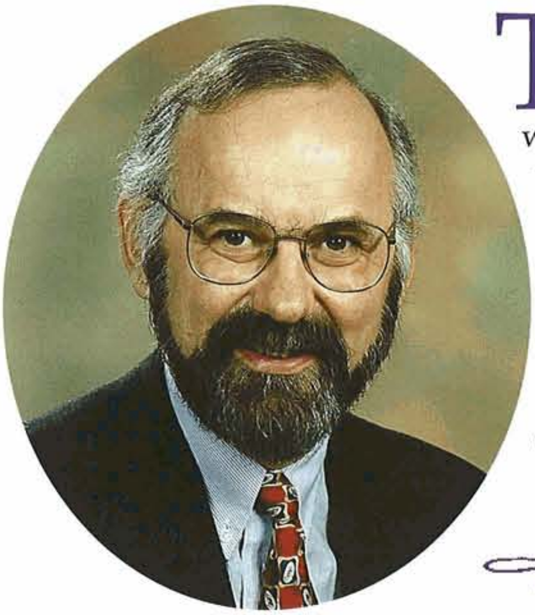
Central Laser Facility Highlights

CLRC
CENTRAL LABORATORY OF THE
RESEARCH COUNCILS

Preface



The Central Laser Facility is a partnership between its staff and the large number of members of UK and European universities who use the specialised laser equipment provided to carry out a broad range of experiments in physics, chemistry and biology. We hope that this booklet can convey some of the excitement and achievements of this community.

It is a pleasure to record my thanks to the editor, Colin Danson, not only for his hard work but also his enthusiasm and patience.

Professor MHR Hutchinson
Director, Central Laser Facility

Events

The Central Laser Facility has important roles in disseminating information to the public and the scientific community alike and in the transfer of state of the art technology developed in-house. The following section highlights some of the events which illustrate these activities.

Final assembly of the French disc amplifier by Trevor Winstone of the Vulcan Operations Group (97RC2783).


R.A.L.
LASER

Signing of the LEA

An agreement was signed at CLRC Rutherford Appleton Laboratory in July 1996 to establish a new collaboration agreement between the Central Laser Facility and the LULI laboratory, Palaiseau, France. The establishment of the LEA (Laboratoire Européen Associé) Research in high power laser science formalises a productive pooling of expertise between LULI (Laboratoire pour l'Utilisation des Lasers Intenses) France and the CLF at the CLRC Rutherford Appleton Laboratory covering many areas of research in high power lasers. The two institutes have a long record of co-operation and a broad spectrum of areas of common interest. The joint venture enhances the performance of existing programmes and will provide the opportunity to develop new research activities.

The agreement was signed by Dr Paul Williams, CCLRC Chief Executive, and the heads of the three organisations which co-own LULI: Monsieur Guy Aubert, Director General of CNRS (Centre National de la Recherche Scientifique) in Paris; General Henri Marescaux, Director General of the Ecole Polytechnique in Palaiseau, and Monsieur Jean Lemerle, President of the University of Paris VI.

(96RC3531)

Marshall Sluyter Visits CLF

The CLF was pleased to receive a visit from Dr Marshall Sluyter (below, centre) in March 1998. Dr Sluyter, formerly the Director of the US Department of Energy's Office of Research and Inertial Fusion, is an advisor to the laser programme at Lawrence Livermore National Laboratory. He toured the CLF's high power lasers with Dr Gordon Walker, Director, Research and Development (below, left) and Professor Henry Hutchinson, Director, CLF (below, right) and discussed future opportunities for collaboration between the CLF and Livermore.

(98RC2160)

TMR Round Table Co-ordination

The Central Laser Facility has been charged with the task of co-ordinating the European Round Table for Lasers. This is an EU funded concerted action programme with participants from laser laboratories throughout Europe. The mission of the Laser Round Table is to develop links between the laser facilities in Europe, identify opportunities for collaborative development and stimulate the transfer of results and techniques to industry. The photo shows representatives at the meeting held on the 3rd April 1998 at the LENS Laboratory, Florence, Italy.

Intense Femtosecond Laser Applications Meeting

A one day meeting held on 21st January 1998 brought together UK researchers working in the area of intense femtosecond laser interactions to discuss oportunities in the field with an emphasis on atomic and molecular physics. The meeting acted as a forum for the exchange of ideas and highlighted areas for future collaborations.

(98RC1146)

Lisbon CPA Laser System

An ultra-short pulse laser system, designed and commissioned at the Central Laser Facility, has been installed in the Instituto Superior Tecnico (IST), at the University of Lisbon, Portugal. The system uses the technique of Chirped Pulse Amplification (CPA) to produce a picosecond pulse at ultra-high powers. Goncalo Figueira (pictured) spent two years at the CLF on secondment from the IST to assist in the construction phase of the project.

(96RC5432)

Disc Amplifier Technology Transferred to Ecole Polytechnique

Disc amplifiers designed at the CLF have been in use on Vulcan for 10 years. The technology has been transferred to the LULI laser facility at Ecole Polytechnique, Palaiseau, France. The amplifiers were assembled in the CLF's clean rooms and transported to Ecole Polytechnique. Electrical engineers from the CLF also advised on the design and construction of the high voltage capacitor banks needed to power the amplifiers. The photograph shows the disk amplifier being installed at Ecole Polytechnique under supervision of RAL staff, Trevor Winstone and Robert Wellstood.

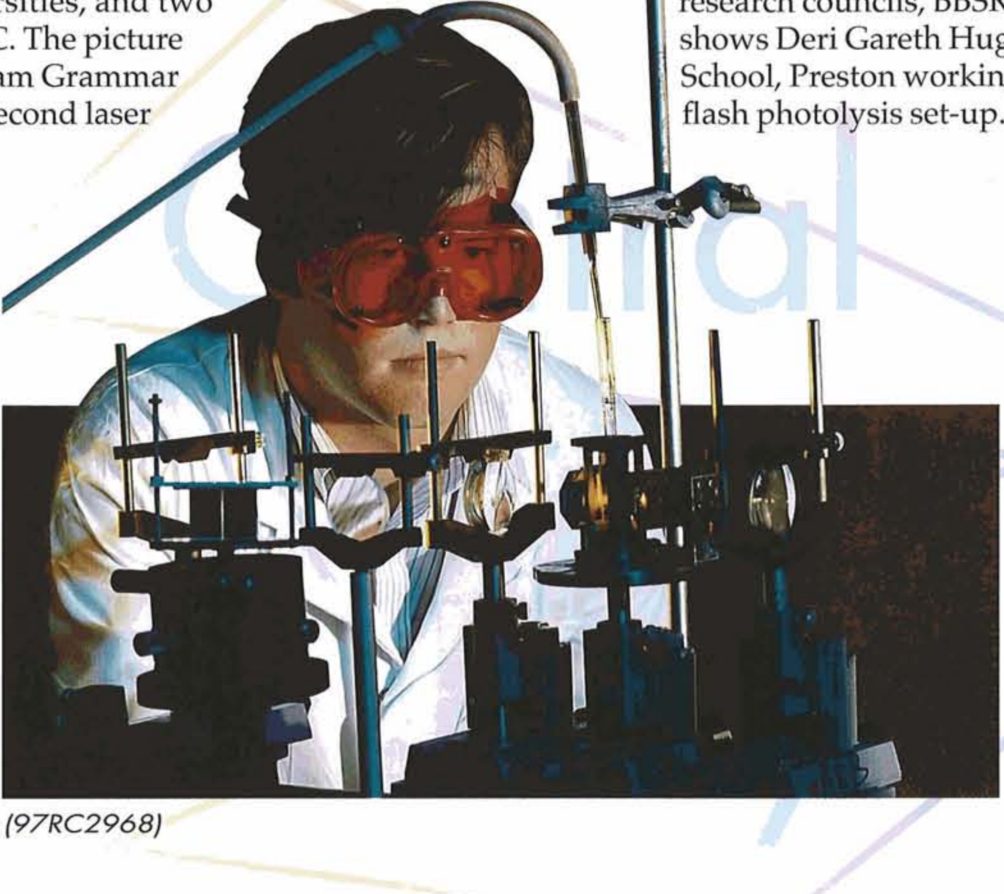
CLF Hosts Time Resolved Vibrational Spectroscopy Conference

Recent advances in short pulse tunable laser technology and light detection technology have enabled time resolved vibrational spectroscopy to grow rapidly. The CLF is extremely active in this research area and hosted the Eighth International TRVS Conference which was attended by a hundred delegates from 15 countries.

(97RC2157)

CREativity in Science and Technology

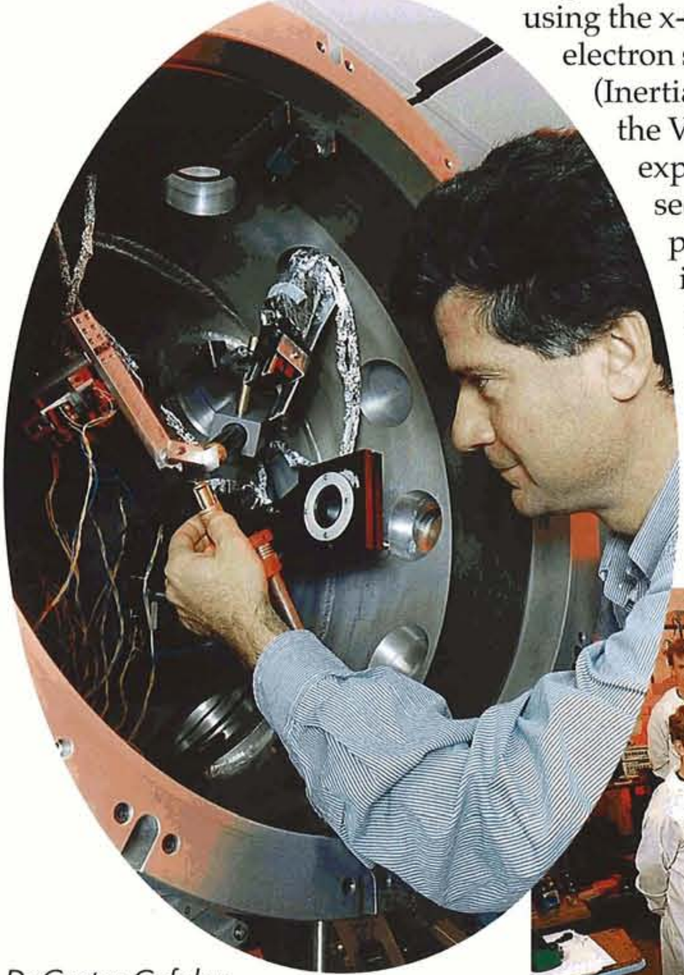
The CREST master class provides top A-level students with a unique opportunity to get involved in cutting edge research. A group of 6 students spent a week, at the LSF, learning how lasers are used to investigate the photochemistry of an anti-cancer drug. The scheme is supported by the DTI, several major industrialists and universities, and two research councils, BBSRC and EPSRC. The picture shows Deri Gareth Hughes of Kirkham Grammar School, Preston working with the nanosecond laser flash photolysis set-up.



(97RC2968)

EU Access to the CLF

The CLF has been host to a large number of researchers under the TMR Large Scale Facility access scheme operated under Framework III & IV of the European Union. The experiments have covered a broad spectrum of research from the investigations of damage mechanisms in yeast cells, using the x-ray source, to the first measurements of electron stopping power relevant to the ICF (Inertial Confinement Fusion) concept, using the Vulcan laser facility. A number of these experiments are presented in the highlights section of this document. The experiments performed under this scheme have increased collaboration between research groups across Europe, and have introduced researchers to state of the art facilities not available in their home institutions.



Dr Costas Cefalas, National Hellenic Research Foundation Athens, Greece (97RC1371).

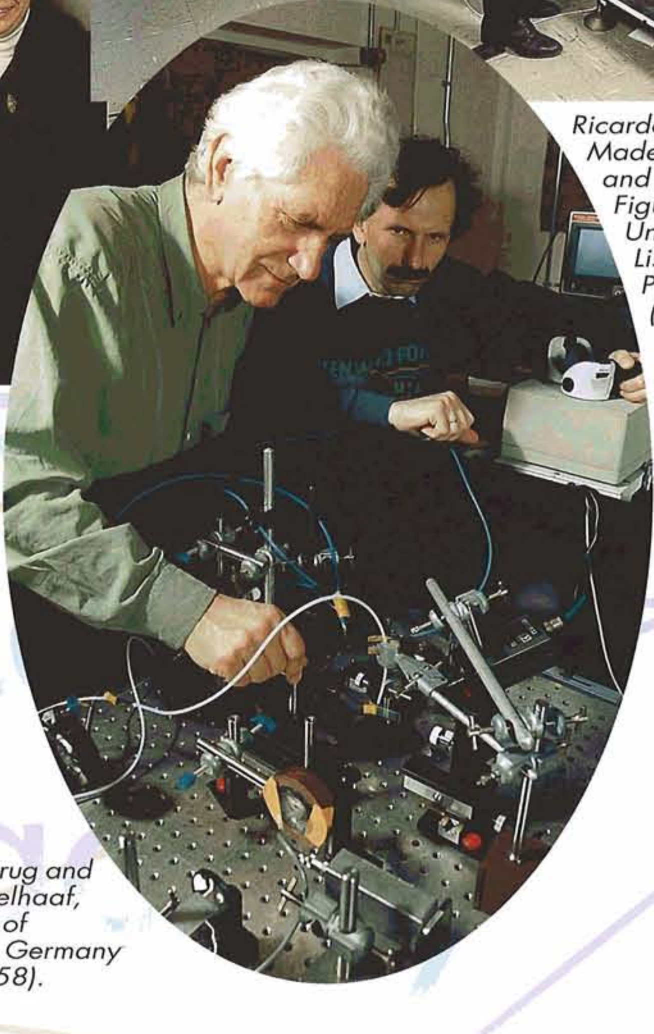
Dr Peter Nickles (front, centre), (Max Born Institute, Berlin, Germany) with colleagues, collaborators and RAL support staff (96RC4730).

Professor Marziale Milani (back row, 4th from left) and group, University of Milan, Italy (97RC1365).

Dr Schnurer and Dr Kalachnikov, Max Born Institute, Berlin, Germany and Elisabeth Wolfrum, EU Research Fellow (now Oxford University) (96RC4566).

Ricardo Fonseca, Madelena Eloy and Goncalo Figueira, University of Lisbon, Portugal (97RC1766).

Dr F Worral, Loughborough University, Kevin Henbest, RAL, Dr A Oliveira and Professor L F Vieira Ferreira, University of Lisbon, Portugal (97RC1310).

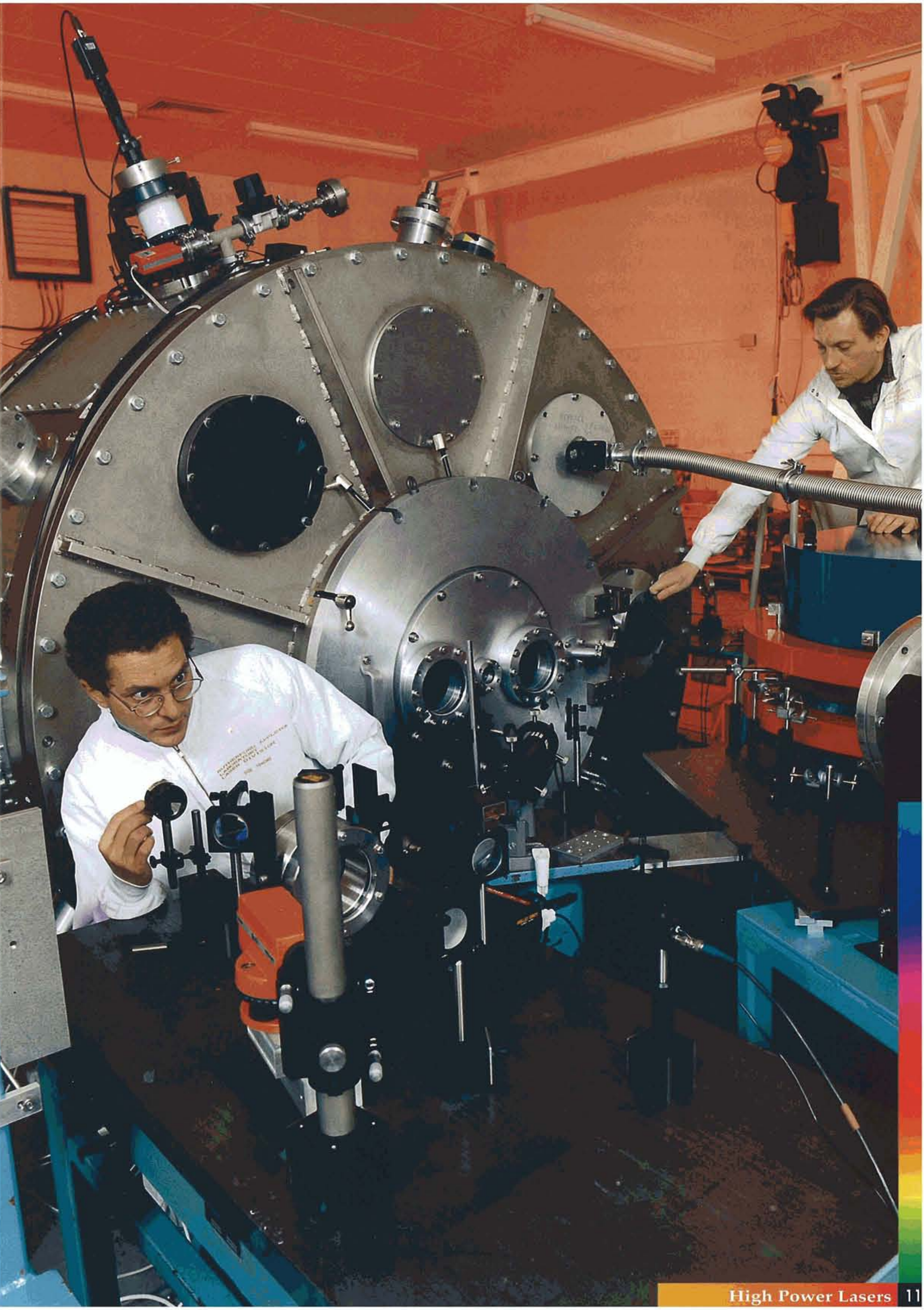


Professor Dr D Oelkrug and Dr H J Egelhaaf, University of Tubingen, Germany (98RC1758).

High Power Laser Science

Researchers using the high power lasers at the CLRC Rutherford Appleton Laboratory have conducted world class science, producing new results and many publications at the highest level. Most of the experiments highlighted in this section are funded by the EPSRC and conducted by UK scientists with international collaboration. Several experiments were funded under the European Union Training and Mobility of Researchers (TMR initiative) Large Scale Facilities Access programme and encouraged collaboration between continental EU and UK users. The wide variety of research reported in this report and international recognition for the work undertaken clearly demonstrates the strength of UK research in the area.

Victor Malka of Ecole Polytechnique, France and Karl Krushelnick of Imperial College, London prepare the interaction chamber for electron acceleration experiments (98RC1067).



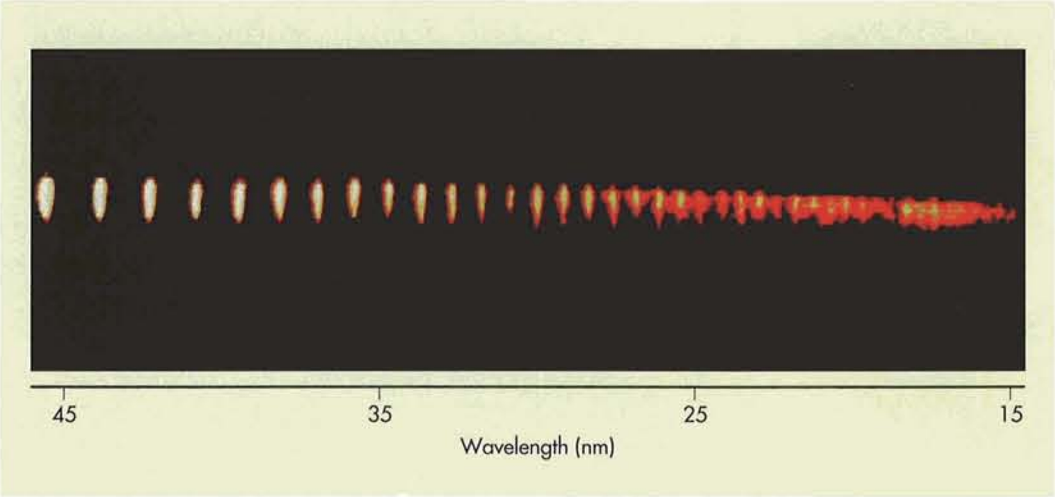
Solid Target Harmonics

Efficient conversion of laser light into soft x-rays is an internationally active area of research. Recent studies at the CLF show that harmonics at short wavelength can be generated with extremely high efficiency in the interaction between a solid surface and an ultra-high intensity laser pulse.

In this work the Vulcan laser beam was focused to a small spot (< 30 microns diameter) at intensities of 10^{19} Wcm^{-2}, on a solid plastic target. The high electric field of the laser in the focal spot pulls electrons out of the solid and into the vacuum. It then drives them back into the solid surface at high velocities. The resulting anharmonic motion of these electrons gives rise to high harmonic generation. The best result to date is the generation of the 75th harmonic at 14 nm, produced with an overall conversion efficiency of 10^{-6}.

Theoretical simulations predict even higher conversion efficiency as the focal intensity of the drive beam is raised to the 10^{20} Wcm^{-2} level, a regime available to users for the first time following the recent upgrade of Vulcan.

AE Dangor, M Zepf, A Dyson, P Lee	Imperial College, London
S Moustaizis, M Bakerezos, P Loukakos	FORTH, Greece
J Wark, J Zhang	Clarendon Laboratory, Oxford
P Gibbon	Max Plank Institute, Germany
A P Fews	University of Bristol
P Norreys, C Danson, D Neely, F Walsh	RAL



High harmonic spectrum showing generation of the 75th harmonic at 14 nm using focused intensities of 10^{19} Wcm^{-2}.

Highest ever Accelerated Electrons Observed in the Laboratory

The accelerating field gradient of current particle accelerators is limited by electrical breakdown of the surfaces of the accelerating structures. An alternative scheme for the next generation of machines is to harness the much higher electric field gradients available from a high power laser in a plasma.

The ultra-high intensity capabilities of Vulcan have been used in a highly successful experimental campaign. A 25 J sub-picosecond pulse was focused into a jet of helium gas giving rise to a large amplitude plasma wave by self-modulation of the laser pulse. This large amplitude plasma wave traps and accelerates plasma electrons to very high energies. The latest results demonstrate the creation of plasma waves with electric field gradients in excess of 100 GV / m and the acceleration of electrons to above 100 MeV. This is the highest collective electric field ever produced in the laboratory and represents a factor 10,000 increase over conventional accelerators.

The next challenge for the team is to establish the accelerating field over a greater length in order to produce even higher particle energies. Non-linear and relativistic plasma effects offer a potential mechanism for acceleration and channelling of the laser beam over a larger distance. Such behaviour has already been observed on Vulcan and experiments to exploit these effects in an acceleration experiment are planned.

AE Dangor, Z Najmudin, K Krushelnick, M Tatarakis, E Clark, M Santala, M Salvarti	Imperial College, London
CE Clayton, D Gordon, C Joshi, KA Marsh, P Muggli, WB Mori , LC Tzeng	UCLA, California, USA
F Amiranov, A Modena, V Malka	Ecole Polytechnique, France
D Neely, CN Danson, R Allott	RAL

Chris Clayton of UCLA checks the alignment of the detectors in the electron spectrometer (96RC2662).

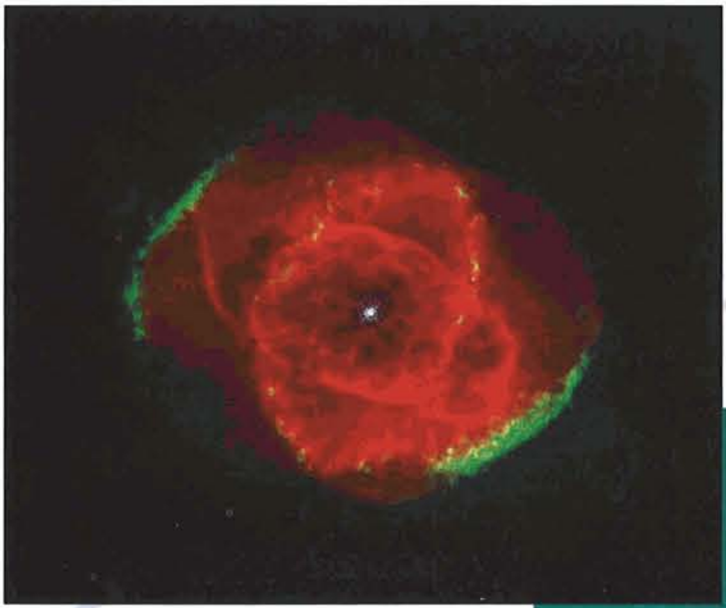
Hohlraums used to study Fusion and Astrophysical Plasmas

Interaction between high power laser radiation and gold is very efficient in the production of soft x-rays. These in turn can be used for various applications including Inertial Confinement Fusion and the study of plasmas of relevance to astrophysics. In a gold cavity called a hohlraum, up to 50% of the laser energy can be converted to x-ray radiation.

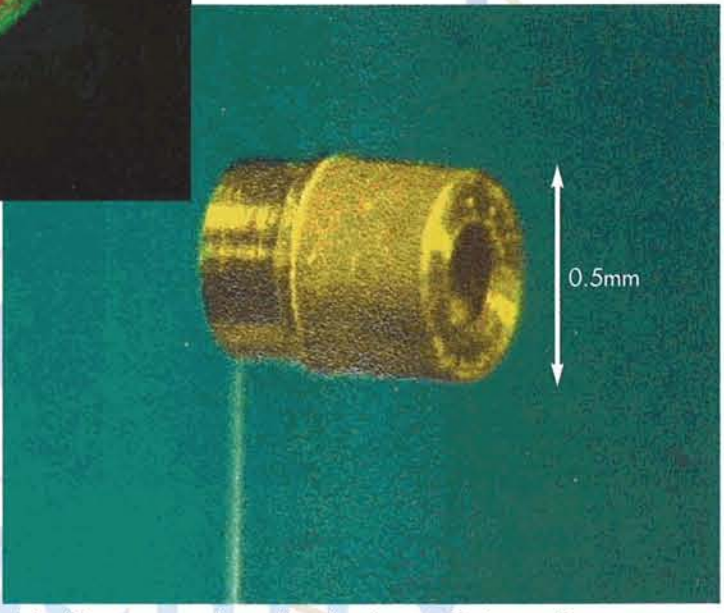
The inside walls of a cylindrical hohlraum, only 1 mm in diameter, are irradiated with a number of Vulcan laser beams. Measurements show that the hohlraum emits radiation with a temperature of more than a million degrees.

Several unique experiments have been carried out at the CLF using hohlraums. The growth rate of the Rayleigh-Taylor instability has been measured in a wavelength range not previously accessible. These studies are important for laser driven implosions which rely on uniform compression. In addition, the emission from a hohlraum can also be used to simulate astrophysical phenomena. One example is the propagation of an ionisation front through stellar matter. Depending on the x-ray flux the propagation will be supersonic (which doesn't generate a hydrodynamic disturbance) or subsonic (in which case a strong shock is launched).

O Willi, C Meyer, L Barringer, S Nurruzaman, R Taylor, D Hoarty Imperial College, London



Plasma physics in action - a NASA Hubble Space Telescope image showing the 'Cat's Eye Nebula' (NGC6543).



A hohlraum, produced in the Space Science Department at RAL, used in the efficient conversion of laser radiation to x-rays.

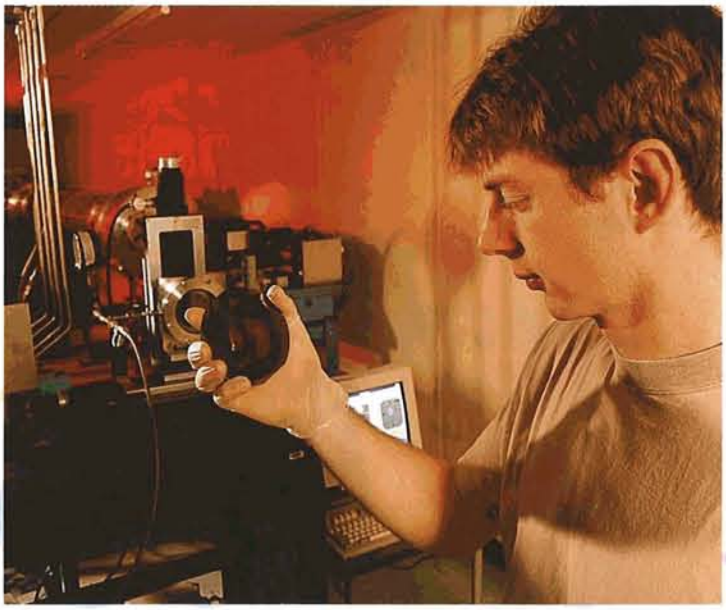
Displays to Benefit from Laser Processing

CLF's ultraviolet short pulse lasers are being used to improve the performance of miniature, high resolution electro luminescent flat screen displays as an alternative to LCDs and LEDs, offering improved performance at potentially lower cost.

Annealing of the devices is required in order to increase their light output. The short pulse laser enables just the right amount of energy to be delivered to the active region of the device, avoiding damage to other heat sensitive areas. It is hoped that the laser technique will enable blue light-emitting devices to be produced economically, completing the range needed for full colour screens.

The high energy beam available from the Titania facility offers the possibility of processing a whole wafer in a single shot. Experiments to optimise the processing parameters are underway and initial results are encouraging. There are immediate commercial applications for head-up displays.

W M Cranton, E A Mastio, R Stevens, C B Thomas	Nottingham Trent University
C Staveley	Frazer-Nash
D Beer	Avimo Ltd.
A Damerell, G Hirst, I C E Turcu	RAL



PhD student Emmanuel Mastio of Nottingham Trent University examines a wafer annealed using the ultraviolet output of the Titania laser (98RC2063).

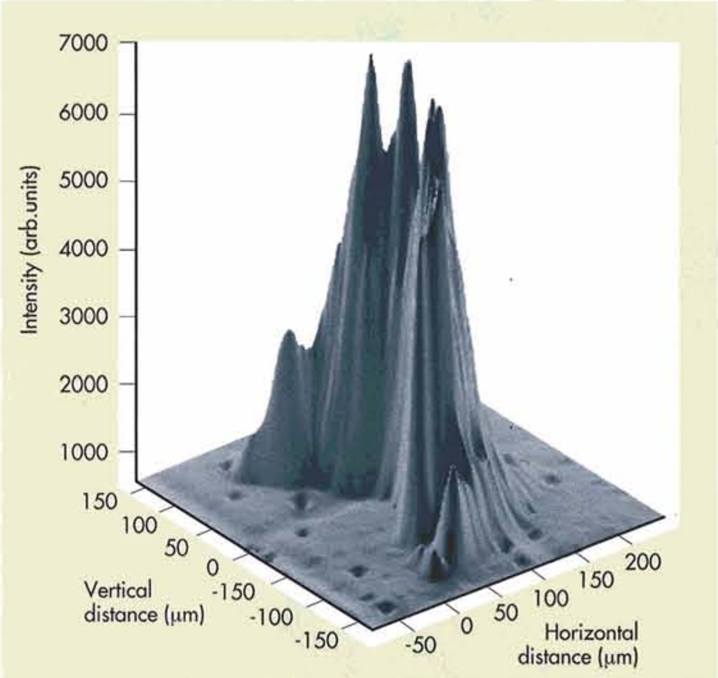
A New Generation of X-ray Lasers

Major increases have been made in the efficiency of x-ray lasers, enabling coherent radiation to be obtained at shorter wavelengths. The advances have arisen from the use of an optical laser 'pre-pulse' to generate a plasma with ionisation and density parameters which are optimised for pumping by a second pulse. Two schemes, using different pulse durations and intensities, have been investigated.

Using a pulse of 80 psec duration, saturated output was obtained from Ni-like samarium lasing at 7.3 nm. This represents a 20 fold increase in efficiency over previous experiments. This improvement will enable the investigation of even shorter wavelength schemes previously inaccessible to the Vulcan facility.

Using much shorter picosecond pulses at higher intensity, saturated output from Ni-like tin at 12.0 nm, Ne-like titanium (32.6 nm) and Ne-like germanium (19.6 nm) have been demonstrated using a travelling-wave pumping scheme. Extremely high gain coefficients (~30 cm^{-1}) were achieved which allow saturation with relatively short plasmas (~ 5 mm long) and reduced pump energy requirements.

GJ Pert, SP McCabe, P Simms University of York
CLS Lewis, RMN O'Rourke, AG McPhee,
GF Cairns, PJ Warwick Queen's University Belfast
J Wark, E Wolfrum, J Zhang Clarendon Laboratory, Oxford
G Tallents, J Lin, R Smith,
A Behjat, A Demir University of Essex
J Nilsen,TW Barbee, Jr., MH Key LLNL, California, USA
PV Nickles, MP Kalachnikov,
M Schnurer, W Sandner Max-Born-Institut, Germany
D Neely, CN Danson RAL



A CCD near field image of the Ni-like Silver x-ray laser output at 14 nm.

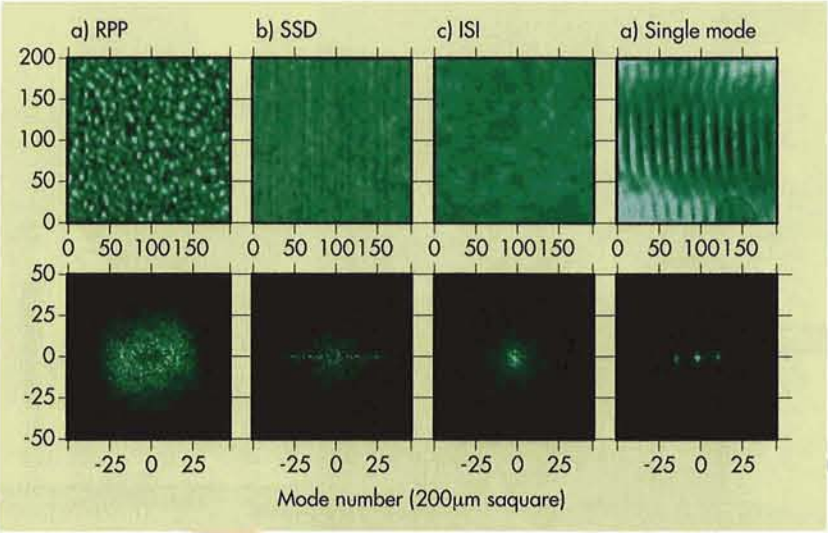
Radiography is One of the First Applications of X-ray Lasers

X-ray lasers have been developed to the point where they can be used as a diagnostic tool. They offer high brightness, short wavelength, narrow bandwidth and short pulse duration. These features have been exploited at the CLF in a series of experiments, which used radiation at 19.6 nm from the Ne-like germanium laser to investigate the development of density perturbations in laser-plasma interactions. Better understanding of such effects is crucial to the design of Inertial Fusion Energy (IFE) experiments, which require uniform compression of a plasma to high temperature and pressure.

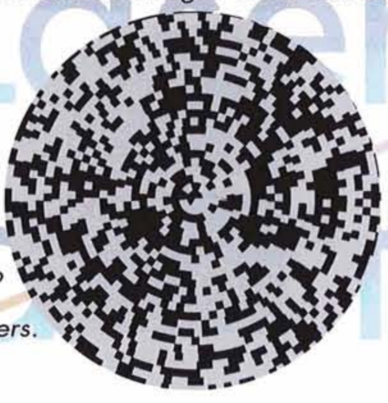
The CLF experiments probed the interaction of the laser beam with a thin foil. The x-radiographs obtained, enabled quantitative measurements to be made of the evolution of the density perturbations.

The experiments have been extended to investigate the effectiveness of different optical smoothing techniques of the drive, including random phase plates (RPP), induced spatial incoherence (ISI) and smothing by spectral dispersion (SSD).

E Wolfrum, J Zhang, JS Wark	Clarendon Laboratory, Oxford
D Kalanter, MH Key, BA Remington, SV Weber	LLNL, California, USA
J Warwick, CLS Lewis, A MacPhee	Queen's University, Belfast
J Lin, R Smith, GL Tallents	University of Essex
D Neely, S Rose	RAL



XUV radiographs of modulation in an aluminium foil recorded with an x-ray laser onto a CCD camera. The lower images show computer generated far-field images of the various patterns.



The mask pattern used to generate a Random Phase Plate (RPP) used to smooth the output of high power lasers.

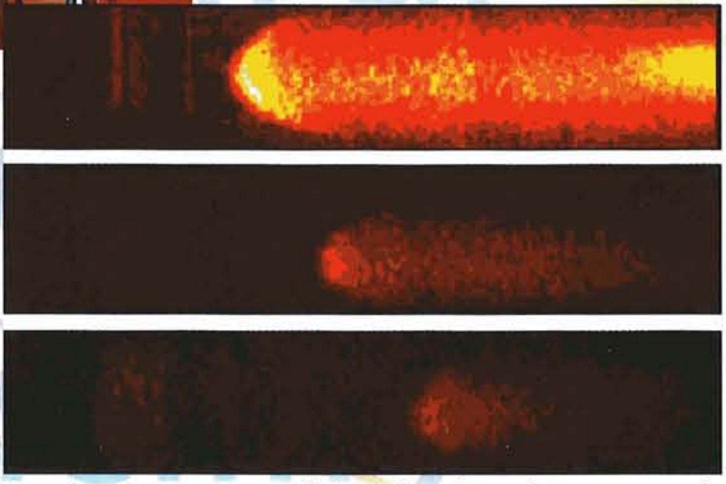
Fast Electron Heating of Shock Compressed Plasmas

The upgraded Vulcan laser is particularly well suited to the studies of the fast ignitor route to inertially confined fusion (ICF). This scheme uses an ultra-short pulse to ignite a pre-compressed fuel pellet. Electrons, generated in the interaction between the high intensity laser pulse and the compressed fuel, travel through the target to the high density region where they deposit their kinetic energy, heating the fuel and triggering ignition.

The experiment, conducted by a team led by Dr Dimitri Batani (University of Milan) and funded through the Framework IV Large-Scale Facilities Access Scheme, compared the electron energy deposition rate in a plasma compressed to a few times solid density with that in cold material. It was shown that under these conditions ionised, compressed plastic is less effective, by a factor of two, at stopping the fast electrons than uncompressed, unionised plastic. Further work is planned, at yet higher density, to enable extrapolations to the fast ignitor regime.

D Batani, A Bernardinello, V Masella University of Milan, Italy
M Koenig, A Benuzzi, J Krishnan, F Pisani Ecole Polytechnique, France
T A Hall, S Ellwi University of Essex
A Djaoui, P Norreys, D Neely, S Rose, M H Key* RAL
P Fews University of Bristol
**Current address LLNL, California, USA*

Andre Bernadinello of Milan University and Fransesca Pisani of Ecole Polytechnique, France align the target in the EU Large Scale Facility access experiment to study fast electron heating of shock compressed plasmas (97RC1761).



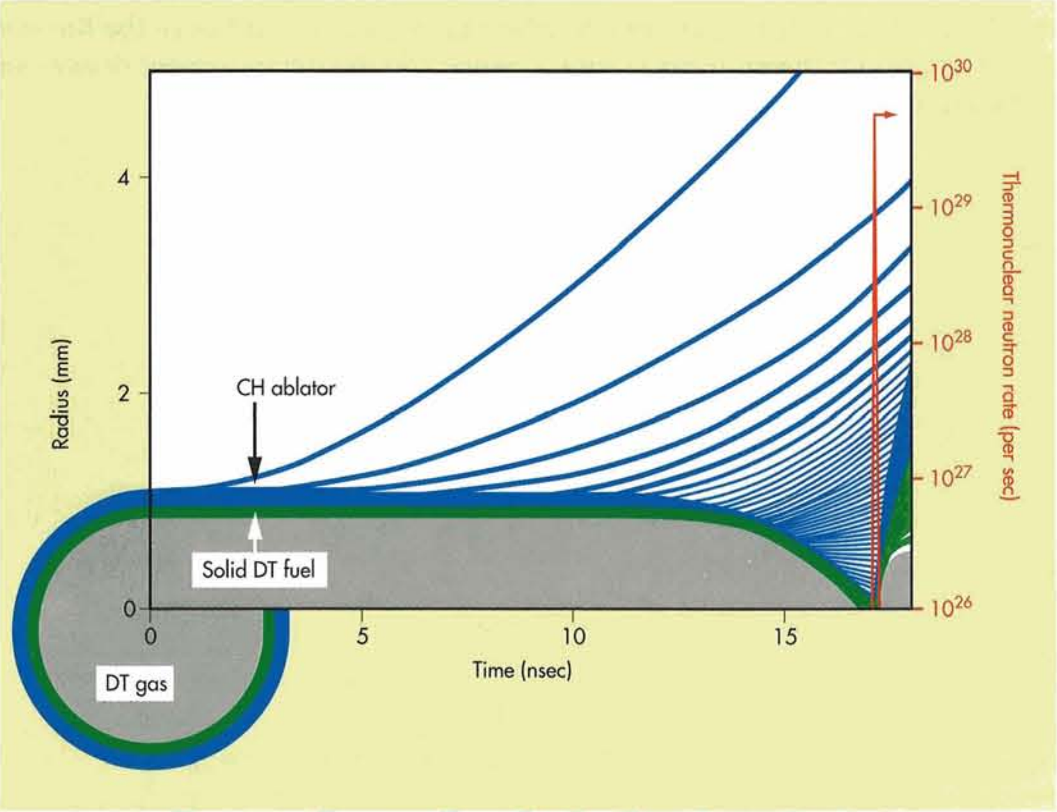
Streak camera images of shock breakouts from targets of different thicknesses.

Modelling of Inertial Confinement Fusion Energy Production

Within the next few years a large laser facility currently being constructed in the United States (the National Ignition Facility) will demonstrate energy breakeven (more energy produced by thermonuclear reactions than is delivered to the target by the laser).

Detailed computer modelling of this process at the CLF shows the complex behaviour of the spherical capsule containing the deuterium-tritium thermonuclear fuel. Intense x-rays are generated by shooting the laser beams into a cylindrical gold cavity, or hohlraum, which ablate the plastic surface of the spherical capsule within. The energy generated by thermonuclear reactions resulting from the subsequent implosion, is predicted to be approximately ten times the energy initially delivered by the laser.

A Djaoui, S Rose RAL



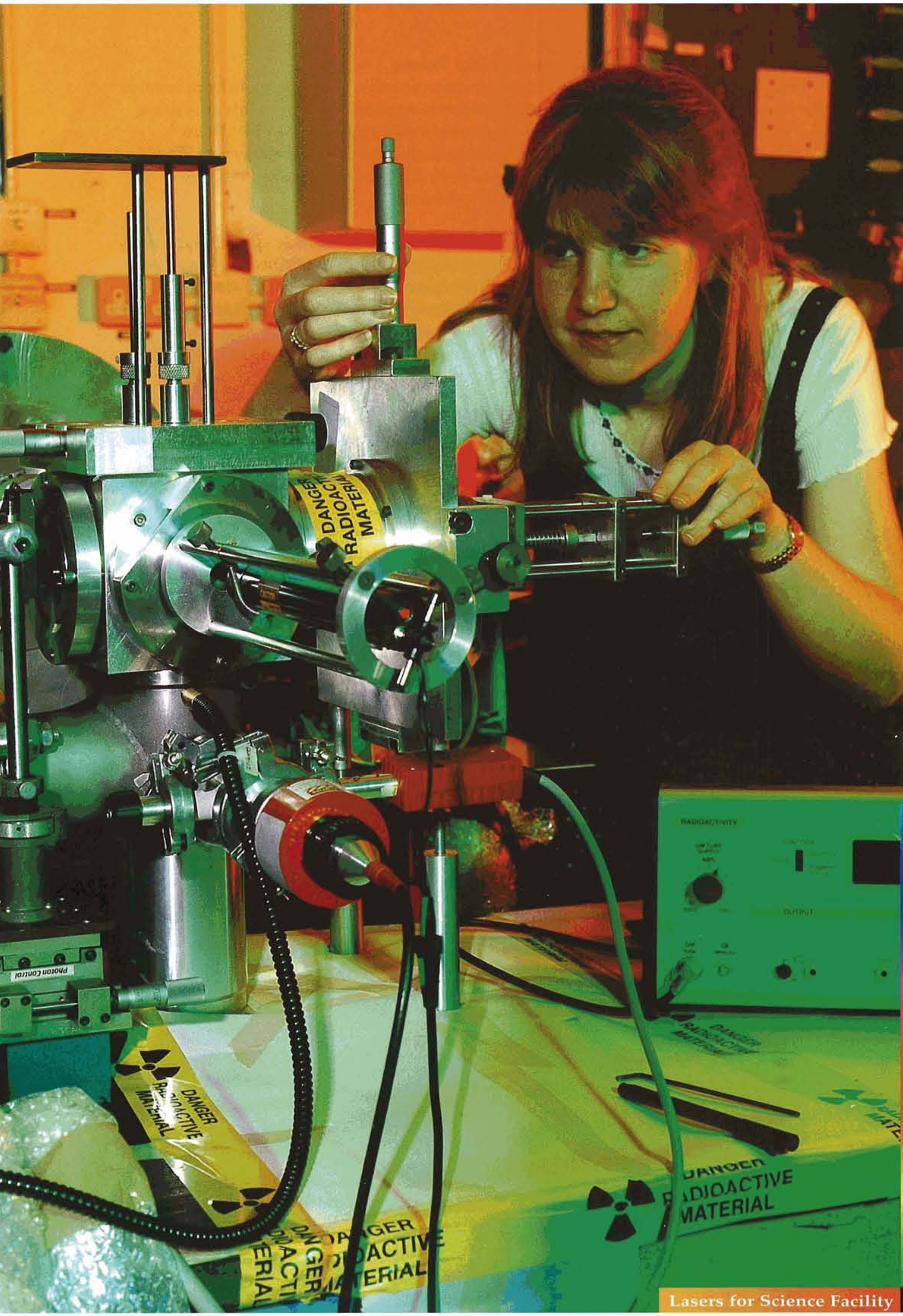
Modelling of the temporal evolution of a Fusion target demonstrating how it is compressed by the x-ray drive.

Lasers for Science Facility Experiments

These laser laboratories enable a wide variety of research themes to be undertaken across the physical, biological and medical sciences for EPSRC, BBSRC, MRC, NERC, the EU TMR Large Scale Facility access programme and commercial contractors.

The experiments highlighted in this section are typical of the broad scope of research supported by the LSF. This ranges from biochemistry and the studies of the life saving chemistry of vitamin E through to material science and the development of ever smaller microchips and faster magnetic recording techniques.

Research Assistant Oonagh Meighan of Dublin City University prepares the laser target to probe the electronic structure of heavy ions by absorption spectroscopy in the extreme ultra-violet spectral region (97RC3437).


DANGER RADIOACTIVE MATERIAL
Photon Control
RADIOACTIVITY
OUTPUT
DANGER RADIOACTIVE MATERIAL
DANGER RADIOACTIVE MATERIAL
DANGER RADIOACTIVE MATERIAL

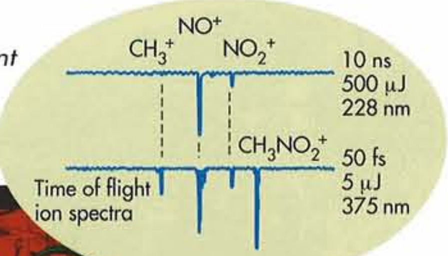
Molecular Dissociation with Ultrashort Laser Pulses

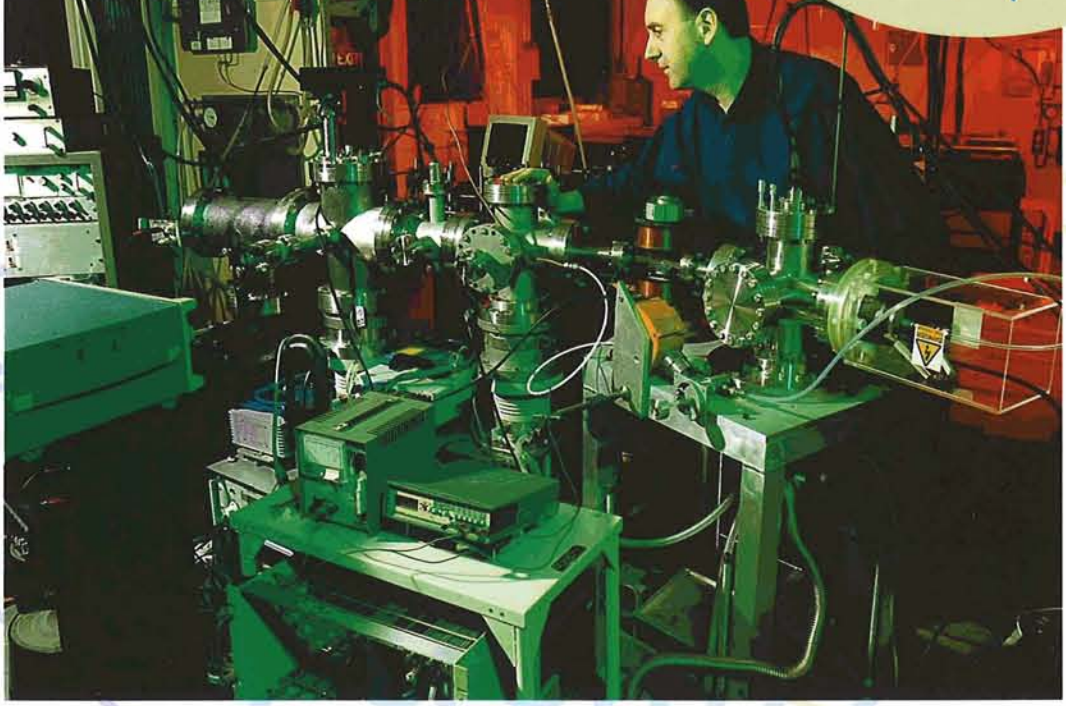
The CLF is a centre for molecular dissociation studies. User scientists from several universities carry out both fundamental and applied research in this area using ultrashort (50 fs) laser pulses focused to intensities greater than 10^{16} $\mathrm{Wcm^{-2}}$. Researchers take advantage of the intense femtosecond pulses in several ways. The laser pulse duration is shorter than the vibrational period of most molecules, and this simplifies the study of molecular Coulomb explosions.

This new laser technology has enabled scientists to induce and study spatial asymmetry during molecular dissociation by carefully controlling the superposition and relative delay of ionising pulses of different colours. Ultrashort laser pulses have also overcome a problem in analytical science. A disadvantage of using long (nanosecond) laser pulses is that polyatomic molecules often dissociate into many small fragments which render the parent molecule unidentifiable. Researchers have found that, with femtosecond pulses, large mass fragments are detected - often including the parent ion.

KWD Ledingham, RP Singhal, DJ Smith, T McCanny	Glasgow University
P Graham, HS Kilic, WX Peng, SL Wang, C Kosmidis	University of Ioannia, Greece
JH Posthumus, J Plumridge, MK Thomas, K Codling, LJ Frasinski	Reading University
JH Sanderson, RV Thomas, WA Bryan, WR Newell	University College London
ID Williams	Queen's University Belfast
AJ Langley, PF Taday	RAL

The appearance of the $CH_3NO_2^+$ parent peak in the lower time of flight trace demonstrates the advantage of using ultrashort pulses.





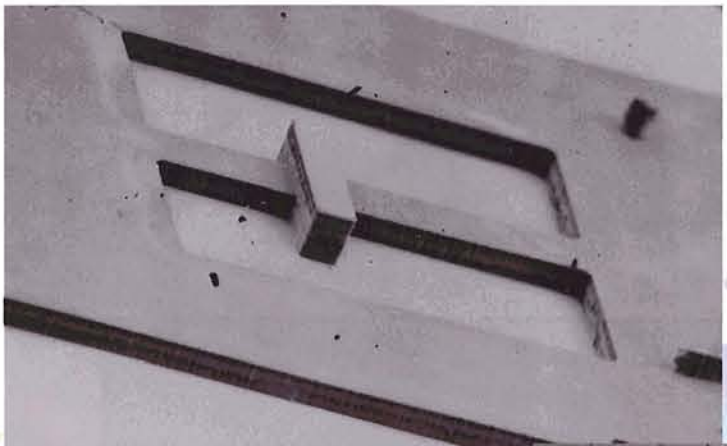
Ian Williams of Queen's University, Belfast aligns a time of flight spectrometer to investigate the photodissociation of molecules (98RC1762).

X-Ray Nano- and Micro-Fabrication

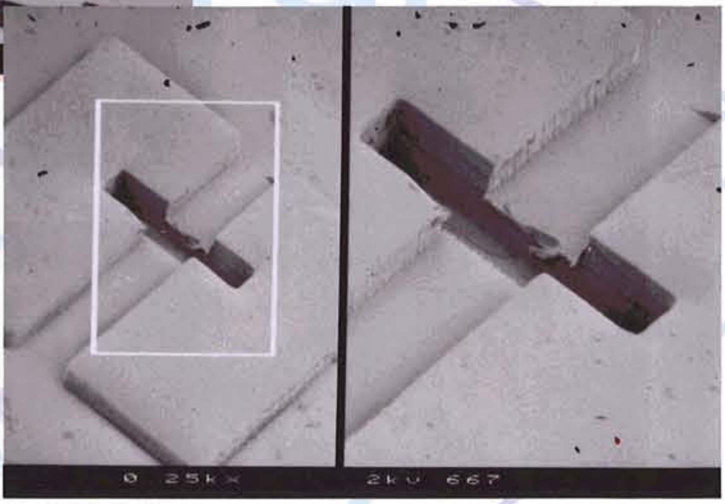
Nano- and micro-fabrication are fast becoming the norm for the microelectronics, sensor and telecommunications industries of the future. Soft x-ray radiation with nanometer wavelength is ideally suited for the fabrication of such devices because of its high (nanometer) imaging resolution as well as deep (micrometer) penetration in photoresist material. The laser generated plasma source, developed at the CLF, is a relatively compact and inexpensive source of soft x-rays which could be owned by medium sized companies.

Nano- and Micro-structures are printed by photo-lithography using the x-ray illumination from the plasma light source. 180 nm long transistor gates, required for the Gbit memory chips of the next century's computers, are fabricated using soft x-rays. Such x-rays are also used to micromachine 50 nm three dimensional structures for 2.5 terahertz electromagnetic waveguides and cavities required for microwave telecommunications.

MR Davidson, GJ Berry, JA Cairns, AG Fitzgerald, B Larenson, J Thomson	University of Dundee
C Reeves, JTM Stevenson, AWS Ross	Edinburgh University
AM Gundlach, B Koek, P Mitchell	Leica Cambridge Ltd.
P Anastasi	King's College, London
ICE Turcu, R M Allott, IN Ross, N Lisi, BJ Maddison, SW Moon, P Prewett, C McCoard, NS Kim, W Shaikh, N Spencer, N Takeyasu, CM Mann	RAL



2.5 terahertz microwave waveguide and cavity micromachined with x-rays with applications in telecommunications for satellites (96RB1561).



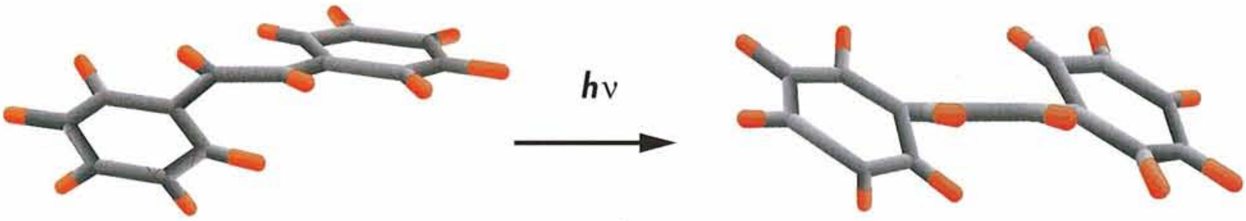
(96RB1558)

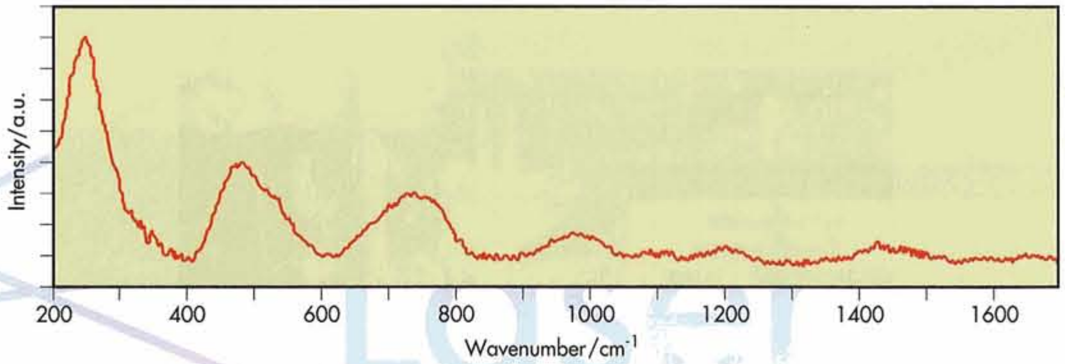
Bright Future for Raman Spectroscopy

A number of very important fundamental chemical and biological processes occur on picosecond timescales. Such events can be probed using picosecond time-resolved resonance Raman spectroscopy revealing both structure and kinetics of the short-lived species involved. The technique involves two independently tuneable laser pulses; the first pulse, tuned to the electronic absorption band of the molecule in the ground state, pumps or excites the sample and a second time delayed pulse, tuned to the electronic absorption band of the intermediate, probes the changing chemicals as the reaction proceeds.

The laser has already been used in spectroscopic studies throwing light on crucial chemical and biochemical reactions. The work includes studying the molecular dynamics of isomerisation. Whilst a prolific amount of research studies have been performed on the trans- to cis- photoinduced isomerisation of stilbene, there have been relatively few on the reverse reaction i.e. cis- to trans- which occurs a hundred times faster. Other scientific objectives include understanding the picosecond relaxation of solute molecules in condensed liquid phase, and measuring the way electronic transition energy perturbs the vibrational (Raman) spectrum and how the immediately produced states (Franck-Condon) vibrationally relax on ps timescales. Such processes influence the outcome and yield of the products ultimately produced by the chemical reaction. The biologically important class of compounds known as carotenoids are also being probed by Stokes and anti-Stokes Raman spectroscopy.

D Phillips	Imperial College, London
TG Truscott	University of Keele
WT Toner	Oxford University
AW Parker, P Matousek, M Towrie	RAL





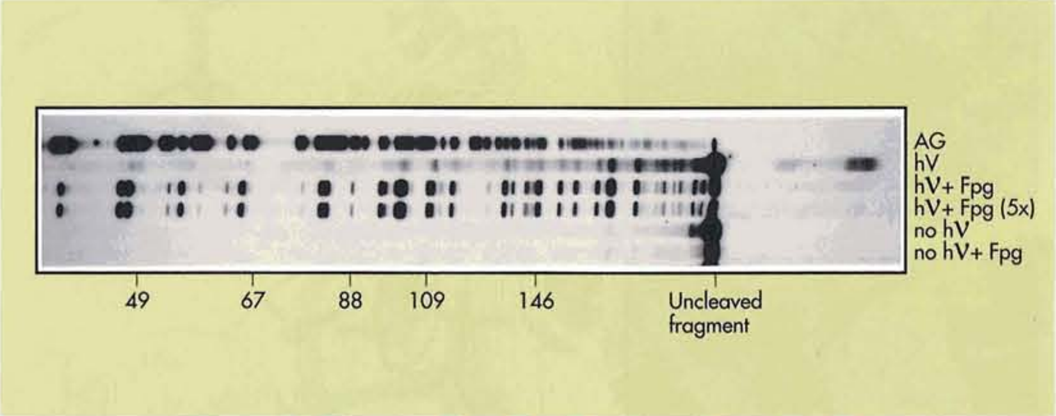
A vibrational spectrum of the photoexcited cis-stilbene molecule which lives for only one picosecond.

DNA - an Electron Relay?

Most human cells have a nucleus which contains a person's genetic fingerprint. The genetic material containing this fingerprint is known as DNA, which must be preserved to transfer instructions precisely to daughter cells. However, if damaged by radiation or other environmental insults, changes in the DNA may lead to mutations and ultimately cancer.

The x-ray facility is being used to investigate the precise processes by which a radiation insult to DNA leads to its damage. Radiation or light in the presence of a photo-active drug leads to the ejection of an electron from the DNA. This leaves a positively charged centre which attracts an electron from its neighbouring site. This in turn attracts an electron from its neighbour thus relaying the positively charged centre along the DNA chain. This happens until this centre becomes trapped at guanine, the most favoured trapping site in DNA. Guanine is one of the four DNA building blocks which form chains of stacked nucleobase pairs. This stacking facilitates the movement of the electron loss centres. Since guanine stops the charge relay process it can be thought of as an insulator set within the conductive DNA 'wire'. This insulative property of guanine makes it a 'hotspot' for damage. The use of enyzmes which recognise and remove particular damages in DNA have been very useful in verifying that damage is localised at guanine. If this damage is not repaired then it constitutes an alteration in the genetic fingerprint and may have significant biological consequences.

P O'Neill, T Melvin, S Cunniffe MRC, Harwell
T Roldan-Arjona Clare Hall Labs
AW Parker RAL



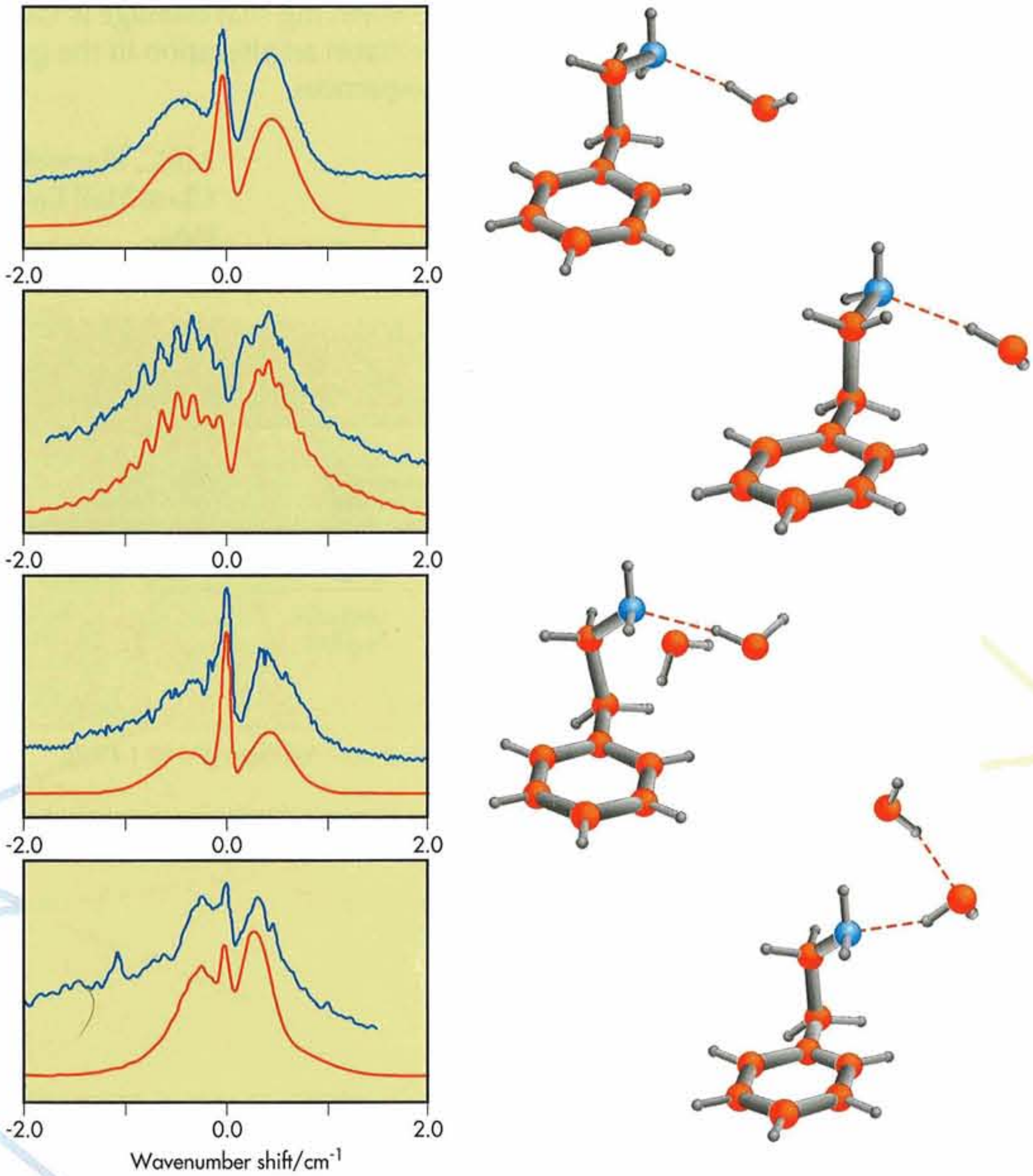
An enzyme sensitive probe recognises specific nucleobase damage (96RB1432).

Laser Spectroscopy of Biological Model Molecule Clusters

The chemical structure and nature of large biological systems, such as proteins and DNA, are governed by the subtle effects of hydrogen bonds, which produce very weak attractions between neighbouring atoms. For example, the shape of a protein markedly affects its function within the body, and this shape is determined by very specific hydrogen bonds within its structure and with neighbouring molecules such as water. A major scientific goal is to understand how these bonds define the structure of large systems.

An excellent technique has been developed for studying the structures of flexible organic model molecules, such as neurotransmitters and amino acids, which provide insight into the influence of hydrogen bonding on structure. Using the technique of high resolution laser spectroscopy researchers are able to determine the changes induced by the presence of water molecules hydrogen bonded to an isolated molecule.

JP Simons, EG Robertson, M Hockridge,
JA Dickinson Oxford University



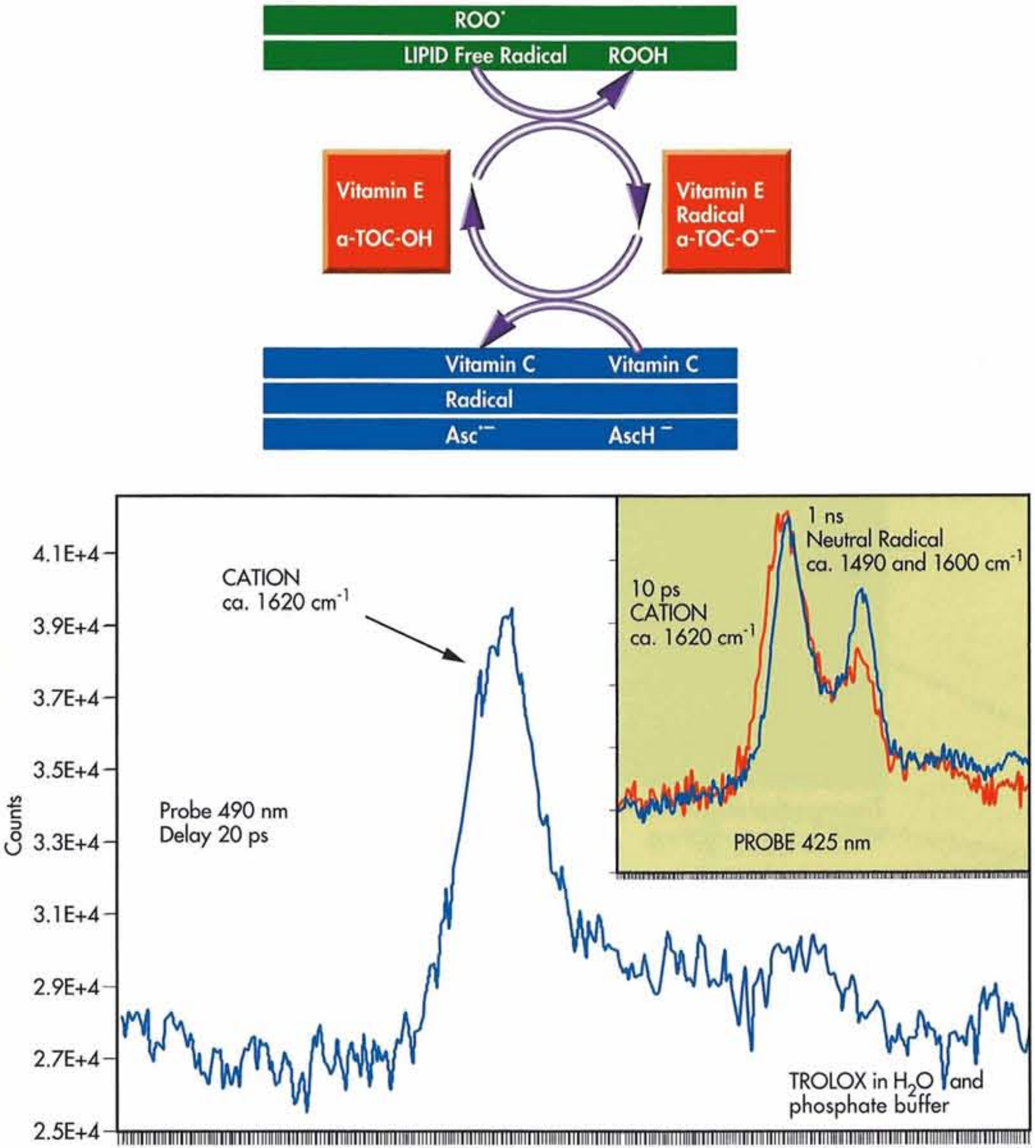
High resolution laser spectroscopy is used to study the effects of hydrogen bonding, demonstrated with the experimental and theoretical structures obtained for a simple neuro transmitter.

Life Saving Chemistry

A newly developed dual beam optical parametric laser system is being used to investigate the life saving chemistry of vitamin E. This vitamin's function is to protect us from harmful free radicals which, if left unchallenged, would cause diseases related to premature ageing and cancer. The chemistry of this process involves measuring the time taken for a hydrogen atom to be lost from the vitamin E molecule.

This process is little understood because this seemingly simple process can occur in three distinct ways: the one step transfer of a hydrogen atom; the initial transfer of an electron followed by a proton; or the initial transfer of a proton followed by an electron. The work involves photochemically activating the vitamin E molecule and spectroscopically monitoring it (with time - resolved Raman spectroscopy and transient absorption measurements). It shows that whilst initial electron transfer is favoured, the process is immediately followed by a proton transfer reaction. The data show two cases, an instantaneous electron transfer reaction and a rapid but concerted reaction involving an electron and a proton. A full study of this concerted reaction is still underway and it is thought fundamental to the life saving properties of vitamin E.

RH Bisby Salford University



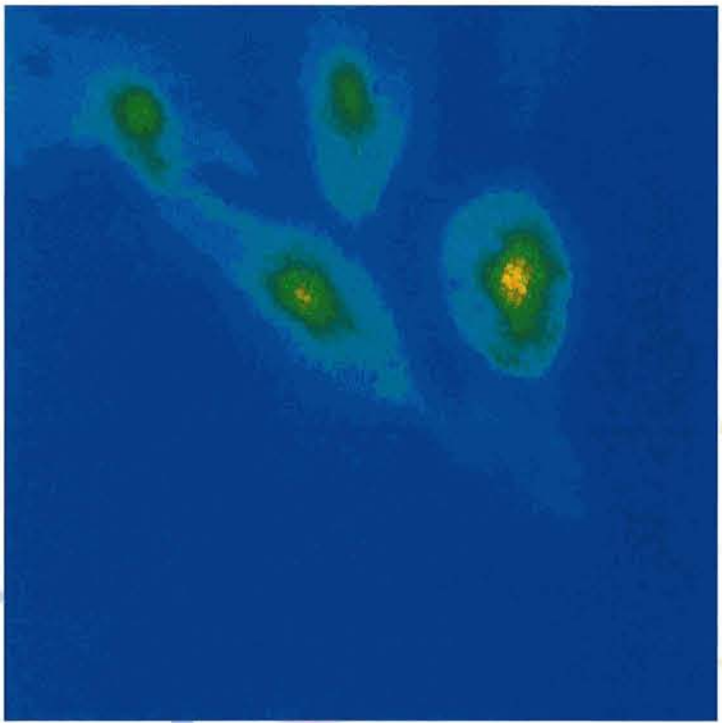
How Vitamins E and C act together to combat toxic free radicals. Picosecond Raman spectra showing the ultrafast chemistry of a vitamin E analogue.

Photodynamic Therapy to help Optimise Drug Effectiveness

Photodynamic Therapy is a treatment which combines the use of light-activated fluorescent drugs, known as sensitisers, and low power laser light to induce the destruction of tumour cells in the body without permanently damaging neighbouring healthy cells. However the sensitisers in current use are relatively insensitive to tissue penetrating wavelengths. This means that the depth of tumour destruction is limited and the treatment time is long. For this reason there is great interest in second generation sensitisers.

The time-resolved confocal microscope has been used to study the behaviour and environment of the promising second generation pyridinium Zn(II) phthalocyanine (ZnPPC). A picosecond pulsed laser beam activates the drug within the cell and images are taken on sub nanosecond timescales after excitation. By monitoring the kinetic and spatial distribution of the fluorescence emission, both the activity and local environment of the drug can be established to help understand the mechanisms involved and optimise the drug's effectiveness.

D Phillips, A Waite Imperial College, London
AJ MacRobert, D Pattison University College, London
AW Parker RAL



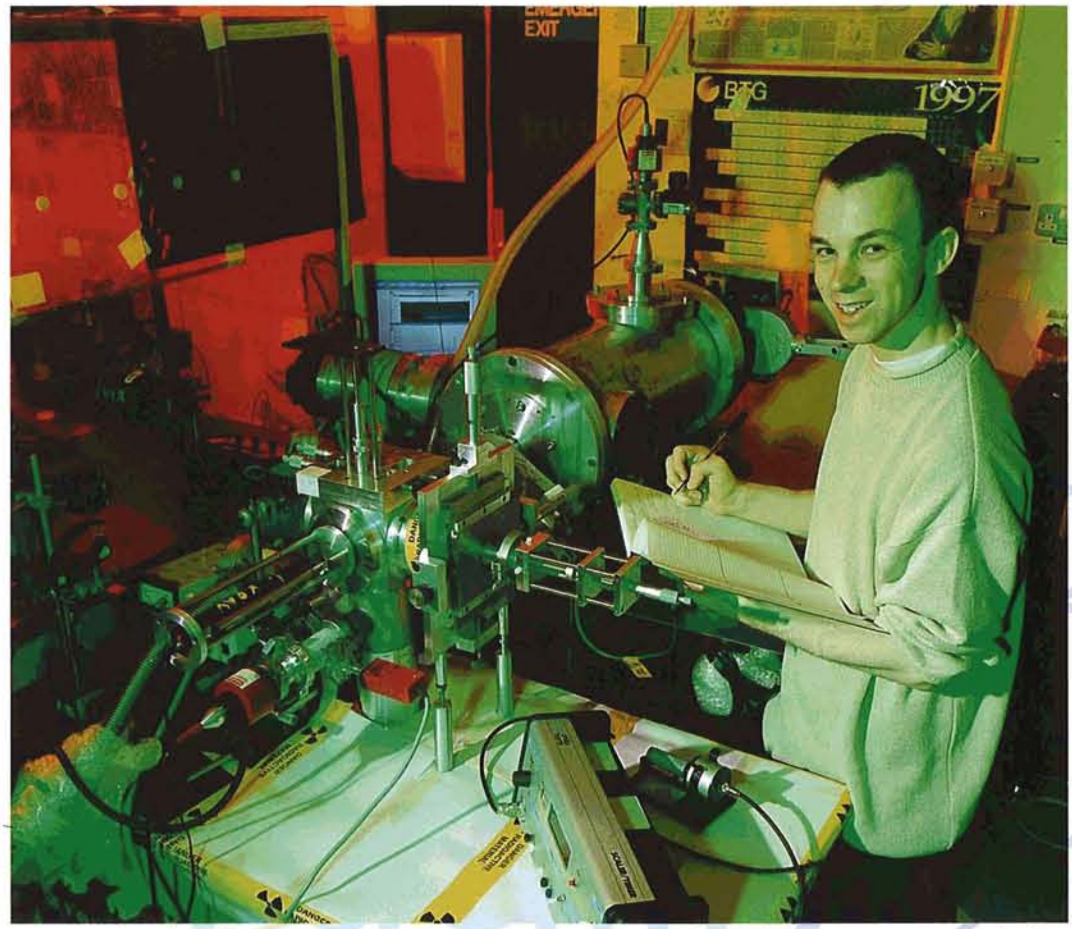
Time-gated fluorescence image of cells incorporating the light activated drug.

Space and Time Resolved Absorption Spectroscopy

When an extreme-ultraviolet (EUV) photon interacts with an atom or ion several electronic excitation and de-excitation processes occur which require sophisticated experimental and computational techniques to understand. These studies are of considerable practical importance in many laboratory and astrophysical plasma processes. For neutral atoms, experimental techniques for photoabsorption and photoionization are well developed. For ions, the situation is much less satisfactory mainly due to the great difficulty in generating high density ion beams.

An extremely versatile technique for the recording of EUV photoabsorption spectra of atoms and ions is the Dual Laser Plasma (DLP) method in which one laser plasma constitutes the 'sample' while the other becomes the EUV / soft x-ray backlighting source. When the laser is focused on samarium targets, the plasma emits a smooth continuum spectrum ideal for absorption spectroscopy. Using the picosecond plasma source of radiation, the controlled collapse of an actinide 5f electron wave was observed for the first time.

J T Costello, O Meighan, L Dardis,
C Moloney, CMcGuinness, A Gray,
J-P Mosnier, W Whitty Dublin City University
C L S Lewis, R O'Rourke, A MacPhee Queens University, Belfast
I C E Turcu, R Allott, A Lamb, W Shaikh,
S Huntingdon, N Takeyasu, C Danson RAL



Lee Dardis of Dublin City University working on an EU funded experiment to study the electronic structure of heavy ions (97RC3441).

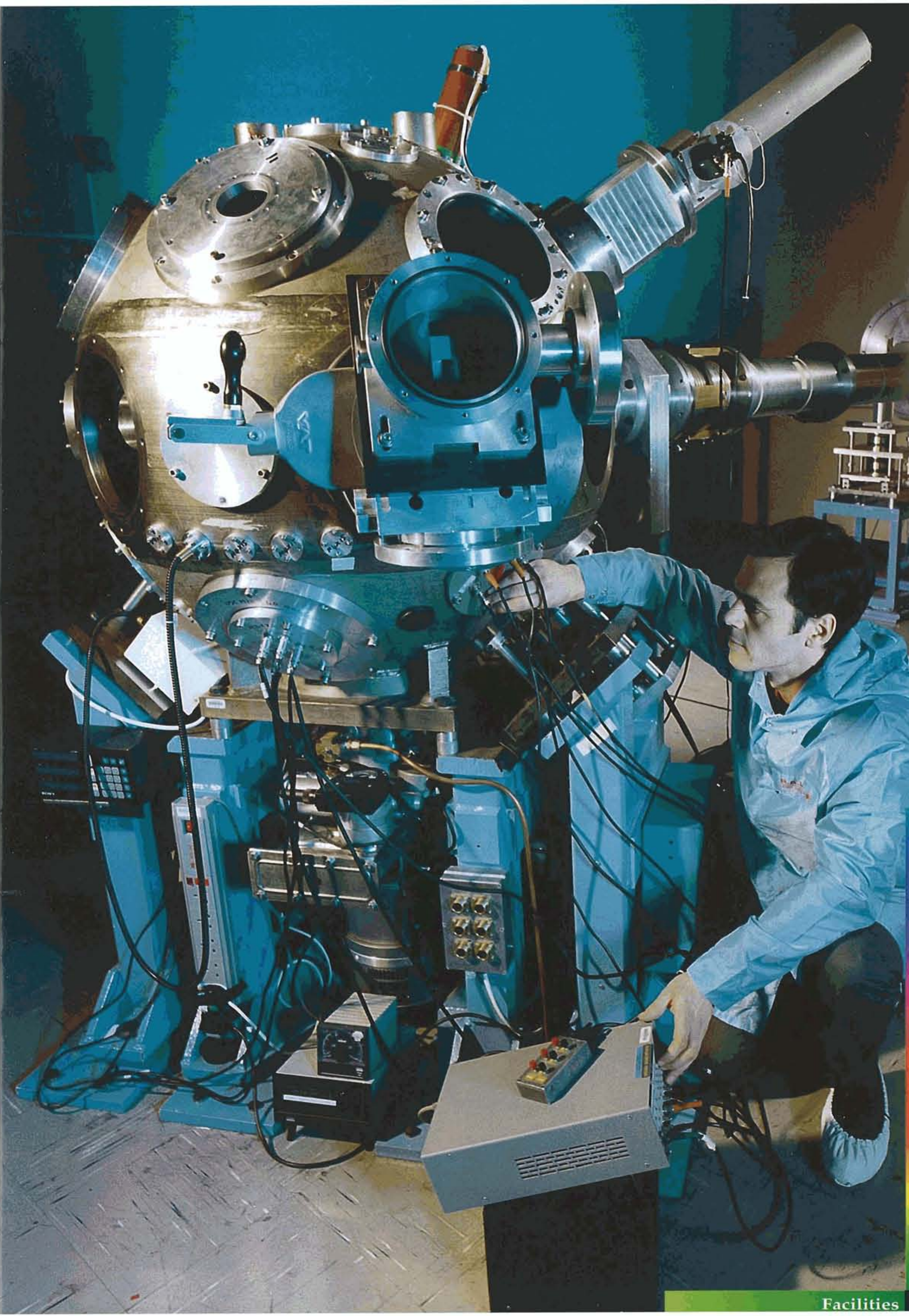
Facilities

The Central Laser Facility provides access to large scale laser systems for researchers from the United Kingdom and other EU countries. The Facility operates high power glass and KrF laser installations and a number of smaller scale, tuneable lasers. A vigorous development programme ensures that facilities maintain their international competitiveness.

Access to Facilities

For researchers from UK universities access to the facilities is provided, in the main, via tickets associated with research grants from the major funding bodies. Time is made available under "direct access" for trial experiments in exciting new areas of science. European researchers can gain access by application to the Large Facilities Access scheme of the EU TMR programme. Use by commercial enterprises or government bodies outside the EU is available at contract rates. Potential new users should contact the director of the CLF in the first instance for further information.

Jim Lister of Titania operations shown in the Titania target area (Photograph by Derek Cattani).



Vulcan Glass Laser

Vulcan is the main high power laser facility operated by the CLF. It is a powerful, versatile, Nd:glass laser system capable of delivering up to 2.6 kJ of laser energy in nanosecond pulses and over 100 TW power in sub-picosecond pulses at 1054 nm. Frequency conversion to the second harmonic gives 1 kJ at 527 nm. Pulse durations between 700 fs and 5 ns are routinely available.

The sub-picosecond pulse is produced using the technique of chirped pulse amplification (CPA). In this mode, a low intensity pulse is stretched in time from a few hundred femtoseconds to a few hundred picoseconds. This is then amplified before being recompressed and focused onto the target producing intensities of 10^{20} Wcm^{-2}. This pulse can be synchronised to the long pulses, enabling sophisticated interaction and probing experiments.

Placement student Steven Hawkes of Sheffield Hallam University aligning the output stages of Vulcan (97RC4284).

Testing of Vulcan's new broad bandwidth pre-amplifier based on the Optical Parametric Chirped Pulse Amplification (OPCPA) scheme developed within the CLF (98RC1697).

Vulcan Target Areas

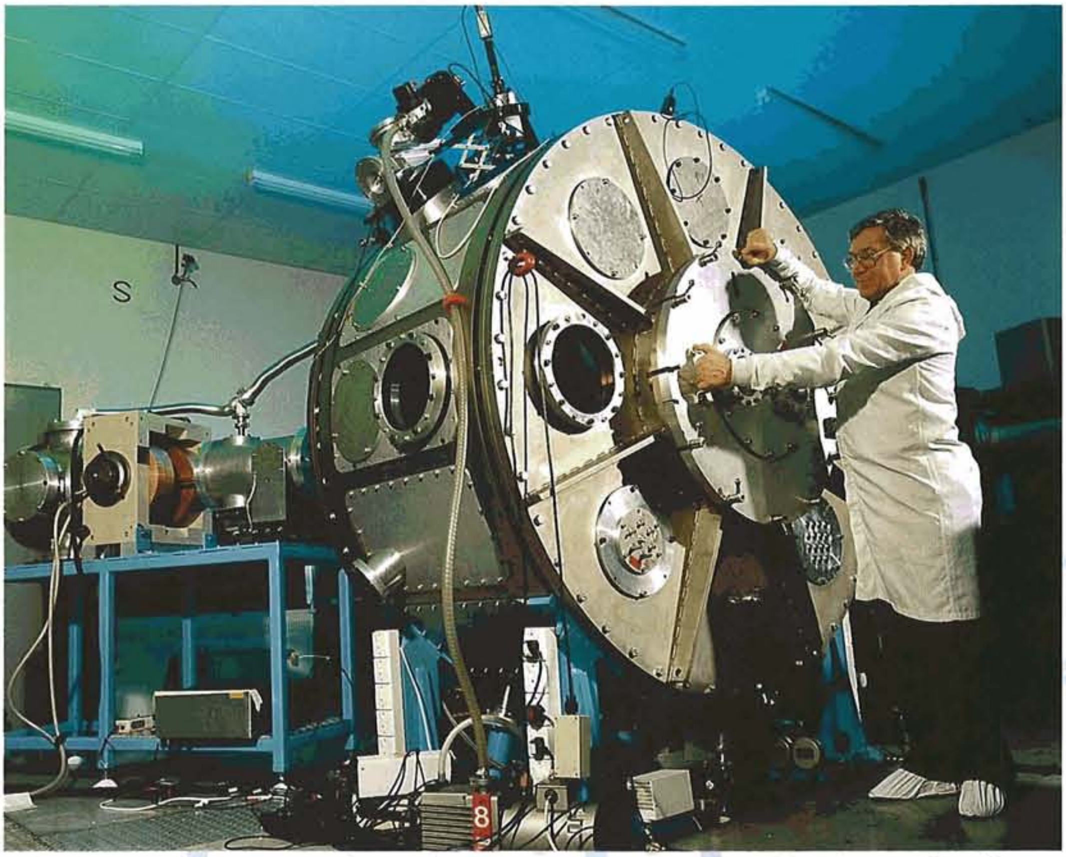
Four target areas are available for experiments using Vulcan.

Target Area West is equipped for short pulse, high intensity interactions using Vulcan's short pulse capability. The beam is 3 times diffraction limited and can be focused to spots as small as 10 micron diameter using reflective optics. Line focus geometry is also available. Up to 1.8 kJ is available from the other Vulcan beams, in combination with a low power, frequency doubled or tripled sub-ps optical probe.

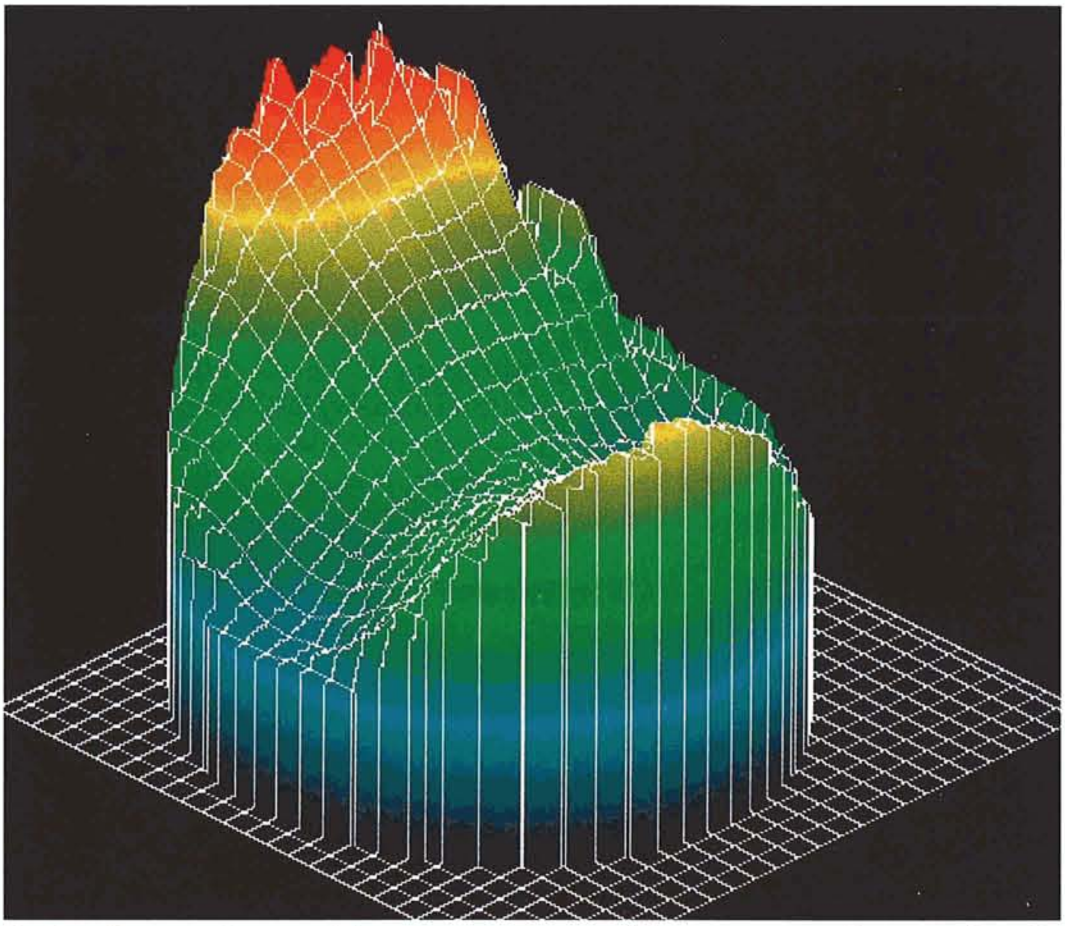
Target Area East is a versatile interaction area with access to the full output of Vulcan. A line focus of between 7 and 40 mm length can be produced for x-ray laser pumping; cluster geometry can be provided to deliver the full Vulcan output to a single spot; opposed beam geometry is available for driving plasma shocks and radiative heating experiments. Frequency doubling is provided for all beams as required.

Target Area Two uses three of the 108 mm diameter laser beams in long pulse mode (0.1 to 5 ns) at either the fundamental wavelength or second harmonic. Nanosecond laser pulses of up to 200 J per beam can be supplied into this area.

Target Area Four is a small target area, equipped to use a single 40 mm diameter long pulse beam at the 10 J level. This area is ideal for instrument development and other applications work where the higher repetition rate (~5 minutes between shots) is particularly advantageous.



Peter Hatton of the CLF mechanical engineering group seen with Vulcan's ultra-short pulse interaction chamber funded through the EPSRC Phase I Petawatt grant (97RC4799).



An interferomter image giving a measurement of the output wavefront quality of one of Vulcan's eight beams.

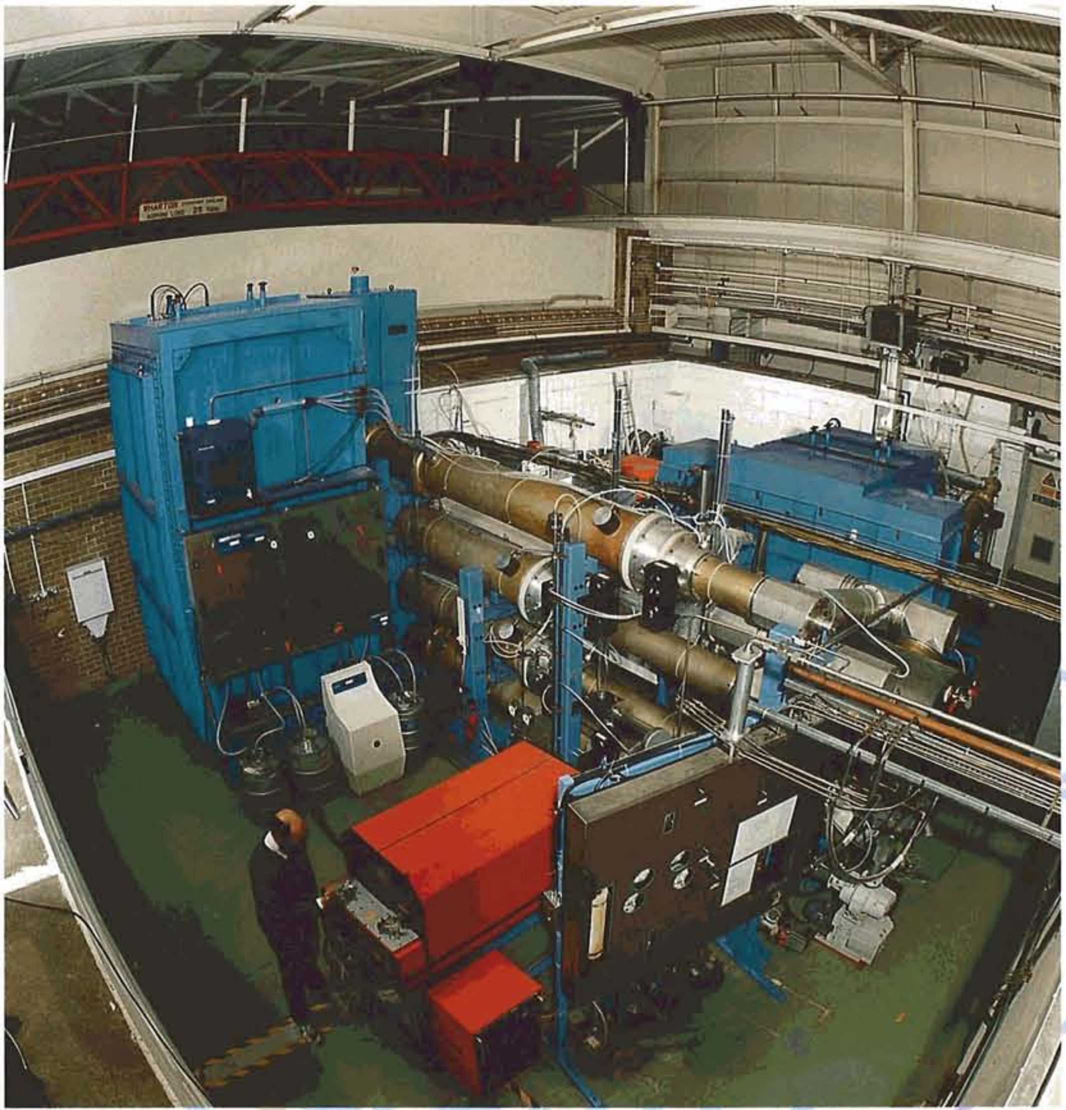
Nigel Woolsey, a Research Associate at Queen's University, Belfast adjusts diagnostics for an x-ray scattering experiment (98RC2390).

The Titania KrF Laser System

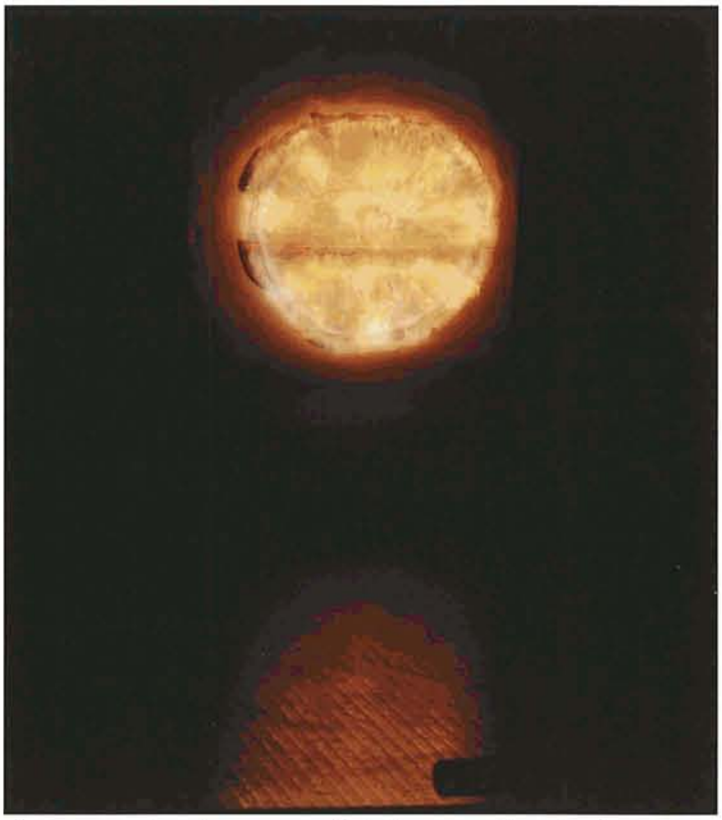
Krypton fluoride, KrF, is a gaseous laser medium which amplifies pulses of ultraviolet light. The Titania system, which occupies 1000 m^2 of floor space, is based around two of the world's largest KrF laser amplifiers, Sprite and Titania. These machines can deliver very large amounts of laser energy in a single pulse. The broad gain-bandwidth of KrF also allows the pulse duration to be short, producing terawatt powers, and the ultraviolet wavelength allows these powers to be tightly focused, resulting in exceptionally high intensities.

Titania is a versatile system, capable of operating in at least three different modes. In CPA mode the technique of chirped pulse amplification is used to deliver the shortest possible pulse durations of 300 to 400 fs. Titania can also be used to power a Raman laser beam-combining system, using methane gas as the Raman medium. This produces pulses which are tens of picoseconds long but which contain much more energy - tens of joules. The Raman process also generates minimal prepulse so the main pulse can irradiate targets which have not been preheated.

The third operational mode is used mainly for materials processing. The pulse duration is now 10-20 ns and several unfocused beams can be overlapped on the target. Energies of more than 100 J are available allowing large samples to be processed uniformly in a single shot.



Graeme Hirst, group leader of Titania, adjusts the laser used to trigger the spark gaps in the pulsed power area (96RC2151).



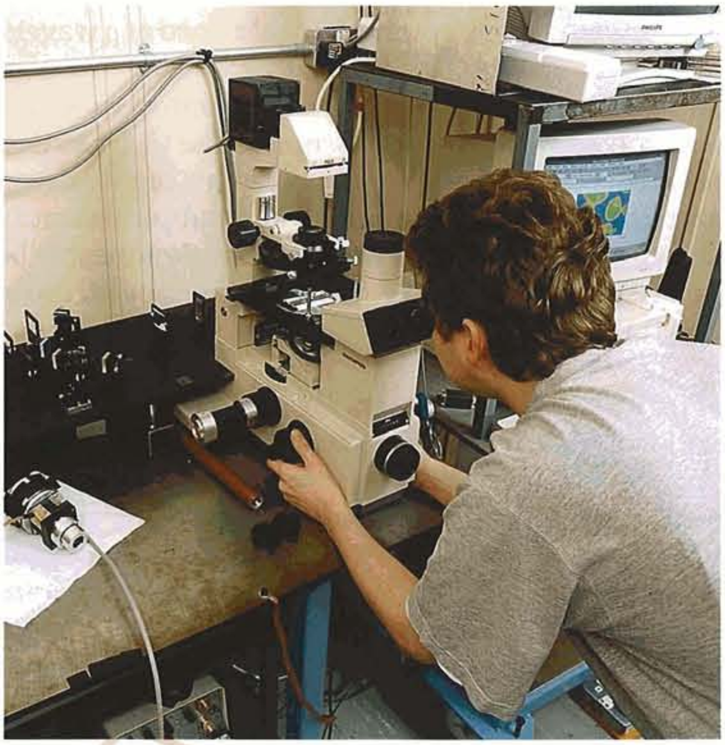
An image showing a near field burn on Titania during development for materials processing experiments (96RC5122).

Peter Norreys of the Physics Group inspects the newly installed Titania target chamber (96RC2144).

The Lasers *for* Science Facility

The LSF provides user scientists and technologists with a wide range of lasers, laser-based techniques and expertise for their own use. It is divided into four laser laboratories and a laser loan pool facility.

The Confocal Microscopy Laboratory has established a versatile laser-based fluorescence microscope having a time resolution of 120 ps. Samples are optically excited with a Nd:YAG pumped dye-laser, emitting pulses of 10 ps duration over the wavelength range 560 - 640 nm. Frequency doubling allows wavelengths in the UV from 280 - 320 nm to be achieved. Applications include imaging the distribution of cancer drugs within living tissue.



Kevin Henbest uses the ultra-high resolution Confocal Microscope in the Lasers for Science Facility (96RC5362).

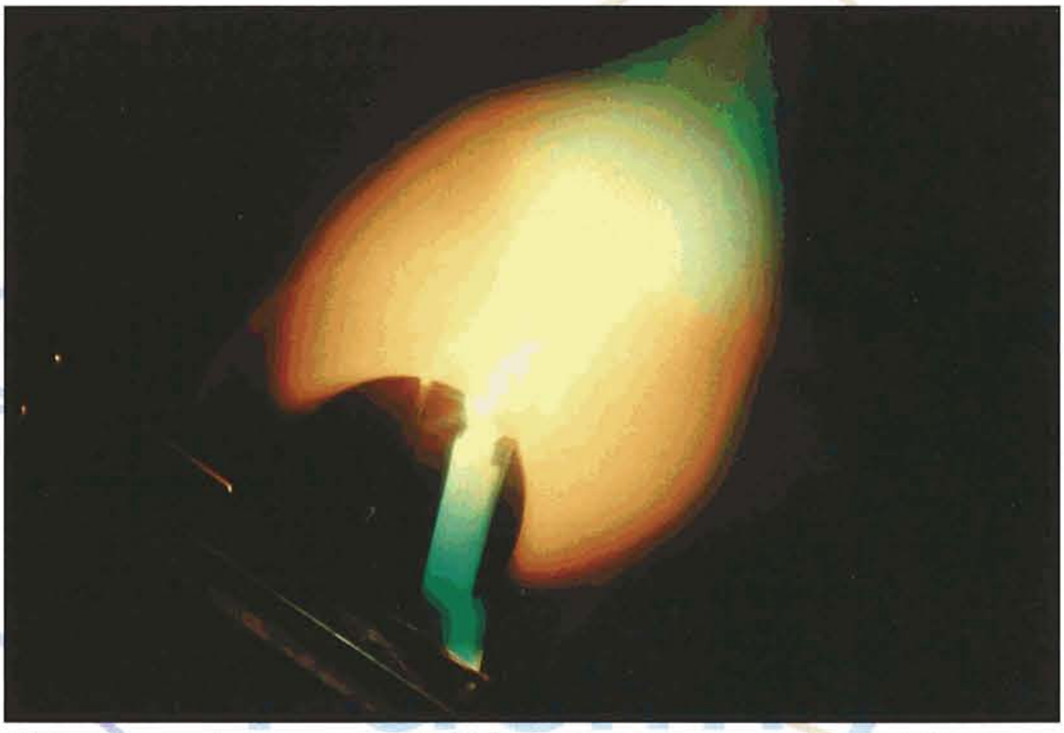
A state of the art optical parametric amplifier developed at the Lasers for Science Facility for picosecond Raman spectroscopy (95RC3797).

The Nanosecond Science Laboratory offers a diverse range of techniques for spectroscopically investigating the dynamics of chemical reactions by characterising the structure and reactivity of intermediates that form on a time scale down to a few nanoseconds. Time-resolved resonance Raman spectroscopy, laser flash photolysis and resonance-enhanced multi-photon ionisation are the main techniques employed. Two lasers are available, an excimer-pumped dye laser and an optical parametric amplifier, covering the tuning range between 205 and 1680 nm.

The Laser X-Ray Source offers a broad wavelength range of bright x-rays of high average power which have applications in fields as diverse as radiation medicine and x-ray lithography. High conversion efficiency of laser light to x-rays is obtained by using a train of picosecond pulses amplified to high power in two high repetition rate excimer (KrF) lasers. Average x-ray powers of 1 watt, in the forward direction, have been obtained at a wavelength of 1 nm.

The Ultrafast Spectroscopy Laboratory specialises in femtosecond transient-absorption and picosecond time-resolved Raman spectroscopies. The CLF has developed the world's first double tuneable picosecond laser system to meet this highly demanding need. Two optical parametric amplifiers (OPAs) are pumped by a subpicosecond titanium-sapphire oscillator to generate two synchronised and independently tuneable beams, covering the spectral region between 220 and 2200 nm, with pulse energies exceeding 0.5 mJ, and to an accuracy of better than 0.15 ps.

The Laser Loan Pool provides scientific lasers for researchers to use in their own laboratories. The lasers can be borrowed for feasibility experiments, used in extended research programmes or to enhance users' existing research facilities. The loan periods normally last between 3 and 6 months. The range of lasers available includes nanosecond-pulsed Nd:YAG-pumped dye lasers which, with harmonic generation, cover most of the visible and UV spectrum. Recent acquisitions have enabled the near infra red region to be accessed (1.6 to 3.5 microns) using difference frequency generation techniques. Also available are a fluorine excimer laser, a 5 W (all-lines) argon-ion laser and an all solid state femtosecond titanium-sapphire laser system.



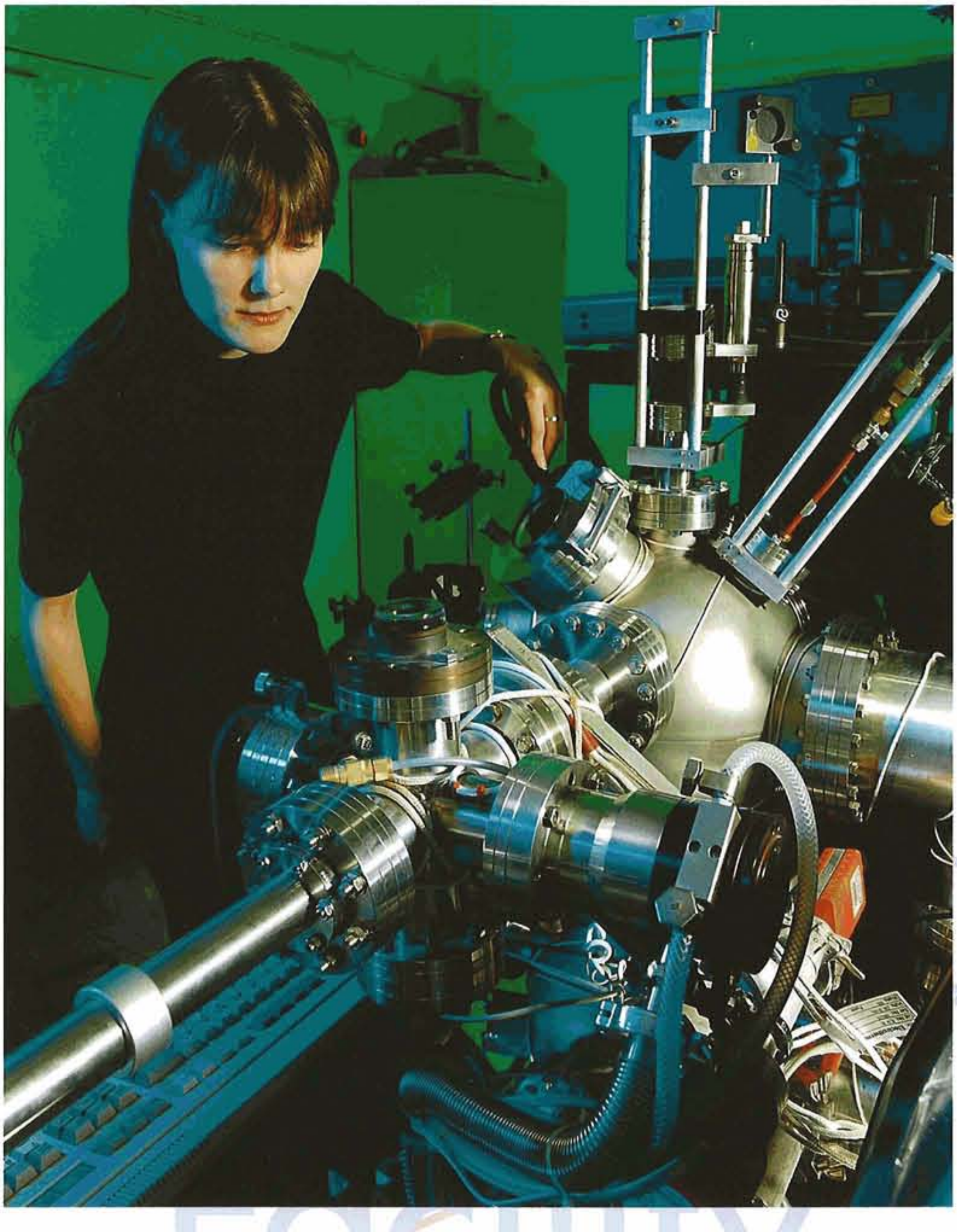
Million degree plasma source emits high average power x-ray radiation in the x-ray laboratory (90RC7388).

High Intensity Femtosecond Science Laboratory

The High Intensity Femtosecond Science Laboratory enables user scientists to investigate the interaction of highly intense, extremely short (~50 fs) laser pulses with matter.

The high power, high repetition rate laser (HPHR) is being upgraded. The anticipated performance is a pulse energy of >0.5 J in ~30 fs corresponding to powers approaching 20 TW. The system will retain the important feature of operating at the high repetition rate of 10 Hz.

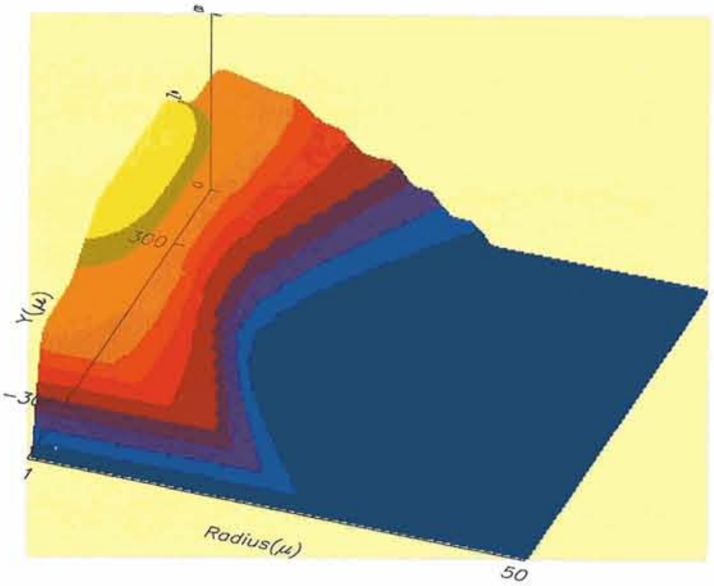
A wide variety of high intensity experiments are carried out including multiphoton dissociation and ionisation of both small and large molecules. The enhanced laser performance will provide user scientists with ultra-high intensities (>10^{18} Wcm^{-2}) for femtosecond timescale studies of chemical reactions, VUV and x-ray generation, materials science applications and laser-plasma interaction studies.



PhD student Alison Hollingsworth of the University of Edinburgh, using the High Intensity Femtosecond Science Laboratory to carry out experiments on biological molecules using femtosecond laser mass spectrometry (96RC4634).

Theory and Computation

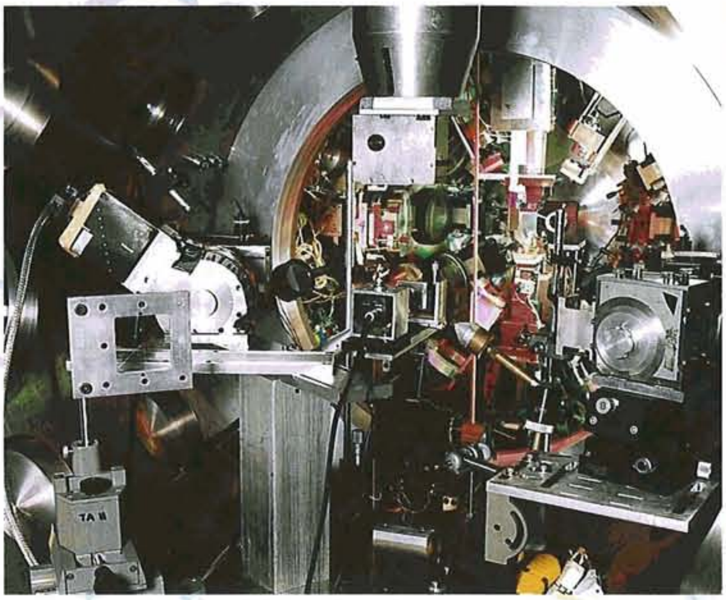
Theory and simulation support is provided for the design and interpretation of high-power laser experiments. A suite of hydrodynamic and atomic physics modelling codes are operated and developed to simulate the plasmas produced by the interaction of high-power laser light with solid and gas targets.



Average ionisation stage of a neon gas target, following the passage of an ultra-short, ultra-intense laser beam.

Engineering

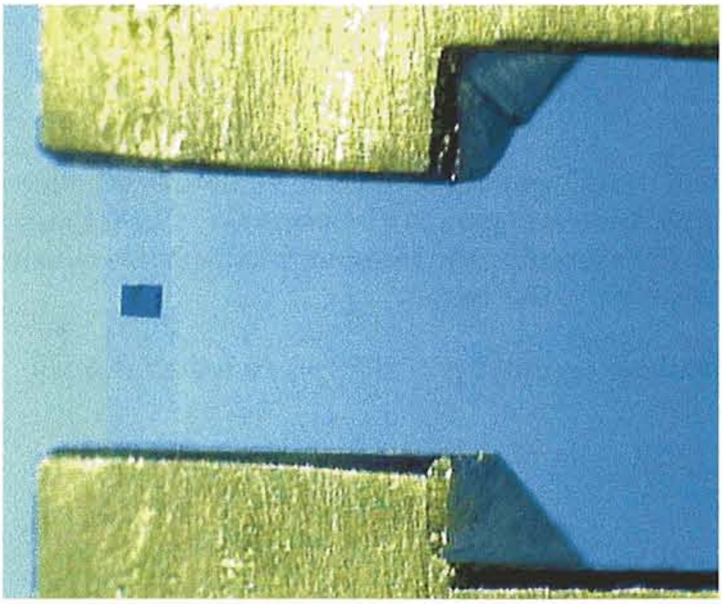
Mechanical, electrical and computing engineering expertise is provided in support of the experimental programmes and to underpin the research and development activities of the CLF. Scheduled experiments are supported by experienced staff who are available at all stages of the work, from initial planning, through the design, manufacture, assembly, and commissioning of dedicated systems and instruments, to the running of the experiments. Mechanical and electrical workshops give a rapid response service to users in support of scheduled experiments.



A view inside one of the high power target chambers during an x-ray laser experiment demonstrating the complex optical and instrumental configurations required (93RC1256).

Target Fabrication

A target fabrication facility is operated within the CLF. It is equipped with a wide range of target production and characterisation equipment, including evaporation and sputter coating plants, interference microscopes and a plasma etch facility. A rapid turnaround service responds quickly to the developing demands for targets, essential for maintaining the scientific productivity of the programme.



A 100 times magnified image of a microdot target mounted on a plastic sheet for spectroscopic studies.

Instrumentation

A wide range of diagnostics is provided for visiting scientists to measure the extreme conditions generated in laser matter interactions. Specialised instrumentation is used to examine radiation emitted from plasmas covering a large portion of the electromagnetic spectrum from gamma rays to the infrared. Ultra-fast optical and x-ray streak cameras can measure the rapid changes as conditions evolve in the plasma, and particle detectors are used to measure the high energy interaction products left as the plasma expands.

Margaret Notley of the Target Area Support Group adjusts a Von Hamos x-ray spectrometer designed to measure the density and temperature of a plasma (98RC1706).

Acknowledgments

I would like to thank the large number of users and CLF staff who have generously contributed. My appreciation also goes to ½8 Design Co., CLRC Press and Public Relations section and Photographic and Reprographic Services who have all played a major role in the production of this report.

This report is also available on the WWW at http://www.clf.rl.ac.uk

Colin Danson

J Lin Essex University prepares the ultra-short pulse interaction chamber on Vulcan (97RC3316).


RUTHERFORD APPL
RUT ATORY
LA R DIVISION
SIZE 112CMS

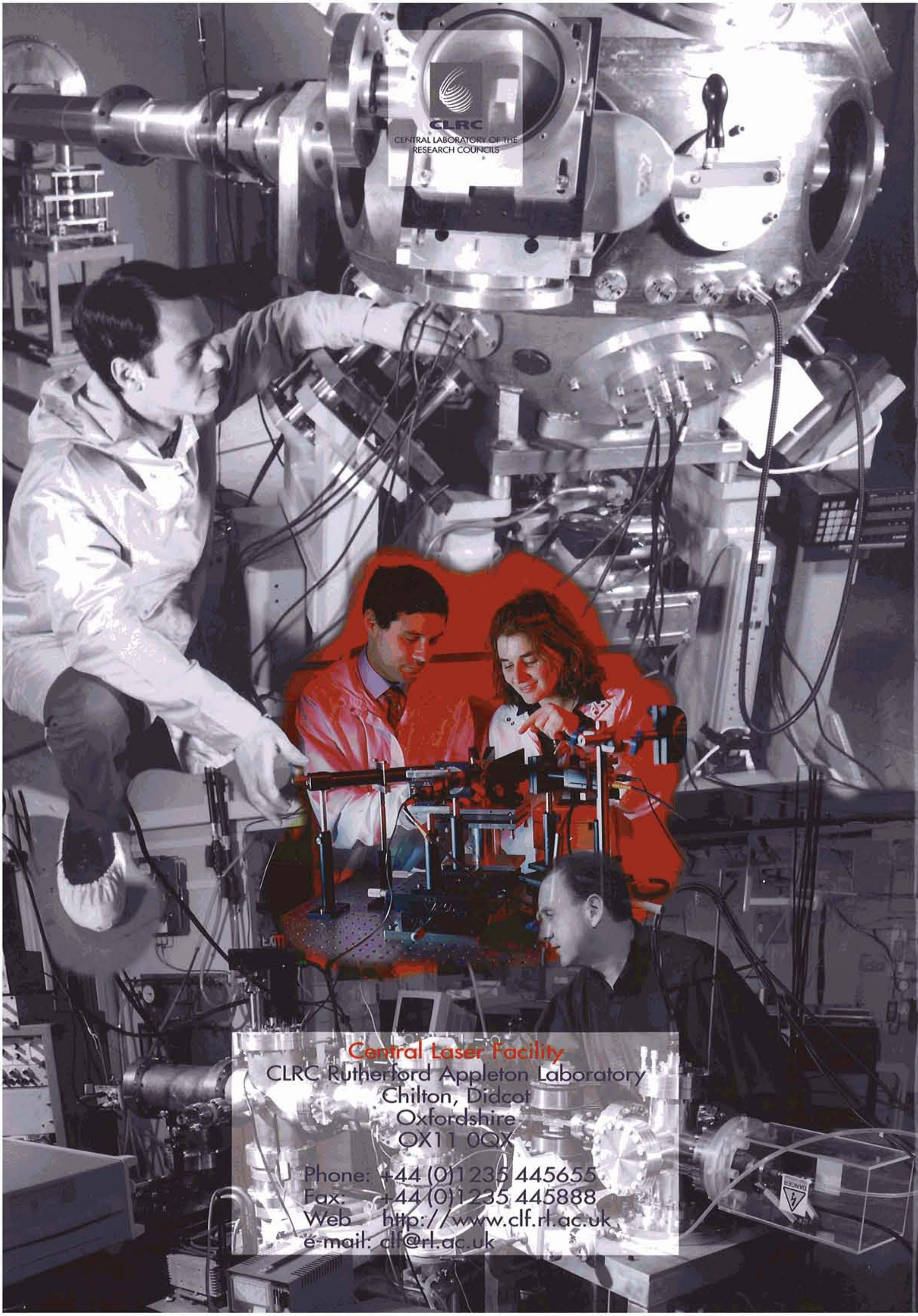
Central
Laser
Facility

Central Laser Facility

CLRC Rutherford Appleton Laboratory
Chilton, Didcot
Oxfordshire
OX11 0QX

Phone:	+44 (0)1235 445655
Fax:	+44 (0)1235 445888
Web:	http://www.clf.rl.ac.uk
e-mail:	clf@rl.ac.uk

Aerial view of Rutherford Appleton Laboratory in Oxfordshire, which since 1 April 1995 has been operated by the Council for the Central Laboratory of the Research Councils (93RC3392).



CLRC
CENTRAL LABORATORY OF THE
RESEARCH COUNCILS

Central Laser Facility
CLRC Rutherford Appleton Laboratory
Chilton, Didcot
Oxfordshire
OX11 0QX

Phone: +44 (0)1235 445655
Fax: +44 (0)1235 445888
Web http://www.clf.rl.ac.uk
e-mail: clf@rl.ac.uk