

# The Control and Instrumentation of the Reactor HIFAR

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A brief description of the reacting core of HIFAR is given, together with some data on the reactivity balance. The principles of the coarse, fine and safety control systems are outlined. Mention is made of the various installed thermal neutron flux measuring channels. The electrical safety and interlock circuits and the ways in which they influence the operation of the reactor are discussed. An outline is given of the other associated instrumentation such as health monitors and general industrial instruments.

## INTRODUCTION

HIFAR is a high flux thermal reactor, moderated and cooled with heavy water. The design and construction of the reactor is described elsewhere by Roberts (1958).

It uses 2.5 kgm. of highly enriched uranium 235 as fuel, and is designed to run at a maximum heat power of 10 megawatts, when the maximum thermal neutron flux is  $10^{14}$  neutrons per sq. cm. per sec. The reacting core, approximately cylindrical in shape, is located centrally in an aluminium tank containing the heavy water reflector. There are 25 vertical fuel elements in a 4, 6, 5, 6, 4 array arranged on a 15 cm. lattice pitch. The maximum burn-up of the fuel is approximately 20 per cent., the average being 10 per cent. The average rating of the fuel is 4 kW. per gm. The minimum number of fuel elements for divergency is 11 (see Watson-Munro (1958)).

The excess reactivity of the cold unpoisoned, undepleted reactor containing only horizontal experimental facilities and 25 fuel elements is approximately 15 per cent. The reactivity absorbed by the experimental facilities is approximately 4.5 per cent. and is made up of absorption in the vertical thimbles in the heavy water, including voids (approx. 3.3 per cent. total), that in the horizontal thimbles in the heavy water, including voids (1.0 per cent. total), and that in the vertical and horizontal holes in the graphite, (0.2 per cent. total), giving an overall total of approx. 4.5 per cent.

If the average temperature rise of the heavy water is 30° C., this will account for the absorption of approximately 1.0 per cent. of reactivity. Long-lived fission product poisons (mostly Sm 149) absorb approximately 1.2 per cent. of reactivity at equilibrium. Xenon poisoning at equilibrium is approximately 3.6 per cent. of reactivity, giving a total of approximately 5.8 per cent. of reactivity absorption.

For more information on the reactor physics of HIFAR, see Hicks (1957).

## THE CONTROL SYSTEM

The control system was purchased from H. M. Hobson Ltd., of Wolverhampton, United Kingdom.

Because of mechanical design problems associated with water and gas rotating seals in

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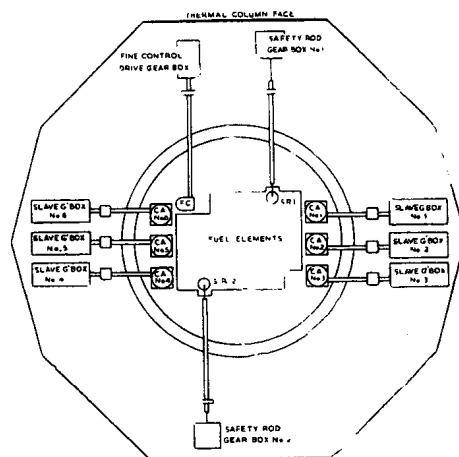


FIGURE 1.

either the walls or bottom of the reactor aluminium tank, it was decided to instal and operate the neutron absorbing control system through the radiation shielding plug in the top of the aluminium tank. The general layout of the top of this plug is shown in Figure 1.

- The control system is divided into four parts:
- (i) Combined coarse control and shut-down system.
  - (ii) Fine control system.
  - (iii) Safety system.
  - (iv) Partial dumping of the heavy water reflector.

### The coarse system

The combined shut-off and coarse control system consists of a total of six signal arm type cadmium absorbers (see Figures 1 and 2). These are placed three on opposite sides of the reactor core in such a way that four of the arms move in the spaces between rows of fuel elements, the other two being outside, but close to the core. The arms are moved from the horizontal down to an angle of 56° from the horizontal. In this latter position a total of 11,500 sq. cm. of cadmium is inserted into the reactor core, causing an absorption of approximately 25 per cent. of reactivity. Because the maximum excess reactivity of the core is about 15 per cent., a considerable safety factor has been provided.

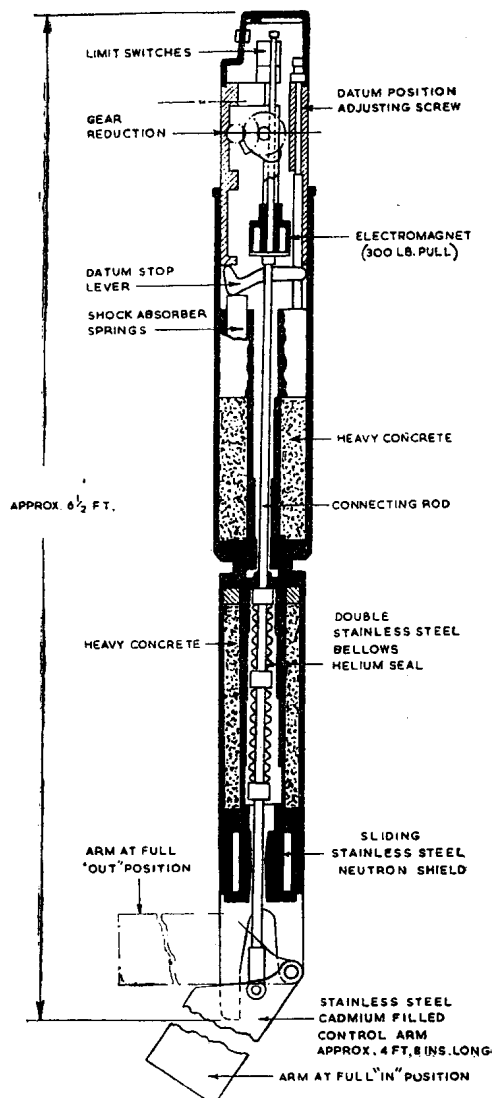


FIGURE 2.

The arms do not need any special cooling, because they are all immersed in the circulating heavy water.

The six control arms are mechanically coupled to six slave gearboxes, which are driven by a selsyn synchronous link transmission system from a single master gearbox in the control room (see Figure 3). "Slow-in" or "slow-out" electric motors move the six control arms through their full 56° travel, in or out respectively, in 25 minutes. An additional "fast-in" motor is provided to drive in the arms in five minutes.

In the case of an emergency, all the control arms can be simultaneously released electromagnetically to drop into the core under gravity in approximately 0.8 seconds. Under these conditions, ring springs are used to absorb the kinetic energy of the arms.

The whole coarse control system is designed with sufficient accuracy so that the position of each arm is repeatable to one minute of arc. Coarse and fine indication of the position of the arms is provided by a magstrip system with a sensitivity of approximately 1/100 of a degree of arc of the arms.

A coincidence magstrip system is also provided,

- (i) to give meter indication of misalignment of up to two minutes of arc between control arms,
- (ii) to shut down the reactor if the misalignment exceeds one minute of arc between any arms.

#### Fine control system

Fine control of the power level of the reactor is achieved with a movable vertical rod containing 205 sq. cm. of cadmium (see Figure 4) and located just outside the reacting core (see Figure 1).

The rod can be driven in and out at a continuously variable speed through a gearbox by a special 1/10 h.p. two phase servomotor (see Figure 5). A D.C. permanent magnet tachogenerator on the same shaft as the motor provides feedback information for the speed control equipment, which consists of a combined electronic and magnetic amplifier. Provision has been made in the speed control system for the later addition of equipment for the automatic control of the reactor power level by means of fine control rod position.

At maximum speed, 61 cm. travel of the rod is covered in 20 seconds. By careful design the friction and inertia of the system have been kept as low as possible, in order to allow the rod to be moved fast enough to compensate for reactor surges.

The maximum reactivity absorbed by the rod is 0.17 per cent.

Since the rod moves in a "thimble," light water cooling is necessary to remove several kilowatts of heat resulting from neutron and gamma absorption.

#### Safety rod system

To safeguard against an unforeseen gain in reactivity, particularly during a reactor shut-down, two vertical safety rods are provided (see Figure 6). They are located just outside the reacting core (see Figure 1), and each is capable of inserting 800 sq. cm. of cadmium into the reactor core, corresponding to the absorption of 1 per cent. of reactivity, i.e., a total of 2 per cent. of reactivity for both rods.

Each rod is connected by means of a stainless steel cable to a gearbox containing an electromagnet which, on release, allows the rod to fall into the reactor under gravity in 1½ seconds. The kinetic energy of the rod is absorbed by a cam and spring system without "snagging" of the cable.

Even though the safety rods move in "thimbles" in the reactor, no special cooling is required because the rods are normally right out of the reactor or right in the "shut-down" reactor. The heat generated in each rod is no more than 15 watts.

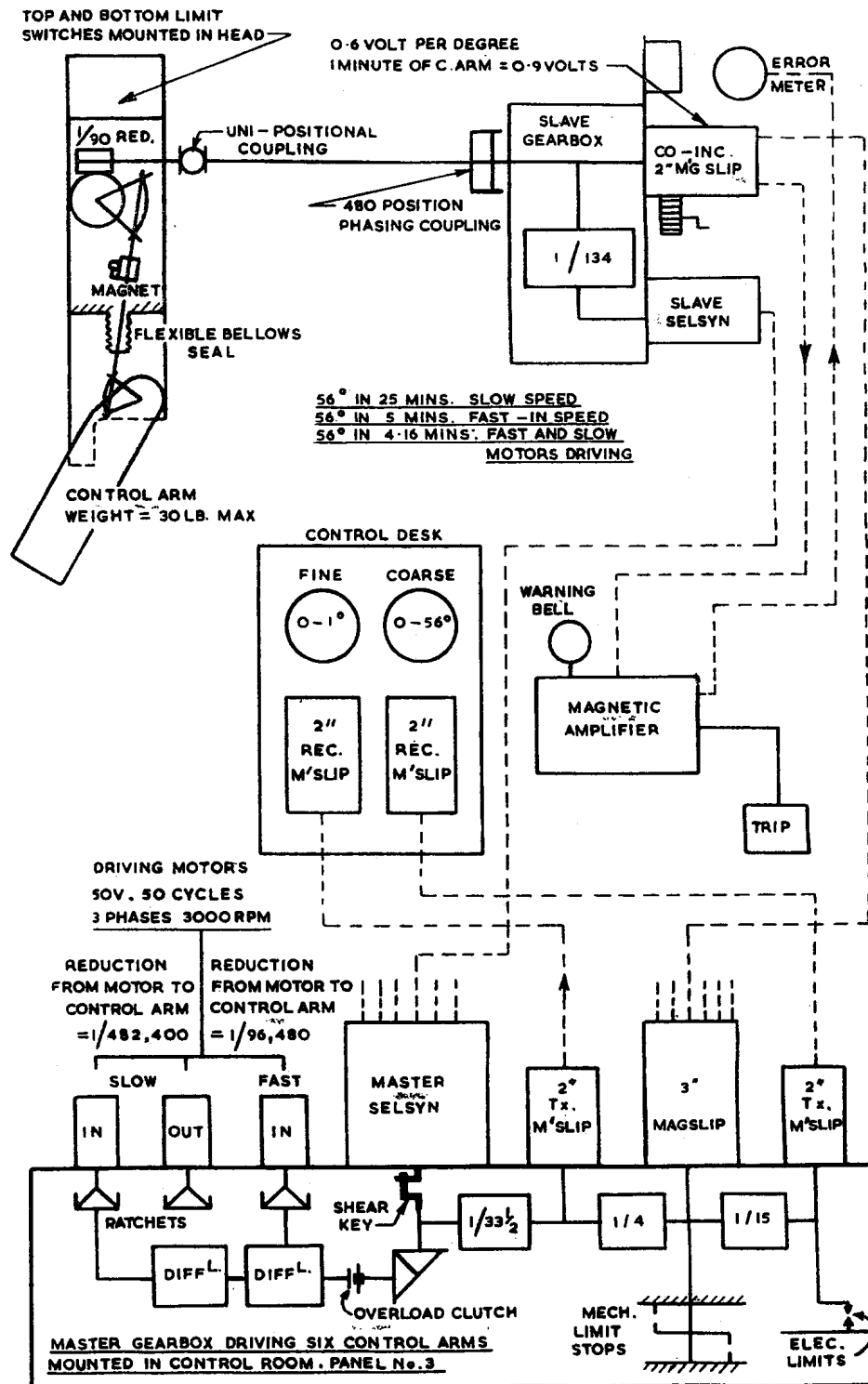


FIGURE 3.

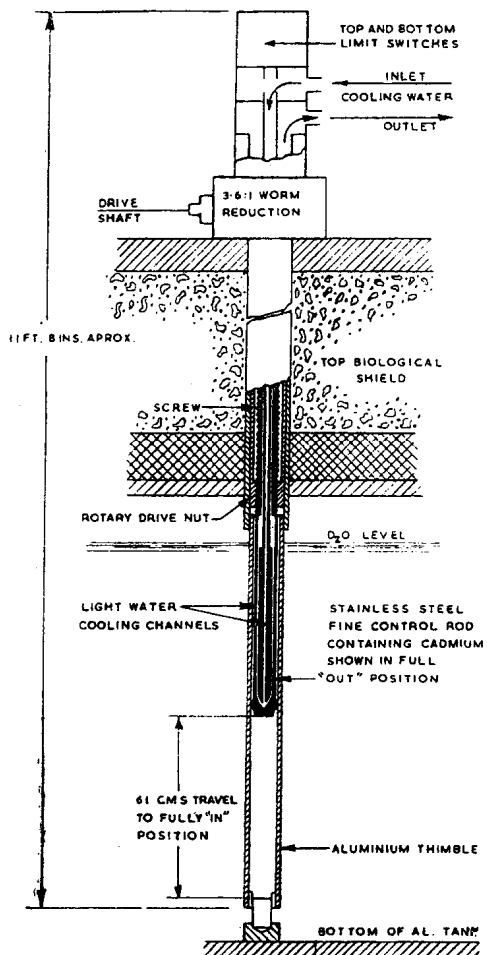


FIGURE 4.

#### The partial dump facility

A further emergency method of removing reactivity from the reactor is by reducing the thickness of the heavy water reflector above the fuel elements, thereby allowing neutrons to leak out of the reacting core.

A stainless steel tank is available for the "dumping" in 150 seconds of the top 2ft. of the heavy water in the reactor aluminium tank. This is equivalent to a loss of reactivity of about 3 per cent. at a rate of about 1 per cent. per minute.

A push button in the control room breaks the circuit to an electromagnet holding closed a gravity operated valve controlling the heavy water flow in a 3in. diameter pipe to the "dump" tank.

No more than 2ft of heavy water can be "dumped," because at no time must the heavy water level fall low enough to uncover any part of the actual fuel elements. This is because gas convection cooling of part of an "old" burnt-up fuel element is not sufficient to remove the fission product heat, so that serious damage could occur to the fuel elements.

#### Control summary

Absorption of the control systems:

Coarse and shutdown system	25%
Fine system	0.17%
Safety system	2%
Partial heavy water dumping	3%
Approximately	30%

#### XENON POISONING

With all thermal reactors having fluxes of  $10^{14}$  n/sq. cm./sec., and higher, the large thermal neutron capture cross-section of two of the fission products, xenon 135 and samarium 149, have always to be borne in mind. This is discussed in detail by Cox and Walker (1956), Glasstone (1956) and Glasstone and Edlund (1956).

In the case of HIFAR, at equilibrium the xenon 135 absorbs 3.6 per cent. of reactivity and the samarium 149, 0.86 per cent. When the reactor is shut down after prolonged operation at 10 MW the xenon 135 builds up as its parent, iodine 135 (half-life, 6.6 hr.) decays, thereby absorbing more and more reactivity until, about 10 hours after shut-down, a maximum reactivity of over 25 per cent. is absorbed. Because this is more negative reactivity than can be offset by all the fuel elements, it is impossible to start the reactor under these conditions. The xenon 135 concentration then decays away (half-life 9.4 hr.) until at about 36 hours after the shut-down it is possible to withdraw the coarse control arms and make available sufficient reactivity to enable the reactor to diverge again.

#### FLUX MEASUREMENT

Three pairs of holes penetrate the biological shield as far as the graphite reflector. They are located symmetrically on either side of the thermal column. Suitable holes have been left in the boral lining (Roberts, 1958), to allow a reasonable flux of thermal neutrons to be available for measurement.

Into these holes are inserted boron-containing ionisation chambers, types RC1 and RC2 as described by Abson and Wade (1956).

The RC1 chambers are filled with enriched boron trifluoride and have a thermal neutron sensitivity of  $1.27 \times 10^{-14}$  amps/n/sq.cm./sec. and a gamma-sensitivity of  $9 \times 10^{-13}$  amps/r/hr.

The RC2 chambers are coated with boron 10, and filled with hydrogen to a pressure of 15cm. of mercury and have a thermal neutron sensitivity of  $1.7 \times 10^{-15}$  amps/n/ sq.cm./sec., and a gamma-sensitivity of  $3.3 \times 10^{-13}$  amps/r/hr.

Each ionisation chamber can be moved approximately  $\pm 12$  cm., providing adjustment in flux of a factor of about three.

#### Reactor power error meter (E. K. Cole type 1462A)

The ionisation chamber is an RC2, which is placed in the top left hole where the neutron flux is between  $1.7$  and  $5.2 \times 10^{14}$  n/sq.cm./sec. at 10 MW power. A lead "muff" surrounds the chamber in order to reduce to a minimum any current due to gamma-radiation, particularly when the reactor is shut down.

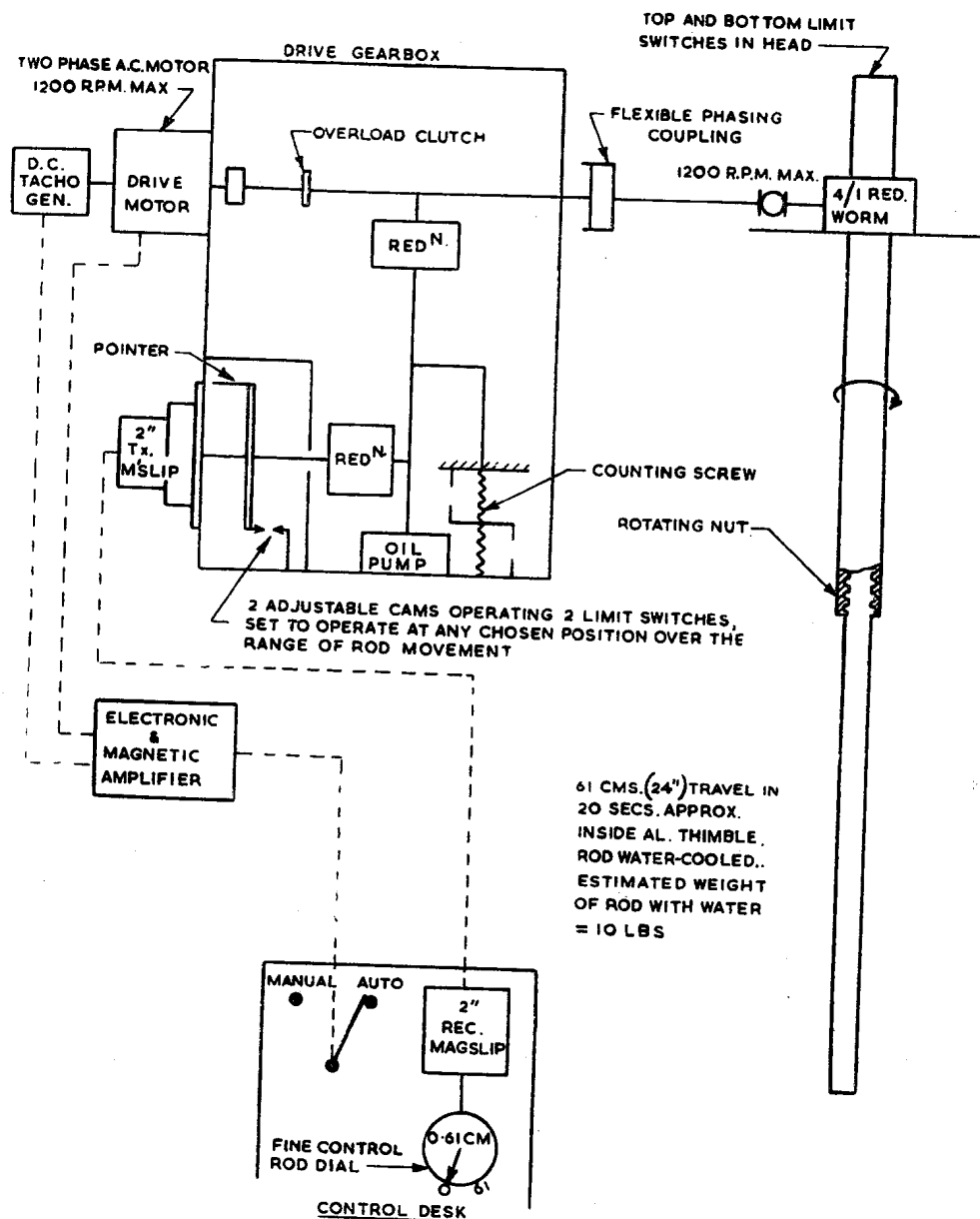


FIGURE 5.

In this instrument, effectively, the current from the ionisation chamber is backed off by the current from a battery. The former current is proportional to reactor power and the latter is the "demanded" power. The error between the two is displayed on a centre zero meter of high sensitivity. The demanded power is variable in 100 KW steps from 100 KW to 12 MW.

The stability of the centre zero meter is a measure of the stability of the operating power level of the reactor. A signal is available from this equipment for future use in the automatic control of the reactor power level.

#### Multi-range linear recording of nuclear power

The ionisation chamber is an RC2, which is placed in the top right hole where the neutron flux is between  $1.7$  and  $5.2 \times 10^{10} \text{ n/sq.cm./sec.}$  at 10 MW power. A lead "muff" is used here also.

In this instrument, the D.C. ionisation current is fed into a special high impedance mechanical chopper followed by A.C. amplification with display on a fast linear pen recorder (2 seconds full-scale deflection). This is a system made by Geo. Kent Ltd., of Luton.

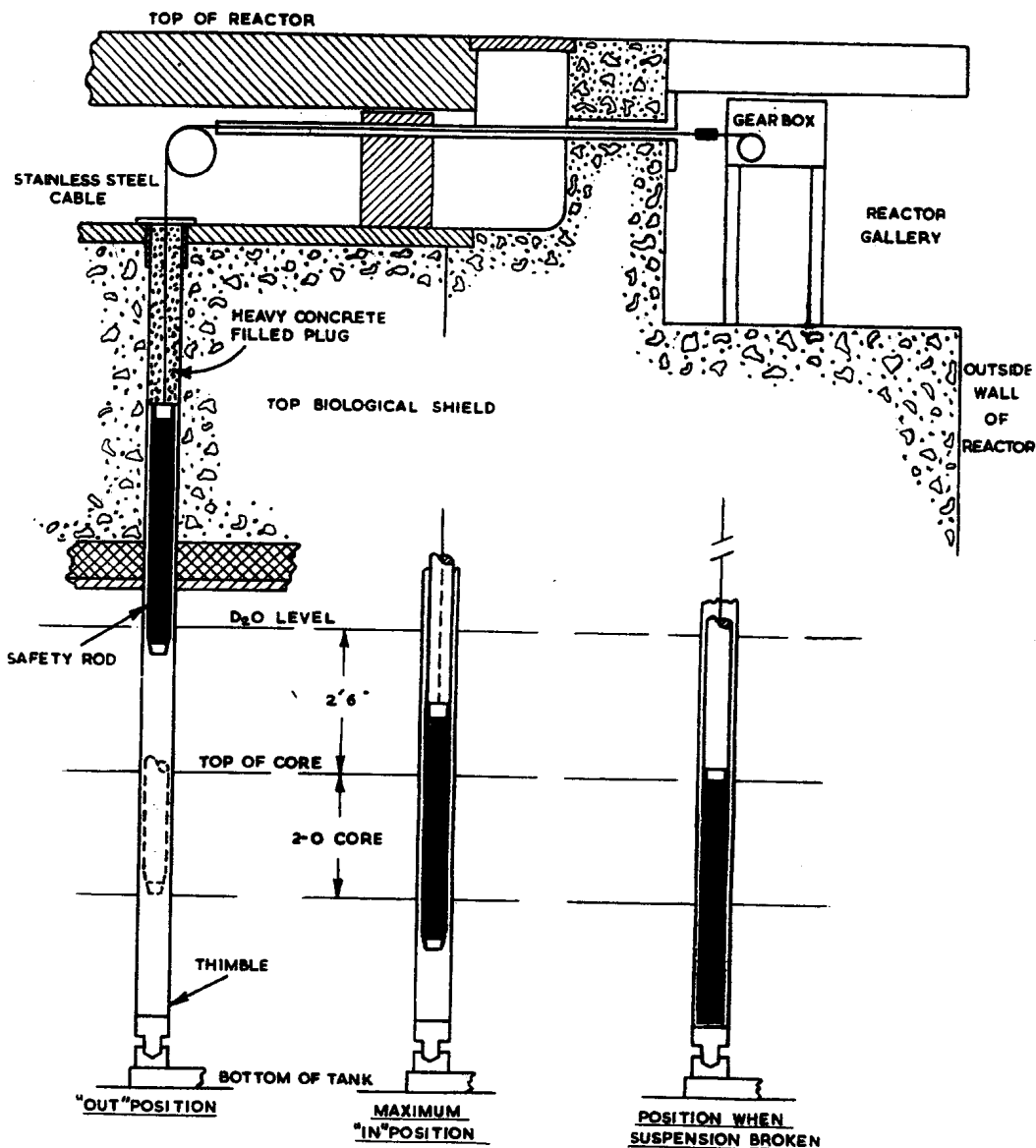


FIGURE 6.

Five ranges are provided for full scale deflection of 1.5 KW, 15 KW, 150 KW, 1.5 MW and 15 MW.

**Log power and reactor period meter (E. K. Cole type 1513A)**

The ionisation chamber is an RC2 which is placed in the middle left hole where the neutron flux is between  $1.1$  and  $3.5 \times 10^{10}$  n/sq.cm./sec. at 10 MW power. A lead "muff" is also used here.

The D.C. ionisation current is fed into a special feedback D.C. amplifier with a logarithmic characteristic such that the output voltage is proportional to the logarithm of the input voltage over six decades. This is pre-

sented on a high speed pen recorder scaled from 10 W to 20 MW on a special logarithmic chart.

The log output of the amplifier is also fed into another special amplifier where it is electrically differentiated and amplified, thereby giving an output that is proportional to the reactor period, i.e., the time taken for the power of the reactor to increase or decrease by a factor  $e = 2.718$ .

This is presented on a meter scaled in reactor doubling time from  $-20$  secs. through infinity to  $+5$  seconds. Also included in the reactor period amplifier is a relay circuit which can be preset to control the reactor if the period is too short either on positive or negative

periods. A signal is also available from the reactor period amplifier either to feed a recorder or to be used with other equipment for the automatic start-up of the reactor.

#### Single range linear measurement of nuclear power with mechanical power/time integration

The ionisation chamber is an RC1, which is placed in the bottom left hole where the neutron flux is between  $1.8 \text{ \& } 6.3 \times 10^6 \text{ n/sq.cm./sec.}$  at 10 MW power. A lead "muff" is not used here, as one is not interested in trying to accurately measure low nuclear power under shut-down conditions.

The D.C. ionisation current is fed into a special high impedance mechanical chopper followed by A.C. amplification and display on a fast linear pen recorder (two seconds full scale deflection) scaled 0 to 15MW. Mechanical power/time integration is presented on dials in megawatt hours.

#### High flux reactor shut-down amplifiers (Isotope Development Ltd. Type 1461A)

Four RC1 ionisation chambers are placed in the bottom right hole where the neutron flux is between  $1.8 \text{ and } 6.3 \times 10^6 \text{ n/sq.cm./sec.}$  at 10 MW power. Each is independently adjustable over about  $\pm 12 \text{ cm.}$

The D.C. ionisation current is fed into a D.C. feedback amplifier, which has been carefully designed to incorporate "fail safe" features. This amplifier operates relays which shut down the reactor when the nuclear power exceeds a pre-set value. It also operates a meter scaled in percentage of trip level at which the reactor is operating.

This general type of reactor instrumentation has been discussed by Gillespie (1956).

#### SAFETY OF THE REACTOR

More than 200 relays are employed in circuits to ensure, as far as humanly possible, that the reactor is operated in a safe manner. In almost all cases, fault and warning conditions open-circuit contacts and de-energise relay coils in "fail to safety" arrangements.

Mention will first be made of warnings and fault conditions.

Some forty "WARNING" conditions are indicated by lights in the control room. To prevent a later automatic reactor shutdown, it is necessary to take immediate corrective action. Typical of these conditions are:

- (i) Reactor helium gasholder less than 10 per cent. full.
- (ii) Reactor helium gasholder greater than 90 per cent. full.
- (iii) Instrument compressed air supply less than 30 p.s.i.g.
- (iv) Too high gamma-activity in the heavy water, etc.

If the warnings are ignored, sooner or later a condition will develop that will cause an automatic reactor shut-down. This is brought about in the following ways:

#### Control reversal

The coarse control arms are driven fast (13.4 minutes of arc/sec.) into the reactor. If the fault is cleared, then it is possible to reverse the motion of the control arms and move them

out again to the previous operating position. The nine conditions that initiate a control reversal are:

- (i) Control arms all at top limits, i.e., horizontal;
- (ii) heavy water plant room doors open;
- (iii) reactor helium gasholder less than 5 per cent. of full capacity;
- (iv) no heavy water flow down overflow pipe;
- (v) fine control rod secondary coolant flow less than 75 per cent. of normal.
- (vi) fine control rod primary coolant temperature greater than  $80^\circ\text{C.}$ ;
- (vii) only two (out of three) cooling water pumps running;
- (viii) heavy water flow through reactor less than 90 per cent. of normal;
- (ix) only one (out of two) heavy water pumps running.

#### Trip

As was mentioned above, the coarse control arms are lifted through electromagnets. When any of the 16 conditions listed below occurs, then these electromagnets are de-energised, allowing the coarse control arms to drop into the reactor under gravity in about 0.8 seconds from the horizontal position, and proportionally less time from other angles. At the same time, the fine control rod is driven fast into the reactor core.

- (i) Greater than one minute of arc misalignment between the six combined coarse control and shut-off arms.
- (ii) No. 1 and No. 2 reactor helium gasholder protection valves closed.
- (iii) Fine control rod primary coolant flow less than 75 per cent. of normal.
- (iv) Only one (out of three) cooling water pumps running.
- (v) Heavy water outlet temperature greater than  $58^\circ\text{C.}$
- (vi) Heavy water reactor inlet/outlet temperature difference greater than  $8^\circ\text{C.}$
- (vii) Heavy water flow less than 30 per cent. of normal.
- (viii) No heavy water pumps running (out of two).
- (ix) Failure of mains supply to reactor building.
- (x) Two out of four flux trip channels high.
- (xi) Dump valve open.
- (xii) Safety rods No. 1 and No 2. not up.
- (xiii) Reactor power doubling time less than eight seconds.
- (xiv) Emergency reactor shutdown buttons pressed.
- (xv) Low head of cooling water at cooling towers (indicates a broken pipe).
- (xvi) Low level of water in cooling tower basin.

Even if the fault is cleared immediately after the reactor has been tripped, it is necessary to wait for the magnets to be driven down to pick up the control arms. Then it is possible to withdraw the coarse control arms from the core only at the slow rate of  $56^\circ$  in 25 minutes. Thus, a spurious trip can cause a delay of up to 30 minutes before the reactor is back to its original operating condition.

### Complete shut-down

The reactor is tripped as above, but in addition the safety rods are dropped, the inlet and extract building ventilation fans are stopped and the inlet and outlet seal valves in the ventilation system are flooded.

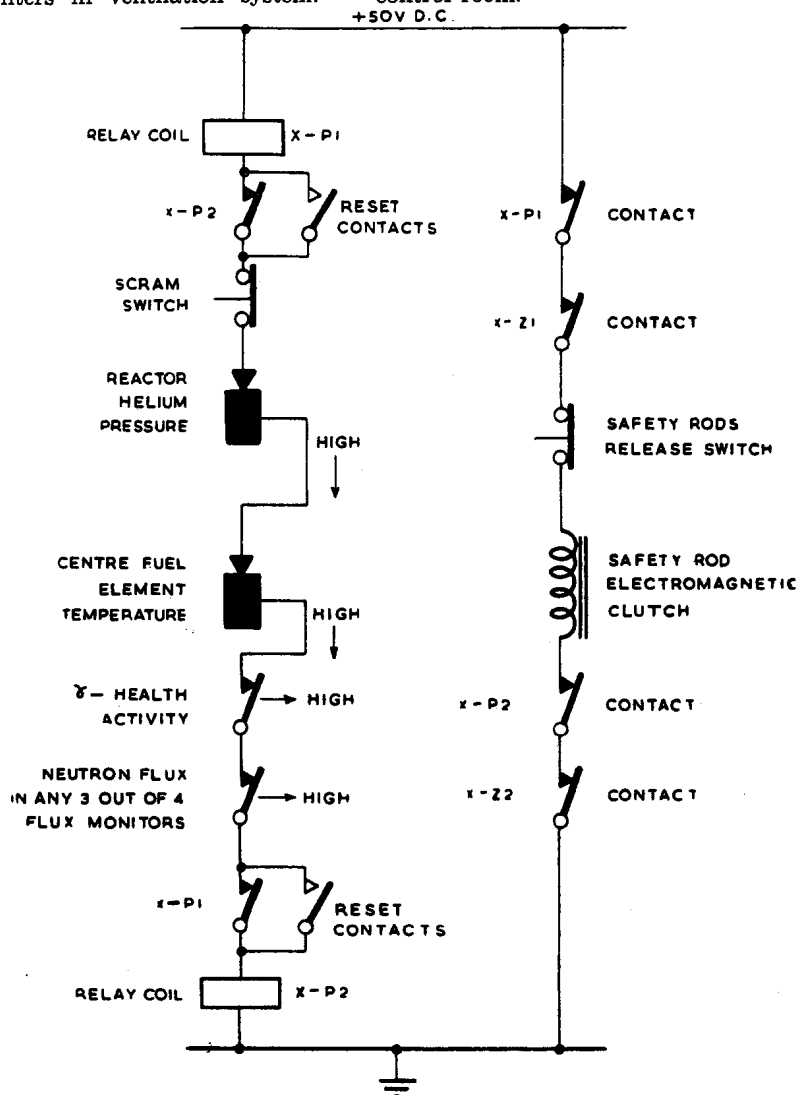
The conditions that initiate this type of shut-down are:

- (i) Reactor helium pressure greater than 12in. of water gauge.
- (ii) Centre fuel element surface temperature greater than 98°C.
- (iii) High gamma activity by control room.
- (iv) High gamma activity in No. 1 or No. 2 extract filters in ventilation system.

- (v) Three out of four flux trip channels high.

### Scram

This is initiated by a push button in the control room, and also by one in the emergency control room. In addition to shutting down the reactor as for a complete shutdown, the scram button also sounds off eight sirens located in the reactor group of buildings. This is to warn people to leave the reactor building and follow the "scram" drill. The scram sirens can be temporarily stopped by a spring-loaded switch in the control room in order to allow the public address system to be used. The scram condition can be cancelled and reset only with a special key normally housed in the emergency control room.



NOTE - Contacts are shown in the condition for normal reactor operation

FIGURE 7.

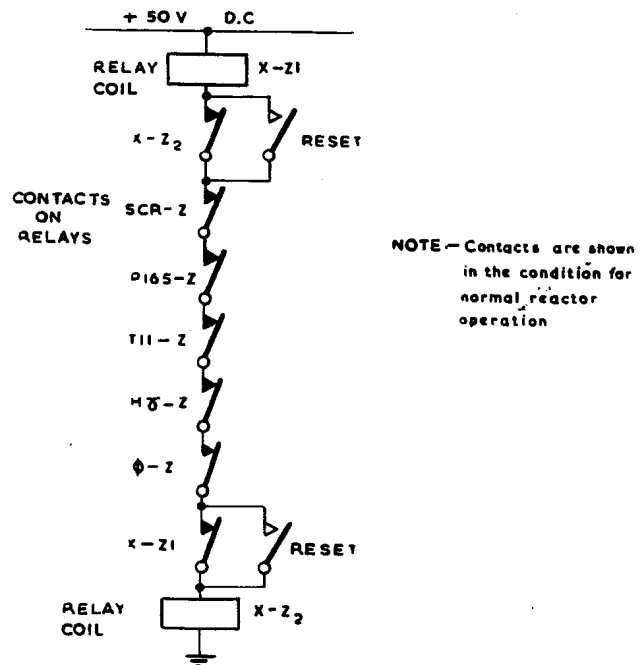
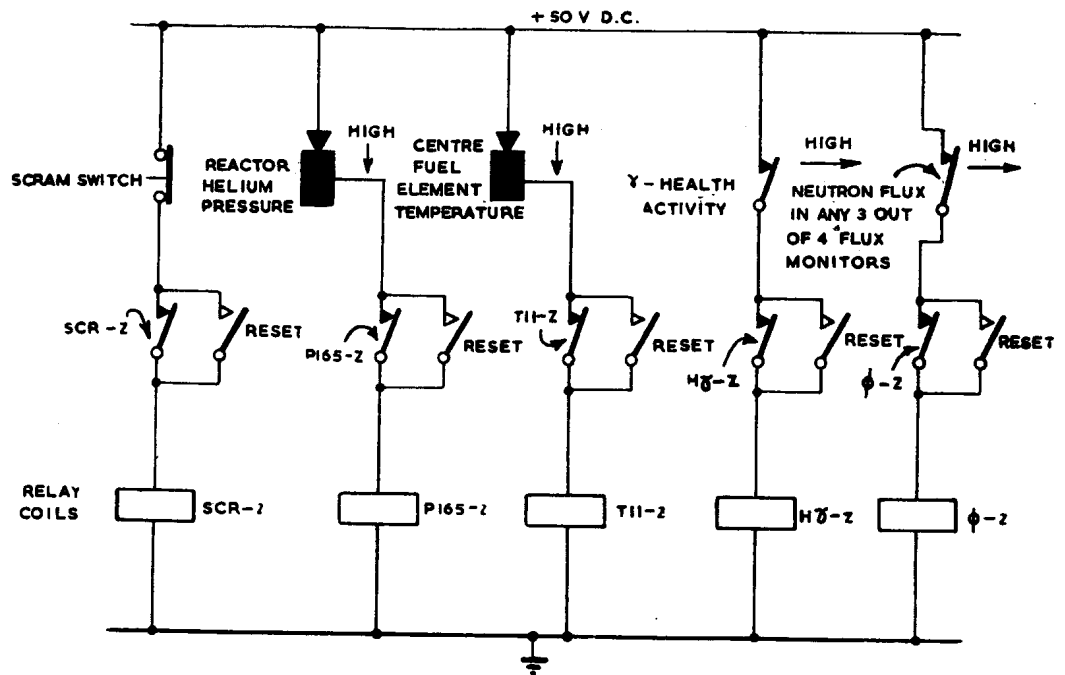


FIGURE 8.

### Safety when shut down

When the reactor is shut down for maintenance or loading or unloading experiments, the safety rods are held out of the core and will be automatically dropped in if for any reason the shut down power should rise to 10 kW, or if a reactor power doubling time of less than eight seconds should occur.

### Relay circuits

The basic principles of the relay circuitry are illustrated in Figures 7 and 8. (In this case it is a simplified version of the complete shutdown system.) The relay power supply is + 50-volt D.C., and most of the relays are G.P.O. Type 3000, made to inter-service specifications. The circuits are all designed to incorporate failure to safety features. For each condition that initiates an automatic shutdown of the reactor there are provided at least two independent change-over contacts that are incorporated in the "primary" and "secondary" guard circuits respectively.

Referring to Figure 7, a typical "primary guard" circuit, it will be seen that it is divided into two main sections. At the left there is the "monitoring" chain, and at the right the "operating" chain.

Consider the "monitoring" chain. The electrical contacts on the measuring instruments are all connected in series. It will be noted that the fault condition open-circuits the chain. At either end and in series with the chain there are the coils of the two monitoring relays X-P1 and X-P2. It is necessary to have both relays so that an earth fault part way down the chain will operate one or the other relay. Holding contacts from relays X-P1 and X-P2 are also inserted in series with the chain, so that restoration of a fault condition does not automatically complete the chain. To energise X-P1 and X-P2 relay coils, the reset contacts must be momentarily closed by pressing the "TRIP RESET" button in the control room.

Now consider the "operating" chain. To release any of the reactor neutron flux control mechanisms, it is necessary to de-energise the appropriate electromagnets. Here, one of the safety rods is illustrated. Contacts from both the primary and secondary guard chain monitoring relays, X-P1, X-Z1, X-P2, X-Z2, are connected in series with the safety rod electromagnet so that the opening of any of these contacts breaks the circuit.

Referring to Figure 8, a typical "secondary guard" circuit, it will be seen that this again is divided into two main sections. When the electrical contacts on the measuring instruments are closed (i.e., normal reactor operating conditions), each contact operates an individual relay through a relay holding contact with reset contacts. For instance, when the "SCRAM" button is pressed, SCR-X relay coil is de-energised and the SCR-Z holding contacts are open circuited so that on releasing the button, relay coil SCR-Z is not re-energised until the "TRIP RESET" button is pressed. Additional contacts on these relays are used to operate lights, bells, etc., in order quickly to localise faults.

One set of contacts from each relay is connected in series to form the secondary guard monitoring chain with monitoring relay coils X-Z1 and X-Z2 in a very similar way to the primary guard monitoring chain already described.

### HEALTH INSTRUMENTATION

Permanently installed in suitable locations are 16 gamma health monitors and six fast neutron monitors.

#### Gamma-Monitors (Isotope Development Ltd. Type 1529A)

Each of these consists of two parts, an ionisation chamber and preamplifier, which can be mounted anywhere around the reactor, followed by a logarithmic amplifier which is mounted in or near the control room.

The ionisation chamber is made entirely of materials of low atomic number in an endeavour to make it an equivalent air-wall so that dose-rate readings are independent of energy over a wide range of gamma-ray energies. The output current is proportional to gamma-flux, the sensitivity being  $6 \times 10^{-12}$  amps for a dose rate of 10 mr./hr.

The ionisation current is fed into a D.C. feedback amplifier with a logarithmic characteristic to give a five decade indication of dose rate on a meter scaled approximately logarithmically from 0 to  $10^5$  mr./hr. The zero of the logarithmic scale is achieved by attaching to the wall of the ionisation chamber a weak gamma-source equivalent to a dose rate of 1mr/hr and calibrating the meter to give true readings of any further gamma-radiation.

An output is provided to drive a recorder and the output of 13 of the installed instruments is displayed on recorders in the control room.

Two relay trip circuits are provided. One is a low-level adjustable trip, usually set at about the international health tolerance level of 7.5 mr/hr. This gives only a warning in the control room if the gamma level is exceeded. The other trip is a high-level one, and can be set anywhere between 10 and  $10^6$  mr/hr. For certain locations, two-head units are installed alongside each other and this high-level trip is set to shut-down the reactor if the gamma level is high in both units at the same time.

#### Fast neutron monitors (E. K. Cole Ltd. Type 1463A)

Each of these consists of two parts, a proportional counter sensitive to fast neutrons and a preamplifier which can be mounted anywhere around the reactor, followed by a linear rate-meter, which is mounted near the control room.

The proportional counter is lined with polythene, a hydrogenous material with which the fast neutrons interact to produce energetic recoil protons which are detected in a methane/argon filled proportional counter. The detector responds to fast neutrons in the energy range 0.15 to 15 MeV, and the energy response is adjusted to be proportional within  $\pm 20$  per cent. to the international biological dose per neutron.

The ratemeter provides a stable EHT supply for the proportional counter. The ratemeter is a rather versatile instrument, and for this application the integrating time is set at 20 sec., the gain at 500 and the counting rate meter at 3 counts per sec. full scale. The discriminator is set at 30 V, which greatly reduces the gamma sensitivity of the equipment.

A relay trip circuit is incorporated, and can be preset to operate at any desired level, or on failure of certain parts of the circuit.

The approximate overall sensitivity of the fast neutron detector is:

Sensitivity to fast neutrons (0.15 to 15 MeV) = 0.9 counts/sec. for maximum permissible level.

Sensitivity to radium gammas = 0.1 counts/sec./r/hr.

Sensitivity to slow neutrons = 0.002 counts/sec. for maximum permissible level.

The slow neutron sensitivity can be reduced to zero by surrounding the counter with cadmium sheet, 1mm. thick.

### INDUSTRIAL INSTRUMENTATION

This was supplied by Geo. Kent, of Luton, Eng.

The term industrial instrumentation, as used here, covers the measurement of temperature, fluid pressures, flows, levels, etc.

In both the heavy water and reactor helium circuits, all parts of instruments in contact with the fluids must be made of either approved types of stainless steels, e.g., 18/8/1, or high purity aluminium, with glass being permitted in one or two special cases. Another requirement is that the majority of both circuits must be pressure tight to withstand both a pressure of 30 p.s.i.g. without leakage, and a vacuum of 100 microns of mercury with negligible leakage. These restrictions alone limit the types of instrumentation that can be used.

Temperatures are measured either by Heraeus type platinum resistance thermometers, or by the Rototherm type of instrument inserted into stainless steel pockets.

Pump pressures are indicated on Schaeffer type diaphragm gauges.

Pivoted stainless steel floats, magnetically operating contacts through non-magnetic stainless steel diaphragms, are used to provide liquid level information to automatically stop and start pumps, light warning lights, etc.

Pneumatically operated differential pressure transmitters (made by the Foxboro Co.), using the force-balance principle, are used in conjunction with suitable orifice plates or Dall tubes (improved type of short venturi tube) to measure liquid flows. These same transmitters are also used to measure heavy water levels in large tanks.

Gas flow in the reactor helium circuits is measured with Rotameter type instruments.

All the above instrumentation applies only to the heavy water and reactor helium circuits. The other liquid coolant circuits use demineralised water, except the main cooling tower circuit, which uses ordinary mains water. Hence the instrumentation is conventional.

Temperatures are measured either with Rototherm type thermometers or by mercury in steel thermometers.

Pump pressures are indicated on either diaphragm or Bourdon tube gauges.

Stainless steel bellows are used to operate electrical contacts to provide liquid level information.

Liquid flows are measured by orifice plates and differential bellows instruments, or by Rotameter type instruments.

### OTHER SPECIAL INSTRUMENTATION

#### External heavy water leaks

All the stainless pipes containing heavy water are joined by flanges, usually tongued and grooved, with neoprene gaskets. Any heavy water leaks will occur from these flanges. It is necessary to detect these leaks immediately, both because of a possible tritium health hazard, and also because of the high cost of heavy water (about £150 a gallon).

Accordingly, some 450 flanges have electrical sensing elements fitted and these are connected in groups to a 100 channel detector unit.

The sensing element consists of a strip of filter paper wrapped around the clean edges of a mating pair of stainless steel flanges. The metal side of a strip of paper-backed aluminium foil is next wrapped around the filter paper. A wide neoprene band with "quick release" buckle is stretched over the whole to clamp it securely together and keep dirt out. Electrical contact is made on to the aluminium foil, and normally the resistance to ground (i.e., the flange) is of the order of at least  $10^6$  ohms.

If this resistance falls to 100,000 ohms or less because of a leak of heavy water wetting the filter paper, a simple radio valve operated relay is de-energised, thereby giving a warning of a leak. By a chart and a switch system the faulty flange can quickly be located from outside the heavy water plant room.

#### Leakage of heavy water into light water

The only place where this can occur is in one of the three heavy water/light water heat exchangers. It appears that the most sensitive method of detecting these leaks is by taking advantage of the short-lived nitrogen 16 activity formed in the heavy water when the reactor is running at full power. It is a fast neutron reaction  $O16(n,p)N16$ , the nitrogen 16 having a half life of 7.3 sec. emitting a 10 MeV beta-particle and a 7 MeV gamma-ray.

Into a water by-pass line across each heat exchanger is inserted a sodium iodide crystal and scintillation head to detect the 7 MeV gamma-ray from any nitrogen 16 that will have been carried through a leak by the heavy water. To achieve maximum sensitivity, it is necessary to install lead shielding around the detectors, particularly because by the time the water reaches the detector, up to two half lives of the nitrogen 16 may have elapsed due to the flow velocities.

The head unit feeds into a linear ratemeter (E.K.-Cole Type 1463A) identical to that used with the fast neutron detectors mentioned

above. Due to the high gamma-energy to be detected the discriminator level can be set up to reduce the background count rate by a considerable fraction.

#### Isotopic purity of the heavy water

To reduce any reactivity loss in the heavy water, it is necessary continuously to monitor the light water content. This is done by an infra-red absorption apparatus, the TRI-NON, manufactured by the Perkin-Elmer Corp., U.S.A.

The basic principles of the instrument as used for hydrocarbon gas analysis are described by Woodhull et al. (1954).

The infra-red radiation from a suitable filament is split into two parts and "chopped" at 13 cycles/sec. by a rotating shutter. Into one path is introduced a continuously flowing heavy water sample about 0.1mm. thick.

Because all the light water in the nearly pure heavy water is in the form of HDO, which has a distinct infra-red absorption band at a wavelength of about 2.8 microns, energy is absorbed in this path. Into the other path a wedge attenuator is driven by a servomechanism controlled by the detector. This is a chamber containing ammonia vapour, which also has an infra-red absorption band at about a wavelength of three microns. Energy from both paths falls alternately at 13 cycles/sec. on to the detector, which experiences a fluctuating temperature change due to energy absorption at three microns, unless both beams are of the same energy. Temperature changes are translated into electrical capacity changes which operate the servomechanism adjusting the attenuator until both beams are of equal intensity. The isotopic purity is a function of the position of the attenuator which drives an electrical potentiometer, the output of which actuates a linear potentiometric pen recorder in the control room with a scale range of 99.0 to 100 mole per cent. D<sub>2</sub>O.

For general information on infra-red methods of heavy water isotopic analysis see Gaunt (1953).

#### Gamma-activity of the circulating heavy water

One of the gamma-health monitors mentioned above is located as nearly equidistant as possible from the four heavy water outlet pipes of the reactor aluminium tank. It indicates on a recorder in the control room and detects both any induced gamma-activity in the coolant (Laurence 1956) and also any large leakage of fission products into the heavy water coolant from a defective fuel element.

#### REFERENCES

- ABSON, W., and WADE, F. (1956).—Nuclear reactor-control ionisation chambers. Proceedings I.E.E., Paper No. 2029 M. March, 1956 (103B).
- COX, R. J., and WALKER, J. (1956).—The control of nuclear reactors. Proceedings I.E.E. Paper No. 2068 M. March, 1956 (103B).
- GAUNT, J. (1953).—The isotopic determination of water by infra-red spectrometry. A.E.R.E. C/R1264.
- GILLESPIE, A. B. (1956).—The control and instrumentation of a nuclear reactor. Proceedings I.E.E. Paper No. 2058 M. March, 1956 (103B).
- GLADSTONE, S. (1956).—"Principles of Nuclear Reactor Engineering." (Macmillan & Co. Ltd., London.)
- GLASSTONE, S., and EDLUND, M. C. (1956).—"The Elements of Nuclear Reactor Theory." (Macmillan & Co. Ltd., London.)
- HICKS, D. (1957).—Experiments with DIDO/PLUTO mock-ups in DIMPLE. A.E.R.E. R/R 2337.
- LAURENCE, G. C. (1956).—Shielding for reactors. British Journal. Appl. Phys. Supplement No. 5: S54-S59.
- ROBERTS, W. H. (1958).—The design and construction of HIFAR. (Paper presented at this symposium.)
- WATSON-MUNRO, C. N. (1958).—Divergency Data for HIFAR. Atomic Energy 1: No. 2. March, 1958.
- WOODHULL, E. H., SIEGLER, E. H., and SOBCOV, H. (1954).—Sensitising Nondispersive Infra-red Analyser. Ind. & Eng. Chem., 46:1396-1400.