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TSBEZ/MEM/0002/93

MEMORANDUM

RECENT DEVELOPMENTS IN REMOTELY OPERATED EQUIPMENT FOR USE IN THE POST IRRADIATION EXAMINATION OF FUEL AND COMPONENTS

**By G F Hines, T Molloy and R I Hey,
Engineering & Operational Services, BTC**

Task TSBEZ 37001

**For presentation at the EEC Hot Laboratories
and Remote Handling Meeting to be held at
Chinon in June 1993**

May 1993

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MAY 1993

Approved for Issue:

M J Routley

Date:

23-5-93

Mr M J Routley, Sites & Services Branch Manager

SUMMARY

This note describes selected items of specialised equipment provided for the post irradiation examination of Advanced Gas Cooled Reactor fuel elements at BTC. The equipment enables,

- [1] fuel elements and fuel pins to be inspected
- [2] fuel pin dimensions to be measured to an accuracy of < 10 microns
- [3] gas samples to be taken and analysed
- [4] test samples to be prepared.

The equipment is designed to be remotely serviceable and is free standing to allow easy removal for major repair or to accommodate changes in the examination schedule.

Key Words: AGR, Equipment, Post Irradiation Examination

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1. INTRODUCTION

The cave line at Berkeley Technology Centre has been refurbished and re-equipped for the examination of fuel elements from Nuclear Electric's Advanced Gas Cooled Reactors (AGR). The caves resumed active work in June 1992 and since that time about 40 fuel elements have been subjected to detailed examination. In addition, a number AGR fuel stringer tie bars have been examined, together with selected fuel pins that were irradiated at Halden.

The cave layout is shown in fig.1 and a typical AGR fuel element is shown in fig.2. Since this unit weighs ~ 100Kg special lifting devices are required in the cave line to ensure that the master slave manipulators (MSM) are used within their operating specification.

Within the reactor core each channel contains 8 fuel elements held on a central tie bar which is used for charging and discharging the fuel stringer. The tie bar is manufactured from a nimonic alloy (PE16) and is ~ 10mms in diameter. The core section, which is ~ 12m long, is cut into sections ~ 1m long for examination.

The examination programme requires the provision of equipment for the detailed visual and X-ray examination of elements and pins, for measurement systems accurate to < 10 microns, for gas sampling and for the precision cutting and machining of samples. The details of selected items of this equipment are the subject of this report. Some of the other pieces of equipment and a general outline of the BTC cave system have been described in papers to previous meetings (refs 1 and 2).

In designing the equipment a principal requirement was the ability to carry out repairs within the cave line and to achieve this all key components can be remotely replaced. Should a complete unit need to be removed for repair it can be posted into a roof top glove box or be taken into one of the maintenance bays where it can be reached through glove ports.

All equipment is free standing and can be relocated or replaced within the cave line according to the needs of the examination programme. This allows the maximum flexibility in cave line use.

2. VIEWING SYSTEMS

Two viewing systems have been installed (see fig.3), both incorporating transfer optic tubes located in the cave wall which bring the images to a point on the operating face where they can be viewed by CCTV systems. Solid state (CCD) cameras are preferred as they can provide adequate resolution and are more compact than tube cameras.

The image is viewed on a high resolution video screen which allows details down to ~ 10 microns in diameter to be identified. From the control desk it is possible to rotate, slew and translate the object being examined and to vary the field of view from 250 to 20mms for fuel elements and 50 to 4mms for the fuel pins.

The CCTV cameras are linked to a computer controlled data recording system which allows images and descriptive data to be stored digitally on an optical disc (fig.4). This information can be recalled for interrogation, collation or editing, either at the control desk, or at a remote monitor screen that forms part of the computer network.

Although the image quality obtained is slightly inferior to that obtained by direct viewing through an eyepiece, this system has the advantages of improved light transmission, reduced strain on the operator and allows the control desk to be located away from the cave face. Since the image is stored digitally its quality can be improved by standard image enhancement techniques. There is also considerable time saving as a result of computer manipulation and recall of the information.

3. MEASUREMENT SYSTEMS

A variety of measurement devices are in regular use for recording dimensional changes on graphite sleeves, fuel pins and tie bars. The frequency and accuracy of the measurement varies so that both simple systems that are MSM operated and accurate to ~ 0.25 mm and automatic precision measurement systems accurate to ± 5 microns are in use.

The simple systems have dial gauges for measurement and are used, typically, to measure graphite sleeve dimensions. Calibration standards are kept in the caves to ensure that measurement accuracy is maintained.

For tie bars, an accurate assessment of the surface imperfections (wear scars) that are formed during service, is required. These affect the mechanical strength of the bar and to measure their depth and extent two instruments are available.

The first is the tie bar editor which traverses a tungsten carbide contact stylus along the bar in order to locate the wear scar and provide an indication of its extent. The process is automatic and comprises 80 traverses with a 4.5° rotation of the bar between each of them. This technique has an axial positional accuracy of 1mm and a measurement accuracy of 5 microns. If the extent of the wear scar is sufficient to merit more detailed measurement, the tie bar is moved to the second device. This is basically a Talysurf adapted for remote use and works by using stepper motors to traverse a diamond contact stylus across the defect. The stylus is contained in an aluminium holder which moves on an accurately machined granite block that acts as a reference (fig.5). The stylus is traversed in fixed steps and after each step the reading is logged on the computer. By rotating the bar between traverses it is possible to build up a 3 dimensional picture from which the angle and root radius of the notch can be measured. This equipment is in daily use and many hundreds of tie bar lengths have been examined.

For the assessment of pin profile changes to ≤ 5 microns, a 3 axis measurement machine is used (fig.6). As the name implies, the machine relies on 3 precision slides set at right angles which are used to define a point in space. A touch probe (which has a profile suited to the measurement required) locates a point on the pin surface and dimensional changes are determined by relocating the probe and calculation of the probe movement. All positioning and calculation is computer controlled and the machine is programmed to prevent the probe being driven into the pin by the operator. The measurement head also incorporates a radiation hardened CCTV camera sighting through a prism to enable the point of measurement to be directly viewed by the operator. A typical surface profile taken between the anti-stacking grooves of an AGR fuel pin is shown in fig.7.

The machine has been built from commercially available precision measurement components and is used whenever detailed information on surface deformation is required. It also carries a system for the measurement of deposit thickness on pin surfaces. For this measurement the probe is used in a resistive mode to allow contact with the deposit surface to be established at an applied pressure of only 15gms. The probe co-ordinates are recorded and glass beads ~ 40 microns in diameter are blown through a tube at the deposit to remove it and expose the underlying metal surface. This operation takes place within a small suction chamber which ensures that all the beads are collected. When the abrasion cycle is complete exposure of the metal is confirmed by camera inspection and the probe is moved to locate the surface. The deposit thickness is determined by subtraction of the probe co-ordinates.

This device is in the final stages of commissioning and its ability to determine accurately the surface profile of complex objects has been confirmed. Its disadvantage is that its method of operation is inherently slow so that repetitive measurements over lengths ≥ 250 mm are time consuming. There is also the problem of operating a precision measurement device within a busy cave system where the relative humidity is often 80% at a temperature of ~ 25°C.

4. GAS SAMPLING

Within the cave line it is possible to sample and analyse gas from both the transport bottles in which the fuel elements are delivered and from within fuel pins.

A computer controlled system enables the operator to select a gas sample from within the transport bottle and to transfer it to a γ spectrometer and a Hiden quadrupole mass spectrometer analyser which are located in series outside the shielding. The γ spectrometer is used to check the gas sample for Kr⁸⁵ and thus determine whether the transport bottle contains a leaking fuel element. The gas composition is determined from the mass spectrometer output.

The system for sampling gas from within fuel pins is shown in fig.8 and the gas collection system in fig.9. After evacuating the system, the gas is released by operating a lever to drive a sharp wedge into the can. Once it is breached the pin internal pressure forces the gas into the evacuated system and the equilibrium pressure is recorded. The gas is then expanded into a known volume which enables the pin internal pressure and volume to be calculated. The next stage is to draw the gas into metal collection vessels on the cave face (fig.9), via a capillary pipework system by means of a single stroke Toepfer pump. The total volume of the system and its individual components can be measured by evacuation and backfilling with argon. It is also possible to add a large variable volume to the system to enable pins with high gas releases (> 5%) to be sampled. Gas analysis is carried out on the Hiden mass spectrometer.

This system is in regular use and has worked well. Its major advantage is the avoidance of the use of glass and of an extensive pumping system to recover the fission gas sample. This removes the requirement for a cave face glove box.

5. SAMPLE PREPARATION

Various machines are available for sectioning fuel pins and components and there is also a Denford Triac CNC bench top milling machine for the preparation of test specimens.

The cutting machines are simple systems based on commercially available equipment. The machine for sectioning fuel pins uses a hydraulically operated vice to present the pin to a diamond cutting disc rotating at ~ 1500 r.p.m. Transverse and longitudinal cuts can be made and the operation is fully contained. Water is used as a cutting fluid and drains away into a collection tray from which it can be recovered and reused. The total water volume is ~ 2 litres. Cutting debris accumulates in the collection tray which is changed as required and the solid residue recovered after it has dried out.

For sample preparation to predetermined dimensions the CNC milling machine is used (fig.10). This has been adapted for remote use by replacing all plastic components with metal, arranging for all the drive units to be remotely changeable and also ensuring that the tools can be changed with manipulators. The computer and associated electronics have been separated from the machine so that they stand on the cave face where the irradiation dose is negligible.

This machine has been in regular use for ~ 2 years and a range of samples have been produced. The most important of these are the Hounsfield tensile test samples which are prepared from the broken halves of Charpy impact samples used in investigations related to the embrittlement of pressure vessel steels (fig.11). The half Charpy samples are of 10mms square section and ~ 27 mms long. For the preparation of tensile specimens the first step is to cut holding and drive locations in the Charpy sample so that it can be placed between centres and rotated. A powered headstock and a tailstock are then attached to the milling machine bed which allows the tensile specimen to be machined to shape with a standard milling cutter. The whole process is automatic and controlled by a predefined computer programme. To date, ~ 50 tensile samples have been produced with a dimensional accuracy of ± 0.08 mms on the 4.54mm nominal diameter of the test section.

There is also a machine which has been specially constructed to prepare graphite sleeves for testing and to cut samples from the sleeves (fig.12). The graphite sleeve is ~ 1 m long x 250mms diameter and is seated on rollers so that it can be rotated to the required position. A diamond cutting wheel, driven by an air motor is used that can be positioned to slit the sleeve transversely or longitudinally. This allows the sleeves to be prepared for internal stress measurement or for 'windows' to be cut into the sleeve for inspection of pins in-situ. The cutting wheel can be replaced by a core drill driven by an air motor for trepanning samples from the sleeves. When the machine is in use a vacuum cleaner is attached which collects the dust produced and transfers it directly to a waste container. This is essential to prevent the spread of dust across the bench working surfaces.

6. DISCUSSION

The first of the caves was re-commissioned after refurbishing at the beginning of 1991 and since mid 1992 the complete cave line has been available for active work. With the exception of the pin and graphite cutting machines, considerable experience has been accumulated with the remote operation of the equipment described above. Wherever possible designs have been based upon equipment or systems available commercially so that costs are minimised and spares and service advice are readily obtained. Another basic design concept was to ensure that, as far as possible, faults could be remedied remotely so that operator dose during servicing was reduced. As room in the cave line was limited it was important that the machines were free standing and of a size that could be readily handled by the in-cave lifting equipment. This, together with the availability of a variety of through-the-wall service plugs provides maximum flexibility in preparing the cave layout and allows the in-cave arrangement to be easily changed as examination requirements vary.

In most respects the equipment has worked well. There is clearly a problem in the operation of precision measurement equipment in an open cave line where a wide variety of tasks are performed. The close proximity of cutting and machining operations is detrimental and these should be segregated. However, this is difficult to achieve without limiting other examination procedures. This is an area that will require review as operational experience builds up.

7. ACKNOWLEDGEMENT

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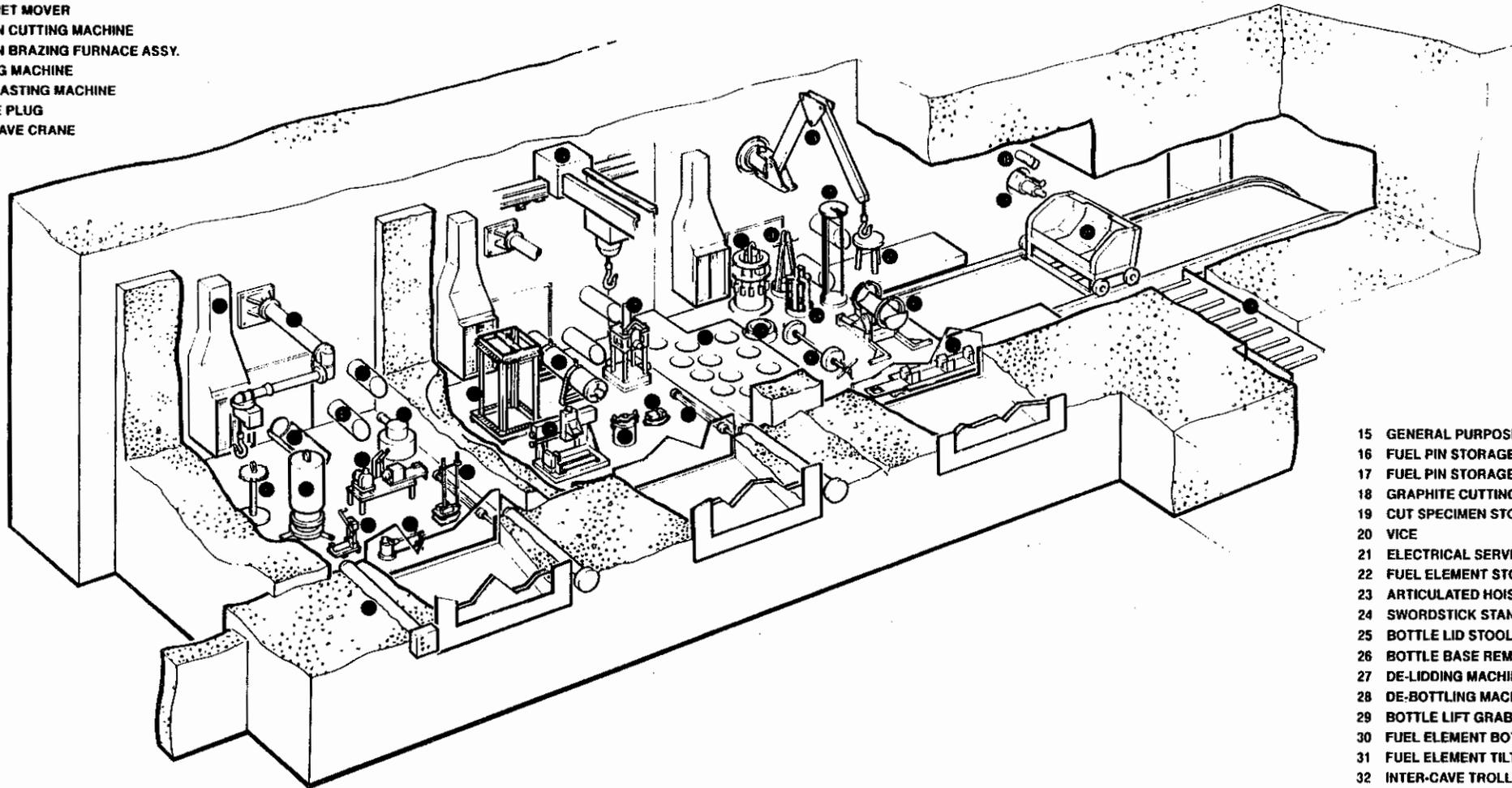
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2. Refurbishment of Shielded Facilities in the UK, G F Hines, M S Stucke and E J Fulton, EEC Hot Laboratories Meeting, Marcoule, June 1992.

FIG.1a

Berkeley Nuclear Laboratories Shielded Area Caves 1, 2 & 3. A.G.R. Fuel P.I.E.

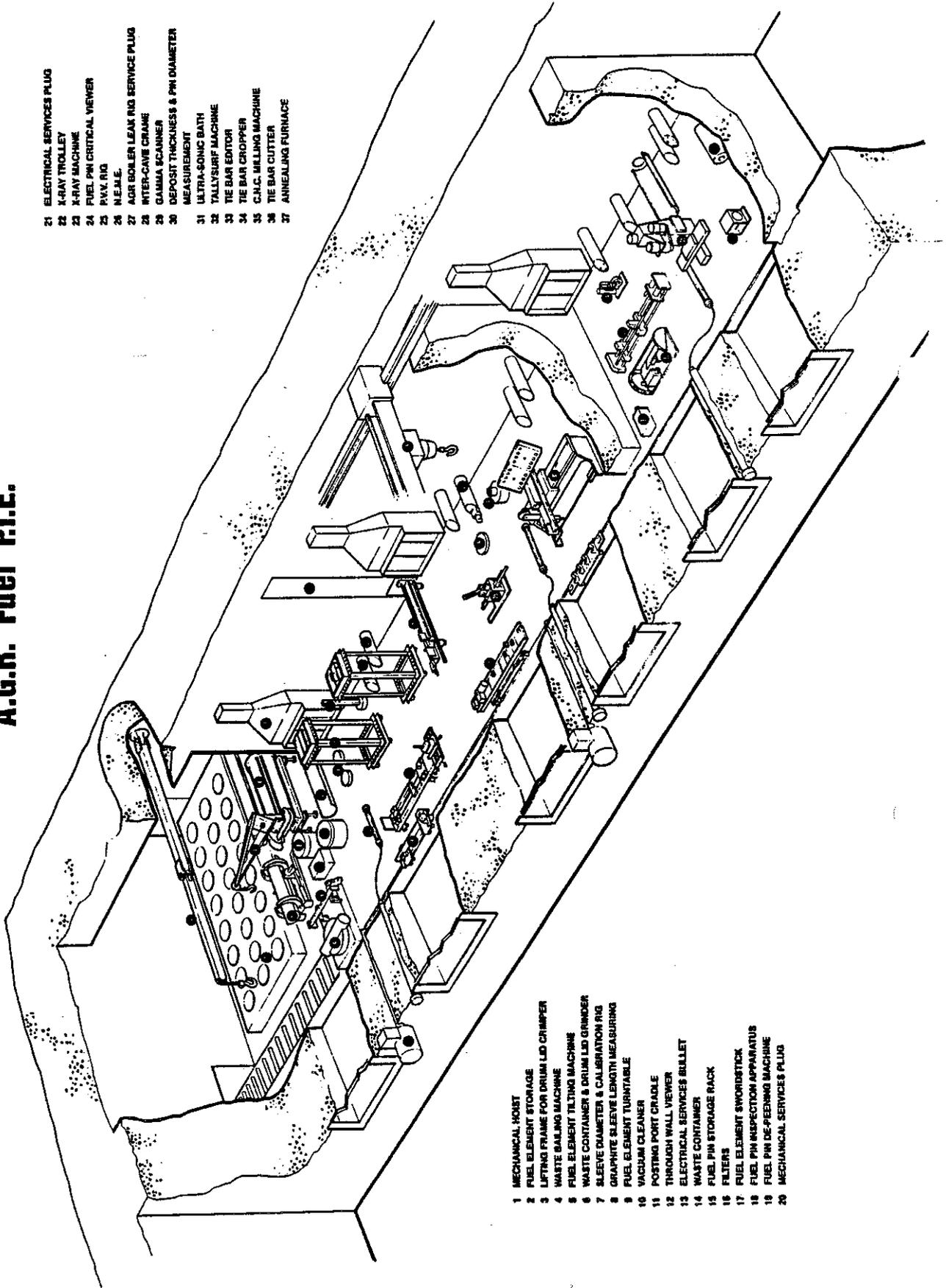
- 1 FILTERS
- 2 HOIST (CAVES 2 & 3)
- 3 ELECTRICAL SERVICES
- 4 MECHANICAL SERVICES
- 5 POSTING PORT CRADLE
- 6 STRESS RUPTURE PIN STORAGE
- 7 FUEL PIN STRESS RUPTURE RIG
- 8 FILTER JET MOVER
- 9 FUEL PIN CUTTING MACHINE
- 10 FUEL PIN BRAZING FURNACE ASSY.
- 11 DRILLING MACHINE
- 12 SANDBLASTING MACHINE
- 13 SERVICE PLUG
- 14 INTER-CAVE CRANE



- 15 GENERAL PURPOSE CUTTING MACHINE
- 16 FUEL PIN STORAGE CONTAINER
- 17 FUEL PIN STORAGE RACK
- 18 GRAPHITE CUTTING MACHINE
- 19 CUT SPECIMEN STORAGE CONTAINER
- 20 VICE
- 21 ELECTRICAL SERVICES BULLET
- 22 FUEL ELEMENT STORAGE
- 23 ARTICULATED HOIST
- 24 SWORDSTICK STAND
- 25 BOTTLE LID STOOL
- 26 BOTTLE BASE REMOVAL TOOL
- 27 DE-LIDDING MACHINE
- 28 DE-BOTTLING MACHINE
- 29 BOTTLE LIFT GRAB
- 30 FUEL ELEMENT BOTTLE DAMPER GRAB
- 31 FUEL ELEMENT TILTING MACHINE
- 32 INTER-CAVE TROLLEY
- 33 BUCKET RAM
- 34 TV CAMERA
- 35 POND ELEVATOR BUCKET & CARRIAGE
- 36 BUCKET CONVEYOR

**Berkeley Nuclear Laboratories Shielded Area Caves 4, 5 & 6.
A.G.R. Fuel P.I.E.**

FIG. 1b

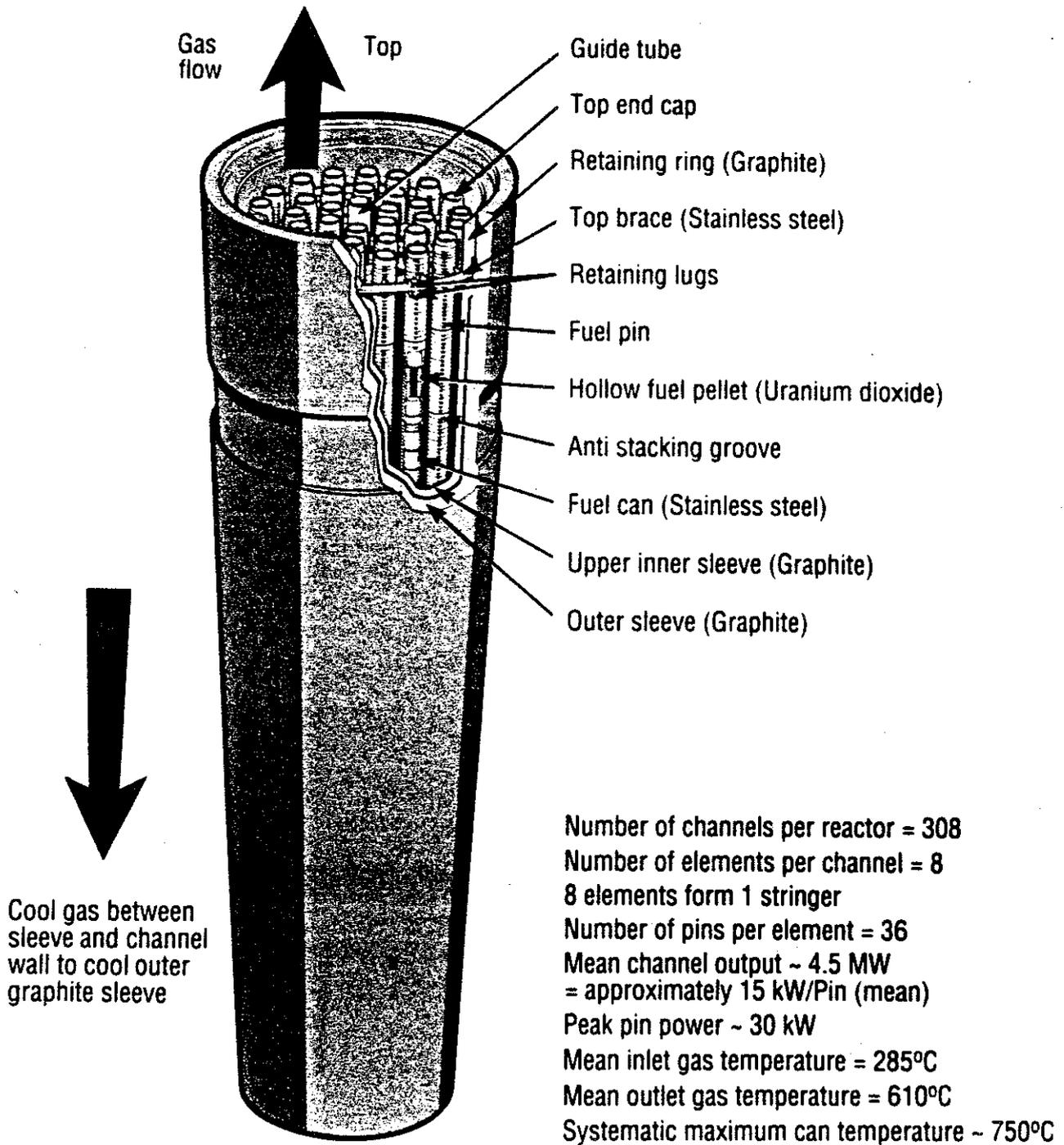


- 21 ELECTRICAL SERVICES PLUG
- 22 X-RAY TROLLEY
- 23 X-RAY MACHINE
- 24 FUEL PIN CRITICAL VIEWER
- 25 P.V.V. RIG
- 26 N.E.M.E.
- 27 AGR BOILER LEAK RIG SERVICE PLUG
- 28 INTER-CAVE CRANE
- 29 GAMMA SCANNER
- 30 DEPOSIT THICKNESS & PIN DIAMETER MEASUREMENT
- 31 ULTRA-SONIC BATH
- 32 TALLYSURF MACHINE
- 33 THE BAR EDITOR
- 34 THE BAR CROPPER
- 35 C.N.C. MILLING MACHINE
- 36 THE BAR CUTTER
- 37 ANNEALING FURNACE

- 1 MECHANICAL HOIST
- 2 FUEL ELEMENT STORAGE
- 3 LIFTING FRAME FOR DRUM LID CRIMPER
- 4 WASTE GAILING MACHINE
- 5 FUEL ELEMENT TILTING MACHINE
- 6 WASTE CONTAINER & DRUM LID GRINDER
- 7 SLEEVE DIAMETER & CALIBRATION RIG
- 8 GRAPHITE SLEEVE LENGTH MEASURING
- 9 FUEL ELEMENT TURNTABLE
- 10 VACUUM CLEANER
- 11 POSTING PORT CRADLE
- 12 THROUGH WALL VIEWER
- 13 ELECTRICAL SERVICES BULLET
- 14 WASTE CONTAINER
- 15 FUEL PIN STORAGE RACK
- 16 FILTERS
- 17 FUEL ELEMENT SWORDSTICK
- 18 FUEL PIN INSPECTION APPARATUS
- 19 FUEL PIN DE-PENNING MACHINE
- 20 MECHANICAL SERVICES PLUG

FIG.2

AGR fuel element assembly



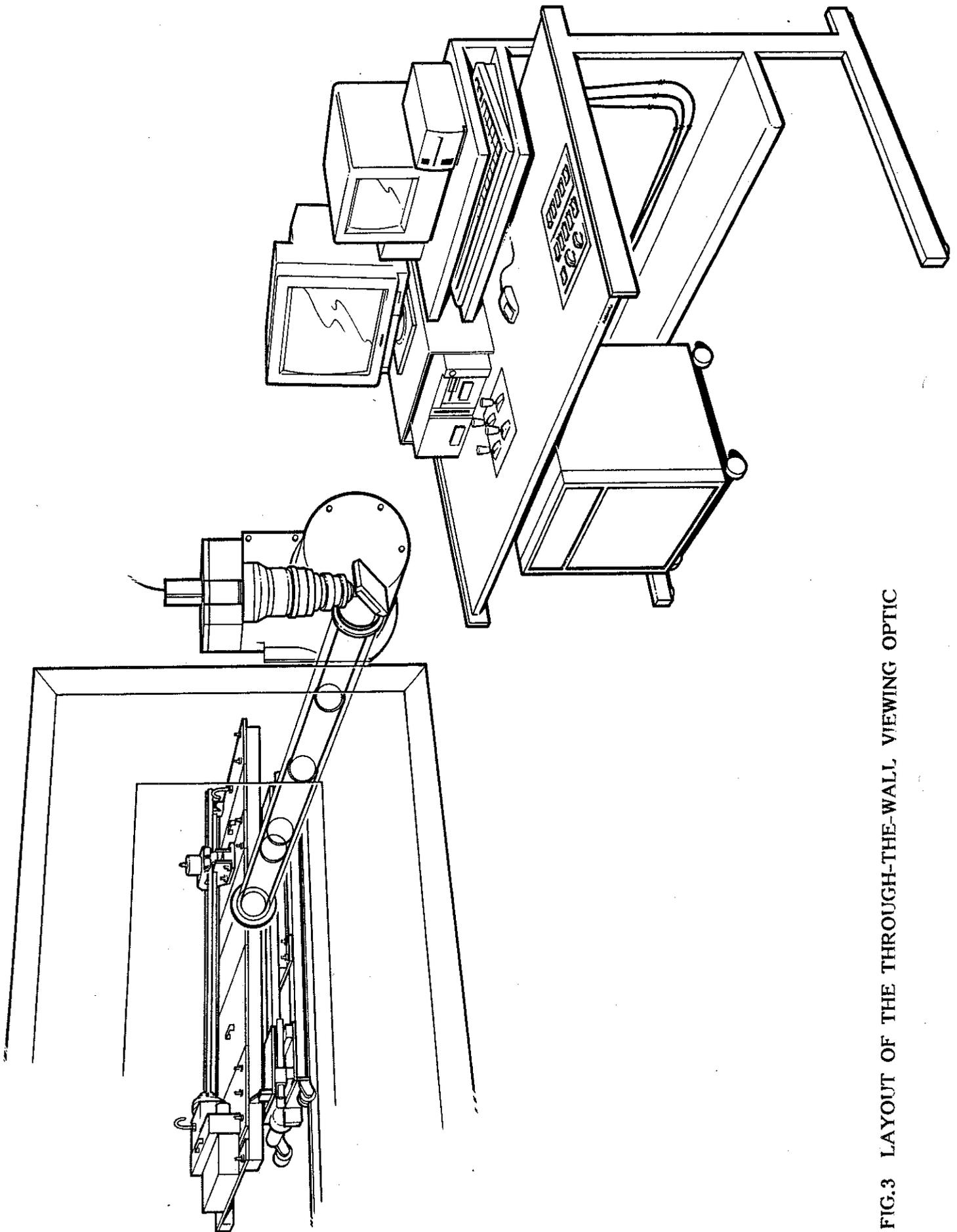


FIG.3 LAYOUT OF THE THROUGH-THE-WALL VIEWING OPTIC

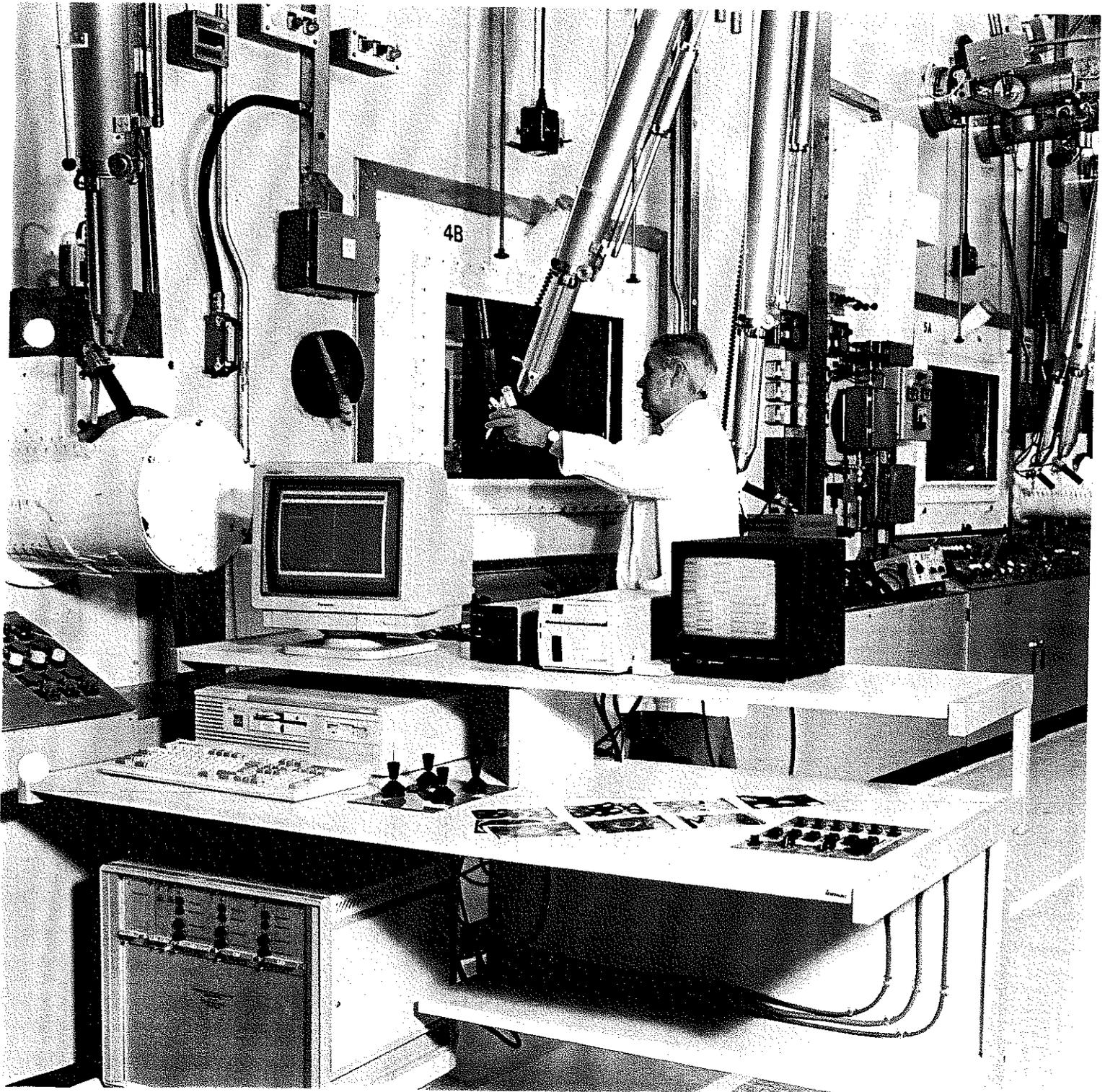


FIG.4 ELEMENT VIEWING RIG OPERATING CONSOLE

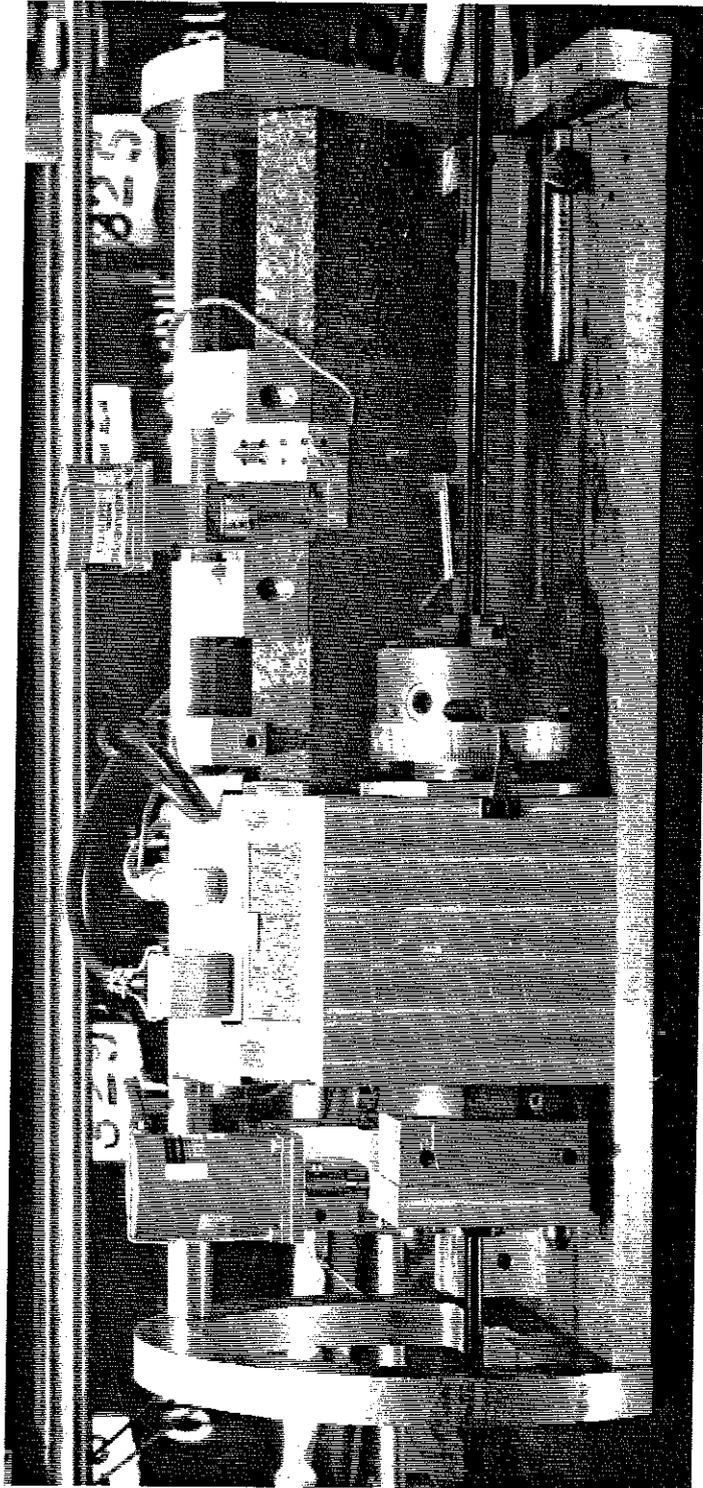


FIG.5 WEAR SCAR MEASUREMENT APPARATUS

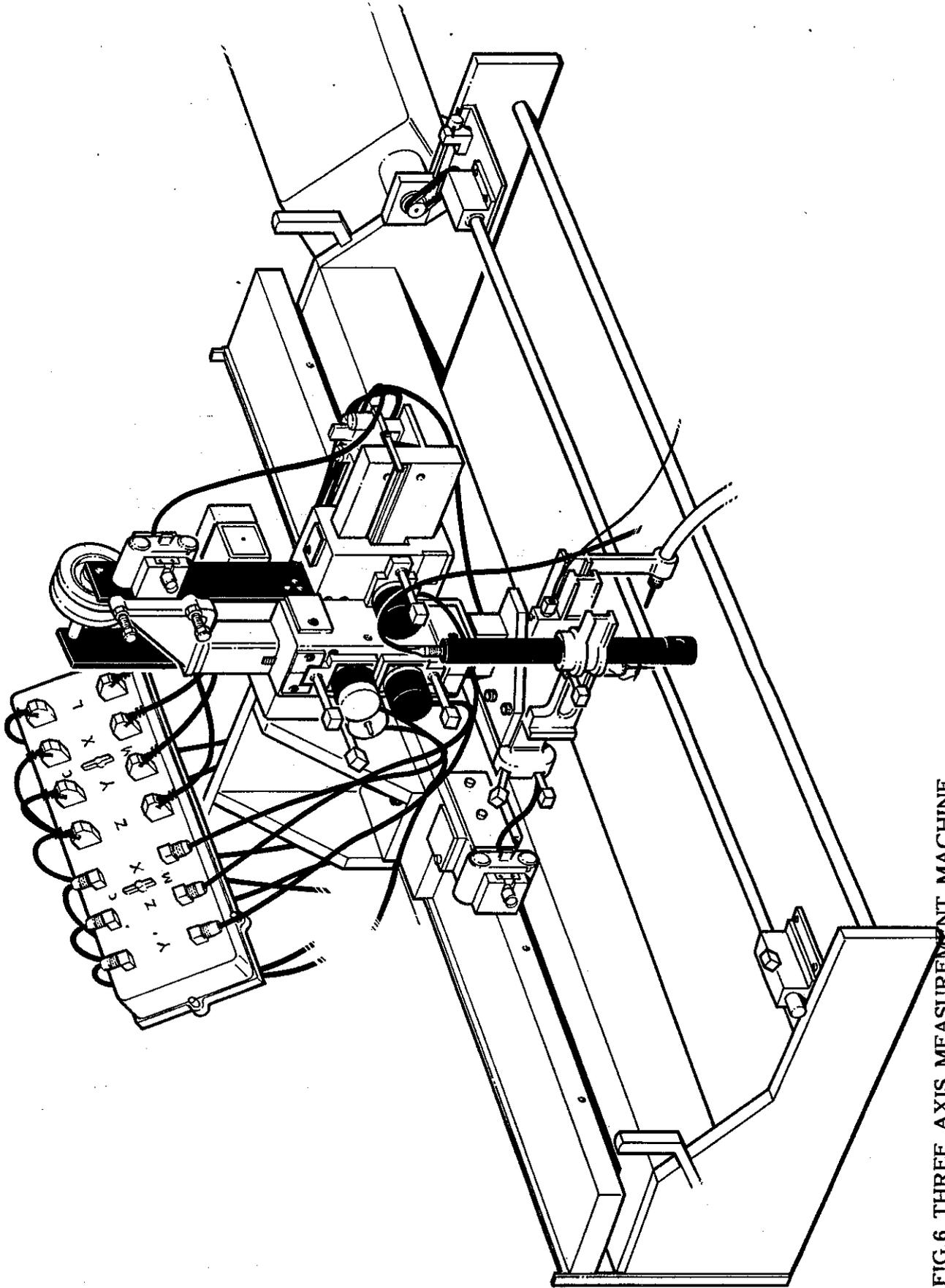


FIG.6 THREE AXIS MEASUREMENT MACHINE

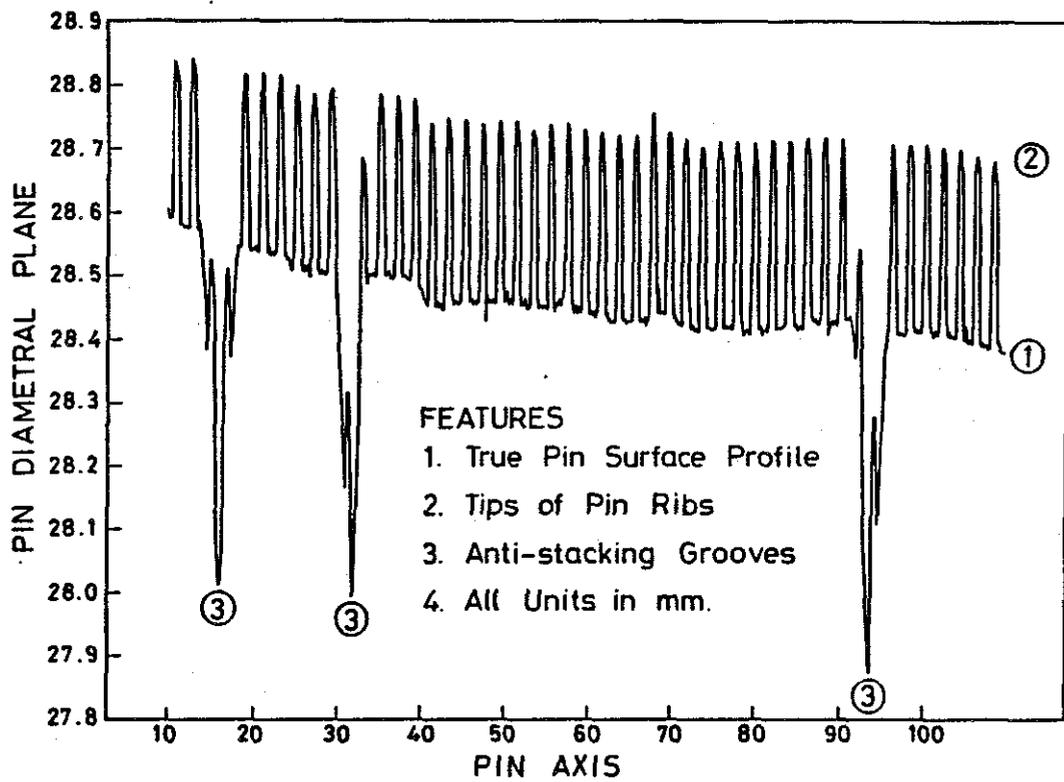


FIG.7 AGR FUEL PIN PROFILE

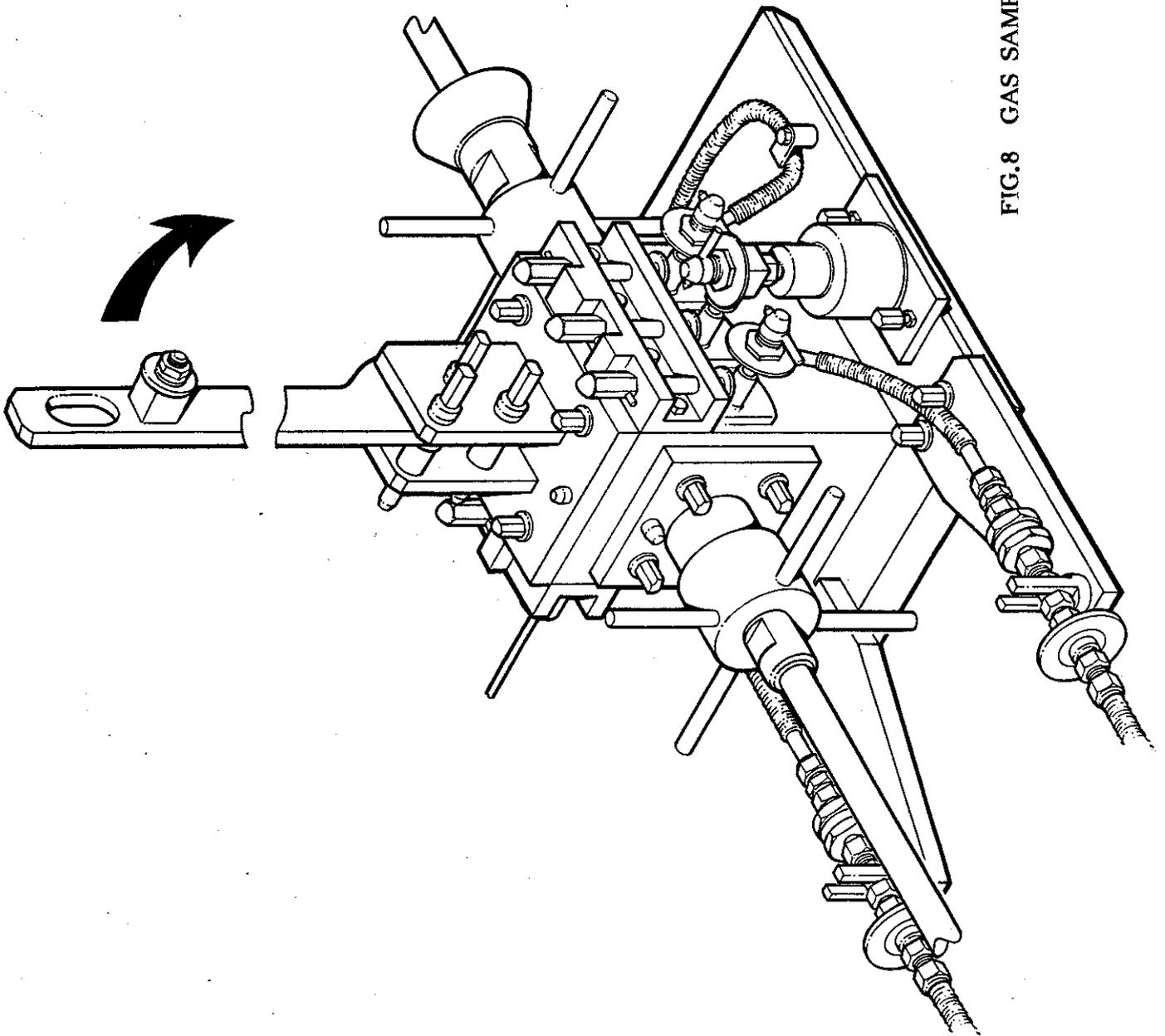


FIG.8 GAS SAMPLING SYSTEM FOR FUEL PINS

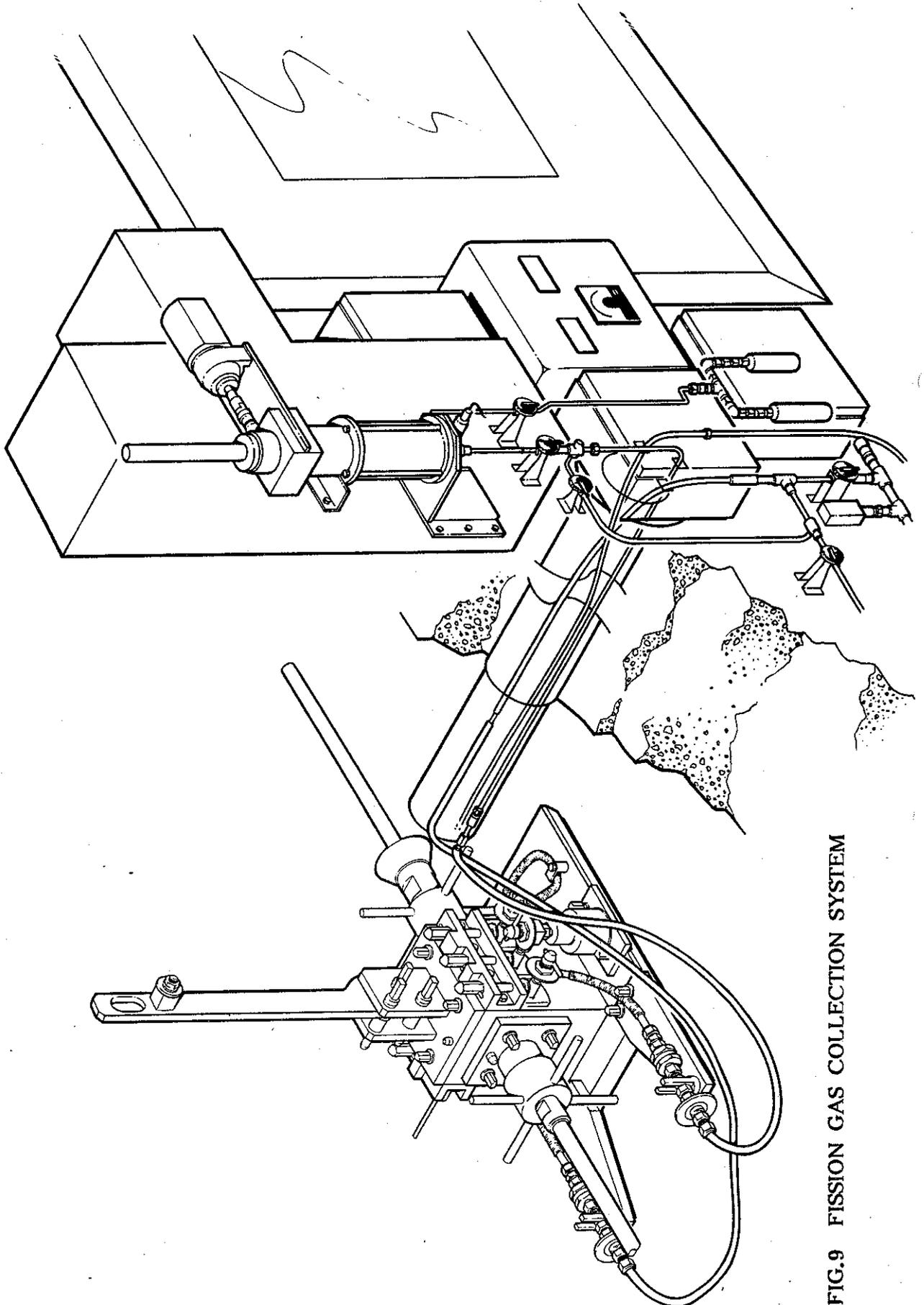


FIG.9 FISSION GAS COLLECTION SYSTEM

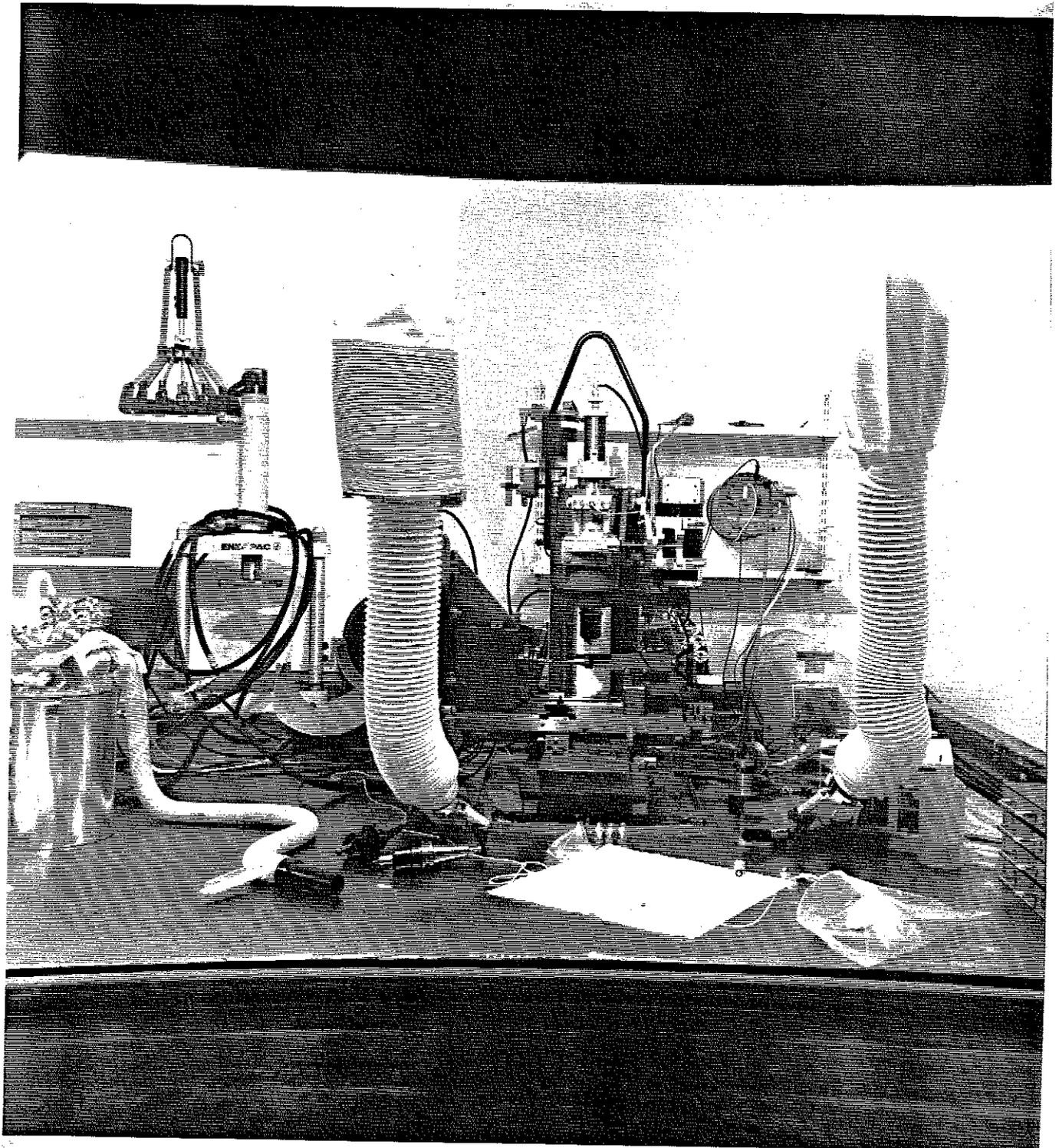


FIG.10 REMOTELY OPERABLE CNC MILLING MACHINE

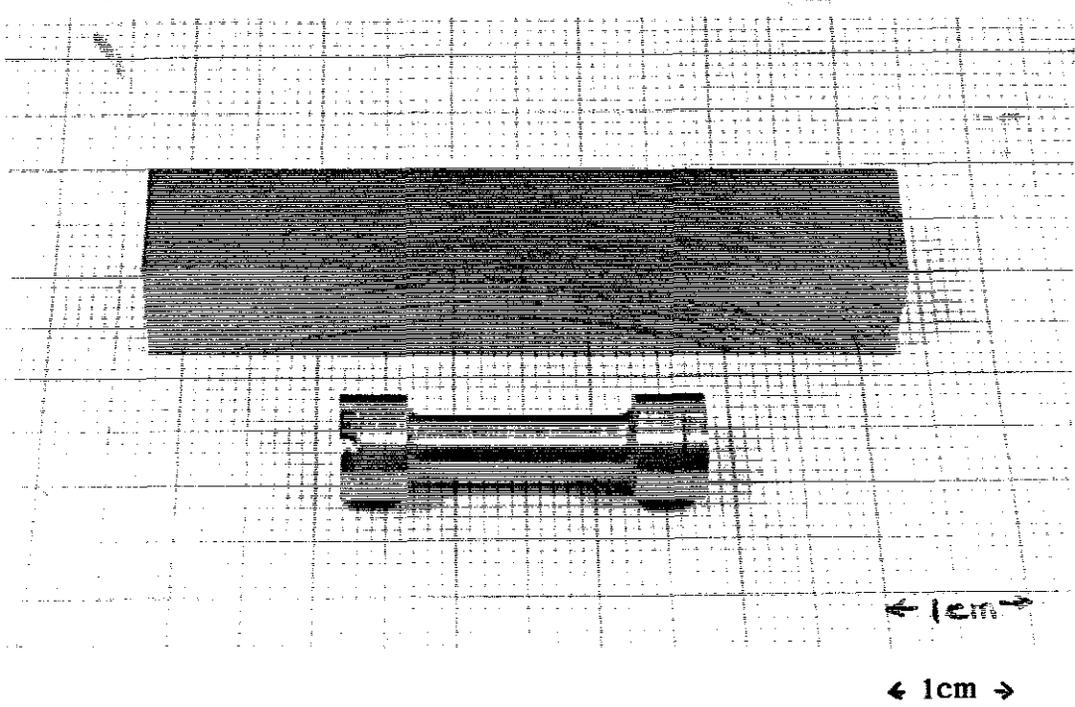


FIG.11 CHARPY AND HOUNSFIELD TEST SAMPLES

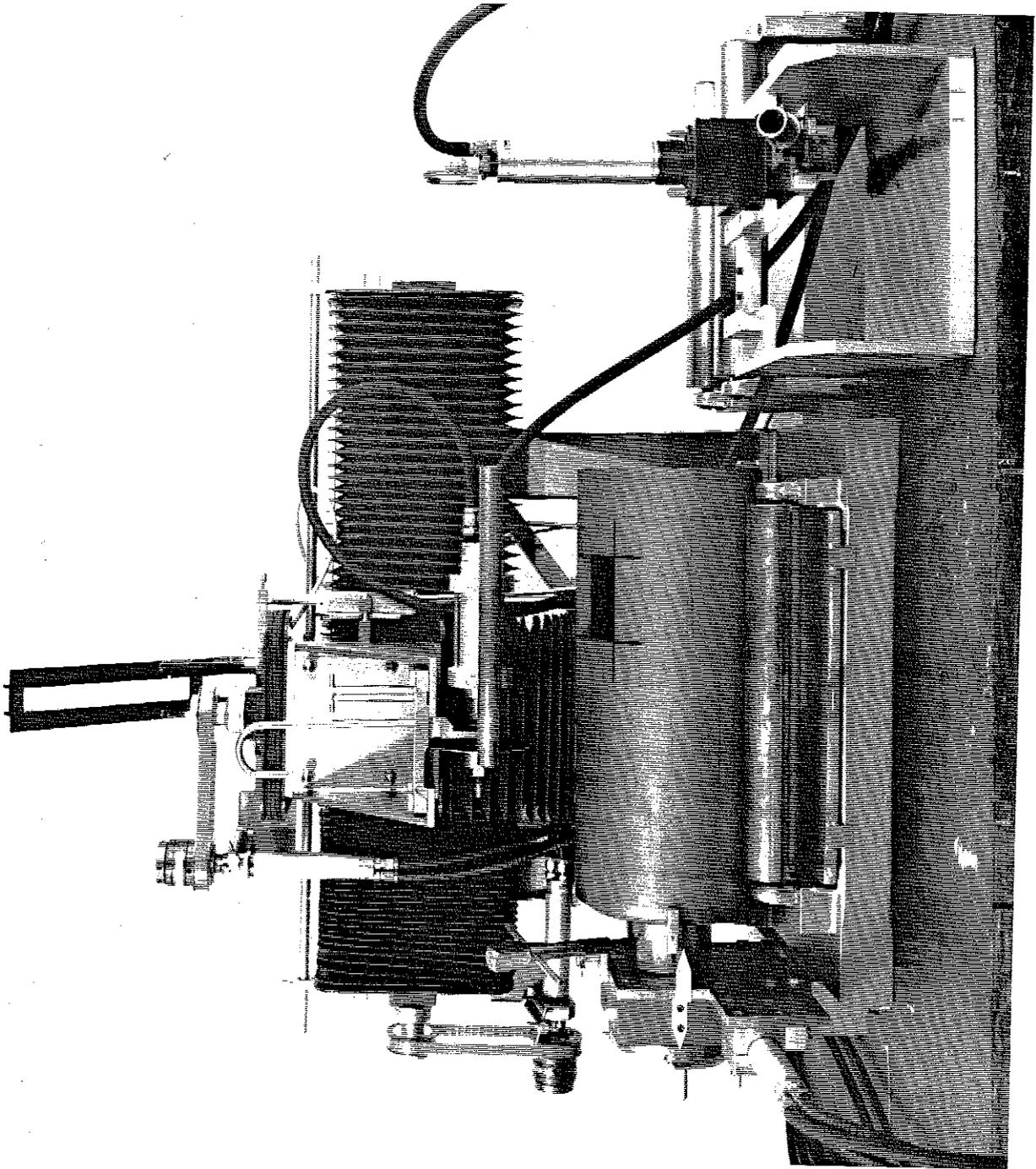


FIG.12 GRAPHITE SLEEVE CUTTING MACHINE

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