

A3 RCD/N/004(93)

**AEA Technology**

**Reactor Services**

**Advanced Remote Handling Techniques  
Associated with Specialised Fuel Studies**

**R C Smith and R Williamson**

28 May 1993

**AEA Technology**

**Reactor Services**

**B540.1 Harwell, Didcot**

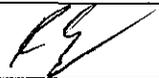
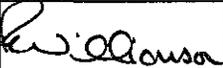
**Oxfordshire OX11 0RA**

**United Kingdom**

**Telephone 0235 435561**

**Facsimile 0235 436314**

RECORD OF INTERNAL REVIEW FOR RCD/N/004(93)

	Name (Capitals)	Signature	Position	Date
Lead Author	R C SMITH		Project Manager	28-05-93
Peer Reviewer	R WILLIAMSON		Section Manager	28/5/93
Approver	N BEATHAM		Department Manager	28/05/93

## Advanced Remote Handling Techniques Associated with Specialised Fuel Studies

R C Smith and R Williamson

# Abstract

AEA Technology operate a comprehensive range of Post-Irradiation Examination (PIE) and fuel dismantling services including, extensive analytical and testing services, fuel experimentation and modelling capabilities together with facilities for the design and supply of specialised PIE equipment.

Specialised experiments on fuel behaviour are undertaken in the B220.29 Remote Handling Facility at AEA Technology, Harwell. This modern integrated suite of five shielded cells, designed for high level  $\alpha$   $\beta$   $\gamma$  and neutron operations, is based on the use of mobile, high integrity containment boxes in which radioactive work is performed. The sequential use of the primary containment boxes maximises the use and efficiency of the facility and offers an extremely high level of versatility.

This paper describes briefly the B.220.29 facility and the development of a new experimental apparatus to provide data on clad failure due to swelling in irradiated fuel. Short lengths of irradiated AGR fuel will be heated by means of a tungsten heater fitted through the bore of the pellets. The apparatus is designed to achieve fuel bore temperatures in the range 2,000 - 2,500°C with cladding final temperatures of 900 - 1,100°C, at a heating rate of 1 - 10°C s<sup>-1</sup> at the pellet bore.

Relatively simple modifications to the basic apparatus design will allow an even broader range of temperature conditions to be achieved together with the capability for conducting tests in an oxidising atmosphere relevant to post-failure fault conditions.

To be presented at a meeting of the Commission of European Communities Working Group 'Hot Laboratories and Remote Handling' at Chinon, France 15/16 June 1993.

AEA Technology  
Harwell  
Didcot  
Oxfordshire  
OX11 0RA  
United Kingdom

May 1993

# Contents

	Page No.
Introduction	1
Remote Handling Facility Background	1
Project Background	3
Furnace Design	3
Assembly of the furnace in-cell	4
Installation	5
Out-of-cell equipment	5
Service connections to the cell	6
Instrumentation	6
Data acquisition system	6
Development potential	7
Commissioning	7
Summary	8
Acknowledgements	9

## Figures:

Figure 1. B.220.29 Facility plan.

Figure 2. Schematic diagram of furnace assembly.

Figure 3. Instrumented dummy fuel assembly.

# Introduction

Advanced studies into the behaviour of highly irradiated fuel are being performed at AEA Technology, Harwell, aimed at providing data for the development of thermal reactor fuel modelling codes, which are used in reactor safety assessments and for the licensing of Advanced Gas Cooled Reactor (AGR) and Light Water Reactor (LWR) systems. Current programmes include: (i) the determination of fission product release and fuel swelling behaviour of oxidised uranium at high temperatures; (ii) measurement of volatilisation rates of oxidised uranium at high temperatures; (iii) melting point determinations of  $\text{UO}_2$ ,  $(\text{U,Pu})\text{O}_2$  and  $(\text{U,Gd})\text{O}_2$  and (iv) fuel particulate production and sizing studies. All these studies utilise unique in-cell apparatus that have required considerable development and incorporate many novel features. This paper aims to provide an overview of a remote handling facility operated by AEA Technology together with an insight into the development of one of these pieces of apparatus together with a description of some of the engineering challenges and solutions encountered during its development.

## Remote Handling Facility Background

AEA Technology operates a comprehensive range of Post-Irradiation Examination (PIE) and fuel dismantling services including, extensive analytical and testing services, fuel experimentation and modelling capabilities together with facilities for the design and supply of specialised PIE equipment.

Specialised experiments on fuel behaviour are frequently undertaken in the B220.29 Remote Handling Facility at Harwell. A schematic diagram of the facility is shown in Figure 1.

This modern integrated suite of five shielded cells, designed for high level  $\alpha$   $\beta\gamma$  and neutron operations, is based on the use of mobile, high integrity containment boxes in which radioactive work is performed. These box modules allow experimental equipment to be installed and commissioned inactively in a dummy cell located in the box commissioning area before transfer to the shielded cell line. Decommissioning of containment boxes is also performed outside the cell line in the primary decommissioning cell. This sequential use of the primary containment boxes maximises the use and efficiency of the facility as a whole.

Key features of B220.29 are:

- large volume boxes; containment box dimensions are 2.4m wide, 1.8m deep and 2.5m high
- boxes can be interconnected (vertically or horizontally) to provide up to 6m length to accommodate large operations (eg pilot scale nuclear reprocessing plant)

- when commissioned, boxes are moved to the active work station behind a heavily shielded cell line, where experiments are carried out using modern Walischmiller master-slave manipulators
- high integrity containment allows the handling of fissile materials or experiments involving releases of fission products (eg oxidation of irradiated fuel, fire testing of immobilised wastes)
- heavy shielding allows safe handling of radioactive materials up to  $\sim 10^{12}$  Bq (gamma) of mixed radio nuclides ( eg high burn-up, short-cooled fuel, dissolver residues, high level wastes)
- double-lidded posting (Drath and Schrader) provides for transfer of radioactive material and equipment
- a reception area capable of handling flasks up to 15 tonnes weight: routine radioactive movements to the facility utilise the Modular flask system, whilst movements within the facility are normally undertaken using Padirac flasks
- in addition to the electrical, liquid and gas supply services standard to the containment box, a custom built shielded service plug may be used to supply non-standard services to a specific item of apparatus: for instance gas or water supplies requiring very high flow rates or high current electrical supplies

Supporting facilities at lower activity levels are available in the adjoining main building (B220), comprising thirteen laboratory suites and extensive  $\alpha$ -handling facilities.

A wide range of analytical radiochemical services are available within the B220/220.29 complex enhancing the benefit of performing experiments at this location. A selection of the back-up analytical services routinely available are listed below:

- ◆ analysis of major constituents in nuclear fuels: uranium and plutonium by controlled potential coulometry and isotope mass spectrometry
- ◆ burn-up analysis; retained fission gas analysis;  $\gamma$ -scanning
- ◆ identification and measurement of active constituents of nuclear materials, with or without chemical separation: radiochemical and  $\alpha$ ,  $\beta$ ,  $\gamma$ -spectrometric methods (performed in an adjacent cell in B220.29)
- ◆ miscellaneous tracer methods: fluorimetry for sub-microgram quantities of uranium; activation analysis; nuclear microprobe analysis.

This close coupling of in-cell work and radiochemical back-up has produced a powerful, unique, combination.

This facility is part of the coherent strategy developed by AEA Technology with respect to the evaluation of irradiated fuels. Main stream PIE usually starts with receipt and dismantling of fuel assemblies and progresses through a comprehensive range of non-destructive and destructive examinations in facilities suited for each task. The specialised fuel studies work performed in B220.29 is an important component of AEA Technology's ability to offer the 'one stop shopping' philosophy that customers are usually seeking.

Of the various projects carried out in the B.220.29 facility one will be described in more detail below.

## Project Background

Further experimental data are required to assess the overall performance of AGR fuel pins during postulated reactor power transients during which fuel bore temperatures may exceed 2,000°C.

A new facility is being prepared with the aim of providing experimental data on clad failure due to swelling in irradiated fuel. The main objective of the initial programme is to provide experimental data relevant to AGR fuel on the dimensional changes occurring in the fuel cladding due to fuel swelling as a consequence of transient upratings in which the fuel bore temperature exceeds 2,000°C. Measurements will also be made of the radial distribution of fuel swelling and the extent of closure of the pellet bore, (initially ~6 mm  $\phi$ ). The information generated from these experiments will be used to validate or refine the pellet/cladding interaction and swelling models currently employed. The proposed range of temperature conditions is as given below:

Fuel bore final temperatures	2,000 - 2,500°C
Cladding final temperatures	900 - 1,100°C
Heating rate (pellet bore)	1 - 10°C s <sup>-1</sup>

The following sections summarise the general furnace design together with a brief description into issues that must be tackled before introducing it into an active cell.

### FURNACE DESIGN

The principal requirement for the new facility is that it should be capable of reproducing, as closely as possible, the temperature profiles expected to be generated within an AGR fuel pin during a power transient.

At an early stage in the project it was decided to investigate the feasibility of using an electrically heated element inserted through the pellet stack as a primary heat source. A preliminary study of this approach demonstrated that it was theoretically possible to obtain the required temperature conditions.

Based on this study, the initial concept for the furnace was for a short length (50 to 60

mm) of clad AGR fuel to be heated by means of a tungsten heater element fitted through the bore of the pellets. The element was to consist of a thin walled tube, to give a high electrical resistance so that element surface temperatures of 3,000°C could be achieved using a relatively low current. The tubular design also allowed the use of an optical pyrometer, sighted down the bore of the tube, to measure and control the furnace centre temperature. Further pyrometers, sighting through the furnace containment, monitor the temperature of the fuel pin cladding.

The radial temperature profile across the fuel pin may be controlled by varying a flow of coolant gas in the annulus between the fuel pin and the inner wall of the furnace containment, a water cooled aluminium alloy block. The ability to vary the coolant flow independently of the heater power in this manner allows high power transient upratings to be simulated.

Figure 2 shows a schematic arrangement of the furnace assembly.

A test rig was assembled with the aim of conducting trials to examine the thermal and mechanical stability of vapour deposited tungsten tubes for use as heater elements. With a current of 297 amperes at 7.6 volts, applied to a 0.25 mm wall thickness tungsten furnace element, a temperature of 3,000°C was achieved.

Heat transfer calculations were also performed in order to define the furnace element temperatures, furnace dimensions and sweep gas conditions required to meet the specified range of fuel and clad temperature conditions and be representative of AGR fuel temperatures.

It was established from the results of thermal analysis, that for a heater rating of 25 kW m<sup>-1</sup> and laminar helium flow rate of 1.0 g s<sup>-1</sup>, producing a fuel bore temperature of ~2,600°C at the specimen axial centre line, that the axial temperature profile over the central 30 mm length of the fuel pin would be relatively flat. Thereafter the temperatures drop away sharply with top and bottom end fuel bore temperatures of ~1,700 and 1,500°C respectively. The corresponding clad temperatures are ~1,250°C at the axial centre line, falling off to ~800 and 600°C at the top and bottom ends respectively.

## **ASSEMBLY OF THE FURNACE IN-CELL**

The furnace is made up of components all of which are small enough to be posted into cell through the 295 mm diameter posting port. However, it is anticipated that initially the furnace will be introduced into the cell pre-assembled, following remote handling and commissioning trials in the box commissioning area. O-ring seals are used throughout to maintain gas tightness.

The furnace consists of a water cooled body mounted between two horizontally disposed circular flanges. The upper and lower flanges incorporate the cooling gas inlet and outlet galleries respectively. The section of fuel pin under test, which will be ~60 mm long and contain four annular UO<sub>2</sub> pellets, will be pre-equipped with stainless steel extension pieces. The fuel sub-assembly will be inserted from the top and is located concentrically in the furnace body by ceramic bushes which provide

electrical and thermal isolation. Standard remote handling techniques will be employed, in conjunction with a special insertion tool, to load the fuel assembly into the furnace.

Following installation of the fuel assembly, the furnace element will also be inserted from the top, passing through the bore of the fuel pellets. When installed, the upper end of the element which is electrically isolated from the furnace assembly will be clamped in place by means of a bolt-on, water cooled, flange which is connected to the high voltage (15v) line of the power supply. The lower end of the element will dip into a bath of liquid Wood's Metal which is bolted to the lower flange. This bath is equipped with an electrical heating coil to melt the Wood's Metal prior to the insertion of the element. The adoption of this method of completing the electrical power supply circuit will ensure that the effects of thermally generated stresses on the fragile tungsten element are minimised. In addition, the necessity of making a mechanical connection is eliminated. The low voltage line of the power supply will be connected to the lower flange thus completing the circuit.

Flexible leads will connect the furnace assembly to the various services. Standard box services will be utilised for thermocouple connections, Wood's Metal reservoir heater power supply, cooling water and auxiliary gas supply. Convolute stainless steel tubing will be used for the cooling gas inlet connection to the service plug. The furnace power supply connections to the service plug will be sleeved stranded copper cables.

The cooling gas, initially helium, will pass from the flow controller, situated out-of-cell, through the service plug to the inlet connection on the top flange of the rig, then via radial passages, to the annular space between the interior of the water cooled furnace block and the exterior of the fuel pin. The gas then passes, via similar passages in the lower flange, to the exit connection and the cell atmosphere. The sudden introduction of this large mass flow of cooling gas into the cell could result in a cell ventilation system trip. Therefore, arrangements will be made to progressively increase and decrease the gas flow over an agreed period at the beginning and end of the tests.

## **INSTALLATION**

The experiments will be conducted in a cell situated in the active handling suite in B220.29 at Harwell. During the later stages of commissioning, facilities in the B220.29 box commissioning area will be required. Arrangements are in hand to supply the specialised services required for this furnace. A dedicated service plug and a helium supply line from a bank of cylinders situated outside the building will be needed. This latter requirement is necessary because of the anticipated high consumption of cooling gas ( $>1 \text{ g s}^{-1}$ ).

## **OUT-OF-CELL EQUIPMENT**

The out-of-cell equipment will consist of the furnace electrical power supply, temperature control and monitoring system, the data acquisition system and the cooling gas supply and monitoring system.

The high current transformer associated with the furnace power supply and the cooling gas flow control valve will be located in the Transfer Area (T/A) behind the cell. The furnace control equipment will be located in a console at the cell face. The data acquisition system and ancillary monitoring instrumentation together with the cooling gas flow control and monitoring system will be housed in a console also situated at the cell face.

The cell face instrumentation and control equipment will be connected to the units in the T/A by electrical and fibre optic cables passing through the conduit situated in the between cell partition. The standard box service connections will be utilised for thermocouple connections.

## **SERVICE CONNECTIONS TO THE CELL**

The furnace power supply, cooling gas and the optical cable links serving the pyrometers will be introduced into the cell containment box via a purpose made 210 mm diameter x 1.5 m long service plug. Cooling water will be supplied through the standard box connections. Loss of flow protection will be incorporated.

## **INSTRUMENTATION**

The temperature of the furnace element is monitored and controlled, in the range 500 to 3,000°C, by means of a four channel optical pyrometer/controller. The radiation pyrometer will be located at the cell face. It will be connected by means of fibre optic cables to a lens unit positioned axially above the tubular furnace element, and focused such that it measures the temperature of the element at the level of the mid-length of the fuel pellet stack. Three additional pyrometer channels will be used in a similar manner to monitor the temperature of the cladding. Three lens units arranged in three horizontal planes at azimuthal intervals of 120° will be focused on the outer surface of the cladding through quartz windows sealed into the furnace body. The fibre-optic cables lens units and quartz windows are replaceable. The pyrometer/controller may be programmed to provide independent pre-set ramp rates in any of 16 control segments. A wide range of operating conditions will be possible by varying the furnace power input and the cooling gas flow. In order to achieve the specified experimental conditions a combination of high heater power and high mass flow of cooling gas will be required. The flow of cooling gas will be controlled from the cell-face by means of a mass flow control valve located in the T/A. Furnace currents of the order of 300 to 500 amps coupled with coolant mass flows in the range 1 to 3 grams per second are anticipated. Thermocouples are provided to monitor cooling gas outlet temperature, an alarm being initiated by temperatures exceeding the set limit, and the temperature of the Wood's Metal bath. Low flow protection devices are incorporated in the cooling water and cooling gas circuits, both of which initiate furnace trips.

## **DATA ACQUISITION SYSTEM**

A computer based data acquisition system is used to monitor all sensors and provide on-line displays of all input channels. A control function is used to control the temperature of the Wood's Metal bath.

## DEVELOPMENT POTENTIAL

Consideration has been given to the further development of the furnace to enable tests to be carried out in oxidising atmospheres and at higher differential pressures.

The provision of a furnace element capable of operating in an oxidising environment, will extend the capability of the furnace in its present configuration, to tests at ambient pressures in CO<sub>2</sub> based atmospheres. The practicality of producing an iridium furnace element tube by the vapour deposition method is being investigated. The adoption of iridium elements will allow fuel bore temperatures of ~2,000°C to be achieved in an oxidising environment. Also, tests will be conducted to assess the endurance of the current design of tungsten element operating in an oxidising environment. If this proves to be inadequate a possible solution is to provide a protective barrier on the surface of the elements

Modification of the design of the fuel sub-assembly to incorporate welded extension tubes will permit tests under conditions of high pressure differential and, in conjunction with the use of an iridium furnace element, the ability to operate with an internal oxidising atmosphere. A specialised welding facility will be required for the manufacture of this assembly. As an interim measure, a semi-sealed fuel sub-assembly is proposed. This will utilise pressed on extension pieces, similar to those used in the current design, instead of the welded assembly. This arrangement will permit operation with an oxidising internal environment at ambient pressures.

## COMMISSIONING

The apparatus is currently undergoing out-of-cell commissioning trials. The capability to achieve a heating element temperature of 3,000°C at a ramp rate of 10°C s<sup>-1</sup>, with temperature control to within ±5°C has been demonstrated. A dummy instrumented fuel assembly, (Figure 3), has been manufactured comprising an alumina simulant fuel stack within a section of AGR cladding. This assembly is instrumented with three thermocouples, inserted between the cladding and dummy fuel stack at axial positions corresponding to those of the clad monitoring pyrometers. A fourth thermocouple is inserted into the lower end of the heater element via a modified Wood's metal reservoir. It is thus possible to calibrate the rig pyrometers against the thermocouples, although the maximum achievable temperature is limited by the melting point of alumina. The services plug required for this work is being manufactured. The apparatus will shortly be transferred to B.220.29 and set up in the commissioning area within a containment box, together with its services plug, where remote handling trials will be carried out. A further programme of in-box commissioning trials will then be performed, culminating in two fully representative tests using unirradiated AGR fuel pin sections. Full in-cell installation will then take place followed by a series of experiments using irradiated fuel.

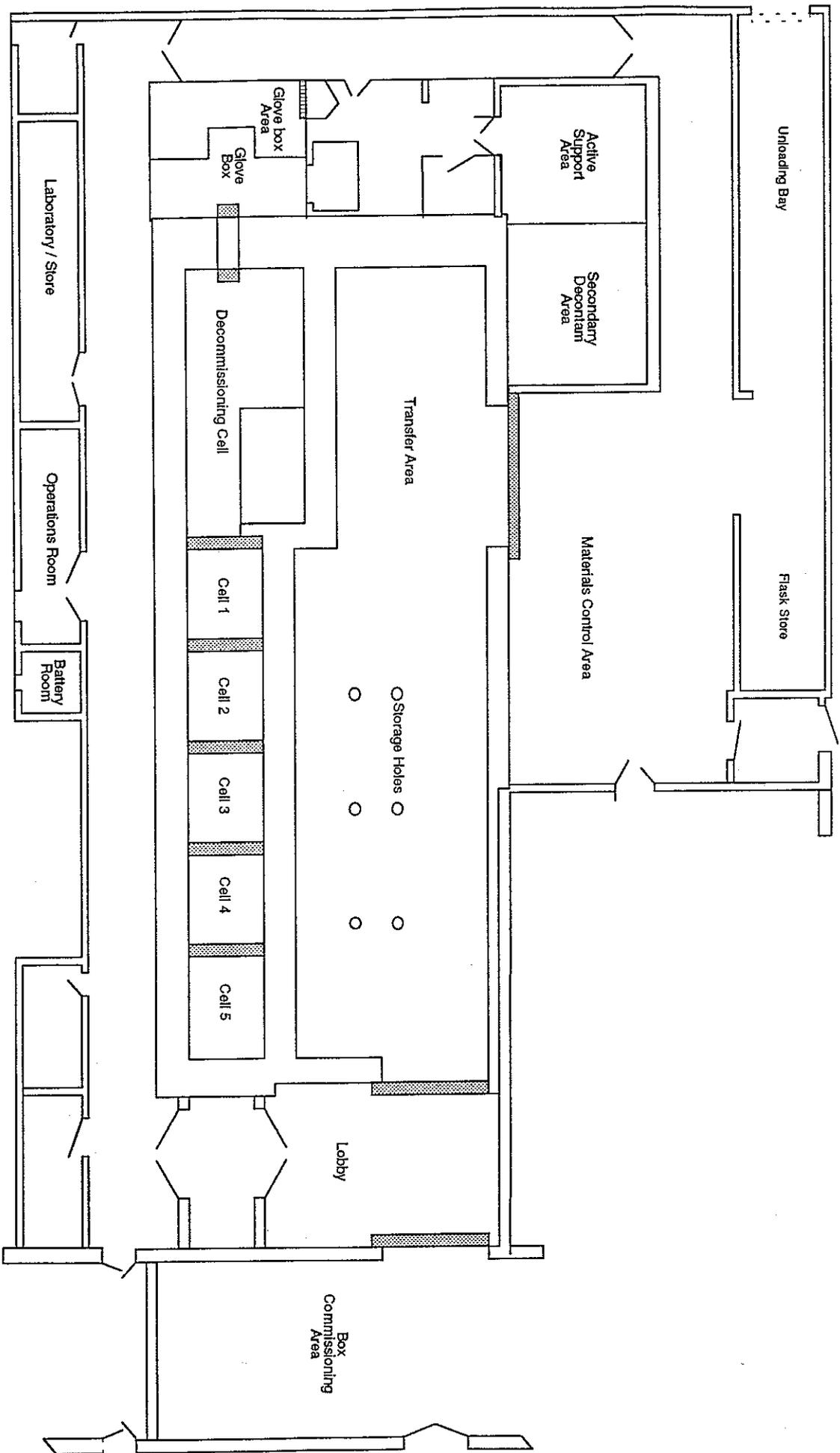


Figure 1. B.220.29 Facility plan.

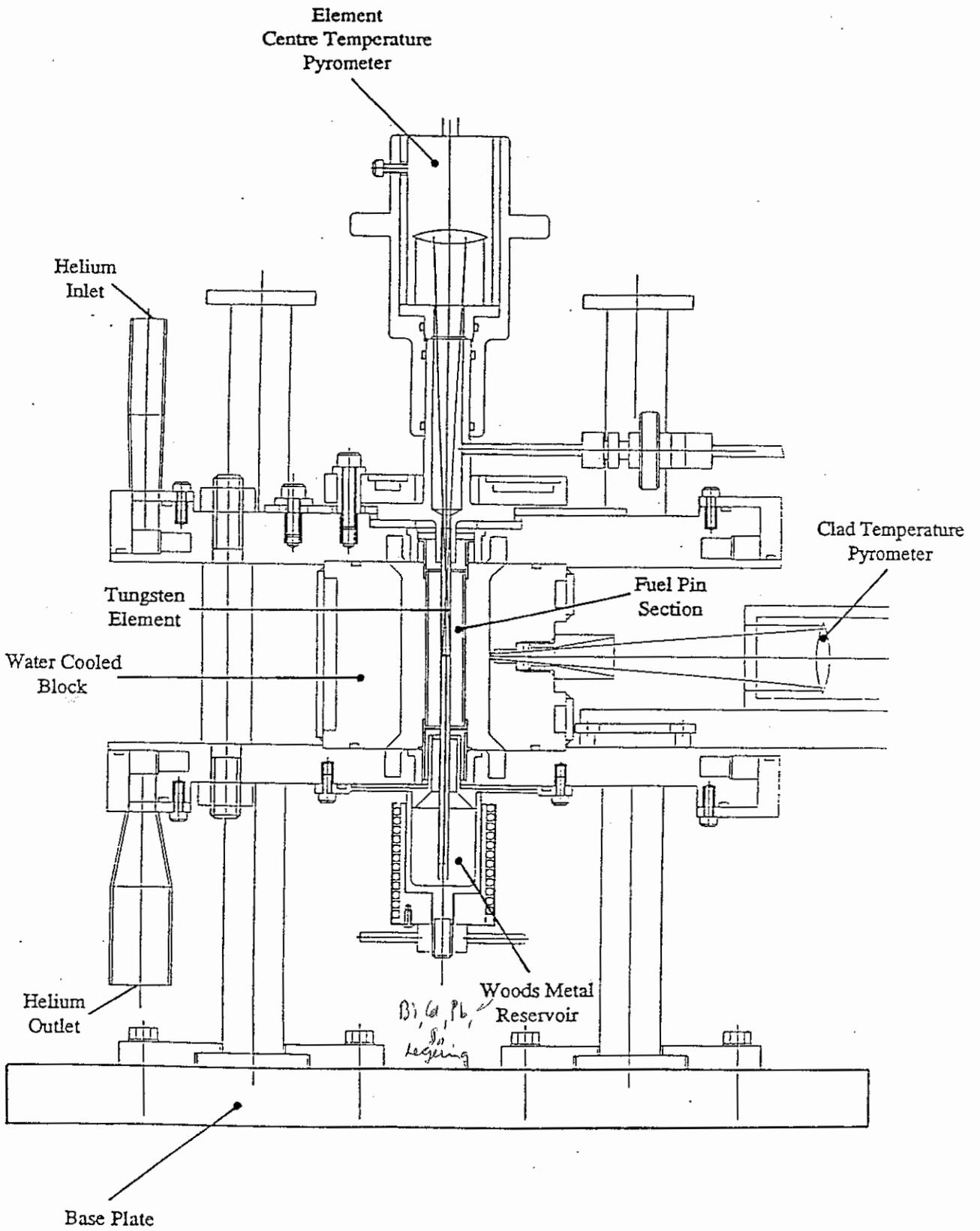


Figure 2. Schematic diagram of furnace assembly.

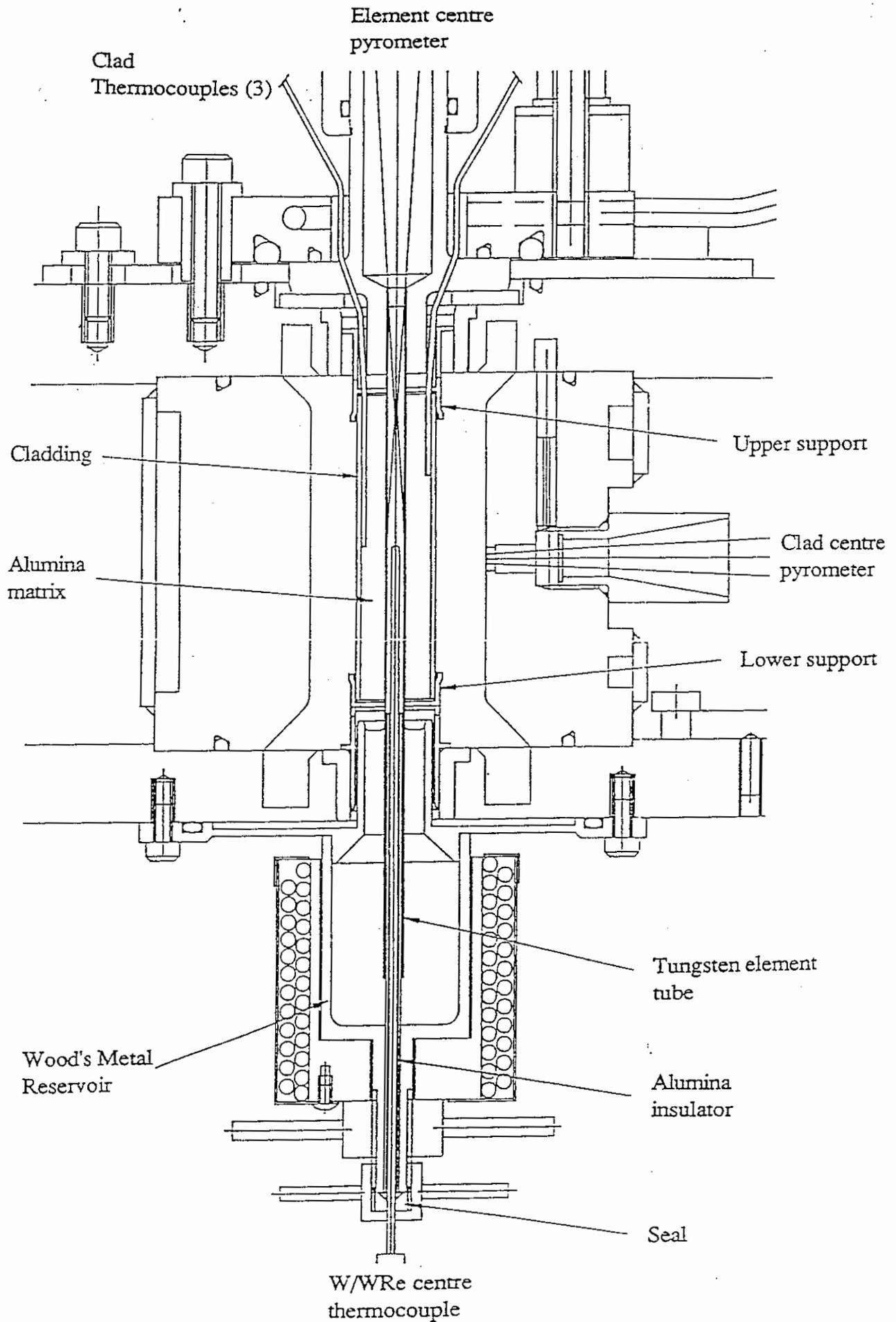


Figure 3. Instrumented dummy fuel assembly.

# Distribution

BOHME Georg 3 Copies  
Kernforschungszentrum Karlsruhe  
Abt. HIT  
D 7514 EGGENSTEIN-LEOPOLDSHAFEN  
Germany

POTT Gunter 3 Copies  
Kernforschungsanlage Julich  
IRW/ Heisse Zellen  
Postfach 1913  
D 5170 JULICH  
Germany

VAN DE WELDE Jose 4 Copies  
Laboratory of SCK/ CEN  
LHMA  
Boeretang 200  
B 2400 MOL  
Belgium

CARLSEN Hans 2 Copies  
Riso National Laboratory  
Metallurgy Dept  
Hot Cell Facility  
PO Box 49  
DK 4000 ROSKILDE  
Denmark

BAUDOIN Jean-Claude 5 Copies  
CEN Fontenay-aux-Roses  
Departement de Genie Radioactif  
Boite Postale No 6  
F 92260 FONTENAY-AUX-ROSES  
France

CHALONY Andre 12 Copies  
LCND  
DEC/ SDC  
CEN Cadarache  
F 13108 SAINT PAUL LEZ DURANCE CEDEX  
France

TREZZA Gaetano ENEA - Casaccia Dipartimento ciclo del combustibile Casella Postale N 2400 I00100 ROMA Italy	2 Copies
DUIJVES Klaas Stichting Energieonderzoek Centrum Hot Cell Laboratory Postbus 1 NL 1755 ZG PETTEN (NH) Netherlands	2 Copies
HARGREAVES R AEA Technology AEA Reactor Services Windscale	1 Copy
STUCKE Martyn AEA Technology AEA Reactor Services Windscale	3 Copies
SAMSEL Gerard Transuranium Institute Postfach 2340 D 7500 KARLSRUHE Germany	6 Copies
CAUWE Juste Centro Comune di Ricerche Ispra LMA I 21020 ISPRA (VA) Italy	3 Copies