



**AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS**

**DESIGN OF IRRADIATION EXPERIMENTS FOR MATERIALS
TESTING REACTORS**

by

R.S. McANENY

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(Paper presented to the IAEA Symposium on Irradiation Facilities for Research Reactors held at Tehran, Iran 6-10 November 1972).

ABSTRACT

This report discusses an approach to the design of in-pile assemblies, and the fundamental problems facing designers of these assemblies. The irradiation rig programme at the Australian Atomic Energy Commission is discussed, and some general purpose rigs used at Lucas Heights are described.

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CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. IRRADIATION RIG PROGRAMME AT THE AAEC	2
2.1 Materials Division	2
2.2 Isotope Division	3
3. GENERAL PURPOSE RIGS AT THE AAEC	3
3.1 Cakestand Rigs	3
3.2 Self-Service Rigs	5
4. FUNDAMENTAL DESIGN PROBLEMS OF IRRADIATION RIGS	6
4.1 General	6
4.2 Neutron Flux Data	7
4.3 Gamma Flux Data	8
4.4 Temperature Control	8
4.5 Data Recording	11
4.6 Re-Usable Shield Plugs	12
5. REFERENCES	13
TABLE I HIFAR RIGS FOR MATERIALS RESEARCH PROGRAMME	
TABLE II HIFAR RIGS FOR ISOTOPE PRODUCTION PROGRAMME	
TABLE III RE-USABLE SHIELD PLUG DATA	
FIGURE I MARK IV HOLLOW FUEL ELEMENT	
FIGURE II LOW TEMPERATURE CAKESTAND RIG	
FIGURE III TYPICAL CAN ASSEMBLY	
FIGURE IV THERMAL NEUTRON FLUX VARIATION WITH COARSE CONTROL ARM MOVEMENT IN HIFAR CORE	
FIGURE V ISOTOPE PNEUMATIC TRANSFER COMPLEX	
FIGURE VI COOLANT FLOW v. TEMPERATURE IN SELF-SERVICE RIG IRRADIATION TUBES	
FIGURE VII DETAIL OF ELECTRICAL HEATER CONNECTION	
FIGURE VIII STANDARD IRRADIATION RIG PLUG SECTION	

1. INTRODUCTION

With the ever increasing demand in most industries for cost saving by design improvement, much has been reported in recent years of new approaches to the basic design function, and the importance of design is now universally recognised. In the nuclear engineering field 'good design' has always been of prime importance, particularly with respect to in-pile assemblies, but as we are all aware this is extremely difficult to achieve. Man is by nature a designer, (how many sponsors of an experiment, e.g. chemists, physicists, metallurgists, always feel they can design their own equipment?) though his ability to design may remain latent. Where the ability to design does develop, many years are likely to pass before it can be said to have developed sufficiently to guarantee results which can be labelled 'good design'. Design as an occupation, by its very nature demands powers of imagination, a creative flair, intellectual ability and all of these faculties are essential for the design of in-pile assemblies.

Many irradiation experiments are extremely expensive, and their success depends in large measure on the ingenuity and engineering judgement of irradiation rig engineers. Every irradiation rig poses a potential threat to the continued operation of the reactor and careful and judicious design by the rig engineers is needed to reduce this threat to insignificant proportions.

What basic requirements must be satisfied in the design of an in-pile assembly?

- (1) It must produce the information required by the user, who often specifies very stringent operating conditions.
- (2) It must be safe under all conditions of operation, thus creating no hazard to either the reactor or personnel.
- (3) It must be manufactured and operated within an acceptable budget, consistent with satisfying the requirements of (1) and (2).

In solving the problems associated with these requirements, the rig engineer is confronted with conditions which are peculiar to the nuclear energy industry.

- (1) The design must often produce results of a high order of accuracy under stringent conditions in a reactor which is itself not a precision machine.
- (2) The in-pile assembly must function satisfactorily immediately it is inserted into the reactor flux environment. Modifications or repairs to a damaged component are virtually impossible; the cost

of using high activity handling cells becomes so restrictive that only very simple repairs can be contemplated.

- (3) The design must provide the necessary integrity and safety in operation, when suitable codes of practice are not often available.
- (4) Due to the neutron economy required, the choice of construction materials is limited and 'exotic' materials must sometimes be used, demanding fabrication techniques which may require development.
- (5) The design must be kept within the restricted physical limits of a given reactor facility.

These are some of the problems which face the rig designer, and it is essential that he has the background and expertise which will lead to 'good design' principles functioning throughout the detail design of any in-pile assembly. This, of course, will not guarantee success, as most in-pile assemblies are subject to some degree of uncertainty, but most problems can be eliminated by careful design and thorough testing of the equipment prior to installation in the reactor.

2. IRRADIATION RIG PROGRAMME AT THE AAEC

The Rig Group at the AAEC Research Establishment is responsible for the design, development, manufacture and commissioning of all irradiation rigs and neutron collimators which are inserted into the High Flux Materials Testing Reactor (HIFAR). This is a DIDO-type high flux heavy water moderated reactor, with numerous test facilities penetrating the solid biological shield, some terminating in the moderator and others in the graphite reflector. Twenty-five fuel element facilities, provided by a MK IV type fuel element (FIG. I), eighteen vertical facilities (sizes 5 - 15 cm dia.) enter the moderator, nine vertical facilities (sizes 5 - 25 cm dia.) enter the graphite reflector, nine horizontal facilities (sizes 5 - 25 cm dia.) enter the moderator and fifteen horizontal facilities (sizes 5 - 30 cm dia.) enter the graphite reflector.

The rig programme is sponsored mainly by the Materials and Isotope Divisions, although some rig design is also undertaken for other divisions on site and clients outside the AAEC such as Australian Universities and other research organisations.

2.1 Materials Division

The bulk of this programme is concentrated towards zirconium/water reactor systems, and includes fuel fabrication and cladding performance, corrosion studies and reactor coolant chemistry, the creep rupture properties of irradiated zirconium and its alloys and generally the effect of

irradiation on the properties of materials. Rig types in use at HIFAR as part of this programme are listed in TABLE I, which also lists essential design parameters and design objectives.

2.2 Isotope Division

In the past five years the demand for radioisotopes and radiopharmaceuticals has increased tenfold, and is expected to continue to increase. Generally, radioisotope production in Australia is concentrated in supplying those isotopes, which by reason of their short half-lives or excessive transport costs arising from heavy shielding requirements, are not available from overseas suppliers, or are available only at considerable expense and difficulty. The AAEC is committed to the regular supply of radioisotopes and radiopharmaceuticals to medical, scientific and industrial bodies in Australia and South East Asia, and this supply is completely dependent on the irradiation facilities available in HIFAR. Rig types in use at HIFAR as part of this programme are listed in TABLE II, which also lists activation parameters and typical radioisotopes produced.

3. GENERAL PURPOSE RIGS AT THE AAEC

3.1 Cakestand Rigs

A cakestand rig is an irradiation vehicle which accommodates a number of specimens arranged in vertical tiers about the reactor core centre plane, the specimens being easily replaceable by means of conventional remote handling equipment. The rigs are located inside MK IV Hollow Fuel Elements with an inside diameter 5.4 cm, and two types of cakestand rig are used in this facility:

- (a) Low Temperature Rigs
- (b) High Temperature Rigs

3.1.1 Low temperature rigs

These rigs (see FIG. II) operate nominally at reactor moderator temperature ($50^{\circ}\text{C} - 55^{\circ}\text{C}$) and cover a thermal neutron flux range of 4×10^{13} neutrons/cm² sec - 1.35×10^{14} neutrons/cm² sec. The specimens are packed in aluminium powder or special holders and contained in standard aluminium sealed cans approximately 3.2 cm dia. and 13 cm long, which are cooled by direct forced convection of the reactor D₂O. A reduced diameter at the top of the can facilitates the location of handling tongs and simplifies load/unload procedures in a Portable Handling Cell. Each rig accommodates a maximum of eight specimen cans, and five rigs of this type are operating in HIFAR at present. Three rigs are operating on the standard twenty-four day cycle, and two are operating on a six day cycle, necessitating three short reactor shutdowns of approximately 40 minutes for radioisotope production.

Since no instrumentation is associated with these rigs, other than integrated neutron flux monitors which are standard equipment in each specimen can, the rigs are cheap to manufacture (costing approximately \$A2000), and enable a turnover of irradiation targets in a reasonable time with no 'rig downtime' for target changes other than normal monthly shut-downs.

A rig which will enable specimen cans to be loaded and unloaded with the reactor operating at full power has been designed. This rig will obviate the need for mid-cycle shutdowns as required by the existing cake-stand rigs, which although not causing real operating problems will be an embarrassment to the Materials Division when the Zircaloy Creep Programme starts. The basic difference between this rig and the standard cakestand rig, is that a sealed rig liner will be used to prevent breach of the reactor primary containment during load/unload procedures. Also the specimen cans will be cooled by natural convection within the sealed thimble, and some instrumentation is required to monitor rig water level and water temperature, with purge facilities being necessary to remove build-up of radiolytic gases in the rig liner.

An average of twenty-five to thirty specimen cans are loaded each month, the packing of the targets being under strict administrative procedures in clean room conditions. The cans are identified by etching the reactor programme number, rig number, rig position number and where necessary which part of the reactor cycle, seal welded, leak tested, contour tested in a can loading jig, chemically cleaned and despatched to Reactor Chemical Services Group where they are 'soak tested' prior to insertion in HIFAR.

3.1.2 High temperature rigs

These rigs operate in the temperature range 200°C - 1000°C , cover a thermal neutron flux range of 8×10^{13} x 1.3×10^{14} neutrons/cm² sec and are similar in construction to those described in 3.1.1. The main differences are that the specimen cans are manufactured from stainless steel and have aluminium or graphite specimen holders. The cans operate in a gaseous environment in an instrumented sealed liner. The specimen cans are approximately 3 cm dia. x 13 cm long and their bottom caps have an integral re-entrant tube which serves to locate the can in the experimental section of the rig and carries thermocouples for can temperature measurement (see FIG. III). The can temperature is manually controlled and maintained, by varying the percentage flow of a helium/nitrogen gas mixture through a pre-determined parallel gas gap between the specimen/can heat source and the

reactor moderator heat sink. Three can positions are available in this rig, but close temperature control can only be achieved in one position, the other two can positions being subject to change with reactor loading and Coarse Control Arm movement throughout the reactor cycle. Typical temperature variation in the two non-controlled cans over a reactor cycle is within $\pm 20^{\circ}\text{C}$ while the control can is being held at $\pm 10^{\circ}\text{C}$. Variation in the thermal neutron flux over the length of the fuel element throughout a typical reactor cycle is shown in FIG. IV.

Four of these rigs are available, but only two are at present operating in HIFAR, and although designed for longer irradiation periods than those described in 3.1.1, they can be unloaded during mid-cycle shutdowns. The rigs are operated from individual consoles; gas control, temperature recording equipment and leak detection instrumentation are integral equipment in the consoles. These rigs cost approximately \$48000 including the control console.

3.2 Self-Service Rigs

A self-service rig is an irradiation vehicle which allows target irradiations at any time during the reactor operating cycle, and provides facilities for load/unload procedures as an integral part of the rig system. Six rigs of this type are currently in use in HIFAR mainly for the production of radioisotopes, with one rig having a tube reserved for neutron activation analysis purposes. Three rigs of a very early design, which terminate in the graphite reflector, provide relatively low thermal neutron fluxes (approximately 10^{13} neutron/cm² sec), and the three remaining rigs which are to an improved design terminate in the D₂O moderator and provide a high thermal reactor flux (approximately 5×10^{13} neutron/cm² sec). These rigs provide a total of sixty-seven irradiation positions all in horizontal facilities. A prototype vertical self-service facility in a hollow fuel element was installed but failed due to a faulty weld at the nose cone at the base of the rig and had to be withdrawn (K. Lloyd, AAEC private communication).

Prior to August 1970, the irradiated targets from the early rig designs were unloaded into shielded containers at the reactor face and transferred to the Isotope Handling Cells for processing. This procedure was cumbersome and uneconomical as well as potentially hazardous, and was highly restrictive with respect to short lived isotopes. To overcome this, and to meet the increased demand for these isotopes, a pneumatic transfer system was designed and installed (see FIG. V).

The three latest rig designs are directly connected to their associated

processing laboratories by pneumatic transfer systems, manufactured either of stainless steel or nylon tube, via delay stations located inside the Reactor Sealed Building. Radiation detectors inside these delay stations monitor the activity levels of the targets as they leave the rig, and ensure that the maximum approved levels are not exceeded before despatching the target to the appropriate laboratory. If this level is exceeded the cans can be posted to a basement unload station. The delay stations are shielded and can accommodate up to four UO₂ targets, stored at any one time under saturated activity conditions. Transport operations between the irradiation facility and the process building use low pressure compressed air, and simple electronic interlocks are used for personnel and equipment safety protection. Air blowers provide cooling for the targets when they reach their irradiation position, and typical flow rate temperature curves for one of the rigs are shown in FIG. VI.

These irradiation rigs are multi-specimen rigs, two rigs accommodating a maximum of seven targets, (approximate can size - 1.5 cm dia. x 5 cm long) and the remaining rig accommodating three targets of larger volume (approximate can size - 4.5 cm dia. x 8 cm long). The seven can rigs have a common target inlet pipe to the rig head, and the irradiation tube is selected via a rotary selection barrel mounted in the rig head prior to blowing the can into position. In the three-can rig, separate tubes are connected to the rig head, and two of these pass to a delay station before proceeding to the process building, while the third tube goes direct to a small laboratory mounted adjacent to the Reactor Sealed Building. This tube will be used for fast access neutron activation cans, where transfer times of less than 2 seconds are possible with low mass targets, and automatic control of irradiation time and can ejection under high temperature conditions is built into the system.

All operations are carried out from the individual system's control consoles, with intercom units providing liaison between the operator's console and the associated processing building.

4. FUNDAMENTAL DESIGN PROBLEMS OF IRRADIATION RIGS

4.1 General

Probably the most important parameters in the design of in-pile rigs, and in the analysis of experimental results, are the neutron flux and the reactor gamma flux which the experiment experiences during its reactor life. Each reactor has its own operating characteristics which can have profound effects on any experiment within it. This is exemplified by the variation in neutron and gamma flux from facility to facility in the reactor core,

both radially and axially, throughout the reactor cycle due to control arm movement, fuel burn-up, rig loading, etc. (see FIG. IV).

It is apparent that provision of accurate data for the rig designer is very difficult, since data available at the design stage can change drastically by the time the experiment is loaded into the reactor, and late manufacturing action may be necessary as a result of refined calculations prior to the loading date.

4.2 Neutron Flux Data

Fast and thermal neutron fluxes and their distributions in HIFAR are measured continuously, and flux scanning rigs are used each month in facilities which are not being used for other experiments. If it is a requirement of the experiment, flux scan facilities can be provided in any rig. Wire scans using nickel wires and the $^{64}\text{Ni}(n\gamma)^{65}\text{Ni}$ reaction for thermal flux measurement and the $^{58}\text{Ni}(np)^{58}\text{Co}$ reaction for fast flux measurement are made absolute by comparison with flux measurements at specific points using gold detectors and the $^{197}\text{Au}(n\gamma)^{198}\text{Au}$ reaction. Monthly plots are provided of the fast and thermal fluxes in various facilities, taking into account the average representative fuel and experimental loading and changes to be expected throughout the cycle. To verify the integrated flux dose under which any experiment operates, neutron flux monitors are standard insertions in each irradiation rig or specimen can, where no continuous measurement is specified. The routine detector materials used are titanium and cobalt, and wires of the chosen material weighing a few milligrams are loaded into sealed alumina tubes, to prevent contamination of the wire, and to make recovery easy in the high activity handling cells.

Where instantaneous neutron flux intensity and its fluctuations are required, devices of the primary emission neutron activation type have been used in a limited number of experiments. These self-powered devices use rhodium as the primary emitter, and the beta activation produced by neutron absorption causes a flow of electrons, proportional to the neutron flux, between the central rhodium electrode and a conducting outer sheath which is insulated from the electrode. Connecting cables from the in-pile detector carry the electron flow to amplifying and measuring equipment mounted at the rig head. Fission chambers using ^{235}U as the source element will be used for some future rigs in which the change in flux with the axial movement of a fuel pin is required to be continuously monitored [1].

Although the data obtained by these methods suffice for most design purposes, it is essential in fissile specimen experiments to take account of

the flux depression within the rig, as this can reduce the mean flux in the specimen by as much as a factor of five relative to the unperturbed flux, when highly absorbing materials are used. In simple geometries this flux depression factor can be calculated using computer codes based on multi-group diffusion theory, with accuracies of order $\pm 35\%$. However, in complex geometries or in facilities which are close to the control arm influence, flux depression predictions with these codes may be inaccurate by as much as $\pm 70\%$. In the latter case with low power simulated absorption rigs, copper foils to measure the activity in the fuel pellets, and mica discs to measure the fission rate in the ^{235}U , have proved extremely useful. These techniques have been used at the AAEC to determine power outputs from large fissile specimens in a highly absorbing environment [1].

4.3 Gamma Flux Data

Non-fissile heating of components is unavoidable in reactors and it is essential that the most accurate data is available for any facility. Gamma flux data for HIFAR is very scant and most of the data were extrapolated from measurements carried out at very low reactor powers (approximately 10 watts) when the reactor was first operated. Early rig designs indicated that the extrapolated data was optimistic by a factor of approximately two, and two of these early rigs were used as 'thermal simulation' rigs. These rigs were the forerunners of a number of rigs of this type (see 3.1), having similar geometry and materials of construction, and 'equivalent nuclear heating' rates were calculated from temperatures obtained in various Hollow Fuel Element positions. These 'equivalent nuclear heating' rates are not claimed as absolute values, since they include a number of uncertainties, such as the heat transfer mode operating, and the effects of radiation on the thermal conductivity of the gases used. However, using these rates, the gas gaps required to obtain the desired operating temperature for future rigs of similar construction can be estimated with a degree of accuracy unobtainable by any other method. The only effects which cannot be accounted for other than dimensional tolerances is the variation in reactor gamma flux with time. Using this technique, operating temperatures of the rigs can be estimated to within $\pm 10\%$, and even though a wide range of temperature control is available with a helium/nitrogen mixture, the axial temperature profile follows the gamma flux profile to a large extent, and this order of accuracy is necessary on single can control rigs.

4.4 Temperature Control

Control of the temperature of some part of an in-pile assembly or sample under irradiation is usually fundamental to the purpose of the experi-

ment, or to its safety, or both. It is important that all necessary data as discussed in Section 4.1 are available, thus enabling the equipment to be designed to achieve the desired temperature distribution. In practice, inadequacies in the heat transfer model, uncertainties in thermal conductivities, manufacturing tolerances on components and the inaccuracy of the nuclear heating estimates, make it extremely difficult to meet the stringent temperature requirements often imposed. For this reason it is essential that a facility is available in the rig to enable wide temperature variation to be achieved after the rig is loaded.

4.4.1 Gas mixing control

Numerous methods of temperature variation using the mixing of gases between the heat source and the heat sink have been developed in the past decade [2], but experience at Lucas Heights has been mainly concentrated on gas mixing in parallel gaps. In the past, the research programmes were such that close temperature control was not essential for the majority of irradiations undertaken, and temperature deviations of $\pm 10^{\circ}\text{C}$ from the set point were acceptable; this was the main reason that this method of temperature control was chosen. Where possible, gas gaps were designed large enough that machining costs were kept to a minimum with open tolerances on components, and small enough that natural convection was inhibited, thus making the heat transfer model relatively simple to analyse. Helium and nitrogen (chosen because of characteristics, cost and availability) were found to give a sufficiently wide band of temperature variation, and possible build up of nitric acid due to moisture in the rig was prevented by using a continuous purge. This also prevented stratification of the gases, which had occurred in some of the earlier rigs. Changes in gas flow ratio from $30\text{ cm}^3/\text{min}$ to $100\text{ cm}^3/\text{min}$ have insignificant effect on rig temperature, and no serious activation problems are inherent with these gases. In a typical rig designed to operate at 600°C , a temperature range of 200°C - 900°C was achieved from the condition of all helium in the rig to all nitrogen.

Because of the variation in nuclear heating during a 24 day reactor cycle, continuous adjustment of the gas mixture is needed to compensate for specimen temperature divergence, and the system is dependent on reasonably quick remedial action by the rig operator to control within the desired temperature range. Alarms set at $\pm 5^{\circ}\text{C}$ of the specified operating temperature enable the temperature to be controlled within $\pm 10^{\circ}\text{C}$.

Automatic temperature control by gas mixing was investigated at Lucas Heights some years ago, but the cost and development time associated with

such a system outweighed the advantages of closer temperature control.

4.4.2 Electrical heater control

Since the Materials Division Creep Programme began in 1969, the need for close temperature control and fast response systems has increased the number of in-pile rigs demanding reliable electrical heaters. Electrical heaters used in early rig designs had very limited success due to the lack of facilities and manpower for long term testing of these heaters. The lack of facilities limits the amount of work that can be undertaken during the life of a project and we have tended to look to overseas companies for such items, since the limited market makes small developmental contracts unattractive to Australian manufacturers.

There are also problems associated with using heaters obtained from overseas. While a high standard of manufacture can be achieved, it is often the case that the necessary installation techniques are not available, and modified techniques can reduce the effectiveness of the heater.

Since most heaters have to be 'tailor-made' for a specific rig application, purchase of heaters from overseas is of necessity a long term process, and remedial action for unsatisfactory items presents difficulties due to the geographical location of Australia.

Most of the problems with the electrical heaters used in early rig designs, which comprised a bare wire wound on a ceramic former, were associated with embrittlement of the wire at temperatures $> 900^{\circ}\text{C}$ in a CO_2 environment. Other failures resulted from breakdown of electrical continuity at the connection between heater and lead due to corrosion at the joint and overheating of the terminal block due to gamma heating. It was suspected that contamination in the ceramic formers may have occurred due to graphite permeating through the insulation tape leading to a reduction in the breakdown voltage between the coils. In more recent rigs, using heaters fabricated from mineral insulated stainless steel sheathed/nichrome core cables we have experienced problems at the connection of this cable to a similar diameter copper sheathed/copper core mineral insulated cable. Because of restricted space the connector had to be kept to just above the cable diameter; the detailed joint design is shown in FIG. VII. This joint is embedded in a stainless steel matrix to reduce 'hot spot' possibilities; initial designs using a brazed joint failed under test due to brazing flux residue causing corrosion at the electrical connection, resulting in intermittent operation. Difficulty was experienced in producing a joint without using conventional brazing techniques, since only copper sheathed leads were readily available and vacuum induction brazing facilities for this type of application

were not. After investigating various welding techniques and joint designs, a fluxless brazed joint employing a metal spray technique to join the copper/nichrome cores and the stainless steel/copper sheaths was developed. The metal is a nickel/chrome alloy and produces a non-porous fused bond between the components, and pre-irradiation tests show excellent leak tightness and good electrical continuity. Two rigs using this type of heater joint are being commissioned and are due to be loaded into HIFAR.

Future work planned for the temperature control aspects of rigs at the AAEC will concentrate on three approaches:

- (1) We are in the process of installing a vacuum induction brazing facility and further work on fluxless brazed joints for miniature connections will be undertaken.
- (2) A mineral insulated heater cable with a continuous outer sheath of stainless steel or inconel having a fluxless brazed copper/nichrome conductor fabricated prior to the swaging of the cable is manufactured by Société Anonyme d'Études et Réalisations Nucléaires (SODERN) of France, and we have ordered some random lengths for testing in out-of-pile rigs.
- (3) Due to the questionable reliability of electric heaters operating at high surface heat fluxes, a feasibility study of a control system using automatic gas mixing to produce temperature control to within $\pm 5^{\circ}\text{C}$ of set operating temperature will be undertaken, to compare the economics of the system with electrical heater control systems.

4.5 Data Recording

Past practice at Lucas Heights was to design and manufacture instrumentation and control consoles for each rig, but a stage was reached where the top gallery of the reactor was so packed with consoles that manoeuvrability and data collection became a real problem. Also, since all levels of staff were involved in the design, fabrication and testing of the consoles, which on completion of the experiment would either undergo extensive modifications or be completely stripped to recover instruments, a real economic penalty is unavoidable with this type of rig instrumentation. Thermocouples are used predominantly and temperature measurements account for approximately 75% of all variables logged or alarms scanned in the console system. To enable the temperature to be expressed in engineering units, a separate recorder or trip amplifier is required for each type of thermocouple combination and the recorders operate with a fixed temperature

range and are restricted to a limited number of input channels. The subsequent duplication and accumulation of recorders and trip amplifiers in such an inflexible system is inevitable. With the advent of a high pressure water loop and its high capital cost instrumentation implications, and the uneconomical usage of existing instrumentation, it was decided that a data acquisition system was economically desirable. The system has been installed and has been accepting rig and selected reactor inputs since June 1972, and high and low alarm limits are available on each output. Although no control functions are available at present, the system is used for computing creep data, fuel pin power output, coolant activity and other simple data in addition to standard parameter logging such as temperature, pressure, flow etc. Trend recorders mounted on the operator's console enable any point to be trended at any time, and print-out facilities can be programmed at any time interval. In conjunction with this installation we are installing a common rig electrical control console, assembled on a module basis, and using silicon controlled rectifier units in lieu of the magnetic amplifier saturable reactor units used in the old consoles. Although faster response is available from the S.C.R. units the main reason for the change is a saving in space.

4.6 Re-Usable Shield Plugs

With the number of irradiation rigs used in earlier research programmes at Lucas Heights, disposal of the shield plugs as high activity waste caused an acute lack of storage space in the old disposal facility. As approximately 90% of an irradiated shield plug is inactive (less than 5 mR/h induced activity), expensive and limited high activity waste disposal space is not properly utilized when the whole of the irradiated shield plug occupies this space. Also a significant portion (10 - 15%) of the total in-pile rig manufacture involves the production of the shield plug, and thus valuable time is taken up in ordering materials and in plug manufacture. Therefore a major rig component, such as the shield plug body, which can be re-used saves project time and manufacturing costs. For these reasons a standard re-usable shield plug has been designed and used on general purpose rigs since 1966 [3]. The plug body consists of a stainless steel re-usable plug section approximately 1.2 metres long and a stainless steel disposable plug section 20 cm long, which are coupled together by an aluminium adapter (FIG. VIII). After irradiation the rig services are cut at the rig head and the re-usable section of the plug is removed from the rest of the rig by unscrewing and slipping over the rig services tube in the high activity handling cells. The re-usable plug is wiped with a silicone impregnated cloth until the activity level is reduced to approximately 60 mR/h at the surface, and then finally cleaned by immersion in an ultra sonic cleaning bath. Typical results of plug activities after irradiation and cleaning are

illustrated in TABLE III, which shows that even when attached to rigs which have been subjected to long irradiation periods, e.g. 9000 hours in a flux of 4×10^{11} neutrons/cm² sec, the re-usable plug section can be handled, stored, re-used or disposed of as low activity waste.

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TABLE I
HIFAR RIGS FOR MATERIALS RESEARCH PROGRAMME

Rig Type	Design Parameters	Experimental Objective
Cakestand Rig (4 off)	Thermal neutron flux 6×10^{13} - 1.3×10^{14} n/cm ² sec Specimen temp: 250 ^o C - 800 ^o C Irradiation period: 24 days - 4 months	Irradiation effects on tensile properties of Zirconium alloys, irradiation of Izod impact steel specimens, corrosion of stainless steel pressure vessels, irradiation of single crystal of Zirconium.
Sweep Gas Corrosion Rig (6 off)	Fast neutron flux $> 2 \times 10^{13}$ n/cm ² sec Specimen temp: 250 ^o C - 800 ^o C Specimen environment: Wet Helium, CO ₂ , O ₂	Irradiation effects on corrosion resistance of Zirconium alloys in varying sweep gas environments and controlled temperature.
Single Specimen Creep Rig (Reloadable Specimen, Continuous Measurement, In-Pile) (1 off)	Fast neutron flux $> 2 \times 10^{13}$ n/cm ² sec Specimen temp: 300 ^o C - 500 ^o C Specimen stress: 280 megapascal max. Specimen extension Better than measurement: 10 ⁻³ cm Oxygen content in Helium < 10 ppm	Continuous measurement of primary, secondary and tertiary creep of Zirconium alloys under conditions of constant load and constant strain. Investigation of stress rupture properties of Zirconium alloys.
Multi-Specimen Creep Rig (UKAEA Collaborative Programme, In-Cell Measurement) (2 off)	Fast neutron flux $> 2 \times 10^{13}$ n/cm ² sec Specimen temp: 300 ^o C - 500 ^o C Specimen stress: 400 megapascal max. Specimen extension Better than measurement: 5 x 10 ⁻⁴ cm Irradiation period: 3 months	Creep measurement of Zirconium alloys under conditions of constant strain. Specimen extension measured every three months in special measuring cell.
High Pressure Water Loop (1 off)	Fissile specimen rating /Kd0 > 40 watt/cm Loop max. pressure: 14 megapascal Loop max. temp: 330 ^o C Mass flow rate: 4.5×10^{-4} kg m ² /hr	Fuel pin performance studies. Fuel/cladding interactions and cladding fabrication performance. Fission gas pressure measurement, power cycling experiments, dryout studies, defect pin experiments.

TABLE II

HIFAR RIGS FOR ISOTOPE PRODUCTION PROGRAMME

Rig Type	Activation Parameters	Purpose
Hollow Fuel Element Cakestand Rig (3 off)	Thermal neutron flux $> 8 \times 10^{13}$ n/cm ² sec Fast neutron flux $> 2 \times 10^{13}$ n/cm ² sec Irradiation cycle 24 days	Production of high specific activity, medium and long lived radionuclides, e.g. Iridium-192, Ytterbium-169, Phosphorous-32.
Hollow Fuel Element, 2" and 6" Vertical Cakestand Rig (17 off)	Thermal neutron flux $6 \times 10^{12} - 10^{14}$ n/cm ² sec Irradiation period 2 years - 5 years	Production of high specific activity Cobalt-60
Cakestand Rig (2 off)	Thermal neutron flux $> 8 \times 10^{13}$ n/cm ² sec Irradiation period 5 days	Production of high specific activity short lived radioisotopes - manual transfer to processing facilities, e.g. Molybdenum-99, Tellurium-131
4" Horizontal Self-Service Facility (Small Target Volume) (2 off)	Thermal neutron flux $> 2 \times 10^{13}$ n/cm ² sec Irradiation period 1 min - 24 days	Production of high specific activity short lived radioisotopes - automatic transfer to processing facilities, e.g. Sodium-24, Potassium-42, Copper-64, Fluorine-18, Technetium-99m, Bromine-82.
4" Horizontal Self-Service Facility (Large Volume Target)	Thermal neutron flux $> 10^{13}$ n/cm ² sec Irradiation period 1 min - 24 days	Production of high specific activity short lived radioisotopes - automatic transfer to processing facilities, e.g. as above.

TABLE III

RE-USABLE SHIELD PLUG DATA

Shield Plug No.	Plug Material (BS.970)	Plug Activity (Before Loading) mR/h	HIFAR Facility	Hours at Full Power	* Plug Activity (After Unloading and Decontamination) mR/h
1	En 58 J	0	HFE.C-2	3,780	2
2	En 58 J	0	HFE.D-4	1,220	2
3	En 58 J	0	4V-3	7,640	5
4	En 58 J	0	4V-3	3,460	3
5	En 58 C	0	HFE.D-5	4,630	20
6	En 58 J	0	4V-4	6,950	3
7	En 58 J	0	4V-4	3,650	3
8	En 58 J	0	HFE.C-2	5,060	5
1**	En 58 J	2	HFE.D-4	5,300	7
2**	En 58 J	2	HFE.B-2	2,570	10

* Activity was measured with a BERTHOLD hand monitor held against the lower end of the plug. The activity reduced to zero 1 - 2 inches up the plug. Readings were taken approximately one month after unloading.

** Second loading of re-usable plug.

NOTE: At a power of 11 MW (thermal), the peak thermal neutron flux in HIFAR is 1.7×10^{14} neutrons/cm² sec and the flux immediately below the vertical shield plugs is of the order of 4×10^{11} neutrons/cm² sec.

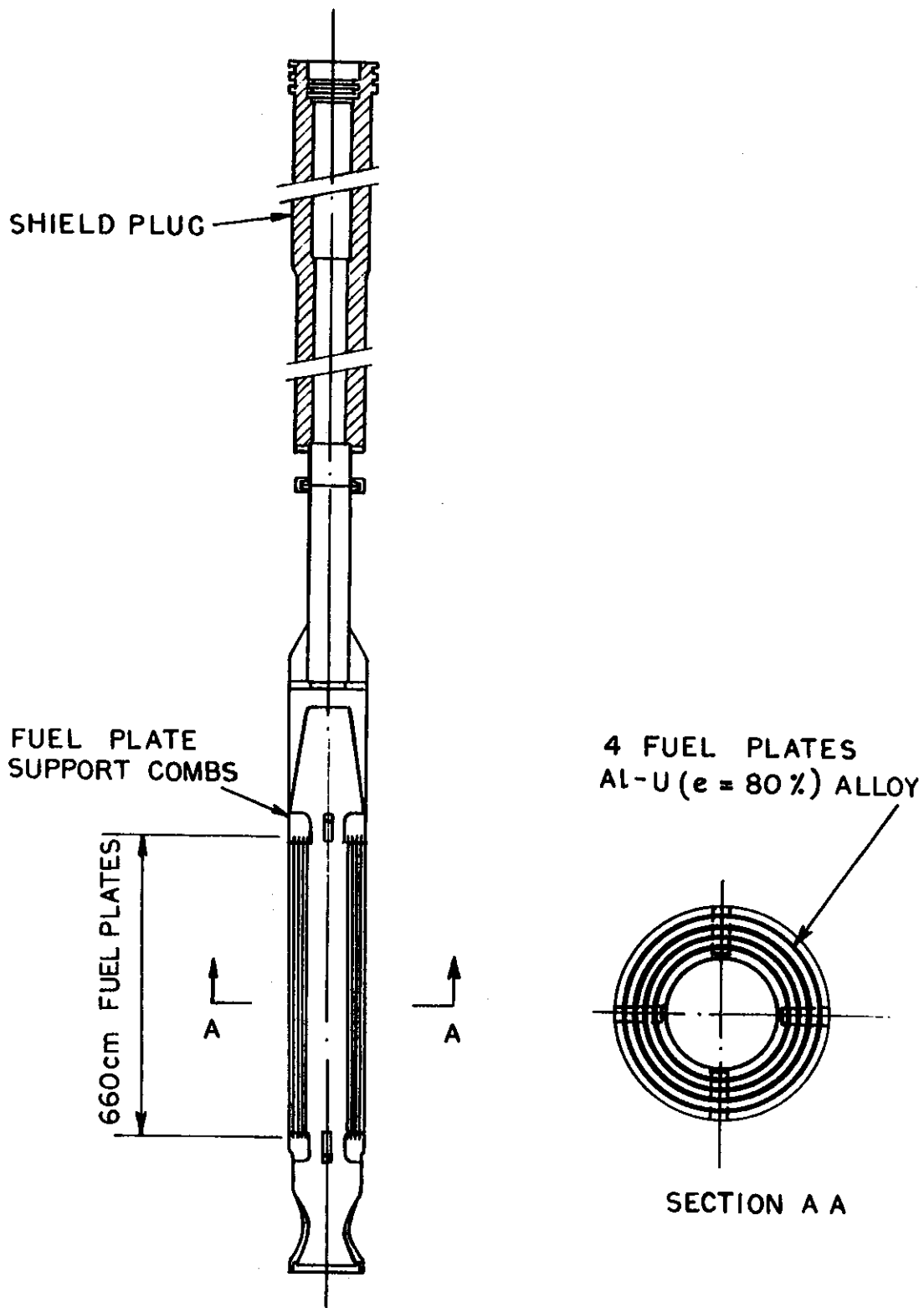


FIGURE I MK IV HOLLOW FUEL ELEMENT

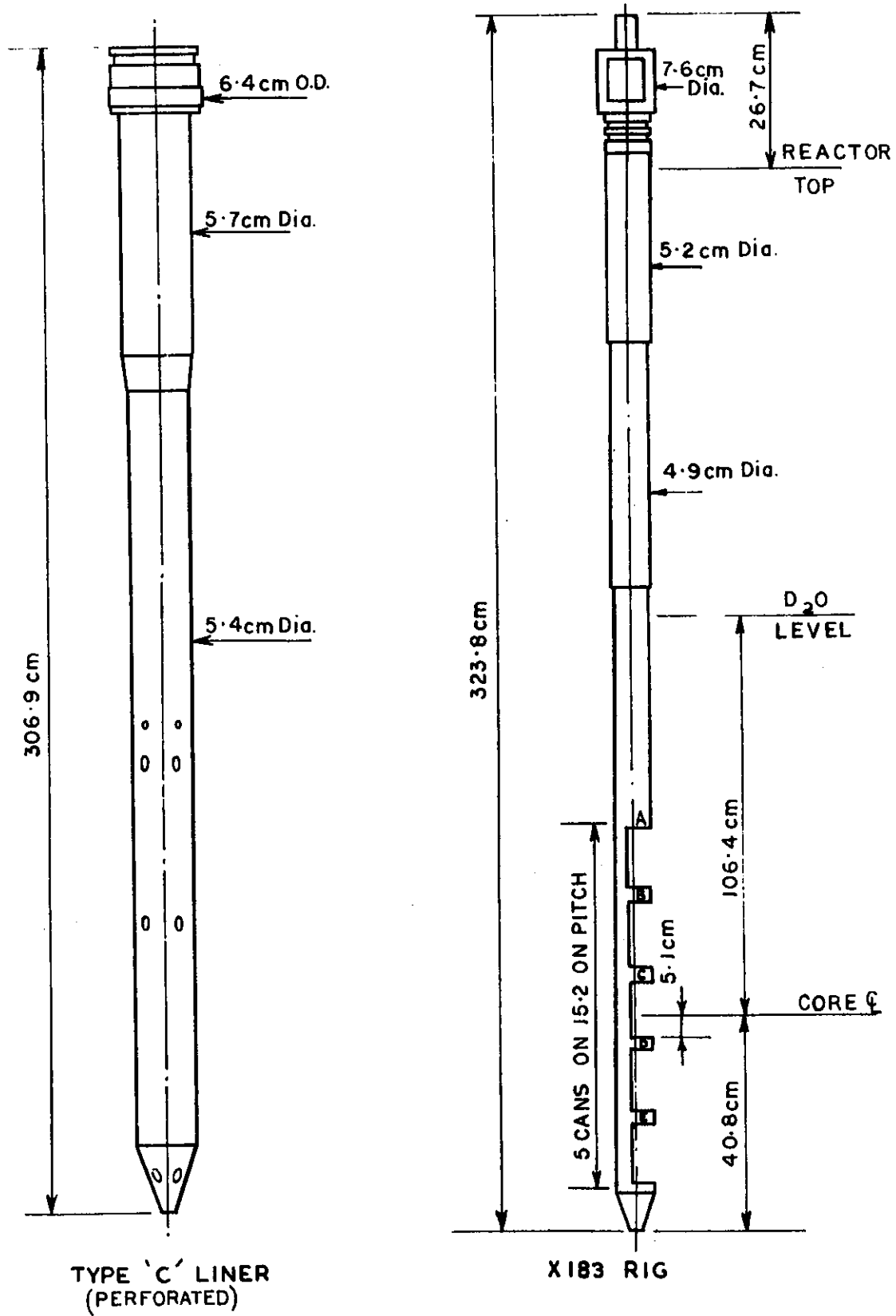


FIGURE II LOW TEMPERATURE CAKESTAND RIG

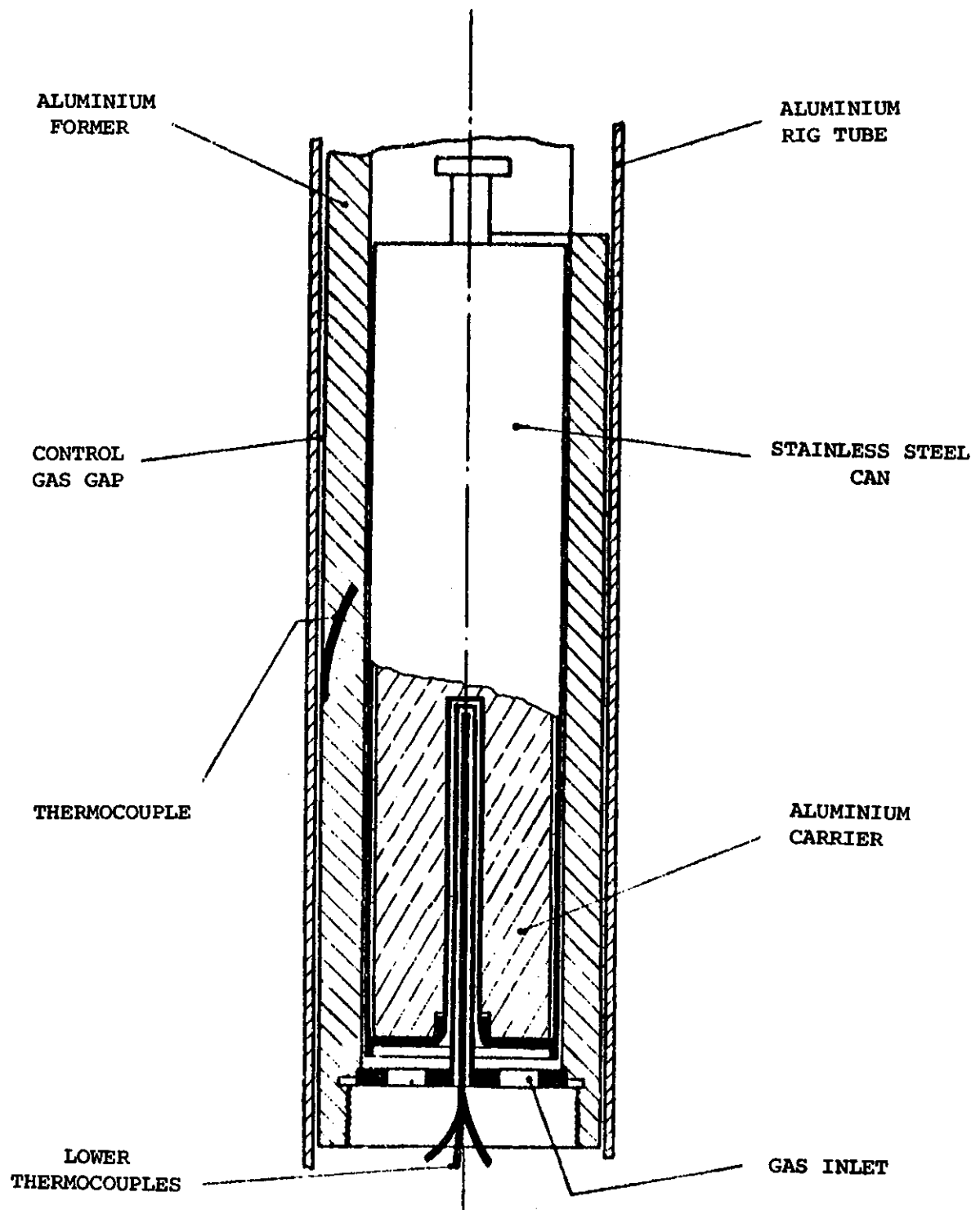


FIGURE III TYPICAL CAN ASSEMBLY

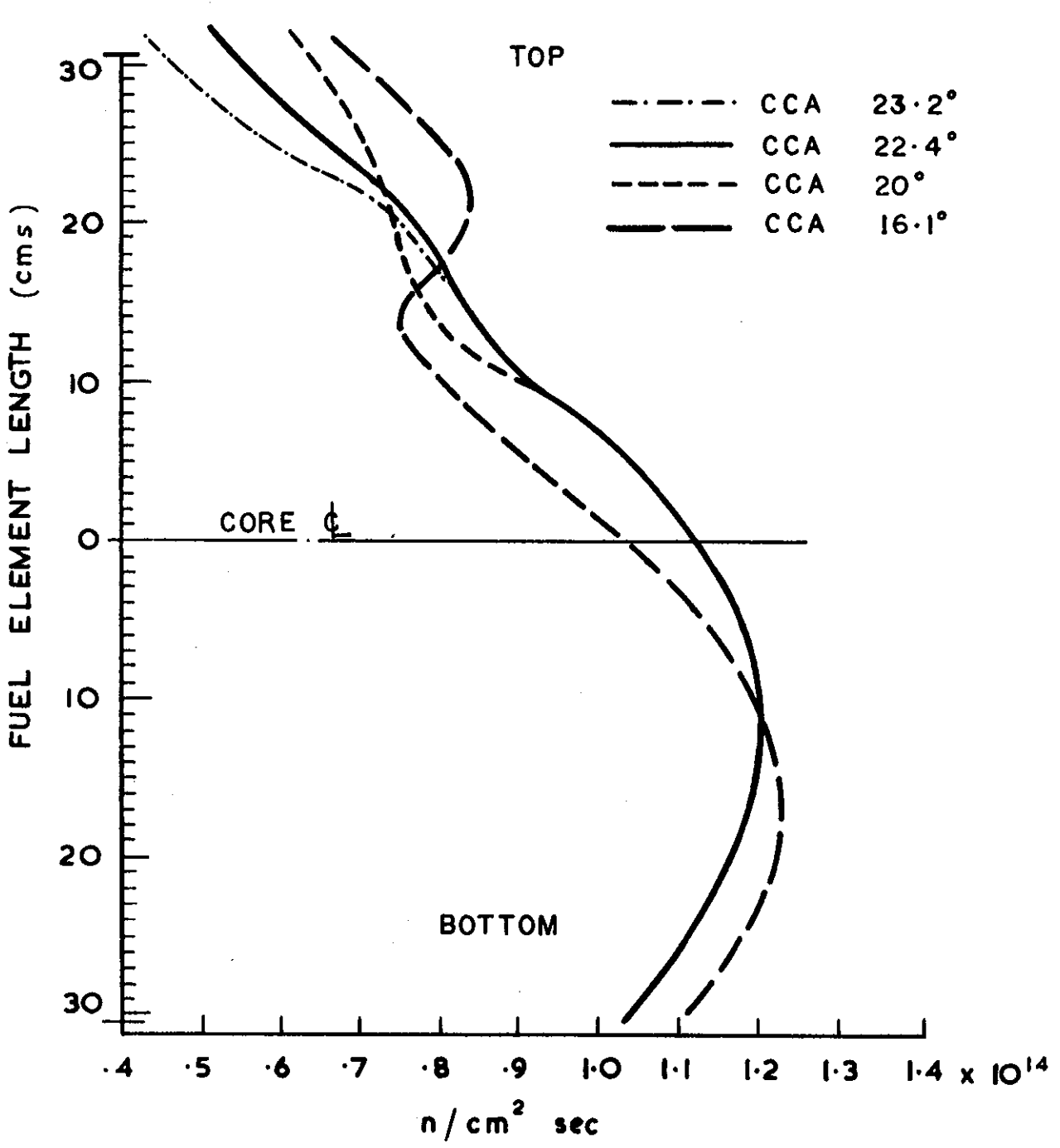


FIGURE IV THERMAL NEUTRON FLUX VARIATION WITH COARSE CONTROL ARM MOVEMENT IN HIFAR CORE

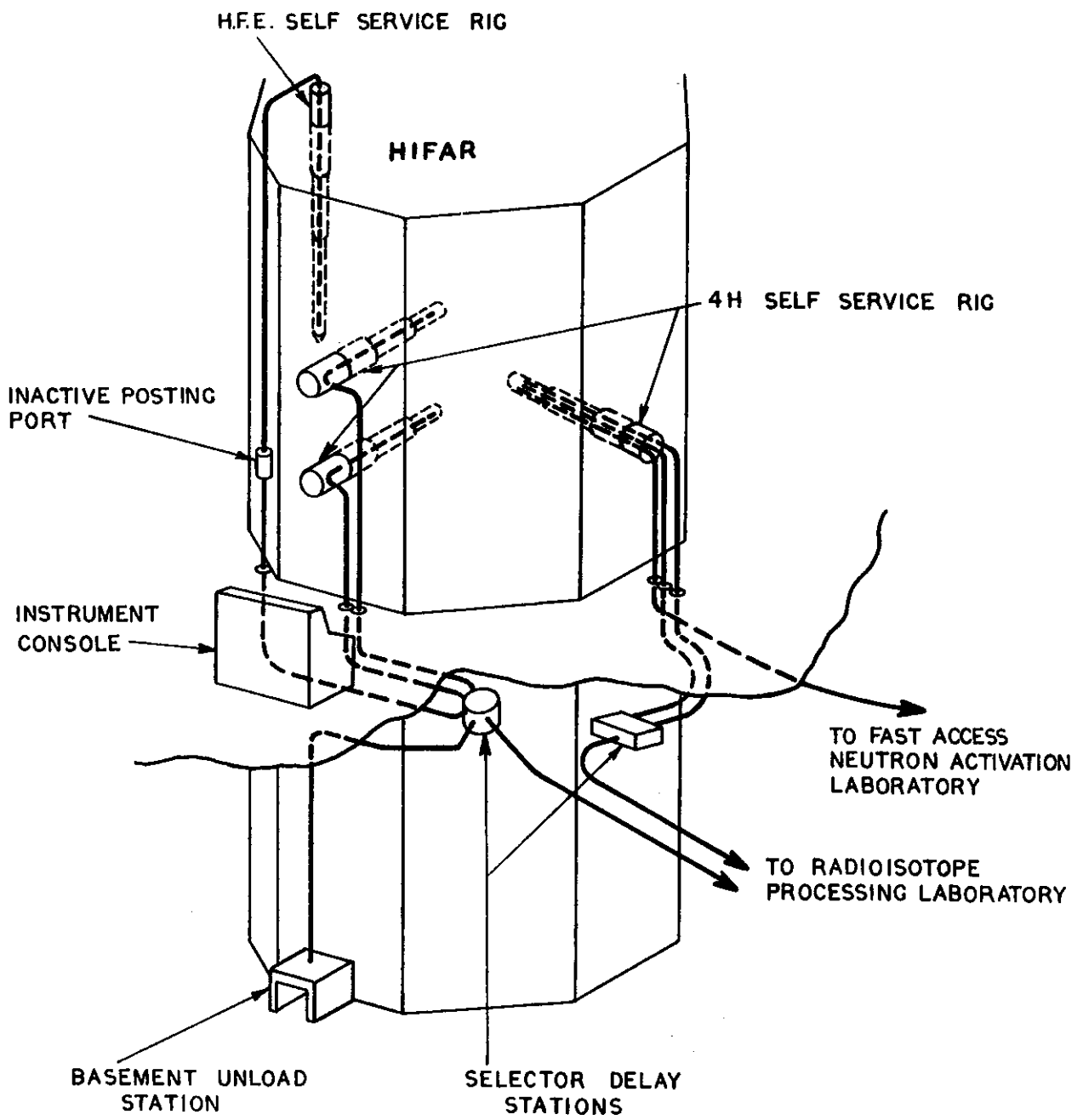


FIGURE V ISOTOPE PNEUMATIC TRANSFER COMPLEX

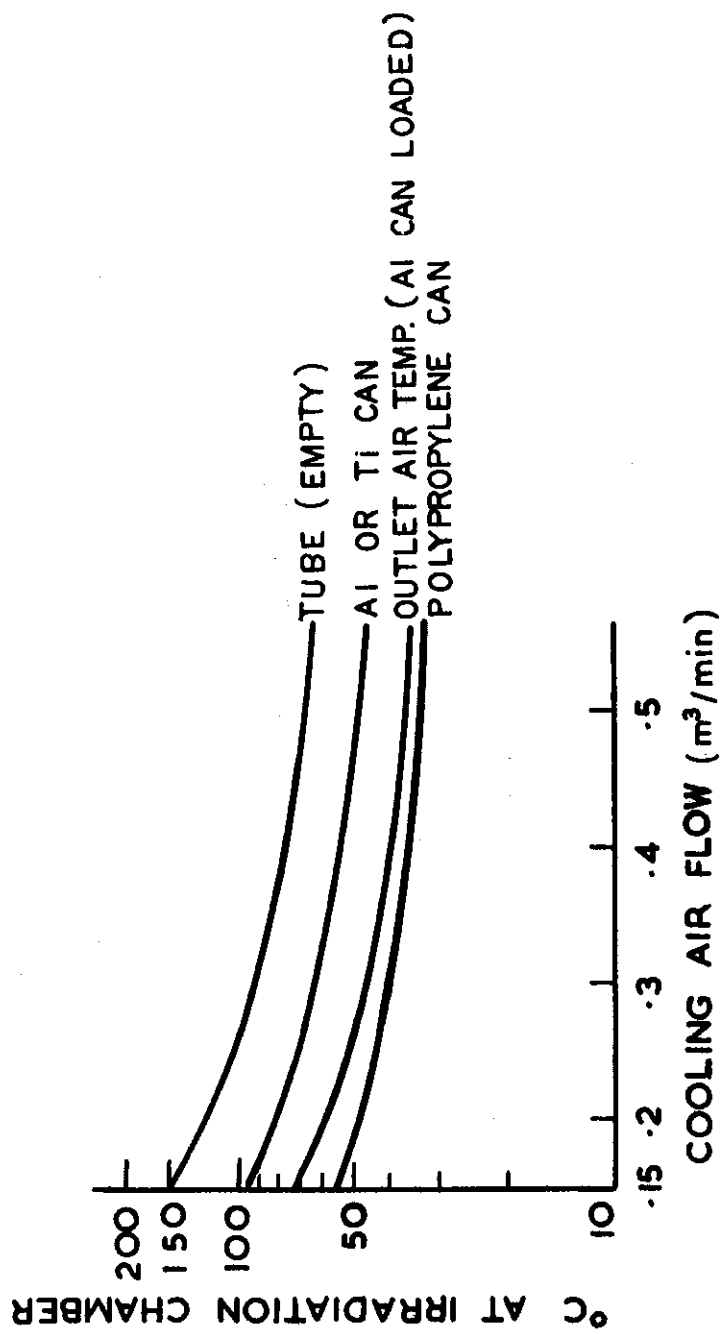


FIGURE VI COOLANT FLOW v. TEMPERATURE IN SELF-SERVICE RIG IRRADIATION TUBES

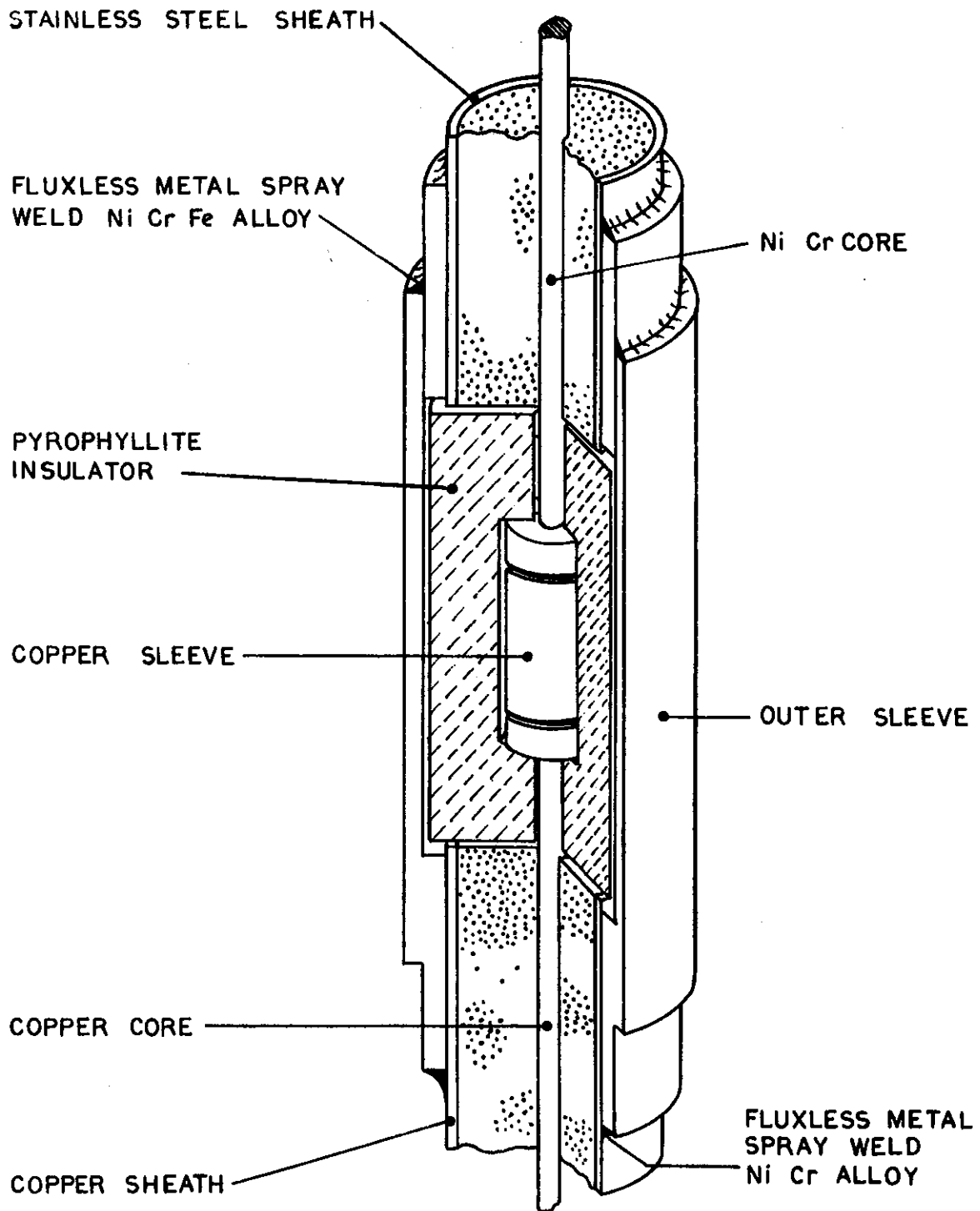


FIGURE VII DETAIL OF ELECTRICAL HEATER CONNECTION

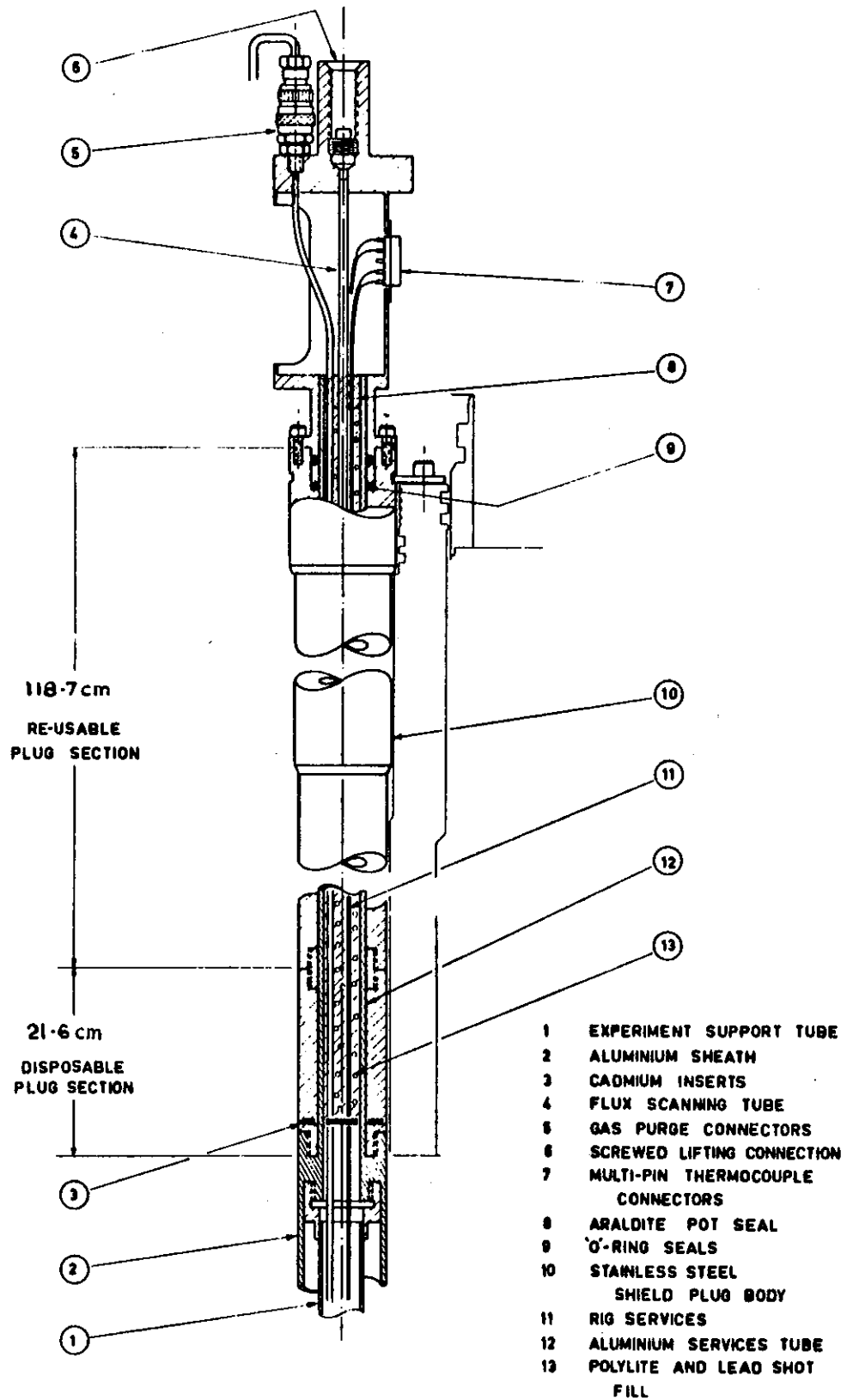


FIGURE VIII STANDARD IRRADIATION RIG PLUG SECTION