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Interim Report of the H.F.B.R. Irradiation Facilities Working Party

September 1966

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1. INTRODUCTION

1.1 The Working Party was formed at the request of the Chairman of the H.F.B.R. User Committee, with the following terms of reference:

(1) To obtain from potential H.F.B.R. Users a specification of their requirements for sample irradiation in terms of neutron spectrum and flux density required, specimen volume, temperature control, dwell time and sample change facilities, etc.

(2) To assess the availability of locations in the H.F.B.R. where these requirements can be met, paying attention both to probable costs and interaction with other reactor users.

(3) To assess the out-of-reactor facilities required to complete the work, report on their present availability and the cost of any necessary extension.

(4) To report and make recommendations to the H.F.B.R. Users Committee on the preferred installations.

1.2 The membership of the working party is:

Dr. V. S. Crocker (Chairman)
Mr. D. B. Halliday
Dr. R. K. Webster
Mr. C. B. G. Taylor
Mr. R. West
Dr. B. R. T. Frost
Mr. J. R. Hind (Secretary)

The working party held two meetings in February/March and a third meeting in August 1966.

1.3 The availability of suitable positions for facilities located in the H.F.B.R. reflector tank was found to be influenced by (a) beam tube layout and (b) the overall height of the beam shutter upperworks, which limited the maximum angle of inclination of the facilities. Data presented in this report is aligned to Beam Tube layout scheme XI issued on 10.8.66 (RRD 2245), and for an overall shutter height appropriate to a High Angle Beam Hole inclination of 55° to the horizontal.

1.4 The specification of out-of-pile facilities is incomplete at this stage. The space available on the experimental and operations floor, and the shape and size of the reactor building will affect the layout of rig handling cells, storage blocks, etc. Until these matters are settled, little more than a general review of required out-of-pile facilities is appropriate.

2. LOSS OF NEUTRON DOSE DUE TO RIGS

2.1 General

An overall loss of neutron dose at the beam tubes will result from the introduction of rigs into the H.F.B.R. This loss is due to the following factors:

(a) The additional time required at scheduled reactor shut downs in order to unload, load and commission rigs.

(b) Loss of neutron output caused by unscheduled shut downs due to rigs which have failed in a manner likely to endanger the safety of the reactor if the reactor were to continue to operate.

(c) Insertion of a rig into an unperturbed thermal neutron flux causes the flux to be depressed locally and any beam tube in the vicinity of the rig will suffer a flux loss as a result of this depression.

(d) To provide additional excess reactivity to cover the rig load the fuel loading must be increased which, for a given reactor power output, results in a lowering of the thermal neutron flux in the reflector.

The Working Party considered these points in the light of the directive from the H.F.B.R. Users Committee that the overall loss in neutron dose to beam users due to rigs must not exceed 20%.

2.2 Scheduled Shut Downs

It was considered that the additional time required at scheduled shut downs to unload, load and commission rigs need not be greater than half a day. Numerous improvements over current DIDO/PLUTO practices could be achieved, viz:

(a) Universal use of multi-way plug and socket connectors at the rig heads for instrumentation and heater leads.

(b) Quick release devices for locking rigs into position.

(c) The ability to unload reflector rigs without the need to isolate the reactor tank helium blanket.

(d) More extensive out-of-pile commissioning of the rig coupled to the actual panel to be used during the irradiation.

An additional shut down period of half a day for rig handling represents a 4% loss in the annual neutron output of the reactor.

2.3 Unscheduled Shut Downs

Any unscheduled shut down of the reactor will result in a 'poison out' and, unless occurring at the start of a reactor cycle, will necessitate a complete fuel change. Clearly, unscheduled shut downs imposed by rigs must be kept at a much lower level than is currently accepted in DIDO/PLUTO. This can be achieved by:

(a) Exclusion of those types of rigs which demand shut down of the reactor to prevent a fault condition in the rig developing to the point where the safety of the reactor is in jeopardy. It may be impracticable to apply this principle absolutely, but it is recognised that some rig types impose far greater control on a reactor than others (see 2.6 below).

(b) Acceptance by rig users that a 'write-off' of their experiment is not, in itself, sufficient reason to call up an unscheduled shut down.

A less rigid attitude than that outlined above could be adopted if it is shown that faulty rigs could be unloaded with the reactor at reduced power but sufficient to prevent a poison out. This procedure requires further examination and clearly would not be suitable for in-core rigs.

By one approach or the other, it is felt that unscheduled shut downs can be reduced to the point where the loss in neutron output is negligible.

2.4 Flux Depression

Although flux depression calculations have been carried out on some rig types, this work is as yet incomplete. However, based on experience with many rigs in DIDO and PLUTO some consistency in the flux depression characteristics has been observed. In general terms, insertion of a rig into an unperturbed thermal neutron flux causes the flux at the rig surface to be depressed to around 50% of the unperturbed value. At a distance of 10 cms from the rig the flux is about 25% lower than the unperturbed value and at 20 cms it is about 10% lower. The Working Party felt that a 20 cm separation between rig axis and beam tube tip was of the right order to aim for. The interaction between rig and beam tube fluxes is discussed further in sections 5.2 and 5.9.

2.5 Increased Fuel Loading

Consideration of the overall flux loss contributed by the above factors against the allowable total of 20% determines at 7% the flux loss to be set against the allocation of reactivity for rigs. Core loading calculations show that by increasing the fuel inventory until the peak flux is reduced by 7% produces a gain of 2% in excess reactivity. Thus the reactivity allocation for rigs must be limited to 2% (i.e. about ¼ of the DIDO/PLUTO value) and severely restricts the number and size of rigs which may be permitted either in-core or in the peak reflector flux positions.

2.6 Loops

Reference was made in 2.3 above to certain rig types which impose close control on the state of the reactor. This is particularly true of loops which consist of a closed cooling circuit, usually pressurised, independent of the reactor coolant. The test material in loops is usually fissile, often at high ratings, and departure from normal operating conditions can lead to dangerous situations if unremedied. Certain fault conditions, particularly loss of coolant flow, can only be countered satisfactorily by tripping the reactor. Further, since loops are quite complex pieces of equipment then any requirement for the loop to be operating before the reactor can start up is inevitably a frequent cause of shut downs over-running their scheduled start up times. In addition, the in-pile sections of loops invariably are heavy flux depressors and control greater reactivity than non-dynamic rigs. Any proposal for installation of a loop in H.F.B.R. would have to evaluate these aspects in detail, but it is difficult to see how any such proposals would be able to keep within the 20% flux loss limitation laid down.

2.7 Summary

The factors by which the overall neutron output of the reactor is reduced due to the presence of rigs is summarised in the table below.

	Flux loss factor
Scheduled shut downs	0.96
Unscheduled shut downs	1.00
Flux depression	0.90
Reactivity	0.93
Overall flux loss factor	0.80

3. IRRADIATION FACILITY USERS

Potential users of H.F.B.R. irradiation facilities fall into three main groups:

Isotope Production Unit (RCC)
Metallurgy Division
Chemistry Division

3.1 Isotope Production Unit (R.C.C.)

The H.F.B.R. would be a most valuable tool for general isotope and cobalt production. However, since the Radiochemical Centre is not attached to any Group and operates on a commercial basis, any utilization of the H.F.B.R. by the R.C.C. is dependent on and subject to the formulation of satisfactory costing arrangements for isotope production.

3.2 Metallurgy Division

Metallurgy Division interests in the H.F.B.R. stem mainly from the fact that the proposed siting of the reactor is at Harwell. The reactor itself does not offer any outstanding advantages for fissile irradiations in support of fast reactors, the fast flux being much lower than D.F.R. The high thermal flux in the reflector permits the use of lower enrichment in fissile isotopes to achieve a given rating, and for experiments in support of thermal reactor systems a clear advantage exists in that burn-up can be achieved on small samples in a shorter time than is possible in DIDO or PLUTO. Metallurgy Division interests in the H.F.B.R. would be significantly lessened if a Fast Materials Testing Reactor was to become available.

3.3 Chemistry Division

The major usage of the H.F.B.R. would be by Analytical Chemistry Branch, the main applications being in the fields of (a) activation analysis and (b) the determination of nuclear parameters. Limited usage by Fission, Reactor and Radiation Chemistry Groups is also envisaged.

4. LOCATION OF FACILITIES

4.1 General

There exists three alternative locations for facilities in the H.F.B.R.

(a) In-core

Experiments which demand high damage or fast neutron fluxes can be catered for by positioning the experiments in the reactor core where fast fluxes (> .82 MeV) of 0.6 x 10^{15} n/cm^2 sec are available. Such rigs can be force cooled by the reactor D_2O but will be subject to an external pressure of 500 p.s.i.g. In-core rigs will be severely limited in size and number (see Section 5) and require to be unloaded at each reactor shut down in order to change reactor fuel elements.

(b) Reflector

A larger number of rigs can be accommodated in the low pressure D_2O reflector surrounding the core. Thermal neutron fluxes ranging from 10^{14} n/cm^{2}sec at the reflector tank walls up to the peak value of 2 x 1015 n/cm^2 sec near to edge of the core are available for general activation studies, isotope production, transmutation reaction studies and fissile irradiations. The radial thermal flux distribution in the reflector is shown in Fig.1 and the signal/noise ratio $\frac{(\text{ Flux Group } 4 \text{ })}{(\text{Flux Group } 1+2+3)}$ at the core mid-plane is shown in Fig. 2.

(c) Thermal Shield/Reflector Tank Interspace

The helium filled thermal shield/reflector tank annular interspace can be used to accommodate up to six vertical facilities of 6-inch diameter. Although no demand at present exists for such facilities, they would be particularly useful for stock irradiations in thermal fluxes of a few 10^{13} n/cm^{2}sec in the event of closing down either BEPO, DIDO or PLUTO. For this reason the Working Party recommended that the top thermal shield be designed such that these facilities could be incorporated if required.

The in-core and reflector locations for facilities are discussed in greater detail in sections 5 and 6 and summaries of irradiation facility requirements in these locations are contained in Appendices 2 and 3.

5. IN-CORE RIGS

5.1 Environmental Conditions for In-Core Rigs

All in-core rigs or capsules will be subject to the following environmental conditions:

Mode of cooling	Forced convection
Coolant	Reactor D_2O
Coolant pressure	500 p.s.i.g.
Coolant bulk temperature	49 - 130°C
Coolant velocity	40 ft/sec
Coolant water conditions	5.0 pH
Fast neutron flux ($>$ .82 MeV)	0.6 x 10^{15} n/cm^{2}sec
Thermal neutron flux	0.15 - 1.0 x 10^{15} n/cm^{2}sec
Gamma heating	15-30 w/gm

5.2 Rig Types

In-core rigs, as specified to date by potential Users, fall into three groups:

(a) Uninstrumented small capsule type irradiations at core ambient temperature.

(b) Uninstrumented large scale fissile or non-fissile irradiations at core ambient temperature.

(c) Instrumented and serviced rigs operating at temperatures other than core ambient.

5.3 Small Capsule Type Irradiations

Fast flux facilities are available for the irradiation of small samples at bulk D_2O temperature in the centre space of the reactor fuel elements. The inner fuel ring is 0.65 inches inside diameter and requires a coolant gap of 0.050 inches. Taking a wall thickness of 0.050 inches for the capsule containing thimble, capsules of up to 0.45 inches diameter could therefore be accommodated. The thimble would be open ended to provide cooling for the capsules and to avoid a differential pressure across the wall. A routine procedure is envisaged at reactor shut downs for unloading the thimbles complete with capsules from spent fuel elements and transferring them into new elements. These facilities would be suitable for Isotope Production and for Chemistry Division work on the determination of nuclear parameters (see Appendix 2).

5.4 Uninstrumented Large-scale Irradiations

A technique used by Metallurgy Division on occasions in DIDO/PLUTO has been to replace either a whole or a part of a reactor fuel element with an experimental element which is then irradiated for several cycles at reactor temperature conditions. Should data be required at temperatures other than the temperature at which the experimental element operated, post irradiation heat treatment can often go some way to providing this. Such experiments are usually conducted on fissile material although the possibility of large scale tests on solid control materials should not be ruled out. One use of the technique would be in the irradiation of prototype H.F.B.R. fuel elements of new design or material where the penalties incurred by this type of experiment would presumably be negligible. On the other hand, bulk irradiation of non-fissile material would impose severe reactivity penalties (see 5.6 below) and such an irradiation might well have to be carried out at the expense of the majority of other in-core and reflector experiments.

5.5 Instrumented Rigs

Requirements exist from both Metallurgy and Chemistry Division for in-core rigs operating at elevated temperatures. To maintain temperature control the rigs must incorporate in-pile heaters and it may also be necessary to employ gas mixture control. Accurate knowledge of specimen temperature demands that the rigs be extensively instrumented. This type of rig, therefore, must pass through the reactor primary circuit containment in order that instrumentation, heater and gas mixture services may be led away to the rig panels.

From experience in the BR.2 reactor, the minimum diameter for rigs of this type is considered to be in the order of 1 inch, which could be accommodated in selected fuel elements with the three inner fuel rings removed. Since all reactor fuel elements are changed every reactor shut down, it will be necessary to unload instrumented rigs at each shut down.

The only suitable place for rigs to penetrate the primary circuit is through the top closure which is some 16 ft above the top of the core. The rigs must pass through the inlet plenum chamber, where turbulence of the incoming D_2O is likely to be high, and then through a region where D_2O velocities are of the order of 20 ft/sec. Clearly, under these conditions, the rigs will require supporting at intervals along their length to prevent excessive vibration.

Should several (i.e. 4-5) instrumented in-core rigs be considered as the normal charge, then the possibility of treating the in-core rig assembly, consisting of rigs and support members, as a single entity for the purposes of load/unload is worth considering. The rigs might be split into two distinct parts - a service tube some 15 ft long carrying the service pipes, leads and instrumentation, and the rig proper of about 5 ft in length mounted and sealed to the lower end of the service tube. The service tubes could then be permanently attached to the support members to produce a robust vibration-free structure aligned within the reactor inlet header by means of pads in contact with the inlet header containment walls. By making the service tubes of cadmium or other absorbing material, some thermal neutron attenuation in regions vertically above the core could be achieved. The proposal is dependent on the ability to remotely connect the rig services to the service tube leads and then to seal the connection between the rig and the service tube such as to withstand 500 p.s.i. external pressure without leaking. Further study coupled with practical demonstrations and testing would be necessary before such a scheme could be regarded as practicable.

If the normal charge of instrumented in-core rigs was only 1 or 2 the savings in load/unload times would be small as would the saving on rig costs, and could not be justifiably set against the additional costs incurred in providing a 20 inch diameter flask and in development of suitable connectors and joints.

5.6 Reactivity Worth of In-Core Rigs

The reactivity worths of typical in-core rigs have not yet been fully evaluated. However, measurements made in the Brookhaven reactor serve as a good guide. It was found that a voided thimble of 1.37 inches diameter in the centre of the core controlled 1.1% reactivity, compared to 0.23% when placed in the reflector peak flux position. It has already been shown (see 2.5) that the total reactivity controlled by all rigs must be limited to about 2% which suggests that the total reactivity worth of in-core rigs must be restricted to about 1.5%. A single uninstrumented large scale non-fissile experiment or two 1 inch instrumented rigs would be expected to absorb this order of reactivity according to Brookhaven data, which is the best available until measurements are made in the Zero Energy Reactor. Clearly, the size and number of in-core rigs are severely restricted by reactivity considerations.

6. REFLECTOR FACILITIES

6.1 Influence of reactor and beam tube layout on reflector rig accommodation

The space available to accommodate rig heads at the level of the top thermal shield is bounded internally by the 60 inch diameter plenum chamber upper flange. Taking a minimum clearance of 6 inches between the centre line of a rig and this flange, the minimum radial distance of a vertical rig from the axial centre line of the core is 36 inches, at which plane the thermal flux is only 5×10^{14} n/cm^{2}sec. In order to place the active ends of reflector rigs in zones of higher flux it becomes necessary to incline the rigs towards the core. In cases where a pair of rigs are placed one behind the other, inclining the inner rig causes the outer rig also to be angled in order to maintain separation between the rig heads. The inclination of inner rigs is limited by the need to clear the lower flange of the plenum chamber, whilst the inclination of the outer rig of a pair is limited by the need to prevent the rig fouling the shutter drives during load/unload.

From Fig. 4 it will be seen that the half of the tank containing both multipod assemblies has the greater proportion of free D_2O space. The other half contains the through tube and the D_2O outlet pipe and in addition the main D_2O inlet pipe passes across the top of the tank adjacent to the D_2O outlet pipe and hence precludes the presence of rigs in that area. Thus, out of the ten rig positions available, nine are collected in one half of the reflector, and the interaction between rig and beam tube fluxes becomes correspondingly more significant.

6.2 Interaction between rig and beam tube fluxes

The reduction in beam tube flux due to a vertical irradiation facility can be estimated by consideration of the flux reduction at the beam tube tip. This reduction is a function of both the absorption strength of the rig and its separation from the beam tube tip. One arrangement of irradiation facilities in the reflector tank is shown in Fig. 4 and is applicable to the current beam tube layout drawing RRD 2245 issued on 10.8.66. The circles number VI to V10 represent the positions of the lower ends of the irradiation facilities. The following comments may be made about the arrangement:-

(a) Rigs V2 to V6 occur mainly in symmetric pairs with respect to the beam tubes and thus are more severely limited in absorption strength by an imposed limit on the beam flux perturbation than are the other rigs. This limitation could be negated by removal of V3 and V5 which would permit the absorption strength of V2, V4 and V6 to be doubled.

(b) If a limit if x% is placed on the flux reduction at the tip of any one beam tube, and if all rigs are assumed to be of about the same perturbation strength, the maximum permissible perturbation by a single rig at 15-20 cm separation is about ½x%, (or ¼x% in V2 to V6 if V3 and V5 are loaded).

(c) If V10 is omitted, the permissible perturbation by V1 can be doubled.

(d) If some of the V1 to V6 and V10 rigs fall below the permitted perturbation limit it may be possible to raise the limit in some of the other rig positions. In general, the permitted increase in the V7, V8 and V9 positions will be at least twice that in any of the other positions.

The permissible rig absorption strengths to produce various perturbations in beam tube fluxes with a 15-20 cm separation have been calculated by McGill(1) and are tabulated below, together with typical masses of materials giving these absorption strengths.

TABLE 1

Perturbation at 15-20 cm separation	$V\Sigma a$ (cm^2)	Weight or Volume per cm length							
		Aluminium		Stainless Steel		Co^{60}	U^{235}	Pu^{242}/ Cf^{252}	B10
		cm^3	gm	cm^3	gm	gm	gm	gm	gm
10%	0.6	51	138	2.9	24	1.6	0.35	8	.0025
5%	0.25	21	57	1.2	10	0.7	0.14	3.4	.0006
2½%	0.12	10	27	0.575	4.9	0.33	0.07	1.6	.0003

(The above data is applicable to rigs of diameter 2 to 6 cms where the neutron loss due to streaming up the rig was found to be insignificant.)

Reflector irradiation facilities are specified in some detail in Sections 6.4 to 6.8 and are reviewed briefly with respect to their potential interactions on beam tube fluxes in Section 6.9.

6.3 Facility types

Reflector facilities, as specified to date by potential users. fall into three broad categories:-

(a) Self serves. Facilities which enable batches of canned samples to be loaded into and unloaded from the reactor during normal operation of the reactor.

(b) Rabbits. Hydraulic or pneumatic systems which enable samples to be dispatched from send stations, which may be remote from the reactor, to dwell in the reactor for a specified period before being returned to the send station.

(c) Thimble rigs. Facilities which permit samples to be unloaded only during reactor shut downs.

For the purposes of discussion it is convenient to treat the self serves and rabbits together in one group and to consider separately the requirements of the three main user bodies for this group.

6.4 Isotope Production Unit requirements for self serves and rabbit facilities

Self serve nests

Sample Types : Stable high melting point metals, oxides and some E.M. enriched stable isotopes.

Sample Weight : Typically in range 1-100 mg.

Thermal neutron cross-section : Typically about 0.01 cm^2/sample.

Can size : $\frac{3}{8}$ inch dia x $2\frac{1}{2}$ inches long.

Irradiation times : About 50% for 1 cycle or multiples of 1 cycle; about 50% divided typically between 1, 3, 7 or 10 days.

Load/Unload : Time to load or unload a single sample or a small batch of samples should not exceed 30 minutes.

Cooling of samples : By D_2O flow.

Source transport : Hydraulic - by means of coolant.

Number and position of self serves :

(a) one nest of 3 tubes holding about 40 samples at 2×10^{15} n/cm^{2}sec.

(b) one nest of 4 or more tubes holding 60 or more samples at 1×10^{15} n/cm^2 sec.

(c) one self serve acting as a stand-by for DIDO/PLUTO in 10^{15} n/cm^{2}sec.

Rabbit facilities

Occasional use of Chemistry Division rabbit facilities is envisaged.

6.5 Chemistry Division requirements for self serves and rabbit facilities

Requirements for two self serves, four rabbit facilities and one flash system are set out in Appendix I. In view of the limited number of facility positions available in the reflector it is proposed to group Rabbits 1 and 1A together in one hole at 5×10^{14} n/cm^{2}sec and Rabbits 2 and 2A together with the Flash system in one hole at 10^{14} n/cm^{2}sec.

6.6 Metallurgy Division requirements for self serves

A Metallurgy Division requirement exists for an instrumented self serve in which fuel samples at very high ratings would be irradiated for short periods of time to study the structural changes induced. Samples would be required to operate at elevated temperatures which would be continuously monitored during residence of the sample in pile.

Fuel sample dimensions : 1 cm dia x 6 cm length
Wt of fuel/sample : 2 grams (UO_2 density)
Rating : 1000 watts/gm
Heat output : ~2 kW
Canning material : stainless steel
Can temperature : 500-600°C
Thermal neutron flux : $5\text{-}8 \times 10^{14}$ n/cm^{2}sec
Residence times : 30 secs to 2 hours

6.7 Thimble rigs

Four types of reflector thimble rigs have been specified by Users and are detailed below.

(a) Coated particle fuel irradiations. Metallurgy Division consider that the H.F.B.R. would be a suitable vehicle for the irradiation of highly rated coated particle fuel specimens in two or three Unit Irradiation type rigs in fluxes of at least 5×10^{14} n/cm^{2}sec. This type of rig dissipates the fission, gamma and electrical heat generated within it through the surface of the rig into the reflector D_2O. Surface heat fluxes would be several tens of watts/cm^2 and result in surface boiling of the D_2O. The question of boiling on rig surfaces has been considered by the Working Party and is discussed in para. 6.10.

(b) Transmutation reaction experiments. Thermal fluxes in the order of 10^{15} n/cm^{2}sec would be suitable for studying the $^{10}B(n,\alpha)Li^7$ reaction to doses of about 10^{21} n/cm^2. Two or three 1 inch nominal diameter thimble rigs would be required by Metallurgy Division for this purpose.

(c) Rare gas fission products. A thimble rig for the study of rare gas fission products has been specified by Chemistry Division. Little information regarding this experiment is available other than it requiring a flux position of about 10^{15} n/cm^{2}sec.

(d) I.P.U. thimble rig. A simple thimble rig of larger diameter is required by Isotope Production Unit for the irradiation of kilogram quantities of cobalt and for general isotope production. This requirement might be catered for by other methods. For instance, it may be possible to lodge large pieces of cobalt metal in simple holders located at the bottom of the reflector tank aligned such that the samples can be loaded and unloaded through existing facility holes. Alternatively, study is being made of using cobalt as the reactor control absorber material. If the cobalt could be incorporated into the control absorbers in a form suitable for its eventual recovery an extensive cobalt production facility would be available.

6.8 Other Experiments

Two Chemistry Division experiments have been specified which the Working Party consider will not require individual facilities. Both experiments are in the transplutonic field as follows:-

(a) Irradiation of 10-100 milligrams of Plutonium 242 in the form of a plutonium oxide/aluminium oxide compact for a period of about 6 months at 2×10^{15} n/cm^{2}sec to form Curium 244.

(b) Irradiation of about 10 micrograms of Californium 252 for periods ranging from a few hours up to 3 months at fluxes of about 10^{15} n/cm^{2}sec to form higher isotopes.

The Working Party considered that both of these experiments were suitable for irradiation in the self serve nests already specified by Isotope Production. In particular, use of the peak flux nest for the Pu^{242} irradiation and the 10^{15} nest for the Cf^{252} irradiation was suggested.

6.9 Feasibility of reflector rigs from flux interaction considerations

A summary of requirements of the irradiation facilities specified in Sections 6.4 to 6.8 is contained in Appendix 3, from which the following comparison of demand and availability of reflector positions can be made.

TABLE 2

Flux Position	Number of Positions Required	Number of Positions Available
2×10^{15}	1	1
10^{15}	5-6	5
5×10^{14}	5-6	4
10^{14}	3	

Since there is a greater demand for reflector irradiation facilities than there are positions available to accommodate them, there exists a large number of possible reflector rig loadings. It has been demonstrated in Section 6.2 that the permitted absorption strength in any one rig position is dependent on the absorption strength in other rig positions and any change in beam tube layout is likely to appreciably alter these relationships. Although further study is essential when this situation becomes less fluid, some general points can be made at this stage.

(a) The specified self serves, rabbit facilities and the flash system appear acceptable, provided some restrictions are placed on sample absorption strengths. The empty facilities have $V\Sigma a$ values well below those permitted in Table 1, although an improvement over the standard terelene filled epoxy resin rabbit container which has a $V\Sigma a$ of about 0.15 cm^2/cm length should be sought.

(b) Experiments involving elevated temperature fissile and non-fissile irradiations using rigs well tried in DIDO and PLUTO in the past (i.e. Wigner and Unit Irradiation rigs) are clearly unacceptable on flux depression grounds. New rig forms, compatible with the conditions and limitations applicable in H.F.B.R., must be sought if these types of experiments are to be permitted. Emphasis would have to be placed on small samples and the use of canning materials of lower absorption cross sections than stainless steel. If the axial flux distribution in the reflector is found to remain essentially constant throughout the reactor cycle, adequate temperature control of samples might be maintained solely by use of a dynamic gas mixture system, thus permitting in-pile heaters to be dispensed with.

6.10 Boiling on reflector rig surfaces

When the temperature on the surface of a heated rig placed in a pool of D_2O at atmospheric pressure and at 50°C reaches 115°C, subcooled nucleate boiling at the rig surface will be initiated. The heat flux at the incidence of surface boiling is calculated to be 8.6 watts/cm^2. Increasing the heat flux increases the bubble population/unit surface area but does not affect the maximum bubble size. Gunther and Kreith(2) found that bubble size was a function only of subcooling, and for 50°C subcooling the maximum bubble radius is 0.025 inches with a lifetime of ~.002 seconds, the bubbles collapsing on reaching a hemispherical shape. The bubble radius and lifetime can be computed with the bubble population to obtain a void volume/unit surface area. The normal way of expressing this quantity is by the vapour thickness, defined as the void thickness on the heated surface when the bubble volume is assumed to cover the whole surface area. Extrapolating from work carried out by Costello(3) the following relationship between vapour thickness and heat flux is found:-

Heat flux (w/cm^2)	Vapour thickness (ins x .001)
50	0.8
75	2.7
100	6.5
125	20.0

It will be noted that at the higher heat fluxes the vapour thickness begins to increase very rapidly. The Working Party felt that vapour thicknesses of ~.006 inches were probably tolerable on rigs positioned in thermal fluxes of 10^{15} n/cm^{2}sec and lower and tentatively recommended that surface heat fluxes of up to 100 w/cm^2 would be acceptable for such rigs. The effect of voidage on reactor dynamics would have to be experimentally checked however before these recommendations could be confirmed.

6.11 Reactivity worth of reflector rigs

As in para. 5.6, reference is made to measurements made in the Brookhaven reactor. It was found that a voided thimble of 1.37 inches diameter controlled 0.23% reactivity when located in the peak flux position, whereas a voided thimble of 3.5 inches diameter at a radial distance from the core centre line of 29 inches controlled only 0.04%. In the H.F.B.R. the thermal neutron flux at the equivalent position would be 5×10^{14} n/cm^{2}sec. The Working Party concluded that there would be no real worry on reactivity grounds for reflector rigs in flux positions up to 10^{15} n/cm^{2}sec.

6.12 Load/Unload procedure for reflector rigs

The load/unload procedure is complicated by the fact that the reflector rigs are angled in towards the core. Rigs cannot therefore be loaded or unloaded between their inclined in-reactor positions and the verticle rig flask standing on the operations floor without some manipulation at a transitional stage. Further if a rig was withdrawn to a point just clearing the top thermal shield, the inclination angle of the rig is such that the rig head would be in a position vertically above the beam shutters. Pivoting the rig about the rig head to enable the rig to take up a vertical position would thus be prevented by the presence of the shutters. Translation of the pivot point radially towards the reactor centre line to overcome this results in offsetting the rig from the vertical lift of the flask hoist. The procedure outlined below and illustrated in Fig. 5 offers a solution to these problems but demands a minimum clearance between the underside of the operations floor and the topside of the shutter drives of 13 feet. At present, this clearance is dictated by the angle of inclination selected for the High Angle Beam Holes and ranges from 10 feet for 40° H.A. holes to 20 feet for 55° holes. Thus if 40° H.A. holes are finally preferred, the presence of irradiation rigs in the reflector will impose a special requirement on the reactor layout, namely that of raising the operations floor and hence the height of the building by some 3 feet.

The procedure envisages a special rig handling machine mounted on rails beneath the operations floor from which a pivoted transfer tube is hung. The pivot point is adjustable in a radial direction to suit the position of the particular rig being handled. The lower end of the transfer tube can be swung between the vertical and the desired angle of inclination by means of an electrically driven actuator. The lower end of the transfer tube is arranged to clear the top of the shutter drives thus enabling the rig, in its transitional stage between the flask and its in-reactor position, to be swung into a vertical position above the shutters. A load tube, passing through the fuel element handling machine floor and inclined at the correct angle to suit the rig beinghandled, will span between the lower end of the transfer tube and the facility head attached to the top thermal shield. In this manner the flask hoist can be utilized at all stages of rig manoeuvering.

Should preference be finally given to High Angle Beam Holes at 55° inclination, the distance between the upper end of the transfer tube and the underside of the operations floor can be spanned by a vertical load tube introduced through the appropriate access hole in the operations floor.

7. OUT-OF-PILE FACILITIES

The out-of-pile equipment required in association with irradiation facilities is briefly specified below.

(a) Flasks

21 foot vertical flask for handling in-core rigs.

13 foot vertical flask for handling reflector and interspace rigs.

Small flask for handling capsule containing thimbles in fuel elements.

(b) Reflector rig handling machine

As described in para. 6.12.

(c) Handling Cell

Required for: (a) Sample changing on rigs.

(b) Cutting up rigs to extract samples.

(c) Mounting and dismounting incore rigs.

Introduction of rigs into the cell should be in the vertical direction and the cell should be provided with large zinc bromide viewing windows. It would be desirable to partition the cell into separate clean and dirty areas, the former area to be used for sample changing and the latter for cutting operations. The following equipment and services are tentatively specified:-

Manipulators of the Argonne Mark 9 type.
Remotely operated milling machine and reciprocating saw.
Effective disposal system (for dirty area).
Radiography facilities.
Photography facilities.
Lighting.
Ventilation system incorporating changeable absolute filters.
Power points.
Local compressed air supplies.
Leak testing equipment.

(d) Storage Block

Required to house irradiated in-core and reflector rigs. Some or all storage block holes should be provided with water cooling.

(e) Radiochemistry Laboratory

Required for unloading cans so that contents can be removed to other buildings and also for unloading cans and contents for immediate radiochemical separations. To be fitted with fume cupboards and cells.

(f) Counting Rooms

Equipped with suitable γ spectrometer system.

(g) Fast Rabbit Unload Station

Equipped with means to rapidly eject inner capsules from their outer containers and with immediate access to Radiochemistry Laboratory to permit rapid treatment of solutions.

(h) Commissioning Area

Used for finally checking rigs immediately prior to loading. A shielded storage hole in this area would be a useful facility together with about 300 square feet of work space. Pressure and vacuum testing equipment should be available in the area.

(i) Operations floor space

Space on the operations floor is required for:-

Rig instrumentation panels
Gas (He, CO_2, Neon) panels
Load/unload stations for rabbit and self serve systems.

The final sizing, layout and positioning of the Handling Cell, Storage Block, Radiochemistry Laboratory, Counting Room and the Commissioning Area is strongly influenced by, and hence must await a decision on, the diameter and height specified for the reactor containment building.

8. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. In-core rigs. Excluding small samples loaded directly into the centre tubes of fuel elements, a requirement exists for five instrumented in-core rigs. Although these rigs can be readily accommodated on engineering grounds, Brookhaven measurements indicate that the number of in-core rigs of this size will have to be limited to two or three on reactivity considerations. A more detailed evaluation of the reactivity worths of in-core rigs is required.

2. Reflector rigs. The maximum number of reflector rig positions that can be physically accommodated with reasonable separation from beam tubes in the current reflector tank layout (scheme XI) is limited to ten whereas the demand for rig positions totals fifteen. Restrictions will have to be placed on the absorption strengths of the majority of installed rigs in order to prevent excessive flux interactions between these rigs and the beam tubes. At this stage, the specified self serves, rabbit facilities and the flash system appear acceptable on flux interaction grounds provided some limitations are placed on sample absorption strengths. On the other hand, experiments involving elevated temperature fissile (and non-fissile) irradiations using existing rig types in general result in unacceptable flux depressions. New, low absorption, rig forms housing small scale samples must be sought if such irradiations are to be acceptable. Since the permitted absorption strength of a rig in any one position is dependent on the absorption strengths of adjacent rigs, it will be necessary to evaluate typical rig loading arrangements in order to obtain a better appreciation of the absorption strength limitations to be placed on reflector rigs. In contrast to the in-core rigs, no limitations on reactivity grounds are anticipated for reflector rigs positioned in fluxes up to 10^{15} n/cm^2 sec.

3. The additional time required at scheduled shutdowns to handle rigs need not be greater than half a day.

4. Unscheduled shutdowns can be reduced to the point where the overall loss in neutron output is negligible.

5. The total reactivity allocation for rigs must be limited to 2%.

6. Any proposal for installation of a loop in H.F.B.R. is unlikely to be able to meet the 20% flux loss limitation.

7. The reactor should be designed such that irradiation facilities can be loaded into the thermal shield/reflector tank interspace.

8. Unload procedure for in-core rigs is dependent on the number of rigs involved and requires further study.

9. Reflector irradiation facilities require to be angled in towards the core to reach the higher flux zones.

10. Surface heat fluxes of up to 100 watts/cm^2 can be accepted, subject to experimental confirmation, on reflector rigs positioned in fluxes up to 10^{15} n/cm^2 sec.

11. A special load/unload machine is required to handle reflector rigs.

12. If High Angle Beam Holes at 40° inclination are specified, the presence of irradiation rigs in the reflector will necessitate raising the operation floor of the reactor by 3 feet.

13. The layout and positioning of the majority of out-of-pile facilities must await a decision on the final size and shape of the reactor building.

APPENDIX 1

RABBITS AND SELF-SERVE SYSTEMS REQUIRED BY CHEMISTRY DIVISION

	Self-Serve 1	Self-Serve 2	Rabbit 1	Rabbit 2	Fast Rabbit 1A	Fast Rabbit 2A	Provision for Flash System
Nominal size	1"	1"	1"	1"	$\frac{1}{2}$"	$\frac{1}{2}$"	$\frac{1}{4}$"
Useage	General activation studies	Exclusive to nuclear cross-section detmn.	General	General	General	General	General
Flux	10^{15}	5×10^{14}	5×10^{14}	10^{14}	5×10^{14}	10^{14}	2×10^{14}
Flux gradient		$\ngtr$ 5% and preferably $\ngtr$ 2% across external container for all systems					
Samples							
Size, type and containment	Note (a) Note (c)	Note (b)	Note (a) or Note (e)		Note (d) or Note (e)		
Cross-section (excluding external container)	type (a) $\ngtr 0.25\ \mathrm{cm}^2$ typically 0.02-0.05 cm^2	$\ngtr 0.25\ \mathrm{cm}^2$	$\ngtr 0.25\ \mathrm{cm}^2$		$\ngtr 0.1\ \mathrm{cm}^2$		
Timing Requirements							
Irradiation time	1 hour - months $\sim$ 1 minute	Months to years $\sim$ 1 minute	Up to 1 hour $\sim$ 1 minute		1 second - 5 minutes 1 second		20 millisecs

Activity	For (a) Perhaps 25,000 γ MeV curies on completion of irradiation
	10-50 γ MeV curies 30 seconds after completion of irradiation
	1-5 γ MeV curies 5 minutes after completion of irradiation
	For (c) Possibly 5 times longer at 30 seconds and 5 minutes
					Lower than values for larger systems by factor of $\sim$ 10		

*See notes on attached sheet.

Appendix 1

Notes

(a) Sample for activation analysis

Container size (internal dimension): 2 cm diameter x 5 cm long
Container material : aluminium
Typical contents : 6 quartz tubes 5 mm o.d. x 5 cm long (1.5 gm)
Sample size : 200 mg per tube, i.e. 1.2 gm total
Typical sample materials include :

Any metal element (except mercury)
Stable metal oxides
Stable metal chlorides
Stable metal bromides
Stable metal iodides
Anhydrous metal sulphates
Non-metallic elements

Gases such as O_2, N_2, CO_2, N_2O, NO, NO_2, NH_3, He, CH_4

Miscellaneous inorganic materials:
e.g. rocks, minerals, meteorites, semi-conductor materials, steels, non-ferrous alloys, mineral ashes from organic matter, ceramic materials.

Miscellaneous organic materials:
e.g. dried biological materials (vegetation, soils, tissues), hair, dried animal organs (liver, lungs, etc.), cellulose materials, rubbers, ion-exchange resins, polymers and plastics, dried foodstuffs, natural cellular material (mg of wet material).

Solutions:
e.g. dilute aqueous solutions of inorganic materials, with the addition of mineral acids (HCl, HNO_3, H_2S_4) to 1N (subject to prior testing in irradiation rig).

(b) Samples for determination of nuclear parameters

Container size (internal dimensions) : 2 cm diameter x 5 cm long
Container material : welded aluminium can
Typical contents : 15 quartz tubes, 4 mm od x 3 cm long
Samples: stable fission products on fissile oxides (e.g. $^{241}PuO_2$) mixed with 100-fold excess silica powder; flux monitors
Sample size: 100 μg (maximum) fissile oxide and 10 mg silica powder per tube (i.e. total of 1 mg (maximum) fissile oxide and 0.15 gm silica powder per can)

(c) Samples for fissile material studies

10 mg fissile material e.g. ^{239}Pu, ^{241}Pu, sealed inside aluminium sandwich to facilitate heat dissipation.

(d) Samples for activation analysis using fast rabbit

Container size (internal dimensions): 1 cm diameter x 2 cm long
Container material: Polythene for short irradiations
Suitable metal of low activation cross-section for longer irradiations
Typical contents: 2 polythene containers at 1 cm diameter x 1 cm long
Samples: As on list for note (a); typically 1-10 mg in each of the two inner containers, or 2-20 mg directly in outer container.

(e) Samples for fissile material studies

As for (c) using 1 mg of fissile material.

APPENDIX 2

SUMMARY OF IRRADIATION FACILITY REQUIREMENTS - IN CORE POSITIONS

Facility	Experiment/Usage	User	Nominal Size	No. of holes required
Thimble rig	High temperature steel/graphite BR2 type experiment	Met.	1"	4 *
Partial replacement of Fuel Element	Large scale non-instrumented fissile or non-fissile irradiation	Met.	Up to complete Fuel Element	1 *
Thimble rig	Gas/metal corrosion at high temperature	Chem.	1"	1 part time *
No rig required) Samples loaded) into new Fuel) Elements)	Determination of nuclear parameters	Chem.	$\frac{1}{2}$"	
	Isotope production	I.P.U.	$\frac{1}{2}$"	

*From reactivity considerations the maximum number of 1" rigs permitted in core at any one time is limited to two. This limitation may be revised later in the light of measurements to be made in the Zero Energy Reactor.

APPENDIX 3

SUMMARY OF IRRADIATION FACILITY REQUIREMENTS - REFLECTOR POSITIONS

Facility	Experiment/Usage	Main User	Nominal Size	Flux	No. of holes required
Self serve	General Isotope production (40 samples) Transplutonic irradiations (Pu 242 to CM 244)	I.P.U.	Nest of 3 $\frac{3}{8}$" dia.tubes	2×10^{15}	1
Self serve	General Activation studies	Chem.	1"	10^{15}	1
Self serve	Exclusive to nuclear X-section determination	Chem.	1"	5×10^{14}	1
Self serve	General Isotope production (60 or more samples). Transplutonic irradiations (Cf 252 to higher isotopes)	I.P.U.	Nest of 4 or more $\frac{3}{8}$" dia tubes	10^{15}	1
Self serve	Instrumented fissile irradiations	Met.	$\frac{1}{2}$"	$5\text{-}8 \times 10^{14}$	1
Self serve	Stand by for DIDO/PLUTO. Mainly I.P.U.usage	I.P.U.	1"	10^{14}	1
(Rabbit (No.1) (Fast Rabbit (No.1A)	) General activation studies) Occasional I.P.U. usage	Chem.	1" $\frac{1}{2}$"	5×10^{14}	1 (Both systems in- (stalled in same (hole
(Rabbit (No.2) (Fast Rabbit (No.2A) (Flash System	) General activation studies)) Occasional I.P.U. usage	Chem.	1" $\frac{1}{2}$" $\frac{1}{4}$"	10^{14}	(All systems in- (stalled in same (hole
Thimble Rigs	Coated particle fuel irradiations	Met.	2"	5×10^{14}	2-3
	Transmutation reaction studies	Met.	1"	10^{15}	2-3
	Rare gas fission products	Chem.	1-2"	10^{15}	1
	General Isotope and Cobalt Production	I.P.U.	3"	10^{14}	1

Flux position	No. holes required	No. holes available
2×10^{15}	1	1
10^{15}	5 - 6	5
5×10^{14}	5 - 6	)) 4)
10^{14}	3	

References

(1) I. McGill - Private communication.

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(3) C. P. Costello "Aspects of local boiling effects on density and pressure drop". ASME paper 50-HT-18 (1959).

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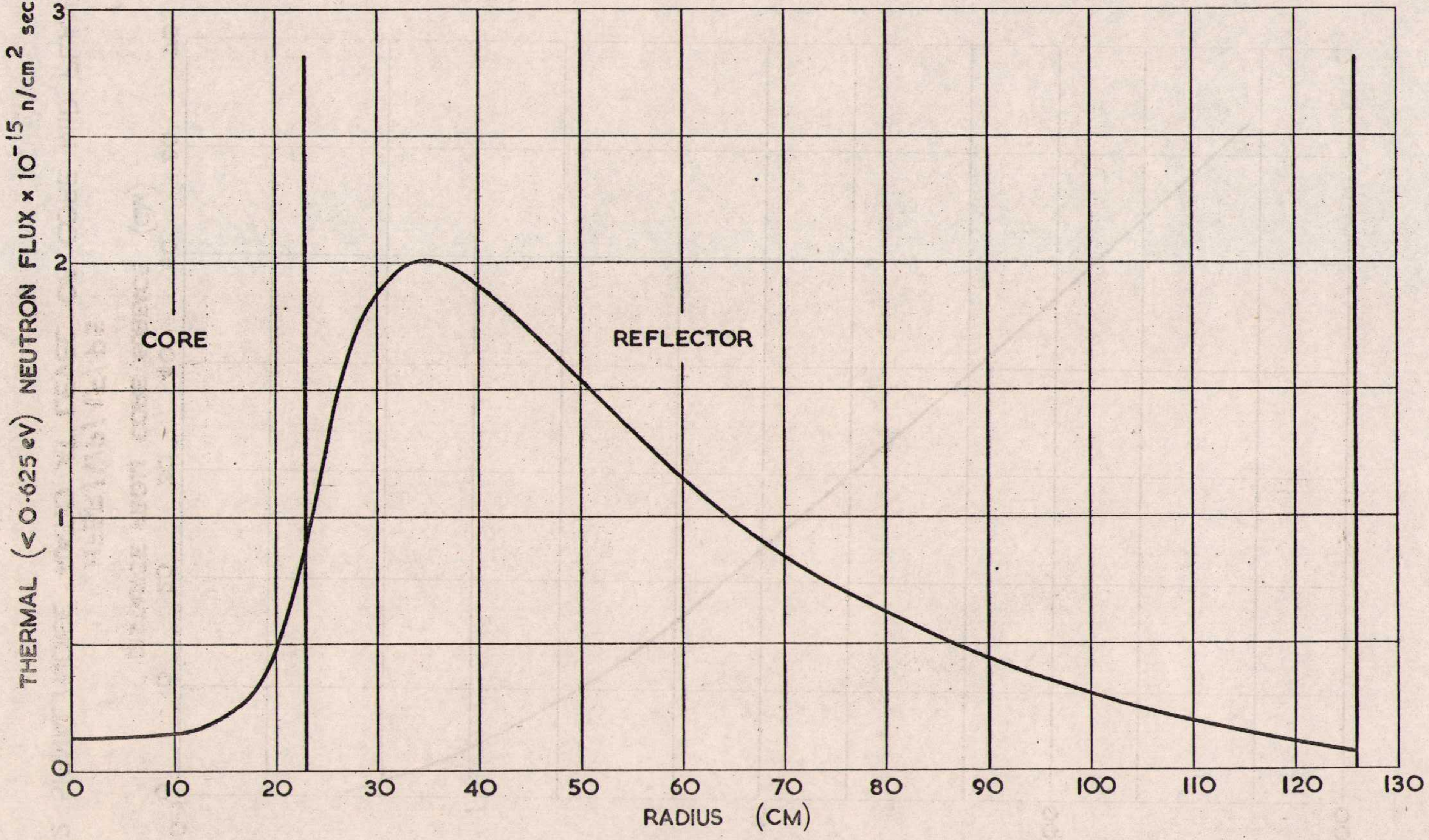

HFBR/WP/IF/P5

FIG. I RADIAL THERMAL FLUX DISTRIBUTION AT CORE MID PLANE.

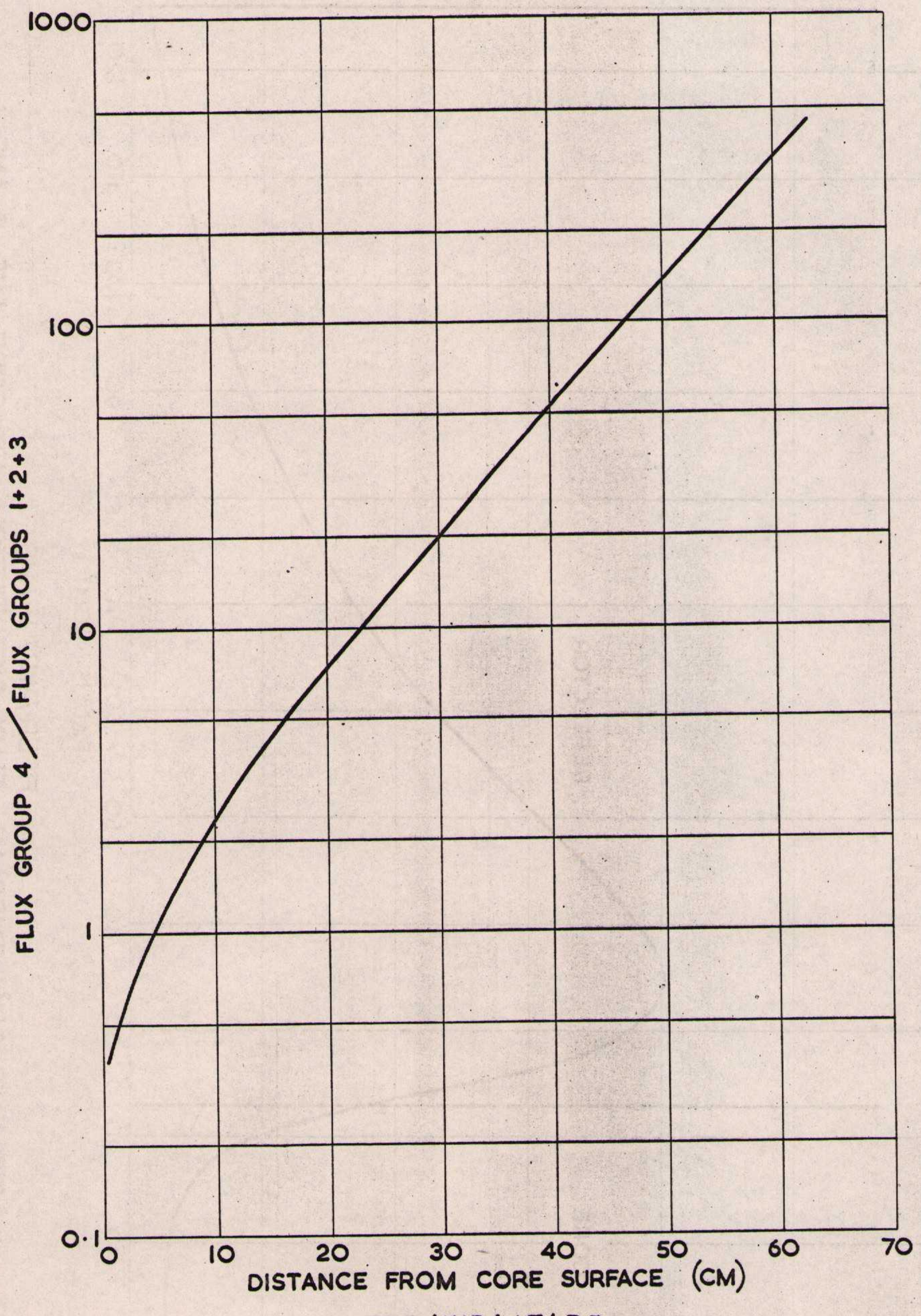

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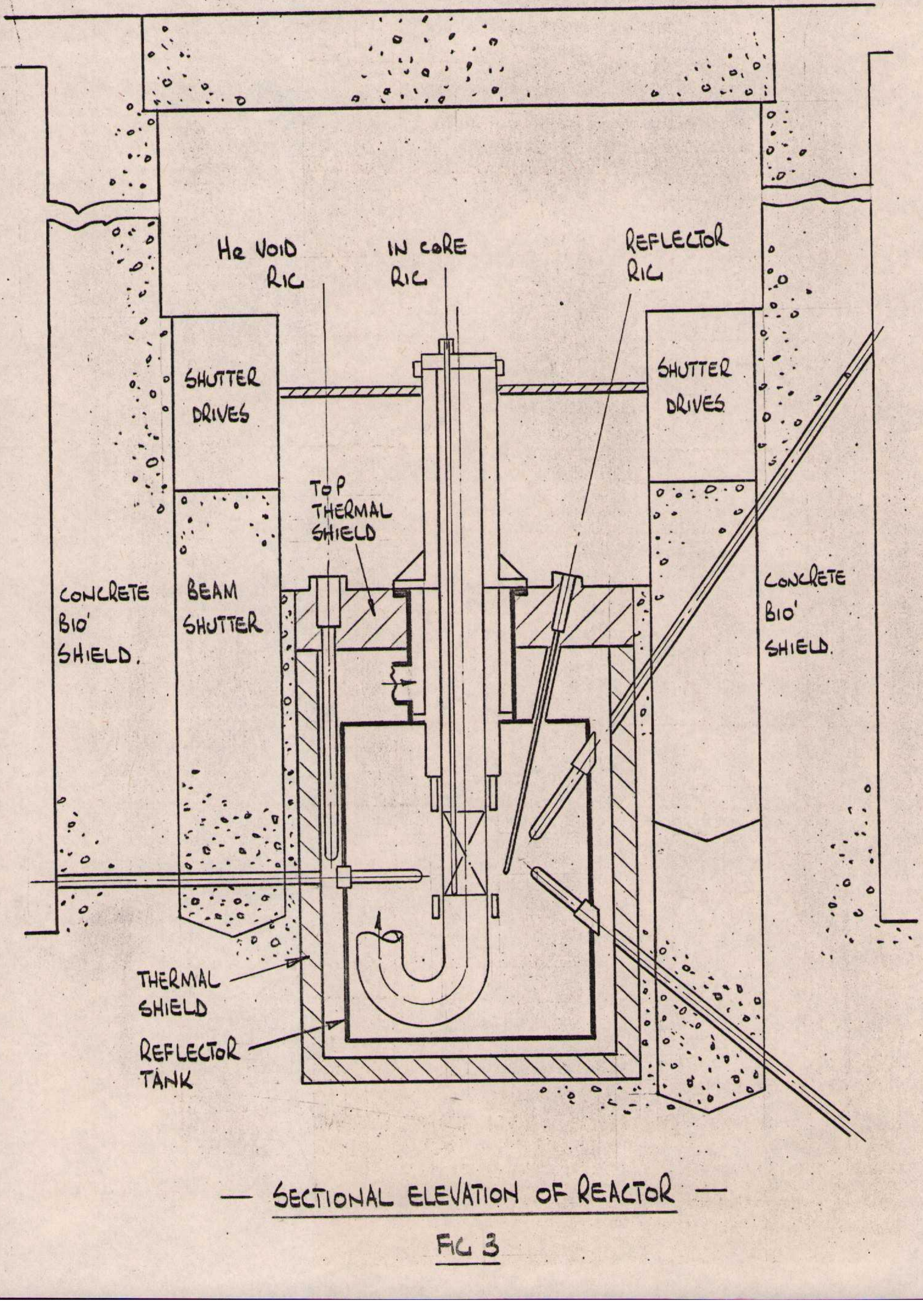
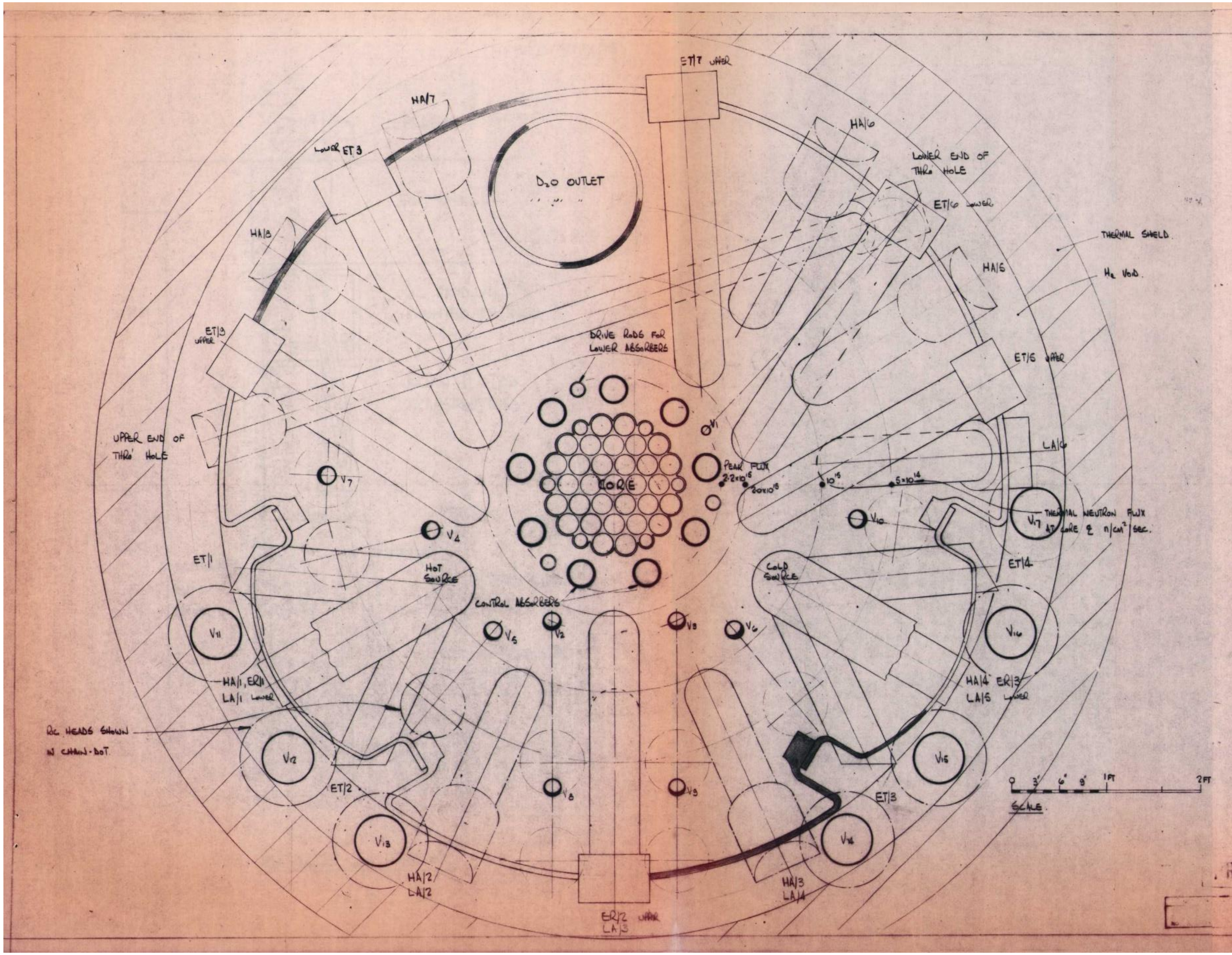
FIG. 2 SIGNAL / NOISE RATIO AT LEVEL OF CORE MID PLANE.



— SECTIONAL ELEVATION OF REACTOR —

FIG 3



IRRADIATION FACILITIES N° OFF AND FLUX			REFLECTOR	H_2 VOID
TH. n. FLUX	PEAK	$>10^{15}$	$>10^{14}$	$>10^{14}$
N° OFF	1	5	4	7
NOMINAL DIA	1"	2"	2"	6"

KEY :-

HA = HIGH ANGLED
LA = LOW ANGLED
ET = EQUITORIAL TANGENTIAL
ER = EQUITORIAL RADIAL.
V = VERTICAL

NOTE :- BEAM HOLES ARE SHOWN AT
THERE MAXIMUM DIA. OF 6"
BEAM TUBES MARKED UPPER ARE 8" ABOVE CORE ℄
" " " LOWER " " BELOW " "
IRRAD. FACILITIES SHOWN AT A NOMINAL DIA OF 2"

HARWELL HIGH FLUX BEAM REACTOR
SECTIONAL PLAN ON REACTOR TANK
SHOWING BEAM & IRRADIATION FACILITIES
SCHEME XI BEAM TUBE LAYOUT SEE RRD. 2131 SHT 11

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FIG 4

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