NOT FOR PUBLICATION

WINDSCALE NUCLEAR POWER DEVELOPMENT LABORATORIES

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PAPER A1 (REVIEW PAPER): THE VALUE OF NON-DESTRUCTIVE EXAMINATION APPLIED TO IRRADIATED FUEL ASSEMBLIES

by

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SUMMARY

The non-destructive examination (NDE) of irradiated water-reactor fuel assemblies is considered in logical sequence. There are strong arguments for carrying out NDE of the whole assembly underwater, either in the reactor pond or in storage ponds at the fuel re-processing facility.

Although some of the fuel rod examination may also be done underwater for selection purposes, the use of dry, shielded caves allows a greater variety of NDE techniques to be employed.

A distinction is drawn between primary NDE of fuel rods where a representative number of fuel rods are sampled from each assembly, and more detailed secondary NDE which is carried out on a smaller number of rods, selected on the basis of the initial inspection. Most of the required PIE information can now be obtained by these non-destructive methods, resulting in cost savings and a reduction in contamination and waste disposal problems associated with cut fuel rods.

INTRODUCTION

Non-destructive methods of examination are particularly attractive for the examination of irradiated materials since they introduce less contamination and waste disposal problems than destructive methods. Non-destructive examination (NDE) is here defined as covering visual inspection, metrology and non-destructive testing using a variety of techniques.

OPERATIONS ON WHOLE FUEL ASSEMBLIES

NDE starts with the examination of the whole fuel assembly and at least for water-reactor fuel there are strong arguments for carrying out the examination underwater, either in the reactor pond or in the storage ponds at the re-processing facility:-

(i) since the assemblies are normally stored in cooling ponds, an assembly selected for examination only needs to be moved to a suitable inspection bay in the same pond, thus reducing the need for expensive flask movements.

(ii) the water provides cheap shielding, it keeps fuel rod temperatures close to ambient and thus allows metrology to be carried out without the need for temperature corrections.

(iii) Excellent viewing can be achieved using underwater TV cameras supplemented by the use of close-up 35 mm film cameras, both contained in water-proof housings (Fig. 1).

(iv) Deposits on fuel rods may be sampled at an early stage underwater, using an adhesive pad clamped to the rods(2).

(v) Fuel rod bow measurements can be made with the assembly clamped in a vertical position, using linear variable differential transformer (LVDT) probes. (A description of the technique is given elsewhere(1), Fig. 2 shows the equipment used at Windscale).

TV inspection cameras also allow other dimensions to be checked against a scale to ± 10% relative accuracy. AECL have demonstrated that underwater profilometers can achieve high measurement accuracies on elements up to 600 mm in length(3).

(vi) Assemblies are normally partially dismantled in pond; the equipment used at Windscale is shown in Fig. 3. Measurements of rod withdrawal loads give a useful indication of the loads exerted by the spacer springs and the axial forces exerted on the rods in service.

(viii) For assemblies suspected to contain leaking rods wet sipping can be used to confirm fission product leakage, and methods have been developed elsewhere for identifying leaking fuel rods without removing them from the assembly, eg by using ultrasonic methods to detect the presence of water in the plenum(1), or by gamma-scanning the plenum region for the presence of selected gaseous fission products(4). If this procedure can be carried out in the reactor pond with assemblies designed for easy replacement of defective fuel rods, then it is often economic to carry out the replacement and re-irradiate the assembly to reach full burn-up.

Ideally it should be possible to chemically clean the element to remove the crud which obscures surface detail, prevents accurate rod diameter measurement, and contributes to the spread of $\beta\gamma$-active contamination. At Winfrith this cleaning can be done in the SGHW reactor before the element is discharged, but it is also practicable to carry out the cleaning in a separate facility(5).

OPERATIONS ON EXTRACTED FUEL RODS

The primary applications of NDE are on complete fuel rods and may be defined as:-

(i) Obtaining information on a representative number of rods in given assembly (say 10 - 25%).

(ii) Selecting those rods where further NDE or destructive examination is required, eg to confirm and characterise failure regions.

Fuel rods extracted from an assembly may be examined using eddy-currents, gamma-scanning and gas sampling. Since examination under water is generally more restrictive than under dry conditions, at Windscale only eddy-current testing is employed under water, and is used as a sorting process to reduce the number of rods going to a dry concrete-shielded cave, where most of the NDE of fuel rods is done.

The basic requirement for these in-cave tests is a system for driving the fuel rod through a sensing head and recording the signals and their position along the rod during the test. The philosophy at Windscale has been to develop a fully-automated rod-drive machine with a central space for various interchangeable test modules eg for eddy-current testing, non-contact diameter measurement(6) and leak location (Fig. 4). Provision is also made for simultaneously gamma-scanning the rod and for making a visual record of the rod surface, either photographically or using a TV camera to record on video-tape. Further test modules are being developed to measure oxide thickness and deposit thickness. The system is described in paper A3.1.

The system can cope with moderately large numbers of rods and it is planned to store the data on discettes and process the results using a computer, to reduce the effort required to analyse charts etc. One of the disadvantages of the system is that, the rod cannot be rotated as it is driven; it is therefore not possible to scan the pin surface.

After the primary NDE has been carried out, the results are used to select rods for other tests. These include:-

(i) gas sampling and analysis, and also void volume measurement.

Although this is strictly speaking a destructive technique, the rods are re-sealed after puncturing and may be regarded as intact for subsequent tests. In choosing rods for gas sampling, the total gamma-scans are of value; they give a rough guide to the relative rod burn-up and show the extent of Cs migration to pellet ends, which is a guide to the fission gas release in the fuel rod (see paper A3.1).

(ii) isotopic gamma-scanning is used to give relative rating and burn-up information(7).

(iii) X-radiography has been used to check the sizes of fuel pellet axial gaps and stack lengths, but in most cases the gamma-scan information is adequate. Although neutron radiography(8) is acknowledged to be a useful tool (eg for detecting hydride concentrations in Zircaloy cladding and fuel cracking) in the absence of a suitable reactor source of neutrons the cost may be prohibitive.

(iv) New techniques are being developed to obtain information on fuel-cladding gaps. At Kjeller in Norway and later at Harwell a method has been developed for measuring diametral gaps (to ± 10 μm) by applying an increasing diametral load on the fuel rod and observing the elastic deflection of the cladding onto the fuel(9). Another approach is to use thermographic imaging of fuel rods following pulse electrical resistance heating in order to estimate radial fuel-clad gaps(10).

A notional flow chart for examining irradiated fuel assemblies is shown in Fig. 5. Presumably there will always be a need to examine or test a small number of rods destructively in order to check on the NDE methods and to provide samples for microstructural and chemical analysis. Mechanical tests and other destructive tests may also need to be carried out on rods. However it is clear that for routine monitoring purposes wider use of NDE can increase the amount of useful information obtained and minimise the number of fuel rods required to be destructively examined, with consequent cost savings.

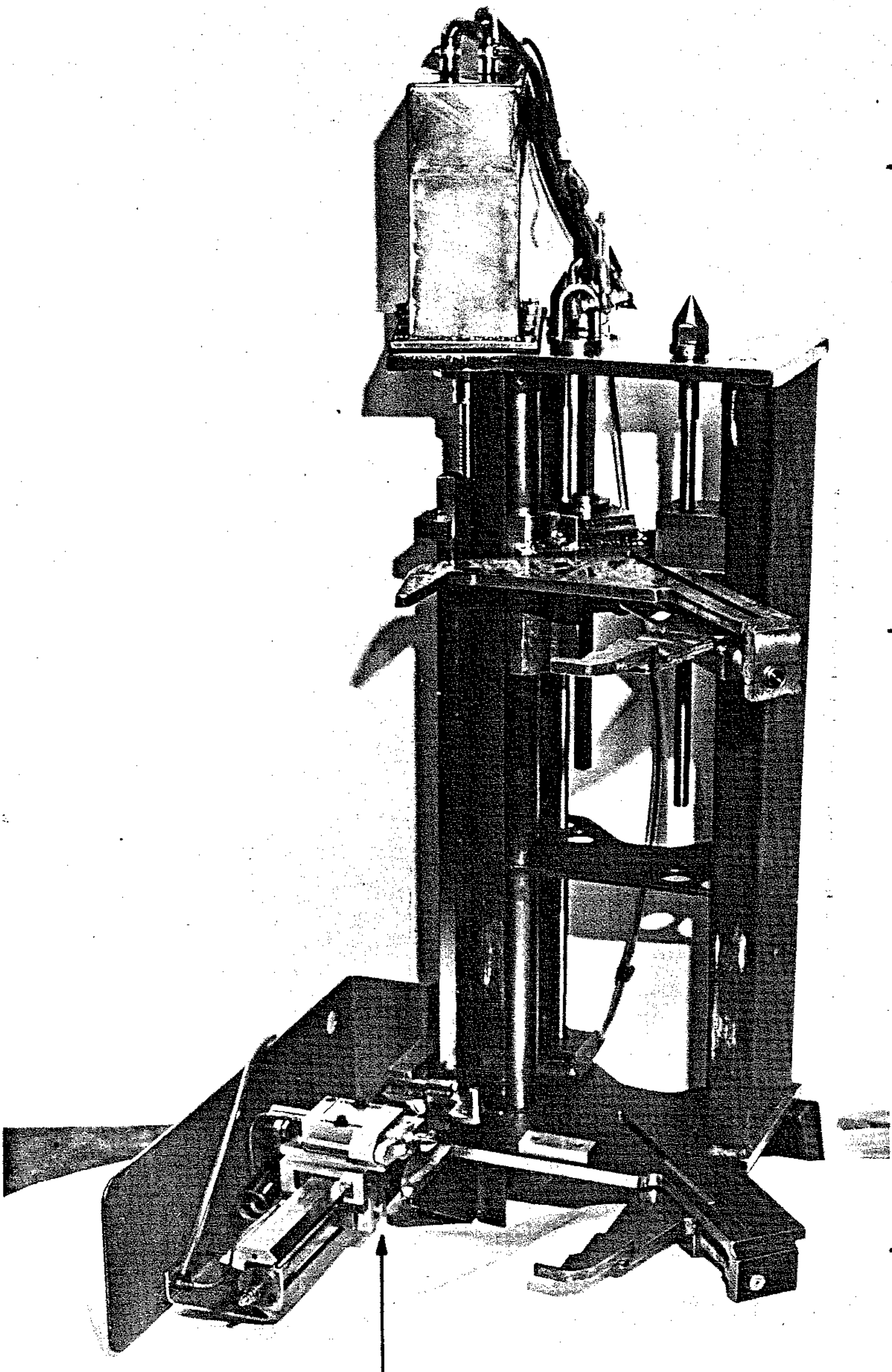
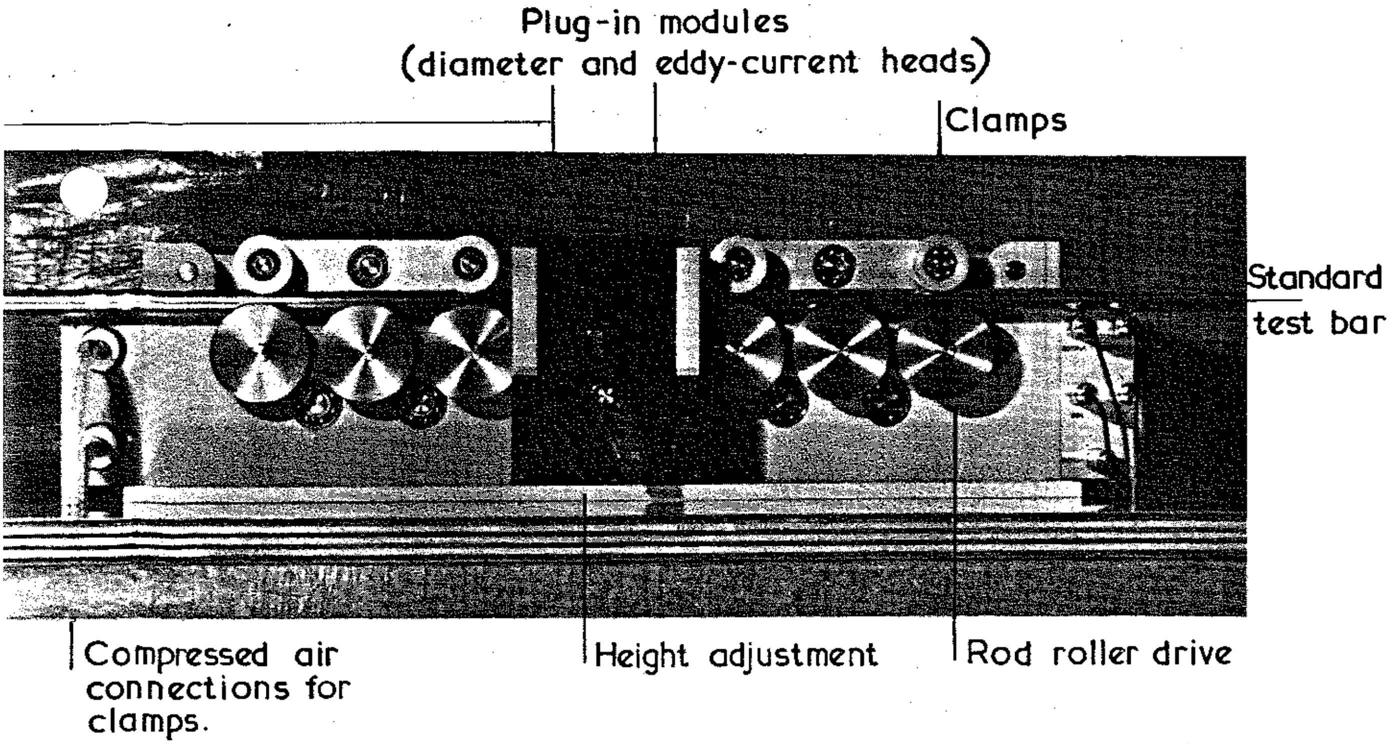
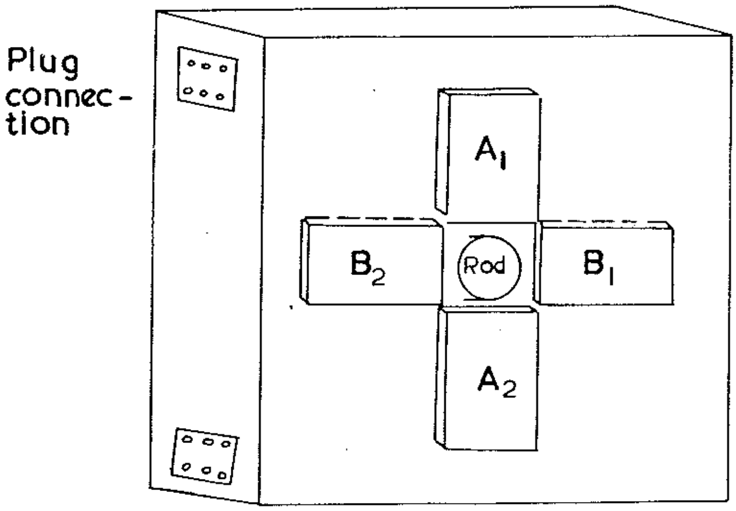


FIG. 2 UNDERWATER BOW MEASUREMENT EQUIPMENT



Rod drive machine and plug-in modules



Sketch of capacitance gauge module 10x10x3cm.

$A_1 - A_2$, $B_1 - B_2$ } Matched pairs of heads

ROD-DRIVE MACHINE AND CAPACITANCE TRANSDUCER MODULE FOR DIAMETER MEASUREMENTS

BE

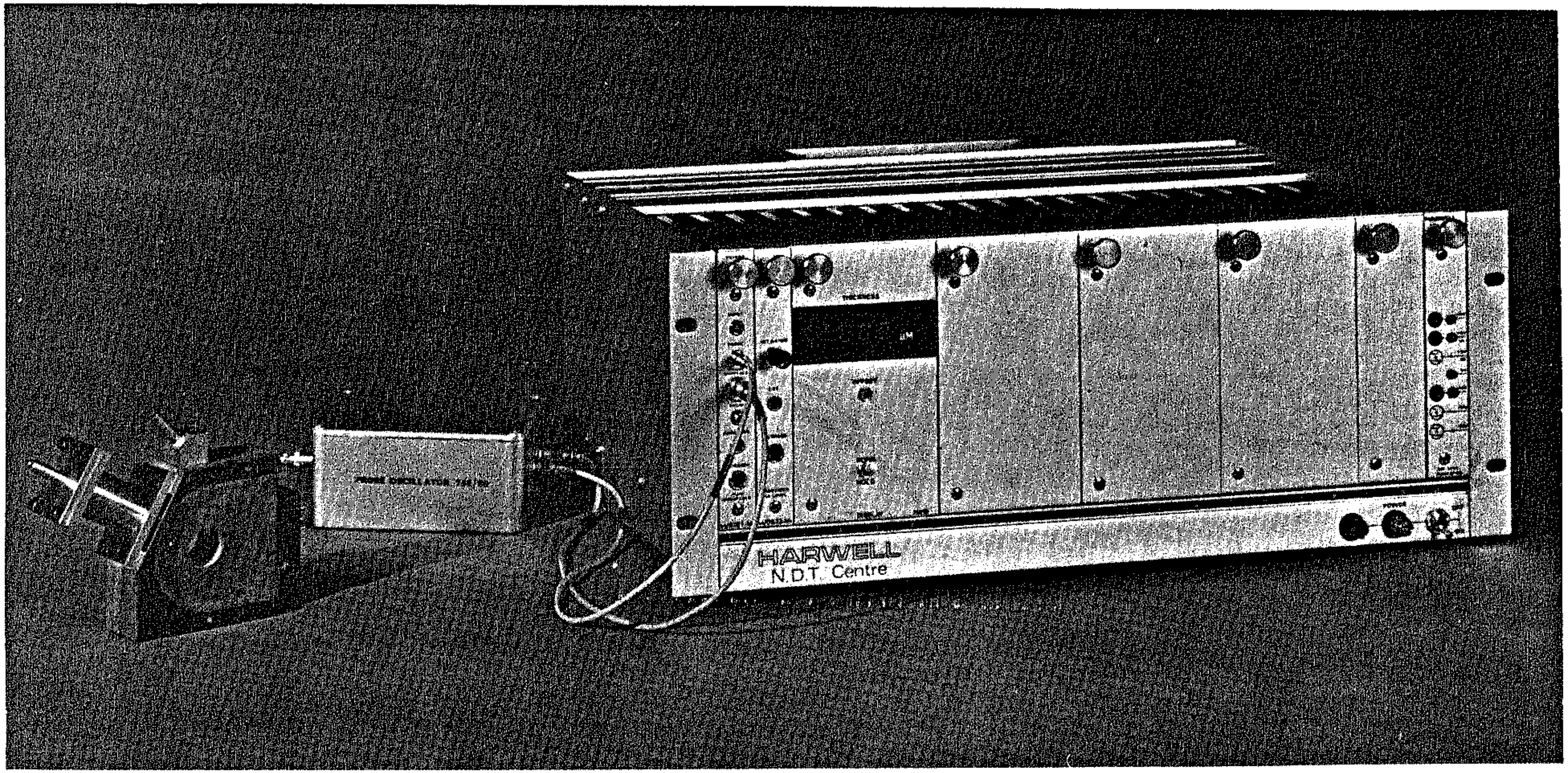
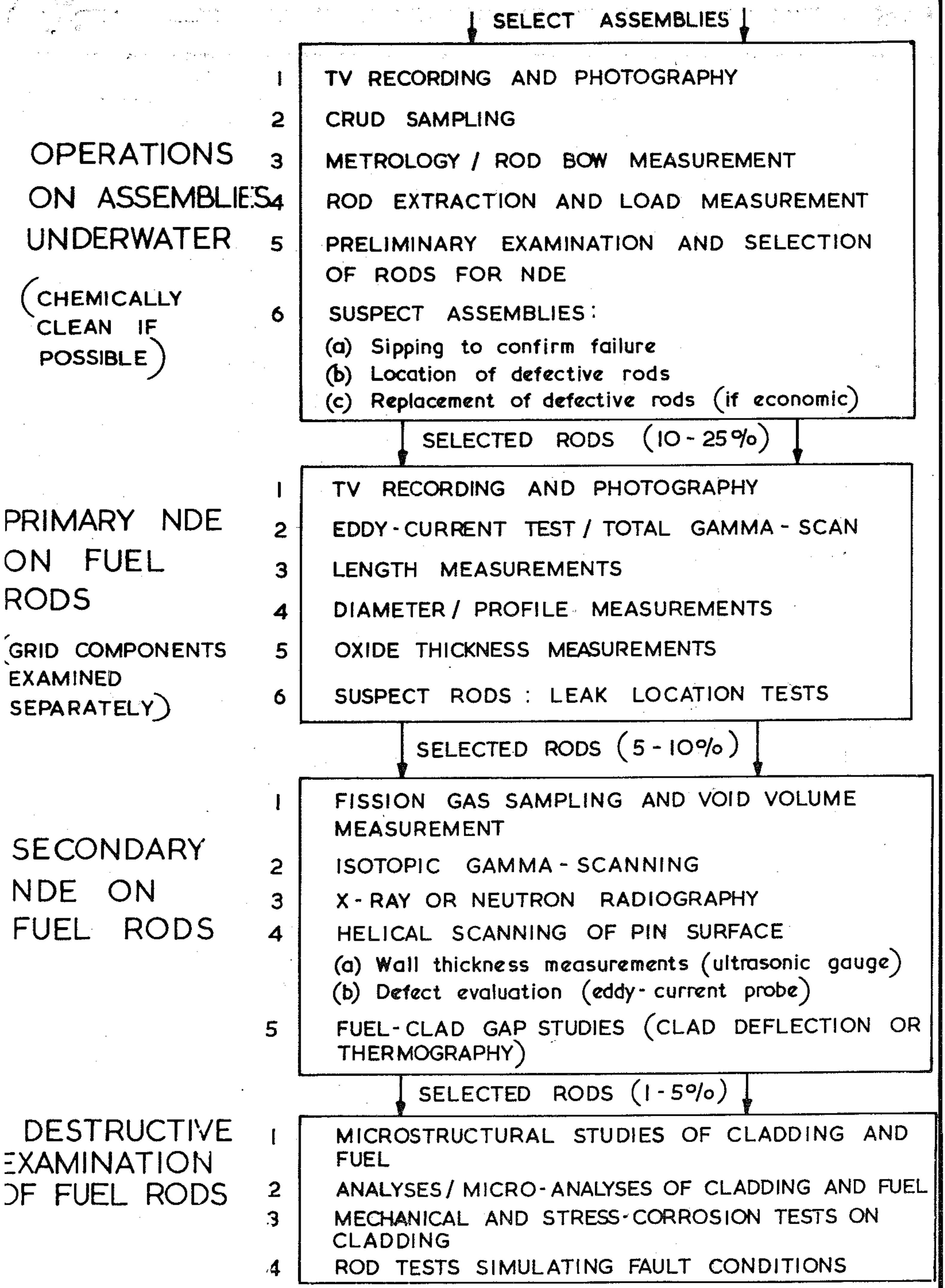


FIG. 9 OXIDE THICKNESS GAUGE DEVELOPED BY THE N.D.T. CENTRE, HARWELL.



G.5 NOTIONAL FLOW-CHART FOR P.I.E. OF WATER REACTOR ASSEMBLIES