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REFABRICATION OF IRRADIATED LWR FUEL RODS

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Paper prepared for the plenary meeting of the Working Group for Hot Laboratories and Remote Handling, Chinon, 15 and 16 June, 1993

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CONTENTS

SUMMARY

In this paper an overview is presented of the activities to produce six refabricated fuel rods, selected out of two 2 meter long fuel rods.

The work was carried out in the main hot cell section and in the alpha-tight hot cell section of the ECN Hot Cell Laboratory. Before starting the in-cell activities excercises were performed on inactive zircaloy 2 (certified material). Not only to determine the correct welding parameters but also to avoid miscalculations during adapting the lathe. Also several welds on active zircaloy 2 were produced and examined by microscopic examination.

Directly after unloading of both fuel rods in the main hot cell section verification of the identification numbers on the rods and a brief visual inspection took place.

On both fuel rods gamma scanning was performed to obtain the fuel stack length and the pellet positions. These results were used to determine the exact cutting positions prior to refabrication.

Profilometry was carried out to compare the diameter before and after refabrication.

Puncturing of both fuel rods was performed on the standard puncturing device and vacuum gas collecting unit. After puncturing the holes were sealed with synthethic resin.

The fuel rods were cut using the so called "bag technique" in combination with a clamping device. After drying, pressurizing and closing of the stem valve the refabricated fuel rod was transported back to the alpha-tight hot cell section to weld the second containment.

Visual inspection was performed and several photographs were taken, in particular of the weld zone on top and bottom of the refabricated fuel rods.

The exact fuel stack length and the pellet positions of the refabricated fuel rods were determined by gamma scanning. This information was essential for a correct performance of the irradiation programme. Profilometry measurements were carried out on all 6 refabricated fuel rods.

Before and after each transport a decontamination procedure was performed.

1. INTRODUCTION

For more than 20 years, the High Flux Reactor (HFR) Petten and the ECN Hot Cell Laboratory (HCL) at Petten have been supporting the LWR fuel irradiation programmes related to the investigation of fuel rod performance under various operation modes, mostly transients. The test fuel rods for these programmes consist mainly of pre-irradiated fuel rod segments which previously have been operated in commercial power reactors.

The testing methods employed at Petten are being constantly improved. During the last 4 years they have been extended with hot cell techniques for refabrication of test fuel rods from full length power reactor fuel rods, re-instrumentation of pre-irradiated fuel rod segments with pressure sensors and instrumentation of refabricated fuel rods or fuel rod segments with a central thermocouple and/or pressure sensors.

During 1992, the refabrication system was installed at the Petten HCL in order to cope with the increasing demand for HFR testing of advanced and/or high burn-up fuel rods, of which only pre-irradiated full length fuel rods from commercial power reactors are available. Meanwhile, several test fuel rods have been refabricated and successfully tested in programmes related to the investigation of power transient behaviour. In addition, this new technique provides the basis for the preparation of pre-irradiated fuel rod segments and of segments from full length fuel rods, for re-instrumentation with central thermocouples, pressure sensors and other instruments.

In 1989 a system for re-instrumentation of pre-irradiated fuel rod segments with pressure sensors was introduced in the Petten HCL. Fuel rods re-instrumented by this method have been successfully tested in programmes addressing transient fission gas release phenomena.

Both the refabrication and the re-instrumentation technique, together with a special drilling and assembling method, provides the basis for re-instrumentation of both types of fuel rod segments with central thermocouples, pressure sensors and other instrumentation. Studies and preparatory work for various combinations have been performed.

2. GENERAL

The refabrication technique at the Petten HCL is based on the method developed earlier at the Risø National Laboratory (NL) in Denmark [2]. Detailed information on this method, the drilling technique for accommodation of a central thermocopule in the fuel and its installation procedure, has been obtained within the framework of a know-how transfer contract between the Petten HCL and the Risø NL. In view of other boundary conditions and availability of equipment at the Petten HCL, several details of the refabrication technique had to be adapted to the requirements of the Petten HCL and are therefore different in comparison to the reference method.

2.1 Reception of the full length fuel rods and preparation for refabrication

In most cases the pre-irradiated full length fuel rods are directly delivered from the commercial power reactor to the Petten HCL. For the transport of fuel rods with lengths exceeding 2 m and up to approximately 4.5 m total length, the R52-type container has been selected. Provisions for reception of R52-type containers have been made and are operational at the Petten HCL.

The available handling space in the Petten HCL is limited to 2 m for objects which need to be handled in all directions. Therefore, full length fuel rods are first punctured and segmented into operable lengths. After the non-destructive investigations further segmentation into the lengths needed for refabrication is performed. Table 1 gives a sequential overview of the preparatory activities. Because the main hot cells at the Petten HCL are not alpha-tight cells, the segmentation is performed within a closed, local containment, formed by a plastic bag. For segmentation a pipe cutter, situated in this plastic bag (Fig. 1), with seals at both sides of the cutting area, is employed. After cutting, the pipe cutter and the two sides of the plastic bag are tightened and isolated by several welds across the plastic bag. The bag is then cut between the welds and provides a temporary seal to the open end of the fuel stack.

Table 1. *Delivery, reception and preparatory work prior to the refabrication pre-irradiated fuel rods*

Step Activities

At the commercial power reactor fuel storage basin

1. Withdrawal of the full length fuel rod from the fuel element. Loading into a transport container (TN6, max. fuel rod length approximately 2 m).
   Direct shipment to the Petten hot cells.

At the Petten hot cells, main hot cell section

2. Reception of the transport container, unloading of the full length fuel rods and temporary storage.
3. Puncturing for pressure measurement and fission gas analysis.

4. Investigation and fuel rod characterization by non–destructive methods like gamma–scanning, eddy current check, profilometry and visual inspection.
5. Selection of the fuel rod sections for refabrication and further segmentation using the plastic bag technique.
   Marking of the segment coordinates and of the original top side.
   Typically fuel rod segments for refabrication are cut into lengths of approximately 390 mm before they are transferred to the alpha–tight hot cell section for refabrication (see Fig. 2 through 8).

2.2 Refabrication of LWR segmented fuel rods

The refabrication of the segmented fuel rods is performed with dedicated refabrication devices. The steps in the refabrication procedure and characterization of non–instrumented fuel rods are summarized in Table 2.
A description of the required qualifications is presented in chapter 3.
A typical lay–out of a refabricated fuel rod is given in Fig. 9.

Table 2. *Refabrication and fuel rod characterization sequence*

Step Activities

At the alpha–tight hot cell section (in argon atmosphere)

1. Cutting of the lower end of the fuel rod just before the bottom using a rotating saw with a diamond cutting blade.
2. Machining the bottom end on the lathe up to the precise bottom coordinate.
3. Removal of one pellet by drilling and machining of the cladding tube internally and externally for preparation of the insertion and welding of a new end plug.
   Determination of the fuel stack position by depth measurement relative to the cladding.
4. Introduction of an isolation pellet and insertion of the lower end plug with a cone shaped fit.
5. Welding of the end plug to the cladding by rotating the rod under a TIG welding head (cell under argon atmosphere).
6. Closure of the central opening in the end plug with a valve type stem; attachement of the lower centering piece and welding to the lower end plug.
7. Cutting and machining of the upper end of the fuel rod to the specified length.
8. Removal of several pellets by drilling and machining of the upper end of the cladding tube in order to adapt it to the upper end plug dimensions. Determination of the upper fuel stack position by depth measurement relative to the cladding.
9. Insertion of an isolation pellet and fixation of the fuel stack by a spring sleeve. The spring sleeve is released automatically during the first start–up to power at the HFR.

10. Welding of the top end plug to the cladding by rotating the rod under a TIG welding head (cell under argon atmosphere).
    Temporary sealing of the central bore in the top end plug.
11. Cleaning and decontamination of the fuel rod external surfaces.
12. Transfer of the fuel rod to the large main hot cell section.

At the main hot cell section

13. Second decontamination of the fuel rod external surfaces.
14. Removal of the temporary top seal and connection to the gas filling system.
15. Insertion into a tube furnace. Alternating sweeping of the fuel rod by evacuation with vacuum and helium filling (above 100°C). Finally, at room temperature, helium filling of the fuel rod to the specified pressure.
16. Closure of the central opening in the top end plug with a valve type stem and cutting the minitube in order to release the refabricated fuel rod.
17. Transfer of the fuel rod to the alpha-tight hot cell section.

At the alpha-tight hot cell section (in argon atmosphere)

18. Attachment of the second containment piece (pos. 5). and TIG welding to the upper end plug.
19. Decontamination and transfer to the main hot cell section.

At the main hot cell section

20. Fourth decontamination of the fuel rod surfaces.
21. Characterization of the fuel rod by non-destructive methods (e.g. visual inspection, gamma scanning, eddy current cladding check, profilometry or oxide layer measurement).
22. Visual inspection.
23. Attachment of the fuel rod support piece and spot welding to the second containment (pos. 5).
24. Loading of the fuel rod into a dedicated transport vessel. Transfer to the HFR.

3. QUALIFICATION

3.1 Requirements

The requirements of the commissioner existed of the preparation of at least 3 weld specimens using length of irradiated fuel rods, demonstrating satisfactory welds by leak testing with an internal pressure of 25 bar absolute, and examination of a metallographic section through the welds.

3.2 Qualification tests

To establish the right welding parameters about 30 welds were produced on zircaloy 2 cladding tube and zircaloy 2 plugs. The same parameters were used for the welding of the top and bottom plugs on the irradiated fuel rods.

For the refabrication of the test fuel rod, parts of a fuel rod coming from the Dodewaard reactor, which was already present in the HCL, were used. Reason for using this fuel rod was the similarity in material (zircaloy 2) and dimensions compared to the fuel rods of the client.

Before usage in the hot cell all tools and equipment were tested. The reliability of the needle valves was checked thoroughly and the moment was set at 2.5 Nm at a pressure of 30 bar He.

Three weld specimens were made using a length of an irradiated fuel rod and of each weld a section was metallographically examined.

To avoid unforeseen circumstances also a completely refabricated fuel rod was produced. The refabricated fuel rod was submitted to all necessary actions, including drying and pressurizing. After connection of the fuel rod to the gas filling panel through an ss minitube and filter (SS6FW, mm15) it was possible to carry out standing leak tests. This way not only the integrity of the weld could be established, but also the integrity of the primary gas line up to the two way valve.

The fuel rod was pressurized in steps of 5 bar each. After each step the He pressure was deventilated through the He exhaust, and the fuel rod was evacuated again up to 10^{-2} bar. During this process the temperature of the fuel rod was kept to 115°C. The maximum pressure during the test was 30 bar. The system was left on standing leak test for 48 hours. There was no detectable gas leakage in the system. The final pressure in the test fuel rod before closing the needle valve was set to 25 bar He absolute, as required. The calibration curves of the pressure gauge of the portable gas panel (Fig. 10) are shown in Fig. 11. After the final pressurizing of the refabricated fuel rod and closing of the top plug needle valve, the remaining He pressure was deventilated through the He exhaust. After closing the valve the system remained in this condition for several hours to check if there was any increase of pressure in the system. After this period no increase of pressure was detected on the pressure gauge on the portable gas panel. Before pressurizing the fuel rod with the final He pressure of 25 bar absolute, the rod temperature was reduced to room temperature. Before the tube furnace was installed in the cell the temperature setting of 115°C was thorougly tested on a dummy pin.

For welding of the top and bottom plug the following information can be given:
- welding equipment: AMI–80–M–3, ATW System, automatic tube welding;
- TIG welding technique;
- the hot cell was put on an argon atmosphere;
- the standard argon flow was supplied directly to the welding electrode;
- rotation speed: 3.5 rpm;
- welding overlapping: 120°.

The parameters set during the welding tests were not changed for the welding of the irradiated fuel rod parts.

4. CONCLUSIONS

* The refabrication method of test fuel rods from irradiated full length fuel rods provides an important and economically viable procedure to the LWR fuel research community. Especially in view of the increasing demand for tests with high burn–up fuel.

* It combines in a very efficient manner, the possibilities of a power reactor and of a test reactor.

* Irradiation testing has confirmed that the fuel rod behaviour of refabricated fuel rods is similar to that experienced with segmented fuel rods.

* The combination of a technically well–equipped, hot cell laboratory and a testing reactor with versatile and modular irradiation devices, flexible testing facilities and experienced staff, is a pre–requisite for the realization of projects using refabricated and/or re–instrumented fuel rods.

FIGURES

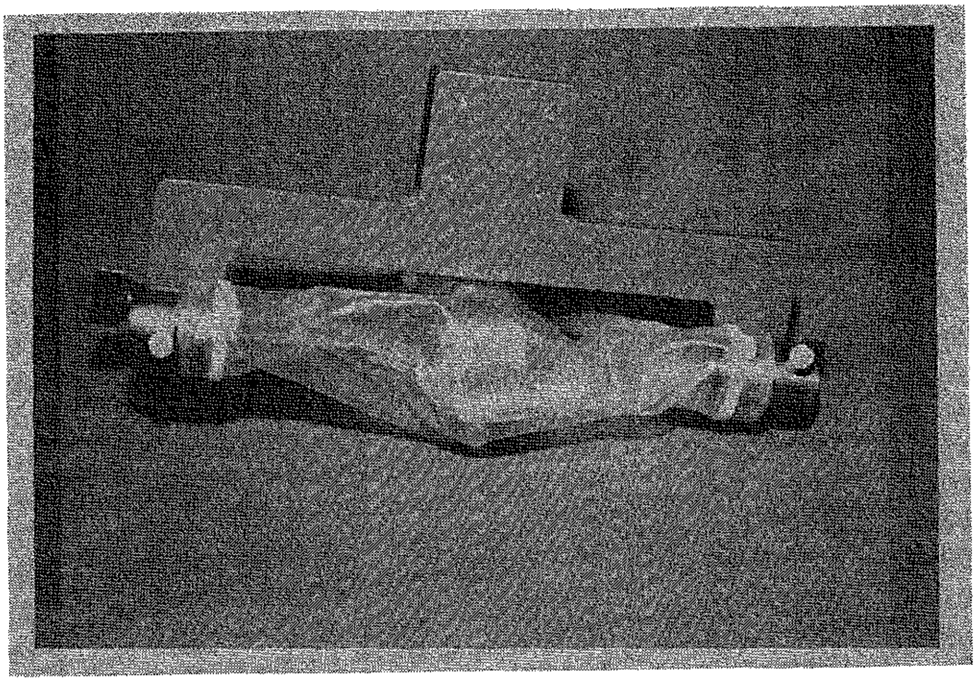


Figure 1.

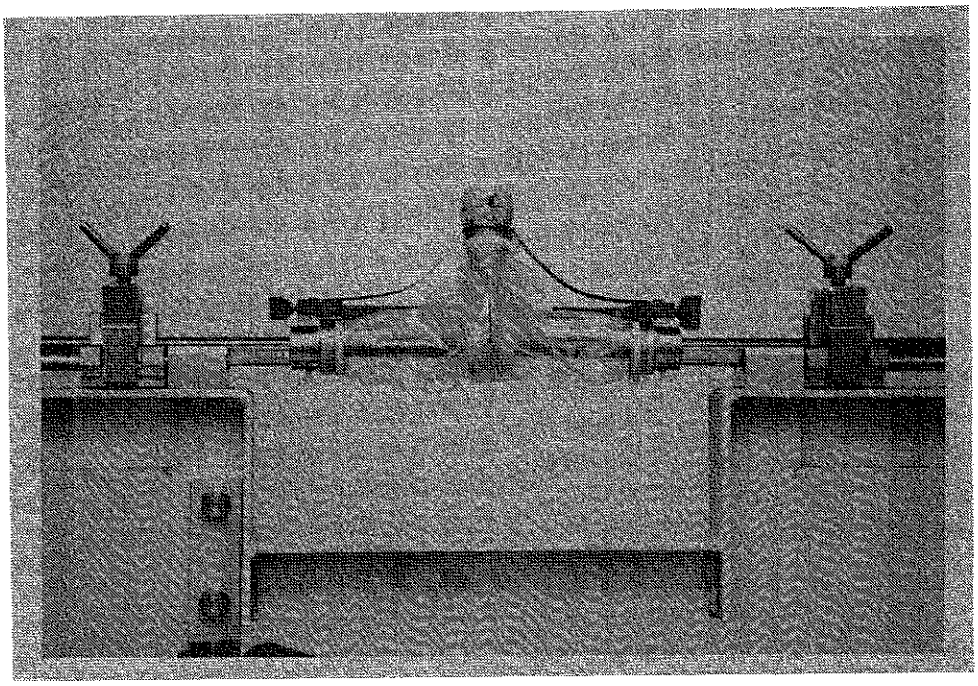


Figure 2.

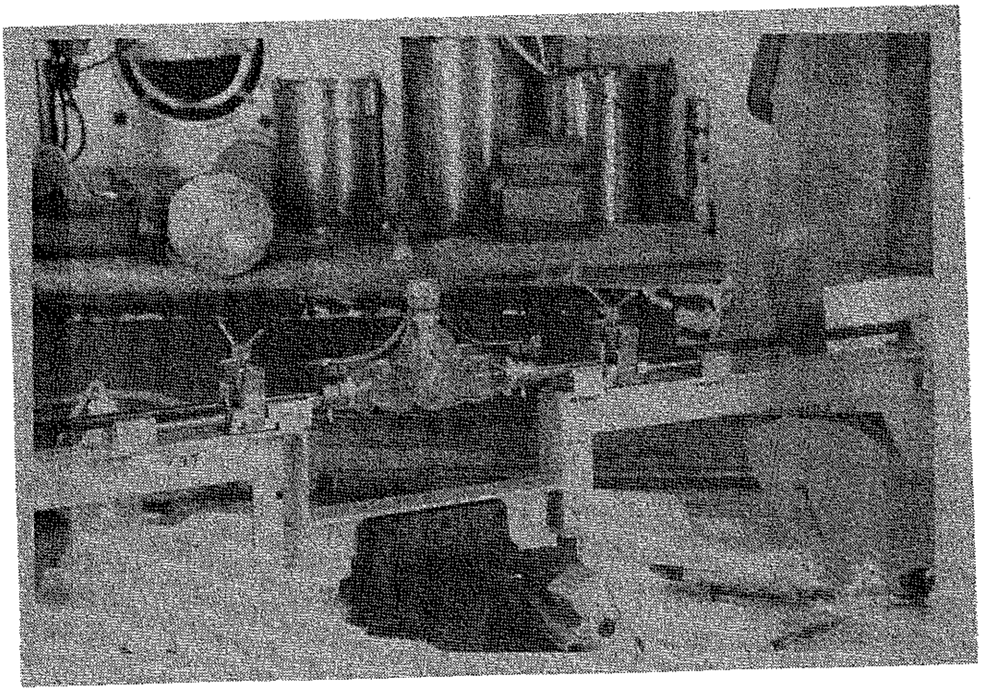
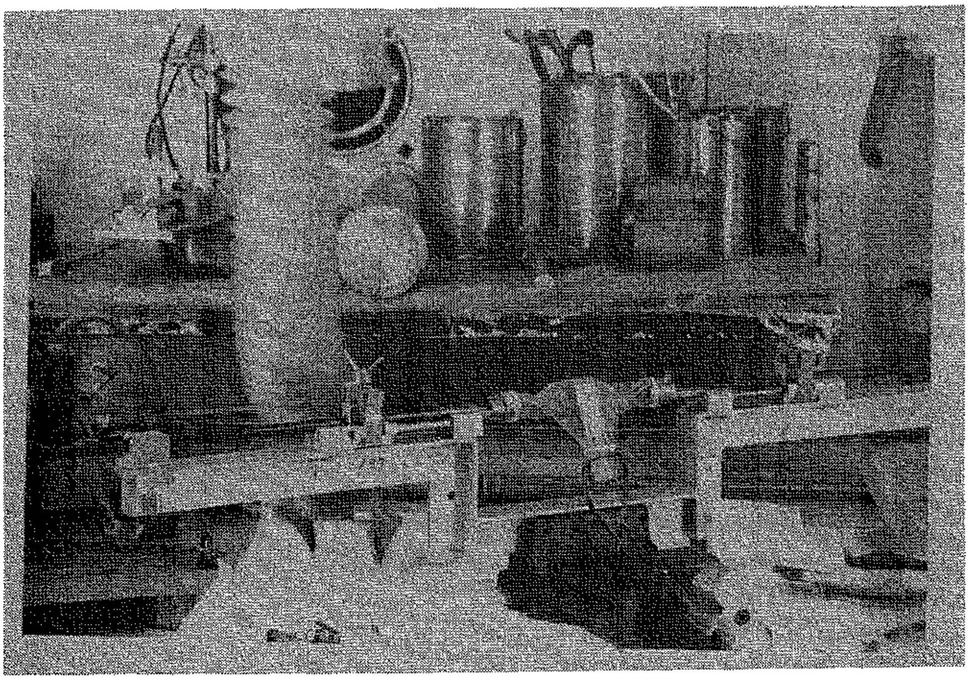


Figure 3.



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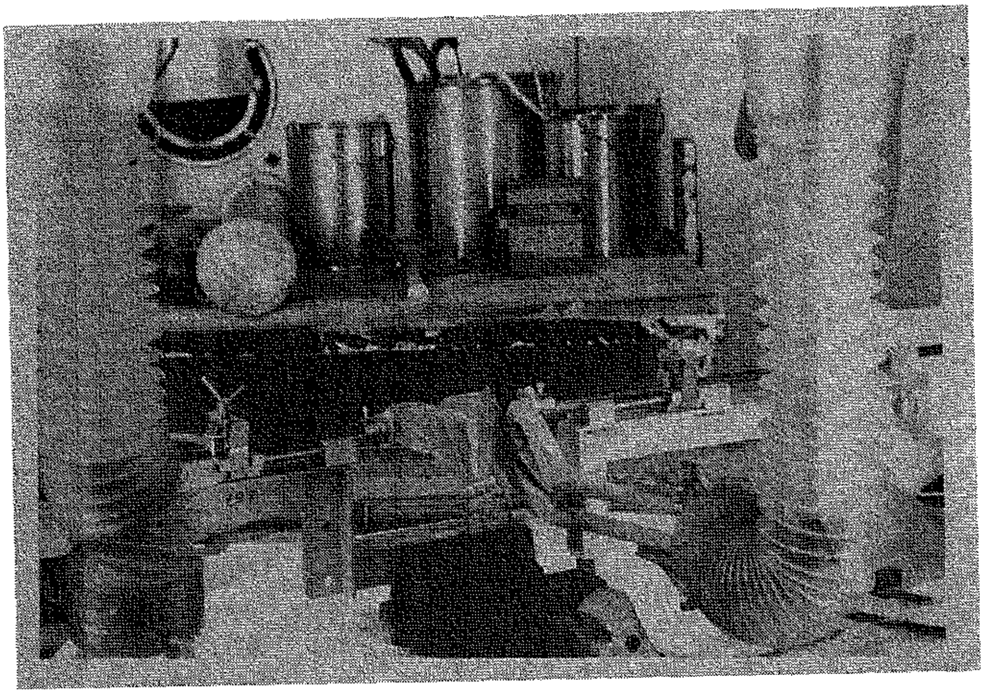

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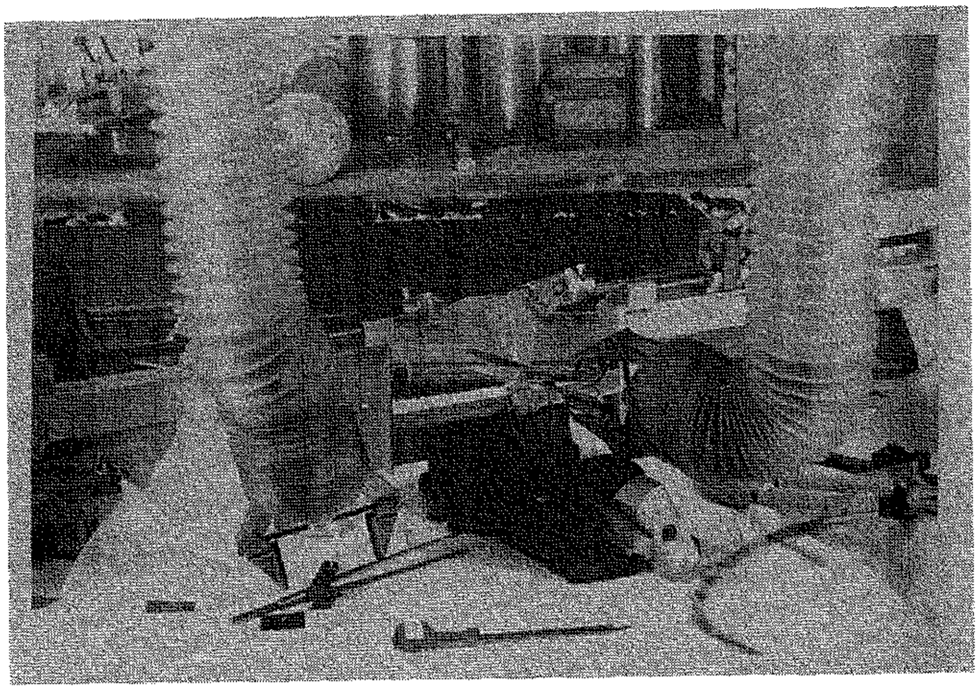

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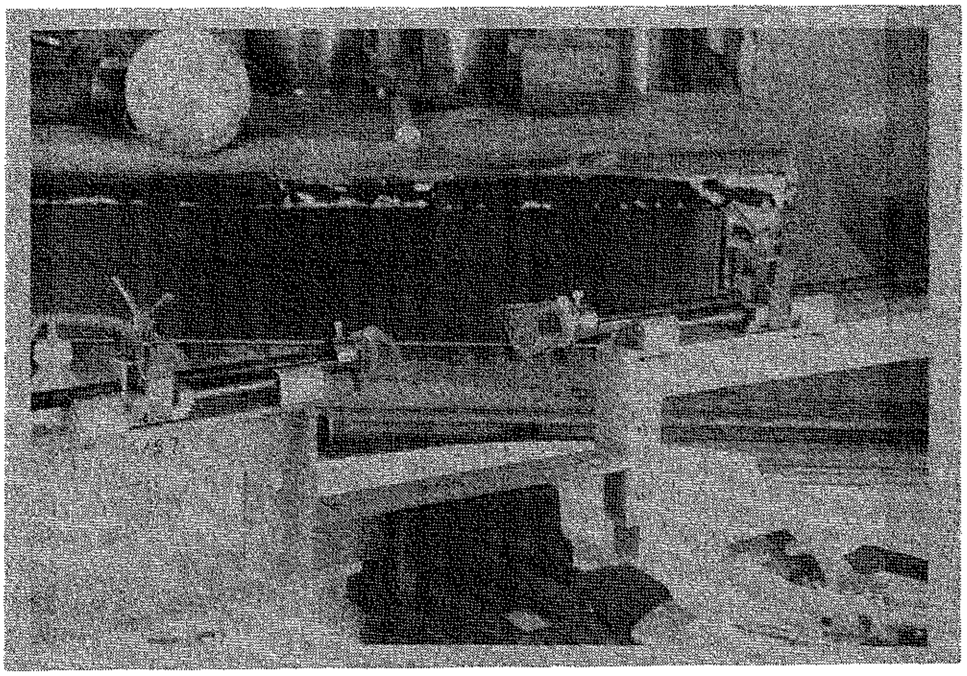

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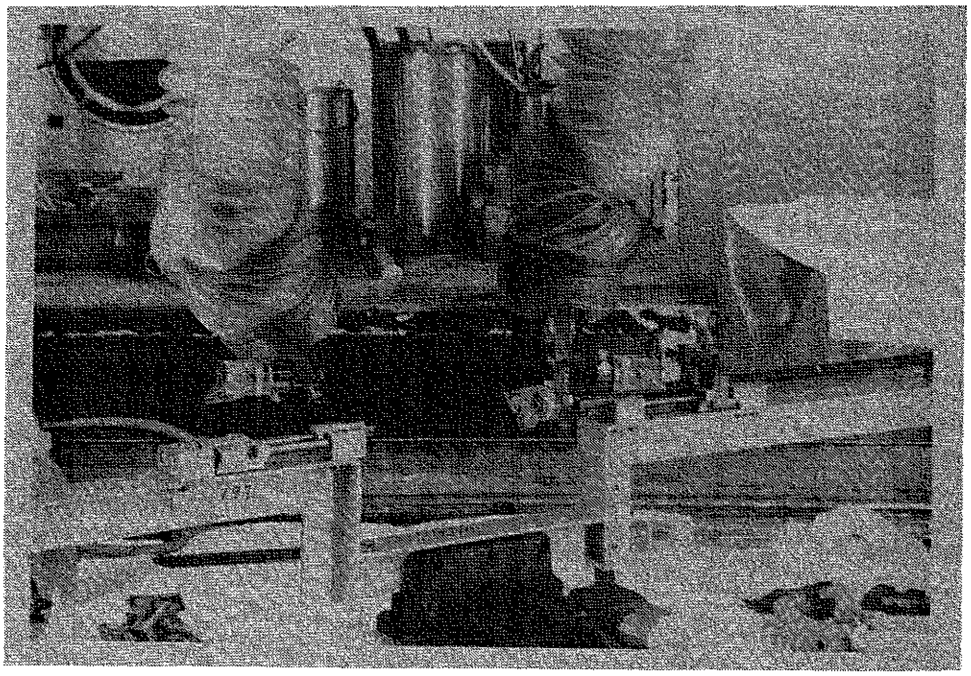
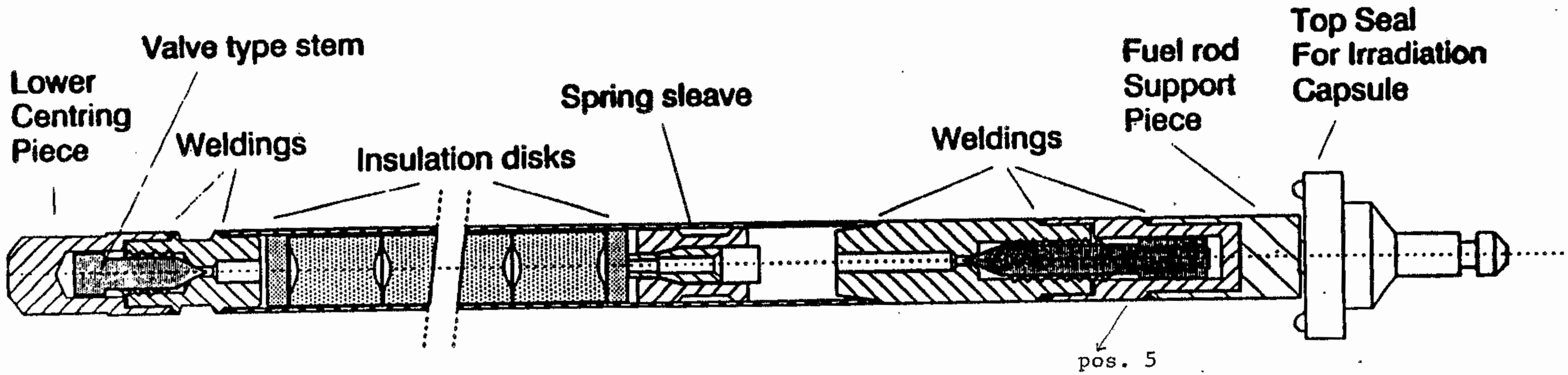


Figure 8.



Typical lay-out of a re-fabricated LWR fuel rod

Figure 9.

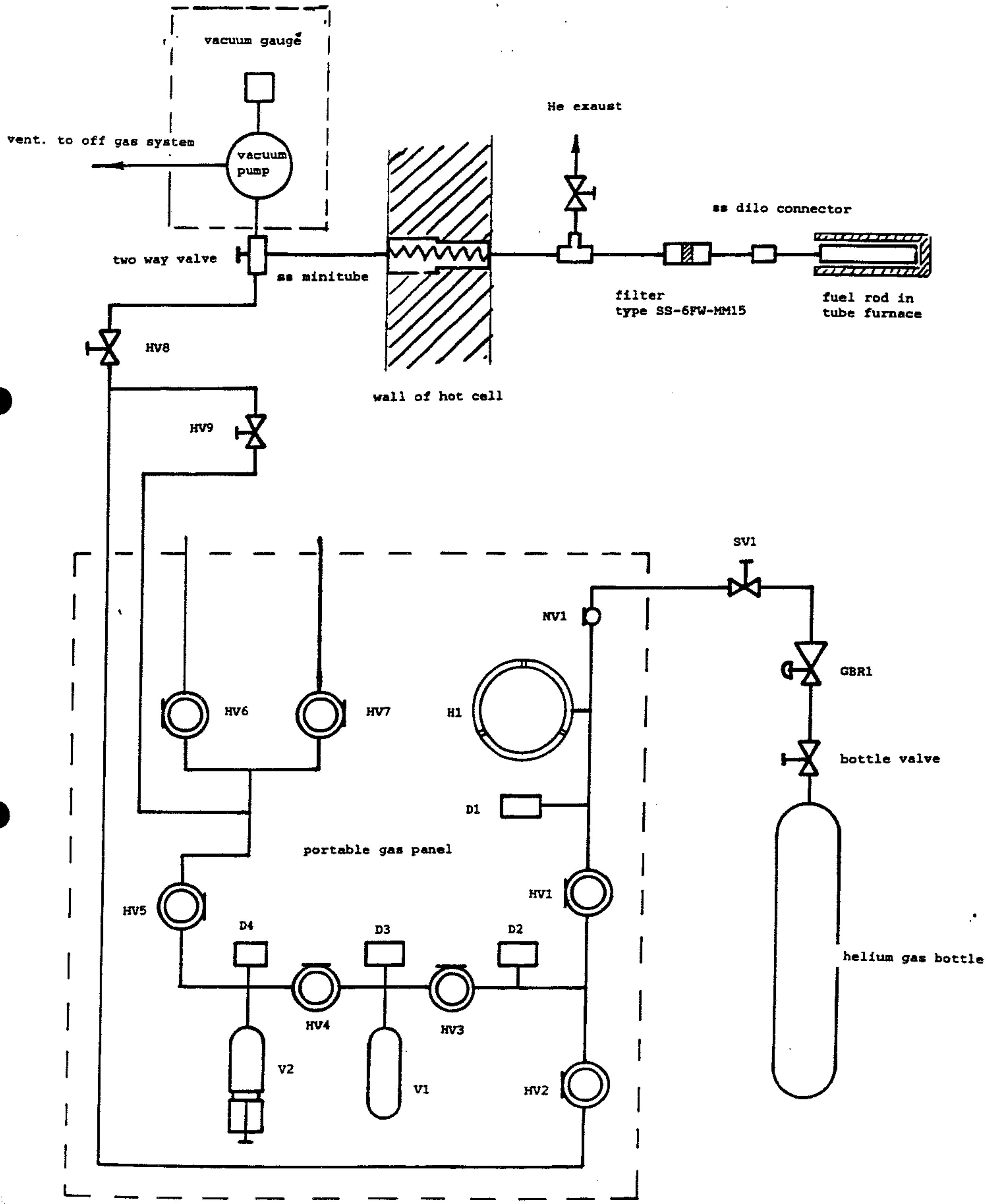


Figure 10.

D1 + D2 digital pressure display

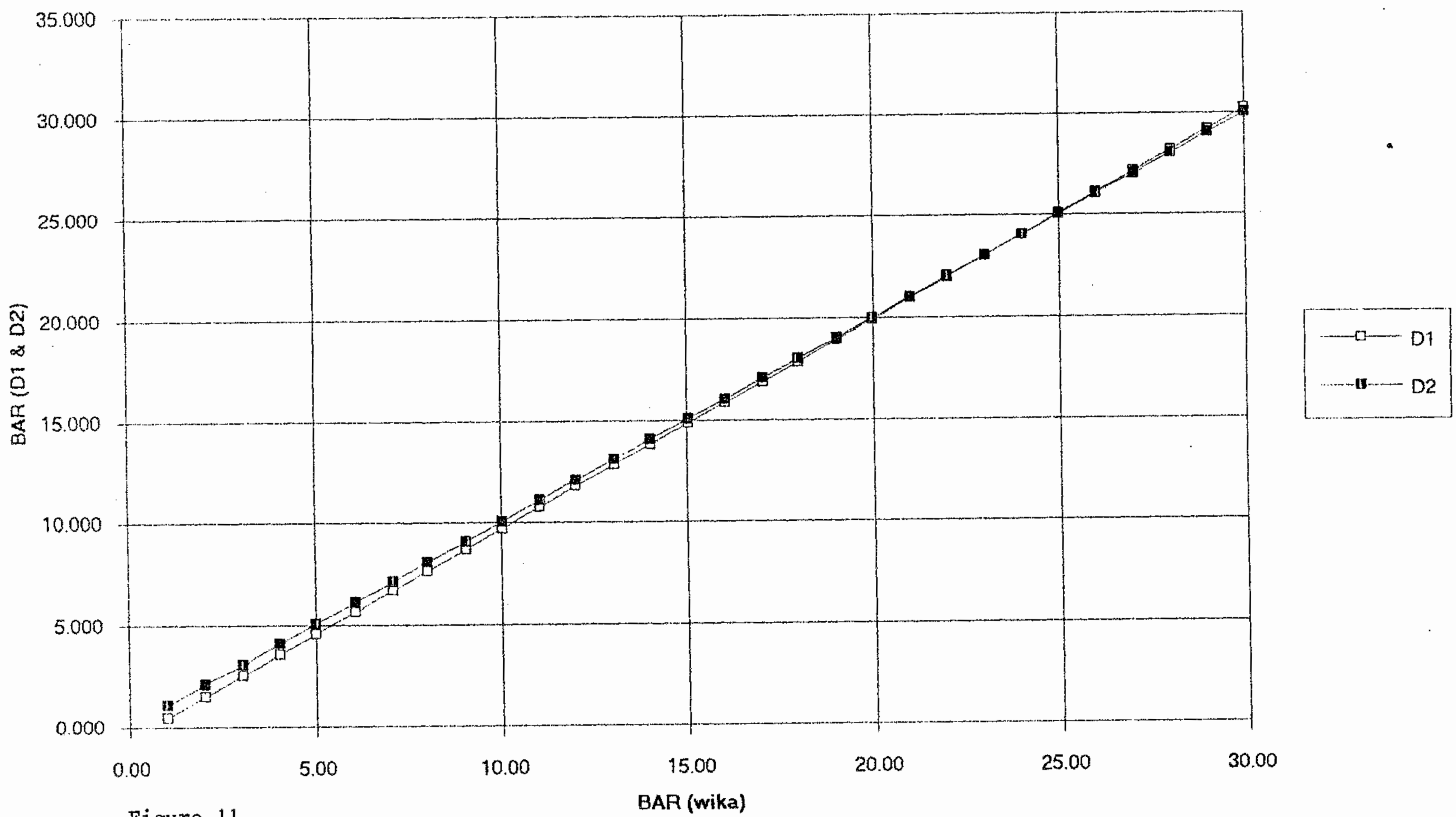

35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
BAR (D1 & D2)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
BAR (wika)
D1
D2

Figure 11.

Het Energieonderzoek Centrum Nederland (ECN) in Petten is het centrale instituut voor energieonderzoek in Nederland. ECN ontwikkelt technologieën voor een veilige, efficiënte en milieuvriendelijke energievoorziening. De units van ECN werken aan duurzame energie (zon en wind), nucleaire energie, energie uit fossiele brandstoffen, en beleidsstudies. De onderzoekers en technici van ECN richten zich op de ECN-missie: bijdragen aan een schone en betrouwbare energievoorziening voor een leefbare wereld. ECN is fraai gelegen in de Noordhollandse duinen even ten noorden van Petten.

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