IFE/KR/F-97/124

Re-fabrication and instrumentation of irradiated fuel rods

Hans-Jörg Kleemann
Knut Lunde
Dr. Barbara C. Oberländer

Institutt for energiteknikk
Institute for Energy Technology

Institutt for energiteknikk
Institute for Energy Technology

	KJELLER	HALDEN	Availability
Address	**N-2007 Kjeller, Norway**	**N-1751 Halden, Norway**	Limited
Telephone	**+47 63 80 60 00**	**+47 69 18 31 00**	
Telex	**76 361 isotp n**	**76 335 energ n**	
Telefax	**+47 63 81 11 68**		

Report type	**Report number** IFE/KR/F-97/124	**Date** 1997-05-25
	Report title Re-fabrication and instrumentation of irradiated fuel rods	**Date of last revision**
	Client Working Group 'European Hot Laboratories and Remote Handling'	**Revision number**
	Client reference	**Number of pages** 21
		Number of issues 80

Summary

The presentation describes the possibilities at the IFE Hot Lab. to re-fabricate and instrument irradiated fuel rods. The main part of the presentation concerns the equipment used in those operations. The equipment used are referred to as: 'Cutting and Grinding Unit', 'Freezing and Drilling Unit', 'Welding and Drying Unit' and a hydraulic 'Encapsulation Bench'. The 'Welding and Drilling Unit' includes also a 'He-leak test chamber' and a 'Hydraulic Press'.

Further, an overview will be given on how the different end-plug instrumentation is attached to high burn-up nuclear fuel rod.

Distribution

Summary:

Directors

Project management, Halden

Department heads

Keywords:

	Name	Date
Prepared by	Hans-Jörg Kleemann Knut Lunde Dr. Barbara C. Oberländer	1997-05-28

Working Group 'European Hot Laboratories and Remote Handling'

Meeting at Studsvik June 5

Topic I

Re-fabrication and instrumentation of irradiated fuel rods

by

Hans-Jörg Kleemann, Knut Lunde and Dr. Barbara C. Oberländer

Institute for Energy Technology, P.O. Box 40, 2007 Kjeller, Norway

Abstract

The special technique 're-fabrication and instrumentation' applied at the Institute for Energy Technology (IFE) make further testing and measuring of irradiated fuel rods in the Halden Boiling Water Reactor (HBWR) possible. Instruments, necessary for such operations were designed and produced at IFE in the years 1991-92. Hot Lab. operations called 're-fabrication' include all modifications necessary to fit an irradiated fuel rod, commercial or experimental, into the Halden reactor for further testing. 'Instrumentation' includes all operations necessary to fit instruments onto an irradiated fuel rod segment to measure temperature in the centreline of the fuel stack, pressure increase in the fuel rod and/or changes of the rod length during reactor experiments.

The presentation describes the possibilities at the IFE Hot Lab. to re-fabricate and instrument irradiated fuel rods. The main part of the presentation concerns the equipment used in those operations. The equipment used are referred to as: 'Cutting and Grinding Unit', 'Freezing and Drilling Unit', 'Welding and Drying Unit' and a hydraulic 'Encapsulation Bench'. The 'Welding and Drilling Unit' includes also a 'He-leak test chamber' and a 'Hydraulic Press'. Further, an overview will be given on how the different end-plug instrumentation is attached to high burn-up nuclear fuel rod.

List of content

Re-fabrication and instrumentation of irradiated fuel rods

1. Introduction

The Hot Lab. of Institute for Energy Technology (IFE), Kjeller, Norway, developed in 1991 a set of equipment and established an advanced technique for 're-fabrication and instrumentation' of irradiated fuel rods.

The set of equipment comprises four main units, suitable for use in the Hot Cells. Those machines are described as 'Cutting and Grinding Unit', ' Welding and Drying Unit', 'Freezing and Drilling Unit' and 'Encapsulation Bench'.

Since 1992 the Halden Reactor Project (HRP) makes use of irradiated, refabricated and instrumented fuel rods in its experimental program to study the thermal behaviour of high burn-up fuel. Of particular interest is, to characterise the fission gas release behaviour as well as changes in the thermal conductivity of high burn-up fuel.

Since 1991 over 90 irradiated fuel rods have been re-fabricated and/or instrumented. 22 of them have been instrumented with fuel centre line thermocouple (TF), 30 are instrumented with a fission gas pressure transducer (PF) and 5 fuel rods with elongation detector (EF). 36 AGR rods have been encapsulated in a zircaloy cladding and instrumented with a combined fuel rod elongation detector (EF) and a failure detector. In addition ca. 20 other fuel rods have been re-fabricated in different ways, but not instrumented.

This paper will give a short description of the re-fabrication and instrumentation equipment used at the IFE Hot Lab. and an overview will be given on how the different end-plug instrumentation is attached to high burn-up nuclear fuel rod.

2. Equipment

The Cutting and Grinding Unit (Fig. 1a and 1b)

This machine is a modified lathe with changeable tools for cutting and grinding and an adapted part for defuelling of irradiated fuel rods. This unit is the workhorse for all re-fabrication and instrumentation operations in the Hot Lab. such as: cutting of a fuel rod with a cutting tool in order to remove the endplugs or to reduce the length of the fuel rod; modify the outer surface of a fuel rod with different kinds of turning and trimming tools; remove oxide of the canning at the welding zones for the new instruments; drilling a hole in the end plug in order to puncture the rod and getting connection between the inside of the rod and the new 'Pressure Transducer' and many other helpful operations like measuring the depth of the defuelled rod part, mounting of new ends to the fuel rod, and, and, and.

The machine and the tools of the cutting and grinding unit and the other 3 working benches are modified and adapted for easy manipulations with a pair of 'Master Slave Manipulators' and a 'Power Manipulator' from outside the Hot Cells.

A three-phase programmable AC motor with a frequency variable speed controller drives the chuck rotation. Two step motors control the x and y directing of the tool holder. All movements are operated from a control panel at the outside of the cells.

The Welding and Drying Unit (Fig. 2a and 2b)

This Unit is just called Welding and Drying Unit, but many other important features are mounted to the machine.

The main part is the TIG welding chamber. It is a closed system, where the fuel rod is circumferential welded in a He atmosphere. The TIG electrode is fixed and the fuel rod rotates, driven by a programmable step motor for chuck rotation. In the same chamber the fuel rod can be pressurised up to 25 bar and seal welded. The normal filling gas is He grade 6, but also mixtures like Helium-Argon are possible. Fuel rods with up to1.5 meter length and different diameters can be welded.

The 'Drying Unit' is a electrical heated vacuum oven, mounted at the outside back of the welding chamber. The oven is used for fuel rod drying, after drilling the center line hole and for he-leak test at the end of the project, to verify that all welds are successfully sealed.

A hydraulic pressbench, for use during assembling of the fuel rod components, is mounted at the front of the 'Welding and Drying Unit'.

The Freezing and Drilling Unit (Fig. 3a and 3b)

The most difficult operation is to drill a hole with 2,5 mm in diameter and a length of up to 45 mm effective in the centreline of the irradiated fuel. This operation is done with the 'Freezing and Drilling Unit'. The name of the machine indicate the sequence of the working steps:

The first operation is to fill the fuel rod with liquid CO_2 and subsequent freezing down with liquid N_2. This is done to stabilise the fuel under the drilling operation. After that, all CO_2 ice at the outside of the rod is drilled out with a standard drill, before diamond drill tubes are used for the centre hole drilling.

A molybdenum tube, for fuel support, is inserted into the centreline hole directly after the drilling operation.

The drill rotation is driven by a programmable AC motor with a frequency variable speed control and the horizontal movement is driven by a step motor and can be used either manually or pre-programmed.

The Encapsulation Bench (Fig. 4a and 4b)

The encapsulation bench is designed to encapsule advanced gas cooled reactor (AGR) fuel rods into a new tube and simulate AGR fuel rod conditions in the Halden Boiling Water Reactor.

Other Equipment

At the outside of the cells is the 'Operation and Control Unit' which contains all driving and control devices for the three machines inside the cell. In addition a TIG welding generator, a Helium leak detector and a liquid nitrogen reservoir is used in the process of re-fabrication and instrumentation of irradiated fuel rods.

3. Re-fabrication and instrumentation procedures

To instrument an irradiated fuel rod with both TF and PF, around fifty different process steps are necessary in the operational sequence. The main steps are as follows:

- The fuel rods have to be transported to the Hot Lab. in Kjeller, Norway, unpacked and identified.
- Neutron radiography of the fuel segment has to be done in order to determine where the fuel rods are to be cut and defuelled.
- In the 'Cutting and Grinding Unit' the fuel segments are machined to a specified length.
- In the same machine the ends are defuelled if necessary.
- Both the inside and outside surface of the fuel rod canning tube ends are ground to remove the oxide before welding of the end plugs.
- New end pellets, plenum spring, end sleeve and lower end plug have to be assembled.
- The lower end plug and thereafter the end sleeve at the upper end have to be pressed in and TIG welded to the canning tube.
- The drilling of the hole in the fuel stack to accommodate the fuel centre thermocouple is performed in the 'Freezing and Drilling Unit'. The Fuel Segment Assembly is filled with liquid CO_2 and subsequently frozen by filling liquid nitrogen in a container surrounding the segment. The CO_2 as a liquid, fills all voids and in the solid state holds the pellet fragments together during drilling. CO_2 also has the advantage of being entirely removed once drilling of the centre hole is complete.
- Centre holes are drilled in the centre of the fuel stack by means of a diamond drill tube (outer diameter 2.5mm). Due to the fragmented pellet structure of the high burn-up fuel, reinforcement of the inner wall of the thermocouple hole is necessary in order to avoid collapse once the CO_2 is melted. After drilling, a tube of molybdenum is inserted in the centre hole.
- Depressurisation, melting and drying. After depressurisation, the rod is placed in the drying oven and vacuum outgassed at elevated temperatur.
- The PF End Plug Assembly has to be TIG welded to the Lower End Plug

- The central fuel thermocouple is inserted into the pellet stack/Mo-tube and the TF End Plug Assembly TIG welded to the End Sleeve.
- The fuel rods are pressurised and seal welded in Grade 6 helium (99.9999 % He)
- He-leak test to verify that the rod is sealed.
- Electric loop test to control that the PF and TF work as expected
- Neutronradiography to verify the TF hole and the thermocouple position
- Packing and sending

4. Quality Control

A number of control operations are included in the re-fabrication process:

- Neutron radiography before re-instrumentation
- Measurement of the inner diameters, profile and length of the fuel rod
- Neutron radiography after instrumentation
  - Integrity of the instrumented fuel rod
  - Depth and alignment of the drilled centre hole
  - Location of the TF hot junction
- Helium leak measurement
- Verification of the thermocouple (TF) integrity by means of electric loop measurements
- Function test of the pressure transducer (PF)

5. Re-fabrication and instrumentation projects accomplished

Over 90 irradiated fuel rods or segments have been re-fabricated and/or instrumented.

Year	Number of Rods	Burn-up MWd/kg U	Instrumentation/Remarks
91	2	50	TF
92	28	20	EF / Encapsulation
94	4	17/28	PF
94	3	14/24	PF
94	1	0	Fabrication (Fresh fuel with irradiated canning)
95	3	59 (68)	TF + PF
95-96	4	43	TF + PF
96	6	40	TF + PF
96	8	12/20	EF / Encapsulation
96	1	0	Fabrication (Fresh fuel with irradiated canning)
97	1	52	EC + TF
97	6	40	TF + PF
97	4	29/52	EC
97	4	29/52	PF

Table 5.1 – Overview of re-fabricated and instrumented fuel rods until June 1997

6. Instrumentation possibilities

Fuel centre thermocouple, TF

Objective:

- Reliable in-pile fuel centre temperature measurements on irradiated fuel rod.
- In-pile study of fuel thermal behaviour at high burn-up levels in relation to fission gas release.

Working steps:

- Neutronradiography
- Cutting of the fuel rod
- Machining to the right dimensions
- Defuelling
- Welding of the end sleeve
- Drilling of the centre hole
- Drying of the fuel rod
- Inserting of the centre fuel thermocouple and welding
- Pressurisation and seal welding
- He-leak test
- Neutronradiography
- Verification

Limitation:

- 25 bar maximum gas (re) filling pressure
- The length of the effective centre thermocouple hole is limited to 45 mm

Fission gas pressure transducer, PF

Objective:

- Reliable in-pile study of the fission gas release behaviour on irradiated fuel rod.
- In-pile study of fuel thermal behaviour at high burn-up levels in relation to fission gas release.

Working steps:

- Neutronradiography *
- Cutting of the fuel rod or puncturing of the fuel rod with an axial hole.
- Machining to the right dimensions *
- Defuelling *
- Attaching of the end plug with the fission gas pressure transducer and welding
- Pressurisation and seal welding
- He-leak test

- Verification

Limitations

- 25 bar maximum gas (re) filling pressure

Working steps market with * are sometimes not necessary, depending on the fuel rod construction.

Cladding elongation detector, EC

Objective:

- Reliable in-pile canning extension measurements on irradiated fuel rod.
- Pellet cladding mechanical interaction at High burn-up.

Working steps:

- Neutronradiography *
- Cutting of the fuel rod *
- Machining to the right dimensions *
- Defuelling *
- Attaching of the end plug with the cladding elongation detector and welding
- Pressurisation and seal welding *
- He-leak test *
- Verification *

Limitations

- 25 bar maximum gas (re) filling pressure *

Working steps market with * are sometimes not necessary, depending on the fuel rod construction.

Encapsulation of irradiated AGR fuel rod with elongation fuel and failure detector, EF

Objective:

- Pellet cladding interaction of advanced gas cooled reactors (AGR) with fuel failure indicator.
- Simulation of AGR temperature conditions in the Hot Water Boiling Reactor in Halden.

Working steps:

- Machining of the fuel rod
- Attaching of a track plug and welding
- Encapsulating of the irradiated fuel rod into a fresh clad tube
- Attaching and welding of the end plugs

- Pressurisation and seal welding
- He-leak test
- Verification

Limitations:
- 25 bar maximum gas (re) filling pressure

7. Other operations at the Hot Lab.

Re-fabrication of irradiated fuel rods – Fresh fuel into irradiated cladding

Objective:
- Loading of fresh fuel into irradiated cladding allows the study of thermal conductivity behaviour of oxide layer on the zirconium canning, hydriding effect, machanical strength, etc.

Working steps:
- Cutting of the fuel rod
- Defuelling
- Machining of the canning
- Inserting of fresh pellets
- Attaching of the end plugs and welding
- Pressurisation and seal welding
- He-leak test
- Verification

Limitations:
- 25 bar maximum gas (re) filling pressure
- 15-17 cm maximum defuelling length

8. Conclusion

The combination of the skill of technicians and engineers and the advantages of the unique working benches described make it possible to re-fabricate and instrument irradiated fuel rods and use them in the Halden Boiling Water Reactor for scientific research. Those experiments are necessary to understand the behaviour of the fuel rods under normal and extreme conditions and with this knowledge it is possible to increase the safety and reliability of the Nuclear Power Stations.

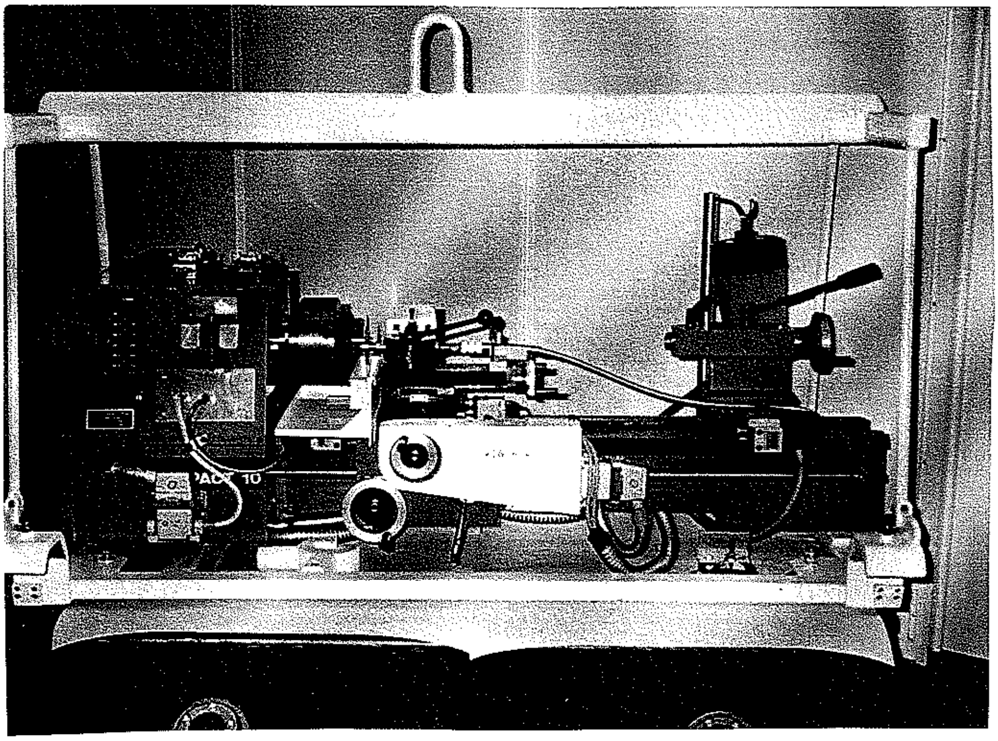


Figure 1a The Cutting and Grinding Unit

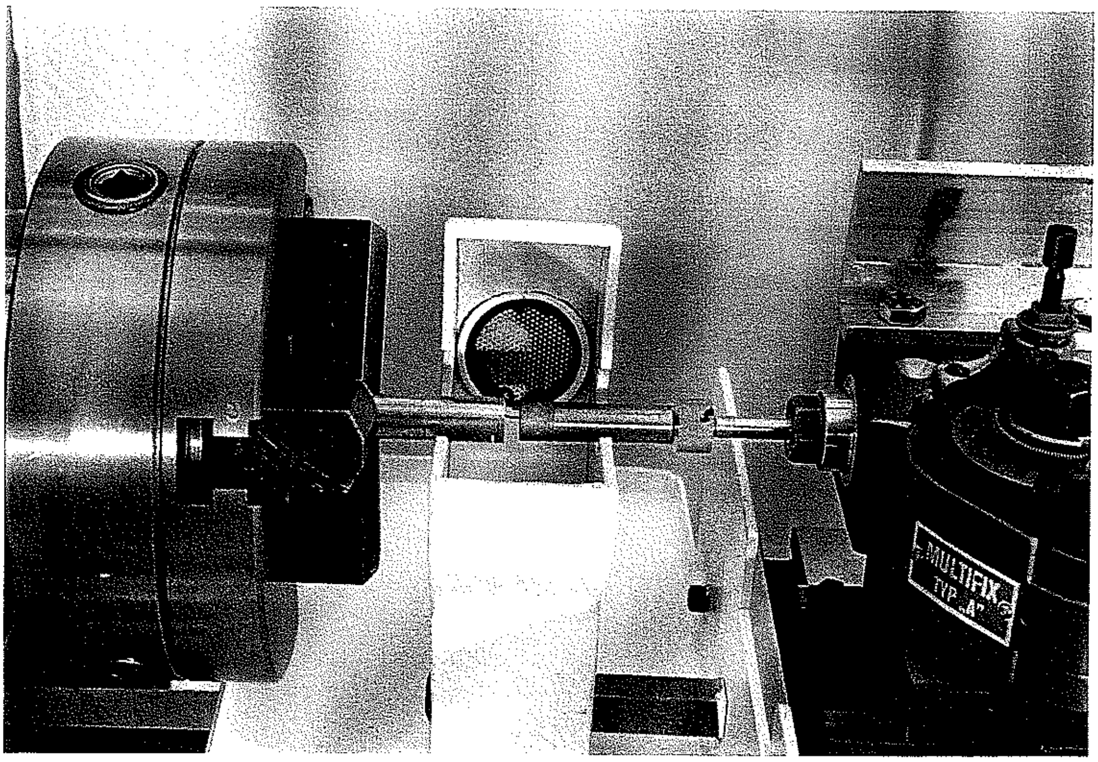


Figure 1b The Cutting and Grinding Unit, showing the diamond drill tube used for defuelling

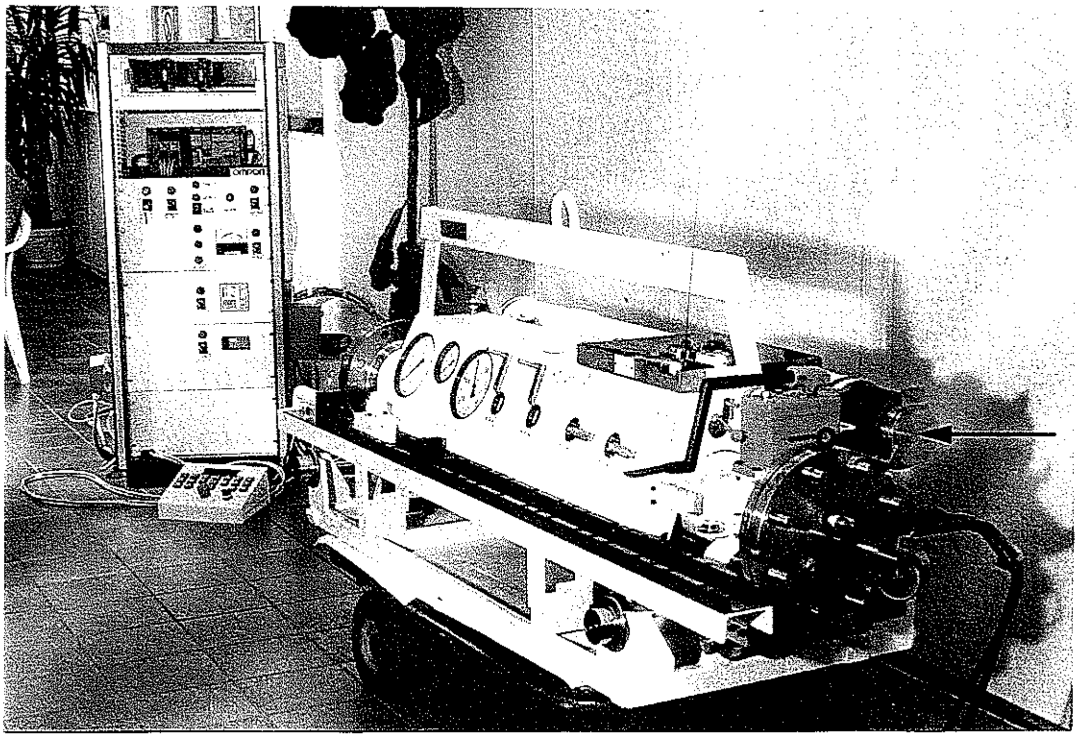


Figure 2a The Welding and Drying Unit

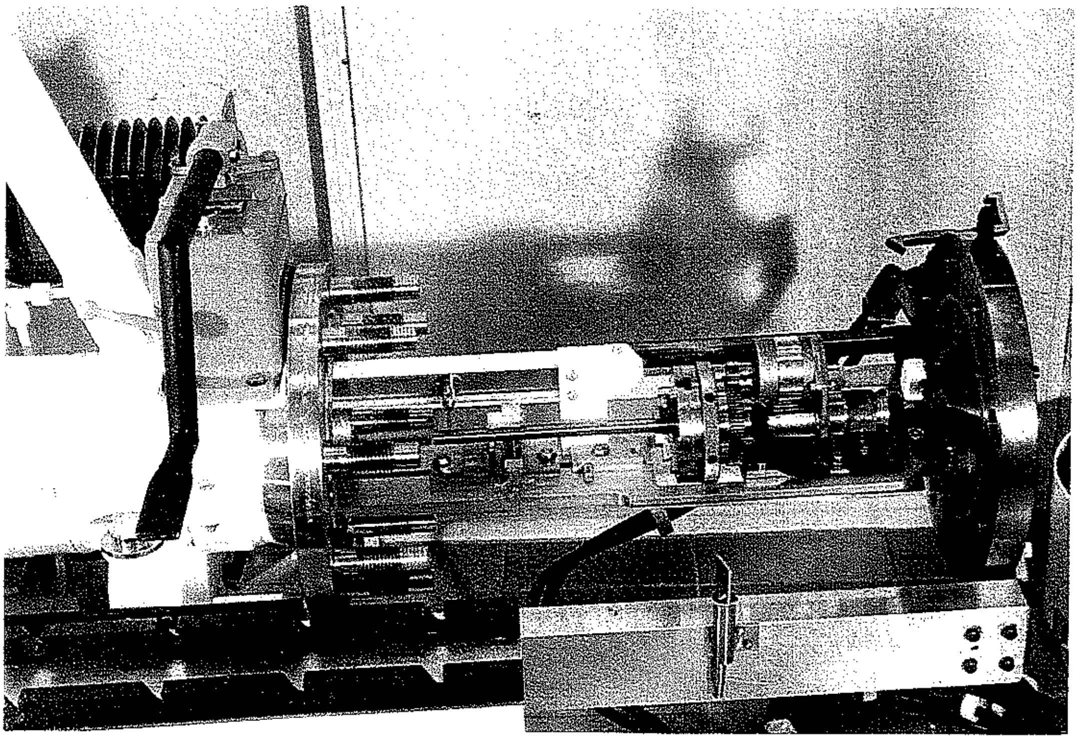


Figure 2b The Welding and Drying Unit, showing the chuck, the rod supports and the TIG electrode

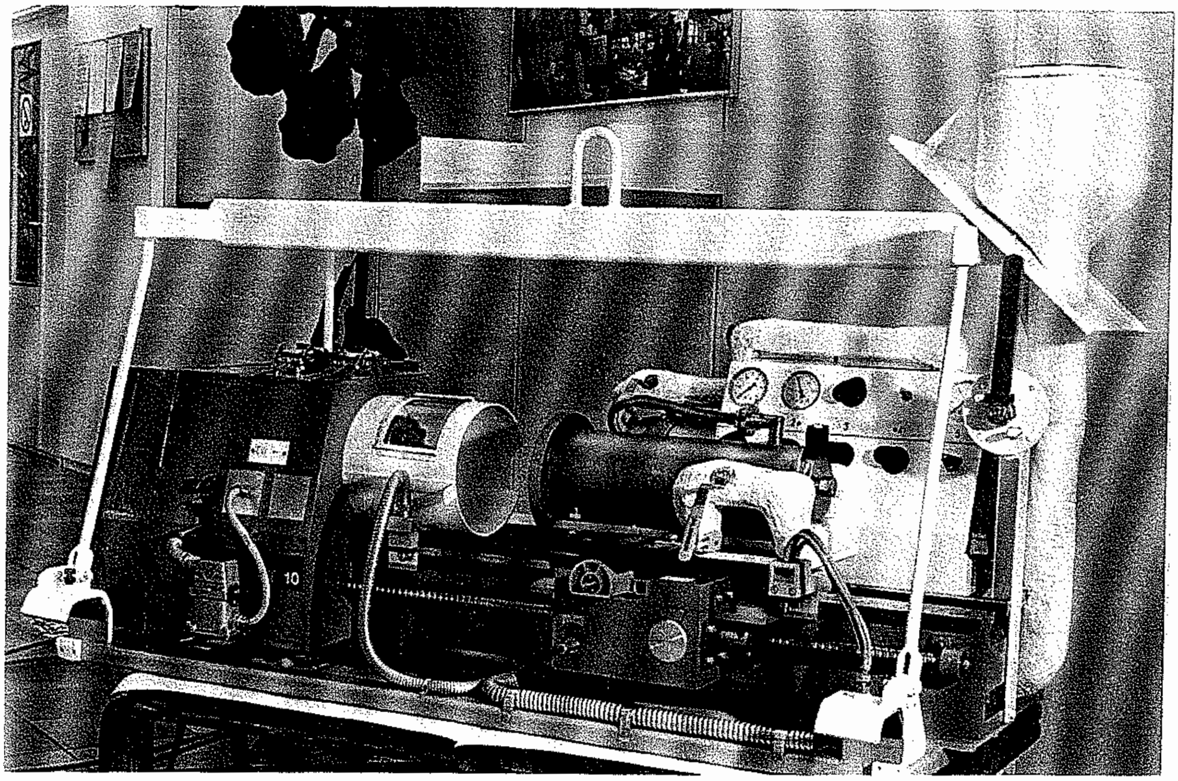


Figure 3a The Freezing and Drilling Unit

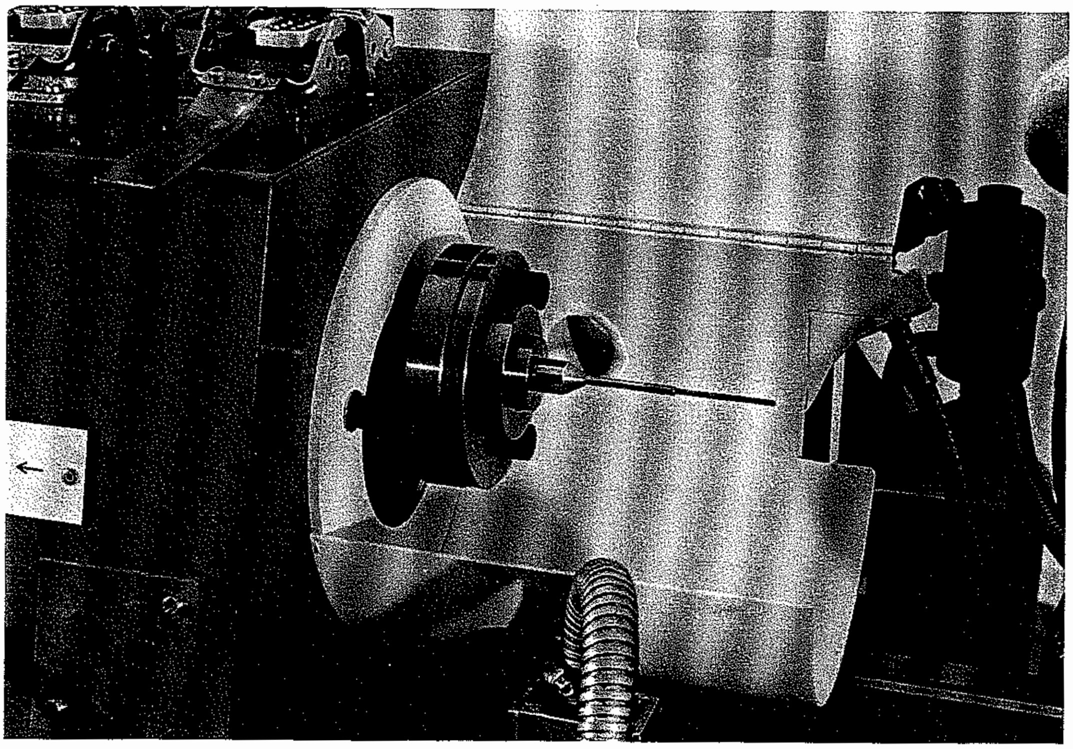


Figure 3b The Freezing and Drilling Unit, showing the diamond drill tube

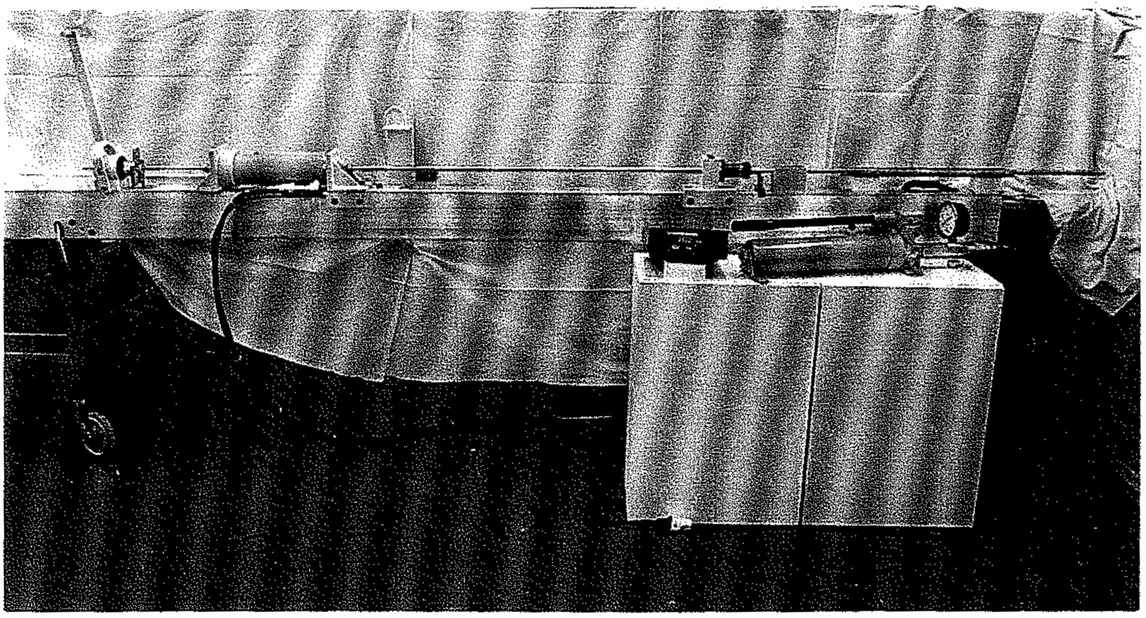


Figure 4a The Encapsulation Bench

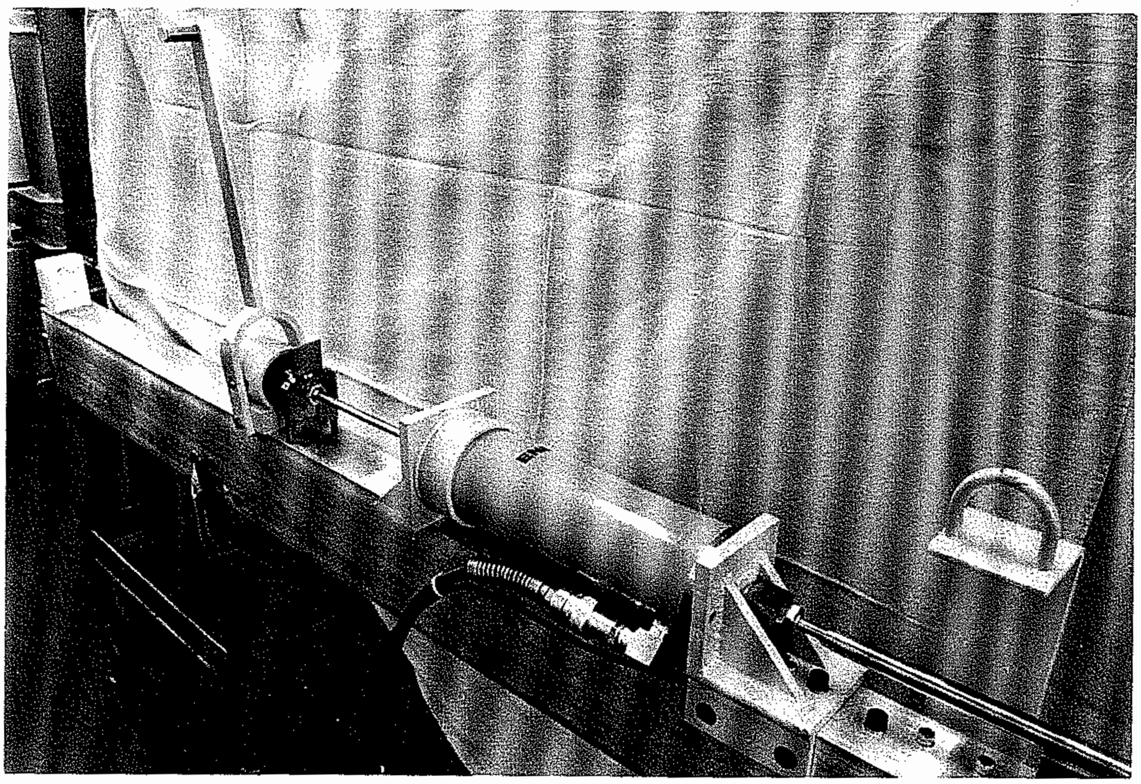
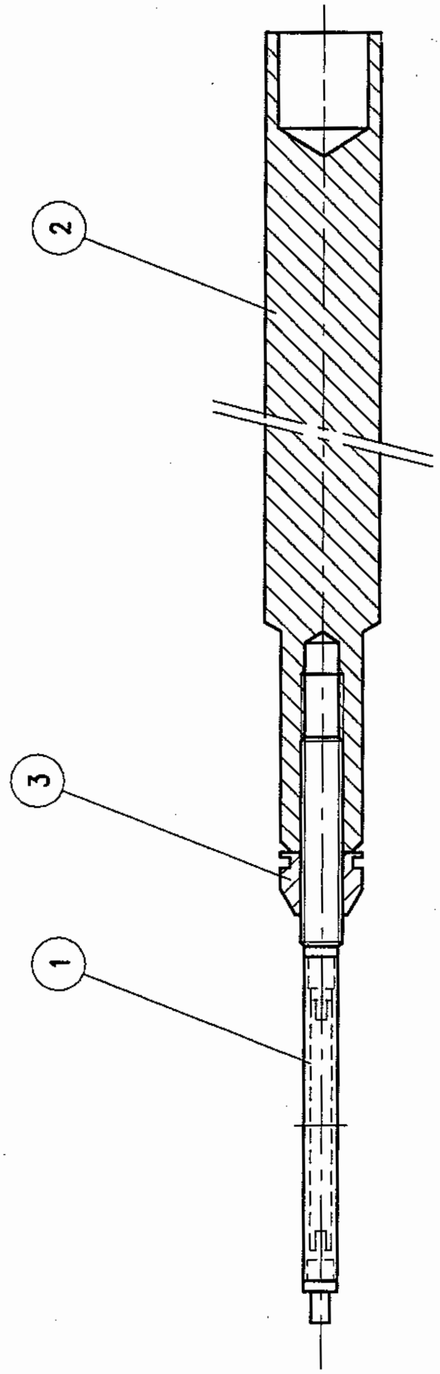
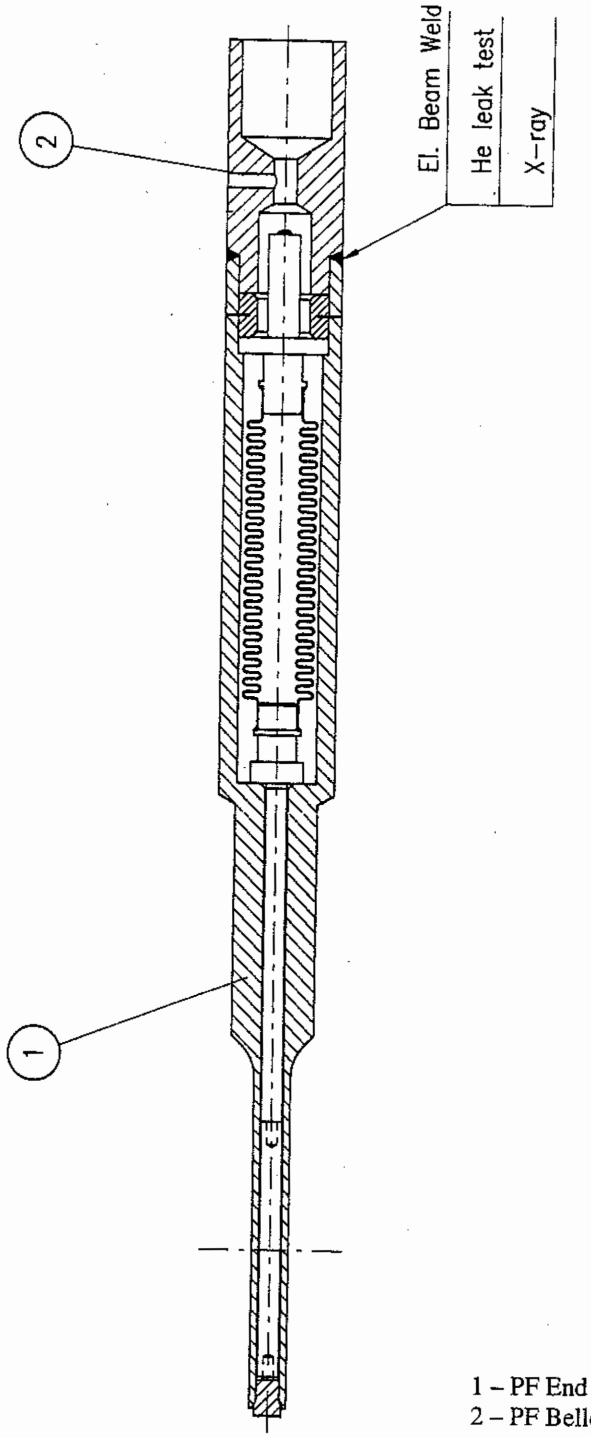


Figure 4b The Encapsulation Bench, showing the hydraulic cylinder with oil connection and force cell



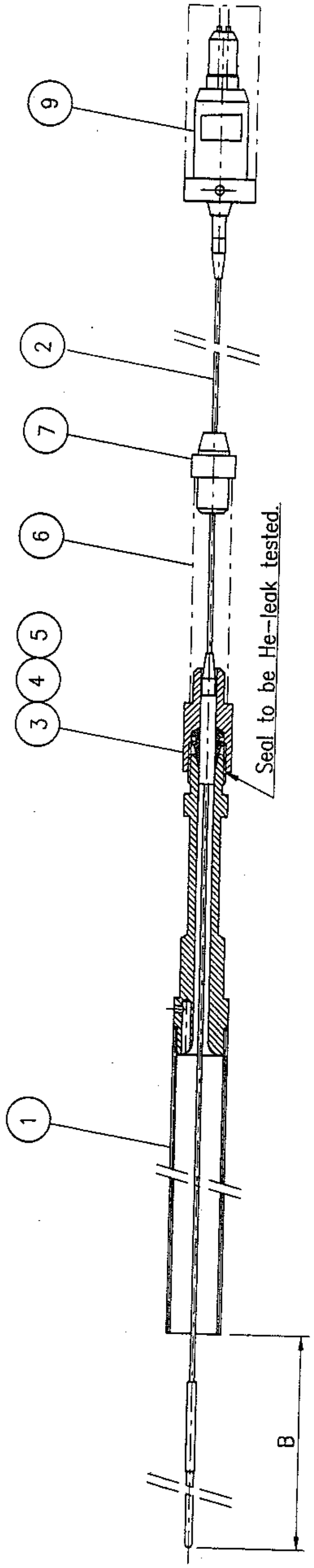
1 - EC Core Assembly
2 - EC Lower End Plug
3 - Nut

Figure 5 Cladding Elongation Detector



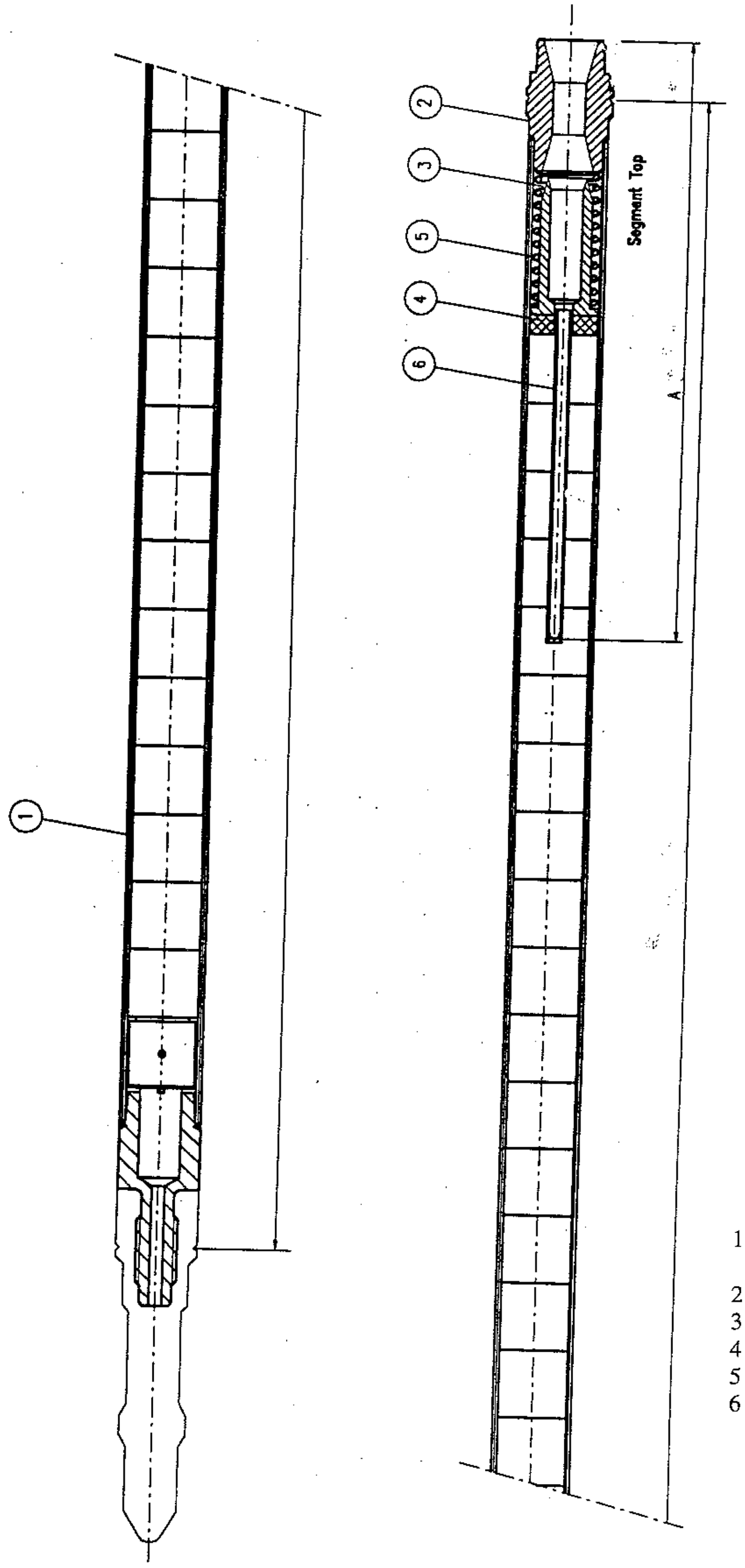
1 – PF End Plug
2 – PF Bellows Pressure Transducer

Figure 6 Pressure Transducer



1 – TF End Plug Pre-assembly
2 – TF Assembly
3 – Front Ferrule
4 – Back Ferrule
5 – Nut
6 – Spring
7 – Lock Knob
8 – Support Sleeve
9 – Contact Unit

Figure 7 Fuel Centre Thermocouple



1 – Segment for reinstrumentering
2 – End Sleeve
3 – Spring
4 – End Pellet
5 – Spring Support
6 – Molybdenum Tube

Figure 8 Instrumented fuel rod after machining

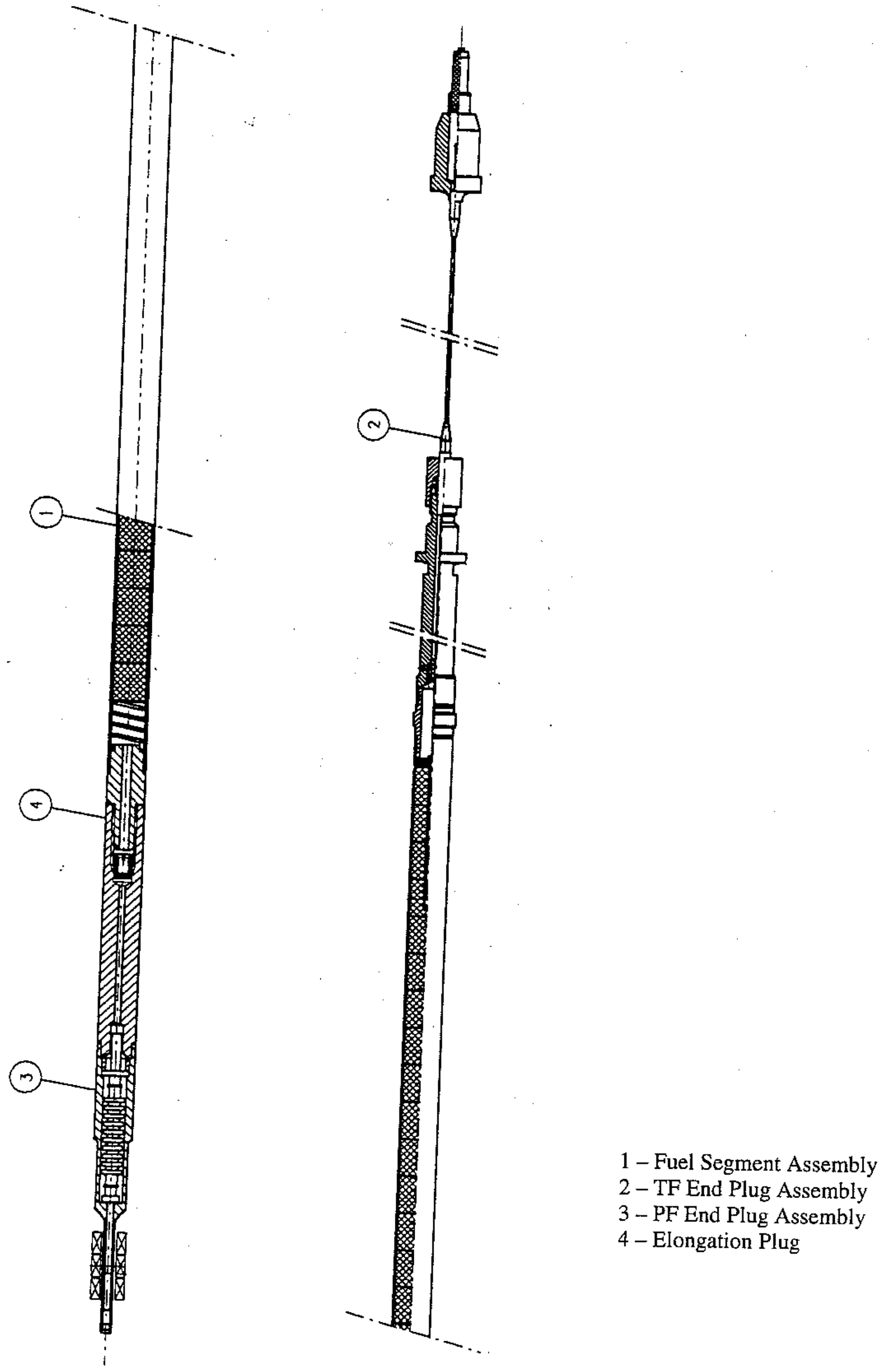


Figure 9 Complete instrumented fuel rod

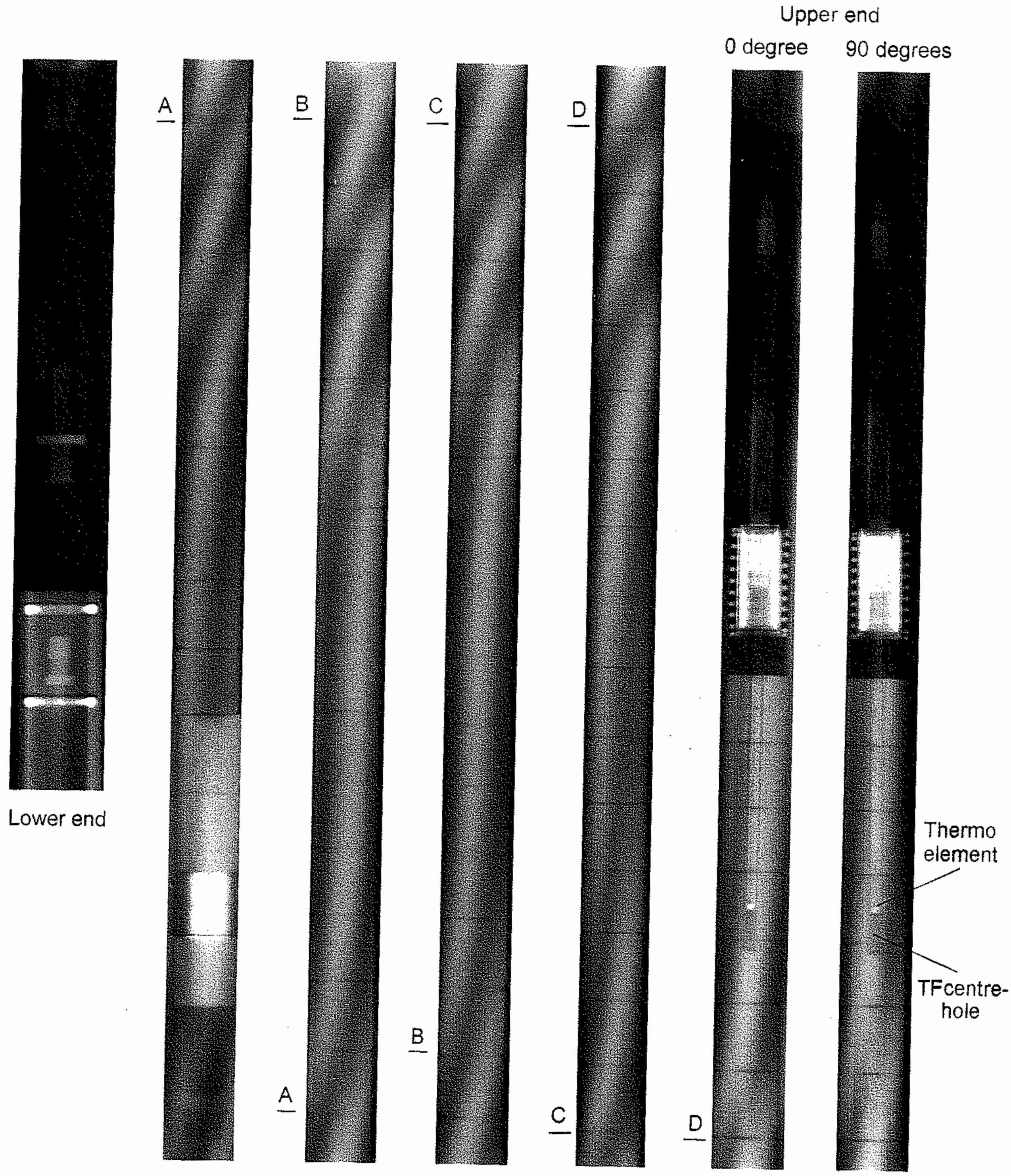


Figure 10 Neutronradiography of instrumented fuel rod