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THE EL.3 REACTOR

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A - REACTOR PROGRAM

I - ORIGIN OF THE PROJECT

At the beginning of 1954, the COMMISSARIAT A L'ENERGIE ATOMIQUE (C.E.A.) only had two experimental reactors: one, ZOE, at FONTENAY-aux-ROSES, the first reactor built in France, was very small (flux 10^{12} n/cm^2.s and maximum thermal power 150 kw), the other, EL.2, built at SACLAY, was larger (flux 10^{13} n/cm^2.s).

The thermal flux of the EL.2 was, however, too small, and its experimental facilities too scanty to enable the C.E.A. to conduct experimental research, particularly on the structural materials needed to build power reactors and to increase isotope production. The C.E.A. therefore decided, in March 1954, to build a high flux laboratory reactor equipped with numerous experimental devices. This was named EL.3 since it would be the third French heavy water ("eau lourde" = EL) reactor.

The C.E.A. first had in mind a heterogeneous reactor to be operated on heavy water and natural uranium, the only nuclear materials then available in France. The proposed thermal neutron flux 10^{14} n/cm^2.s) called for a thermal power of 50,000 kw, the removal of which would have

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required substantial cooling tubes and a large consumption of light water.

Therefore, when in October 1954, the British A.E.C. made available to France some slightly enriched uranium having a U.235 concentration twice that of natural uranium, the project was modified in order to take advantage of this new possibility. For the same flux of 10^{14} n/cm^2.s the required thermal power was only approximately 13,000 kw.

This enrichment had, moreover, the advantage of permitting the addition of stabilizing elements to the uranium, in order to improve its behavior under thermal cycling and radiation.

At the end of December 1954, the C.E.A. had drawn up a sufficiently complete and detailed project for the technological and practical investigation required for the building of reactor EL.3. We give the main outline of the program designed for the building of EL.3.

II - REACTOR PROGRAM

1 -General specifications:

Type: Heterogeneous U.235 enriched uranium reactor (1.4% approximately) using heavy water as a moderator and coolant.

Core: Cylindrical, 1.83 meters in diameter and 1.35 meters in height, made up of 100 elements arranged in a centered hexagonal lattice, with a pitch of 175 millimeters (figure A:1).

Reflectors: The core is entirely surrounded, on its lateral and lower surfaces by a heavy water reflector (first reflector) 40 centimeters thick and a reflector approximately 60 centimeters thick,respectively.

Primary cooling: is effected by the circulation of 1,000 m^3/h of heavy water cooled off in tubular exchangers by light water (rate of flow: 2,000 m^3/h which, in turn, is cooled by exchange with the atmosphere). The heavy water pressure in the core must be only slightly above the atmospheric pressure. The temperature of the heavy water, at the inlet of the cells, is to be 40°C, with an outside temperature of 30°C.

Secondary cooling: the cooling of the graphite reflector and shielding is effected by the open circulation of atmospheric air.

2- Experimental facilities:

The experimental facilities are many and in order to give easy access to the channels and to provide for a good installation of the equipment needed for the experiments, a substantial space (lo meters), is left entirely free for the experiments around the reactor and above the top of its block. The basements under the room which contains the reactor permit the installation of the additional auxiliary circuits needed for the test benches.

In view of the number of experimental devices provided it was necessaryfor the reactor to have an ample reactivity range. This can be done by varying the load but, since the reactor already goes critical on 41 cells, their number may be adjusted, say somewhere between 60 and 100, allowing for burnup and the amount of anti-reactivity due to the experiments. Finally, six compensating rods are provided, in order for the reactor to operate with fairly high burnup rates.

Considerable space is left open on the control board, so that data pertaining to the various experimental devices can be posted on it.

3 - High coefficient of use

Since EL.3 will be the main experimental French reactor for some years, it is important that it operate as often and as much as possible.

Therefore, three heavy water loops, each comprising an exchanger, a main pump and an auxiliary pump, have been provided for cooling off the heavy and light water, even though only two are needed to operate the reactor. Since these loops are installed in concrete rooms which are well protected from one another radiologically, it is possible to carry out maintenance operations on any one of them while the reactor is operating.

Many channels can be unloaded during such operation, and all the relevant mechanisms are outside outside of the reactor block so that repair and maintenance work shall cause as little disturbance as possible.

4 - Safety:

In view of the fact that the Centre d'Études Nucléaires de SACLAY is at some 20 kilometers from Paris, the reactor is housed in a completely gas tight vessel or tank, in order to rule out the possibility of active gas leakage in case of an accident. This vessel can resist a pressure of 1 meter of water and a vacuum of 10 cm. of the same fluid. During normal operation, the air of the secondary cooling circuits is under a slight vacuum with respect to the atmosphere of the gas tight vessel. This is itself under vacuum with respect to the outside, namely, 5 cm. of water approximately.

The pressure margin of 1 meter of water is ample, since it makes the tight vessel capable of with standing the excess pressures, which would be created by the burning of a full load of uranium (about 600 Kg) in heavy water, or by an uncontrolled critical excursion which may bring up the power to 100,000 kw, nearly ten times its normal power, for a period of 30 seconds.

The cooling circuits of the reactor and the current supply needed for their operation are so designed that a stoppage in reactor cooling is exceedingly unlikely.

III - The first building equipment orders were signed at the beginning of 1955, and the project was opened in May 1955. The reactor went critical on July 4, 1957, and its power went up for the first time in December of 1957.

The industrial architects chosen were the CHANTIERS DE L'ATLANTIQUE and the CHANTIERS REUNIS LOIRE NORMANDIE, which are units of the FRANCE-ATOME Company. The CHANTIERS DE L'ATLANTIQUE undertook the building surveys in cooperation with FRANCE - ATOME.

This paper will give a quick description of the physical characteristics of reactor EL.3, together with some indication of the principal technological surveys that were required.

B - DESCRIPTION OF REACTOR EL. 3 (1)

I - GENERAL APPEARANCE OF EL.3

EL.3 is built at the Centre d'Etudes Nucláires de SACALY, approximately 20 kilometers south of Paris. As will be seen on figures B1 and B2, its buildings comprise, from west to east, a conventional building and a gas tight vessel. These consist of two sections, an extensive basement space located under the larger unit and, under part of the conventional-type building, an area for cartridge separation. They are 183 meters long with the diameter and height of the main compartment measuring respectively, 46 meters and 25 meters. The lowest basement floor is below the - 10 m level.

The construction work required 54,000 cubic meters of earth moving, as well as the pouring of 19,000 cubic meters of concrete.

The air circulation radiator, which insures the cooling of the light water loop, and the stack, which discharges the air used for this secondary cooling, are located north of the conventional building of the gas tight vessel.

The conventional building contains mainly offices for the personnel and the staff who operate the reactor and the following installations: the transformers and power supply panels, the stand-by power plants, the auxiliary panels and control console, the lift pumps used on the light water loops, the hot filters, and the air exhaust fans used for secondary cooling.

The air tight vessel, designed to withstand an internal pressure rise of 100 cm of water, and a vacuum of 10 cm of the same fluid, has a total volume of 54,000 cubic meters, of which 37,000, 8,000 and 9,000 cubic meters are for the major section, the basements, and the smaller section, respectively.

In order not to create any discontinuity in the gas tight vessel, access to the main compartment is through special lock chambers and through siphons which can be flooded with water and are located on the ventilation circuits. Thus, the vessel can be completely isolated in case of an accident.

The main compartment mostly houses the reactor block, the control room, the facilities for recombination and space for the experimenters. A 20 ton rolling gantry, which moves on a circular rail, serves the reactor section.

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(1) We give here a brief description of reactor EL.3 concentrating on its most characteristic points. The El.3 book published by the C.E.A. gives a much more complete and detailed description.

The air and water tight basements are of concrete and have very thick walls in order to provide the required radiological shielding. The reactor room floor is a full 2 meters of common concrete in order to eliminate any substantial background count (1) in view of the activity of the heavy water of the primary circuits, located in the basements. The air tight basements are on three floors located at - 3, - 6 and - 10 meters.

The basements under the reactor room are reserved solely for the auxiliary facilities to be used by the experimenters and house , at the -3 meter level, the four ionization channels which make it possible to measure the reactor power, and the one cubic meter cavities.

The remainder of the basements house the heavy water circuits or loops (main circuit, storage, purification, detection of cartridge breaks or cracks) and the main facilities for the carbon dioxide and de-ionized water circuits which are used for the experimental devices.

The smaller compartment or section, 22 meters in diameter and 25 meters in height, is identical in build to the larger one. It houses a concrete cave or cell 7 meters high, 6 meters wide, 13 meters long. This contains the deactivation tank for the elements found to be sound, the deactivation tank for the damaged elements, the observation lock chamber for the hot cells, the transfer lock used to transfer the elements from hood N°1 to hood N°2, a hot chamber which provides for irradiation at the ambient temperature and a cold chamber for γ irradiation at a mean temperature of - 7°C.

The building in which cartridge separation takes place contains, in its northern part, the separation facilities for the cartridges used in EL.3 and, in its southern part, those used in the EL.2 reactor, which is located east of the building.

A bridge, the apron of which is at the +7 meter level, connects the cartridge separation building with the cave or cell provided inside the smaller compartment and with the reactor located inside the large compartment. The discharge hoods can thus be moved about for transfer of these rods from one of the three facilities to the others.

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(1) As an indication, the following are the maximum values of the intensities of the various radiations in the reactor room.

γ rays: $\frac{1}{100}$ of the biological tolerance dose, namely, 3mr/per week

Fast neutrons: $\frac{1}{100}$ of the biological tolerance dose, namely, 0.3 $n/cm^2.s$ of 10 MeV

Thermal neutrons: $\frac{1}{10000}$ of the biological tolerance dose, namely, 0.2 $n/cm^2.s$

II - DESCRIPTION OF REACTOR BLOCK

The reactor, cross sections of which are shown in figures B3, B4, B5 and B6, consists of the following units: The reactor block proper, the thermal shield, the graphite reflector, the tank or vat, the tubular block, the false tubular block, the elements which form the core, the control rods, and the experimental devices.

1 - The reactor block proper

The reactor block proper is 7 meters high, and has the form of a fourteen-sided prism . It could be circumscribed by a cylinder about 10 m in diameter. It is made up of a metal frame which carries, internally and externally, a sheet metal lining serving as an embedded framing for the heavy concrete.

This metal frame has the advantage of making the reactor block appear very clean cut, providing for the more convenient placement and attachment of the many devices it must carry, and avoiding contamination of the concrete, should active fluids be spilled.

This structure is first filled with heavy concrete having a specific gravity of 4.2, in which the aggregate is iron ore from Itabira, Brazil, chosen for its exceptionally high specific gravity.

The reactor block is equipped with all the cavities needed to place the experimental neutralizers and allow fluid passage. It consists of three internal cavities: a lower chamber located under the zero level, containing incoming and outgoing heavy water tubes; a middle chamber, containing the core; and an upper chamber with which it is possible to reach the elements and to lay all the cables serving the upper part of the tubular block and the control rods.

2 - Thermal shielding

All the walls of the middle cavity are covered with a cast iron shield 190 millimeters thick, which makes up the first thermal shield. A 20 mm clearance between this shield and the reactor block allows for passage of part of the secondary cooling air. The lower shield serves as a rest for the graphite pile. Above the one cubic meter cavities and forward of the large cavity and diffusing column, the shield is made of bismuth instead of cast iron. This has the advantage of stopping γ rays and of allowing the neutrons to go through without emitting secondary γ rays

3- Graphite reflector

The graphite reflector, located inside the shielding, has the form of a regular octagonal prism. Between the lateral faces of the graphite block and thermal shields, there is a free space of 20 millimeters which allows passage of secondary cooling air. The graphite block includes, along its axis, a cylindrical hole 2.6 meters in diameter, which ends up in a half ellipsoid of revolution, providing means of installing the tank. Between the tank and graphite an 8 mm free space permits passage of part of the secondary cooling air. The graphite block is made up of nuclear graphite bricks which contain less than 0.3 ppm of boron, having a cross section of 200 by 200 millimeters. Due to geometrical considerations, some bricks have a slightly smaller cross section. The suitably keyed bricks are arranged along 19 horizontal beds or courses which are appropriately crossed with respect to one another. In this fashion, the graphite cannot shift, during the life of the reactor, due to the action of thermal expansion and the Wigner effect. It is kept in place laterally by steel rods which bear heavily, through springs, against the lateral shielding. Above the tangential channels, a free space has been provided between the graphite bricks so that any strains in the bricks will not damage the lining of the channels.

4- Tank

The tank (figure B7) is made of nuclear quality A5 aluminum (contains neither boron, lithium nor cadmium). The inside diameter is 2.56 meters and the height 4.075 meters. It hangs from the tube block, at the upper part by 36.20 mm diameter bolts. A perbunan gasket, crushed between the flange of the tank and the tube block, provides helium-tightness. Electrical insulation has been set up between the tube block and the tank by means of perbunan cement and a dellite sleeve for corrosion reasons.

The heavy water flows into a water chest or box located in the lower part of the tank and is brought in by centrally located pipes 244 millimeters in diameter. The upper part of the water box is made up of a suitably perforated plate, against which the fuel elements and jackets of the compensation and regulating rods rest. At the outlet of the elements and control rods, the heavy water is directly returned to the tank by 230 millimeters internal diameter tubes laterally located on the bottom of the tank.

Some special extensions arranged radially on the tank make it possible to proceed with irradiation inside the heavy water reflector, by means of radial horizontal channels.

The thickness of the tank shell ring is 12 millimeters, and that of its bottom 35 millimeters. It is assembled by argon welding. The welding was a very critical operation in view of the precision required, since the radial free space between the tank and the graphite is only 8 millimeters, and that between the linin of the radial horizontal tubes and the thimbles only 4 millimeters.

The tank is closed up by a tubular block which insures biological protection of the upper chamber and keeps the fuel assemblies the control rods, and the various devices which penetrate into the core, in their respective places. All of the surfaces of the tubular block in contact with heavy water are made of austenitic stainless steel.

5 - Fuel assemblies (cells) -

The assemblies or elements (figure 38) rest on a perforated plate at the bottom of the tank and are provided in their upper parts with a plug which restores protection to the tubular block to which it is attached. The active part of the cell is made up of four uranium rods held in the cell tube.

5. 1 - Uranium rods

The uranium rod consists of a tube of enriched uranium (1.35% U 235) 22 x 29 mm. in diameter. closed at the ends by 4 mm thick pellets of natural uranium. The overall length of the uranium, including the pellets is 320 mm.

In order to facilitate the anchoring of the cartridge and to help heat exchanges, the lateral surface of the rod carries a square thread 1 mm wide and 1 mm in depth. The diameter, at the bottom of the thread, is 28.5 mm, the maximum diameter 29.5 mm, and the mean diameter 29 mm.

The A5 aluminum cartridge, 1 mm thick, which is crimped under very high hydraulic pressure has male and female end pieces welded at each end which make it possible to center the rods in the corresponding tubes, with respect to one another.

5.2 - Cell tubes

This is an A5 aluminum tube (diameters 40 and 43 mm) with 6 internal ribs 2.5 mm high. These make it possible to maintain a sheet of water permanently around the rods, even after they are much distorted due to the effect of the thermal cyclings and irradiation.

The rods are kept in place in the tubes by centering studs arranged in groups of three, and kept in place by aluminum rings crimped on these tubes or linings. Expansion of the rods is free at the upper part. In the lower part, the linings or tubes carry a special end-piece which fits into the perforated plate making up the water chest of the tank.

Above the last uranium rod, the assembly tube or lining is equipped with a diaphragm which:

- insures slight pressurization of the heavy water inside the assembly in order to raise the temperature of the saturated steam
- circulates heavy water in the sampling tube for the individual detection of breaks in the cartridge which goes through the plug.

The pressure measurements on this heavy water sample give the ouput inside the cell.

Above the diaphragm, holes in the cell tubes insure return of heavy water to the unit.

6- Control rods

The reactor is equipped with eleven control rods (fig A1), made of boron carbide, located between the fuel assemblies. They are distributed as follows:

- six compensation rods located on a circle 404 millimeters in diameter, for the purpose of compensating important reactivity variations due, the temperature variations of heavy water, to burnup to the condition of the load, and to poisoning. Each of these rods has an antireactivity of approximately 3000 pcm+ ,

- two regulating rods, located at the edge of the lattice and to the west of it, each one having an antireactivity of approximately 500 pcm, which serves to control reactor operation.

- three trim safety rods, distributed over a somewhat larger circle than that on which the compensation rods are located, with antireactivity of approximately 3,000 pcm, suitable in case of scram and, in the case of normal operation, to establish a sufficient negative reactivity following shutdown.

The compensation and regulating rods are identical mechanically, and are different only in the dimensions of their absorbing units. their speed of motion and strokes. They are actuated through a rack and pinion device driven by servo mechanisms. When in the high position, the rods are sunk 200 millimeters in the tube block. In the core, they are cooled off by a current of heavy water drawn from the primary circuits.

The safety rods are kept in the high position by means of electromagnets. In normal shutdowns, the safety rods fall in two seconds. Their drop is controlled by cutting the electromagnetic current and accelerated by means of compressed carbon dioxide pressure.

7 - Experimental devices

7.1 - General

We give a list of experimental devices with which EL 3 is provided, dividing them into four categories, according to their position:

+ These efficiencies correspond to those measured on the cold reactor with 55 rods, they are substantially different from the values given for other conditions of reactor operation.

a - Experimental devices which penetrate into the core:

- one central channel,
- two positions allowing placement of two independent cells in the core.

b - Experimental devices which penetrate into the heavy water reflector:

- 10 radial horizontal channels, 150 mm in diameter,
- 2 radial horizontal channels, 250 mm in diameter,
- 8 vertical isotope channels,
- 2 vertical converter channels for fast neutron irradiation.

c - Experimental devices which penetrate into the graphite reflector:

- 22 isotope channels,
- 1 channel for irradiation without any γ rays,
- 4 pneumatic control channels,
- 2 large diameter vertical channels,
- 4 tangential channels,
- 2 secant horizontal channels.

d - Experimental devices located in the thermal shield in contact with the shield:

- 1 diffusing column,
- 1 large cavity -
- 2 cavities of one cubic meter

Numerous fluid circuits are used by these experimental devices. We shall name, in particular: a carbon dioxide circuit with which it is possible to scavenge the inside of the horizontal channels and cool off the vertical channels; a demineralized water circuit for the requirements of experimental devices which open up on the lateral faces of the reactor block and for the cooling of the slug; the possibility of placing the channels under some vacuum by connecting them with the secondary cooling air circuit, ruling out radioactive leaks toward the reactor room during operation and to eliminate the scavenged gases.

As an example, here is a channel description of the central horizontal radial channel, 150 mm in diameter, and the one cubic meter cavities.

7. 2 - The central channel

The central channel, with an effective internal diameter of 182 millimeters, is located at the center of the lattice, going through the whole height of it. It is in this channel that the thermal neutron flux is maximal. It is in excess of 10^{14} $n/cm^2.s$. It consists of an A5 aluminum lining, 192 x 196 millimeters in diameter, centered on a part provided for this purpose at the bottom of the tank. Inside this lining is a second one, 182 x 186 mm, the lower part of which is perforated. The samples placed in the channel may be cooled off during operation of the reactor by means of a carbon dioxide current, which passes between the two and comes up over the samples.

The shielding of the tube block is restored by a plug which slides into the inside lining. At half the height of the tube block, an unhooking device makes it possible to maintain the efficiency of the shielding. The plug is made up, from bottom to top of an aluminum nose with a cadmium shield 2 mm thick, 400 mm of lead, and 1,000 mm of heavy concrete, specific gravity 4.2., Some pipes, arranged in a spiral buried in the mass of the concrete and lead, make it possible to cool the plug, during operation of the reactor, by means of a current of carbon dioxide.

A plug located in the false tube block, arranged in the same fashion, gives access to the channel plug.

Unloading and loading of this channel can be effected by means of a suitable hood located above the reactor block.

7.33 - Radial horizontal channels 150 mm in diameter -

Access to all the radial horizontal channels is had in the horizontal plane located at 1.1 meter above the ground. The channel is made up of a cylindrical cast iron lining, the mean inside diameter of which is 200 mm, buried in the concrete of the reactor block, plus a cylindrical A5 aluminum lining having an inside diameter of 150 mm, which passes through the shield and graphite, and penetrates into one of the thimbles provided in the tube. The channel is closed up by a cast iron plug filled with heavy concrete, with an unhooking device at half length. The nose of the aluminum plug carries two cadmium shields. An A5 aluminum container, which is locked against the nose of the plug, penetrates inside the lining, affording means of carrying out irradiations in the heavy water reflector.

The plug is equipped with a demineralized water loop which cools it during reactor operation. A port buckler insures tightness of the channel on the side of the reactor room.

The unloading of the radial 150 mm horizontal channels is taken care of by turret mounted coffins. These coffins are provided with two sets of wheels, whereby they move either on circular rails, which go around the reactor block, or else on radial raisl which service each channel (see figure 9B9). Passage from one set of wheels to the other is by means of four screw type jacks operated by electrical motors. The turret arrangement provides a means of inserting a new plug each time an irradiated one is removed, in such a way that the channel always is closed. The weight of a coffin and its carriage is 17 metric tons empty.

7. 4 - Cavities of one cubic meter

Two cavities with an approximate volume of one cubic meter each, located at the block proper, under the main compartment, open into the gallery located at the -3 meter level. They protrude forward, under the graphite pile, and reach the lower shield, which is made of bismuth at this point, through two 550 x 750 millimeter stacks. They are isolated by two horizontal aluminum sheets which restore the continuity of the floor of the intermediate cavity of the reactor block.

These cavities are designed to carry out irradiation in thermal fluxes of some 10^8 n/cm^2.s., or fast neutron fluxes of 10^6 n/cm^2.s.

During these irradiations, radiation must be as low as possible. This is why, on the one hand, the shield is made up of bismuth, above the stacks mentioned, while the side walls of these are covered with boron shields buried in bismuth (see D VIII below).

For irradiation by fast neutrons, there are uranium plates at the lower part of the stacks, which act as converters.

Access to these cavities is arranged to make it possible to push in and take out the substances to be irradiated. Currently, we propose to use these cavities for biological work. They will be used for the irradiation of small animals.

III - FLUID LOOPS -

1 - General

In this paragraph, we shall give a description of the heavy water loops provided for primary cooling of the reactor, and give some indications on the air circuits or loops used for secondary cooling.

We shall not describe the light water circuit, which is cooled by means of a radiator in contact with the atmosphere, and itself cools off the heavy water.

We shall also leave out many other fluid circuits provided for in the EL.3 reactor, most of which are conventional-type facilities and show no great originality. For instance, those which are provided for the distribution circuits for carbon dioxide, deionized water, city water, compressed air, city gas and effluents. We have already mentioned the carbon dioxide and demineralized water loops in paragraph B II 7.1 above. Let us now mention:

- a compressed air circuit, from which all oil has been carefully eliminated, (called "nuclear air"), used for the scavenging of horizontal channels, concurrently with carbon dioxide.

- a special system for the collecting of radioactive effluents, which are gathered in special tanks, from which they are hauled by truck to the processing plant.

2 - Heavy-water and helium loop -

The heavy water and helium loops have been built with extreme care: this is due, (on the one hand, to the perfect purity which must be maintained for the heavy water and, on the other hand, to the need for avoiding any escapees to the outside because of the danger of radioactivity and the high cost of heavy water.

In manufacturing the components of these circuits, the following materials have been used, to the exclusion of all others:

- aluminum (A5 and AG3) of nuclear purity, containing neither cadmium, boron, or lithium;

- austenitic stainless steel (very low carbon content), with or without molybdenum. However, for reasons of procurement, we have accepted some products containing titanium stabilized austenitic stainless steel;

- stainless steel containing 17% chromium, inconel and stellite;

- perbunan and polyethylene;

- silicone oil (for helium tanks and liquid packed valves).

The heavy water circuits are provided with a number of flanges, so that they can be disassembled in order to facilitate maintenance and to allow for possible modifications. The flanges used are of two types:

- metal to metal contact flanges (See Par D III below);

- perbunan gasket type flanges;

The tightness of the loops has been insured with painstaking care. This entailed the following precautions:

- very careful tightness tests of all the materials prior to delivery, meaning an extensive use of the helium mass spectrograph method of searching for leaks as possible;

- electromagnetic monitoring of the exchanger tubes by the Probolog method;

- utilization of tight valves without any packing box (by including stainless steel bellows);
- use of perfectly tight pumps with a submerged rotor and no outside packing box.

In addition, a whole system of leak detection is provided in order to call attention to any such escapes as might appear at various points on the circuit, particularly at the flanges, (see paragraph D II, below).

Finally, in order to avoid any heavy water loss, in case of substantial leaks, all the rooms in which there are heavy water loops are equipped with leak-proof catch-pans made of stainless steel and connected by a special system of ducts, to a leak recovery tank.

2. 2 - Main heavy-water loops:

Figure B 10 gives the schematic of the facilities involved in the main circuits, which consist principally of the following:

- the tank
- **a cooling circuit divided into three parallel mounted loops, each of which includes: an exchanger cooled by light water which circulates counter-current; a main circulating pump with a rate of flow of 500 m^3/h of the sealed type 90 with a rate of flow of m^3/h, followed by another check valve, 3 distributing valves which make it possible to isolate the whole loop, the duct element, which has the 2 circulating pumps, or finally, the exchanger.**
- 5 tanks for the storage of heavy water having a capacity of 5 m^3 each;
- 2 lift pumps of the sealed type, with a unit rate of flow of 5 m^3/h, one of which is a stand-by pump, providing for lifting the heavy water and maintaining the level in the reactor vessel.

Two loops normally are adequate to insure cooling of the reactor, the third being a stand-by. This arrangement, which is favorable from the safety standpoint, makes it possible to carry out maintenance on one of the loops during operation of the reactor. The total heavy water output is 1,000 m^3/h (500 m^3/h per exchanger). The total light water output is 2,000 m^3/h (1,000 m^3/h per exchanger).

The pumps feed back the heavy water to the exchanger. From there it goes through the water box located at the bottom of the tank, flows through the assemblies, the control rods, the vertical converter channels, is returned to the vessel, and then comes out by two pipes located in its lower part.

The operating temperatures, which correspond to the maximum power of the reactor, 18,000 kw (maximum flux of neutrons above 10^{14} $n/cm^2.s$), and for an outside air temperature of 30°C, are shown in Figure B 10.

Under these conditions, the flux through the hottest rod cartridge is 233.5 W/cm^2, and the highest temperature of the cartridge is 120°C. The velocity of the heavy water in the assembly or element being 5.6 m/s. A slight pressurization of heavy water in the element, tube, thanks to the diaphragm located in its upper part, rules out any boiling, even local boiling, at the contact of the rods.

2. 3 - Purification of heavy water -

It is most important to avoid any accumulation of impurities in the heavy water, due to corrosion of the materials which are in contact with it. Indeed, during passage through the reactor, these impurities are activated, and they contribute to an increase in the radioactivity of the primary circuit. In addition, these impurities promote radiolytic decomposition of the water, and can have only a noxious effect on the thermal, hydraulic, and mechanical characteristics of the circuit.

Therefore, we have decided to maintain a very low total impurity content for the primary heavy water (2 ppm). This requires the continuous processing of 300 liters per hour of heavy water. Should this be inadequate, the rate of flow can be brought up to 600 l/h by operating the two parallel loops. This heavy water flow passes through deuterium-treated ion exchangers of the "mixed-bed" type, then over sintered stainless steel. The water is cooled off prior to entering the ion exchangers, which must not be subjected to a temperature higher than 40°C.

2. 4 - Recombination -

The formation of radiolytic gases from the decomposition of water due to the effect of ionizing particles is limited by the inverse reaction, promoted by γ rays.

The production of radiolytic gases is small if the purity of the water is maintained. This is one of the reasons for a suitably designed heavy water purification facility (See III of 2.3 above).

Design was computed for a mean rate of dissociation of 10 cm^3/kwh and a maximum of 30 cm^3/kwh. The dimensions of the recombination facilities were so chosen that the deuterium concentration above the vessel is, at the most, 1.2%, at the maximum rate.

Degassing of the heavy water takes place mostly at the level of the free surface of the tank. It is promoted by the expansion created by the diaphragms located at the outlet of the assemblies. It can also take place at the free surface of the storage tanks under certain circumstances, and this is why the atmosphere of these tanks is scavenged by helium.

The facility is west of the large compartment, at the second level of the metal frame. Figure B 11 shows a schematic.

2. 5 - Detection of cartridge breaks -

It is important to detect the breaks which may take place in the cartridges in order to limit to a maximum the contamination of the primary fluid, and to quickly eliminate the cells that may be faulty by reason of the accidents which may be caused if their cooling is inefficient due to the swelling and distortion of the rods.

The search for broken cartridges is carried out cell by cell, by detecting the presence of gas fission products in heavy water samplings made from each cell. Detection also takes place on a heavy water sample from the tank outlet manifolds, and on a helium sample in the atmosphere of this tank.

Each time a sample is taken out, a helium injection saturates the heavy water and, thereafter, this helium is removed in a hydro-cyclone by centrifugal effect. A measurement of the activity of the gas so obtained will reveal the presence of gaseous fission products. We have avoided making this measurement directly from the heavy water, for the background count due to this very heavy water would not permit sufficient sensitivity.

We provide for other experimental processes of detection during the life of the reactor, using in particular the principal heavy water and helium samples.

3 - Air loop - secondary cooling -

An air loop with a total rate of flow of 22,500 m^3/h insures, in series, the ventilation and air conditioning of the main vessel or compartment, and secondary cooling for the reactor. The power to be absorbed is approximately 140 kw.

The series arrangement which has been adopted makes it possible to maintain the slight vacuum of the secondary cooling circuit with respect to the atmosphere of the gas tight vessel on the one hand, and between this atmosphere and the outside air on the other hand.

Description of facility -

An air flow of 22,500 m^3/h enters the vessel through a battery of paper filters having an efficiency of 75%, by way of a gallery located at the -6 meter level, to the north of the conventional building. This gallery is equipped with a siphon which can be flooded with a water protection of more than one meter, making it possible to isolate the water-tight vessel in case of an accident.

A part of this air output, 2,000 m^3/h, is directed to the small compartment or section for ventilation and air conditioning.

The secondary cooling of the reactor block is effected by an air flow of 20,500 m^3/h, which first goes through a battery of paper filters having an efficiency of 97%, then through the reactor block by way of three passages: between the tank and the graphite, between the graphite on the shield, between the shield and the concrete. It then flows through the hot air duct installed in the basement south of the conventional building. This gallery is equipped with a quiet air room having a total volume of 1,100 m^3 and a flood-type siphon similar to that used in the north duct. After the siphon, we find three batteries of hot filters, made of paper, with an efficiency of 99.98%, two of which are operating and one is on standby. The exhaust fans located at the street level of the conventional building push the hot air back towards the 30 meter stack located to the north of the reactor building (see D VIII).

The hot air which goes out of the reactor takes 210 seconds to reach the siphon located downstream from the quiet air chamber. This time affords a suitable lag during which to cut off the tight vessel both in case of an accident and in normal operation, and makes it possible to reduce to a substantial degree, the activity of the air prior to its removal through the stack.

IV - MONITORING AND CONTROL

1 - General

The monitoring and checkup facilities of the reactor include:

- a number of measurements: thermodynamic measurements, which mostly affect the heavy water circuits or loops; nuclear power measurements, which make it possible to determine the power of the reactor and to control it; radiation measurements, with which it is possible to achieve good radiological shielding for the personnel;
- the facilities involved in reactor control and safety.

The main control board and console are located in the West building on the second floor of the main compartment. In addition, there are two panels and an auxiliary console located at the floor level of the conventional building.

We give some indications on measurements and control below.

2 - Thermodynamic measurements -

The point which is deserving of attention, as regards the thermodynamic measurements, is that a provision has been made for measuring the temperature and rate of flow of the heavy water at the outlet of each cell or lattice element.

Suitable equipment gives, at all times, a general view of the 99 heavy water temperatures (see paragraph D V below).

A pressure measurement is made on the heavy water sampling tubes used for the detection of cartridge or jacket breaks in each of the 99 cells, close to the head of the cell, with which the rate of flow of the heavy water which passes through the cell can be evaluated The Bourdon tube type manometers, equipped with potentiometric transmitters, as used for this end, raise difficult problems in design, for they are made entirely of stainless steel, have a small range of measurements, and must be compact.

On the other hand, the measurement of the heavy water level in the tank raised a difficult problem for which two solutions were used:

- a float level giving an indication which i telemetered by means of impedance variation coils accurate within $\pm$ 5 mm on a height of $\pm$ 250 mm about the normal heavy water level.
- a bubble level which gives a measurement within $\pm$ 5 mm on nearly the whole of the height of the tank (see D IV below).

3 - Power measurements -

The reactor is equipped with four measuring systems which indicate its neutron power level from 0 to 20,000 kW. Each system includes a γ compensated ionization chamber located close to the multiplying medium, forward of the plug inserted into an oblique channel ending up in a recess provided in a lead block which penetrates in to the lateral shield at the level of the bottom of the reactor vessel. This lead shield improves the compensation of the chamber for γ rays. In addition, each channel is provided with a perboral lining equipped with a moving shutter made of the same substance. At the high powers, this makes it possible to reduce the flux of thermal neutrons, which reach the chamber by a factor of approximately 1,000. The operation of this shutter is controlled easily by a 300 mm shift of the plug, which may occupy two positions:

- forward position, for measuring low powers up to 20 kw.
- back position, in which the plug falls back, thus protecting the chamber (used from 20 to 20,000 kw).

Of the four measuring chains, three are linear and one logarithmic. The linear preamplifier has two sensitivities which, allowing for two possible positions in the chamber, give four ranges of measurements.

On the linear machines, the power measuring system works by comparing the power voltage to a standard calibrated voltage, which is automatically varied in steps (20 contacts) and by vernier measurement of the difference between the two voltages. The reactivity is determined by the automatic potentiometer method.

4- Control

The control rods have been defined in B II-6 above.

The two regulating rods, only one of which is operated at a time, are controlled through servo-mechanisms, which determine their position or rate of motion by means of a two-phase, 100 watt, 400 cps motor. The control winding of this motor is energized through a magnetic amplifier.

The operation of the regulating rods, which are kept in their zone of maximum activity in the vicinity of the median plane of the core, is completed by that of the trim or compensation rods which are actuated in succession as each regulating rod reaches the end of its effective stroke. As soon as it returns to the middle of this effective stroke, the trim or compensation rods stop moving. As soon as one of them reaches the end of its stroke, another one continues to function, according to a pre-set order.

Control may be manual or automatic. Automatic control used only above 20 kw uses the error signal:

$$u = A\ (P - P_o) - BR$$

in which:

- P_o is the power desired,
- P is the actual power delivered by the power chains,
- A & B are injection coefficients,
- R is a dampening term which contains the reactivity.

V - ELECTRICAL POWER SUPPLY -

1 - General

The electrical facilities used on the EL.3 reactor, of which figure B 12 gives a schematic, must meet the following requirements:

- guarantee, without interruption, current supply to the control facilities and their lighting,

- insure, without a break, the cooling of the reactor,

- avoid serious disturbances in the operation of the reactor due to electrical breakdown.

The installed power of 4,000 KVA, as supplied by the Électricité de France, makes it possible to meet the following requirements:

- ancillary reactor facilities .... 2,500 kw
- reactor monitoring and control.......... 70 kw
- lighting................................ 250 kw
- experimenters........................... 500 kw

Power distribution under 200-127 V provides illumination and the means of operating a certain number of movable devices which can be plugged in. We draw attention, in particular, to the following facilities:

- four canals linings, over the whole length of which plugs can be connected. These are attached to the uprights of the metal structure, around the reactor room. Two of them distribute standard 200-127 v current; the other two deliver 220-127 v current which is voltage adjusted within ± 1% by static regulators (rod sets L1 and L2).

The 380 volt current supply which feeds all the important auxiliary services of the reactor consists of two sets of priority bars B1 and B2. To each of them, we connect:

- an Ac generator of the emergency power plant. The third generator may be connected, indifferently, to one or the other of the sets of bars.

- a main heavy water pump. The third heavy water pump may be connected, indifferently, to one or the other sets,

- a sub-panel (P1, P2) which supplies electricity to various priority services through a certain number of local panels, for instance: the console showing the cartridge breaks and the console for the CO_2 valve.

A set of intermediate bars, between P1 and P2, which supplies current to the main heavy water valve, is connected to P1 or P2. If the set of bars to which it is connected is not energized, it is manually connected to the other.

Under normal operation, the B1 and B13 sets of bars, on the one hand, and the B2 and B24 on the other, are mutually coupled. B5 is independent. The facility is so designed that two transformers can operate in parallel. In case of trouble affecting one of the sets of bars A1 or A2, or the T1 and T3, or T2 and T4 transformers, all the sets of bars can be mutually coupled through B5.

2 - Emergency current supply

In order to be able to supply the essential auxiliaries (priority bars B1 and B2) and their control facilities without any interruption, three diesel-generator sets have been provided to insure current supply in case there is a breakdown. Power supply group No.1 is connected to the bars B1, and power plant No.2 to bars B2, the third may be connected to one or the other of these sets of bars.

Each set has a 450 hp diesel in continuous operation a magnetic clutch, a flywheel which is keyed to the common shaft of a synchronous electrical machine (400 KVA), a 36 KVA generator, and field machines for both.

Under normal conditions (supply from the city mains), two of these three facilities are operating, and the synchronous machines run as motors, energized by the city supply which drives the flywheel of the 36 KVA AC generators which in turn provide an AC electrical supply for the panel.

Should there be a breakdown in the power supply, directional power relays located on the sets of bars B1 and B2 automatically start the two diesels and open the current breakers between the sets of bars B1 and B13, B2 and B24. They also cut out all the equipment connected on B1 and B2 excepting the heavy water pumps. After three seconds, the clutches engage and the diesels drive the synchronous machines, which then operate as generators and energizes the equipment which has not been disconnected.

The flywheel has such inertia that it can start the power plant, in case the automatic starter does not work,in such a way that the frequency drop is less than 4%.

In addition to the directional power relays, an undervoltage relay and a frequency drop relay of the temporizing type can also start the auxiliary groups.

The feed to the control panel is furnished in halves, by the two 36KVA generators, so that there can be no total interruption. If one of the AC generators has a breakdown the half panel which is being used for control purposes is served by the other through automatic switching.

VI- IRRADIATED FUEL - STORAGE - IRRADIATION - OBSERVATION - MAINTENANCE

1 - General

Fuel burn-up is approximately 25 MWd/ton per day of operation at 10^{14} n/cm^2.s, It must be changed several times a year, at least during the early part of the reactor's life. Therefore, it was important to equip EL.3 with suitable storage and handling devices for hot cells or assemblies. The duration of storage of the cells or assemblies prior to fuel processing is of at least three months. The fuel cartridges may very well become distorted under the effects of irradiation and thermal cycling. It seemed indispensable to provide for a device with which one could quickly check the cells as they come out of the reactor, this check up is performed with X-rays.

In addition, the irradiated fuel is utilized for experimental purposes: two chambers, one of which is kept at the ambient temperature, and the other kept at -7°C, provide means for the irradiation of foodstuffs under γ radiation.

The facilities for the irradiated fuel include fixed equipment grouped in a substantial cave and movable equipment: discharge hoods numbers 1 and 2.

2 - Cave

The cave which is located at the floor level of the small compartment is a substantial concrete structure in the form of a **parallelipiped, 14 m long, 3 m wide. and 7 m high oriented in an east-west direction.**

The bulk of the masonry is ordinary reinforced concrete and heavy concrete so that the irradiated fuel is always surrounded by a thickness of concrete equivalent to 1 meter of heavy concrete of 4.2 specific gravity. It contains the following facilities, from East to West:

- the apparatus for hot rod checkup (see D VI below),
- the transfer lock chamber by means of which it is possible to transfer the hot assemblies from hood number 1 to hood number 2,
- a vat or tank for the storage of irradiated assemblies in good condition.
- a tank for the storage of irradiated assemblies with broken cartridges.
- the hot and cold rooms for γ irradiation

In addition, to the East and the West of the hot and cold rooms, some concrete covered sleeves afford means of storing the linings and active plugs of the vertical channels and the irradiated control rods.

The various ancillary facilities for the cooling of the assemblies in the devices and pieces of equipment mentioned above are located in the basement of the small compartment.

In its upper part, the cave is serviced by the track running at the + 7 meter level, which connects the reactor block to the separation room.

3- Unloading of fuel

The moderator and primary fluid of EL.3 are made up of heavy water. In order not to reduce the reactivity of the reactor, we must avoid the introduction of light water or impurities into this heavy water. It seemed indispensable, therefore, to protect the free surface of the heavy water of the reactor from any contact with humid air. This led us to use two hoods for unloading the fuel, one of which works in the heavy water atmosphere above the reactor, the other in the light water atmosphere above the cave. The hot assemblies are passed from the one to the other by means of a suitable transfer lock chamber located in the cave.

The hoods are completely tight, to avoid any risk of spilling dangerous gases such as tritium vapor. Hood No. 1 has a helium cooling circuit and hood No. 2 has an air cooling circuit, which make it possible to cool the irradiated assemblies practically without interruption.

C PHYSICAL PART

I - INTRODUCTION

Design parameters, choice of fuel element, lattice, definition of h and hc reactors

II - COMPUTATION METHODS

Lattice specifications, leakage computation, comparison of the computed number of critical bars with the experimental findings.

III- DISTRIBUTION OF THERMAL NEUTRON FLUX

Distribution on cold h reactor; calibration of ionization chambers, measurements of high power fluxes.

IV - CONTROLS

Definition of strokes, automatic drive, rate of displacement, computation of control rod efficiency, experimental values, decrease in flux due to compensation rods, mean life of neutrons.

V - LOADING OF EXPERIMENTAL CHANNELS

Compensation, similitude ratio, experimental results.

VI - RESULTS OBTAINED DURING THE FIRST POWER PLATEAUS

I - INTRODUCTION

The basic elements used for the project are enriched uranium with an isotope content of 1.35%, and heavy water. The number and arrangement of the experimental channels are determined by the users. The purpose is to achieve a thermal neutron flux of about 10^{14} n/cm^2/sec in the central channel.

It is necessary first to define the shape of the fuel element. This choice does not have much to do with nuclear considerations. In order of importance, the considerations which come into this choice are the following: thermal, technological, mechanical production, nuclear features. The data set by the project require a high specific power.

Thermal considerations lead to a fuel element in which the surface to volume ratio is high; namely, tubes, "bunches", or plates.

The tube, which is cooled on the outside only, is similar to a solid rod, the technology of which is well known. As a result, since the experience of the technologists has progressed, thanks to tests conducted in the reactor itself, the tubes may be cooled on both sides. This lends itself to an increase of the flux. For this reason, this form of element was chosen, at least for the first sets.

The mechanical behavior of the tube requires a minimum thickness, set by the technologists, at 3 or 4 mm. The construction of the tube block is easier if the number of elements is small. At this stage, nuclear considerations rule out the use of elements of too large a diameter.

Thus a rod having diameters of 22/29 mm was chosen.

Thereafter, the pitch of the lattice is computed, seeking the lowest power. The number of critical rods is derived from this allowing for the peculiar arrangement of the experimental channels required by the users.

The project is pursued by an investigation of the control devices, of the neutron flux distributions, and of the radioactivity and protection problems.

Throughout the project, there is one constant difficulty: a definition of the reactor. The cold reactor, with new elements, is critical with 40 elements. The lattice may contain up to 99 of them, which corresponds to a hot reactor, saturated with xenon and samarium, with elements which are producing 2,400 MWd/T, the experimental channels of which are partly loaded. The volumes of the two reactors are in a ratio of 2.5 to one, and it is difficult to consider that one derives from the other by way of a disturbance. Indeed, there is a series of reactors in the lattice which must all be considered as different. They have their control and power measuring devices in common, as well as their experimental channels.

For the purposes of our project, we assume that we have three reactors:

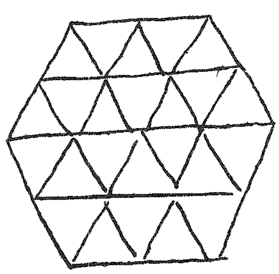
- the cold one, made up of 40 elements,
- the hot and used reactor, 99 elements,
- and an intermediate reactor corresponding to a new load, but saturated with xenon and samarium.

The best control devices and flux distributions have been investigated for these three reactors, and an attempt has been made at choosing an average device, close to optimal for the third, yet still acceptable for the others.

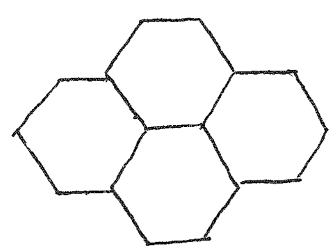
In some cases, it has been necessary to think in terms of intermediate reactors derived from those defined above, but containing a fictitious load in the central channel, as represented by an iron tube.

This difficulty, encountered during the design stages, shows up again in the experimental study. Since this is carried out with a new load at a low power, how is it possible, practically, to achieve reactors having a volume ratio close to 2.5:1 ? This difficulty was solved by modifying the lattice pitch. This modification is easily carried out with a rigid tubular block, by consistently eliminating one rod out of three.

The normal lattice is a centered hexagonal lattice (hc lattice). By eliminating one rod out of three, we achieved an hexagonal lattice(h lattice), so that the pitch of the cell is increased by a factor $\sqrt{3}/2$.



hc lattice



h lattice

The volume of the cold h reactor corresponds, as shown by computation, to the volume of the hot hc reactor, saturated with xenon and samarium, the elements of which are supplying 1,200 MWd/ton.

The measurements carried out on the cold h reactor are valio for the hc hot reactor, provided the similitude ratios defined in paragraph V are used.

In the following paragraph, reference will often be made to figure cl, which represents a schematic plan of the lattice.

Symbols A_1 to L_4 represent the position of the fuel elements. The figure shows an h lattice.

Symbols DS_1 to DS_8 represent the position of the aluminum plungers, used for flux measurements, which are called special devices.

The symbols BC 1 to 6 are the compensation rods

BS 1 to 3 are the safety rods

BR 1 to 2 are the trim rods

The radial channels, where numbered in the figure, will be referred to as CH 1 to 12 in the text.

II- COMPUTATION METHOD

The computation method has the purpose of determining the nuclear parameters of the reactor, and it is identical to that used for natural uranium and heavy water (1). This viewpoint was justified by the experimental results obtained during the startup period(2). These results enabled us to adjust the computation method to the specific geometry of the reactor (3) and thus obtain a set of formulas applicable, with precision, to the next sets of rods: these will be diferent from one another, for they must undergo a series of modifications whereby their behavior under radiation can be improved.

This set of formulas includes the computation of the lattice specifications (material buckling and characteristic length) and the evaluation of the critical dimensions (geometric buckling).

1.) Lattice specifications

The customary factors are computed separately $\xi, \eta, p, f, k_\infty$, with characteristic length L^2, L_s^2 and from these we deduced the value of the material buckling by the critical relation for two groups
$$k_\infty = (1 + L^2 B^2)(1 + L_s^2 B^2)$$

(1) EL3 project - V. RAIEVSKI
(2) CEA report No.794
(3) SPM report No. 369 - B. LEROUGE

a) factor p

A formula is used in which there is no Wigner-Weinberg correction. It can be written:

$$p = e^{-\frac{1}{T}}$$

$$\frac{1}{T} = \frac{\int_{eff} \Sigma_u \frac{dE}{E} V_u \times \int_{eff} \Sigma_{Mo} \frac{dE}{E} V_{Mo}}{\xi \Sigma_s V_m}$$

with the following constants:

- uranium	$\int_{eff} \sigma \frac{dE}{E}$	$= 5 \left(1 + 7 \frac{S}{M}\right)$ barns
- molybdenum	$\int_{eff} \sigma_{Mo} \frac{dE}{E}$	= 13 barns
- heavy water	$\xi \Sigma_s$	= 0.178 cm^{-1}

b) factor f

The thermal utilization factor consists of two terms due to absorption:of aluminum for the first of the moderator for the second.

$$\frac{1}{f} + 1 = \frac{\Sigma_{Al} V_{Al}}{\Sigma_u V_u} \quad \frac{\bar{\varphi}_{Al}}{\bar{\varphi}_u} + \frac{\Sigma_m V_m}{\Sigma V_u} \quad \frac{\bar{\varphi}_m}{\bar{\varphi}_u}$$

the ratio of the mean fluxes in the moderator and uranium $\frac{\bar{\varphi}_m}{\bar{\varphi}_u}$ is computed from the extrapolation length at the surface of the fuel element. This length is obtained as a function of that of a black body having the same outer radius (4).

On the other hand, the current theories give too small a value for the ratio of the mean fluxes in uranium and aluminum respectively $\frac{\bar{\varphi}_{Al}}{\bar{\varphi}_u}$

In approximation P_3, we obtained 1.09 for this ratio. Since the experimental value is 1.19 ± 0.01, we shall take the experimental values of this ratio.

(4) CEA report No.571 - A. Amouyal and P.Benoist

Factor f is computed with the following constants:

$$\sigma_f^{\,5} = 590\,b \quad \text{departure from the } 1/v \text{ law} = 0.977$$

$$\sigma_c^{\,5} = 698\,b \qquad\qquad = 0.974$$

$$\sigma_c^{\,8} = 2.75\,b$$

$$\sigma_c^{\,Al} = 0.2\,b$$

$$\lambda_t^{D_2O} = 2.47 \text{ cm}$$

$$L^{D_2O} = 105 \text{ cm}$$

c <u>factor η</u>

With natural uranium we take the value $\eta = 1.291$ (5,6).

d <u>characteristic lengths</u>

These are computed by the customary formulas, we take, for the slowing down length in heavy water, fission neutrons and neutrons scattered inelastically under the action of uranium, the following law

$$L_s^{\,2} = (125 - 24{,}5\ P)$$

2) <u>Leakage computation.</u>

The two-group theory is used. The influence of the wedges is calculated by the one-group theory (7). The central channel is treated as an additional medium, the extrapolation lengths for the fast and thermal groups being given by Davison's theory (8). Some corrections have to be applied to this theory in order to adapt it to the geometry of the reactor.

a) <u>Heterogeneity.</u>

Davison's theory is established for the case of a homogeneous medium. The leaks, then, are proportional to the flux surface of the channel. In the case of a heterogeneous medium, we must allow for the

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(5) SPM report No.331 - R.Delayre
(6) SPM report No.368 - R.Naudet
(7) Journal de Physique et le Radium, 1951 - J.Yvon.
(8) CRT 319 - B. Davison

fine structure of the flux in the element or assembly, multiplying the reciprocal of the extrapolation length by the ratio of the flux at the surface of the channel to the mean flux in the cell.

$$\frac{\varphi_c}{}$$

b) Curvature of radial flux.

Before the channel is set in place, the undisturbed flux has a curvature, due to the finite dimensions of the reactor, wheras Davison's theory considers an infinite medium. It is therefore necessary to subtract, from the reciprocal of Davison's extrapolation length, its non-disturbed value $\left(\lambda_0^{-1} = \frac{1}{\varphi_0} \frac{d\varphi_0}{dr} \cong -\frac{\beta^2 R_0}{2}\right)$

in which β is the value of the radial laplacian and R_0 the radius of the channel.

The extrapolation length is expressed finally:

Davison

the ratio $\frac{\varphi_c}{\bar{\varphi}}$ is about 0.8:this correction, therefore, is not negligible.

c) Modification of the volume of the moderator in the central area.

The moderating power is modified in the central area. Assuming that this modification affects only the six peripheral rods, according to whether the central channel eliminates a heavy-water volume greater or lesser than the volume of the central cells, the fixed peripheral cells will be under-moderated, or hyper-moderated, with respect to the rest of the lattice. In other words, if b is the radius of the element, radius b' of the elements or cells which are equivalent to the six peripheral rods can be written:

$$6\pi b'^2 = 7\pi (b^2 - R_0^2)$$

d) Computation of the geometric buckling

The flux is considered to be a product of the radial **and axial** functions. They are computed separately, (as are the joint functions,) using a program with a two-group/multi-region theory established for the IBM 650 computer (9)

(9) Program LAGO

In radial computation, the following region is considered:

central channel

lattice b'

lattice b

heavy water moderator.

aluminum wall

graphite.

On the geometric buckling so obtained, we make a wedge correction calculated in the single group theory, and a second correction which allows for the effect of the radial channels (10).

3) Comparison of the number of critical rods, as computed, with the experimental results.

In order to have sufficiently numerous points of comparison, the number of critical rods was measured on four reactors, using the EL3 lattice

The hc and h reactors, with and without a central channel.

In computing the h lattice, allowance is made for the form-factor of the cell or element (11) (12).

The measured number of critical rods is brought down to standard conditions:temperature of the heavy-water, 20°C, no experimental devices in the reactor.

The following table gives the number of critical rods as computed and measured:

Reactor	Computed Nc	Measured Nc
hc without cc.	31.7	32.6 ± 0.4
hc with c.c.	38.2	39.2 ± 0.8
h without c.c.	41	44.1 ± 0.9
h with c.c.	46.5	50.4 ± 1.2

(10) CEA Report No.688 -B. Lerouge and V. Raievski
(11) Geneva, 1955. Report P/669, S.M. Feinberg.
(12) SPM Report No. 249 - B. Bailly du Bois.

Agreement is satisfactory. The largest deviations are observed in the h reactors. Since the h lattice is very large, these reactors are bulky. The result is an assymmetry in the flux, because the lattice is off-center with respect to the tank. (This 9 cm offset makes it possible to fit the largest possible number of rods in the tank.

III - DISTRIBUTION OF THERMAL NEUTRON FLUX

The distribution of the flux depends on the volume of the reactor, which is to say, on the conditions under which it operates. The distribution, as measured on the cold h reactor, is substantially the same as for the hot poisoned hc reactor having the same volume. The difference is due to the characteristic lengths, which depend on the shape of the lattice, and to the existence of a reflector. Computation shows that this difference is negligible.

1) Distribution on the cold h reactor

Distribution is obtained by measuring the activity of continuous copper strips placed on a generatrix of the fuel elements, at approximately 7 mm from the cartridge or jacket. Some of the strips also are located in the experimental channels.

Axial and radial distributions

Figures C.2 and C.3 represent these distributions for reactor h.

The activity of the strip is recorded with the help of an automatic device called a "strip unwinder" (13). The recordings indicated a tracing of the flux between the cartridges. Since the diaphragm chosen is too wide, it is impossible, on these recordings, to know exactly the flux read in the uranium pellets located at the ends of the cartridges. For this reason, an accurate measurement was made by O. Tretiakoff on two special cartridges, with a continuous gold wire on the axis of the cartridges. The activity of the wire is measured with a "wire unwinder" (13).

The latter is equipped with a rotary diaphragm which modulates the radiation β received by the photomultiplier of the unwinder. Thus the definition reaches 0.25 mm. The recording or tracing obtained, (Fig. C V 4) confirms that originally made, but the latter takes place exactly between the pellets. The flux in the pellets is somewhat less than in the rest of the uranium. This measure also indicates that there is no thermal overload at the end of the cartridges.

The radial distributions reveal the dissymmetry of the flux due to the eccentricity of the lattice.

An important result of the flux measurements is the ratio of the activities of identical detectors made of copper placed at the end of a thimble at the point of the maximal flux in the central channel.

On Reactor h, we find the following values:

$$\frac{\phi \quad CH_{12}}{\phi_c} = 0.35$$

$$\frac{\phi \quad CH}{\phi_c} = 0.32$$

$$\frac{\phi \quad CH_8}{\phi_c} = 0.27$$

The ratios are greater if the reactor functions with the compensation bars partially lowered so that they depress the flux in the vicinity of the central channel. We thus measured, for the case of two lowered rods and an 80-rod hc reactor.

$$\frac{\phi \quad CH_8}{\phi_c} = 0.32$$

It should be noted that the fluxes in the thimble are very anisotropic. In order to measure this anisotropy, we carried out the following experiments:

a) a container of heavy water was placed behind the detector.

b) copper detectors having a diameter ϕ = 4 mm separated by a cadmium sheet having a diameter ϕ = 5 mm were irradiated. We obtained the following results:

(13) Le Journal de Physique et le Radium. Tome 14,1953. p.463, V. Raievski. M. Pelle
(14) CEA No. note 216. O. Tretiakoff.

$$\frac{\text{activity of the reactor with a reflector}}{\text{" " " " without "}} = 1.20$$

$$\frac{\text{activity of the detector when turned inward}}{\text{" " " " " " outward}} = 1.30$$

For the experimenter who uses a bundle of rays on the outside, the flux depression caused by the channel is less than for the experimenter who carries out irradiations in this channel without an auxiliary reflector.

2) Calibration of ionization chambers; Measurement of a high power flux.

The relationship between the current in the chamber and the power depends, to a great extent, on the condition of the reactor.

Thus, the indication of the chamber must be considered only as a guide point. The fluxes in the central channel, for a current of 1 m A in the chamber, are respectively, $5.7 \ 10^{14}$ and $7.7 \ 10^{14}$ for h and hc reactors. On the other hand, it is very important to know, while working, the specific power of the most loaded fuel elements which are located close to the central channel. To this end, we use an apparatus consisting of an aluminum band (A 5) drawn by a motor at speeds of 5 and 25 centimeters per second. The strip passes under an ionization chamber which measures its activity.

In order to take a measurement, the motor is started, and the strip or band makes one revolution at a constant speed. Its activity gives an average on the axial flux. Currently, use is made of several devices of this type located in the central channel, with special devices and thimbles. These measurements make it possible to know the flux distributions at the high powers. Thereafter, only one band, DSI, is kept going at a normal pace.

IV CONTROL DEVICES

The devices used for reactivity control consist of cylindrical, aluminum rods filled with boron carbide. They move vertically at the center of the triangles made up by the fuel elements.

This arrangement has the advantage of saving the positions of 11 elements. As a precaution, should a compartment break , the boron carbide is divided into compartments about 10 centimeters in height. In this way, the possibility that the reactivity released be greater than the prompt neutron fraction is avoided.

Since the heat released in the compensation and trim rods is about 5 W/cm^2, they are cooled by the normal heavy water circulation.

This cooling is useless for the safety rods, the characteristics of which are as follows:

Nature	Φ cm	Height	Number	Distance, starting from the axis of the central channel
B.C. compensation	4	140	6	40
B.R, Adjustment	4	18	2	70
B.S, Safety	4	90	3	45

1) Definition of Strokes

We define, for the rods, the total, effective and useful strokes. The total stroke is the maximum distance covered by the rod, which would be of interest only to the mechanics.

The effective stroke is the part of its motion over which the rod acts on reactivity. This extends from the low position, where the center of the bar is in the maximal flux plane and the position in which the lower end of the rod reaches the level of the free plane of the heavy water.

Under normal operation, the stroke of the rod must be less than its effective stroke. Indeed, control depends essentially on the differential effect of the bar, namely, on the variation of reactivity in units of time or, (which comes to the same thing, in the case of a constant speed of displacement,)on the variation of the reactivity as expressed in units of length.

The differential effect is zero at the extremities of the effective stroke. If the rod is operating at one of these ends, it will act only once it reaches the areas in which the differential effect is perceptible. This entails an unacceptable delay. Thus limited, the path of the stroke gives the useful stroke. For this stroke we took the region where the differential effect is greater than half its maximum.

2) Automatic control

The adjustment rods are controlled by the ionizing chambers. When an adjustment rod reaches one of the ends of its useful stroke, a compensating rod is automatically started, stopping as soon as the regulating rod reaches the other end of its useful stroke.

3) Rate of rod motion

If the compensation rod is in its position of maximum differential effect, the adjustment or regulating rod must move faster than the compensation rod at the end of its useful stroke.

As a result, the maximum differential effect of the adjustment rod is more than double that of the compensation rod:

$$\left(\frac{d\rho}{dt}\right)_{\frac{\text{Max}}{\text{BR}}} > 2 \left(\frac{d\rho}{dt}\right)_{\frac{\text{Max}}{\text{BC}}}$$

The compensation rod must be in a position to compensate (at the end of its useful stroke) for xenon poisoning following the accidental dropping of the safety rods.

$$\left(\frac{d\rho}{dt}\right)_{\frac{\text{Max}}{\text{BC}}} > 2 \left(\frac{d\rho}{dt}\right)_{\text{Xe}}$$

The comparison of these two inequalities leads to a third:

$$\left(\frac{d\rho}{dt}\right)_{\frac{\text{Max}}{\text{BR}}} > 4 \left(\frac{d\rho}{dt}\right)_{\text{Xe}}$$

$\left(\frac{d\rho}{dt}\right)_{\text{Xe}}$ being of the order of 10^{-5} sec^{-1}, the above inequality requires a speed of more than 4.10^{-5} sec^{-1} for the regulating rods.

4) Computation of control rod efficiency.

This efficiency depends a great deal on the volume of the reactor; here, once again, we find the difficulties encountered in flux measurements. These difficulties are further enhanced by the fact that the efficiency varies as the square of the flux.

The efficiency of the whole set of compensation rods (15) is so computed that the cold reactor, with 99 rods, could not become critical.

The efficiency of the adjustment (or regulating) and safety rods is achieved by computing the effect of one rod at the center and weighing it by the square of the thermal flux.

5) Experimental values.

The efficiency of the control devices has been measured on the h and hc reactors. To deduce their efficiency on an hc reactor of identical volume while hot and poisoned, one must multiply the result by the ratio of similitude of the reactivities:

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(15) - A.E.R.E. 1952 R/R 8/8 - J. Codd, C.A. Rennie

$$\left(\frac{\rho_{hc}}{\rho_{h}} = 0.96 \times \frac{2}{3}\right)$$

This efficiency was measured by the modulation technique for the compensation and adjustment rods (16) and by an impulsion method for the safety rods.

a) Compensation rods.

Oscillation of the rod, of some $\pm$ 1.02 cm about a mean position, with a frequency of 0.542_{cps} is established from the measurement of the rate of modulation of the density, the differential effect is computed in absolute magnitude. We plotted the curves showing this effect for the h and hc reactors on Figure C.5, as well as the total effect obtained by integrating this curve. These curves call for the following comments:

The maximum differential effect on the hc reactor is:

$$\left(\frac{\partial \rho}{\partial z}\right)_{Max} = 34.10^{-5} \text{ cm}^{-1}$$

On the h reactor, this effect is $31.8.10^{-5}\text{cm}^{-1}$. By using the similitude ratio, we deduce that, on an hc reactor (while hot and poisoned, having the same volume as reactor h,) the effect will be only 20.10^{-5} cm^{-1}, which is a loss of effectiveness of as compared to a new hc reactor while cold.

The sensitivity of the method makes it possible to detect the effect variation due to the removal of one peripheral uranium bar. Thus on an h reactor (65 rods) the removal of D 10 causes the maximum differential affect to rise from $31.8.10^{-5}\text{cm}^{-1}$ to $32.2.10^{-5}$ cm-1.

In this experiment the modulation is affected about a variable level z. When this level is changed, the reactor must stay critical. The simplest method consists of changing the position of the compensating rod BC 3, which is diametrically opposed to BC 6. We have measured the resultant shadow effect due to the lowering of BC 1 close to BC 6. In the h reactor, the depression so produced causes a decrease of 18% in the maximal differential effect.

The disturbance caused by the remote rod, BC 3, obviously is much less than 18%. It would be possible to compute this effect by measuring the depression produced by intermediate rod BC 2 and by extrapolating these results according to a law in $r^{-1}e^{-kr}$, for example.

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(16) note CEA n° 73-V. Raievski.

b) Adjustment or regulating rod.

The method used is the same as for the compensation rods.

The amplitude of the fundamental of the mechanical motion is $\pm$ 1.10 cm.

The oscillation frequency is 0.078 cps.

The results obtained on h reactors of 65 rods and on hc reactors of 55 rods are shown by the curves on Figure C.6. They differ from those obtained for the compensation rods on the following points:

The differential effect is cancelled out above the median plane of the lattice, whereas it was cancelled out in this very plane for the compensation bars.

This is due to the distortion of the flux brought about by the lateral channels. This distortion has been observed in flux measurements, (Fig. C.2b)

Adjustment rod BR2, in the 55-rod hc reactor, is located in the reflector. Experiments were first made with the G2 and H2 uranium rods in place; a rod was then inserted in H1. The insertion of this rod causes an increase of 6% in the maximum differential effect.

In this case, two phenomena work in opposite directions: According to the disturbance thèory, the anti-reactivity due to an absorbent is proportional to the product of the neutron flux absorbed by the importance of these neutrons. Therefore, while the insertion of an additional uranium rod H1 in the vicinity of BR2 tends to depress the thermal flux on the other hand it increases the importance factor of the neutrons. The latter effect is particularly marked at the edge of the core, where the probability of a leak varies rapidly with the radius.

c) Safety rod

Above all we must note the power decrease brought about by the drop of the rods. Their anti-reactivity is no more than a device which makes it possible to compute this decrease. We therefore measured the density of the thermal neutrons direct before, during and after the drop. The curves computed on an analog computer make it possible, by comparison with the experimental curves, to deduce the reactivity variations during the drop of the rods.

The experimental device consists of three proportional BF3 counters set up in parallel. Its impulses are recorded on a magnetic tape which unwinds at a rate of 2m/s. These impulses are then re-read at a speed of 4 cm/s. The phenomenon is then either directly inscribed on a MECI SPIDOMAX recorder (through an integrator) or is expanded once again on the time-scale for a more intensive study, by recording the pulses on a camera film moving at high speed before the screen of an oscillograph.

The initial counting rate during stabilization is 20.000 d.p.s.

The V curves represent these recordings in a 55-rod hc reactor. The drop of BR2 is recorded with and without having the neighboring compensation rod (BC1) in the low position, in order to determine the shadow effect. The pressures used in the pneumatic system were 3 Kg and 5 Kg.

Curve VI represents the computation of the reactivity bearing on a recording made with the BC1 rod at a pressure of 5Kg. We note an increase in the reactivity which must be ascribed to a rebound of the rod. This rebound disappears at the lower pressure of 3 Kg.

The rod anti-reactivity deduced from these recordings, leads to a value of approximately 3% per rod for a 55-rod hc reactor.

6) Flux Depression due to the Compensation Rods.

The presence of a compensation rod modifies the flux distribution in the uranium rods and the temperatures. It was important to make sure that there was no thermal overload. To this end, we used and placed a uranium rod with an accessible center. At the center, of the rod, a miniature fission chamber is moved at a constant speed with the help of an automatic device, the pulses of which are recorded on an MECI, giving the axial distribution of the flux inside the rod. This distribution was measured for various positions of the neighboring compensation rod BC3. The curves shown on Figure C.8 are normalized in order to keep constant the reading of an ionization chamber located in radial channel CH5.

It will be noted that there is no thermal overload but that the depression is substantial (35%) and may bring on a thermal cycling of the uranium rods. Fortunately, this cycling is very slow.

7) Measurement of the mean life of the neutrons.

Knowledge of the mean life of the neutrons is important in order to evaluate the behavior of the reactor in case of the accidental release of a large reactivity.

The mean life was computed by the oscillation method, (17). The following values were obtained:

$$= 1.79 \ 10^{-3} \text{ sec dry, for hc reactor}$$

$$= 2.00 \ 10^{-3} \text{ sec dry, for h reactor.}$$

(17) C.R. Académie des Sciences --237, 1513 - 1515, 1953. V.Raievski

In case of a break in the lining of the central channel, the addition of heavy water causes an increase in reactivity of about 2%. Assuming that, from the beginning, the uranium rods are thermally insulated by a jacket of steam, we deduce, from the value of the mean life, measured in the hc reactor, that the temperature of the bar rises by 200°C after 0.27s. This time corresponds to the duration of the drop of the safety rods. Under these conditions, uranium will not reach a transformation point. On the other hand, the behavior of the jacket is harder to forecast.

V LOADING OF EXPERIMENTAL CHANNELS.

The purpose of these measurements is to determine the number of uranium rods needed to make the hot and poisoned reactor critical with a given load in the experimental channels.

The typical load is simulated by iron tubes in the channel equipped with plungers, and by stainless steel tubes in the cavities where the steel tubes are in direct contact with the heavy water. An investigation was also made of the following effects: neutron transportation in the horizontal channels (these are closed with containers filled with heavy water), and the insertion of fissionable elements in the central channel. These measurements are carried out by compensation on the h and hc reactors. The effect on the hot and poisoned hc pile is deduced by means of similitude ratios.

1) Compensation

Since direct compensation with the uranium rods is difficult, we first calibrate compensation rod BC4 with respect to the number of uranium rods which make the reactor critical. Calibration of BC4 in the h reactor is carried out with uranium rods I5, J4 and J5, so placed as to restore the local flux conditions of the hc reactor. We then measure the variation in the critical level of BC4 caused by any disturbance. The calibration curve makes it possible to derive an equivalent of this disturbance expressed in uranium rods.

The reactivity gain, due to the addition of a uranium rod, is dependent on the number of rods present in the reactor. The variation of this gain depends on the total number of rods. In the results, the effect measured in the h reactor was reduced to that of a rod in the 59-rod h reactor,

2) Similitude ratio.

The variations in the reactivity produced by the same absorbent in reactors h and hc are different. This difference is due to the fact that the two lattices do not have the same characteristic lengths.

The effect of a local absorbent is difficult to compute on these reactors because of the distributions of flux, the exact shape of which is unknown. It is easy to deduce this effect for the hot and poisoned hc pile by measuring on an h reactor having the same volume. These effects are proportional: the coefficient of proportionality, or similitude ratio, is obtained by a disturbance computation (2).

For the reactivity variation ratio, or the number of uranium rods compensating the same effect on these two reactors, we obtain the following values:

$$\frac{\rho_{hc}}{\rho_{h}} = 0.96 \frac{2}{3}$$

$$\frac{\delta N_{hc}}{\delta N_{h}} = 1.15$$

3) Some experimental results:

The loadings were carried out as follows:

a)	cell or element with stainless steel tube		ϕ 32/35 mm h = 1356 mm
b)	stainless steel tube	:	ϕ 35/42 mm h = 2200 mm
c)	iron tube	:	ϕ 225/228 mm h= 620 mm in the wide diameter channels.
d)	iron tube	:	ϕ 126/129 mm h = 620 mm in the small diameter channels.
e)	fissionable element	:	normal rod of the lattice.

The following table gives the equivalent in peripheral uranium rods measured on a 59-rod h reactor.

load	position	equivalente in uranium bars
cell or element with stainless steel tube	F7	- 4.15
" " "	E9	- 2.9
" " "	D10	- 1
" " "	CC	- 3.25
Stainless Steel Tube	C15	- 0.23
" " "	DS3	- 3.05
Iron tube	CH1, 5, 7, 9	- 0.7
" "	CH1, 5, 7, 8, 9,11	- 1.1
Fissionable element	CC	+ 2.7

VI - RESULTS OBTAINED DURING THE FIRST POWER PLATEAU (18)

First a few plateaux under medium power were used to adjust the outputs and to verify the heavy water temperatures in the cells. Then the reactor was operated, on the 6th, 7th and 8th March, at a power of 10 Mw with a full heavy water flow but with reduced light water flow. Throughout this plateau, the thermal neutron flux measured in the central channel ranged between 7 and 8.10^{13}.

The uncertainty will be reduced during the next plateaux, as soon as it becomes possible to use the tape device in the central channel. The indicated flux is obtained from a measurement made with a ribbon type device in channel H8 and by using the ratio of the flux measured at low power:

$$\frac{\phi_{cc}}{\phi_{H8}} = 0.32$$

(18) Physical study of reactor EL3 - lattice made up of 80 rods - The S.G.P.S. "Groupe Physique et Experimentation". CEA report in preparation

This operation was conducted with an overabundance of uranium rods (80). The xenon effect was evaluated at 2.5% under saturation. The temperature effect of the moderator (27 10^{-5}/°C) and that of uranium (1.25 10^{-5}/°C) being 0.5%. The samarium effect was still negligible.

Under these conditions, the operations took place with BC4 in the low position and BC2 at the half efficiency position. The reactivity available for the 80-rod reactor, when saturated with xenon and at its functional temperature, was thus estimated at 3%. When the reactor stopped we measured the variation of the xenon effect by compensation (with a compensation rod). It was observed that maximum anti-reactivity was reached 9.5 hours after the stoppage. Loss of reactivity, at that point due to the increase in the concentration of the xenon, was evaluated at 3.5%. This value concords with a thermal flux ranging from 7 to 8.10^{13} in the central channel.

D. TECHNOLOGICAL ASPECTS OF THE BUILDING OF REACTOR EL.3

I - GENERAL.-

Building the EL.3 Reactor required a number of important studies of a general nature since in 1955, the technological knowledge bearing on heavy water circuits or loops was relatively undeveloped in France. The only reactors in France at that time were: EL.1, which is of very low power, and EL.2, which is cooled by carbon - dioxide. One large reactor was under construction, (G.1), but it was operated with graphite and natural uranium. EL.3 was the subject of fairly important studies, perhaps beyond those strictly necessary, with a view to providing documents that would be useful in the building of other reactors.

Thus, heat-transmission (tests which are discussed in another paper) were carried out in order to determine the cooling conditions of the rods of reactor EL.3. They enabled us to verify that the computations made from existing formulas gave satisfactory results and that the adoption of corrugations on the rods made it possible to reduce the temperature gradient by a factor two or thereabouts as between the heavy water and the outside surface of the jacket. They also had the advantage of creating a test bench and of developing experimental methods, which later made it possible to begin more rapid studies of the cooling of pressurized cells.

Another paper, prepared by M. Grenon, describes the tests which made it possible to develop the break-detection process on the jackets, by looking for fission gases in heavy water, which is used on Reactor El.3 and which we mentioned in Para III-2.5 above.

We shall also draw attention to the conditions under which the manufacturers of heavy water pumps and gates (of the leak-proof type) were chosen. The manufacture of a number of prototypes of pumps and gates was started at the beginning of 1955 by different industrialists and, after a trial of these prototypes, the manufacturers of the final pumps and gates were chosen. Bearing in mind that the reactor was constructed in less than three years, one realizes the great efforts made by French industry.

In addition, a through study of heavy concretes was made. The object was to perfect, for EL.3, a concrete with a specific gravity of over 4, in order to diminish the thickness of the concrete shielding of the reactor block, to reduce its overall dimensions and to shorten the channel plugs so as to make them easier to work with. We shall not linger over this study which bore on a whole series of concretes, from the point of view of method of use, and mechanical properties, and also from that of nuclear characteristics - for it is the subject of another paper.

Information is given here on a few other technological studies: detection of heavy water leakage; metal on metal flanges; measurement of the level of heavy water in the reactor tank; rapid measurement of the cell temperatures; hot observation; hot-air stack; boron shields and machining of graphite.

II- DETECTION OF HEAVY WATER LEAKAGE.

1 - Aim and principle of the facility.

The facility for the detection of heavy water leakage in Reactor EL.3, which is described below in its important aspects, signals, by warning system (acoustic and luminous), any leaks occurring at certain points in the circuits, particularly at the flanges (See Para B, III-21 above).

A heavy water leak will make conductive a braid placed between two electrodes, thus closing the alarm circuit.

The facility comprises principally a certain number of leak-detectors; a certain number of signal cabinets, with 75 detectors each, installed in the vicinity of the workrooms; and a synoptic table, installed at the control board, which indicates, by means of lights and buzzers the cabinet corresponding to the leak detector.

2- Description of facility:

2.1 - Detectors:

A detector, as shown on Figure D.1, consists essentially of a cylindrical stainless steel body adaptable to the capacity on which the detection is to be made. Inside this body, which is grounded and is one of the electrodes, there is a second axial electrode centered with the help of insulating sleeves. This central electrode is covered with a cotton jacket impregnated with a hygroscopic salt. A co-axial contact makes it possible to connect a single-wired electric cable (with a protective covering) to the detector.

2.2 - Signaling circuit (Figure D.2)

There is a detection circuit consisting of a group of 3 detectors in the control room. A 4-position switch makes it possible to connect the three, in parallel (normal position), or singly

(to determine the suspected detector), with a 40-volt signaling circuit. This voltage is reduced when the detectors are dry (R=100,000 to 500,000 ohms) by load-resistor Ri to a value of 24 volts. The coil of the 24-volt relav has an impedance of 750 ohms.

When a detector is wet, its resistance drops to a value of about 75 ohms. The equivalent resistance of the detectors and relay drops, the current in the resistor rises (as well as the ohmic drop). The voltage at the terminals of the 24-volt relay being then to weak, the relay drops, and the following takes place.

- contact 1, a very low value resistor R.2 maintains the voltage-drop in R1, and thus makes it possible for the relay to stay down.
- contact 2 lights a lamp which indicates that there is a leak on the 3-detector group.
- contact 3 energizes , the totalizing relay which, in turn, performs the following functions:

a - contact C.1,on the local cabinet,turns off the "normal signaling light and lights up the "leak" light, as well as, that of the control-board indicating the area in which there is a difficulty.

b - contact C.2 starts, on the one hand, the "howler" of the control board, and on the other hand, the realy which inserts a contact into the pre-alarm chain. A controlled push-button relay makes it possible to stop the "howler" (siren). This last realy returns to normal as soon as the defect has been remedied.

III - METAL ON METAL FLANGES

The purpose was to obtain flanges where metal bears against metal, so that the inside surface of the pipe is practically restored above the flange, in order to avoid any interstitial area in which radio-active deposits might form and make disassembly of the pipes difficult by reason of radiological risks.

On the other hand, it is of interest to avoid the use of plastic gaskets where they may come into contact with heavy water since they always have a tendency to exchange hydrogen and deuterium ions and their behavior under radiation is indifferent.

These fears are only partly justified. In the case of heavy water heterogeneous cold reactor, the use of flanges in which metal bears against metal is something of a luxury, but the C.E.A. is **willing** to use them for testing purposes, since they may well be valuable for highly radioactive circuits.

Two types of flanges, shown on Figure D.3, have been investigated. We designate them as flanges of the A and B types. On the outside, where metal bears on metal, two perbunan gaskets provide two additional leak-proof barriers, which make it possible to install a leak detector (see Par. D.II above).

In the type A flanges, there is no intermediate gasket, and the joint formed is stainless steel on stainless steel. Some tests carried out on 60 and 250 mm. diameter flanges showed that the joint is leak-proof if the crushing pressure is, again, some 5 to 10 kg/mm, once the flange is under pressure, provided that the machining of the surfaces has been very thorough and they have not deteriorated in any way. A leak-proof condition can also be obtained, in spite of small surface defects, provided the tightening is between 20 and 30 kg/mm, instead of from 5 to 10 kg/mm. This type of flange has not been kept however, as it is ill suited to successive disassembling and re-assembling - in the event one point of such contact were ruined, it would be necessary to replace the corresponding flange.

This is what led us to investigate flanges of the B type. They have an intermediate gasket, made of stainless steel, crushed between the bearings of the stellite-treated flanges. The bearing areas of the gasket are in the form of a knife and when they are pressed, they suffer a certain plastic distortion, whereas the flanges do not, because they have a bearing surface which carries stellite. In re-assembling a new gasket is set up and tightness can be achieved under excellent conditions.

The graph on Figure D.3 has to do with distortions of the gasket, in the case of a flange having an inside diameter of 40 mm, as a function of the linear tightening pressure. Curve 2 represents variation Δh of h. We note that the permanent distortion begins at 30 kg/mm and increases regularly with the tightening. Curve 1 shows the shape of edge a . These tests have shown that tightness can be achieved in spite of a scratch 1/10 of a millimeter deep, provided the initial pressure is 90 kg/mm.

IV- MEASUREMENT OF THE HEAVY WATER LEVEL IN THE REACTOR TANK.

Operation of the reactor requires that the heavy-water level be known with a precision which has been set at $\pm$ 5 mm. It has not been possible to find, in commercial practice, any device for measuring this level which has all the qualities required, namely: maintenance of perfect tightness of the heavy water and helium vessel: absence of contamination of the heavy water corrosion risks; absence of deterioration under radiation; lack of spark production, which might bring about a risk of explosion, should the deuterium and oxygen content of the helium atmosphere be too high.

It was therefore necessary to start the investigation of a level which would satisfy all these requirements. The following principle was adhered to (See Fig.D.4). In a tube vertically dipping in heavy water, helium circulation under pressure is effected at a rate of flow which is kept constant, regardless of the height of the water above the low point of the tube in which the gas bubbles escape to the surface. Since the rate of flow is constant, variations in the height of the level correspond to proportional variations in the gas pressure which, therefore, it will be enough to measure.

V- RAPID MEASUREMENTS OF CELL TEMPERATURE.

The rapid scanning facility (figure D.5) permanently shows **on the large diameter screen of the oscilloscope, the temperatures of the heavy water used for cooling each of the 99 cells, as measured by thermocouples. These temperatures are recorded every 400 seconds.**

A rotary selector, driven by a synchronous motor, scans 100 temperatures in two seconds. It is mechanically coupled to a potentiometer system of the sine-cosine type, which provides circular sweeping for the oscilloscope.

The rotary selector supplies rectangular wave signals made up of a succession of low DC voltages representing the temperatures. A transistorized converter transforms these D.C. voltages into 4,000 cps A.C. voltages, with amplitudes **proportional to their values, and a** gain of 400. These A.C. voltages are superimposed on the regulated continuous voltage used to energize the scanning potentiometer.

The voltages so supplied by the potentiometer are applied, following amplification, to the deflection coils of the oscilloscope, thus giving an image of the various temperatures in the form of radial lines of variable amplitude from a luminous circumferance on the periphery of the screen.

The references for the cells are on the support base of the oscilloscope. In front of each reference, there is a neon indicator, which lights up when the temperature of the relevant cell exceeds the maximum value set.

VI - OBSERVATION OF HOT CELLS OR ELEMENTS.

It is indispensable to be in a position to observe the cells or fuel assemblies as soon as they come out of the reactor, in order to secure information on the behavior of the fuels, or detect if need be the causes and effects of an incident such as a break in a cartridge. For this reason a suitable device for the examination of the rods by X-rays has been provided.

An observation ditch for the fuel elements, in the shape of a T, is provided west of the cell. It consists of a vertical steel tube with two magnesium windows facing each other. The cell which descends by means of hood No. 2 passes in a rotating chuck. All the parts of this cell, or element, can thus be brought up before the magnesium windows, since it can be rotated and displaced vertically. During observation, the vertical tube which receives the cell is included in the air circuit of the hood which thus continues to insure the cooling of the cell.

A 150 kv X ray generator is directed toward one of the magnesium windows and the image intensifier is placed against the other window. This image can be examined either with a camera, on a television receiver, or else with a periscope which may be equipped with a camera obscura for taking photographs. Some emulsions which have just been presented make it possible to take a good radiograph direct.

This facility makes it possible to reveal faults of one to two millimeters with 80 keV - X-rays. This energy was chosen to cause the least possible image disturbance by the γ emission which is intrinsic in the cells.

VII-HOT AIR STACKS.-

The hot air from secondary cooling which is achieved in an open circuit. (Cf. B III 3), is quite radioactive at the exit of the reactor. This is due, on the one hand, to the dust, and, on the other, to the activation which it undergoes in the reactor, due mainly to argon 41 with a half life of 1.8 hours produced by the nuclear reaction A^{40} (n γ) A^{41}. **This hot air cannot be ejected into the atmosphere without precautions.**

Radioactive dust is easily eliminated by means of very efficient paper filters (efficiency= 99,98%), for dust grains of less than a micron, placed downstream from the reactor.

However, due to the chemical inertia of argon, the only means of eliminating the radioactivity it creates is to dilute the air of the cell sufficiently for its argon concentration to become less than the permissible dose. Thus, have made a painstaking investigation of the hot air stack to insure this.

The total activity of the air at the outlet of the stack, allowing for the volume it occupies in the reactor, of the neutron fluxes to which it is subjected according to the areas involved and of the rate of diffusion in the graphite, has been evaluated at 1 millicurie per second. The air output being 22,500 m^3/ hr, its activity is 1.6 10^{-4} C/m^3; namely about 3,000 times the tolerance dose for the neighboring population, which is 5.10^{-8} C/m^3.

This 3,000 factor would lead to pro ibitive facilityes if we were trying to dilute the air prior to ejecting it, this is why we investigated a blower stack from the aerodynamic and positional standpoints in order to achieve satisfactory dilution of the smoke in the atmosphere.

Two sets of tests were carried out with the blower, the first was with the isolated stack, and the other with the stack in location.

The first category of tests showed the following law of similitude for the smokes.

$$\frac{\Delta h}{D} = f\left(\frac{W}{u}\ \frac{X}{D}\right)$$

Figure D.6, on the basis of which the parameters are defined, represents a network of curves giving $\frac{\Delta h}{D}$ as a function of $\frac{W}{u}$ for different values of $\frac{X}{D}$. Beyond a certain value of $\frac{X}{D}$ (about 80), the axis of the smoke is practically horizontal and Δh is given, for $3 < \frac{W}{u} < 40$, by the relationship:

$$\frac{\Delta h}{D} = 2,2\ \frac{W}{u}$$

Even though it has not been possible to make a thorough investigation of this point, it would seem that a deflector placed at the top of the stack would have a favorable effect for the small values of W/u, and a generally unfavorable one for the large values of W/u.

The second set of tests has to do with a 30 meter stack, which is the maximum allowed by air traffic regulations. It showed, on the one hand, that it was of interest to place the stack to the north of the building, allowing for the prevailing winds, on the other hand, that in the position chosen, there was no reason to fear any interaction between it and the atmospheric cooling device, or the cool air intake, leading to recycling of active air.

In all cases, the smoke practically reaches the height given by the above formula, but is thereafter dispersed in the atmosphere in a highly variable manner, according to meteorological conditions. The two conditions of smoke production which are most important are, on the one hand, the diffusion system, in which it has the shape of a horizontal axis cone and disperses rapidly in the atmosphere and, on the other hand the temperature gradient inversion system with which the smoke remains horizontal without being dispersed in any perceptible way.

Unde the first system, the ground activity was computed by means of Sutton's formula, allowing for the radioactive decay of argon.

In the second case, it is computed by assuming the smoke to be a horizontal linear source and allowing for the absortion of rays by the layers of air through which it travels.

We found that the activity was maximum at the ground in the diffusion system, and we computed the stack size allowing for the results of the blower tests, in such a way that this activity would remain under the population dose at all times.

In order to obtain this efficient superelevation of the smoke plume, we brought the rate of air flow out of the stack up to 34,000 m^3/hr by blowing 11,500 m^3/hr of cool air at the base of it. This solution was more economical, from the power consumption standpoint, than the one whereby the velocity of output of the air from the chimney is increased.

We thus obtain a stack diameter of 0.65 m. and an outside velocity of 28.5 m/s. Indeed the additional fan would be placed in service only if the activity measurements made on location showed that it was necessary.

VIII-BORON SHIELDS

1. Object and principle.-

It often happens that it is necessary to achieve, in the experimental devices of a laboratory reactor, some shields which give good protection against thermal neutrons while activating themselves as little as possible in order to facilitate subsequent manipulations and avoid producing secondary rays.

It is necessary that the screen be equipped with a cooling system in order to remove the heat produced by neutron absorption.

We achieved such shields, which are made as follows: They are cast in aluminum boxes and, starting at the face exposed to the neutrons, consists of the following: a thin piece of aluminum sheet; a thin layer of bismuth, a plate of sintered boron approximately 10 millimeters thick; **bismuth, in which is embedded a stainless steel coild 10 x 12 millimeters diameter is provided to insure cooling by means of de-ionized water.**

In the case where there is no fear of secondary emission, it is possible advantageously to replace the bismuth by lead, for it is much easier to use.

2 - $1m^3$ cavity shields

As indicated in paragraph B II 7.4 above, the two stacks for the $1m^3$ cavity having a cross section of 550 x 750 millimeters and a height of 705 millimeters, have their side walls covered with boron and bismuth shields. Figure D.7 gives a perspective view of one of these shields. We will note that the A.5 aluminum jacket, of a comparatively complicated form, has a thickness of 5 millimeters.

It is difficult to make such a shield, particularly if it is necessary to achieve good contact between sintered boron and bismuth in order to have a good heat remover. On the other hand the pouring of the bismuth causes changes in the shape of the aluminum mold, which must be provided for and kept within permissible limits.

IX-MACHINING OF GRAPHITE

We gave, in paragraph B II 3 above, a description of the graphite pile. We must remember that, in addition to the hole provided for the tank and that of the tangiential and secant channels, the graphite is also pierced for passing the linings of the radial horizontal channels, larger diameter vertical channels, isotope channels, pneumatic channels, and the channel for irradiation in a γ free atmosphere.

The graphite block is difficult to machine. As the holes necessary for the keying of the beds between blocks have to be considered. It has been made as follows:

In the first place, the bricks have been machined on their four sides, to match the flats on the lateral face of the graphite blocks, to a precision of about 0.05 mm.

Thereafter, the graphite was piled up 3 to 4 beds at a time on the plate of a machine of the reamer-surfacer type, specially designed for the purpose, in order to machine the tank hole and all vertical holes.

This surfacing reamer has a horizontal plate 4.2 m. in diameter, rotating at a speed of 0.5 rpm. Two fixed uprights carry a beam attached at about 1.3 meters above the plateau, on which the milling-carriage moves. This carries a slide which can be inclined to 45°, for contour machining. One of the uprights is equipped with a reaming carriage which can be moved vertically by means of a handwheel.

The semi-elliptical bottom of the tank has been machined by copying on a template, and the cylindrical part of the tank hole has been milled. The plate rotated during these two operations. The vertical holes were drilled by means of a drilling_template. The holes of the radial horizontal channels were drilled by means of the lateral-reaming carriage.

This machine, which weighs 35 tons in all (approx.) has a total height of 4.3 meters. Its width, between uprights, is 5.2 meters, and can be brought up to 7 meters.

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1958 GENEVA CONFERENCE

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D.7	Cavities $1m^3$ Screen of ground boron.

T A B L E

A - REACTOR PROGRAM

B - DESCRIPTION OR REACTOR EL.3

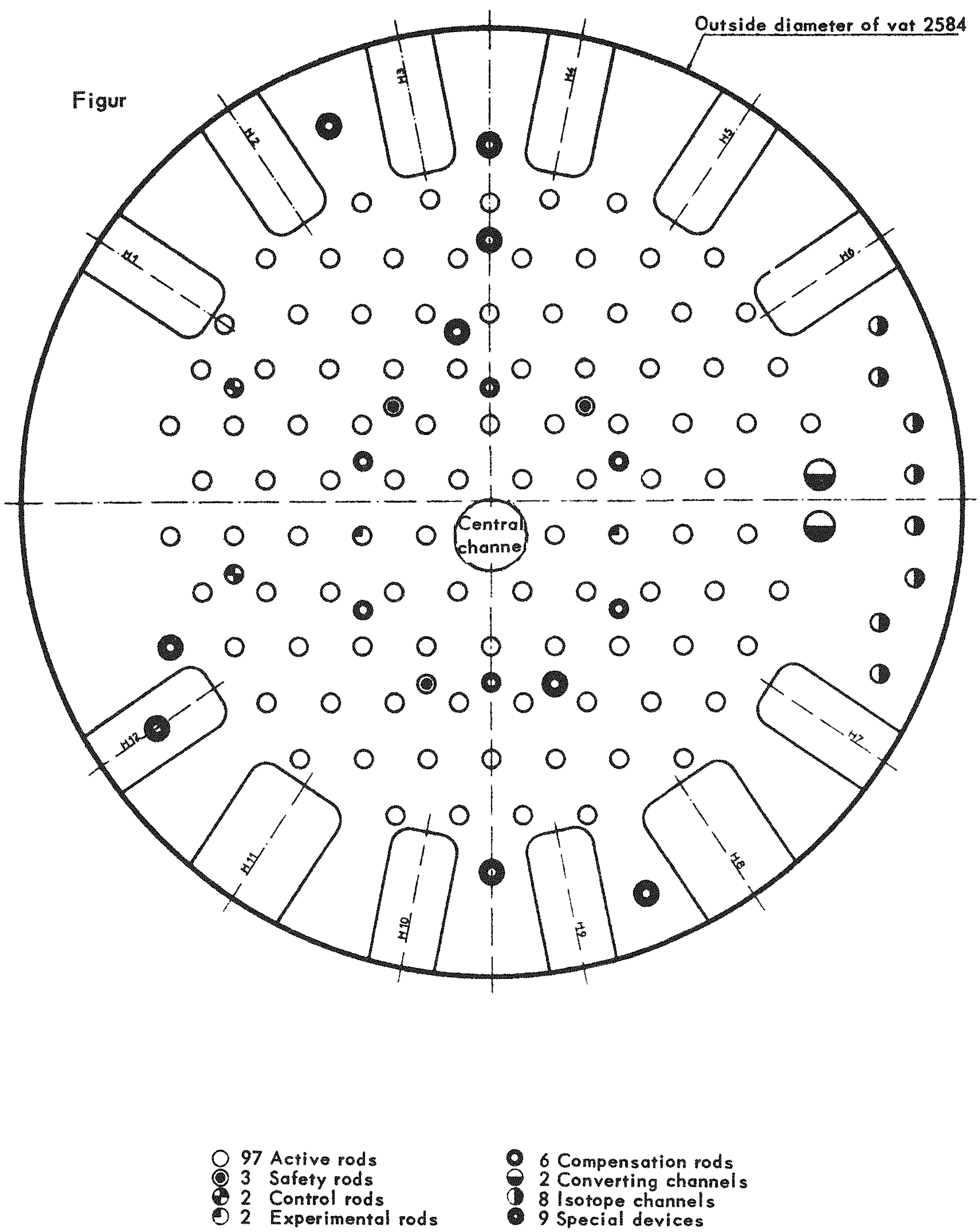


Figure: A.1 REACTOR-BLOCK

DIAGRAM OF THE LATTICE

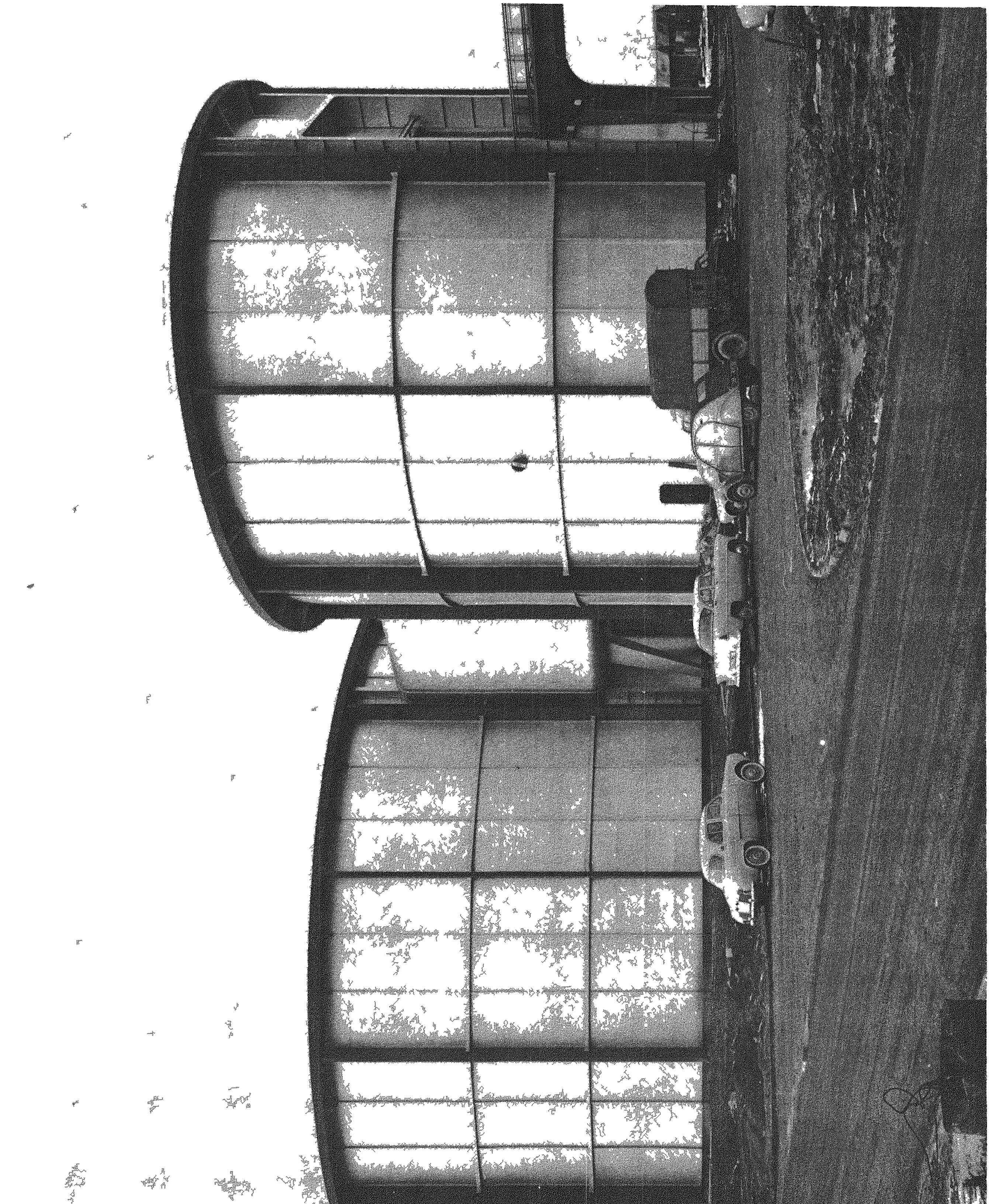


Figure B.1 OVERALL VIEW EL-3 BUILDINGS

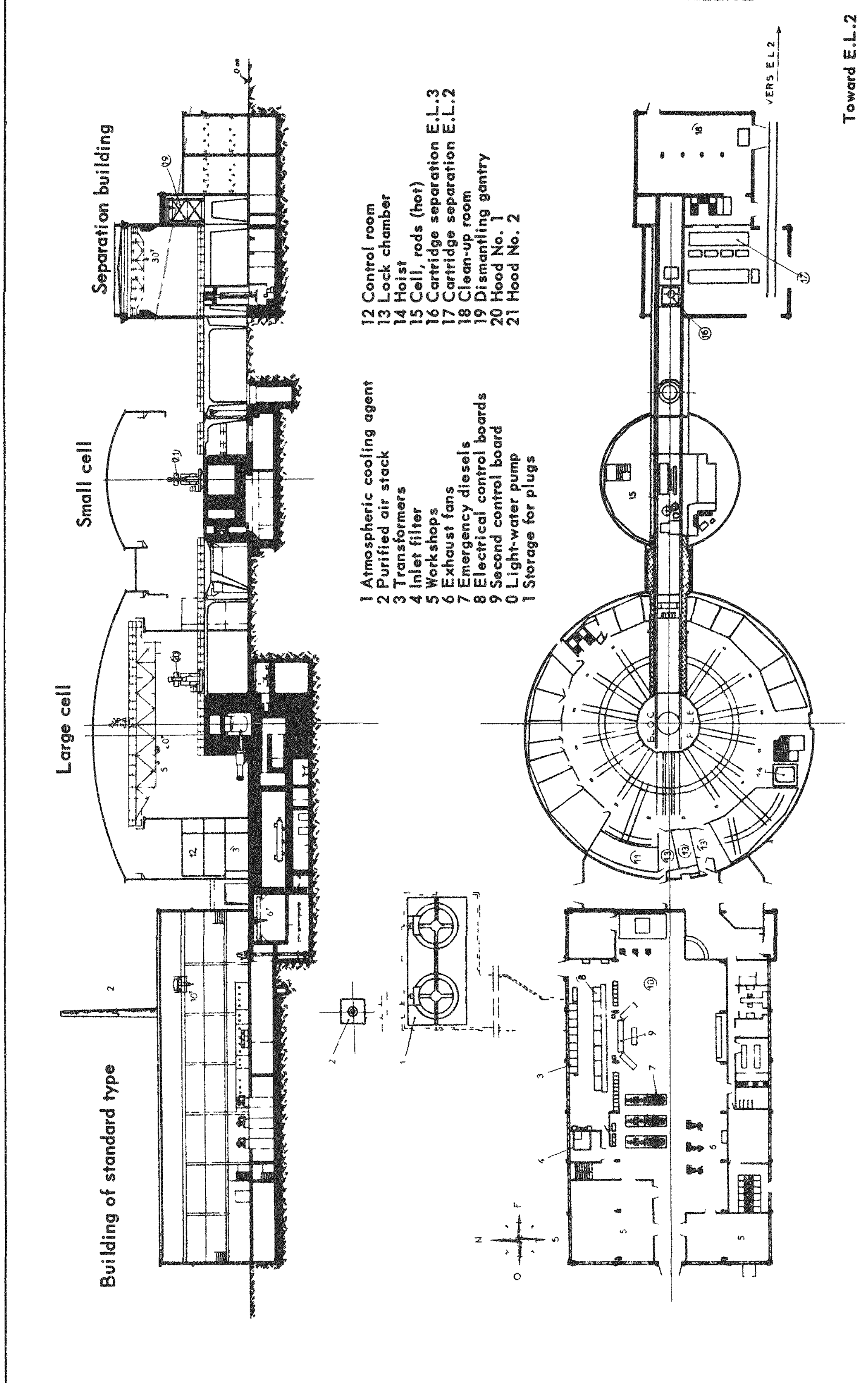


Figure B.2 E.L.3 REACTOR. LAYOUT OF THE FACILITIES

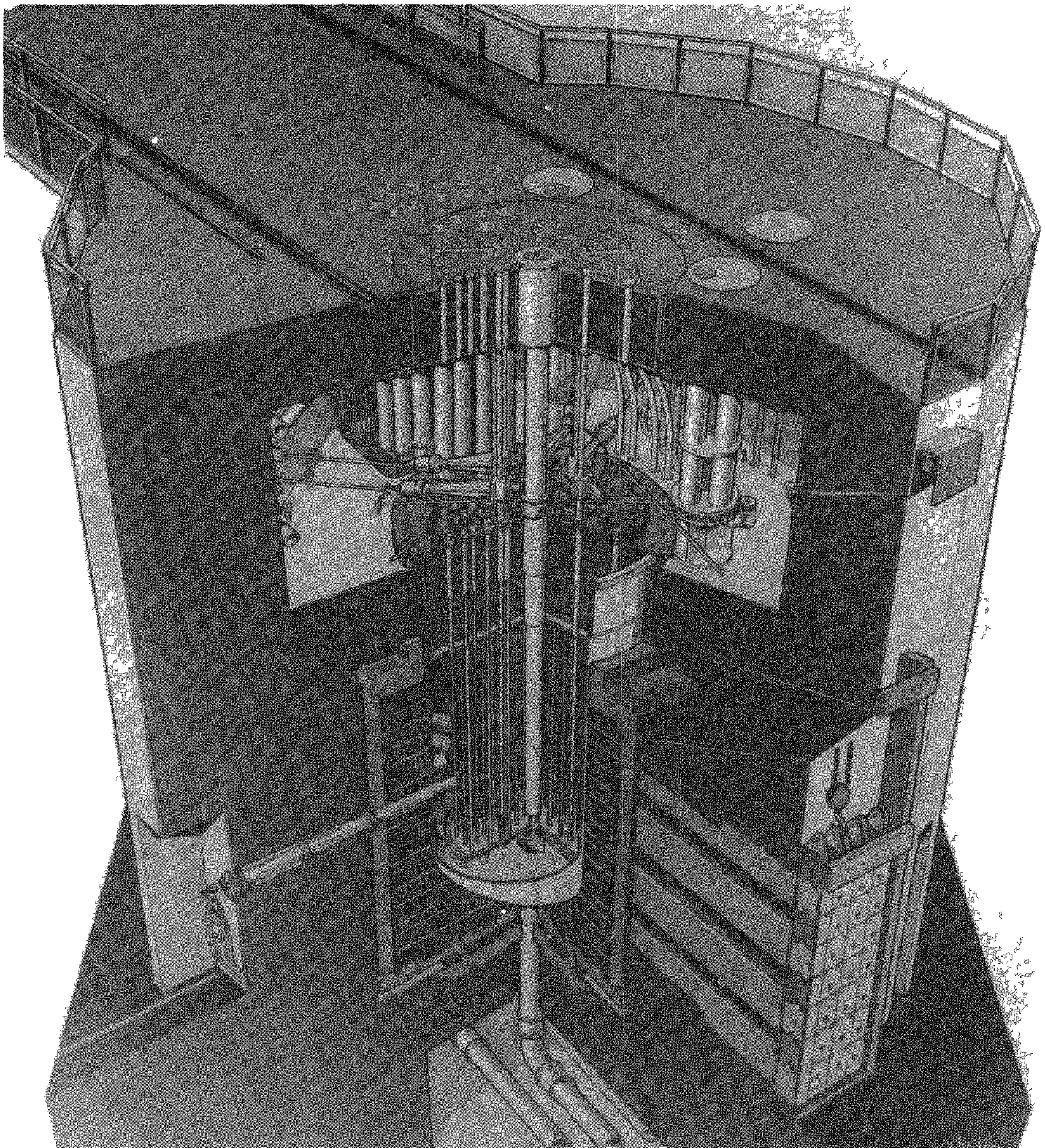
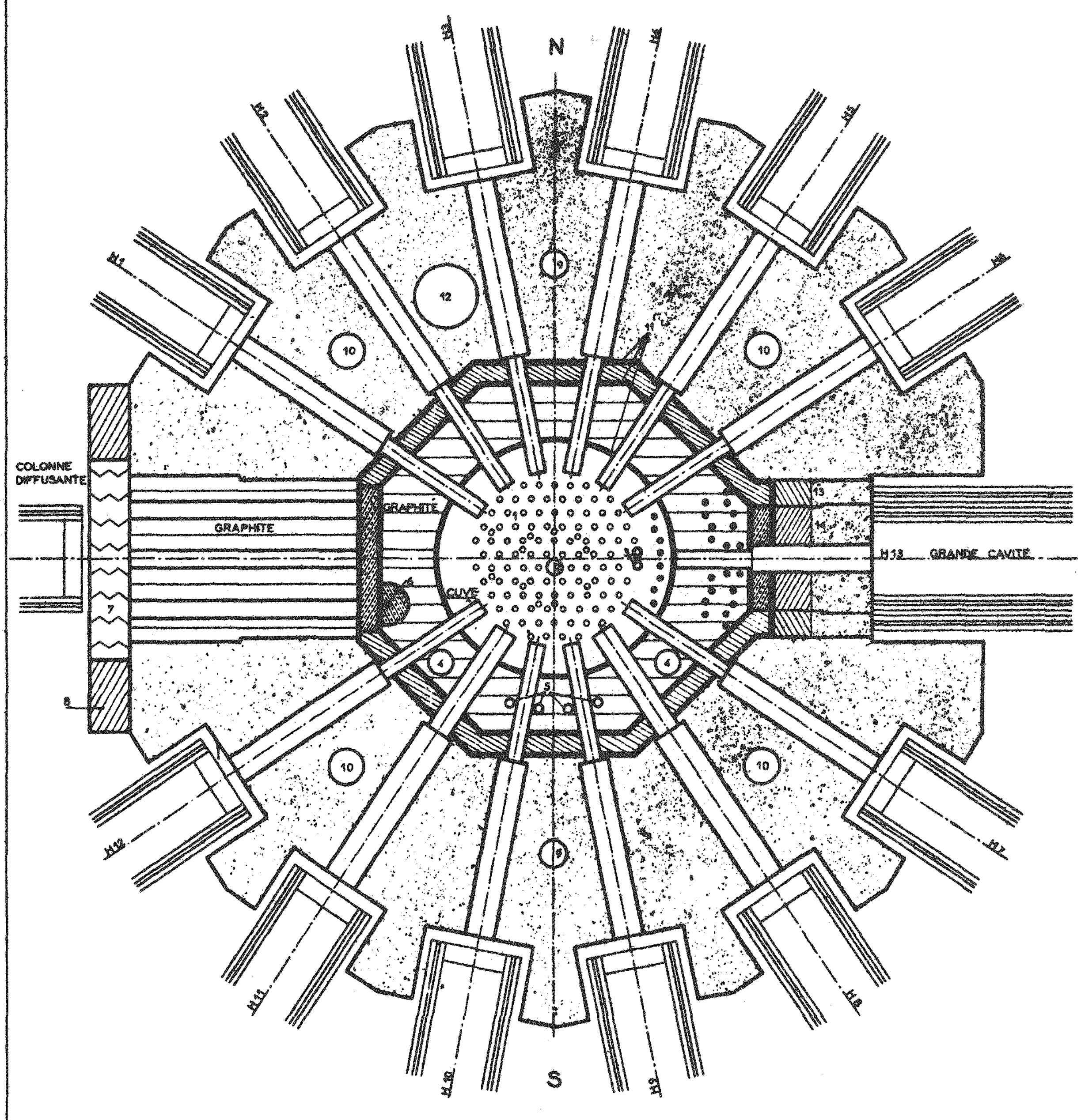


Figure B.3 SECTION OF THE REACTOR-BLOCK



Cast-iron shield
Bismuth
• Isotope channels in heavy water
• Isotope channels in graphite
1 Lattice (see figure)
2 Central channel
3 Converter channels
4 Wigner-effect channels
5 Pneumatic channels
6 Gamma-les channel
7 Movable shulters of the diffusing column
8 Lateral shield of the diffusing column
9 Vacuum
10 Secondary air intake
11 Secondary cooling
12 Vent of the pipe system
13 Ante-chamber
14 Plug

Figure B.4 REACTOR BLOCK

HORIZONTAL CROSS SECTION THROUGH THE AXIS OF THE RADIAL CHANNELS

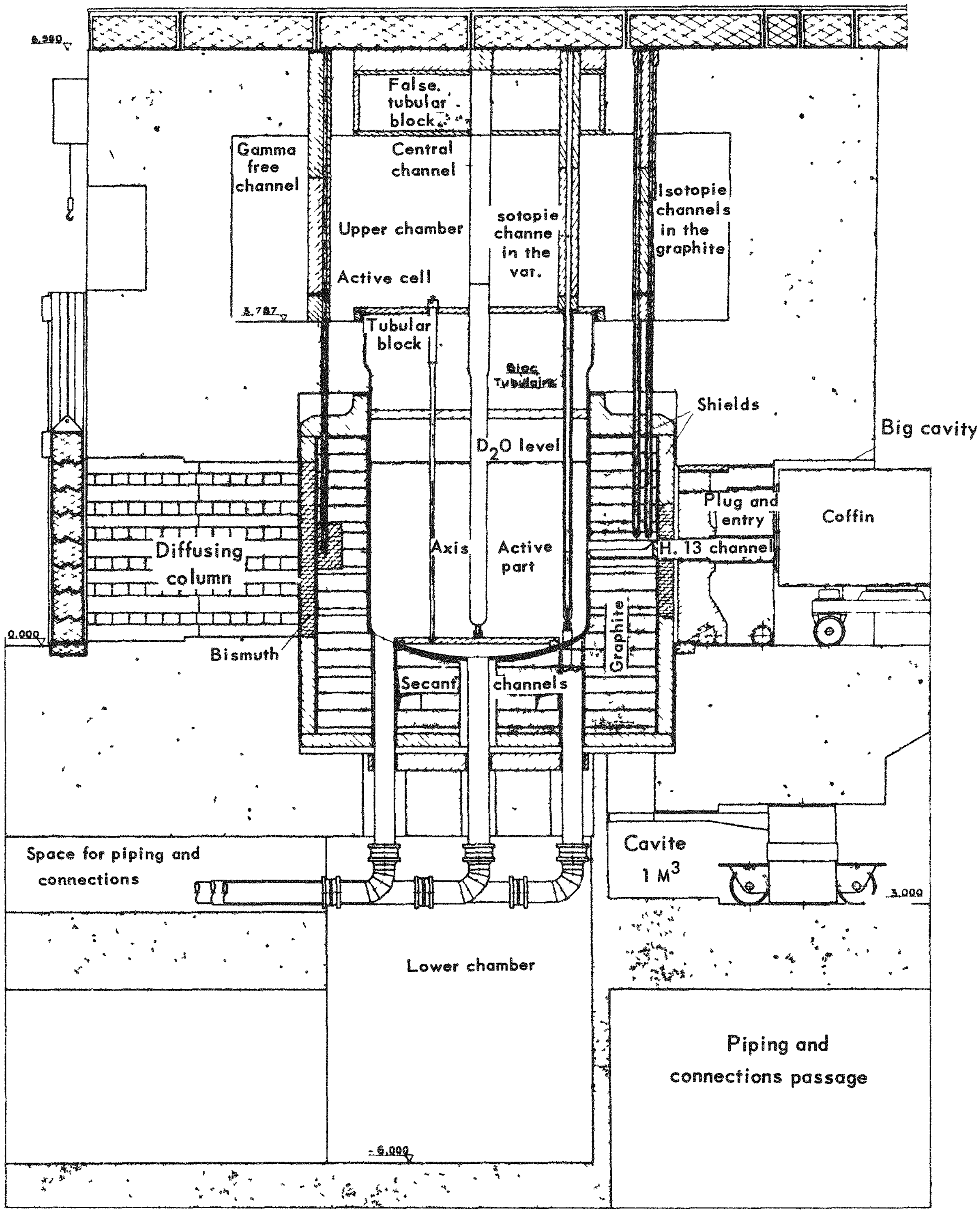


Figure B.5 - REACTOR BLOCK

VERTICAL CROSS SECTION (EAST-WEST)

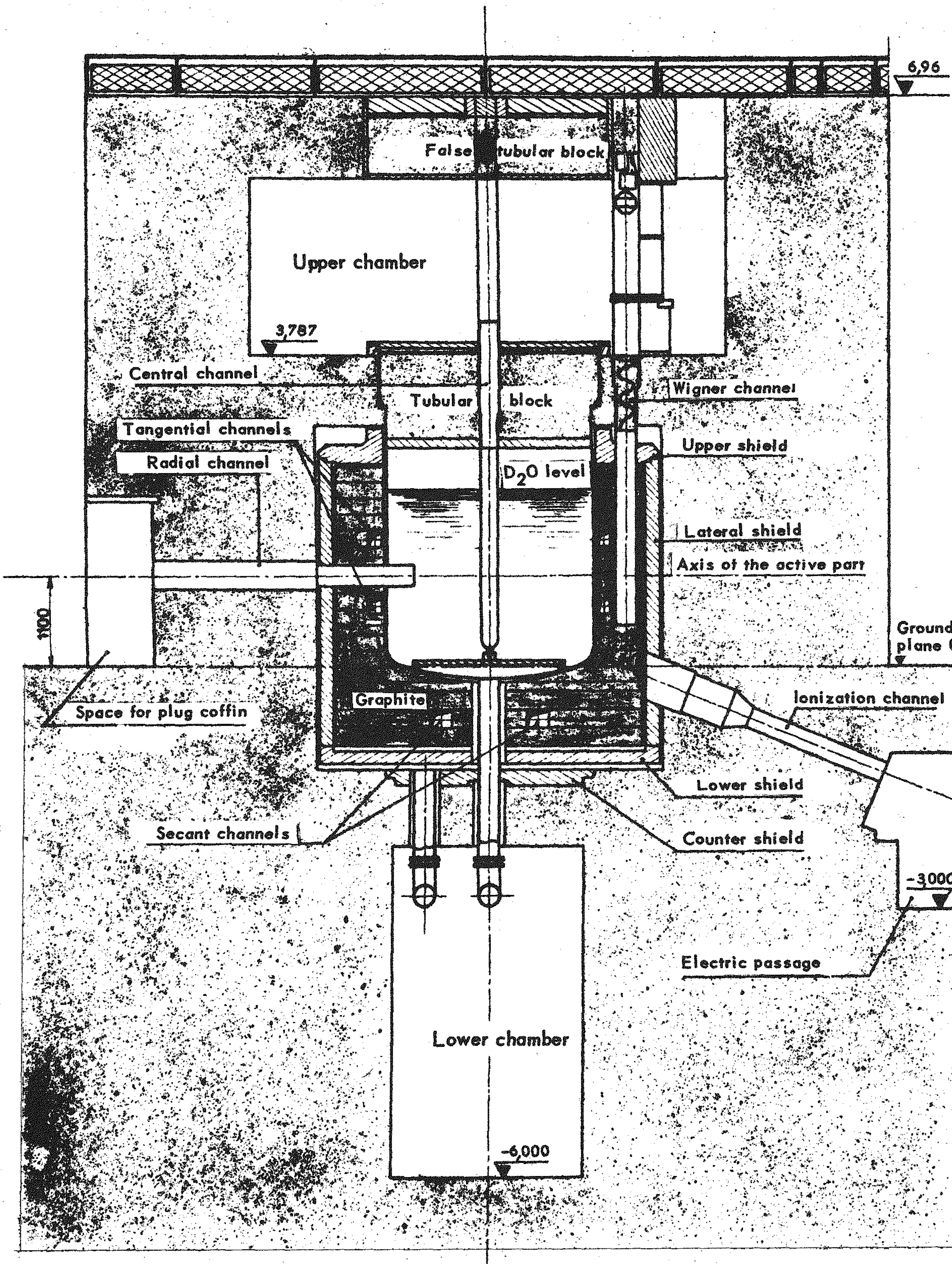


Figure B.6

REACTOR BLOCK. VERTICAL CUT (NORTH-SOUTH)

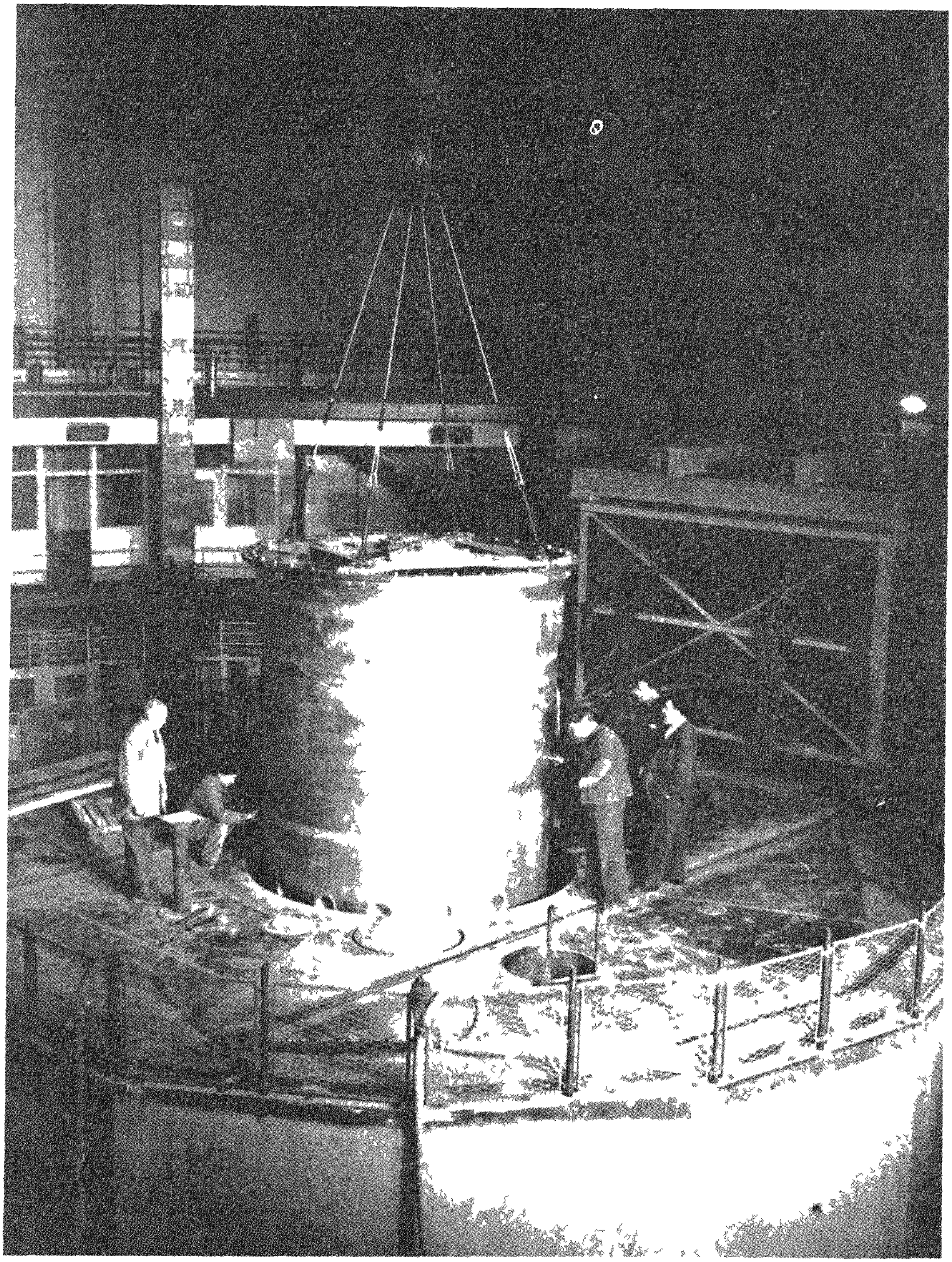


Figure B.7 INSTALLING THE TANK

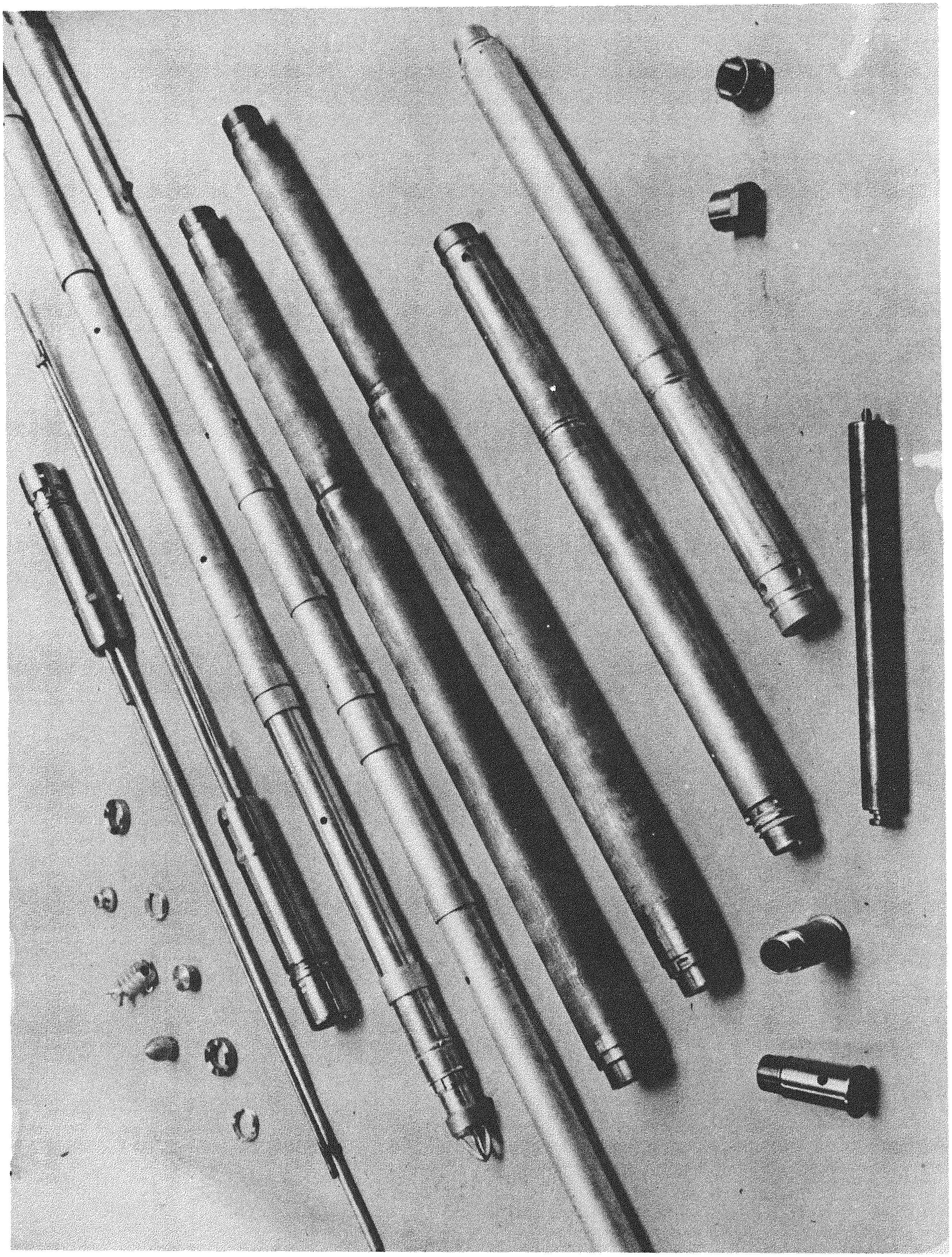


Figure B.8 ELEMENTS OF THE CELL OR FUEL ASSEMBLY

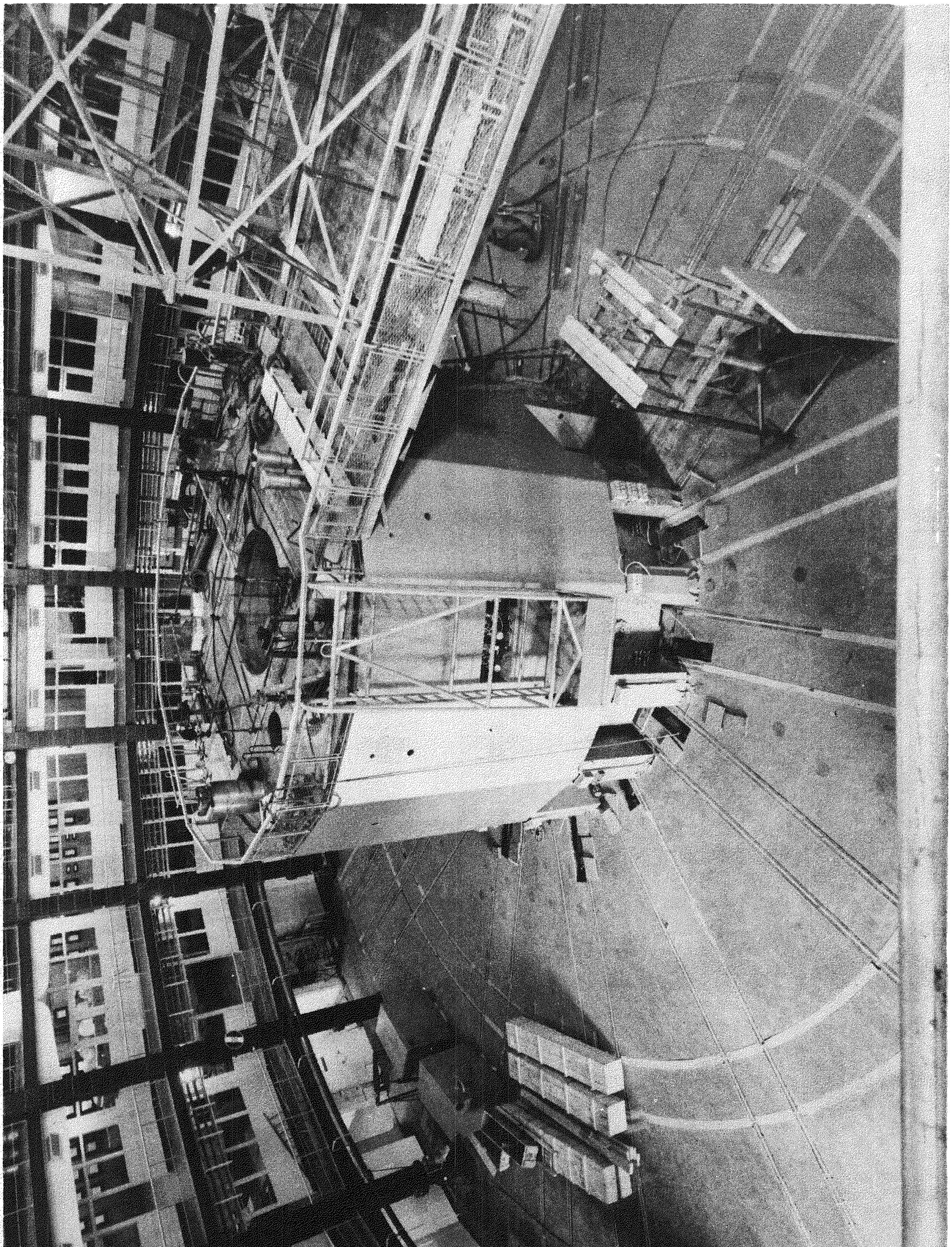


Figure B.9 GENERAL VIEW OF THE REACTOR ROOM

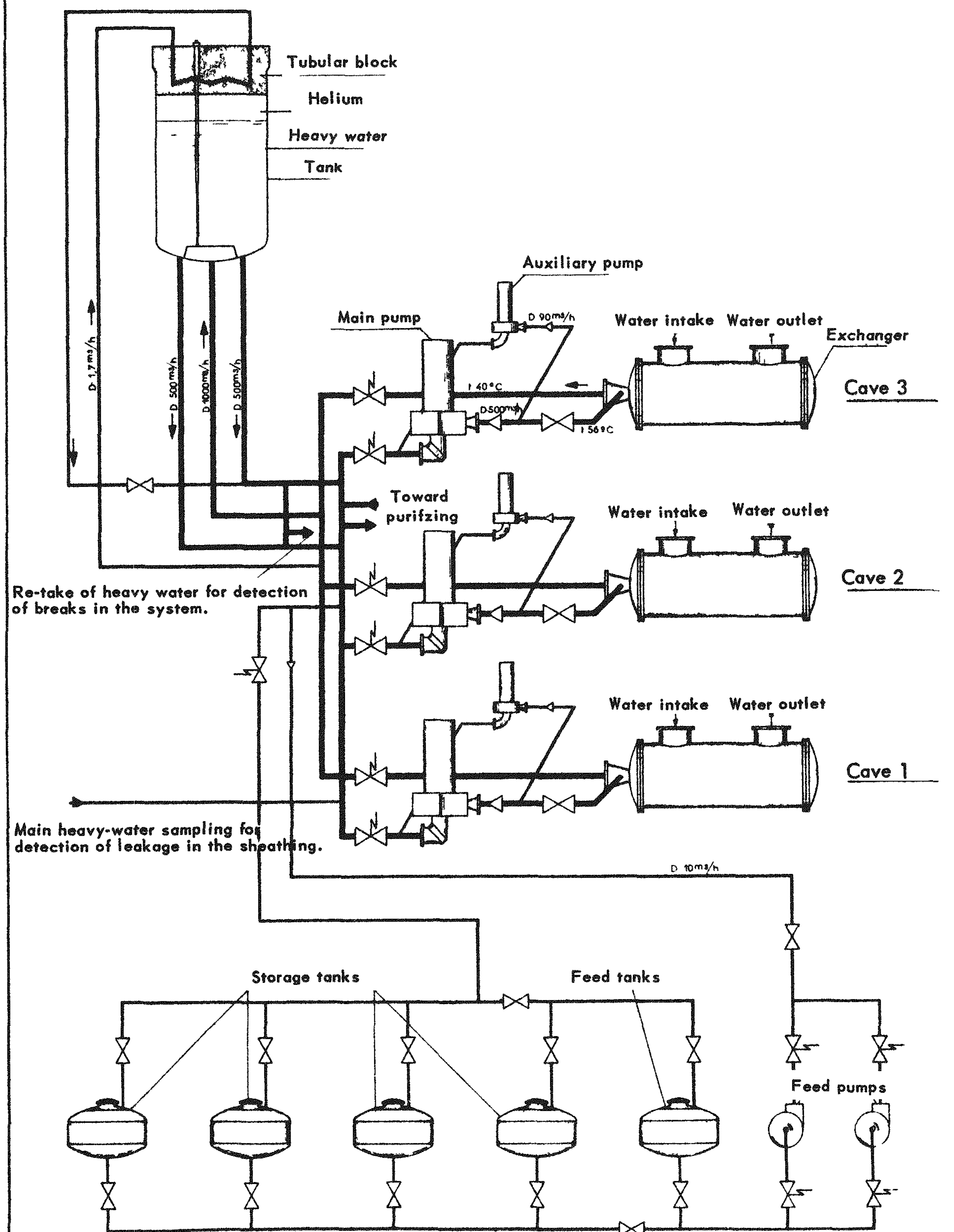


Figure B.10 HEAVY-WATER CIRCUITS
MAIN CIRCUIT DIAGRAM

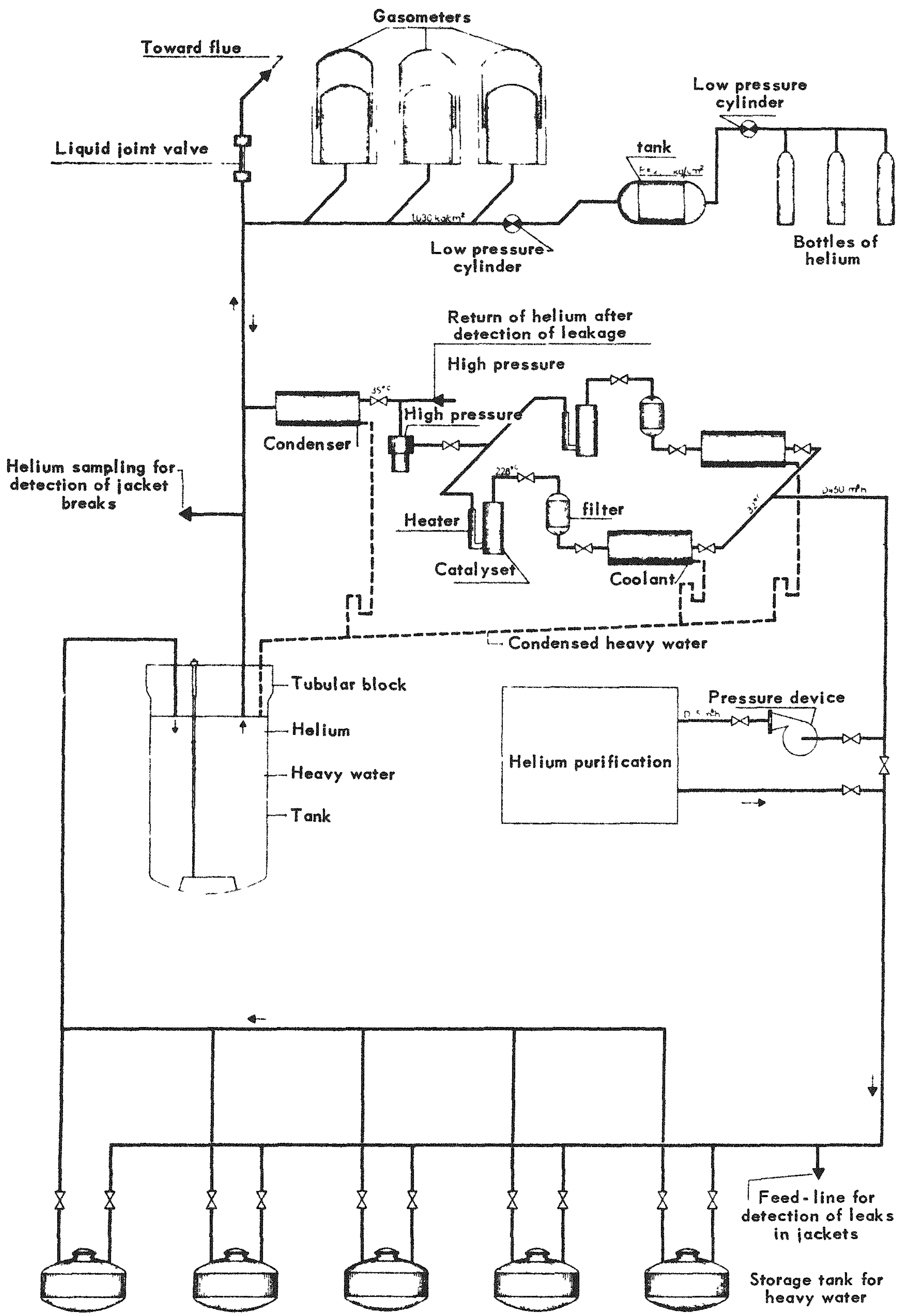
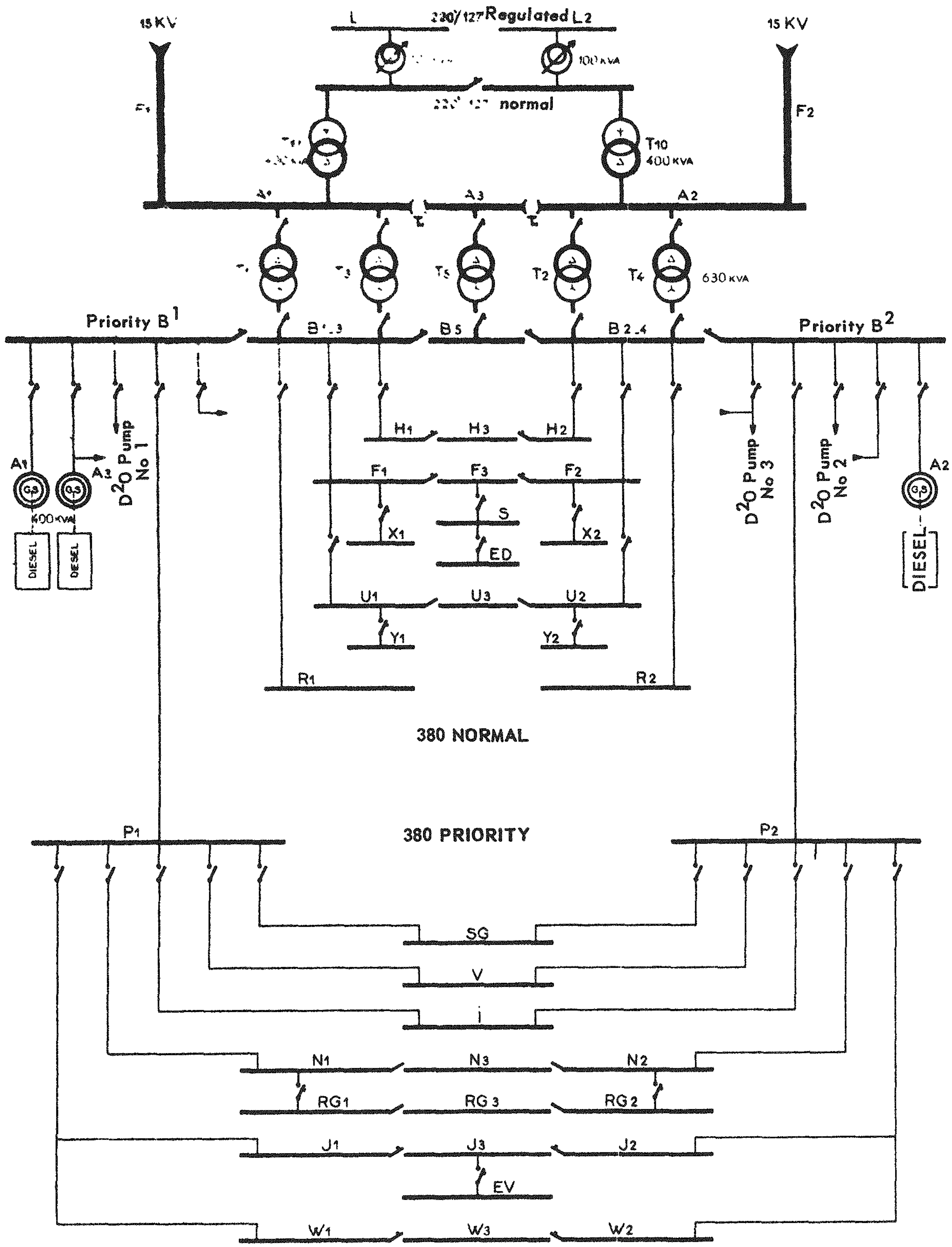


Figure B.11 HEAVY WATER CIRCUITS
RE-COMBINATION SCHEMATIC



SCHEMATIC OF ELECTRICAL DISTRIBUTION
Figure B.12

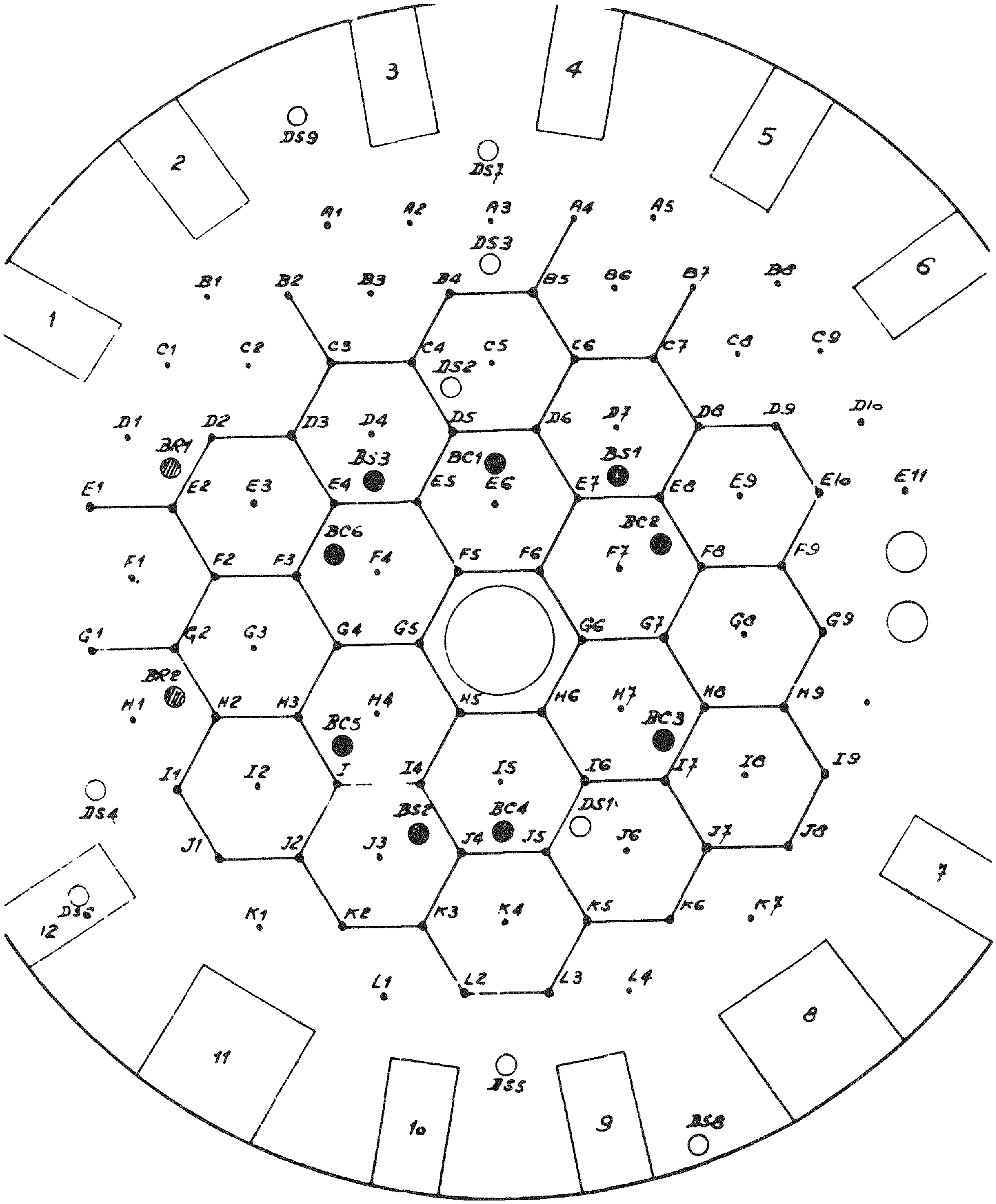


Figure C.1

Median horizontal cut of the reactor. The location of the uranium rods has been indicated by labels AL to L 4

- Special irradiation devices : DS 1 to 8
- Compensation rods : BC 1 to 6
- Safety rods : BS 1 to 3
- Control or trim rods : BR 1 and 2

as well as the channels, shown as shaded.
We have presented the units of an h lattice, used for experiments at low powers. The h c lattice is obtained by placing a rod in the center of each hexagon.

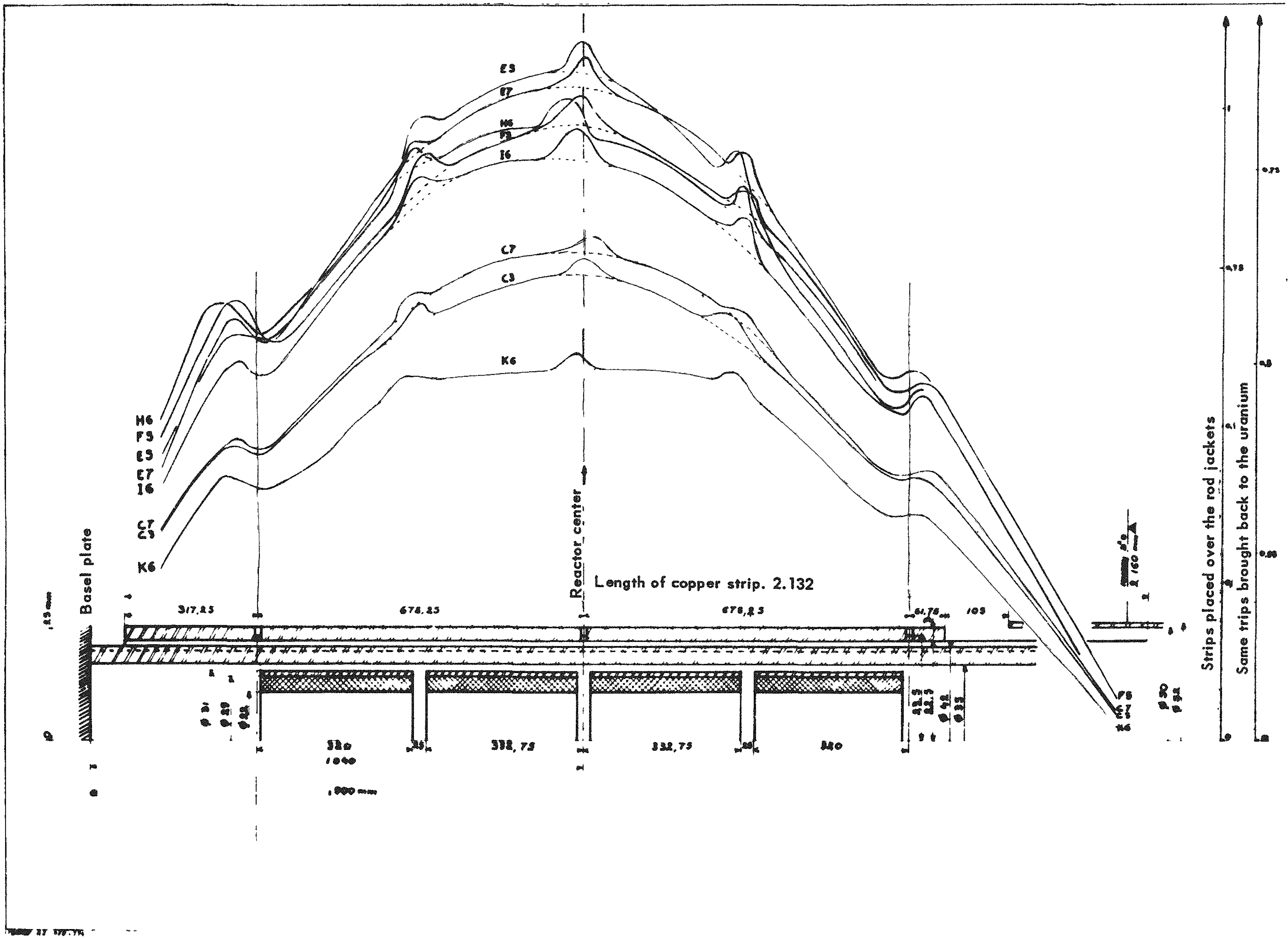


Figure C.2
Reactor h
Axial distribution of the flux along the rod jackets

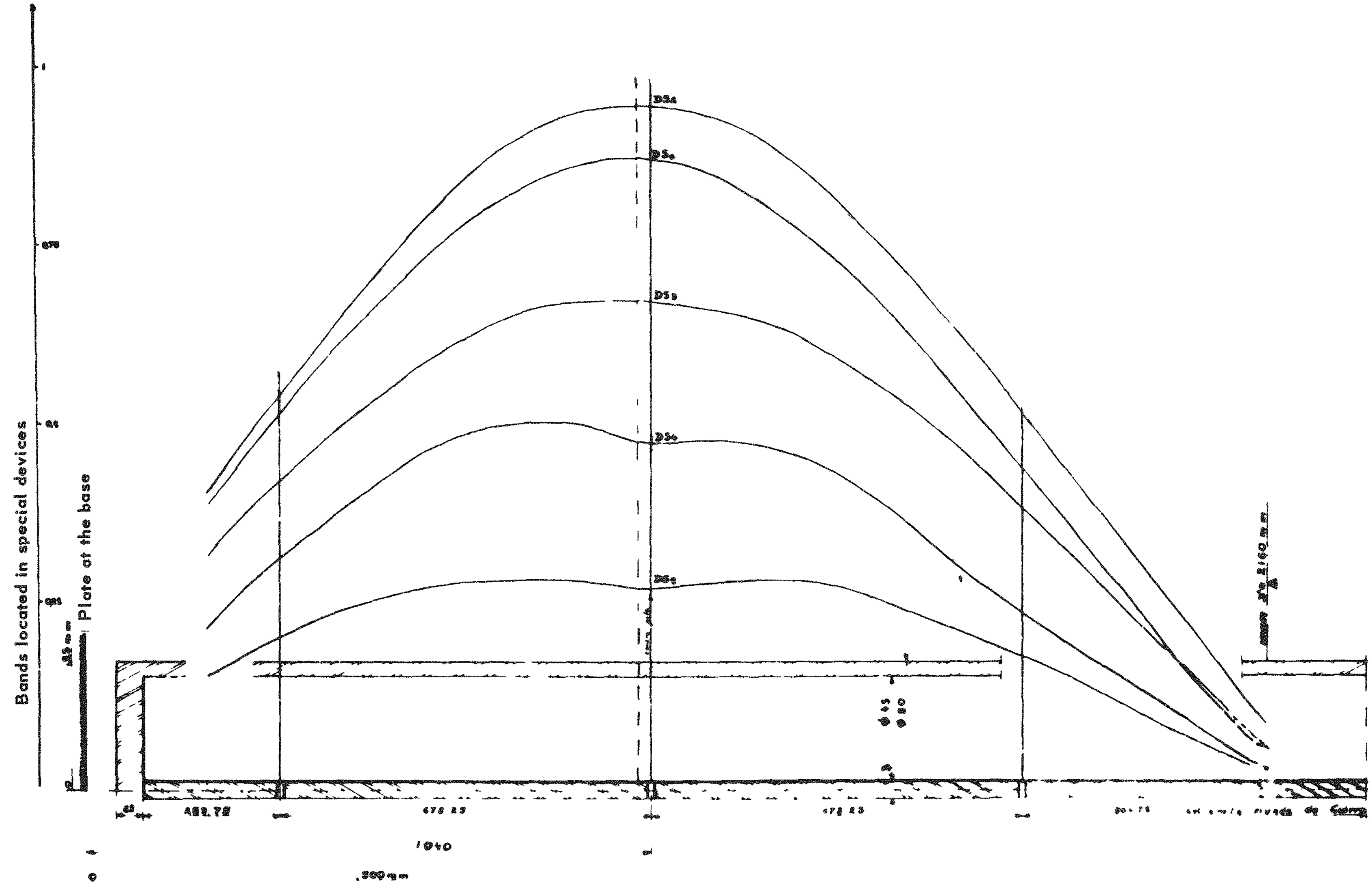


Figure C.2 B

h. reactor

Axial distribution of the flux in the special devices

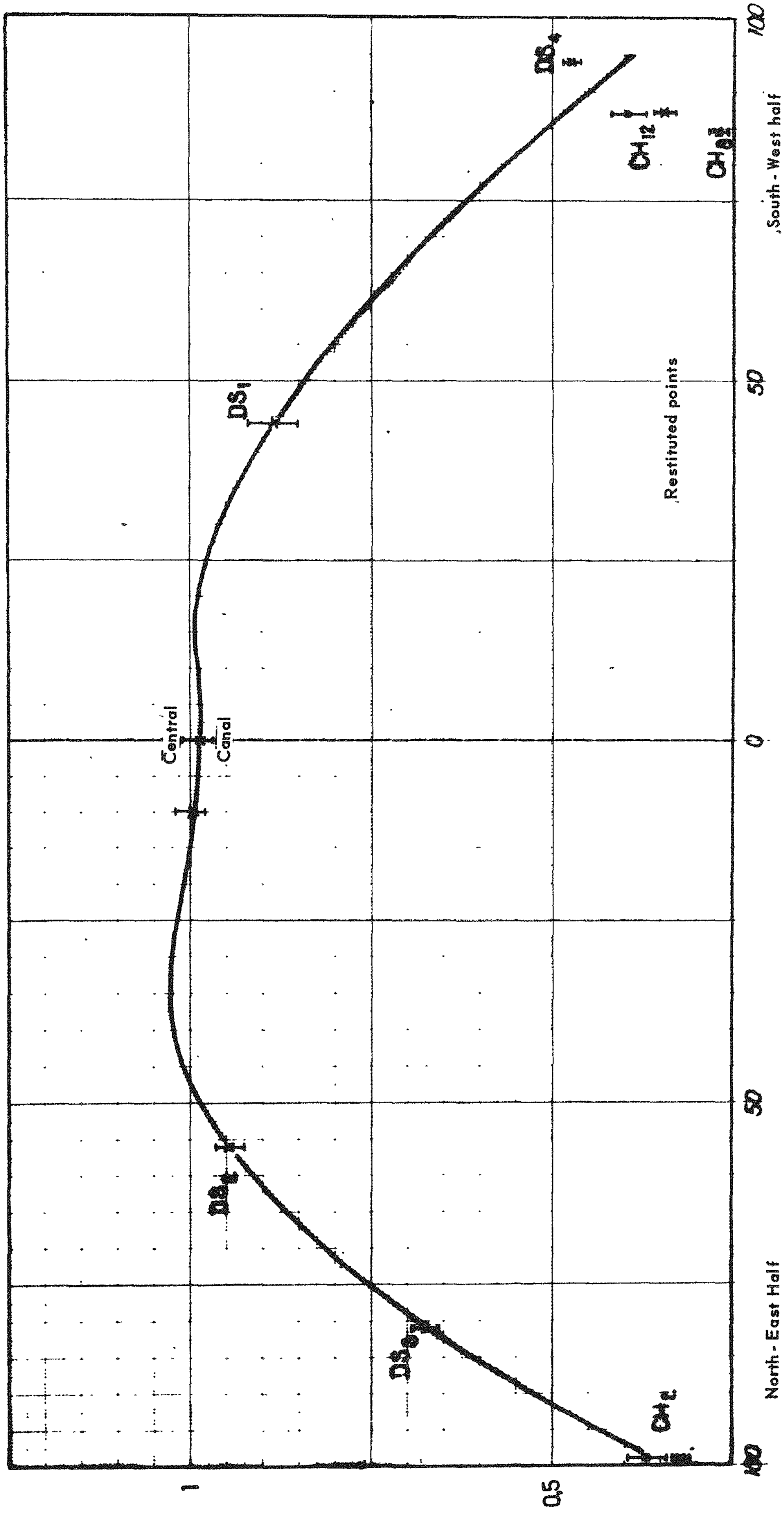


Figure C. 3
h reactor
Radial distribution of flux. Measuring points in the special device and radial channels

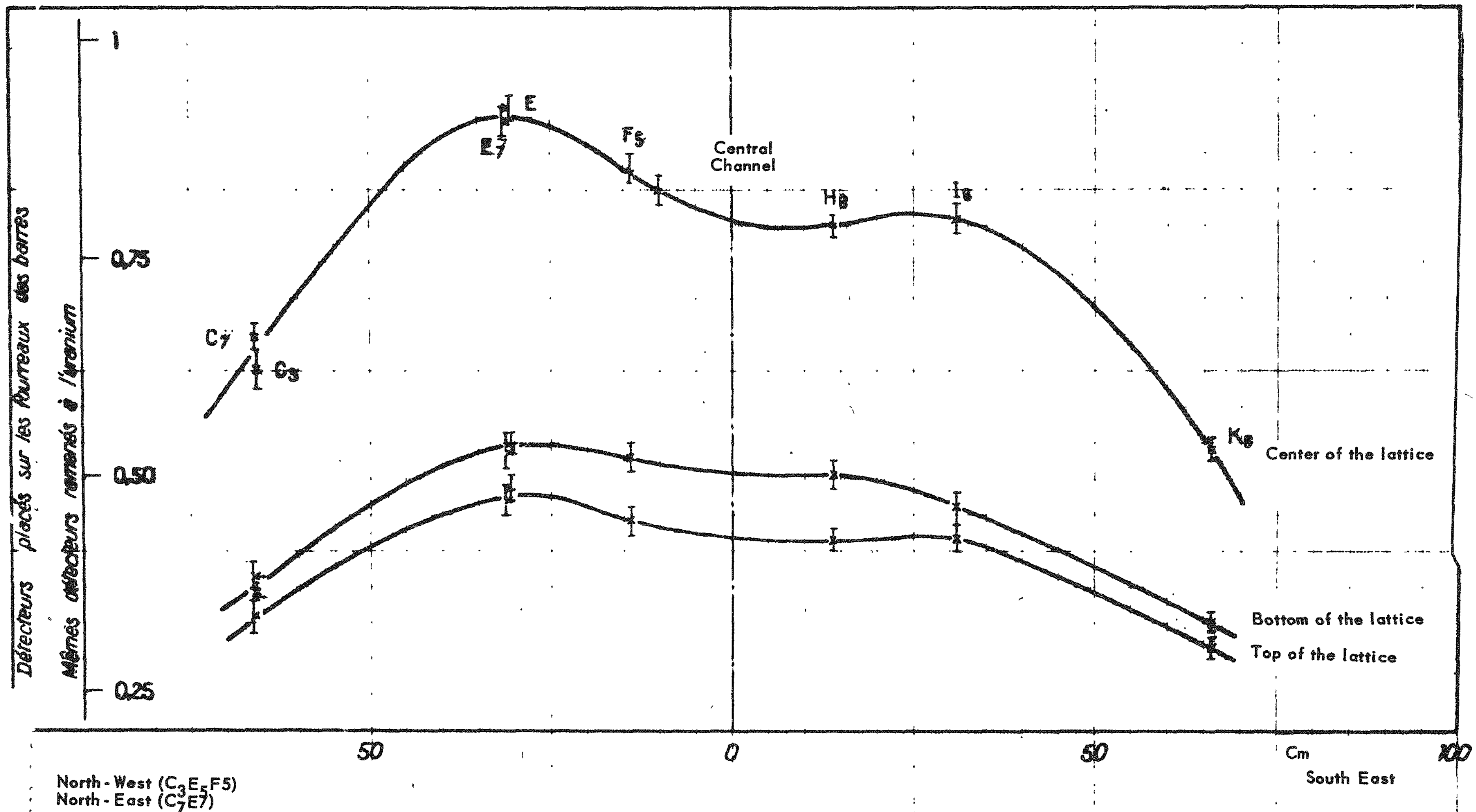


Figure C.3.B

h reactor

Radial distribution of the flux
Datum points against the rod jackets

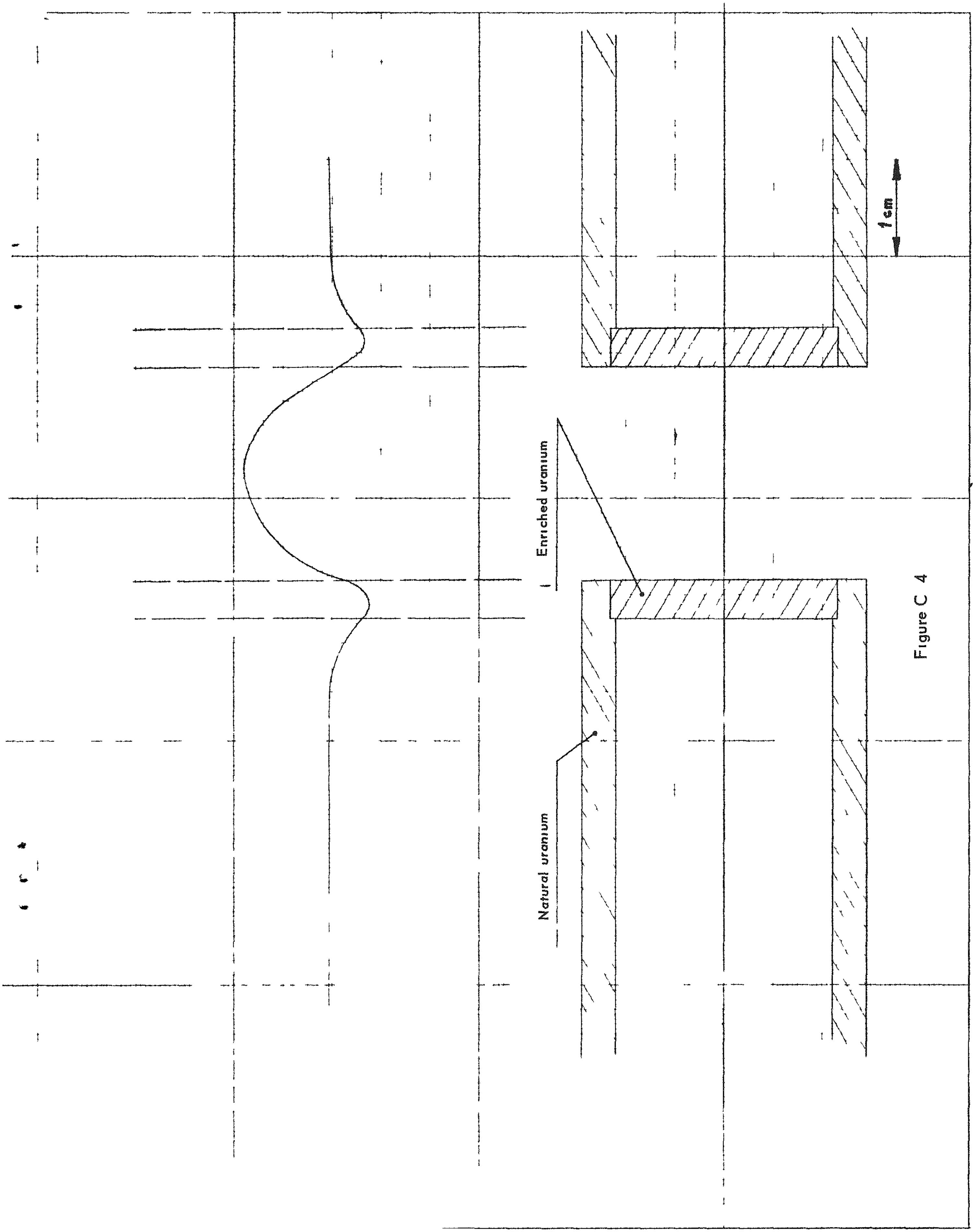


Figure C 4

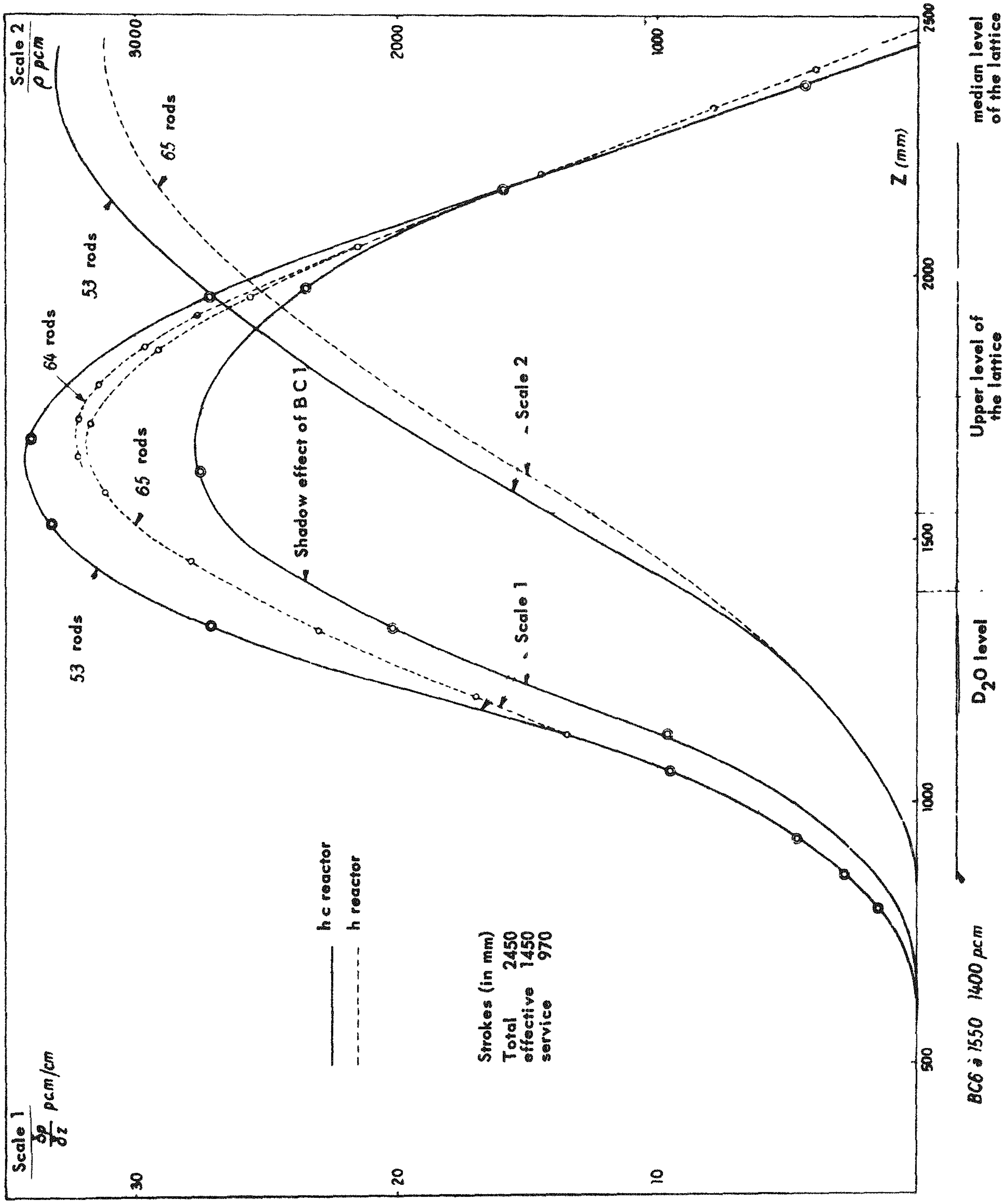


Figure C. 5

Calibration of B C 6 compensation - rod

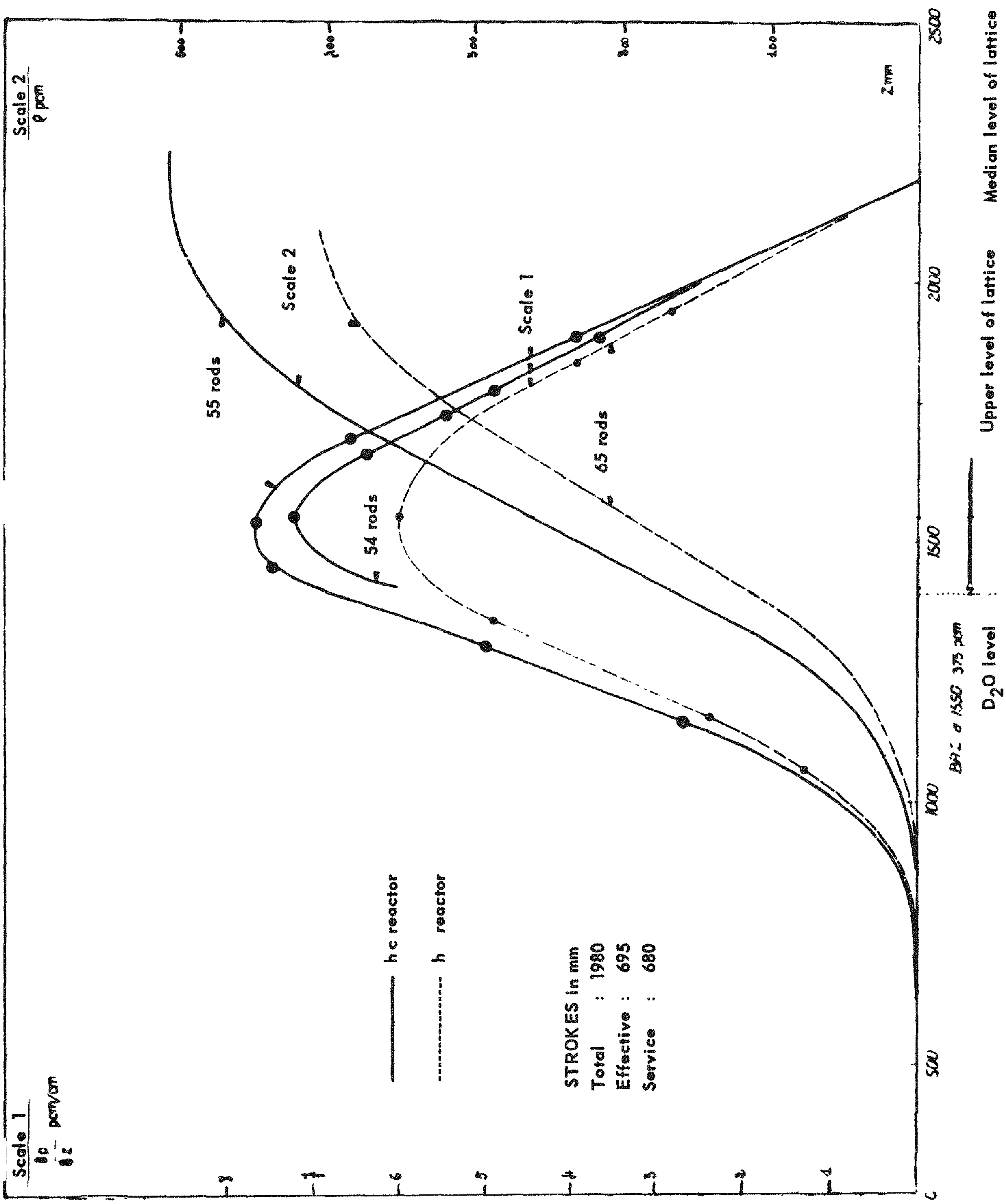


Figure C.6
Calibration of B R 2 regulating rod

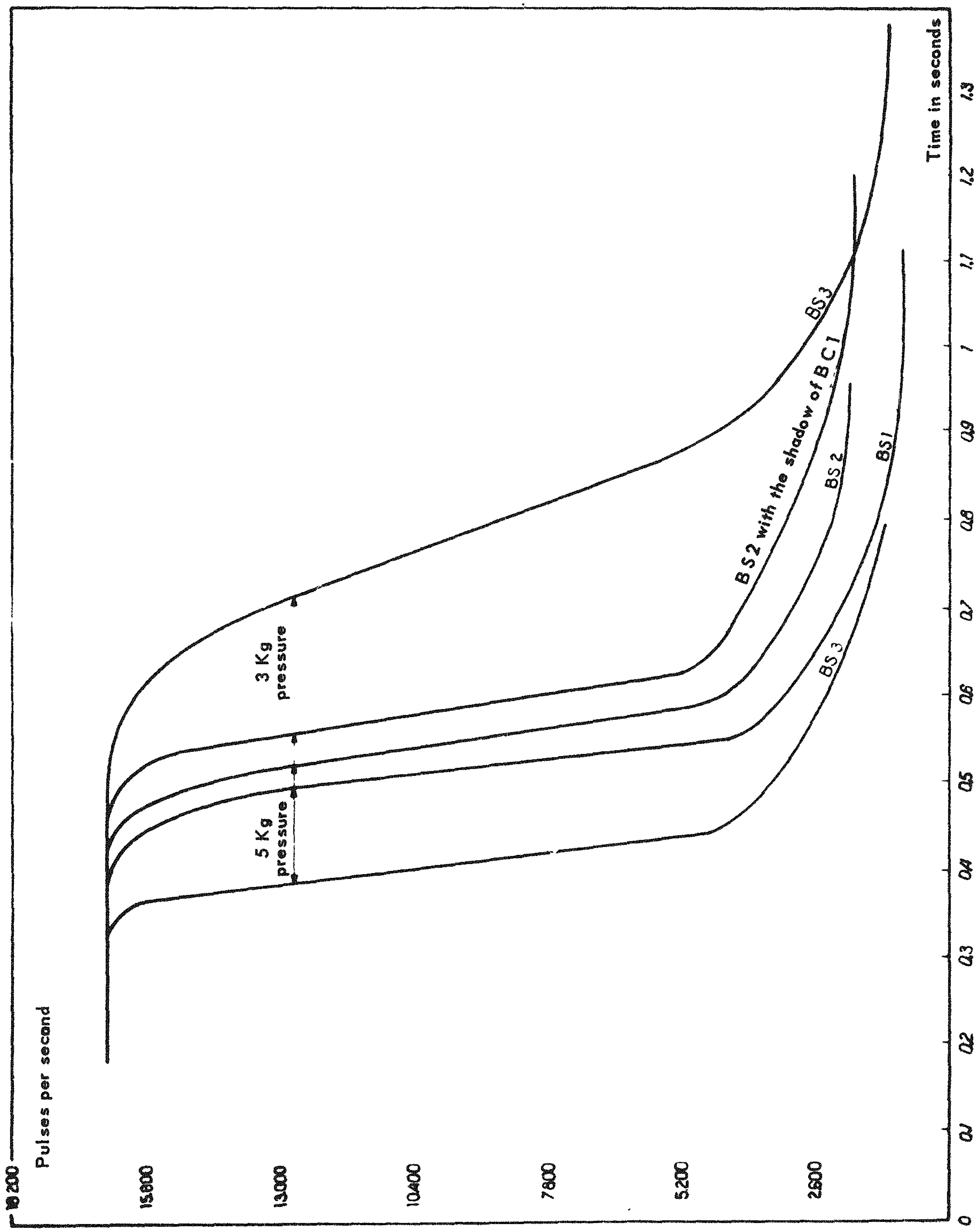


Figure C.7
The drop of the safety rods

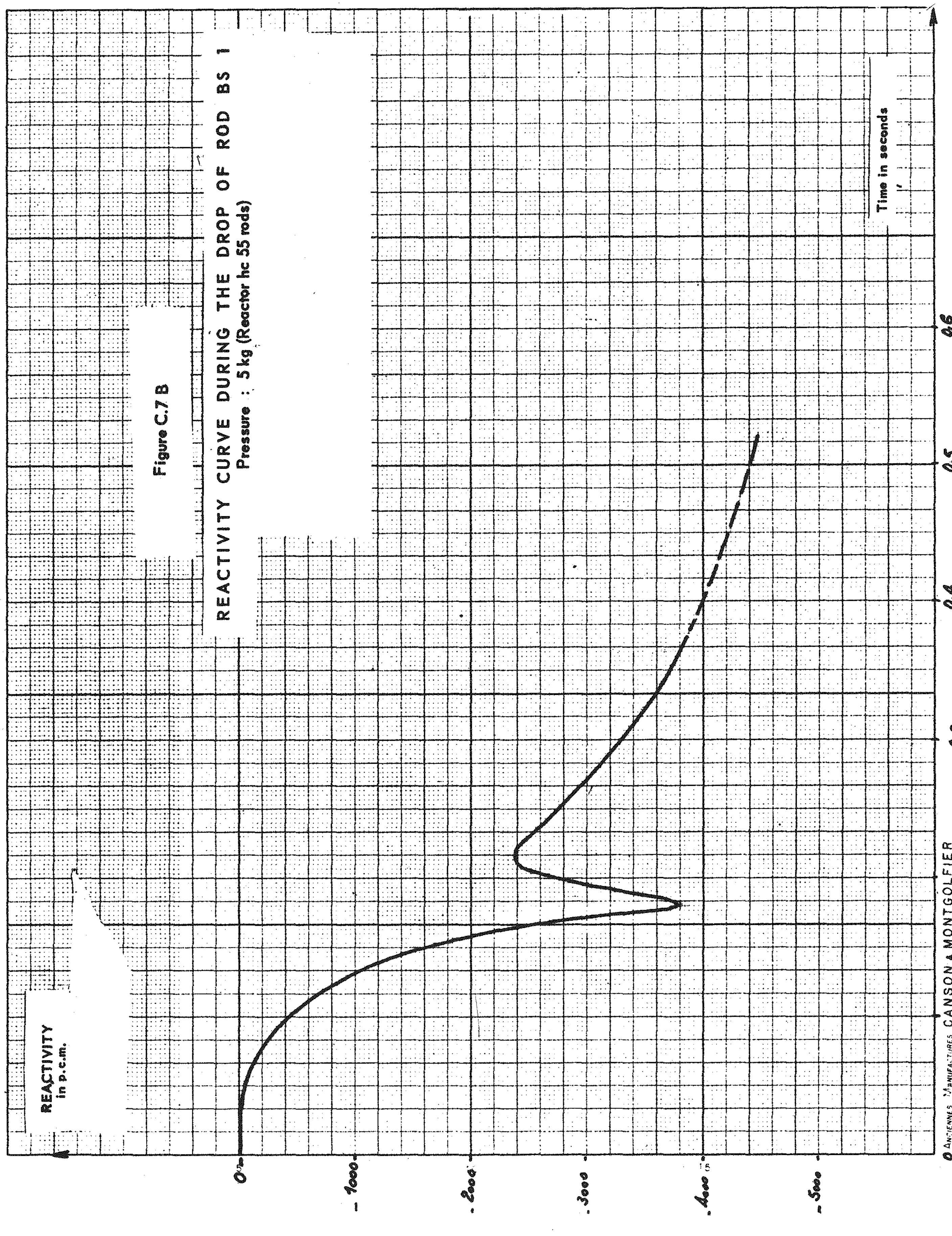


Figure C.7 B

REACTIVITY CURVE DURING THE DROP OF ROD BS 1
Pressure : 5 kg (Reactor hc 55 rods)

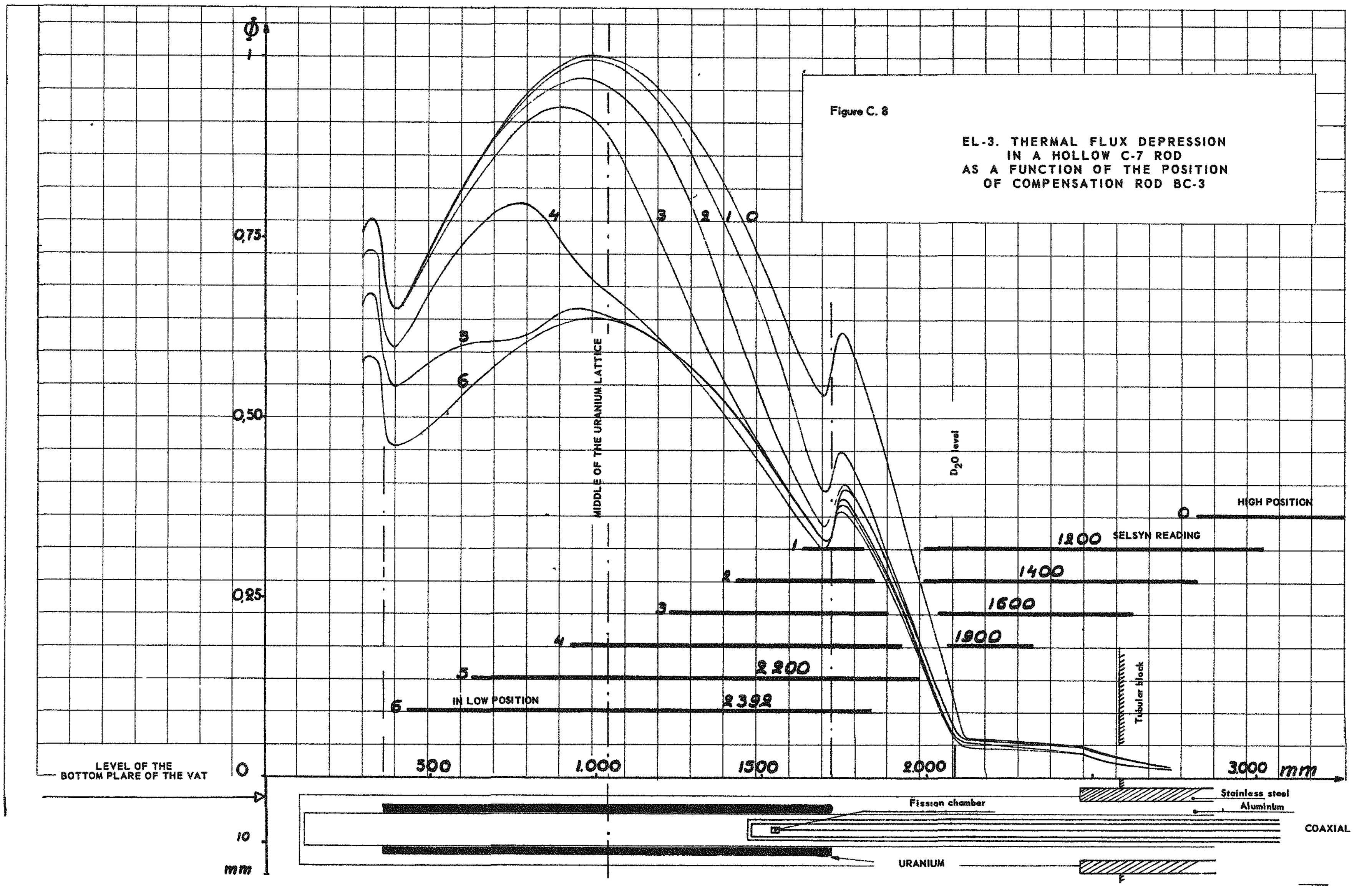
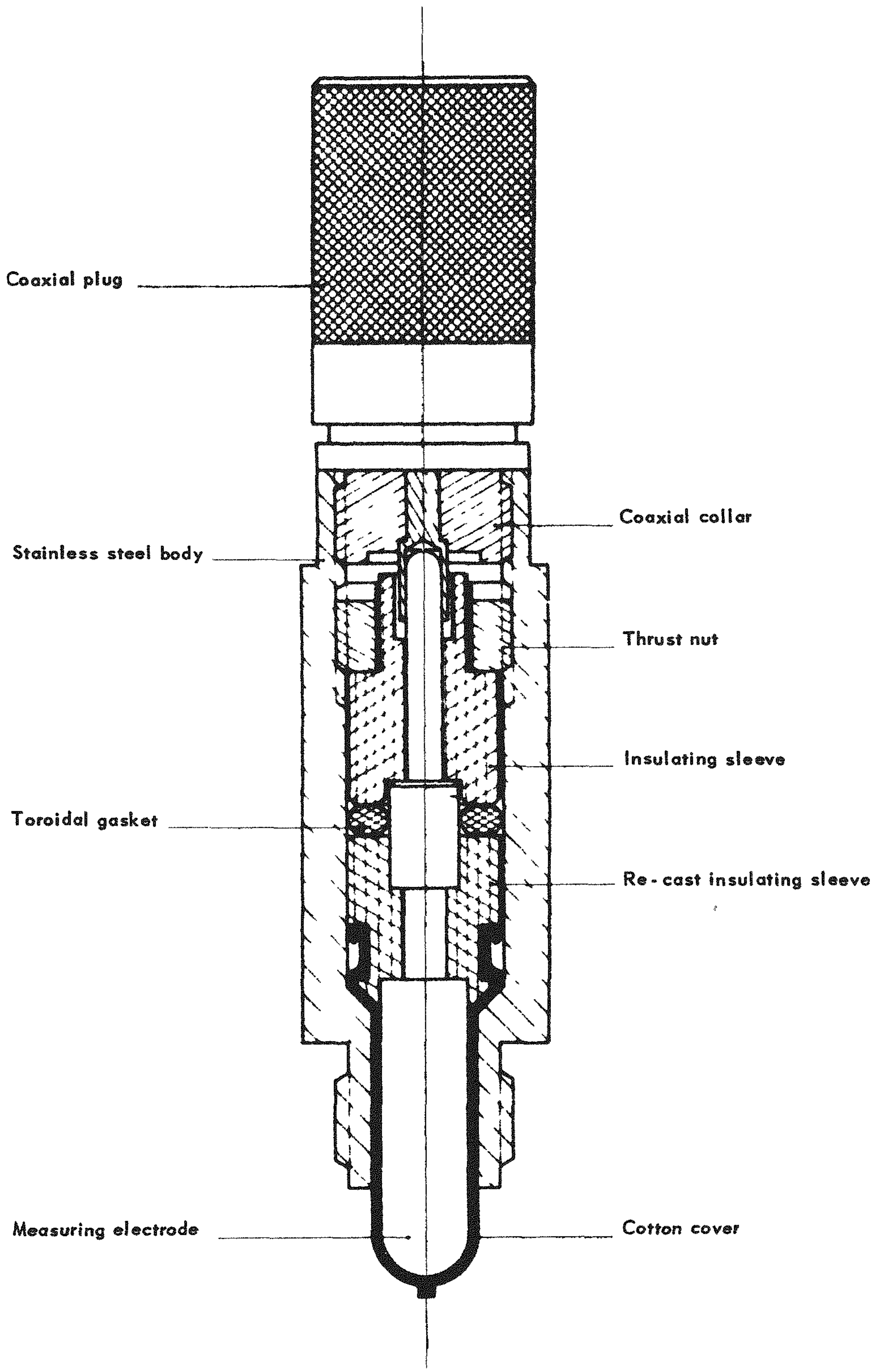


Figure C. 8

EL-3. THERMAL FLUX DEPRESSION IN A HOLLOW C-7 ROD AS A FUNCTION OF THE POSITION OF COMPENSATION ROD BC-3



LEAK DETECTOR
Figure D.1

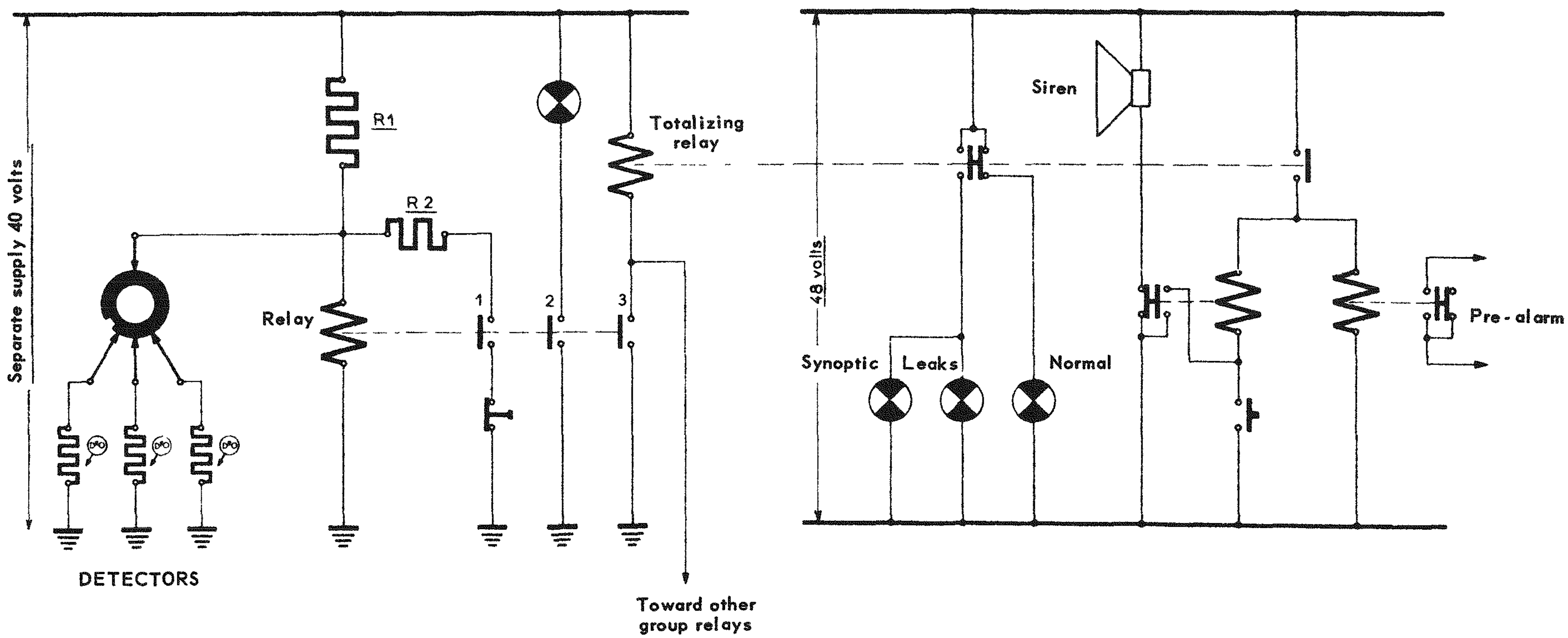
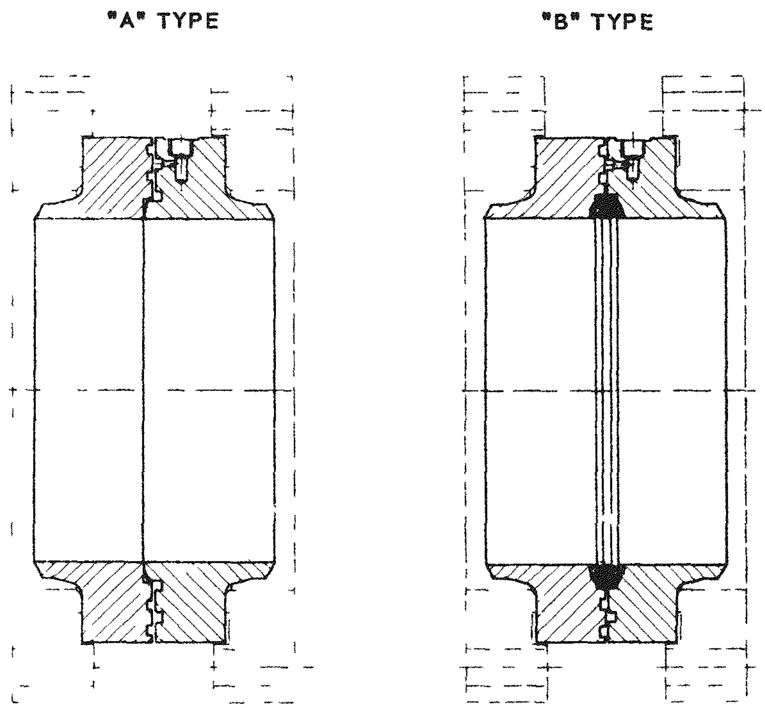
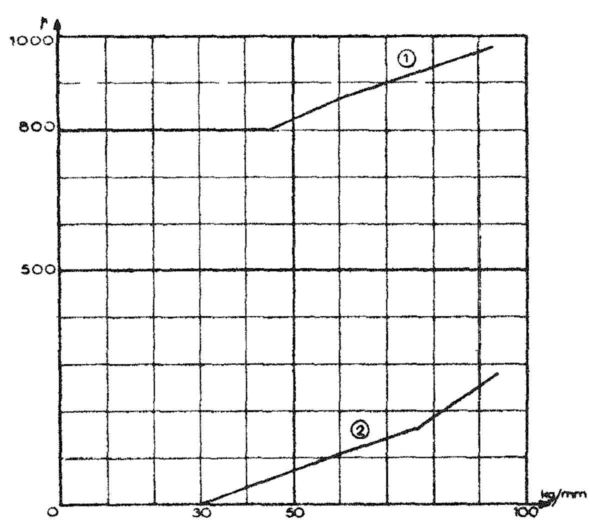


Figure D.2

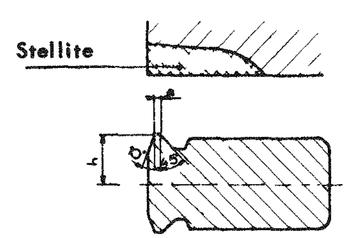
SCHEMATIC OF D_2O LEAK DETECTION



TESTS OF STAINLESS STEEL KNIVES ON STELLITE RESTS



Legend
1. Width of the edge
2. Crushing of the knife



METAL TO METAL FLANGES
Figure : D. 3

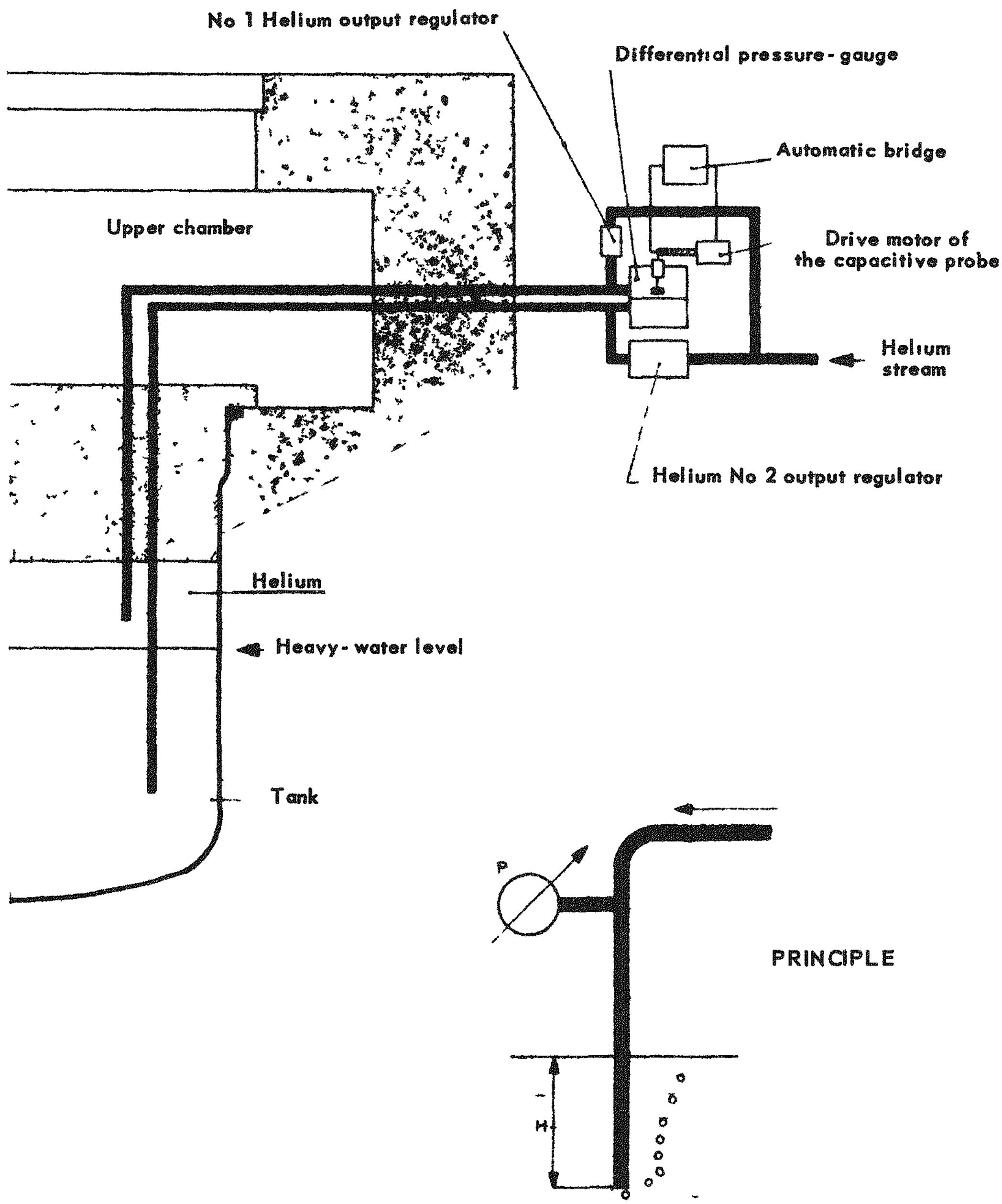


Figure D. 4

MEASURING THE LEVEL OF THE HEAVY-WATER IN THE TANK

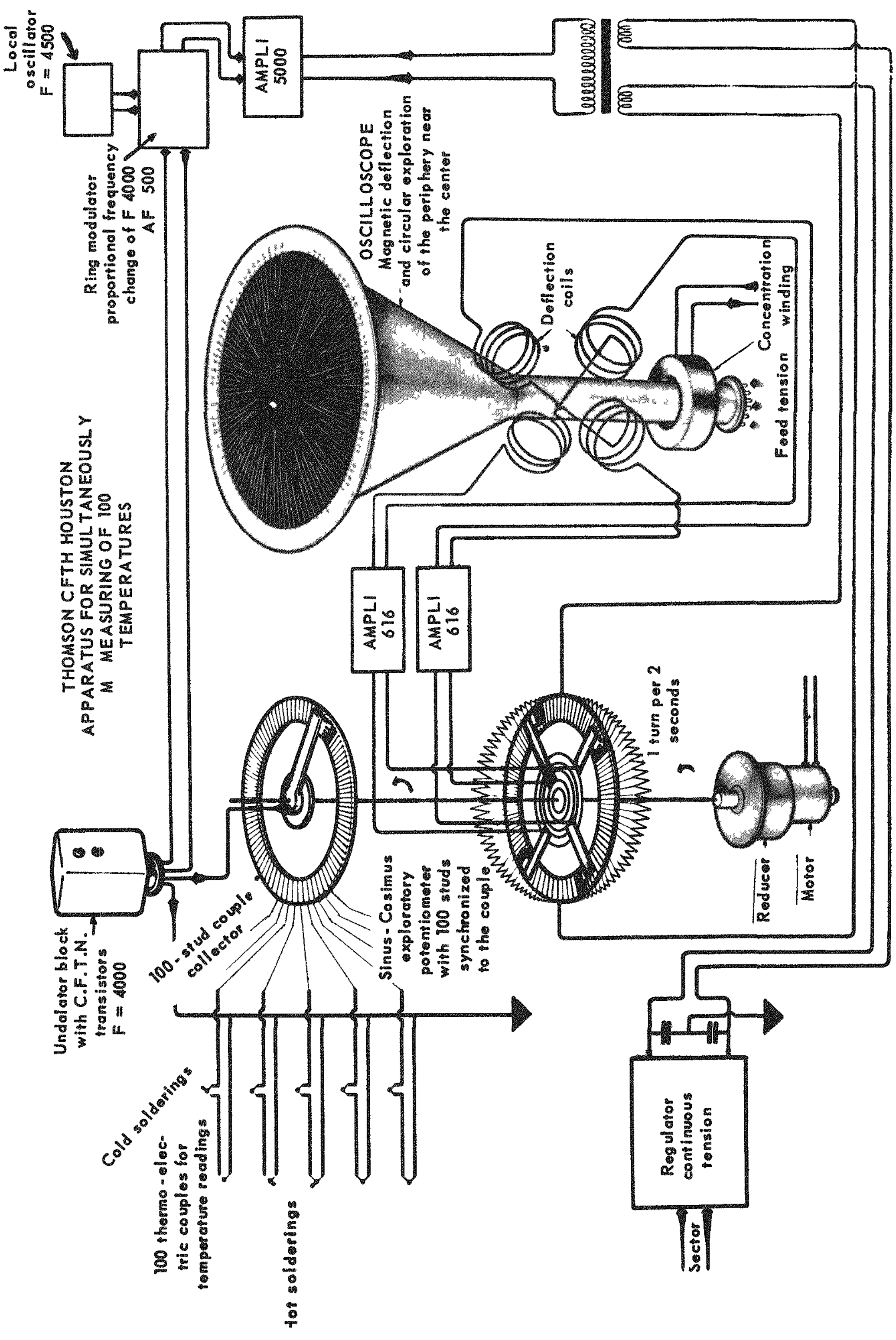

THOMSON CFTH HOUSTON APPARATUS FOR SIMULTANEOUSLY M MEASURING OF 100 TEMPERATURES
Local oscillator F = 4500
Ring modulator proportional frequency change of F 4000 AF 500
AMPLI 5000
OSCILLOSCOPE Magnetic deflection and circular exploration of the periphery near the center
Deflection coils
Concentration winding
Feed tension
AMPLI 616
AMPLI 616
1 turn per 2 seconds
Reducer
Motor
Undalator block with C.F.T.N. transistors F = 4000
100-stud couple collector
Sinus-Cosimus exploratory potentiometer with 100 studs synchronized to the couple
Cold solderings
100 thermo-electric couples for temperature readings
Hot solderings
Regulator continuous tension
Sector

Fig. 9 - D-5

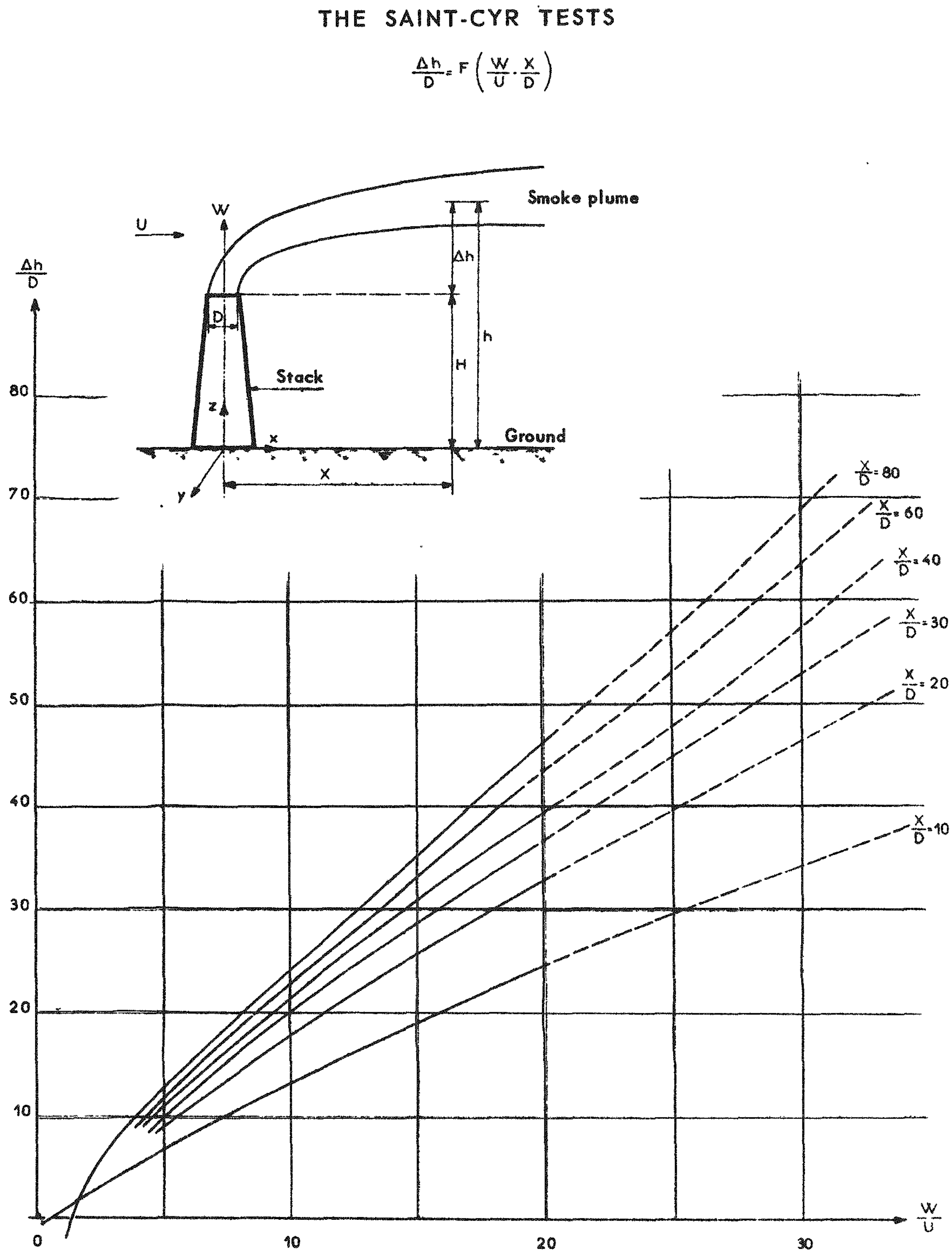
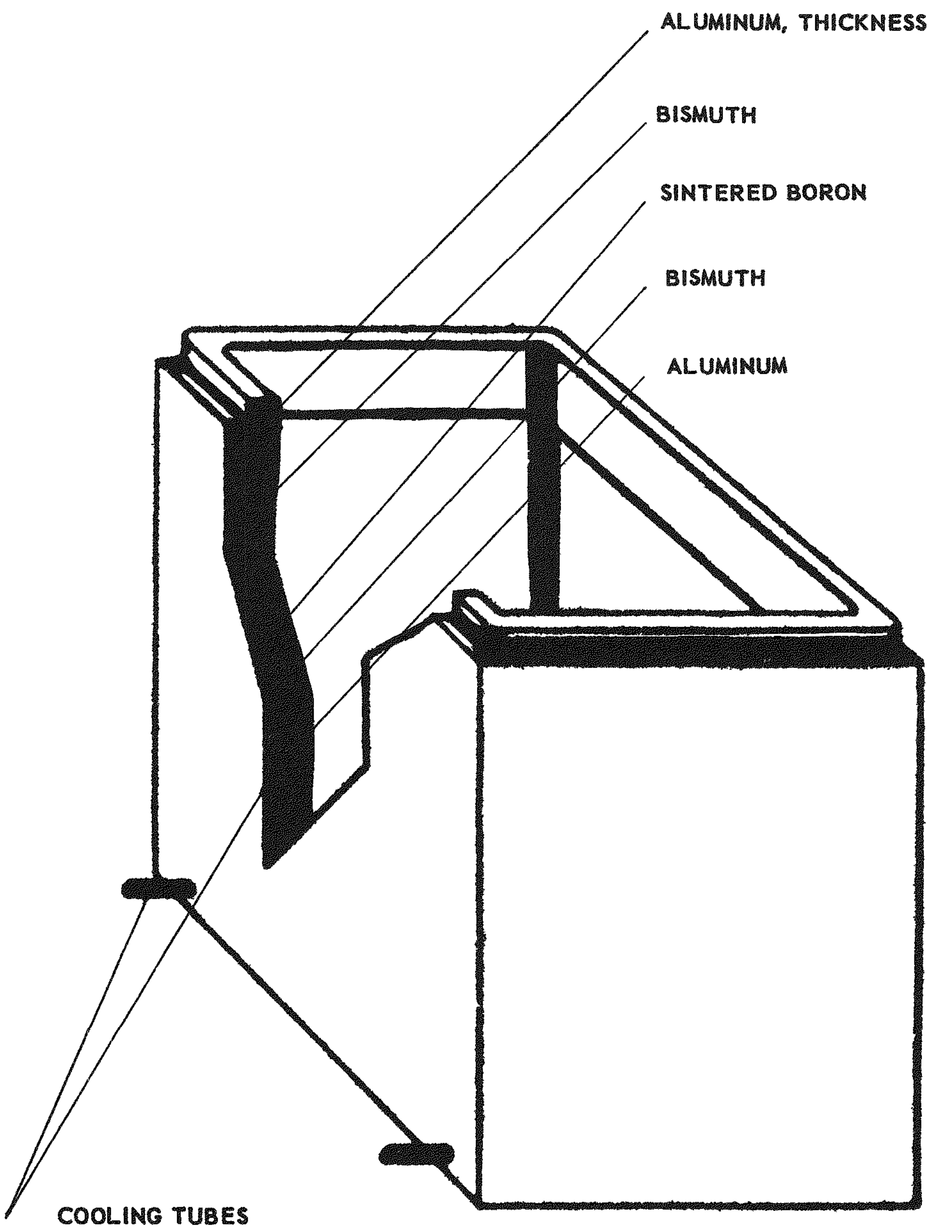


Figure D.6
ELEVATION OF THE SMOKE-GUIDE ABOVE THE FLUE



CAVITIES ($1m^3$) SINTERED BORON SHIELD

Figure D. 7