Materials and all other Engineering Departments

It is expected that each centre will have an annual intake of ten research engineers.

Each centre will be run by its own industrially led management committee. Though distinctive, the centres are seen as developing into a network which will provide the highest quality vocational engineering training at the doctoral level.



Peter Davies, Warwick University.

The centres, the research engineers and the industrial demand will be closely and continuously monitored over the next few years. If the demand from industry continues to grow and industry is seen to appreciate the graduates of the centres, then a bid will be made to expand the pilot scheme as quickly as possible. The pilot scheme will be reviewed by the Engineering Board in five years.

For further specific information, companies or potential research engineers should contact the individual centres:

UMIST/Manchester University
Dr Ray Leonard, Total Technology Department
University of Manchester Institute of Science and Technology, PO Box 88, Manchester M60 1QD
Telephone 061 — 200 4155

University College of Swansea/ University of Wales College of Cardiff/NEWI
David Llewellyn, Department of Materials Engineering
University College, Singleton Park, Swansea SA2 8PP
Telephone (0792) 295287

Warwick University
Dr Peter Davies, Warwick Manufacturing Group, Engineering Department, Warwick University, Coventry CV4 7AL
Telephone (0203) 523102

For general information, contact:

Dr Richard Liwicki
Secretary, Engineering Education and Training Committee,
SERC Swindon Office;
Telephone (0793) 411429.

The Clean Technology Programme launch (left to right): D Hyde, Group Environmental Technology Manager, ICI; D Pounder, Environmental Protection Technology Advisor, Department of Environment; Professor R Clift, Chairman of Clean Technology Management Committee; Dr A Hughes, SERC Director Programmes and Professor B Legg, Director of AFRC Silsoe Research Institute.

Clean technology research themes

The Agricultural and Food Research Council-SERC Clean Technology Unit announced its first three research themes on 21 February 1992. Dr Tony Hughes, Director Programmes, explained that SERC places great importance on environmental research and that the Clean Technology Programme represented a major flagship for research to abate pollution. He said that SERC has earmarked funds rising to £10 million a year by 1994; the corresponding baseline of expenditure by the AFRC is £1 million a year. Professor Roland Clift, Chairman of the Clean Technology Management Committee, outlined the first three research themes: farming as an engineering process, harnessing photosynthesis and the clean synthesis of effect chemicals. The Councils have published reports which indicate promising topics for research towards these targets.

Further information on the Clean Technology Unit and copies of the reports can be obtained from the Director, **Dr Nicholas Lawrence**, SERC, Polaris House, North Star Avenue, Swindon SN2 1ET; telephone (0793) 411122.

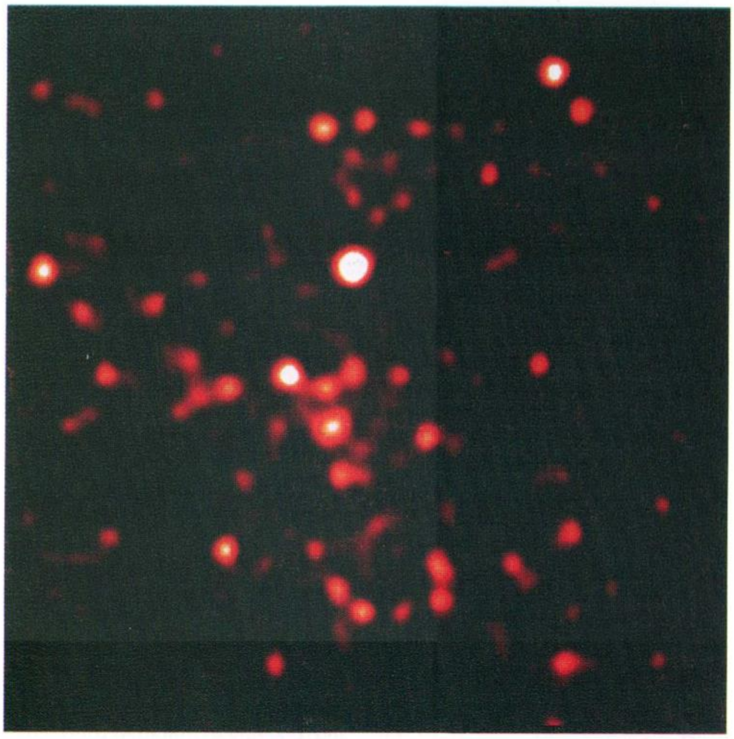


Figure 1: FAST image of the galactic centre region with the CVF, at 1.65μm. The spatial resolution is 0.60 arcsec. The brightest source is IRS7, and the galactic nucleus is just below this, near the IRS16 complex.

Making the WHT go FAST

At the end of the eighteenth century Sir William Herschel published his treatise on 'calorific rays'. By placing thermometers beyond the red end of the spectrum, he was able to show that there was radiant energy carried at still longer wavelengths. In a sense this marked the birth of infrared astronomy. It is thus fitting that some 200 years later the William Herschel Telescope (WHT) should break the 1μm barrier and move into near-infrared observing. This was made possible by a collaboration with the Max-Planck-Institut für Extraterrestriche Physik (MPE) infrared group, which enabled German, British and Spanish astronomers to use a near-infrared camera, called FAST, at the Cassegrain focus of the WHT. It is described here by Peter Andrews and Robin Clegg of SERC's Royal Greenwich Observatory.

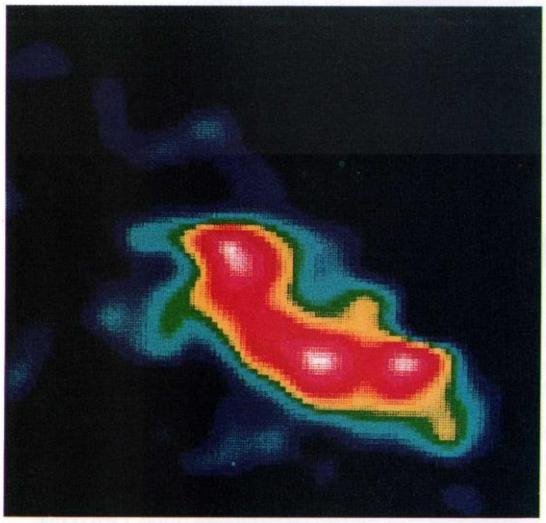


Figure 2: FAST map of the starburst galaxy NGC253 in [Fe II] 1.64μm. The small source structure is probably caused by individual supernova remnants.

FAST is a Fabry-Perot array high-resolution spectrometer. It was designed by Professor Reinhard Genzel's group at MPE, and is used especially to study near-infrared emission-line sources (around 2μm) in galactic and extra-galactic objects. Examples taken from a recent collaborative run on the William Herschel Telescope on La Palma are presented to show what can be done.

The spectrometer consists of a 62 by 58 pixel InSb array, operated at a temperature of only 6K. FAST has a typical dark current of about 50 electrons/sec and a readout noise below 280 electrons.

A warm Fabry-Perot interferometer suitable for the 2μm region is located outside the helium-cooled area (the dewar), at the telescope focal plane. Within the dewar are specially designed lenses to focus the image on to the detector and a circular-variable filter (CVF). The optical system was rebuilt for the WHT run, to match the f/11 focal ratio of the 4.2m's Cassegrain focus. The plate scale is then 0.50 arcsec per InSb pixel. The transmission coatings are optimised for the 2μm region, and the overall spectrometer transmission (including detector quantum efficiency) is about 20% at 2μm.

There are basically three modes of observing. First, filters can be used for broad-band photometry. Secondly, the CVF, operating from 1.4 to 2.4μm, provides low-resolution spectroscopy over the whole field. Lastly, the Fabry-Perot etalon, together with the CVF as order-sorter, provides high-resolution spectroscopy between 1.95 and 2.40μm.

A particular advantage of FAST is this 'tunable' narrow-band imaging capability, whereby images of any narrow emission lines in the spectral window can be made. Also, the resolving power of 950 increases the contrast of the line with respect to the continuum (whether from the background or the source itself). In addition, by scanning the Fabry-Perot in wavelength it is possible to perform velocity-resolved spectroscopy over the whole 30 arcsec field.

The run in July 1991, of 18 (mostly bright-moon) nights, went very well. Liquid helium had to be supplied from mainland Spain, being flown first to Tenerife and then put on the inter-island ferry to La Palma. The weather was excellent, with only about two half-nights lost due to cloud.

During the run, the mean 'seeing' at 2μm was 1.0 arcsec, and stellar images were smaller than 0.8 arcsec about 20% of the time.

The infrared and radio waves can penetrate the interstellar dust that obscures the centre of our Galaxy. It has been known for almost two decades that there is a compact, nonthermal radio source within one arcsecond of the dynamic centre of our Galaxy. Although its maximum elevation at the WHT is only about 35 degrees, the atmospheric conditions for observing this region were extremely good. Clear evidence for this is in figure 1, which shows a continuum image taken by the MPE team with the CVF (spectral resolution $\lambda/\delta\lambda = 50$) at 1.65μm. The very good seeing gave, for the first time, a map of high spatial resolution (approximately 0.6

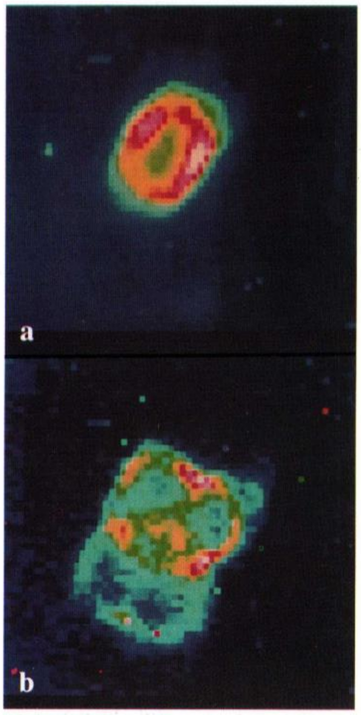


Figure 3(a): Image of the planetary nebula NGC7027 in H I Brackett gamma. Dust extinction causes the ring of ionised gas to appear rather non-uniform. Figure 3(b): Image of NCG 7027 in molecular hydrogen.

arcsec) over an extended region (30 arcsec, or 1.2 pc, assuming a distance of 8.2 kpc). Such an image is the basis for investigating the stellar population in this area in detail.

The newly-discovered cluster of emission-line stars around the galactic nucleus was studied using the CVF and F-P etalon. An extended Brackett gamma map was obtained to derive more reliable mass-loss rates for these stars, and line-imaging made in light from ionised and neutral helium. The indication is that the stars, with He I but not He II emission, are blue supergiants, with luminosities up to a million times that of the Sun showing a huge mass loss, which could well be responsible for the ionisation of the Galactic Centre gas.

FAST was also used to study some important extragalactic systems, including IRAS galaxies, starburst galaxies and active galactic nuclei. The active regions were studied in the lines of He I, H_2, and Brackett gamma in the K window, and of [Fe II] in the H window.

One-arcsec resolution images were obtained of systems such as NGC 1068 (a Seyfert 2), NGC 6240 (an ultra-luminous IRAS galaxy), and NGC 253, a nearby starburst galaxy. For NGC 1068, Fabry-Perot observations of emission from neutral hydrogen in different velocity ranges resulted in the discovery that the molecular material in the nucleus may be in the form of a rotating ring or torus of diameter 100pc, with an enclosed mass of about 10^9 suns.

NGC 6240 has a double nucleus, and the H_2 images show a streamer between the two nuclei. The H_2 is probably excited by the galaxy-galaxy collision.

The infrared spectra of many supernova remnants (SNRs) display very strong [Fe II] 1.644μm, both because of the high iron abundance and the fact that the line is enhanced in shocked gas. Using the CVF to isolate this line, [Fe II] was observed in a number of starburst and Seyfert galaxies. The most spectacular results were obtained on the luminous IRAS galaxy NGC 6240, and the southern starburst galaxy NGC 253 (see figure 2). NGC 253 is very similar to the famous nearby 'exploding' galaxy Messier 82. Both galaxies have a family of compact radio sources, a number of which are believed to be young SNRs. Accurate astrometry still needs to be performed on the [Fe II] images of NGC 253, before we can claim any infrared/radio positional coincidences. However, in the case of NGC 6240, the morphological similarity is quite obvious and the ratios of the [Fe II] line and 6cm radio fluxes in the two distinct components are identical.

The role of supernovae and their remnants is a topical subject in the study of both starburst galaxies and Seyfert galaxies. Narrow band observations of [Fe II] offer a means of identifying regions where supernova remnants are present. Nuclear H II regions in general have much weaker [Fe II] emission with respect to the recombination lines, and they also have quite different radio properties. These new results underline the prospect that infrared emission-line images may be used in a way similar to their traditional optical counterparts, such as Hα and [O III], to trace the spatial extent and physical conditions in the gas. An additional benefit of employing [Fe II] as a diagnostic is that it is subject to far less attenuation than are optical lines, a major advantage when studying dusty regions.

A fundamental problem in stellar evolution studies is that we do not really know how low-mass (1-2.5 suns) and intermediate-mass (2.5-8 suns) stars eject planetary nebulae. Studying the ejection process observationally is difficult, as it happens quickly in astronomical terms (in less than 10,000 years) and as the objects — extreme red giant stars — are shrouded by thick dust shells. It was thus decided to try to 'track' the morphology of the dust shells and young planetaries by observing in the infrared.

Extreme red giants losing mass and young, compact planetaries were observed. The most interesting first results from a 'quick-look' are the morphologies in the molecular hydrogen line.

Figure 3 shows a famous nebula, NGC 7027. The picture in Brackett gamma 2.16μm traces emission from the ring of ionised gas around the (unseen) central star. We know that there is neutral gas, not yet ionised, outside the ring, from observations of CO and H_2 emission. The ionised ring is actually more uniform than the picture suggests, as dust extinction cuts out some of the radiation across the face of the nebula, with the most obscuration being to the south-east (lower left) part of the field.

However, our image in the light of molecular hydrogen is strikingly different. We see no sign of the ring, but rather what appear as two 'loops' of material. One is likely to be at the front and one at the back. The centres of symmetry of the H_2 loops and the ionised ring coincide. The loops may well be low-velocity shock-waves driven into the neutral gas, which would excite the molecular hydrogen levels giving the emission seen. This would be consistent with the observation that the inner, ionised gas is expanding at over 20 km/sec whereas the neutral gas is only expanding at 15 km/sec.

This molecular line can also be excited by a fluorescent process involving absorption of ultraviolet radiation, but in this case too the loops must represent real density enhancements which could be 'wind-blown' bubbles.

The FAST run was so successful and scientifically productive that news of its success quickly permeated through the astronomical community and has resulted in 67 nights being sought by applicants for the 1992 FAST run!

Dr P J Andrews, Dr R E Clegg and Dr M J Ward
Royal Greenwich Observatory

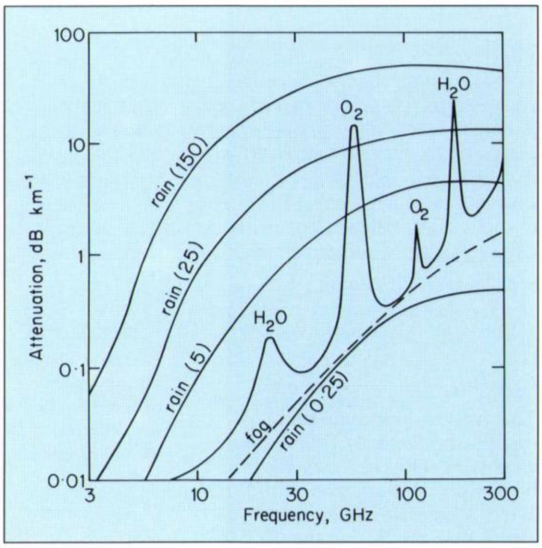


Figure 1: Attenuations due to atmospheric gases (oxygen and water vapour), rain of different intensities (in mm/h) and fog.

Millimetre waves — communications for the future

Because of ever increasing demands for radio communications over recent years, the radio spectrum is rapidly becoming overpopulated. Although it is a re-usable resource, the radio spectrum has a finite capacity, which inherently limits the amount of information which can be transmitted at any given time, especially where very high levels of reliability are required.

A solution to the problem of spectrum congestion may be found in moving to higher and higher frequencies. Already, communications systems operate at frequencies extending well into the microwave region of the electromagnetic spectrum, up to 30 GHz (wavelength 1 cm) and even beyond, into the millimetre-wave region, in the range 30 to 300 GHz (wavelengths 1 cm - 1 mm). This region of the spectrum is still relatively under-used, particularly at the higher frequencies, while the available bandwidths can be so wide that they create new and exciting opportunities for communications channels with a capacity for carrying huge amounts of information. The spectrum and potential applications are described by Dr Chris Gibbins of SERC's Rutherford Appleton Laboratory.

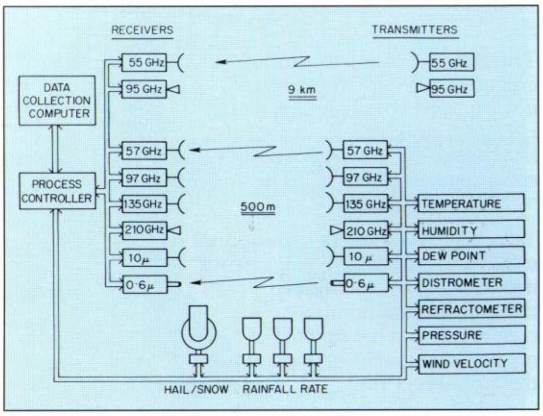


Figure 2: Block diagram of the 500 m and 9 km experimental transmission ranges at Chilbolton.

At millimetric wavelengths, some problems arise which are not encountered at lower frequencies. The Earth's lower atmosphere starts to interact with electromagnetic radiation, resulting in signal attenuation which must be taken into account in the design of millimetre-wave systems. There are two distinct and quite different effects, which are shown in figure 1. First, molecules of oxygen and water vapour absorb radiowaves at certain characteristic (resonant) frequencies, because of rotational transitions within the molecules. Oxygen has a band of 'fine structure' transitions (or lines) near 60 GHz which merge together at sea-level pressures to form a broad absorption band, together with a single isolated line at 119 GHz, while water vapour has a weak line at 22 GHz and many stronger lines at 183 GHz and higher frequencies.

The second effect is that hydrometeors (rain, snow, hail, fog etc) scatter radiowaves, so introducing additional signal attenuation. This effect is mainly non-resonant and increases as the wavelength decreases to become comparable with the sizes of raindrops; in this region, the so-called 'Mie' scattering process becomes most efficient and signal attenuation is greatest.

Molecular absorption is present everywhere, it changes only slowly with varying temperature, pressure and humidity, and it can be predicted with a sufficiently high degree of accuracy that it can reliably be taken into account in systems design.

Hydrometeors, however, present a quite different problem. Rain (and other forms of precipitation) is a stochastic process: it is highly variable in time, space — geographic location — and in intensity and so its effects are generally treated statistically. The attenuation in uniform rain of specified rainfall rates can be calculated from Mie scattering theory, for example, but rain is neither uniform nor does it fall at constant rates.

However, long-term measurements of radiowave propagation at frequencies up to about 40 GHz, at a number of locations around the world, together with simultaneous measurements of rainfall rates, have confirmed statistically the validity of such models, thus allowing predictions of rain attenuation to be made from more readily available rainfall statistics at other locations and in other climates.

Open-air laboratory

Above 40 GHz, however, there is a marked lack of data with which to test the models. To provide information on terrestrial radiowave propagation in the millimetric regions and above, the Rutherford Appleton Laboratory has designed, constructed and operates an experimental transmission range at the Chilbolton Observatory. The range, shown schematically in figure 2, is a well instrumented open-air laboratory in which unmodulated transmissions over a 500 m pathlength (along which meteorological conditions may be considered essentially constant) are monitored continuously, at a rate of 0.1 Hz, at frequencies of 57, 97, 135 and 210 GHz and at wavelengths of 10.6 and 0.63 µm in the infrared and visible regions. Coupled with these is a comprehensive set of meteorological instrumentation, including three rapid-response raingauges located along the path, a rapid-response hail/snow gauge, a distrometer to measure the distribution of raindrop sizes, thermometers, hygrometers, a barometer, anemometer and a microwave refractometer to measure atmospheric refractive index. A 9 km link with transmissions at 55 and 95 GHz provides additional data over a longer, more practical, pathlength, to yield further information, for example on the spatial non-uniformity of rain. Figure 3 shows the 500 m range transmitter cabin at Chilbolton, with the signals being transmitted 4 m above the ground, through transparent windows protected from getting wet in rain by hoods.

Statistical analyses of long-term measurements of propagation have provided cumulative distributions of attenuation, as in figure 4 from an earlier phase of the experiment (with some different frequencies), showing the percentages of time that various levels of attenuation were exceeded over a three-year period, confirming that rain attenuation increases with increasing frequency. The dramatic difference between the millimetric distributions and those at infrared and visible wavelengths is due to the incidence of fog, which has little effect at millimetric wavelengths as indicated in figure 1. Such results can be used for direct application to systems design in regions with similar climatology.

Comparisons between analogous results for rain events only, together with the corresponding concurrent distributions of rainfall rates, are used to establish experimentally deduced relationships of the form:

Figure 3: The transmitter cabin at Chilbolton. Equipment is mounted on benches supported independently from the cabin, on steel pillars within the concrete tubes.

attenuation (dB/km) = kR^{α} where R is the rainrate (in mm/h) and k and α are frequency- and polarisation-dependent coefficients. Such expressions enable the results to be applied to other regions with different rain climates (using local rainrate statistics), and further to assess the validity and accuracy of theoretically derived values of the coefficients k and α. It is found that, in general, the models tend to underestimate rain attenuation at frequencies above about 40 GHz, with the discrepancies increasing with decreasing wavelength. The source of this error is considered to lie in the choice of the distribution of raindrop sizes used in current theoretical models, and that this distribution underestimates the number of very small raindrops, which become of increasing importance for the shorter wavelengths.

Multi-frequency measurements of rain attenuation contain much information on the path-averaged distribution of raindrop sizes, and a technique has been developed at RAL to invert such measurements into more appropriate distributions which may be used as the basis for new calculations of rain attenuation, in better agreement with observations. At the same time, a different technique is being developed independently at Bradford University, using the same database.

Video distribution

One of the first commercial applications of millimetre waves will be the development of MVDS — the Millimetre-wave Video Distribution Service — as an alternative or complementary to cable television, especially for those towns and communities considered not to be large enough for commercially viable cable networks. In such a case, a transmitter located on a local high point will broadcast 20-30 TV channels at a frequency near 40 GHz, over a radius of 2-3 km, to small (about 15 cm diameter) rooftop antennas. In order for MVDS to be widely available and to make the most efficient use of the allocated spectrum, it will be necessary to re-use the same frequencies over quite small distances, say 30-40 km. Since there may then be a possibility of interference between neighbouring systems, RAL is to set up another link at 40 GHz along an obstructed 35 km path, to investigate the likelihood of anomalous, over-the-horizon propagation, while Essex University is to conduct a similar experiment along a coastal path, where anomalous propagation conditions may be more likely to occur.

Another application now becoming available involves using the 60 GHz band for short-range (a few km) unregulated transmissions, where atmospheric attenuation due to oxygen absorption exceeds 15 dB/km and thus provides sufficient isolation that interference problems will be minimal. The facility for covert systems operation is also clearly apparent in this frequency band.

Millimetre waves, then, though long considered somewhat exotic, are finding direct applications in commercial communications systems right now, and, although there still exist many gaps in our understanding of their interaction with the atmosphere and the prevailing meteorology, the work being carried out at RAL and in the universities will greatly improve our knowledge and facilitate a rapid expansion into the millimetre-wave region of the spectrum, creating new opportunities for innovative communications systems and even, perhaps, relieving spectrum congestion at lower frequencies.

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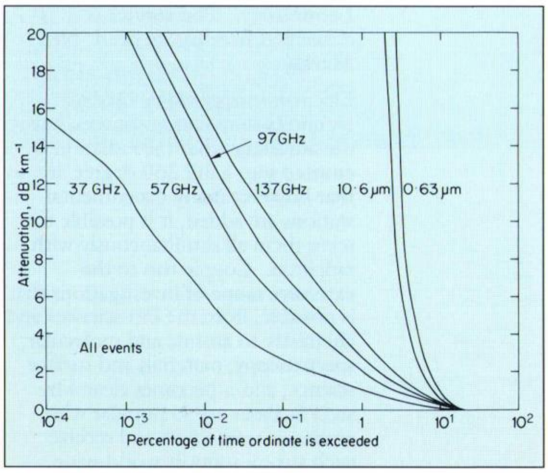
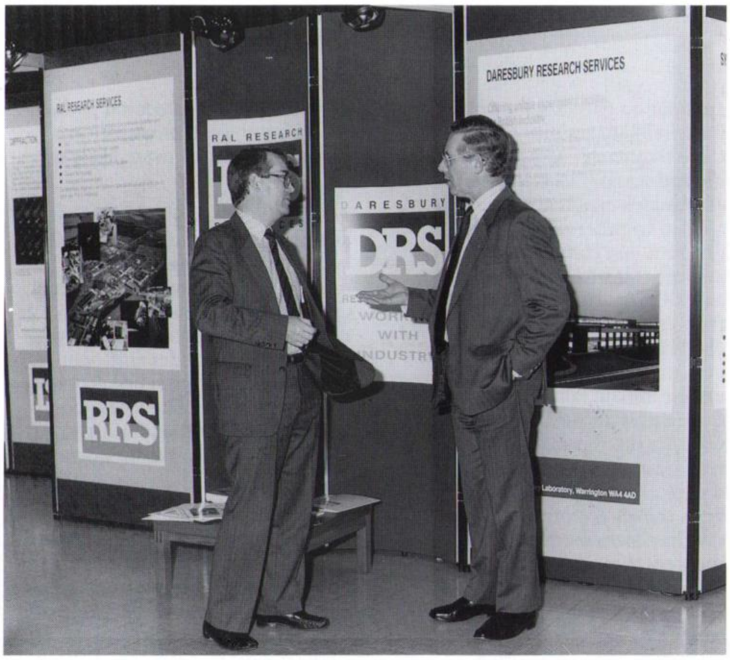


Figure 4: Cumulative distributions of attenuation measured in all types of weather over a three-year period.



DRS collaborates with Rutherford Research Services (RRS) in jointly marketing synchrotron radiation and neutron beams for use in materials science by exhibiting at academic and commercial conferences and meetings.

Daresbury serving industry

Daresbury Research Services, the commercial arm of SERC's Daresbury Laboratory, has now been in business for over three years, during which time it has been promoting industrial use of synchrotron radiation from the Daresbury Synchrotron Radiation Source (SRS), and other facilities and expertise within the Laboratory. The service is described here by its head, Neil Marks.

Electron storage rings, used as synchrotron radiation sources, have the advantage that the radiation is emitted into a full 360 degree arc, so that however many experimental stations are added, it is possible to serve them all simultaneously with radiation. Couple this to the extensive range of investigations that is possible, from the bio-sciences and chemistry to atomic and molecular, spectroscopy, materials and surface science, and it becomes clear why such facilities are so popular with academic researchers and receive such strong support world-wide.

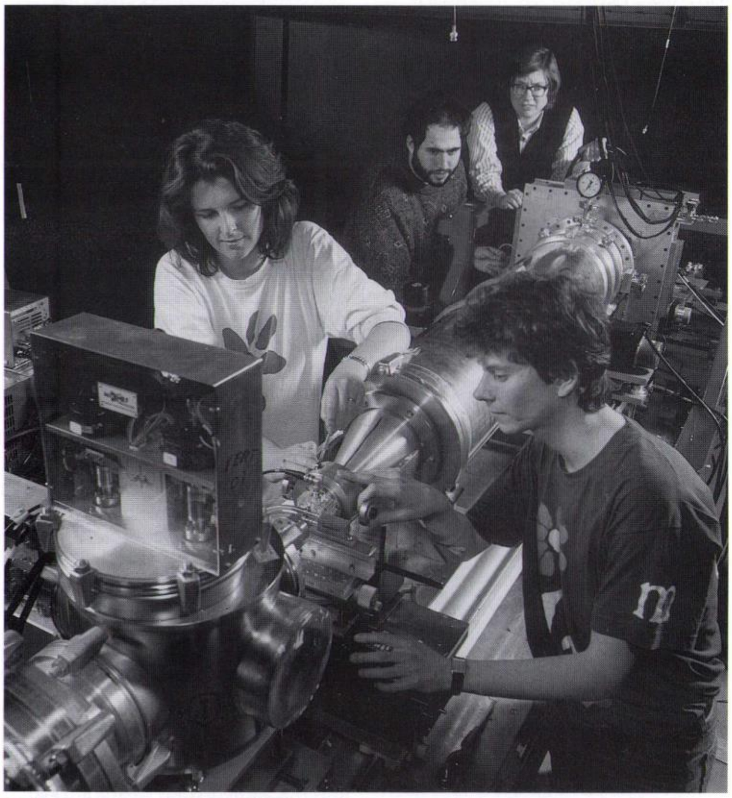
Synchrotron radiation for all

The SRS at Daresbury is no exception. More than ten years have elapsed since it was first commissioned, and the demand for beam time from university users is undiminished; the number of experimental stations is still growing and a major upgrade, in the form of a new wiggler insertion magnet to provide harder radiation, is currently being carried out.

However, the growth in the use of the SRS has not been confined to academic research. From the early days of the facility it became clear that many of the techniques available on the experimental stations could be used for industrial applications. Three major companies, ICI, BP and Shell, set up an 'industrial consortium' and negotiated a contract to use the radiation to enhance their in-house programmes for the development and understanding of their industrial processes. In 1988, just after the high brightness lattice upgrade to the SRS, the SERC Science Board decided that the promotion and support of commercial activities on the SRS should be more positively encouraged, and Daresbury Research Services (DRS) was born. This coincided with the increased emphasis on 'repayment work' within the Council, and the scope of the new unit was rapidly expanded to include all commercial activity between the Laboratory and industry.

Chemical behaviour of toothpaste

Promotional activities concerned with the industrial use of synchrotron radiation have built on the base of the original industrial consortium; major companies, such as Unilever, Glaxo and Pilkingtons, have now been added to the list of SRS users; the use of eight-hour



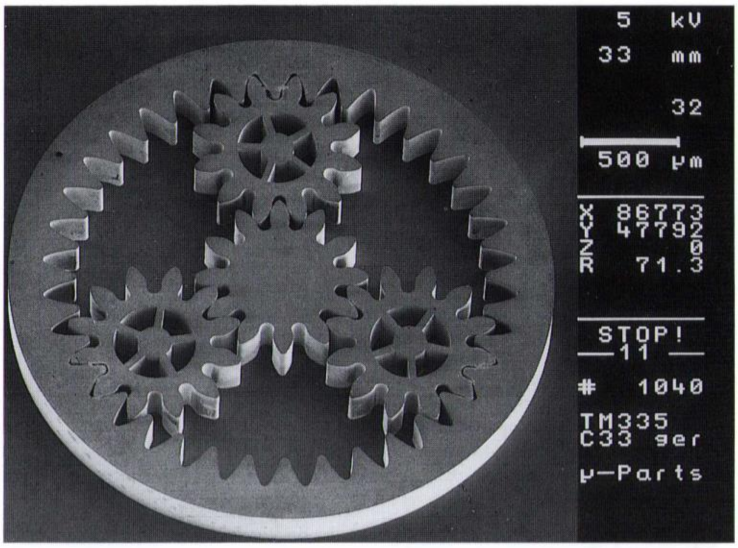
Unilever scientists using X-ray diffraction techniques on an SRS station to examine the structure of their health care products. Photo: Unilever.

shifts by commercial organisations has grown by 45% in two years. While much of this work remains confidential, companies are happy to disclose the general direction of their programmes and sometimes choose to publish particularly interesting results in academic journals. A significant part of the work carried out by the chemical and petrochemical companies involves the investigation, on X-ray spectroscopy stations, of catalysts used in major industrial manufacturing processes. For example, ICI recently published results obtained at Daresbury on the behaviour of catalysts used in the synthesis of methanol. Other chemical applications, using the X-ray diffraction stations, include the analysis of the changing structure of paints and polymers as they solidify, and the investigation of the chemical behaviour of health products such as ointments and toothpastes.

More recently, protein crystallography, an X-ray diffraction technique that identifies the atomic structure of large, complex biomolecules, has become increasingly important to large pharmaceutical manufacturers. By identifying the full three-dimensional structure of viruses, it will be possible to 'design' drugs that will combat diseases in both animals and humans. An example of such activity was the collaborative work between Oxford University and Wellcome, on a protein diffraction station at Daresbury, which identified the atomic structure of the foot and mouth disease virus. Now, a number of pharmaceutical manufacturers, including Glaxo, have sought contracts through DRS for such investigations. This is known to be a major growth area in the economy, and use of the SRS for such investigations is expected to expand.

Micro-mechanics

An unusual and interesting use of synchrotron radiation is highlighted by a recent agreement with the Karlsruhe-based company, MicroParts mbH. This company is engaged in micro-mechanics, and is able to produce microscopic mechanical components in metal, ceramic or plastic, with thicknesses up to a third of a millimetre but with an accuracy and reproducibility of a few tenths of a micrometre. The production process uses a lithography technique known as the LIGA process and synchrotron radiation is necessary to produce the ultra-accurate moulds from which the final product is obtained. Early production trials were carried out at the Bonn synchrotron, an easy journey from Karlsruhe. However, the shorter wavelength and higher intensity available at Daresbury have now attracted MicroParts to the UK, and work for this process is regularly scheduled on an SRS station.



A micro-mechanical component produced by the Karlsruhe company, MicroParts, now using Daresbury synchrotron radiation as part of their LIGA production process.
Photo: MicroParts mbH.

Non-SRS activities

Not all the commercial activities at Daresbury use synchrotron radiation. The Laboratory's accelerator group has recently completed a highly successful contract involving the accelerator design, beam calculations and commissioning services for Helios, a superconducting compact synchrotron that has been built by Oxford Instruments, the major cryogenic magnet manufacturer. This new source will be used for the X-ray lithography that is needed to achieve sub-micron structures in the next generation of silicon chips. The first Helios has now been delivered to IBM in New York State, and has exceeded its beam intensity specification by 30% during commissioning.

More than 25 years' experience in computing, for both experimental and theoretical applications, has led to the Laboratory's Theory and Computational Science Group becoming pre-eminent in the production of software for novel, parallel computer architecture. This is a further area of interest to ICI and a collaborative contract, to explore the value of such techniques for quantum chemistry calculations, has been in place for a number of years. Worthwhile results are being obtained and the contract has recently been renewed.

Repayment work is therefore expanding at Daresbury, and DRS will continue to support and promote these activities to the benefit of both the Laboratory and its industrial clients in the future.

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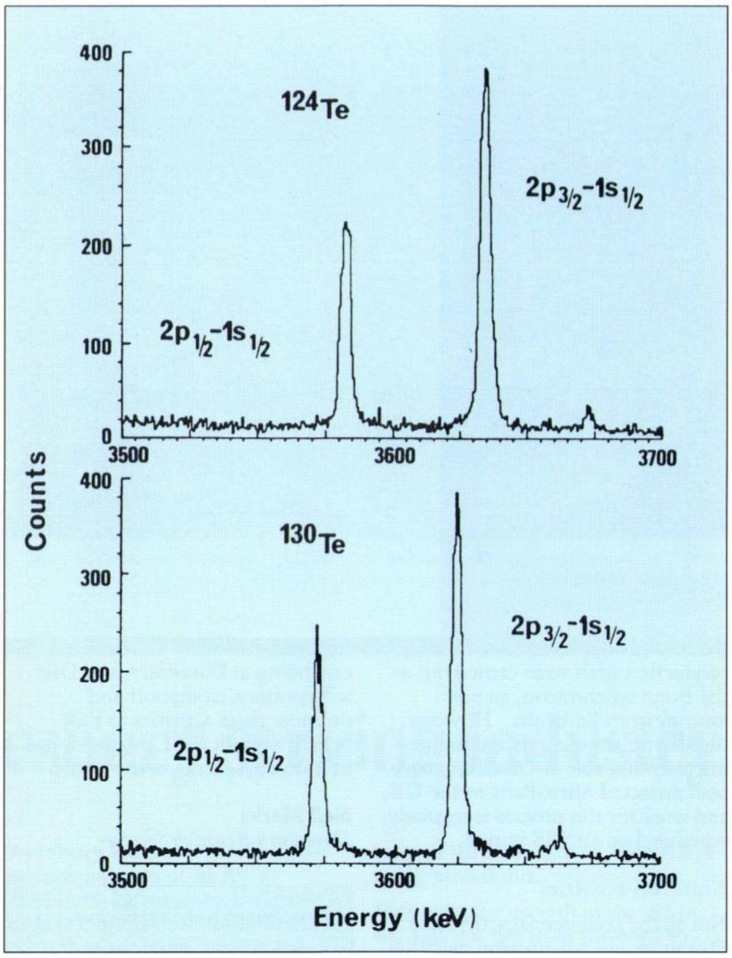

Figure 1: Muonic atom spectra for two Te isotopes measured at LAMPF. The isotope shift is about 20% of the fine-structure splitting. The measurements show that the charge radius of these isotopes differs by $30.1 \pm 0.5 \times 10^{-18}$ *m*.

Exotic atoms

Exotic atoms are of interest in many different branches of physics and in medicine. They are produced by accelerators with energies of a few hundred MeV up to tens of GeV and give information on the basic interactions of elementary particles, the radiative corrections of quantum electrodynamics, the structure of nuclei and the relativistic equations of motion of spin-zero particles. The applications range from radiation therapy to power from nuclear fusion, writes Dr Roger Barrett of Surrey University.

Exotic atoms are formed whenever a negatively charged particle other than an electron is captured by an atom and revolves around it in an atomic orbit. In addition to these atoms with nuclei made up of protons and neutrons, there are purely leptonic atoms such as positronium (e^+e^-), muonium (μ^+e^-) and ($\mu^+\mu^-$). They are important in testing quantum electrodynamics and the predictions of the relativistic two-body Bethe-Salpeter equation which have been verified to very great precision. Here we restrict our discussion to the first type, namely atoms made with μ^-, π^-, p^- and Σ^- particles revolving around an ordinary nucleus. The masses of these particles are hundreds of times larger than that of an electron and their half-lives vary from 2.2×10^{-6} to 1.5×10^{-10} seconds — very much longer than the times associated with the internal motion of an atom. This allows us to study the radiation emitted when the particles cascade down towards the nucleus.

Dramatic difference

As a result of the large orbiting masses, exotic atoms differ dramatically from ordinary atoms: the radius of each orbit is reduced and the energy of each transition is increased by the mass ratio, so that the emitted radiation, usually referred to as X-rays, can have energies usually associated with gamma rays, ie up to several MeV.

We consider first muonic and pionic atoms which have been observed extensively at the 'meson factories' (accelerators which are designed to produce pion beams of high intensity) at TRIUMF (Vancouver), LAMPF (Los Alamos) and the Paul Scherrer Institute (PSI, formerly SIN) near Zurich. In the first, where the interaction is purely electromagnetic, the experiments are used to obtain precise information about the charge and magnetic structure of nuclei.

For states with relatively large orbits (principal quantum number $n>2$ or very low atomic number *Z*), we may either assume that the electric field due to the nucleus is the same as that of a point charge or else reliably calculate the small deviation from this. The transition energy between two such states may then be used to determine the mass of the orbiting particle: the pion mass has been obtained in this way to an accuracy of about 3 ppm (parts per million). The muon is the only 'exotic' particle whose mass may be measured accurately by other types of experiment and it is known to 0.3 ppm. This has made it possible to use muonic X-rays to provide a very accurate test of 'vacuum polarisation', ie the deviation from the inverse square law of force for strong fields. In Mg and in Si the theory predicts a contribution of 0.3% in the $3D \rightarrow 2P$ transition and at PSI in 1985 this was confirmed to 0.03% by very accurate (1 ppm) measurements.

Extraordinary accuracy

Alternatively a very small upper limit may be put on the size of possible unknown muon-nucleon forces. For some nuclei charge radii have been measured to an accuracy of almost 10^{-19}m. Muonic atom measurements combined with electron scattering experiments now give an extraordinarily accurate picture of the radial size and shape of charge densities.

In the case of an orbiting hadron, ie in π^-, p^- or Σ^- atoms, the energy of the lowest levels is also influenced by the distribution of the neutrons, and information about the hadron-nucleus force and about the distribution of neutrons as well as protons can be deduced. The transition energy calculated with purely electromagnetic forces is subtracted from experiment to give the 'strong-interaction shift'— in other words the change caused by the short-range hadron-nucleon force. The width of the lines due to absorption on the nucleus also gives information about the force.

The simplest kaonic atom is hydrogen and it has, surprisingly, turned out to be the most difficult to understand. The problem comes in reconciling the measurements of the strong-interaction shift and width of kaonic hydrogen with scattering experiments. There have been three measurements of the shift and they all indicate that the 1S energy is slightly lower that the Bohr prediction. The scattering results can be used to predict this quantity and the result is that the level should be higher. This situation has persisted for more than a decade and the explanation is either that the kaon-proton force varies with energy in a bizarre way or possibly, that all three of the (admittedly extremely difficult) kaonic atom experiments are wrong. A new experiment underway at the KEK accelerator in Japan is expected to produce far more $2P \rightarrow 1S$ events than all the previous experiments combined and will, no doubt, settle the matter.

Meson factories

Kaon experiments will soon become more plentiful because two new meson factories are under construction. At Frascati the DAΦNE Φ-factory is due to start producing ϕ mesons by 1995 by means of intersecting electron-positron beams. These mesons have a mass of 1019 MeV and 50% of them decay into monoenergetic K^+ K^- pairs which will be ideal for producing atoms and to do scattering experiments on nuclei. The K^+ particles have a relatively weak interaction with nucleons and this makes them an ideal probe for neutrons. (The protons are already well probed by electron scattering experiments). Some two or three years after this the KAON factory at TRIUMF should be completed and there will then be much higher intensity kaon beams available.

The current British interest in exotic atoms experiments has shifted from experiments using kaons and anti-protons to muon-catalysed fusion (μCF). Here the problem is to get a deuterium (d) and a tritium (t) nucleus to approach each other. The standard way is to create incredibly high temperatures such as in the Joint European Torus, but if a muonic d-t molecular ion is formed, then the muon in its small orbit provides substantial shielding of the electrostatic repulsion between the two nuclei so that fusion can occur at a much lower temperature. After one fusion a muon will be captured by another molecule and will catalyse several hundred fusion events before it decays into electrons and neutrinos. A UK-Japan collaboration at Rutherford Appleton Laboratory has begun and will bring more than £5 million into this country. Work at TRIUMF and PSI has shown that μCF has promise as a means of producing nuclear fusion power.

Many different areas of theoretical physics are relevant in the study of exotic atoms. In purely leptonic atoms and in muonic atoms, advanced calculations in quantum electrodynamics are required. The correct relativistic equation for pions and kaons interacting with nuclei is not known: different contenders are the Klein-Gordon Equation, the 'relativistic Schrödinger' equation and the Duffin-Kemmer-Petiau equation. Accurate measurements and calculations may make it possible to choose between these. The interactions between mesons and nucleons are difficult to calculate from fundamental theories such as quantum chromodynamics, but a 'semi-fundamental' theory such as the 'Cloudy Bag' model uses a meson-quark interaction to obtain the meson-nucleon force. Such calculations can be checked by using low energy scattering and exotic atom experiments.

Cancer treatment

π^- beams are used for cancer treatment where the aim is to create pionic atoms in malignant cells which are then damaged when the pion decays or is absorbed in an atomic nucleus. Pion beams are particularly attractive for radiotherapy because they pass through tissue doing little damage to the normal cells while they are slowing down and then each pion releases a vast amount of energy when captured. Careful research is required to make sure that capture occurs at the correct position in the body, and much of this has been done at TRIUMF.

Exotic atoms are of interest in other areas than those mentioned above; muonic molecules can give information about the structure of molecules which contain hydrogen; Σ^- atoms are used to obtain the magnetic moment of the Σ^- particle; Ξ^- and Ω^- atom experiments will no doubt be carried out in the future. The field brings together a large number of different theoretical and experimental disciplines.

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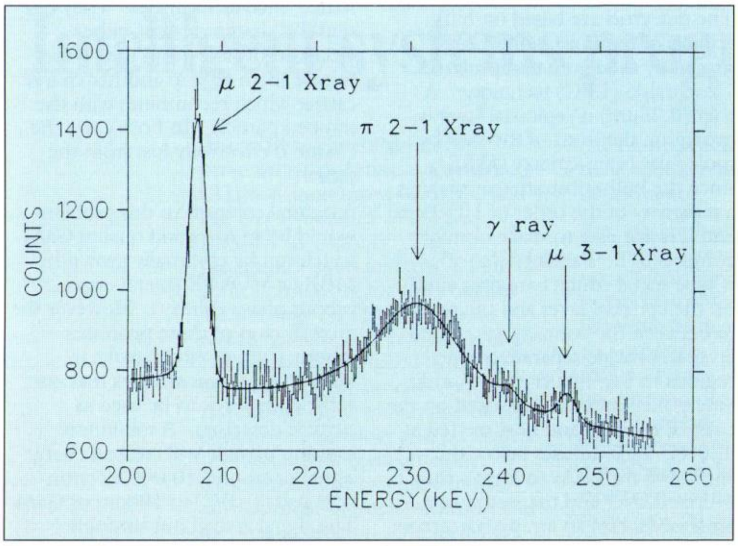

Figure 2: The 22 Ne π^- X-ray spectrum measured at TRUMF

The Sheffield Central Facility was established in 1978 by the Engineering Board for the supply of III - V compound semiconductor material to the academic research community. The facility is presently supported by the Advanced Devices and Materials Committee of the Information Technology Advisory Board. The activities at Sheffield, however, are not only geared to academic research in semiconductor devices. This article describes another area where these advanced semiconducting materials are finding increased application.

Gallium arsenide detectors for high energy physics

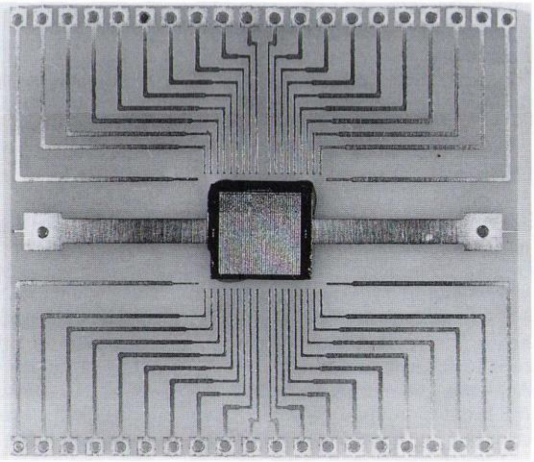

Figure 1: GaAs microstrip detector mounted on printed circuit board. The detector chip is approximately 1 cm square and has 40 microstrip devices each with an integrated bias resistor and decoupling capacitor.

In recent years high energy physicists have made use of silicon technology to develop position sensitive detectors capable of measuring points along the trajectory of a particle with accuracies as great as 5µm. These detectors have been used to study the decays of short lived particles (lifetimes of the order of 10^{-13}s).

However, at the next generation of hadron colliders being proposed for the turn of the millenium, the large hadron collider (LHC) at CERN in Geneva and the superconducting super collider (SSC) in the USA, the detector systems will have to operate in a hostile radiation environment of fast neutrons and gamma rays. The detectors at the LHC and SSC require precision trackers to take full advantage of the physics potential of these facilities, but the hostile radiation environment precludes the use of silicon detectors in some areas of the detector and consequently an alternative detector technology must be found. One such possibility that is being studied in Sheffield is gallium arsenide (GaAs) because of its radiation hardness. Its use is described here by Craig Buttar and Geoff Hill of Sheffield University.

Prototype GaAs microstrip detectors have been fabricated in the SERC III-V Semiconductor Facility, located in the Department of Electronic and Electrical Engineering at Sheffield University. The detectors are based on bulk crystals of semi-insulating GaAs grown by the liquid encapsulated Czochralski (LEC) technique. A thin (0.25µm) n^+ epitaxial layer is grown on the front of the slice by molecular beam epitaxy (MBE), since the bulk substrate material has a resistivity of the order of $10^8\Omega$-cm and it is not easy to make ohmic contacts to it. Parallel strips of n-type metal contact are deposited on the epitaxial layer and the regions in between the contacts are etched away to provide separate contact regions to the bulk crystal. A gold-zinc-gold contact is deposited on the back of the slice and heat treated at 420°C. Zinc diffuses below the surface of the GaAs to form a thin p-doped layer and the resulting p-i-n structure forms an array of detectors.

Detector fabrication

Workers at Glasgow University have used a slightly different approach to detector fabrication, using ohmic contacts to the rear of the slice and Schottky diode contacts to the front. Because of the extremely high resistivity of LEC GaAs, neither the p-i-n structure or the Schottky diode structure exhibit current-voltage or capacitance voltage characteristics typical of more conventional epitaxially grown structures.

The detectors have been tested both with radioactive sources in the laboratory and in a testbeam at CERN and they have successfully detected the passage of ionising particles. However it has also been observed that, unlike silicon detectors, the observed charge signal is much less than expected and is a function of the applied bias voltage. In silicon detectors all the charge created by the passage of an ionising particle is rapidly collected. This charge is a function of the applied bias. This is because the thickness of the depletion layer of the reverse biased diode, which is the sensitive detection region, is dependent on the bias voltage.

The forbidden gap

However, as the GaAs detectors are based on near intrinsic GaAs, the detectors should be fully depleted at very low voltages, implying that the charge collection should be independent of the applied bias. The observed incomplete charge collection, which is a function of the applied bias, is believed to be due to traps that occur in the LEC material. Traps are states which exist in the normally empty forbidden gap of semiconductors due to defects in the lattice, such as vacancies. They can trap the charge carriers, either electrons or holes, and then either release them or trap another charge carrier which recombines with the trapped particle. In both cases the charge is effectively lost from the signal.

A natural solution to this problem would be to use good quality GaAs which can be epitaxially grown by MBE or MOVPE (metal organic vapour phase epitaxy). However the growth rates of these processes (about 1 µm an hour) make it difficult to obtain samples that are sufficiently thick to be used as particle detectors. A minimum ionising particle will create a charge signal of around 10,000 electron-hole pairs (≈1fC) in 100µm of GaAs. The signal is read out through amplifiers that have noise levels of

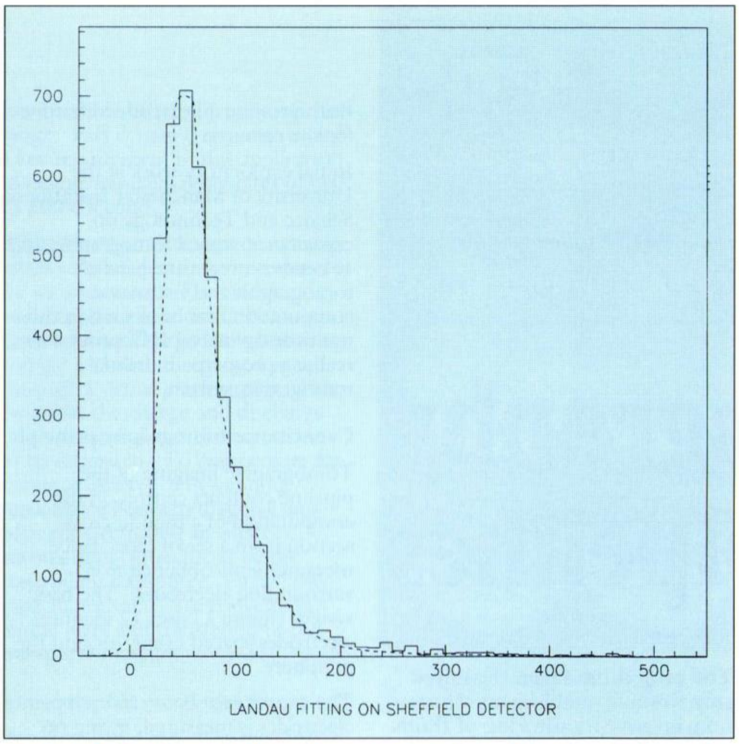

Figure 2: The figure shows the observed energy spectrum from a GaAs microstrip detector in a beam of high energy minimum ionising particles. The histogram is the data and the dotted line is the predicted spectrum due to the particles.

around 1000 electrons. This leads to a signal-to-noise ratio of about 10:1, which is the minimum level that the detector should work at.

Consequently the detectors are based on LEC-grown GaAs despite this being a lower quality material as it is relatively cheap compared to thick epitaxial material and is readily available in thick wafers (~500μm). The properties of the substrate material depend crucially on the annealing that the wafers are subjected to. To try and overcome the problem of trapping, substrates grown under slightly different conditions are being tested to see which performs most efficiently.

Other applications

Outside high energy physics, GaAs detectors are being developed as room temperature gamma-ray detectors. GaAs has several advantages over the conventional semiconductor gamma-ray detectors, silicon and germanium. The larger bandgap of GaAs means that, unlike germanium detectors, it can be operated at room temperature because of its low leakage current. GaAs has a similar atomic number to germanium and so is more efficient as a gamma detector compared to silicon.

The large leakage currents observed in the detectors mean that they must be ac coupled to the readout electronics — coupled through a resistor capacitor to block the dc leakage current. At Sheffield, test structures have been fabricated in which the capacitor network required for ac coupling is integrated on the detector chips. These structures are currently being tested. A possible further extension of integration, which is also being investigated, is the incorporation of a 'MESFET' pre-amplifier on the detector chip.

GaAs microstrip detectors have been developed that can detect minimum ionising particles. Although initial studies show that there are problems associated with GaAs, they are encouraging enough to say that GaAs will provide a radiation-hard alternative to silicon for the next generation of experiments at the LHC and SSC. The potential of a GaAs room temperature gamma-ray detector has exciting consequences for all applications that use gamma rays as probes.

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Intelligent systems programme

A new five-year collaborative programme in Artificial Intelligence (AI) was announced by SERC and the Department of Trade and Industry in October. The programme is an initiative within the Joint Framework for Information Technology (JFIT) and aims to research and engineer leading-edge KBS (knowledge-based systems) decision support systems and technology for a wide range of commercial activities and processes. It offers British companies an opportunity to participate in the development of improved tools and methods, based on advanced KBS techniques, to support their day-to-day business activities and enhance their commercial productivity and performance.

Knowledge-based systems are computer software programs which use artificial intelligence techniques to tackle problems ordinarily requiring human reasoning abilities and expertise. They represent a major advance in the evolution of information processing and its contribution to decision taking. They extend current software capabilities making explicit the structures behind knowledge and they open up approaches that permit the solution of problems that cannot be fully defined in advance, making possible the management of uncertain and incomplete data, and offering alternatives to conventional software methods.

Calls inviting applications for support will appear in the technical press and in JFIT News. Enquiries should be addressed to Mr Tony Conway at the DTI, telephone 071-215 1267 or Dr Heather Crowther, SERC Swindon Office, telephone (0793) 411260.

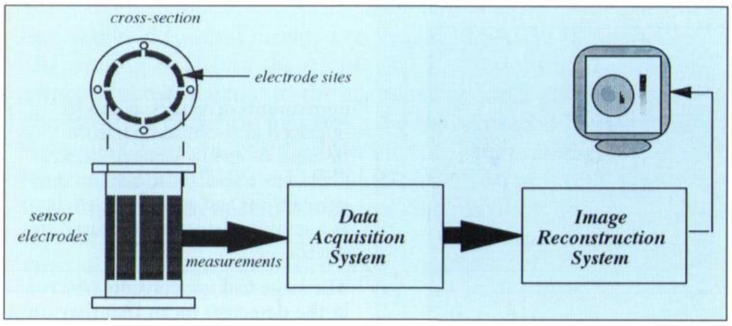

Figure 1: Schematic process tomography system including pipeline section capacitance sensors; data capture and measurement system; image reconstruction transputer network, which also provides system control; and image viewing screen.

Process tomography in pipelines

Process tomography is a visualising measurement technique which has been successfully applied to the examination of the flow of fluids in pipelines and which has resulted in a prototype industrial tomography system. The system was developed by a consortium which formed a multidisciplinary team of researchers from UMIST, Leeds University and Schlumberger Cambridge Research. The work was supported by SERC and the Department of Trade and Industry as a two-year project funded by the Information Technology Board's Control and Instrumentation Committee, as part of its Industrial Measurement Systems (IMS) LINK Programme.

The project has taken the initial step towards enabling continuous non-invasive monitoring of fluids in pipelines. In time this should lead to significant economic savings, and extended lifetime for the well-bore, write Professor Maurice Beck, Dr Brian Hoyle and Dr Chris Lenn.

The on-line measurement of multicomponent flows in oilfields presents a continuing challenge; periodic checks require complex separation equipment to be installed. Continuous monitoring could allow take-off rate to be controlled more closely, this in turn allowing oil/gas component production to be matched more accurately to demand. It could also lead to early detection of degradation of the well-bore. Both promise an extended life-time for the resource.

Initial exploratory work at the University of Manchester Institute of Science and Technology on capacitance-sensed tomography, and at Leeds on real-time parallel tomographic reconstruction computation, has been used in this multi-disciplinary LINK project to realise a prototype industrial tomography system.

Capacitance tomography principle

Tomographic imaging of the pipeline contents centres on the computation of a pseudo cross-section from a set of capacitance measurements obtained from surrounding electrodes. The basic system (figure 1) uses 12 identical electrodes spaced evenly around the periphery.

The capacitance between each pair of electrodes is measured, giving 66 unique values. These clearly depend upon the interposing dielectric distribution. Thus an object at the centre will significantly influence the diagonal, but not the adjacent value. An object close to electrode 3 will influence the adjacent value but also the diagonal value C_{39}. Clearly ambiguity can exist, and to minimise this a reconstruction algorithm is used which simultaneously makes use of all measurements to estimate the pipe contents.

The principle is simple and elegant, but its application presents complex problems.

Sensor design

The current design has evolved from work at UMIST. The use of 12 electrodes is probably the best in terms of sensitivity and resolution. Although some parameters are fixed by the application, some aspects and dimensions may be varied to optimise performance. Colleagues at the SERC sponsored Measurement and Instrumentation Centre at City University carried out CAD studies. A typical result of this work is illustrated in figure 2.

Capacitance measurement

The design of the data acquisition and capacitance measuring system is critical. The standing capacitance is the order of 0.015pF, and the requisite resolution to detect a small gas bubble at the centre corresponds to about 2% of this value: 0.3fF (fF: femto-Farad, 10^{-15}F). To resolve such minute changes the data acquisition system must provide high sensitivity, high signal-to-noise ratio,

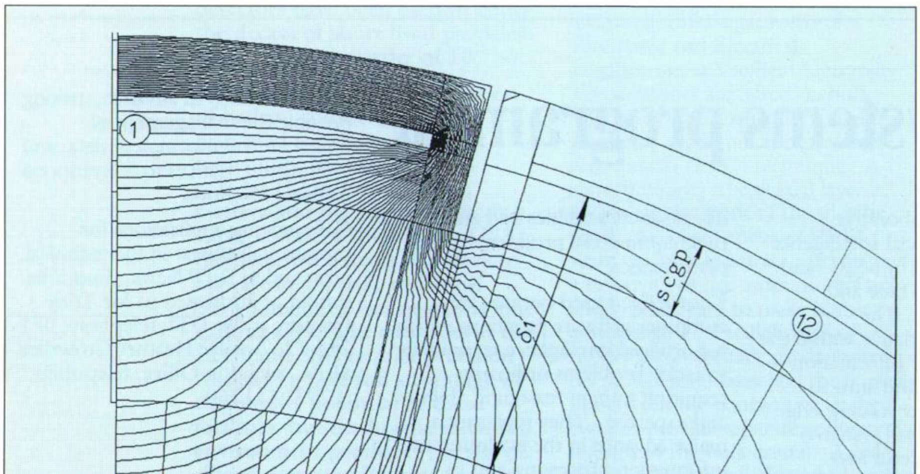

Figure 2: CAD study of electric field distribution around inter-electrode radial guard screens, important in reducing the standing capacitance between adjacent electrodes.

low baseline drift and large dynamic range. Fast dynamic response is also a key requirement in this application to enable frame imaging rates of up to 100 a second.

Multiplexed semiconductor switches select pairs of electrodes in sequence for measurement. The charge transfer principle is used: the electrodes are charged to a known voltage and then discharged again through a virtual earth circuit. This measures the charge and discharge currents, and allows the capacitance to be estimated. To compensate for the large difference in standing capacitance between diagonal and adjacent electrodes, an offset is automatically introduced by the controlling transputer. Finally the capacitance values are converted to digital form and transferred to the transputer network.

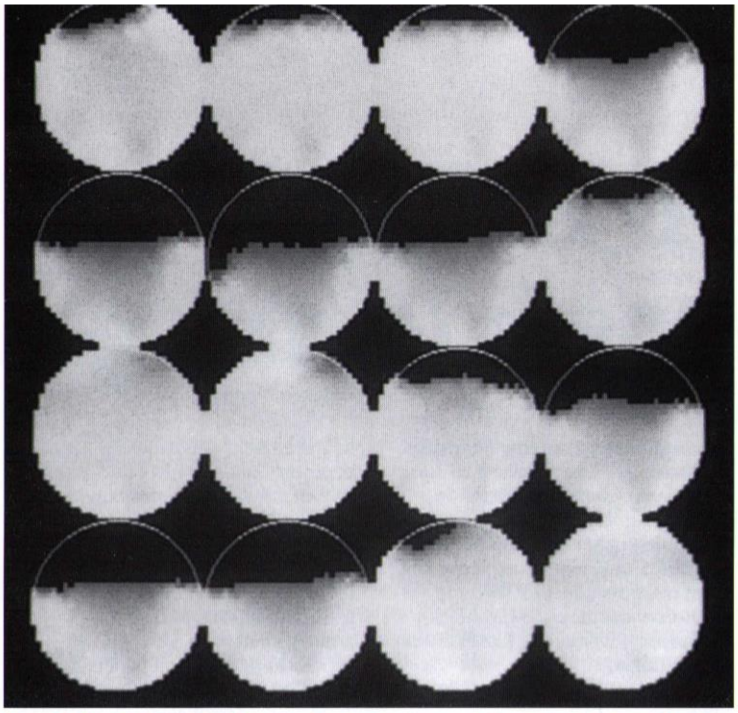

Figure 4: Typical experimental results. From top to bottom, left to right, the picture shows the development of gas slugs of a gas/oil flow in an inclined pipe (6° from horizontal, see figure 6). Time interval between successive images is 80 ms.

Tomographic reconstruction

Reconstructing the cross-sectional image of the pipe contents is an *inverse problem:* when the capacitance values are known, what is the dielectric distribution? Its solution relies upon knowledge of the *forward problem:* for a known dielectric distribution, what are the capacitance values? A solution for a homogenous dielectric, computed using finite element analysis, provides a set of sensitivity distributions. A typical distribution from the six basic forms is shown in figure 3.

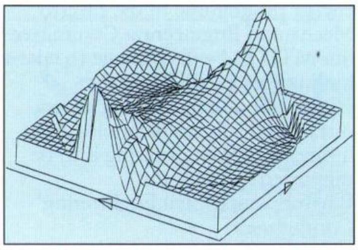

Figure 3: Example of capacitance sensitivity distribution, for diagonal electrode pair (1-7).

A backprojection algorithm is then used to estimate an inverse solution for the set of 66 measured capacitance values, using the appropriate sensitivity distribution for each respective sensor pair. The resulting grey-scale pixels form the estimated dielectric distribution in the pipe. Interpretation is then used to estimate the void (gas) fraction in the pipe.

The algorithm demands considerable computational resources to match the real-time evolution of the flow image in the pipe. To satisfy this need it is realised in parallel occam and implemented upon a network of transputers. Typical results are illustrated in figure 4.

Bubbly, churn and slug flows

A range of static and dynamic performance tests have been carried out using a flow loop at SCR (figure 5). Trials have included horizontal plug and slug flows and vertical bubbly, churn, slug and annular flows. Results have exceeded expectations; a typical calibration curve is shown in figure 6.

Further development of the system is currently being planned for oilfield use to meet temperature, pressure and intrinsic safety requirements.

Other related research work is also in progress for flow measurement in pipes; and in general industrial processes, where tomography can provide an insight into process behaviour for design optimisation. A Brite-Euram European Concerted Action has recently been started to stimulate links between researchers and users of process tomography.

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Department of Electronic and Electrical Engineering
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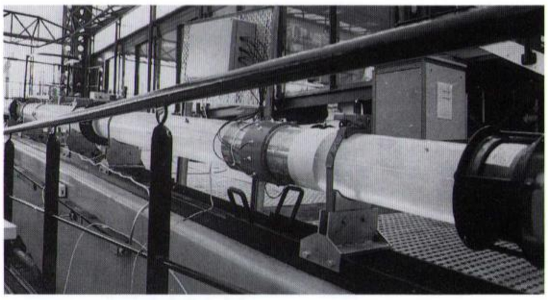


Figure 5: The sensor system in place in the inclinable multi-component flow investigation loop at Schlumberger Cambridge Research, which allows controlled mixtures of oil and gas to be pumped through the sensor section over a range of flow rates and under a variety of flow regimes.

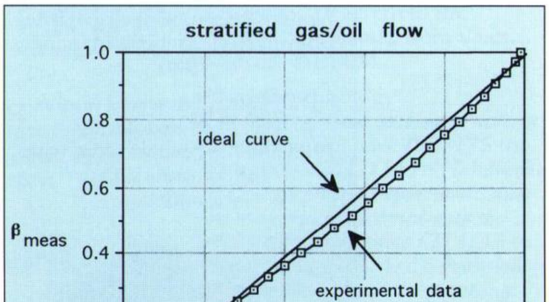


Figure 6: Calibration curve showing the actual volume fraction of oil compared with the volume fraction measured from the tomographic image for stratified gas/oil flow.

MTD Ltd goes from strength to strength

During recent months, Marine Technology Directorate Ltd has been particularly successful in developing and strengthening links with other complementary organisations, aimed at providing greater opportunities for engineers in marine-related disciplines, writes Dr Liz Forster of MTD Ltd.

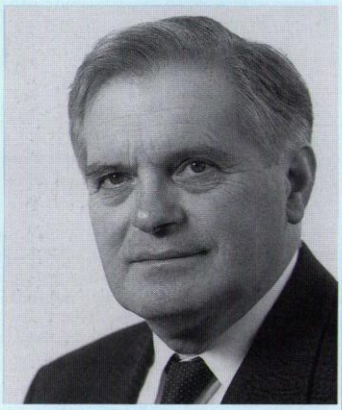
SUT/MTD Ltd

The Council of the Society for Underwater Technology (SUT) and the Board of MTD Ltd have agreed to work more closely together in research, education and training, and information transfer. With effect from January 1992, the Education and Training Committees of both organisations have been combined under the chairmanship of Sir Gordon Higginson. The newsletters of the two organisations have also been brought together under the title of *Underwater and marine technology news.* Increased opportunities for information transfer are provided for academics involved in the MTD Ltd research programme, through an arrangement with SUT on the provision of technical papers for inclusion in the SUT Journal, *Underwater technology.* A joint workshop is planned for late autumn 1992, with key representatives from industry, government and higher education institutes invited to debate long-term R & D trends across marine technology disciplines.

New Chairman for MTD Ltd

Professor T D Patten CBE FEng has been appointed the new Chairman of MTD Ltd from June 1992. He succeeds Admiral Sir Lindsay Bryson, who chaired the company from its incorporation in 1986.

Tom Patten has served on the MTD Ltd Board since 1988 and has been involved with the company since its foundation.



Professor Tom Patten

International links

Cooperation with the European Community has continued to flourish, particularly in education and training. The award to MTD Ltd of a further contract within the Community Programme for Education and Training in Technology (COMETT) provides the UK with the role of setting up and coordinating a university enterprise training partnership in marine technology. This role is being further developed in the new MTD Ltd *Business strategy* (published in April), which recommends the closer involvement of education and training activities with the research programme, the identification of training needs in all aspects of marine technology, and the development of courses in specified areas.

Opportunities for collaboration with France, through the agreement with the Institut Français de la Recherche pour l'Exploitation de la Mer (IFREMER), were developed on MTD Ltd's behalf by Professor Mike Cowling, at the Glasgow Marine Technology Centre. This led to the Subsea Workshop in Paris. The resulting programmes are now being taken forward by MTD Ltd's Tim Downs.

Discussions with the Netherlands and Norway, through CMO (the Netherlands Foundation for Coordination of Maritime Research) and the Royal Norwegian Council for Scientific and Industrial Research (NTNF), on agreed ship and offshore technology research reflect the increasing potential for international collaborative R & D in advanced technology systems.

In March, MTD Ltd was a supporter of Oceanology International '92, together with the Defence Research Agency, the P P Shirshov Institute of Oceanology in Moscow and the USA's National Oceanographic and Atmospheric Administration. This is yet another example of MTD Ltd's growing international involvement.

Advanced technology needs

MTD Ltd is undertaking a study for the Department of Trade and Industry to assess the potential markets for a range of marine technologies. The six-month study is due for completion in September.

Business strategy

In its *Business strategy* (available from MTD Ltd), the Board of MTD Ltd has reaffirmed its commitment to the support of research, education and training and information transfer in all aspects of marine technology.

SERC recently agreeed that its allocation of some £3.5 million a year to marine technology should be predominantly in support of offshore oil and gas, and ship technology. The technologies for mariculture will no longer qualify for SERC funding, and ocean renewable energies will be funded through the renewable energy programme of the Electro Mechanical Engineering Committee but MTD Ltd will continue to take a leading role for SERC in the coordination of its funding for sea surface and sub-sea technology. In future, coastal engineering is to be supported through the Environmental Civil Engineering Committee.

MTD Ltd retains its professional capability to promote R & D in all areas of marine technology, and to seek funding from all other organisations as appropriate. The new Business Strategy allows MTD Ltd to take a pro-active role in stimulating all areas of marine technology where its committees see a need, and it provides members with more influence in identifying these areas in order to target research to the requirements of users.

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Studentships

Cooperative Awards in Science and Engineering

The Council has reintroduced a closing date for nominations of Cooperative Awards in Science and Engineering (CASE) from 1992. This will be 31 July in line with Standard Research and Advanced Course Studentships.

The minimum mandatory contribution from industry has been increased to £1,500 a year for all new CASE students from 1 October 1992. **All CASE students will continue to receive a £250 enhancement of their award from SERC.**

Studentship stipends

The Parental Home Rate of maintenance has been abolished (with effect from 1 April 1992). This reduced rate for students living in the parental home was no longer considered appropriate.

The two remaining basic rates of maintenance allowance received an interim increase (from 1 April 1992) to £4,300 a year for students studying outside London, and £5,400 a year for students attending an establishment in London. These rates will receive a further increase to £4,450 and £5,600 a year respectively from 1 October 1992.

Congratulations to . . .

. . . newly elected Fellows of the Royal Society:

Professor Rodney Davies (Professor of Radio Astronomy, Manchester University and Director, Nuffield Radio Astronomy Laboratories, Jodrell Bank), former member of Astronomy and Planetary Sciences Board;

Professor Robert Ramage (Forbes Professor of Organic Chemistry, Edinburgh University), member of the Science Board;

Professor James Turner (Professor of Inorganic Chemistry, Nottingham University), member of the Chemistry Committee;

Professor John Willis (Professor of Applied Mathematics, Bath University), former member of the Mathematics Committee.

Duddell medal

Professor Peter Smith of Rutherford Appleton Laboratory has been awarded the Institute of Physics Duddell medal and prize, for the development of superconducting composites to achieve an order of magnitude increase in the energy of particle accelerators.

Max Planck prizes

Professor Mike Key (RAL and Oxford University) and **Dr Mick Shaw** (RAL), with Dr Keith Burnett of Oxford, have been awarded one of two 200,000 DM prizes by the Max Planck Society and Alexander von Humboldt Foundation, for scientific work linking German scientists with foreign colleagues worldwide. The award was made in recognition of accomplishments in research and to encourage further cooperation in the study of the generation of ultra high power in ultra short pulses in the krypton fluoride laser.

NASA awards

Members of the ROSAT spacecraft instrument team have been awarded the NASA Group Achievement Award for their outstanding contribution to this important national project. The wide field camera on ROSAT surveys the largely uncharted extreme ultra-violet wavelength and was developed entirely within the UK by a consortium of British universities and RAL. Sixteen of the 45 UK Awards, which took the form of framed certificates, came to RAL staff: **Martin Courtier, Roger Emery, David Ewart, Jock Gourlay, Alan Harris, Barry Kent, Jim Pateman, Doug Reading, Tony Richards, Martin Ricketts, Eric Sawyer, Brian Stewart, Bruce Swinyard, Darryl Taylor, John Wright and John Yates.**

Some new publications from SERC

Unless otherwise stated, all publications are available free of charge from SERC Swindon Office, telephone (0793) 41 + extension number or (0793) 411000.

JFIT annual report

Copies of the *Joint Framework for Information Technology annual report 1991* are available from Elizabeth Strange, ext 1224.

Soft clay research

SERC Soft Clay Research Site, Bothkennar, edited by Dr J A Little, Heriot Watt University. Copies from Dr P Meakin, ext 1155.

Electro and mechanical engineering

Grants current at 1 January 1992 and *Mechanical and materials handling survey*, from Hugh Thurbon, ext 1117; *The EMEC Strategy*, from Richard Bond, ext 1249.

Process engineering

Current grants in separation processes and *Separation newsletter*, from Heather Wray, ext 1476.

Clean technology

Directory of research, Clean Technology Unit: available from Eric Winiarski, ext 1492.

Research grants

SERC research grants — a beginner's guide: copies from Rebecca Bartlett, ext 1077.

Review of IT

A report to the Council of a panel chaired by Sir John Fairclough, *Review of information science and engineering in SERC*: available from Janet Edwards, ext 1256.

SERC and marine technology

SERC review of marine technology research (report of a panel chaired by Professor R T Severn to the Engineering Board), from Vince Osgood, ext 1102.

Marine technology

Dynamics of fixed marine structures (third edition): price £95 (£75 to members of MTD Ltd); *Handbook of UK Government Departments and other agencies concerned with the offshore industry*: price £27 (£13 to members of MTD Ltd); *Probability-based fatigue inspection planning*: price £50 (£25 to members of MTD Ltd); *Safety first — the offshore approach* (the Third Mike Adye Lecture) by Dr H W D Hughes: price £5 (free to members of MTD Ltd); *Annual Review 1990-91*.

All available from Publications Sales Department, The Marine Technology Directorate Limited, 19 Buckingham Street, London WC2N 6EF; telephone 071-321 0674; fax 071-930 4323.

International Space Year

1992 is International Space Year. Twenty-nine national space agencies and ten international organisations are involved. The aim of ISY is to demonstrate and increase public awareness of the benefits of space activities. It focuses on not only the importance of continued space exploration but, crucially, the role of space activities focused on Earth, which are playing a vital role in understanding our environment. These objectives will be met through hundreds of coordinated activities at international and national level, including scientific conferences, exhibitions, competitions, school lectures and media coverage.

International activities include the ISY Conference Space in the Service of Changing Earth, at Munich in April, with some 1200 participants. More than 3000 space experts will be attending the World Space Congress (28 August to 9 September) in Washington DC. Various scientific programmes are being undertaken, for example British and Japanese scientists will be collaborating to produce precise sea surface temperatures around the globe.

Activities within the UK are being coordinated by the British National Space Centre (BNSC), a partnership of all the government agencies, including SERC, involved in space activities; and by BISY (British Industry in Space Year). BNSC have sponsored a schools competition. Schools have been asked to propose ways of using satellite data to help with environmental problems. Almost 450 secondary schools have been involved with the winners being announced in June.

A few of the other events that will be happening in the UK are:

Space Science Exhibition, 7-10 October, Rutherford Appleton Laboratory. A display of SERC's space science work. The exhibition will be open to the public on 10 October. For an invitation to the exhibition between 7 and 9 October contact Mrs J Hutchinson, telephone (0235) 446482.

'Walk through Space' exhibition will tour the country, visiting Goonhilly, Jodrell Bank, the Armagh Planetarium and the Science Museum.

'UK in Space Village' exhibition, 6-13 September, Farnborough Air Show.

European Schools satellite video link.

For more information on BISY activities, telephone the BISY hotline (0272) 363015.

Mrs S A Horne
BNSC
SERC Swindon Office

EISCAT honours its founding father

Sir Granville Beynon, Emeritus Professor of Physics at University College of Wales, Aberystwyth was made the first honorary member of the European Incoherent Scatter (EISCAT) Scientific Association at a special ceremony held at Aberystwyth in December 1991. It was Sir Granville who persuaded scientists and administrators from France, Germany, Norway, Sweden, Finland and the UK to set up the Association in 1975.

The radar system was eventually opened by the King of Sweden in August 1981, when Sir Granville was Chairman of the EISCAT Council. He continued as a member of the Council until 1990.

The picture, taken at the December ceremony, shows (left to right):

Professor H Rishbeth (Southampton University), Professor P J S Williams (UCW Aberystwyth), Professor L Thomas (UCW, Aberystwyth), Professor K Morgan (Principal, UCW Aberystwyth), Dr B R Martin (SERC, former member of EISCAT Council), Sir Granville Beynon, Dr D M Willis (Rutherford Appleton Laboratory), Lady Beynon, Professor S W H Cowley (Imperial College of Science, Technology and Medicine, London), Professor T B Jones (Leicester University, former Chairman, EISCAT Council), D M Schildt (SERC) Swindon Office), Dr M Lockwood (Rutherford Appleton Laboratory).