Paper A.5.1 To be presented to the planary meeting of the
EEC Hot Laboratories and Remote Handling Group
at Brasimone, 21 - 22 May 1986

DOUNREAY EXPERIENCE IN THE USE OF LASER CUTTING FOR THE DISMANTLING OF IRRADIATED FAST REACTOR CORE COMPONENTS

by

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SUMMARY

Laser cutting was selected as the most suitable technique for dismantling of irradiated Prototype Fast Reactor (PFR) fuel sub-assemblies in June 1980. Since that time the technique has been in routine use in both the PFR irradiated fuel cave (IFC) and in the PFR fuel reprocessing plant at DNPDE. The technique has proved to be reliable, clean and versatile and has now been extended to cover the dismantling of a wider range of irradiated core components for examination and disposal by the introduction of higher power lasers.

1. INTRODUCTION

The Irradiated Fuel Cave (IFC) at the Prototype Fast Reactor (PFR) is situated adjacent to the reactor itself and provides primary decay heat storage for 80 sub-assemblies. Facilities are also available for the early examination of irradiated fuel sub-assemblies and core components whilst still immersed and subsequently when removed from sodium together with equipment for dismantling to remove and examine fuel pins. The IFC is also part of the new fuel and core component route to the reactor and thus provides a full pre-irradiation, intermediate and post-irradiation examination capability.

To reduce the amount of non-fissile material being sent to the fuel reprocessing plant that the top and bottom sections of the fuel sub-assemblies are removed in the IFC. Because of the interchange between cave and reactor sodium coolant during fuel transfers, only swarfless cutting techniques can be used. In initial trials pressure wheel cutters were shown to be capable of cutting unirradiated wrapper material but were rejected because of the distortion that they caused. This distortion made fuel pins difficult to remove for reprocessing and invalidated any post-irradiation examination (PIE) results.

Trials carried out at the United Kingdom Atomic Energy Authority Culham Laboratories in 1972 showed that a 650 watt focussed laser beam could produce a virtually swarf free cut in 3 mm thick wrapper material. As a result remote handling equipment was developed (1) which led to the first dismantling of a full size dummy sub-assembly in the IFC in April 1977, using two commercially available 400 watt CO_2 lasers in tandem.

This distortion free laser cutting technique was also attractive to the operators of the new PFR fuel reprocessing plant at Dounreay and a single 400 watt CO_2 laser, using oxygen as a cutting gas, was installed prior to the start of operations in 1980. This unit is still in operation and has been used to dismantle all of the 93 fuel sub-assemblies that have passed through the reprocessing plant.

After four years of reliable operation the two 400 watt lasers were replaced by a single 1000 watt laser in October 1984 at the IFC. The extra power provided by this unit made it possible to use laser cutting for the dismantling of a wide range of core components, cuts being made with inert gas in material sections up to 8 mm thick.

The simplicity, reliability and clean operation of the laser cutting equipment at the IFC has also led to the installation of similar equipment, based on the 1000 watt laser unit, at two other PIE facilities at Dounreay where components are dismantled for examination. One facility, the DMTR Cave, is dedicated to the dismantling of non-fissile components such as guide tubes, control rods and demountable sub-assemblies (DMSA). These items, some made from high nickel alloys, are difficult to dismantle by mechanical means due to irradiation hardening but create no problems for laser cutting.

The development of fuel to operate to high burn-up in the range 15 - 20% in the PFR core, has led to a growing need to disassemble failed fuel sub-assemblies for examination as burn-up levels increase. As a result a 1000 watt laser unit has also been installed in the Plutonium Fuel Examination Facility (PFEF) at Dounreay and is currently undergoing commissioning trials.

2. THE PFR IRRADIATED FUEL CAVE (IFC)

The IFC contains sodium filled sub-assembly storage tanks at one end and PIE facilities at the other end. An inert nitrogen atmosphere is maintained within the cave and shielding is provided by 1830 mm thick concrete walls, clad internally with stainless steel sheeting, and with six lead glass and six zinc bromide filled veiwing windows on the operating face. Remote handling facilities are provided by two master-slave manipulators at each window whilst in-cave there are two hoists, 2000 kg and 500 kg capacity, and a power manipulator capable of 30 kg grip force, (Figure 1).

2.1 The Initial 2 x 400 Watt Tandem Laser System - Principles and Procedures

Laser cutting was first proposed as a cutting technique for the dismantling of irradiated sub-assemblies in the IFC in 1971. The advantages of the laser when compared with more conventional cutting techniques were the minimal requirement for complex machinery in the hot cave environment, the fact that no mechanical force was applied to components during cutting and that the effectiveness of the technique was unaffected by changes in mechanical properties such as irradiation hardening. Further important factors in the choice of a cutting technique were the requirement that swarf production must be minimal because the IFC would also be used to handle fuel before irradiation and that some exchange would take place, between the sodium coolant used in the cave and that used in the reactor primary circuit. High standards of cave cleanliness were therefore required.

Tests to demonstrate the practical feasibility of laser cutting as a technique for sub-assembly dismantling were carried out at Culham Laboratories between 1972 and 1974. These tests showed that the laser power required to cut a given thickness of sub-assembly wrapper reduced as the amount of oxygen present in the gas jet used to remove the material melted by the focussed laser beam was increased. The heat released by the exothermic oxidation of the wrapper material increased the power available at the cut so that a minimum of laser power was required when the cutting gas consisted of pure oxygen. The oxidation process, however, generated large amounts of non-adherent ceramic swarf and a considerable amount of material was dispersed in the form of an oxide smoke.

The tests showed that swarf production was at a minimum when a totally inert cutting gas was used and when the material being cut was also enclosed in a totally inert atmosphere. The absence of oxygen, however, meant that only the laser power was available to heat the wrapper material. The Culham trials established that with an inert cutting gas a minimum laser beam power of 650 watts was required at the beam focus for reliable cutting of the standard sub-assembly wrapper thickness of 3 mm.

The highest power laser available commercially in the United Kingdom at that time was a slow axial flow CO_2 laser rated at 400 watts but capable of delivering 450 watts reliably.[2] To achieve the required laser power for wrapper cutting, two of these lasers were purchased and an optical system developed to bring the two laser beams together at a common focal point. The two lasers were mounted kinematically face to face (figure 2) on stout brackets bolted to the IFC shield wall. The two laser beams were combined using a special 90° knife-edged mirror (Figure 3) and directed to the focussing lens/cutting gas nozzle mounted inside the IFC by means of gold coated Al-bronze mirrors (Figure 4). For safety the laser beam path was totally enclosed in aluminium flight tubes. A twin lens unit was mounted in the beam path at an accessible position outwith the IFC to provide control of laser beam divergence.

For cutting, the sub-assembly, or component concerned was mounted in a special adjustable container which could support it at the correct height relative to the laser cutting nozzle. The container was then rotated for circumferential cutting.

2.2 400 Watt Laser Reliability

Being slow axial gas flow lasers the two 400 watt units had long optical cavities (10 m) which had been folded many times to produce a compact unit. This design resulted in a complex optical cavity with many deflecting mirrors, a large number of water cooled discharge tubes and a myriad of joints in cooling water and vacuum systems. Despite this complexity, however, the lasers proved very reliable and operated without routine maintenance, attention only being given when operational problems such as power loss or water and gas leakages occurred. All such minor maintenance was carried out locally but for major repairs, ie. cavity re-alignment the lasers were returned to their manufacturer. This proved necessary only once during the life of each of the lasers.

With a combined laser power of 750 watts available at the cutting nozzle no difficulty was experienced in making top cuts on sub-assemblies and in making bottom cuts on inner zone sub-assemblies (Figure 5) where there was adequate internal space within the assembly. Difficulty, however, was experienced in removal of the bottom (spike) ends from a number of long cooled outer zone sub assemblies. In these the very tight internal clearances had failed to drain when removed from sodium due to the low decay heat and consequently low sodium temperature. In this condition the available laser power was not sufficient to successfully cut a sodium logged wrapper.

From June 1980 until September 1984 a total of 60 sub-asemblies, involving 120 individual cuts, were dismantled using the 2 x 400 watt laser cutting system.

2.3 1000 Watt Laser

In October 1984 the opportunity was taken to install a new 1000 watt, fast axial gas flow CO_2 laser which had recently become available commercially in the UK. Because it is a fast flow system the optical cavity of this laser is relatively short (3.5 m) in a single fold configuration (Figure 6). Although rated at 1000 watts this laser could reliably provide a peak beam ambient power of 1200 watts when required. An important feature of the laser is the ability to electrically control the output laser power from zero to maximum. The laser is housed within a single cabinet which also contains all the power supplies and gas circulating equipment. Because of the size and weight of the unit it was mounted on the roof of the IFC for accessiblity and stability (Figure 7). The emergent laser beam was then deflected by a single mirror down the vertical axis of the existing laser beam flight tube (Figure 8).

2.4 Operating Experience with 1000 Watt Laser

There were three immediate advantages when using this laser:

a) The ease of single beam targetting

b) Extra power was available for cutting material with high levels of sodium contamination. This was particularly important for long cooled outer zone sub-assemblies.

c) Cuts could not be made on stainless and alloy steels up to 8 mm thick when using nitrogen as the nozzle gas and operating in an inert nitrogen atmosphere. This increased power has allowed irradiated reactor components such as guide tubes, control rods, reflectors and flow meter location tubes to be cut up for either PIE, intermediate or long term storage.

All problems with the laser have been minor and have been dealt with locally in consultation with the manufacturer. The cavity mirrors originally supplied with the laser have been replaced with high reflectivity units thus increasing the maximum power output from 1200 watts to 1400 watts.

The change from twin laser beam to single beam operation required no modification to the in-cave laser cutting facility (Figure 9) and the cutting technique has remained essentially unchanged. The ability to alter the laser beam power to suit the cutting depth and conditions has been particularly useful. From October 1984 until the present a total of 51 reactor components, requiring 230 individual cuts, have been dismantled using the single 1000 watt laser system.

2.5 Optical Component Stability and Reliability

The optical systems of both the twin and single laser system proved to be remarkably stable. In the case of the former an occasional drift of the relative alignment of the beams caused by knife-edge mirror movement could easily be corrected by re-targetting the beam. Overheating of one of the deflecting mirrors in the single beam flight path of the 1000 watt laser was overcome by introducing gas cooling onto the offending components. Under normal circumstances the only checks necessary in routine operation have been simple in-cave alignment checks by exposure of a target at the cutting nozzle immediately before each cutting operation.

The life of the optical components has also proved to be very good with no evidence of any effect of the IFC environment, such as high ambient temperature and high gamma radiation levels, on any of the optical components. The focussing lens in the cutting nozzle has only been replaced when spatter from the cutting of sodium logged components has contaminated the lens surface. Lens changes have been necessary about once per year. The cutting nozzle assembly operated without obvious deterioration from the start of laser cutting in 1980 until October 1984 when the opportunity was taken to remove it for bearing replacement. Similarly the zinc selenide containment window in the beam path has only just been replaced (March 1986) for the first time due to an observed heat stain. Deflecting mirrors have also performed well and are a good indication of the very low levels of dust present in the IFC atmosphere. The copper tips of the cutting nozzle are replaced frequently as a result of mechanical damage or sodium contamination; the exchange is, however, a very simple in-cave operation. Some 30 - 40 tips have been used since the start of laser operations.

3. PFR REPROCESSING PLANT

In 1972/73 it was decided to refurbish the existing Dounreay Fast Reactor (DFR) reprocessing plant to enable it to handle PFR fuel. The original plant included two cave facilities and it was decided, as part of the plant reconstruction exercise, to demolish one of these and build a new cave on that site. This was done as part of a major decommissioning and reconstruction exercise (2,3). The major part of the plant chemical process solvent extraction system was completed in the summer of 1979. The new PFR fuel disassembly cave was structurally completed in 1978 and was progressively fitted out with its remote handling equipment until August 1980 when the cave underwent commissioning trials using an un-irradiated dummy sub-assembly. The cave was sealed on the 5th September 1980 and the first reprocessing campaign involving 14 irradiated and 2 un-irradiated sub-assemblies commenced shortly afterwards.

3.1 The Disassembly Cave

This cave is 11.5 m long, 4.2 m high and 2.4 m wide and is viewed through five zinc bromide fitted windows set in 1.4 m thick concrete walls (Figure 10). The three principal dismantling machines within the cave consist of:

a) A chuck for holding and rotating the transit canister and sub-assembly. This is an integral part of the entrance port.

b) A horizontal moving table for holding the sub-assembly.

c) A horizontal moving tool post to which a variety of jigs and pulling attachments can be fitted remotely.

3.2 400 Watt CO_2 Laser Cutting System

A laser cutting system was provided for the disassembly cave in order to reduce the amount of swarf generated and to avoid short mechanical tool life. This laser, identical to the 400 watt units used at the IFC, is mounted on the cave roof and the beam can be projected to either one of two cutting heads by means of deflecting mirrors mounted within protective beam flight tubes (Figure 11). The laser cutting beam is enhanced by oxygen to provide sufficient power to cut the canisters or sub-assembly wrapper. Such a cut produces slag and particles together with oxide smoke which is contained within the cave and is subsequently extracted by the ventilation system through high efficiency filters housed in a shielded container.

Although provision was made for two cutting stations operating experience has shown that the mid cave position is redundant. Beam alignment through the laser cutting head is carried out remotely by moving the head mounting brackets and adjusting screws. Alignment is also considerably assisted by a visible He/Ne laser beam, which is co-aligned with the invisible 10.6 um infra-red beam, and can be seen in cave.

3.3 Laser Cutting System Operating Experience and Reliability

From September 1980 until March 1982 sub-assemblies were received into the cave bottom end first with the first cut being made over the plenum to expose the bottom ends of the fuel pins for pin-pulling operations. This cut required a variable cutting speed control system so as to maintain a constant cutting speed on the hexagonal shaped wrapper to prevent pin damage during cutting. From March 1982 sub-assemblies were received top end first so that the wrapper was cut above the top of the fuel pins to remove the sub-assembly handling features thus removing the need for programmed cutting speed control.

During subsequent cutting operations the laser proved to be a more flexible facility than had originally been anticipated. Altogether 93 spent fuel canisters and sub-assemblies together with 46 wrapper samples 'coupons' have been laser cut.

Apart from the laser and the beam deflecting mirrors the principal components of the cutting system are the beam expander and laser cutting head, containing the lens package and nozzle assembly. The beam expander lenses themselves were replaced once in the original unit which was itself eventually replaced. During circumferential cutting operations on the hexagonal wrapper the laser cutting head moves vertically within a telescopic housing. This movement eventually became very stiff causing a jerky movement of cutting head within its housing. Eventually in January 1984 the cutting heat seized and a new unit was fitted remotely. Although the laser cutting head occasionally required new lens packages, nozzles and periodic re-alignment during a reprocessing run, the laser has proved to be a reliable and useful cutting facility. This system has successfully performed 651 circumferential and 46 wrapper sample cutting operations, as listed in Table 1.

3.4 Future Development

Commissioning work has started on a smaller lightweight in-cave laser cutting head with telescopic action which will make in-cave beam alignment easier and less time consuming. A proposal is also being considered to replace the existing 400 watt laser with the 1000 watt laser similar to that used at the PFR. It is hoped that this unit will give greater flexibility for laser cutting and simplify the out of cave beam alignment procedures.

4. RECENT LASER INSTALLATIONS

4.1 DMTR Cave

The Dounreay Materials Testing Reactor (DMTR) Cave was refurbished in 1972 to provide a facility which could handle large non-fissile components from the PFR, for post-irradiation examination after removal from sodium and steam cleaning in the IFC. The cave is 6.1 m long, 2.13 m wide and has a 2.5 m operating height. There are three zinc bromide filled windows set in 1524 mm thick concrete shield walls, (Fig 12).

Experience with conventional cutting techniques within this facility has shown the need to use specially hardened tools for successful cutting of the very hard irradiated materials. The result was that conventional mechanical cutting techniques were very slow and time consuming. The milling machine originally provided in the cell and which occupied a large amount of the valuable level bench space has now been removed and replaced by a compact laser cutting system based on the 1000 watt CO_2 laser. This became operational in late 1985 and is currently being used to cut an irradiated experimental vehicle. As in the PFR cave an inert cutting gas is used to reduce the production of active swarf and hence levels of contamination. The cell atmosphere is not inert and hence some oxidation of the material at the back of the cut does occur. This has the advantage that closely adjacent components need not be mechanically separated as they do not tend to weld together during laser cutting.

The cutting head provided in the DMTR cave is more versatile than that installed in the IFC in that it is provided with a built in linear transverse motion which can be operated in addition to the normal longitudinal and rotational cutting motions. With this facility quite complex cutting geometries can be achieved for production of test specimens or for cutting around features within the component.

This laser is also fitted with a pulse unit which allows the attainment of higher peak beam power than when operated in the continuous wave mode thus allowing thicker material to be cut.

4.2 Plutonium Fuels Examination Facility (PFEF)

These caves have been in continuous operation since 1963 carrying out PIE work on irradiated material from DFR, (Figure 13). Initial modifications to allow handling of the larger PFR fuel pins and experimental vehicles (clusters) were carried out in 1972. Fuel pins removed from sub-assemblies in the IFC have been transferred to the PFEF for examination since the start of IFC operation.

The experimental programme in the PFR is primarily concerned with exploring burn-up limits for various fuel sub-assembly designs; the burn-up limit being the point at which fuel failure occurs. The examination of failed fuel is an important aspect of the fuel development programme. Removal of badly failed fuel pins from sub-assemblies within the IFC although possible, is undesirable because of the potential for spread of alpha contamination within the facility, the main concern being the possible cross-contamination of non-fissile components and irradiated experiments that are handled within the IFC. Such contamination would be a severe embarassment if it led to the need to handle plutonium contaminated non-fissile specimens as facilities designed for the examination and testing of such specimens are nominally capable of handling only beta/gamma contamination.

Installation of a laser cutting facility in the machining cell of the PFEF was therefore proposed to allow badly failed sub-assemblies to be dismantled for examination outwith the IFC. The machining cell at the PFEF is 4.88 m long, 3.05 m wide and 3.81 m high. There are five zinc bromide filled viewing windows set into three of the 1.6 m thick concrete shield walls, (Fig 13). This cell was completely cleaned down for refurbishment after 22 years continuous service. The existing mechanical cutting machines were removed and the new in-cave cutting equipment is currently undergoing non-active commissioning trials. The 1000 watt laser is situated on the cave roof and the beam is directed verticaly downwards into the cave and then into the cutting head. The in-cave handling equipment and laser cutting head has the same versatility as that of the DMTR cave unit. The proposed route is that after removing the top and bottom sections of the sub-assembly at the IFC, as required for the re-processing route, the wrapper and fuel pin section will be transferred to the machining cell. The laser will be used to remove the wrapper and, if necessary, grids may be laser cut to release any badly failed fuel pins for examination. The continuously variable power output of the 1000 watt laser is a major asset where such widely different material thicknesses may have to be cut.

5. CONCLUSIONS

1) Laser cutting as used for the dismantling of reactor components at the Dounreay Nuclear Power Development Establishment (DNPDE) is a reliable, versatile and clean cutting procedure.

2) Altogether over 1000 laser cuts have been made on 111 different irradiated reactor components at DNPDE from June 1980 until March 1986.

3) The original 400 watt laser units proved to be reliable but the installation and use of 1000 watt lasers has increased the variety of components that can be dismantled due to the ability to cut a greater thickness of material.

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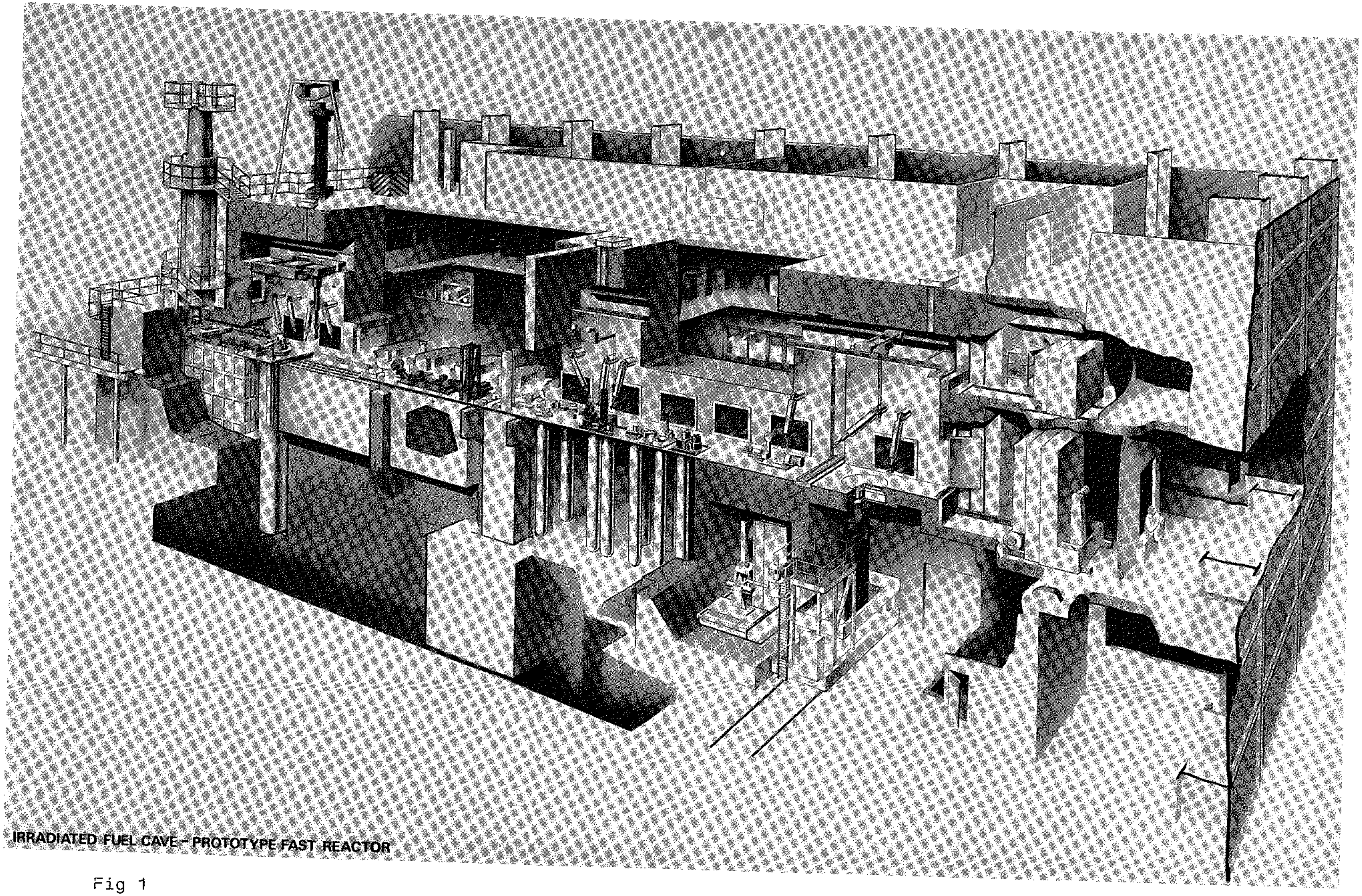
2) Decommissioning and reconstruction of the Fast Reactor Fuel Reprocessing Plant, Dounreay, by T R BARRETT and D THOM, IAEA Symposium 'Decommissioning of Nuclear Facilities', Fiennon, Nov 1978 paper no IAEA-SM-234/9

3) The Reconstruction of the Fast Reactor Processing Plant, Dounreay by T R BARRETT
International Solvent Extraction Conference, Dounreay, May 1979
Society of Chemical Industries.

TABLE 1

REPROCESSING PLANT LASER SUMMARY INFORMATION

REPROCESSING RUN	DATE	SUB ASSEMBLIES	LASER CUTS	LASER NOZZLES	EXPERIMENTAL LASER CUTS	REMARKS
PR3	Aug 1980 to Dec 1980	16	112	2		
PR4	Sep 1981 to Jan 1982	14	98	3		
Coupon Cutting Burnt Pin Experiment	Feb 1982 to Feb 1982				46 1	
PR5	Jun 1982 to Aug 1982	15	105	2		
PR6	Jan 1984 to May 1984	2 6 EQUIV	56	1		New Laser installed in cave in Jan.
PR7	Mar 1985 to Sep 1985	7	49	2		
PR7/8	Oct 1985 to Jan 1986	32 1 EQUIV	231	3		
		93	651			



IRRADIATED FUEL CAVE – PROTOTYPE FAST REACTOR

Fig 1

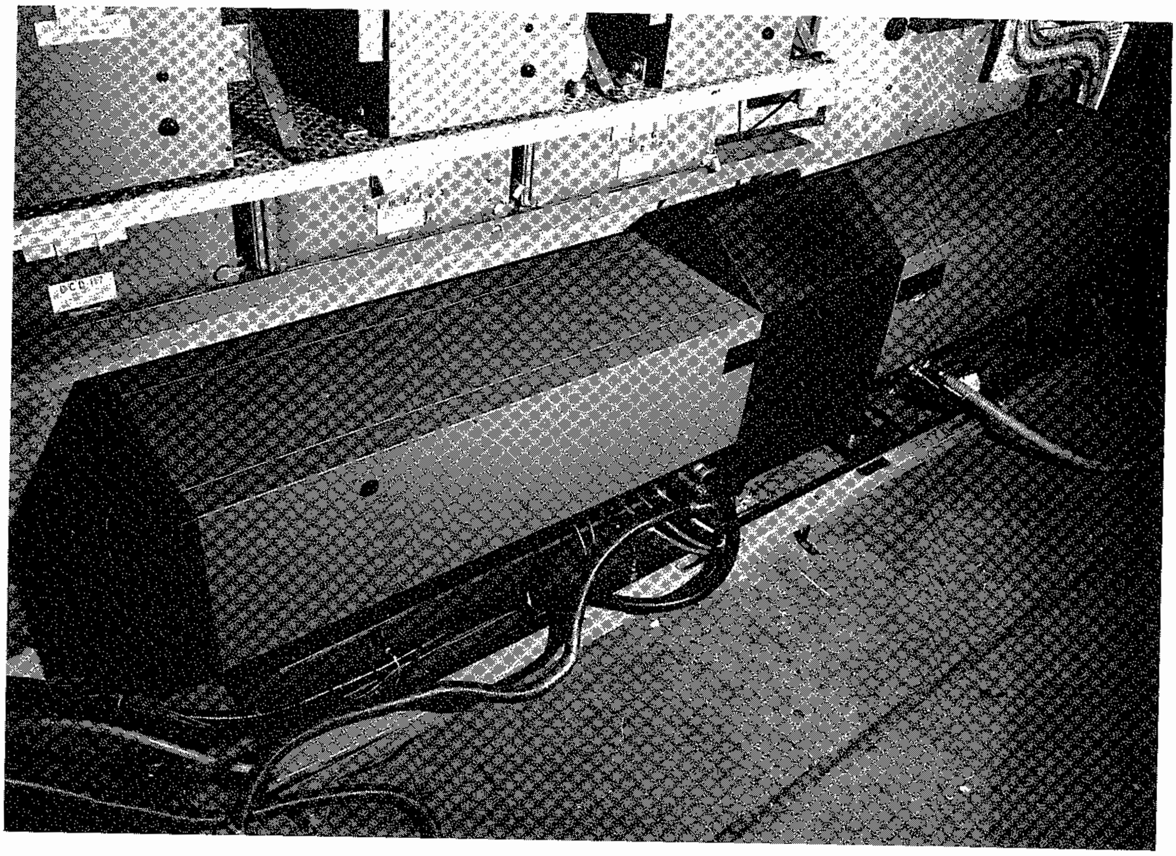


Fig 2. 2 x 400 watt lasers, wall mounted facing each other.

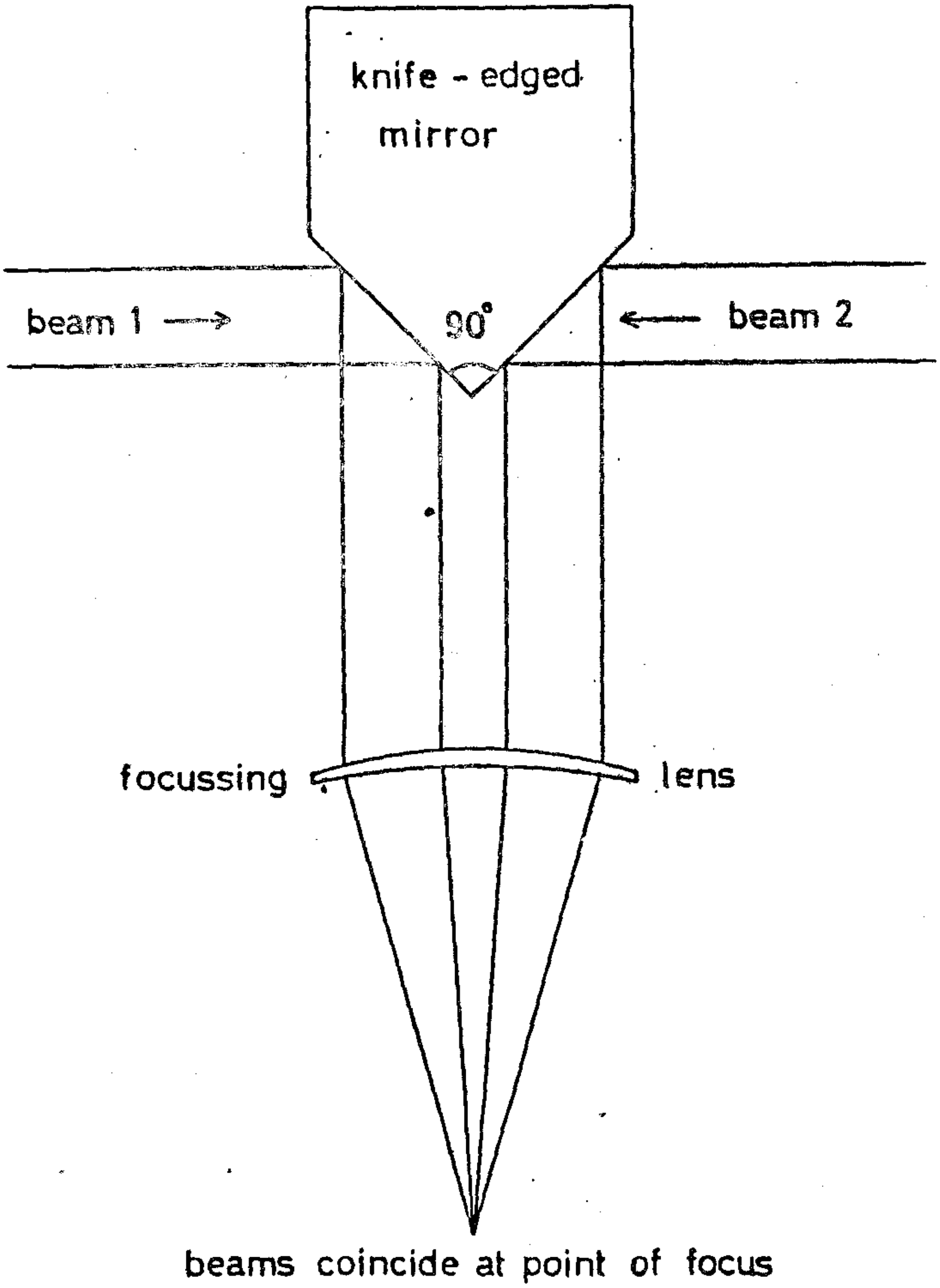
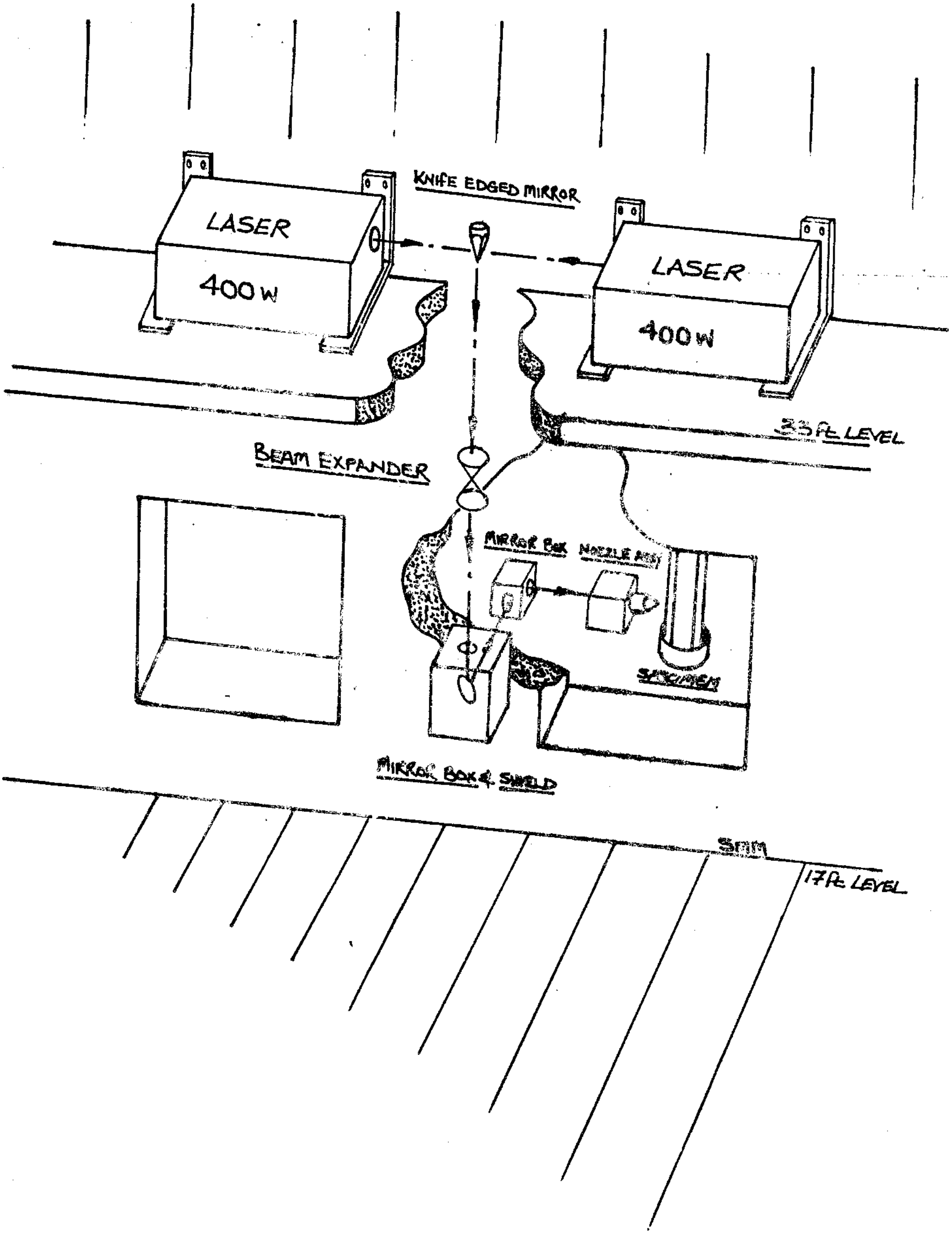
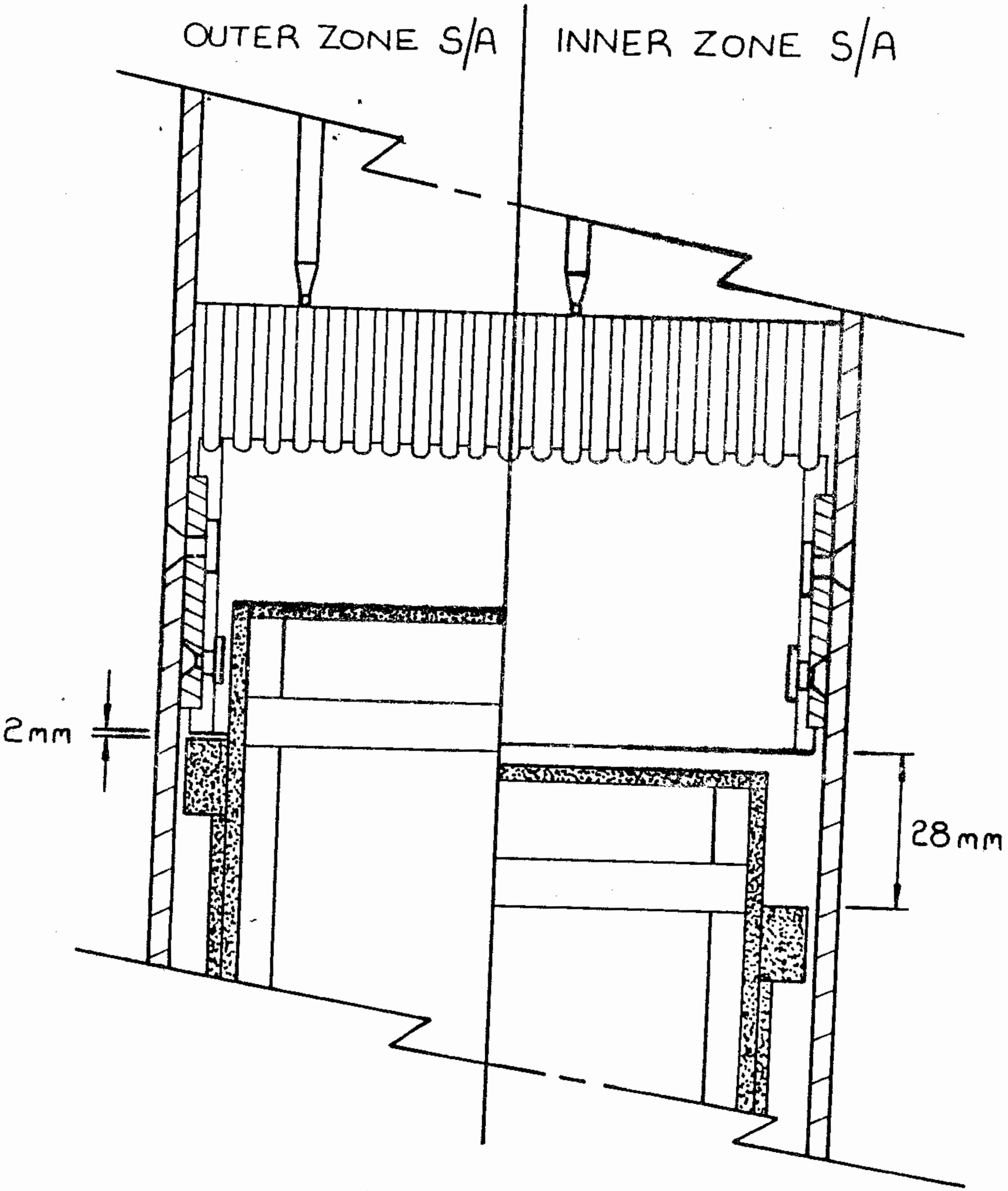


FIG 3 SCHEMATIC SHOWING OPTICAL ARRANGEMENTS FOR COMBINATION OF LASER BEAMS



OPTICAL SYSTEM

FIG 4



Cutting Positions for Inner and Outer
Zone Sub-Assembly Spikes

FIG 5

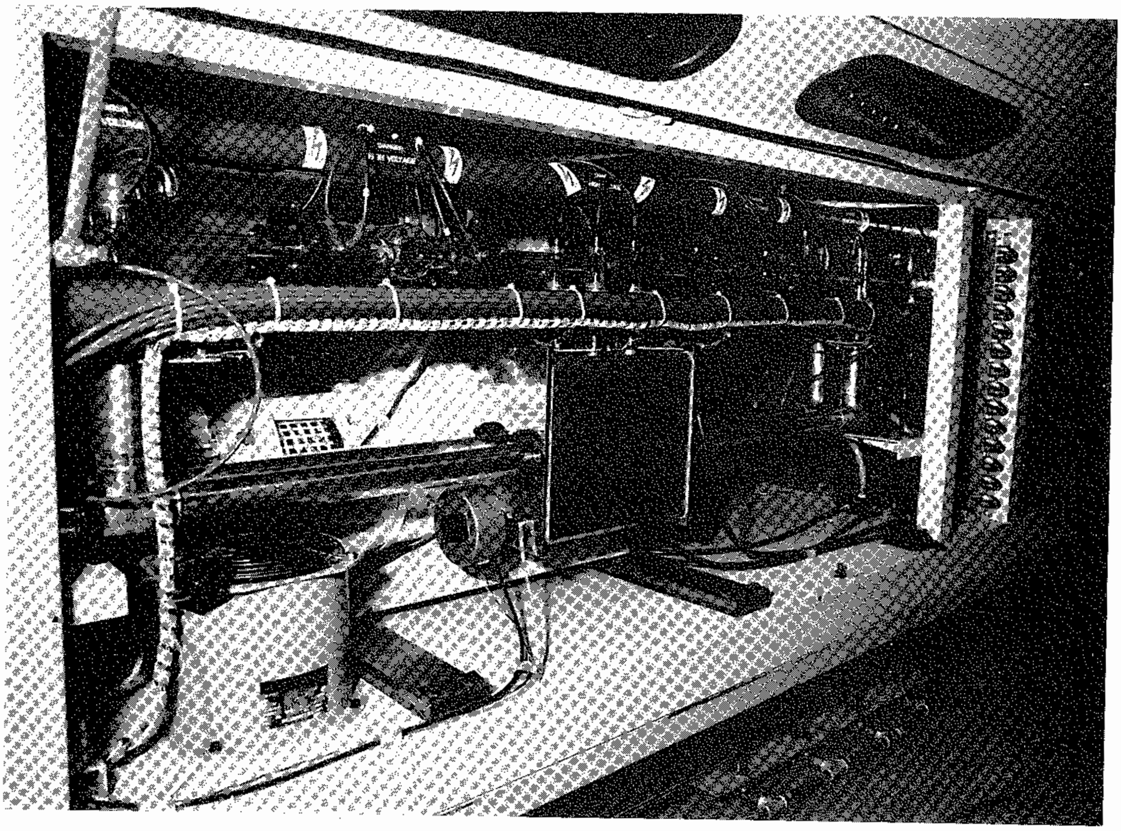


Fig 6. View of laser optical cavity situated within the laser cabinet.

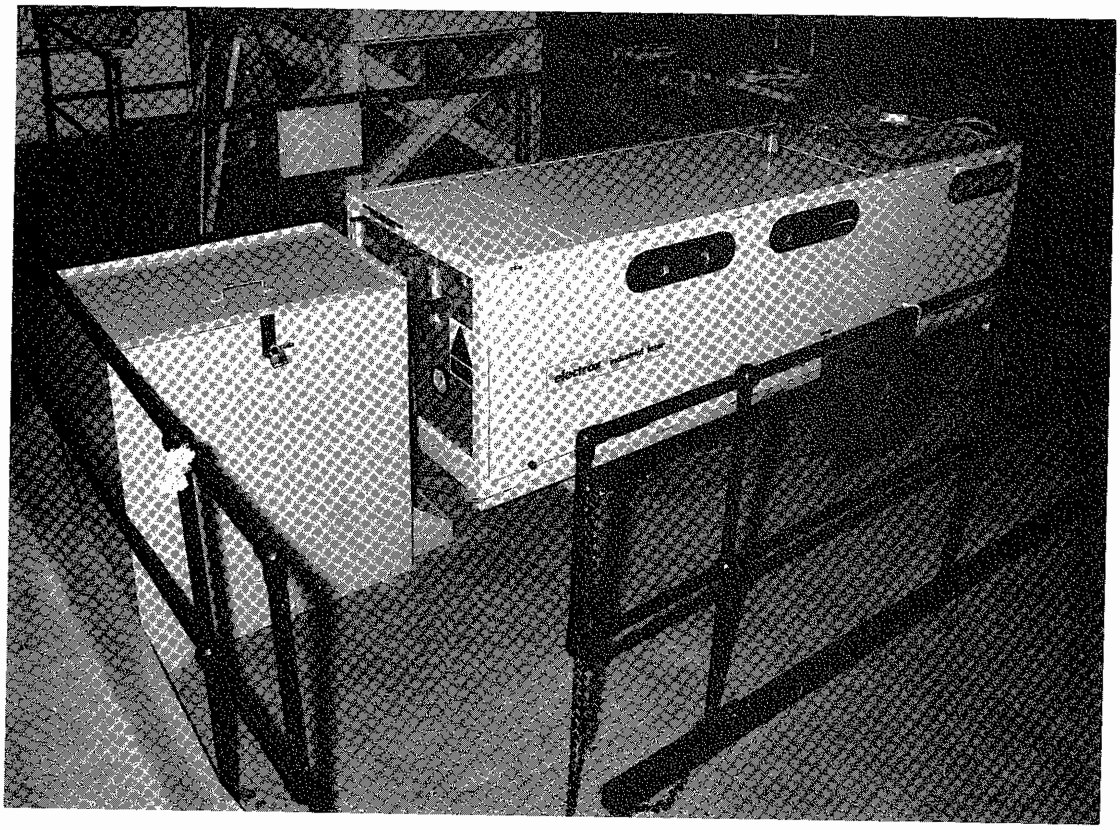
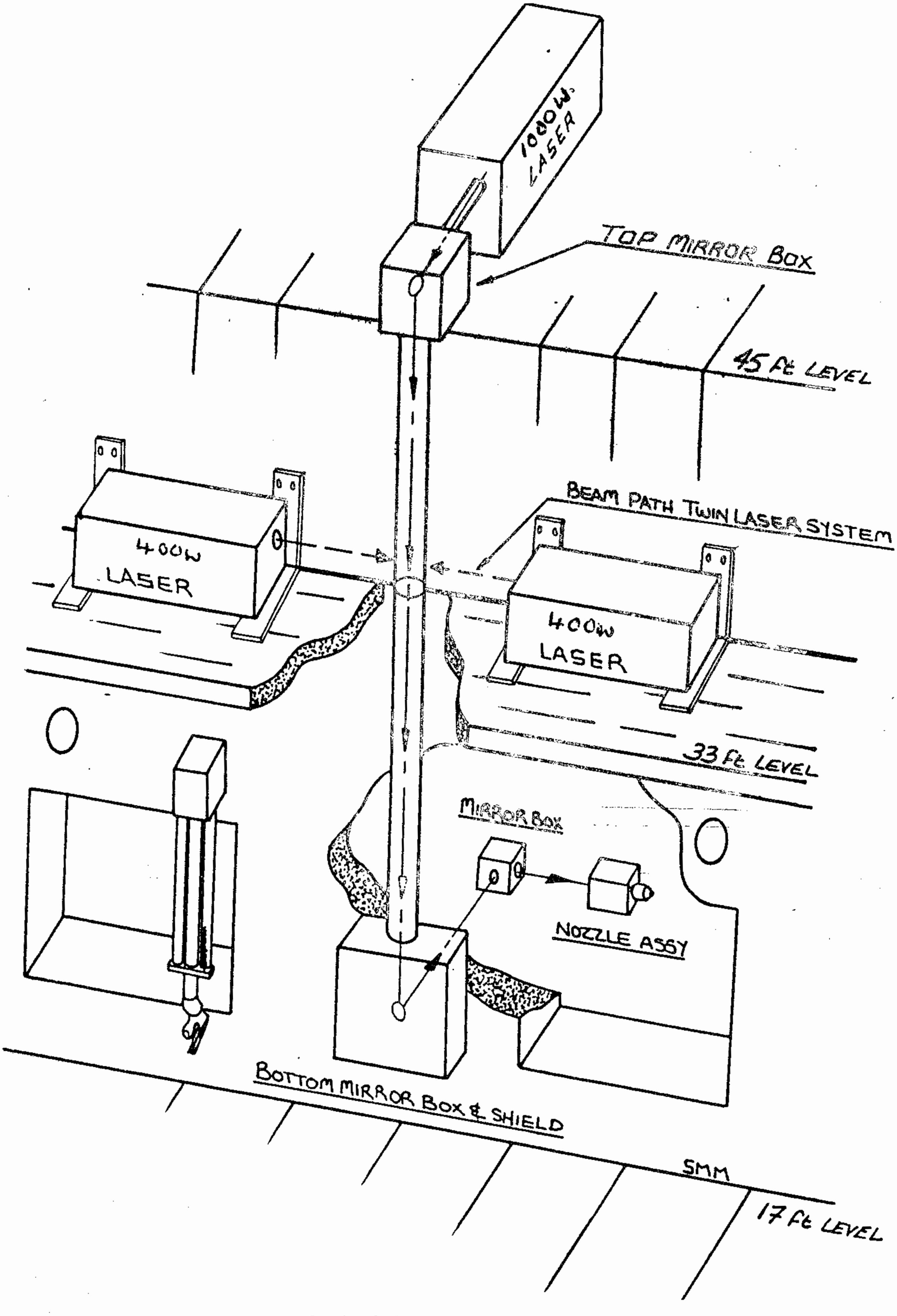


Fig 7. 1000 watt laser and mirror box assembly mounted on IFC Roof.



Optical Beam Paths for Both Laser Systems

FIG 8

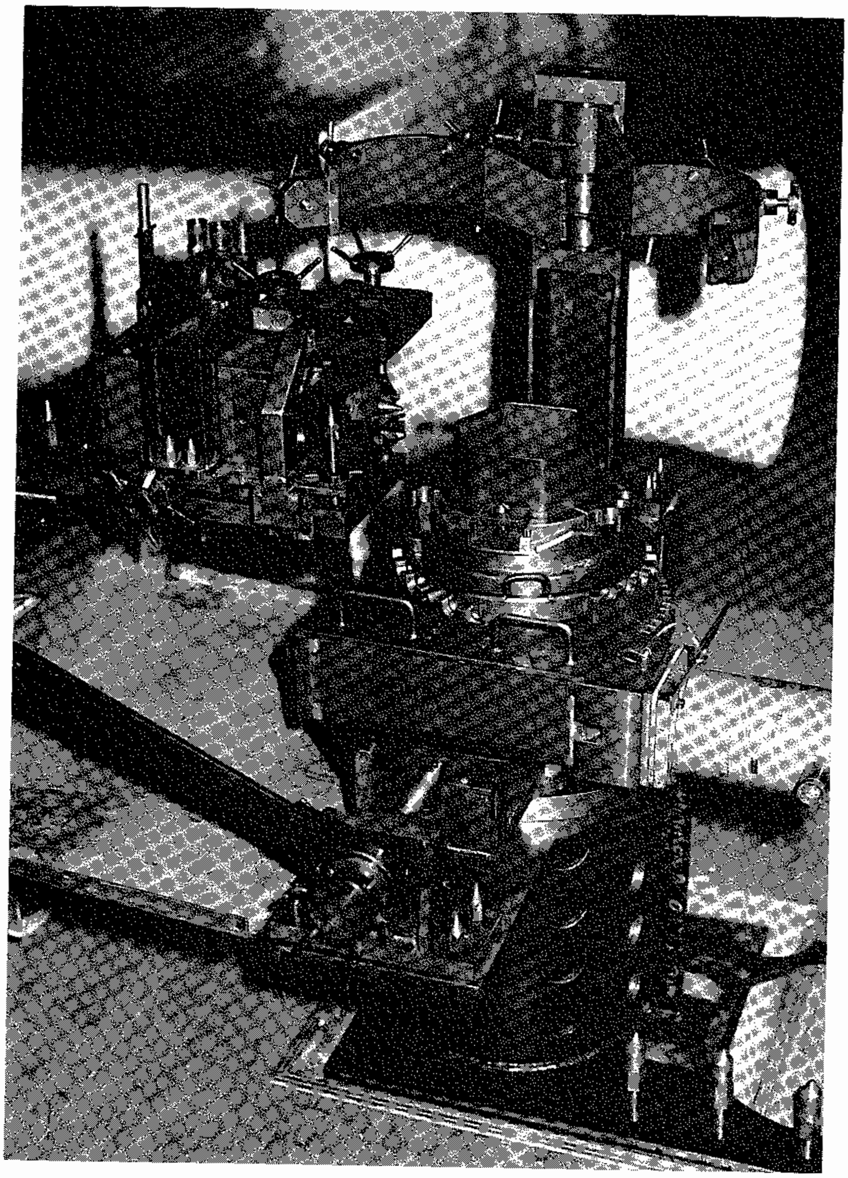
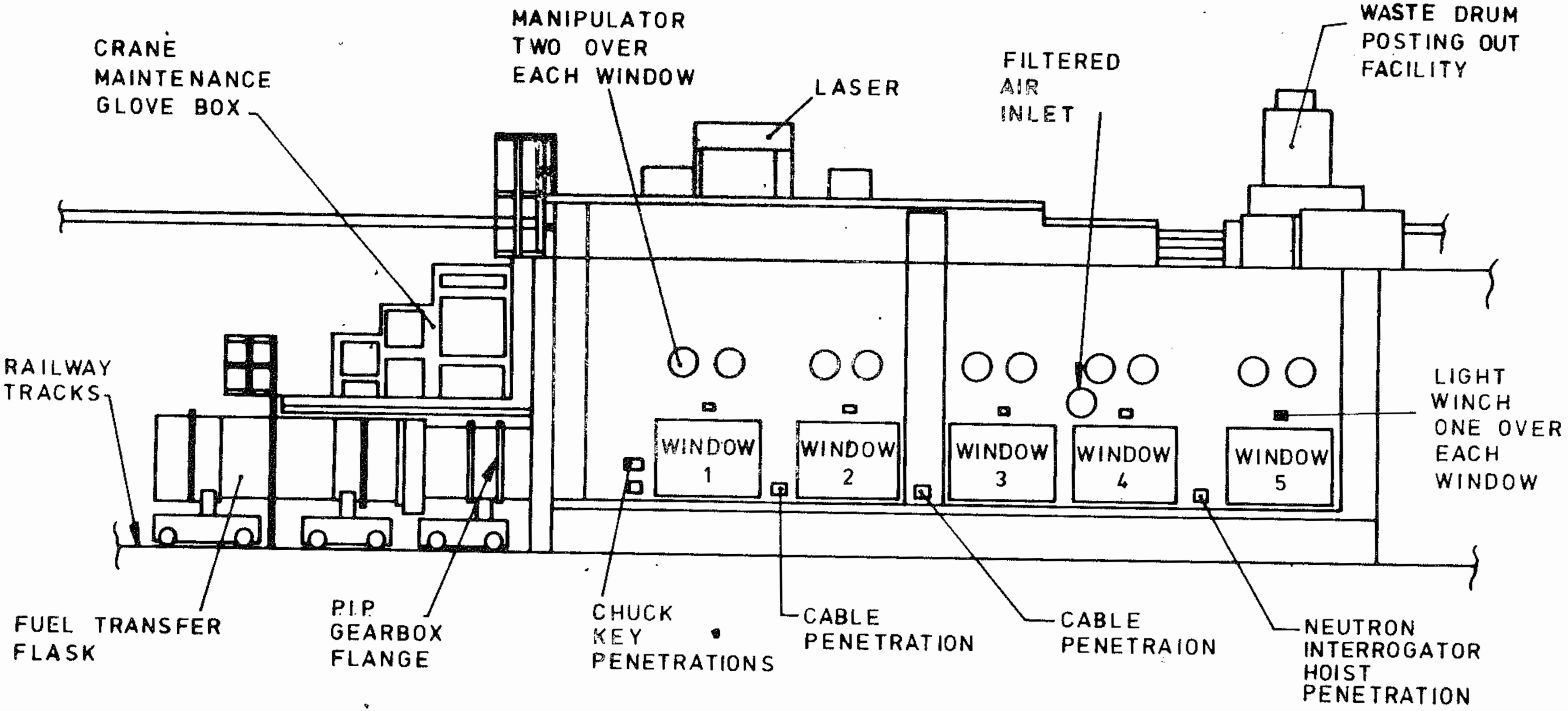
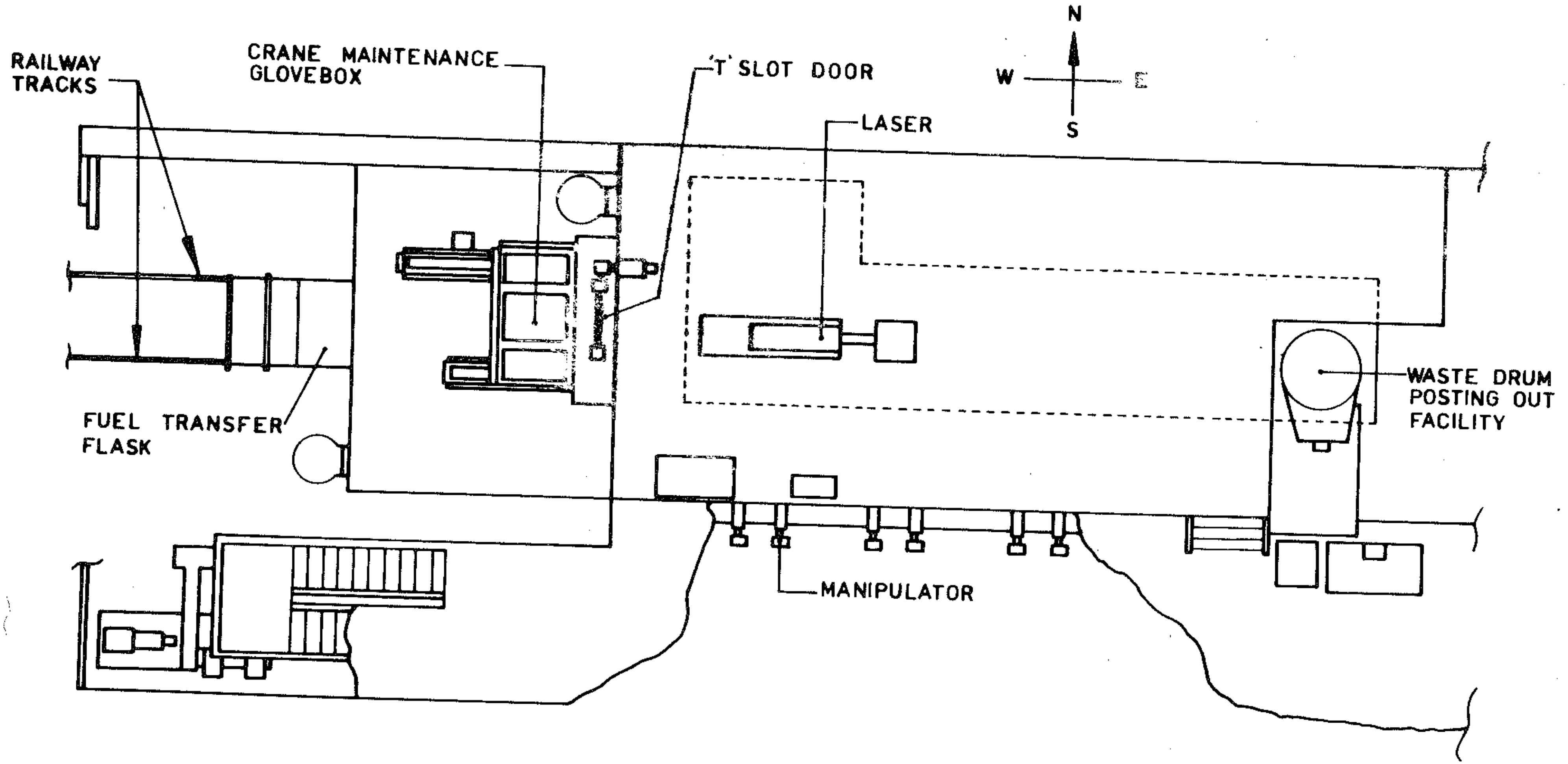


Fig 9. IFC in cave laser cutting nozzle and sub-assembly rotation drive unit.



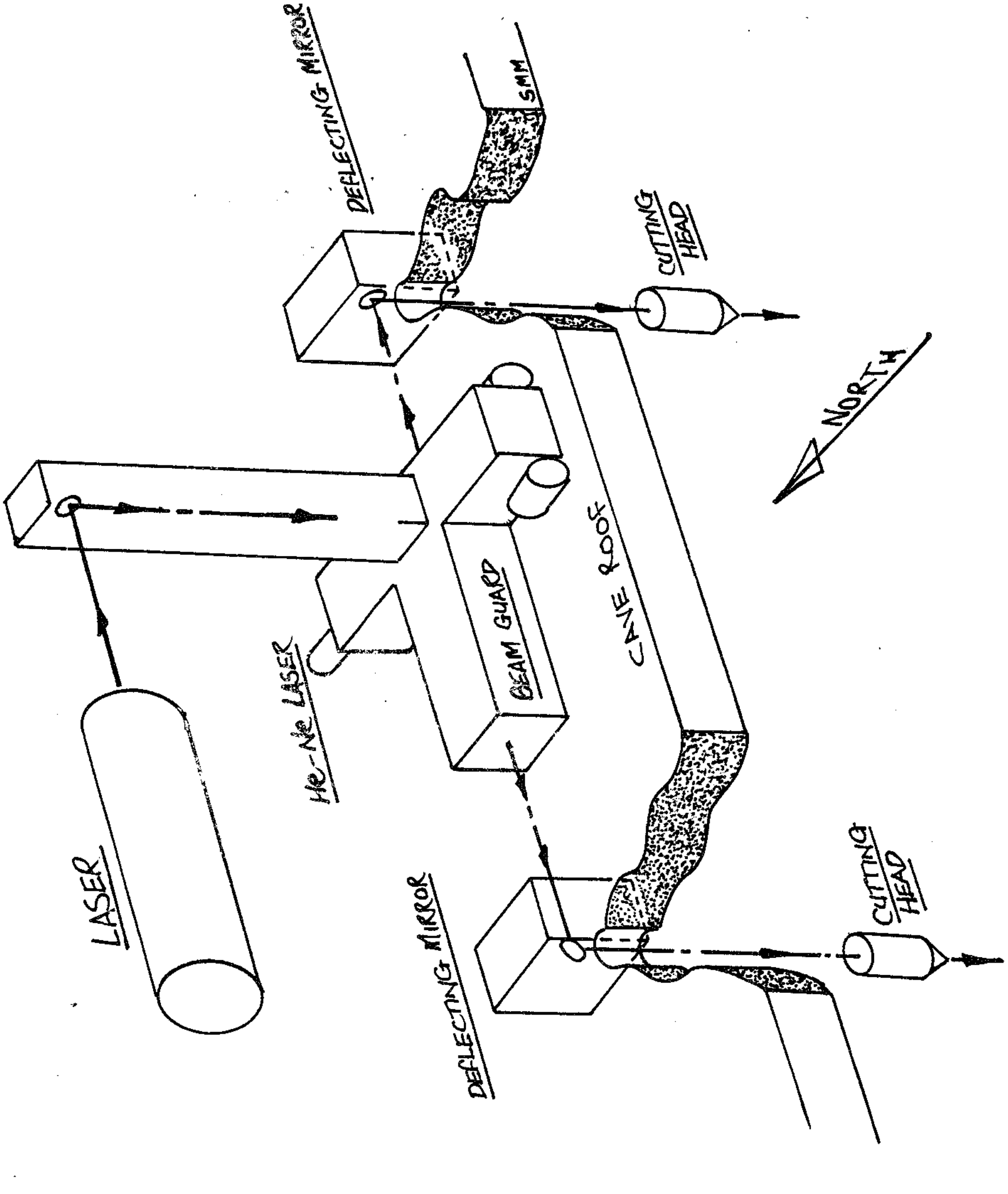
FRONT ELEVATION — FUEL DISASSEMBLY CAVE

FIG.10A



PLAN VIEW — FUEL DISASSEMBLY CAVE

FIG.10B



DISASSEMBLY CAVE

SCHEMATIC OF LASER SYSTEM

FIG 11

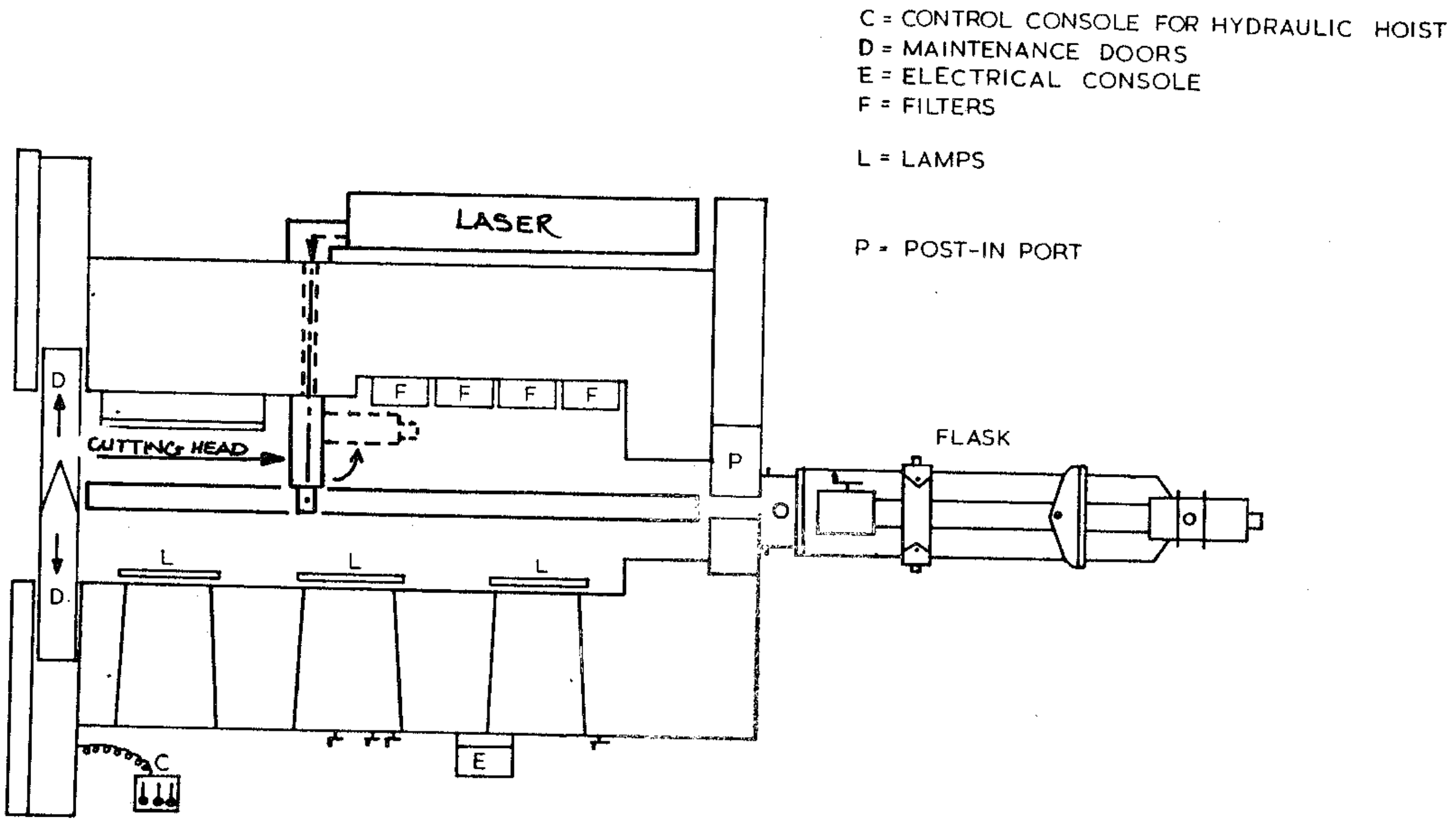
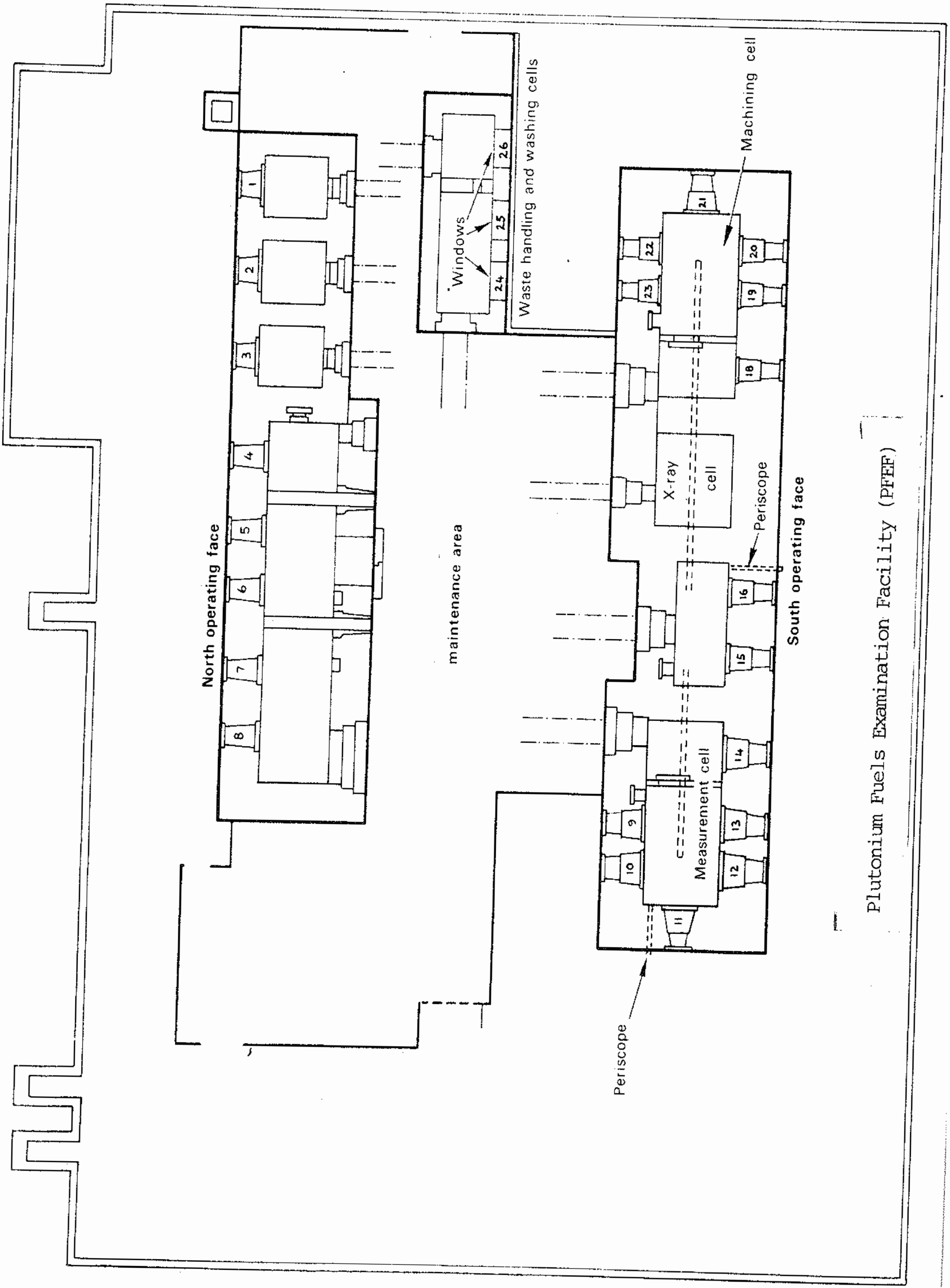


FIGURE 12 DMTR Cave - Layout of cave equipment



Plutonium Fuels Examination Facility (PFEF)

FIGURE 13