

IN CONFIDENCE

Report on a Visit to U.S. Laser Laboratories by
a AERE/Rutherford/University Team 10th Sept - 4th Oct 1974

GENERAL

The team comprised:-

Mr. D.E.T.F. Ashby	}	A.E.R.E.
Dr. C. Whitehead		
Dr. M.H. Key		Queen's University, Belfast
Dr. P.R. Williams		Rutherford Laboratory

The objective of the tour was to visit Laser Fusion Laboratories and Laser Manufacturers with the intention of arriving at a consensus view on what laser equipment should be purchased in the initial phase of setting up an A.E.A./S.R.C. Laser Compression Facility. Dr's L. Hobbs and P.R. Williams have been asked to make specific recommendations to the S.R.C. by mid December; it was this requirement which generated the need for the tour. A similar team comprising -

Prof. D. Bradley	Imperial College
Dr. C. Whitehead	AERE
Dr. P.R. Williams	Rutherford Laboratory

visited French manufacturers at the conclusion of the U.S. trip.

The following laboratories, laser manufacturers and organizations were visited or contacted:-

1. U.S.A.E.C. Headquarters, Germantown, Washington
2. Apollo Lasers Los Angeles
3. Lawrence Livermore Laboratory Livermore
4. Los Alamos Scientific Laboratory Los Alamos
5. Battelle Memorial Institute Columbus
6. K.M.S.F. Ann Arbor
7. Rochester University Rochester
8. G.E. Rochester
9. Raytheon Rochester
10. Quantel Paris
11. CILAS/CGE Paris

It has been intended to visit the Sandia Laboratories in Albuquerque but A.E.C. clearance was not given.

This report consists of appendices describing and commenting on the information obtained at each of the above organisations in the order indicated.

GENERAL COMMENTS

Although the trip was primarily intended to acquire information on Lasers the general laser fusion scene was observed. Politically the major development was a change in the classification guide, layered targets are now unclassified; in fact K.M.S.F. is now offering to sell gas filled glass micro balloons with metallic coatings as an option. It turns out that glass micro-balloons ($\sim 50\mu\text{m}$) filled with D or DT at 50 atmos have been the preferred experimental target for the past year or two.

Experimentally K.M.S.F. are still far ahead in terms of getting well diagnosed results on the compression of spherical targets with Rochester University followed by LASL next.

As far as large neodymium lasers are concerned the short pulses (~ 100 picosec) and resulting large powers ($\sim 10^{12}$ watts) are giving rise to several problems arising from non-linear optical phenomena. Livermore are finding it difficult to get more than ten's of shots from their disc amplifiers but they believe they understand the problem and are confident it can be solved. G.E. have supplied disc amplifiers to KMSF who are satisfied with their performance. Note: G.E. are under-rating their discs by comparison with Livermore and are not insisting on such good beam quality. Rochester, Los Alamos and Battelle are staying with rod amplifiers.

The CO_2 laser is generally considered unsuitable for laser fusion; even Los Alamos are backing off the idea of a 100kJ CO_2 system and hope that the HF laser will continue to develop promisingly.

As regards the possible sources of supply of high power neodymium lasers for the U.S.

1. G.E. are willing to make a quotation for a complete system based on their disc amplifiers or any portion of a system (500J in 300 picosec).
2. Livermore have offered to supply disc amplifiers at cost once the present materials problem is overcome.
3. Raytheon will sell 9cm rod amplifiers as supplied to Rochester University.

C. Whitehead
D.E.T.F. Ashby
January 1975

APPENDIX 2

Notes on the Visit to Apollo Lasers - Mon. 16th Sept. 1974

Apollo Lasers is a small company (3M\$ Sales per year) of some 65 employees of whom about 40 work on lasers the rest being concerned with the electronic side of the company. The main reason for visiting them was that we had a day to spare on the West Coast as the Livermore visit had been put back.

Apollo have expertise in Nd rod lasers up to 1.1/4" diameter. They do not want to move into disc amplifiers and would be wary of taking on a large order which could amount to a "sudden-death" operation. They are capable of supplying smallish systems involving mode locked oscillators and amplifiers up to tens of joules at 100 picosec and would be happy to do this. They are supplying Culham with two small systems and appear to do a competent job. At this meeting we requested a cost and delivery estimate for a 10-20 joule Nd laser, 100 picosecond pulse length and they promised to give such an estimate by 1st November.

We concluded Apollo was a small competent firm from whom we might order either standard optical components or custom-built equipment when the price was not greater than about 50k£.

APPENDIX 3

Notes on the Visit to Lawrence Livermore Laboratory 18th-19th September 1974

1. GENERAL

Two days were spent at Livermore. John Emmett, head of Y-Division spent a lot of time with us and took a great deal of trouble to ensure that we saw everything we wanted to and met with the right people. The programme is continuing much as planned. The budget for '74 was 17M\$ and is 19.9M\$ for '75. The new laboratory, which includes an impressive laser hall, is nearly built and construction has started on the building to house the projected 10kJ neodymium glass laser. The experimental programme at Livermore does not have much steam behind it as the bulk of their effort is going onto development of glass lasers in preparation for the 10kJ system. It appears they are under attack for failing to carry out target experiments at low energies; an attempt is being made to rectify this situation and the Janus system ($\sim 100\text{J}$ in ~ 100 picosec) will be used for spherical irradiation within a few months.

The laser development programme is bogged down in materials technology (see next section) but Emmett is confident that finding a solution is only a matter of time and money.

The question of co-operation between Livermore and the U.K. project was raised and both Emmett and Carl Haussmann (Associate Director and Head of the Y-Programme) voiced this idea and claimed it would be practical for Livermore to supply lasers, manufactured at Livermore, at cost and also to make their laser design and laser system codes available.

Some discussions on targets took place but because of shortage of time no discussions were held with theoreticians. The question of building specifications for laser laboratories was discussed. More details of the discussions are given in the following sections.

2. THE LIVERMORE DISC PROBLEM

The disc amplifier originated at NRL when Emmett was there, consequently Livermore are strongly committed to this approach. The problem of using rod amplifiers at high powers arises as follows. As the rod radius is increased it becomes increasingly difficult to optically pump the glass uniformly owing to absorption; to overcome this problem the percentage of neodymium in the

glass is reduced which results in less stored energy per unit volume and less gain per unit length. The limit to the intensity in a glass laser arises from non-linear refractive index effects in the glass rods - this restraint calls for the higher possible gain and energy storage to minimise the intensity length integral. Discs, which are pumped through their optical faces, overcome the absorption problem and allow heavily doped glass to be used. The major problem with disc amplifiers is that the optical faces experience a light flux several times greater than for a rod and are prone to light induced damage particularly if dust settles on the optical faces. Livermore has found that the gold-plated disc holders sputter material onto the disc faces. Emmett points out that they have a materials problem which he believes is solvable by June 1975. G.E. who supply disc amplifiers to KMSF work their amplifiers at lower powers and employ a better mechanical design.

3. THE JANUS SYSTEM

This two branched system is virtually complete and partially commissioned. Its specification is 100J in 150 psec on target with a maximum energy of 300J.

All the components are of Livermore design and manufacture. Rod amplifiers are used up to the 10J level (~ 4 cm diameter) which are then followed by 2 Type A disc amplifiers (3.5 cm diameter) and 2 Type B disc amplifiers (8.5 cm diameter). This takes the beam to about 50J in 100 psec at which point the beam is split into two branches each of which has a Type B amplifier.

The system has been tested to the split point. The target chamber is in position and the optics (f1 lenses) are being mounted. Two-beam irradiations are expected before the end of the year.

4. BUILDING SPECIFICATIONS

Air isolation systems were used on the individual tables (about 15) for the Janus system. Although such a system isolates the equipment from ground-borne vibrations there was no stability in the relative alignment of the tables. As a result the tables are now mounted on absorbent but firm pads directly on the 4" thick concrete floor. The vibrational displacements that Janus is subject to do not exceed $5 \cdot 10^{-6}$ inches over the frequency range 1Hz to 150 Hz and this has been adopted as the standard for the new laser buildings.

Computer modelling shows that "hard" mounting is superior to air, spring or cork mounting.

In their newest laser building (the Laser Fusion Laboratory) the floor is 3ft thick, ~120ft x 40ft and is mounted on 96 concrete pillars.

Air temperatures at tabletop level will be maintained at $\pm 2^{\circ}\text{F}$ through the circulation of clean air (all particles $> 5\mu$ diameter removed) and they will use clean rooms for assembly.

The area is, of course, very dry. The relative humidity is normally between 30% and 50% and never rises above 75%.

The walls of the new laser hall are non-chalking (painted with epoxy) and the acoustic board (to reduce the room reverberation time) is vinyl coated

The hall is floored with looped, uncut, nylon carpet and a built-in vacuum manifold around the skirting allows vacuum cleaners to be plugged in and the dust collected is vented outside the building. Livermore have found that the use of soft flooring is desirable from two aspects a) the carpet prevents dust from being raised by traffic in the hall and b) the mere existence of the carpet engenders in staff a cleaner approach to work.

5. TARGETS

Laser fusion targets were only discussed superficially. Emmett remarked that the best theoretical target that they had come up with consisted of a hydrogen shell containing a neon coated DT shell. The philosophy behind this configuration of target is clear: the hydrogen shell forms a high thermal conductivity light absorbing corona which, after it makes contact with the inner shell, conducts energy to the neon which ablates and drives the DT shell inwards.

Livermore are working on glass microballoons but also claim to be able to produce frozen hydrogen spheres and are working on the production of frozen hydrogen shells.

Chuck Hendrix talked about the production and delivery of liquid droplets although the principle of producing droplets is simple and has been described in the literature the results obtained are impressive. He showed a movie film of $\sim 50\mu$ diameter drops making head-on collisions after being projected over a distance of 1 metre - a targeting accuracy of $1\mu\text{m}$ in 7m and a timing

accuracy of 10 nsec has been achieved.

6. POSSIBLE COOPERATION BETWEEN LLL AND THE UK

Both John Emmett and Carl Haussmann raised the possibility of co-operation between Livermore and the U.K. programme. In particular they suggested that Livermore could, as a favour, supply, at cost, disc amplifiers once they have overcome the technological problems. Emmett pointed out that once the design was fixed they would get the Livermore production shop to produce large numbers of amplifiers for their 10kJ system and it would be little trouble to produce a few more for the U.K. programme; the cost would be whatever it cost Livermore. The Livermore production program is that by June 1975 the design (and solution of the present materials problems) will be hardened for disc amplifiers A, B, C and C⁻. By October some 220 of these amplifiers will be in production for delivery November to January 1976 for installation in the new Laser Fusion Laboratory.

Both Emmett and Haussmann pointed out that Livermore would not be able to accept contracts for this work. Such an arrangement could be set up on a Director to Director basis between AERE and Livermore and quoted the UK/US underground tests as an example of such co-operation.

It should be noted that such co-operation might be deemed 'unfair competition' by GE who have been approached with a request to tender for a large neodymium system.

Emmett also suggested that the Livermore laser design codes could be made available to the U.K. To transfer such codes would entail AEA staff working at Livermore for a few weeks. This suggested co-operation would be very valuable. Emmett said that although there would be difficulties he did not think they were insurmountable.

APPENDIX 4

Notes on the Visit to Los Alamos Scientific Laboratory 24th-26th Sept '74

GENERAL

The LASL visit lasted three days. Although LASL is committed to the CO₂ laser there is a growing realization that it has serious drawbacks for Laser Fusion work. Basically the long wave targets (10.6 μm) means that classical absorption mechanisms are quite inadequate at the intensities required and collective mechanisms, with ensuing non-Maxwellian distributions, are inevitable. Two problems then arise: firstly energetic electrons can pre-heat the core whilst energetic ions give poor ablation efficiencies; secondly the corona temperature tends to increase giving rise to a decoupling of the corona and core ('blow-off'). The technical problems of CO₂ make it difficult to achieve suitable short pulses; a few hundred picosec is probably the shortest pulse that can be realized at high power. A 10kJ CO₂ system is planned but the proposed 100kJ system may well not be built.

The H.F. laser is being actively pursued. No new results were presented but there is optimism that it will be suitable for a large compression facility. The time scale to develop this type of laser to a stage where it would be used is probably several years.

Work with neodymium lasers is progressing. The four beam system is expected to have two beams operational shortly each capable of delivery up to 250J in 600 picosec. Considerable trouble is being encountered in obtaining good beam quality.

Compression experiments have been done using some 40J in a single beam experiment to irradiation gas-filled glass microballoons in an asymmetric configuration; no neutrons were observed and although volume compression of 50-100 is claimed the experimental data was sparse and far from convincing.

We were shown details of the work on glass microballoons; these are bought from 3Ms and then put through a selection process in which suitable specimens are selected (1 in 10⁴).

Three new buildings are under construction to house the chemical laser work, a large gas laser (nominally CO₂) and offices plus support labs for 135 people, of 12,000, 15,000 and 7,500 square feet respectively.

A short discussion was held with Dr. Morse and members of his group. Tentative arrangements were made for listings of two LASL codes to be sent to AERE namely:

1. PANSY: a code for analysing asymmetries of irradiation using Morse's perturbation technique.
2. IRIS: a 2-D PIC code for investigating asymmetries developing during laser implosions.

Dr. Keith Boyer also promised to send Progress Reports.

2. CARBON DIOXIDE LASERS

There are 60 people in the CO₂ group at LASL. The nominal 1kJ system has given 250J out with 150J on target. A 10kJ system is planned and development work has commenced. The main technological problem arising in building such a high power system lies in the high voltage engineering.

Charlie Fenstermacher, the CO₂ Group Leader, estimated that a group of 3 professionals and 2 technicians could build a 100J 1nsec CO₂ laser from commercially available parts for about \$10⁵. He also expressed the opinion that the prospects for getting sub-nanosecond pulses for CO₂ at high energies were grim, despite the fact that low power pulses of 70 picosec duration had been obtained in Canada by working at 14 atmos pressure. At LASL 3-5 transitions are used simultaneously to increase efficiency in short pulses.

Although the CO₂ work is being pursued energetically there seems little conviction that it will be suitable for laser fusion.

3. Nd LASERS

Los Alamos has two principal Nd glass lasers -

1. 50J, 50psec single beam; used for implosion experiments
2. 1kJ, 600psec, four beam; nearing completion

The first system uses rods up to the 10J level (final rod 51mm diameter) followed by a single disc amplifier containing 12 75mm diameter discs. Gene McCall is the principal user of this laboratory-type system and admits that the beam quality is not good. With f2.5 lenses the beam spot size is

120 μ . Using the rods only a 50 μ spot size with 10J can be achieved. The disc amplifier is of low efficiency and beam quality is adversely affected by the thickness of glass required to achieve the desired gain.

McCall does not believe a satisfactory solution will be found to the dust problem with disc amplifiers and is making studies of a 500J system using rods only. This system is basically a 20-24 beam system but, knowing the alignment problem the Russian 9 & 20 beam systems have, McCall is designing annular modules which contain all 20-24 rods which are rigidly and reproducibly aligned. The 1KJ four beam system uses a YAG oscillator and 3 YAG preamps of 10mm diameter followed by glass rods up to the 15J point (51mm diameter) where a vacuum spatial filter removes the potentially damaging fringe structure. The beam at this point is split four ways, spatially and temporally, and each beam then passes through two 51mm disc amplifiers (12 discs/amplifier and helical flash tubes) and a 86mm disc amplifier (8 discs) followed by a Faraday isolator and a second 86mm disc module. The design specification is 250J in 600psec for each beam. The target hall is new and is being commissioned. Two beam irradiation experiments are expected soon.

4. PELLET PREPARATION

LASL are using gas-filled glass microballoons; the microballoons are brought from 3Ms and after a selection process, which rejects all but about 1 in 10⁴, they are filled with gas at pressures up to 100 atmos by diffusion at high pressure and temperature.

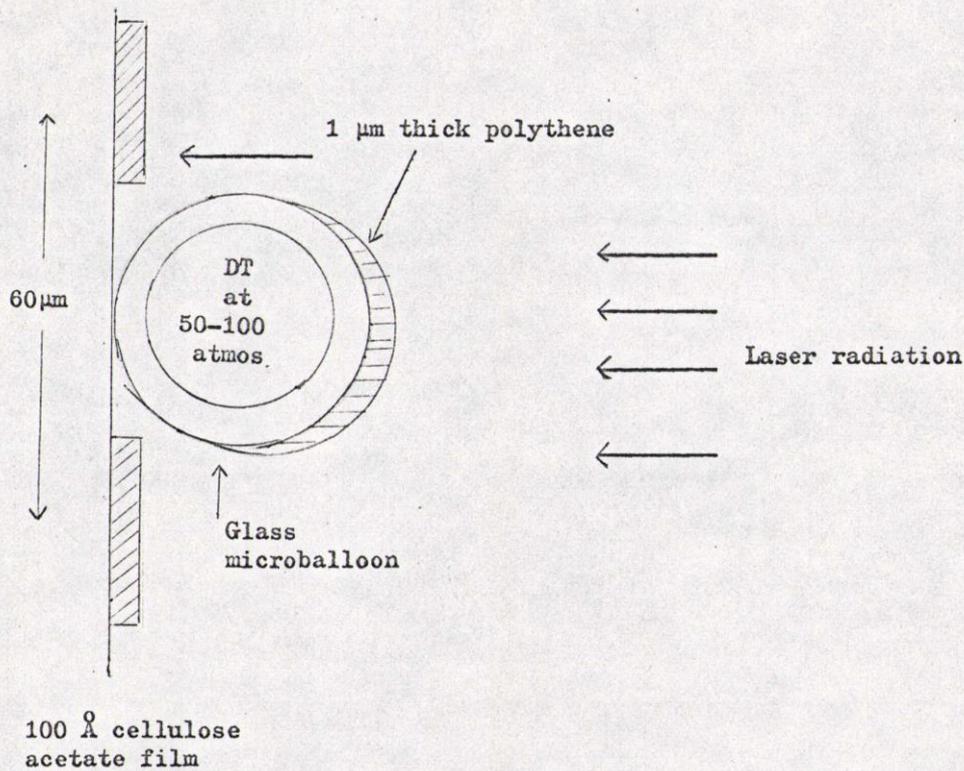
The selection process is as follows:-

1. The microballoons are screened for size by sifting them through meshes with circular holes. Rather than letting the microballoons fall through the sieves, which gives rise to electrostatic problems, they are mixed with alcohol and float upwards through the sieves.
2. After sizing the microballoons are divided into class by mass, by placing pellets of the same size in SF₆ which is then pressurized so that they rise once the buoyancy force overcomes gravity.
3. Next, microballoons of the same size and mass are subjected to high pressure so that all break except the perfect ones.

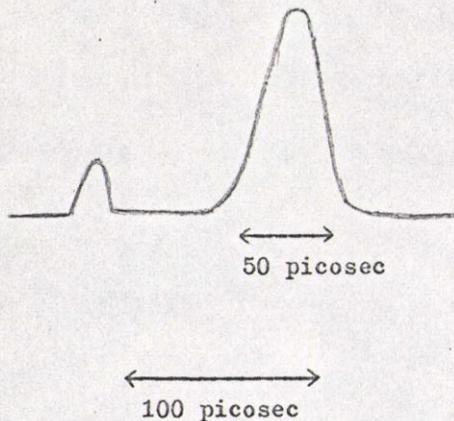
4. At this stage the few remaining microballoons are examined with a optical microscope and imperfect samples are rejected.
5. The microballoons are then filled with high pressure gas which results in more breakages.

5. COMPRESSION EXPERIMENTS

One beam compression experiments were carried out at LASL about a year ago using a few tens of joules from a neodymium laser. The target consisted of a gas-filled glass microballoon attached to a cellulose acetate film and asymetrically coated with polythene which, when plasmaized, formed the corona.



The laser light was in a double pulse as shown; the first pulse formed a corona from the polythene and the second pulse compressed and heated the microballoon.



It was claimed by Morse that, although no neutrons were produced, x-ray pin hole camera pictures showed essentially the same phenomena as seen by K.M.S.F. However when we spoke to the experimentalist who took the x-ray pictures and examined the data we decided that little could be deduced and that the LASL results were much less convincing than the K.M.S.F. data.

6. BUILDING SPECIFICATIONS

The 50J, 50psec system is housed in a conventional laboratory with no particular regard to temperature or dust control.

The 1KJ system is mounted on steel "I" beams with capacitors mounted over the equipment and above a mesh ceiling. The area is carpeted.

For any further systems a filtered and water-scrubbed air supply will be used. On temperature control the Los Alamos philosophy would be to control the temperature of components directly rather than to control the room as a whole.

They had no particular views on vibration problems.

APPENDIX 5

Notes on the Visit to Battelle Memorial Institute Columbus 27th Sept. 1974

GENERAL

One day was spent at B.M.I. General discussion took place with -

Mr. Fred J. Milford	Manager of the Physics & Electronics Dept. and Dept. of Nuclear Technology
Dr. M.R. Vanderlind	Manager of the Plasma Physics and Electromagnetics Section.

Further technical discussions took place with -

Dr. David A. Dingee	Programme Manager of Laser Application
Dr. Peter J. Mallozzi	Head of Laser Fusion Section
Dr. Harold M. Epstein	Chief Experimentalist

B.M.I. has about 20 staff on lasers and 12 full-time technicians; their capital investment is 2-3 M\$ and running expenses are about 1M\$ per annum. The laser work is jointly supported in-house funding and by Government Contracts. An AEC 'no-cost contract' is being negotiated to allow them to work on classified aspects of Laser Fusion. As well as an interest in Laser Fusion B.M.I. are interested in Medical and Military uses of X-rays generated by laser irradiation of targets; they are actively interested in x-ray laser schemes. B.M.I. have a contract with Livermore to work on targets - presumably glass microballoons.

LASER SYSTEM

The B.M.I. laser system uses rods entirely and is based on CILAS equipment with 64mm rods in the final amplifiers. They claim 1400J on target in 3.5 nanosec (from six beams) and make use of a double pass system whereby two pulses of different polarisation and separated by 10 nanosec, pass through a single amplifier. Six amplifiers are used in parallel in the final stage and the twelve beams are then combined spatially and temporary onto the target. The final area of the glass rods is 180 cm^2 running at a power density of $2\text{GW}/\text{cm}^2$ and is expected to provide 72 joules in 100 picoseconds. The beam quality may not be high.

BMI had just taken delivery of a CILAS 10-300 psec oscillator and preamplifiers.

Rather than use Faraday Rotators for isolation an exploding mirror technique is used. In this technique the reflecting surface of a mirror is deliberately destroyed just after the final pulse has been reflected; destruction occurs

because part of the main pulse is delayed and directed onto the back face of the reflector which is made absorbing. Another destruction technique based on aluminized mylar is used to prevent super-radiance.

Soft x-ray yields from heavy (Cu) targets have been in excess of 200J for 1.4kJ of laser input.

The laser system was in the basement and conditions were generally clean and temperature was $\pm 5^{\circ}\text{F}$. Little difficulty was experienced in terms of alignment, long term stability and dust. A Hewlett Packard 2116B computer was used for the control of laser diagnostics; the existing 4kword store was to be increased to 32 kword. The laser beam could be diverted, before the final amplifiers, into a user area for single beam experiments on the production of x-rays; Mallozzi said that this dual function facility worked very well.

MEDICAL USE OF X-RAYS

Soft X-rays of a few keV were generated by irradiation of a heavy target in the single beam user area where up to 20J of laser energy can be focussed into a 100μ spot. The target was held at the end of a long cone which had a thin Be window at its apex; this configuration potentially allows the source to be placed very close to a patient or even inside him! Flash x-ray pictures of live insects were shown as an illustration of the ability to freeze motion.

APPENDIX 6

Notes on the Visit to KMSF on 30th September 1974

1. INTRODUCTION

The visit to KMSF occupied one day. After an introductory discussion with Prof. Siegel, Roy Johnson presented a paper on the experimental results. (This paper had recently been given at a classified meeting at Sandia and we were promised copies as soon as it was de-classified). In the afternoon we saw the equipment and watched as several neutron-producing shots were made. Further discussions took place over dinner in the evening.

The recent classification changes meant that KMSF could describe their targets and talk more freely about results. They are offering to sell targets consisting of glass micro balloons (diameter $\sim 50-200 \mu\text{m}$) filled with a choice of gases at pressures up to 200 atmos. The targets are offered at \$1 - 3 each with an 'entry fee' of 250 K\$ which entitles purchase for 3 years plus 10^4 free pellets.

Keith Brueckner has now left KMSF to return to his post at La Jolla although he is retaining a consultancy with KMSF. Prof. R. Hofstadter now runs the experimental programme. We were exceedingly impressed by the KMSF operation; not least because for the first time we saw experiments in progress together with experimental data.

KMSF now hope to up-grade their laser to about 2KJ in 500 picosec. and a 'bidders meeting' was held the day after we left at which the technical specification of their new laser was discussed with potential suppliers.

Further details of the KMSF is described in the following sections.

2. LASER SYSTEM

Fig. 1 shows the layout of the KMSF laser system; it is based in a highly modified CILAS laser system driving GE disc amplifiers. The shape of the laser pulse can be varied using a pulse stacker, developed at KMSF, which can add a large number of 30 picosec pulse to form a variety of different pulse shapes. The system can deliver pulses from 20J in 30 picosec to 200J in 500 picosec i.e. 0.5 terra watt; longer pulses are not of interest to compression experiments. Soft apertures and 'spacial filtering' are both used to improve beam quality which is not first class. Birefringence effects were introduced by the large rod amplifiers. They have plans to double-pass through some of the disc amplifiers to increase power. The

general conditions of air and temperature control were not ideal. Temperature fluctuations of $\pm 5^{\circ}\text{F}$ were common and although the air was filtered dust was visible on equipment.

3. TARGETS

The spherical targets used by KMSF are glass microballoons 50 - 400 μm in diameter with $\sim 2\text{-}20\mu\text{m}$ wall thickness. These balloons are filled with gas mixture at pressures up to 200 atmos. A catalogue describing the targets availability was given to us. A wide range, including metal coated glass microballoons, can be supplied either mounted or unmounted. KMSF make their own microballoons and then select the 1% suitable for filling whereas Los Alamos, for instance, buy microballoons from M.M.M and then select the 0.01% which are suitable for filling. Note: KMSF have 20 staff working on target fabrication and transfer; this group is the largest in their operation.

KMSF are offering to sell targets at a few dollars each to anyone who pays 250 K\$ entry fee which entitles the buyer to 10^4 targets and the right to purchase extra pellets for 3 years. They are also offering a standard laser fusion laboratory package comprising a GE laser system plus a KMSF target chamber, optics and pellets. The price was not stated and GE insisted that the laser fusion laboratory package was Prof Siegel's idea and that no agreement had yet been reached between themselves and KMSI (Optical Division) on such a package.

4. EXPERIMENTAL RESULTS

Neutron yields of $10^5 - 10^6$ neutrons are regularly derived by irradiating DT-filled glass microballoons with about $\lesssim 100\text{J}$ in ~ 300 picosec. Spectroscopic measurements (H/He type line ratio) show the shell heats to ~ 800 eV. The most direct measurement of compression comes from a time integrated X-ray pinhole camera (10 μm pinhole and a K-edge filter at 1.7 keV). The time-integrated picture, which has resolution compatible with a 10 μm pinhole camera, is compared with the picture predicted by their computer code. The experimental pictures show **systematic** compression and the features predicted by computer code. Volume compressions of about X100 for the gas fill are seen but the code predicts a compression wave in the gas which gives a further compression of about X10. The general behaviour in terms of neutron yield, time history and radiation emitted is not wildly inconsistent with the code

predictions. The biggest discrepancy is the production of high energy ions in the ablated plasma; about 10% of the ablated ions have an energy in the 100keV range thus reducing the ablation efficiency and signalling a non-classical absorption mechanism.

A paper describing recent experiments has been promised.

Brueckner gave a series of talks at the Erice Summer School in September in which he described the recent KMSF results.]

5. FUTURE PLANS

KMSF now intend acquiring a 2KJ 500 picosec laser which they hope will put them near to break-even conditions; they would like this installed in 6 months but cannot realistically expect it in under 12 months.

The general rumour in the laser fusion fraternity is that KMSF are out of money but Kip Siegel was still expressing optimism and claimed that KMSI was sound and that KMSF should stop losing money next year; he said that only one or two more divisions would need to be sold and talked of a large contract with Texas Gas.

6. NEUTRON THERAPY

Dr. Henry Gomberg joined us for a discussion on the medical applications of 14 MeV fusion neutrons.

Interest has been expressed by two organisations, The Sloane Kettering Hospital and one other, in the use of laser fusion neutrons for cancer therapy. In addition to the usual reasons put forward for the use of neutrons in therapy Gomberg added two further reasons, applicable to laser fusion neutrons.

- 1) the small source size which could result in cleaner neutron beam collimation
- 2) the short duration of the neutron beam

In case 1) a source size of 100 μ , say, is much smaller than that produced in conventional neutron-producing accelerators, but the straight geometric advantage will be offset by the scattering and thermalisation of the neutrons in tissue.

In case 2) a first order advantage is undeniable; any reduction of the total time a patient is physically restrained (typically 5 - 30 minutes) during therapy is highly desirable. The second advantage claimed concerns the oxygen enhancement process which unfortunately causes oxygenated (non-cancerous) cells to be more sensitive to radiation than anoxic (cancerous) cells. A possible alleviation of this situation might arise if the neutron dose could be given effectively instantaneously so that the non-cancerous tissue would not have its oxygen content replaced during the dosage and therefore its sensitivity might be closely similar to that of cancerous cells. No experimental work has been performed with neutrons to justify this suggestion; work in the UK using X-rays failed to find any significant effect.

Prof. Siegel had received information through Burmah Oil that Harwell "thought that the future lay with proton beam therapy". The actual Harwell proposals and programs were outlined to Prof. Siegel who said that he would ask the Burmah Oil representation to contact Whitehead so that he, the Burmah Oil representative, could be appraised of the actual situation.

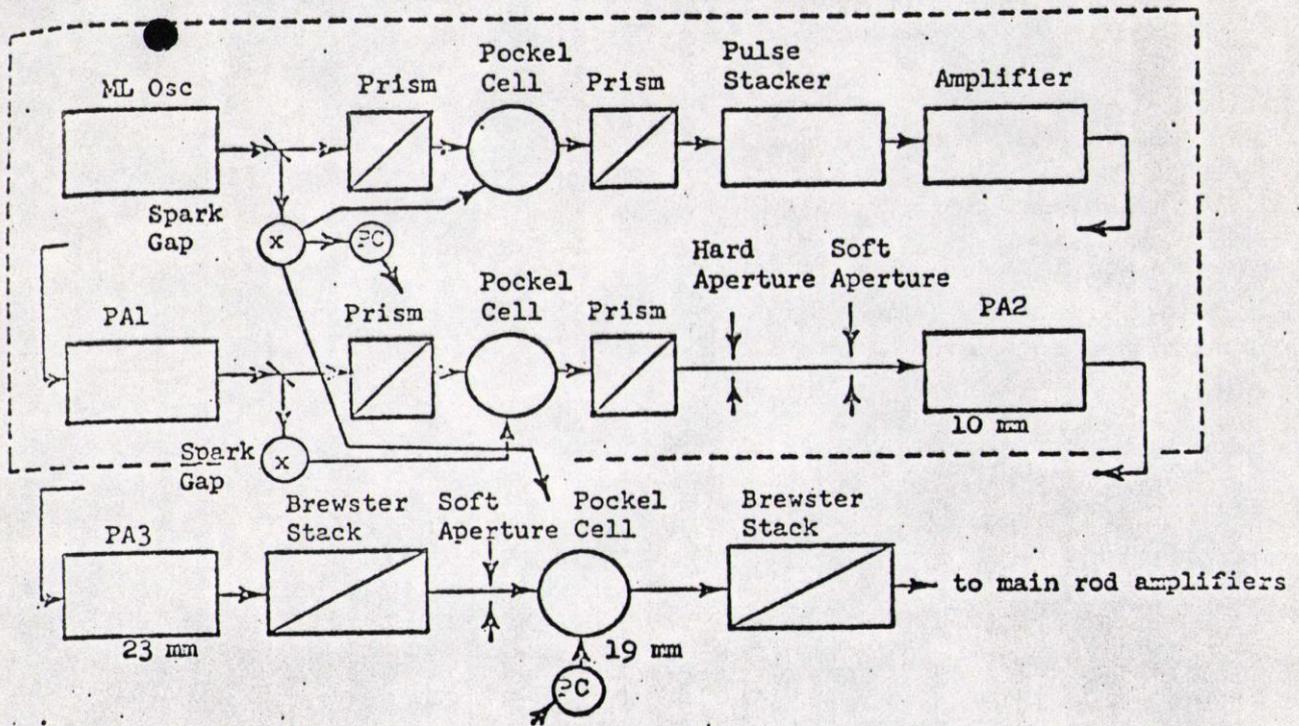


Figure 3. Preamplifier system

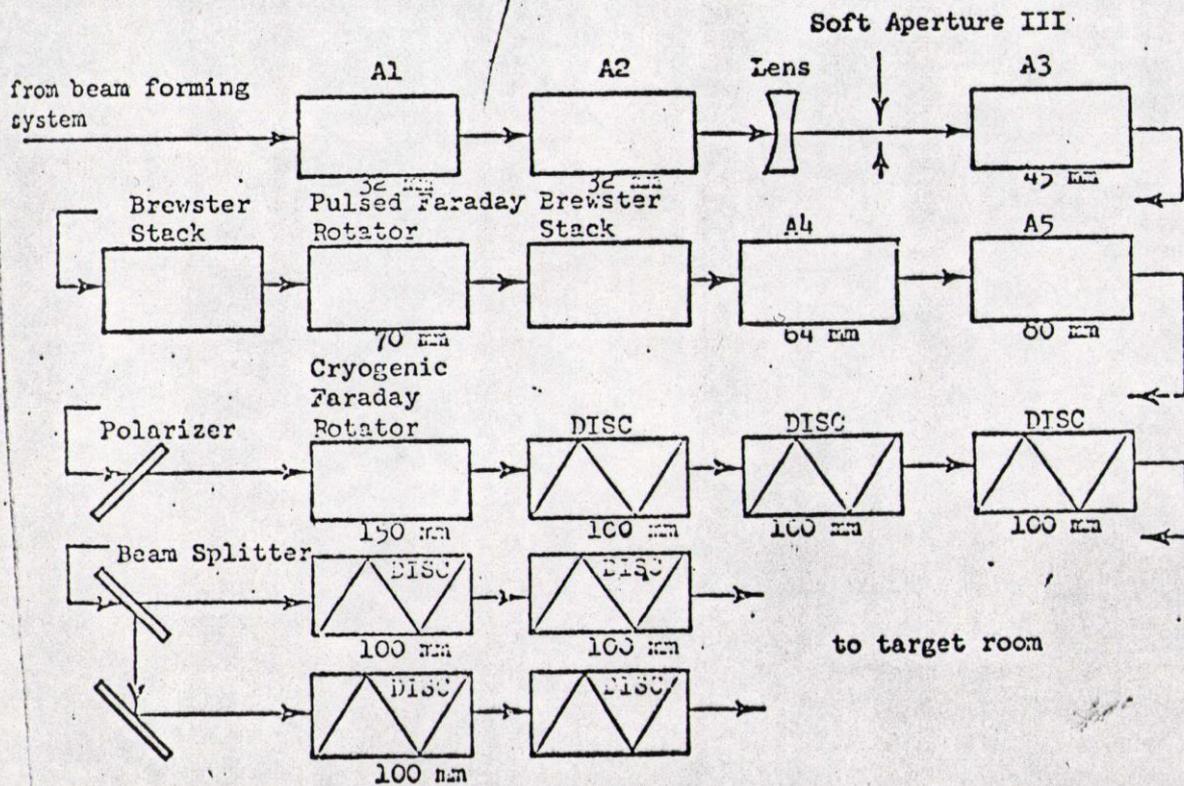


Fig 1.

Main laser amplifier

6.7 x 10"

APPENDIX 7

Notes on the Visit to Rochester University 3rd and 4th October 1974

1. General

One and a half days were spent visiting the Laser Energetics Laboratory at Rochester University. The Rochester Laser had been described by Dr. Gilbert at AEC headquarters as 'the best high power neodymium laser system in the U.S.' General discussions were held with Prof. Moshe Lubin and Dr. Len Goldman. Technical discussions took place with Dr. Jim Soures.

The laser programme has four parts and employs some 40 people including students namely:-

1. Laser Fusion - the largest part of the programme.
2. X-ray emission from - aimed at x-ray lasers
3. Fundamental physics - 'fun physics'

The Laser Energetics Laboratory is jointly funded by Rochester University, Exxon and G.E. The work is watched by the A.E.C. and the Laboratory is visited by the de-classification committee every six months. Moshe Lubin said that they hoped to get AEC money in the future and that a small part of their future programme might be classified. It is interesting to note that access to the laser facility was controlled by means of magnetic card operated locks - nominally in the interest of protecting the facility from un-authorized entry and to help maintain standards of cleanliness.

The present 4-beam system can deliver 400J of useful energy ($< 300\mu\text{rad}$) on target with a pulse length of 100 picosec. The maximum energy is 1600J in 0.7 nsec. Compression experiments were in progress during the visit. Plans are being formulated for a 5-10kJ system, which will entail a new building, and based possibly on the active-mirror type laser proposed by Brett of Quantel.

2. The Laser Assembly

The Laser system is of mixed parentage, GE, Raytheon, Space Rays (now defunct) and the University manufactured parts of the system and was responsible for **commissioning** the whole system up to 64mm rods followed by 90mm rods in laser heads of in-house design manufactured by Raytheon. Part of the control **circuitry was designed and manufactured by GE.** The system uses 4-beams symmetrically placed in the horizontal plane (described in Applied Optics, Sept. 1974). **Cryogenic** Faraday isolators are used and a HP2100 computer monitors the laser performance.

Rochester are not in favour of disc amplifiers in spite of their close association with GE; they have plans to use 110mm rod amplifiers if necessary. Use was being made of spatial filtering and soft apertures to improve beam quality.

Target adjustment was by remote manual control; they argued that feedback control of target position was desirable as it was difficult to maintain accurate focussing.

The experimental conditions were generally cramped and dust control was not first class although shoe covers were used by all visitors and access was controlled. Notwithstanding a daily schedule for cleaning, exposed optical surfaces dust specks were clearly visible. The nominal firing rate was one shot in 20min but 10 shots in one night shift was considered a good performance.

Desirable environmental control was stated to be $\pm \frac{1}{2}$ deg F and $\pm 3\%$ humidity. In practice $\pm 1\frac{1}{2}$ deg F had been achieved and appeared to be satisfactory.

APPENDIX 8

Notes on the Meeting with General Electric 3rd October, 1974

1. Introduction

An afternoon was spent at Rochester in discussions with representatives from G.E. This meeting was the result of preliminary discussions at Harwell with Mr. J. McJilton (G.E.) on 23rd July as a result of which GE were sent a list of questions (attached) aimed at clarifying their ability to supply a completed high power laser system or components thereof.

The GE representatives were:-

Mr. John Cunninghame	Marketing, Laser Fusion Area
Mr. P.A. Willis	Project Manager - Lasers
Mr. T. McJilton	Technical Manager
Mr. B. Bakeman	Senior Engineer
Mr. C. Tanlative	Laser Engineer

The GE capability in the area of high power laser systems is based on the following experience and background:-

1. GE 10cm and 14cm disc amplifiers are being evaluated and used by KMSF which has resulted in valuable operating experience.
2. GE have partly supported the Laser Fusion operation at Rochester University which entitles them to all the know-how generated. Len Goldman, who is a GE employee, occupies a senior position in the Rochester programme.
3. GE manufacture laser ranging systems for the military.

GE have offered to bid on a 500J 300 picosec system and have promised a quotation with details by 21 October 1974. Details of their proposed system are given in the next section.

2. The Proposed GE 1.5 Terrawatt System

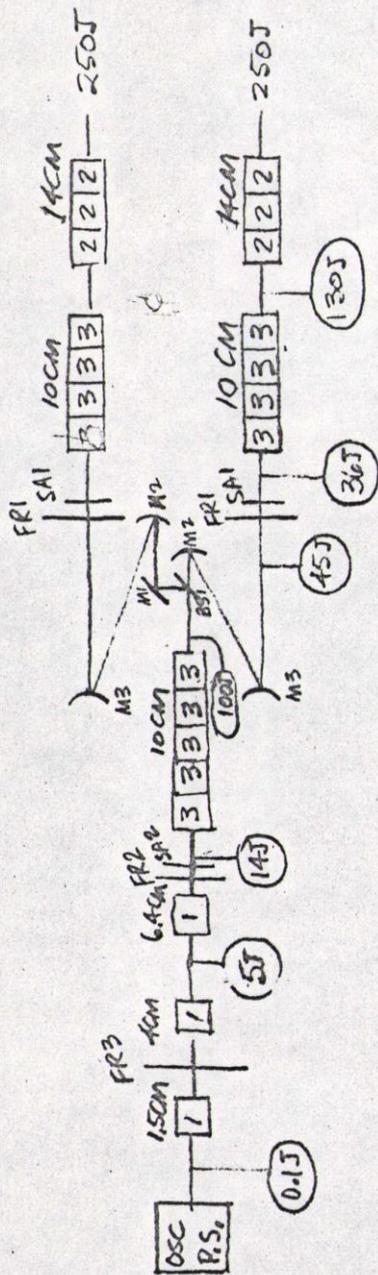
Figure 1 shows a schematic of the proposed GE system to give 500J in 300 picosec via two arms. Figure 2 gives details of the rod part of this system. The oscillator would be a copy of the KMSF oscillator including pulse stacker. Figure 3 shows a schematic of the GE proposal for supplying 2KJ in 500 picosec as required by KMSF; this schematic is included for general interest.

The following notes cover the discussions which took place:-

1. The estimate will be for a turn-key system.
2. Delivery would be about 12 months; to be confirmed later.
3. The system will be fully instrumented but would not include interfaces for a computer monitoring system.
4. The Faraday rotators will be cryogenic.

500 JOULES
300 PICOSECONDS

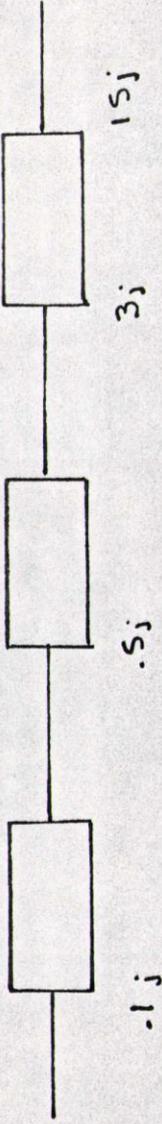
GE Co
10/2/74
ORB



13	10CM	MODULES	LAMPS	104
6	14CM	MODULES		72
<hr/>				<hr/>
19 MODULES			176 LAMPS	

FIG 1

Tanlative Rod Amplifier Scheme



Rod Size	1.6 x 45	4 x 45	6.4 x 45
Doping	3%	2%	1%
Energy Storage	26j	185j	435j
1% Eff	2600j	18500j	43500j
# of lamps FX47 type (11mm)	2	5	12
Pump/Exp	10%	30%	29%

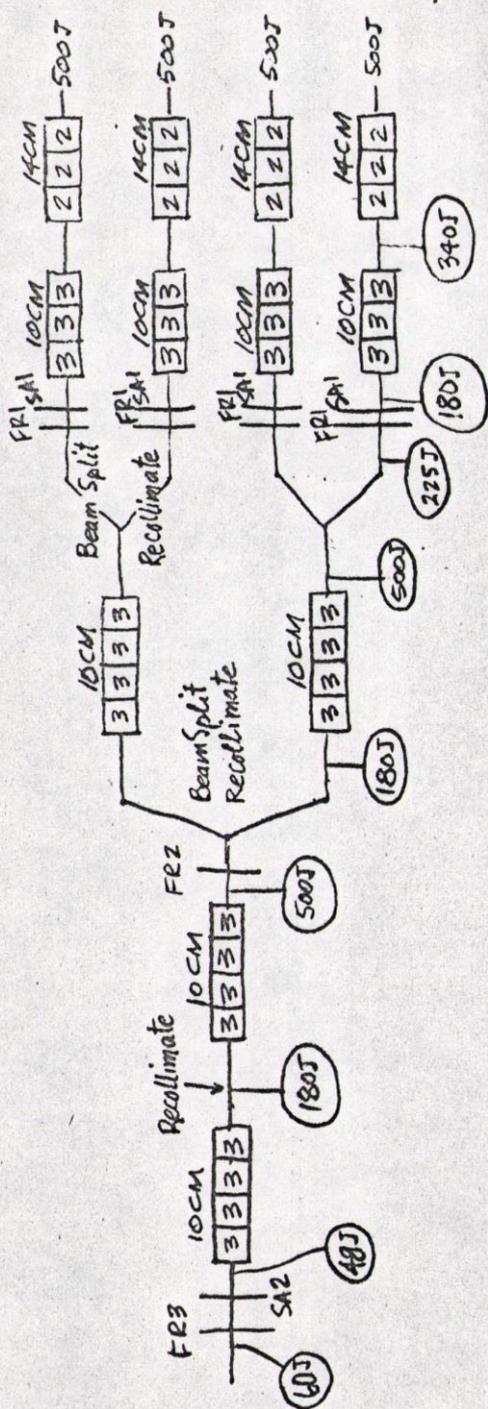
FIG 2.

Linear Flash lamps

MKC

2000 VOLTS
500 PICOSECONDS

GE CO
10/2/74
DEB



32	10CM	MODULES	LAMPS	256
12	14CM	MODULES		144
<hr/>		44 MODULES		400 LAMPS

FIG 3.

APPENDIX 9

Notes on the Meeting with a Raytheon Representative 4th October, 1974

One morning was spent in discussion with Mr. Terry Harris of Raytheon. The meeting was generally unsatisfactory.

Raytheon have supplied Rochester with a few 90mm rod amplifiers - with which Rochester are satisfied. The safety and some engineering aspects of these amplifiers leave a great deal to be desired. Raytheon also supplied the oscillator for KMSF.

Harris expressed interest in supplying computerised control logic for a laser system and associated diagnostics. Close questioning failed to elicit any particularly relevant experience or expertise that Raytheon might have in this field and Harris's understanding of the requirements was limited.

We concluded that Raytheon had nothing to offer.

APPENDIX 10

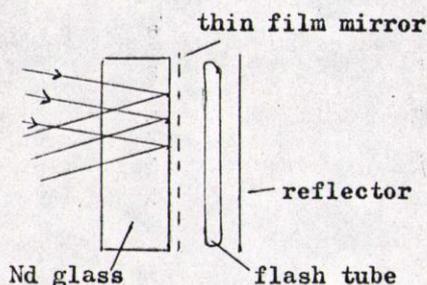
Notes on the Visit to Quantel, Paris - 9th October 1974

Discussions were held with Ms Brett, Aubert and Brasset

Quantel is a young company headed by Dr. George Brett. At present it employs 32 people and its turnover for this year is expected to be \$1.2M and \$2M next year.

They had prepared themselves for our visit and were able to describe the 10J 100ps Nd glass system for which we had made enquiries. It would appear that the technology for such a system lies within their experience. An off-the-cuff estimate of £150K and seven months delivery was given for this system which consisted of oscillator (etalon controlled), YAG preamp, 16mm Nd glass rod, Pockel cell, 25mm Nd glass rod, Faraday Rotator (pulsed, using Hoya FR4 glass), 32mm, 45mm and 64mm Nd glass rods. The integral self focussing stress was 4 for 10J in 100 psec. A second Faraday Rotator would have to be added at the end of the system for target work.

Quantel have no disc experience and are developing the active or reflecting disc amplifier system. Fig. 1 shows the principle of this system. The thin film mirror is chosen such that it is transparent to the pump light from the close coupled flash tube but is reflective to the 1.06 μ laser light thus allowing a double pass through the disc. The advantage claimed for this device is a much



higher efficiency (an order of magnitude increase in pump efficiency). So far Quantel have made a 6cm diameter disc and have achieved stored energies of 0.7 joules/cm². Problems so far are the acoustic shock from the flash lamps (a vacuum mounting may be used), the glass temperature rises by 0.2°C due to improved pump efficiency and this disturbs the pumped levels and a second consequence of this temperature rise is thermal birefringence giving divergence of 80 mr/plate.

Work on the active discs is being carried out by a new company, "Energetic" (President George Brett), which is independent of Quantel.

APPENDIX 11

Notes on the Visit to CILAS/CGE Paris - 10th October 1974

Discussions were held with Ms Roux, Guyot, Sturel and Banjoin and with M. Riffard (Director of CILAS) at lunch. We had had discussions with Mr. Roux and Sturel at Harwell in May and since those discussions the specifications we wished to place on a Nd glass system had changed and become more difficult.

CILAS have supplied lasers to Limeil (CEA) since 1962 and have supplied the majority of the world laboratories with rod systems. However they appear to have allowed their one-time leadership to slip and are still in the development stage for discs larger than 64mm.

We were shown their prototype disc system (> 10cm diameter). They are adopting a modular system of helical skewed flash tube units which fit between glass disc units. They are expecting to get 0.7% pump efficiency and $0.5\text{J}/\text{cm}^2$ storage using Hoya glass. Advantages claimed for this system are that the edge of discs (coated with an antiparasitic index matched layer) are not exposed to the pump light, the slabs are rectangular and therefore cheaper, the Hoya glass they are using does not contain CeO and thus, by omitting the UV filters, even greater pump efficiency may be achieved.

Although these possibilities are interesting one suspects that considerable development and proving lies ahead.

They quoted an off-the-cuff price of £240-270K for a 10J 100psec system and promised an estimate for a two-beam system for 500J in 300psec.