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ZERO ENERGY REACTOR RB TECHNICAL CHARACTERISTICS AND EXPERIMENTAL POSSIBILITIES

by

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1. Introduction

The zero energy reactor RB was constructed in 1958 in accordance with the nuclear reactor development programme of the Boris Kidrič Institute of Nuclear Sciences. The reactor was in operation until the middle of 1959 when the heavy water, serving as the moderator, was transported to the high flux reactor RA, built at the same time at the Boris Kidrič Institute. Owing to the fact that the purchase of new quantities of heavy water was planned for 1961 it was decided to reconstruct the RB reactor in order to improve the safety of the system and to obtain better flexibility in performing the experiments. New control, safety and radiation monitoring systems were constructed. Some changes were also made on the reactor tank, water circulation system and the water level monitoring equipment. The reconstruction was completed in 1961, and the heavy water was delivered early in 1962. The reconstructed reactor was critical for the first time in summer 1962, and from that time was in constinuous operation.

This report presents an outline of the design and construction characteristics of the reactor. The main intention is to inform potential users of the reactor about experimental possibilities, adventages and disandvatages of such a critical facility.

2. Reactor building

2.1. General layout

The RB reactor is situated at the Boris Kidrič Institut at Vincha, about 16 km from Belgrade. The building where the reactor is located consists of a reactor hall and two wings, one going parallel to the longer side of the hall and the other parallel to the shorter side. The hall contains the RB reactor, a graphite standard pile and fuel elements storage containments. In the longer wing of the building are reactor physics and heat transfer laboratories as well as two rooms where a digital and an analog computer are located. The shorter wing contains a number of study rooms. This wing extends to a small conference hall. The reactor control room is close to the reactor hall. A heavy concrete wall and aniron gate separate the hall from control room. An additional shillded room at basement beneath the control room serves as a laboratory for radioactivity measurements. Fig. 1 represents the general layout of the reactor hall and neighbor laboratories.

2.2. Reactor hall

The reactor hall is 26 m long and 15 m wide. The main floor is on the same level as the ground. A large gate opening to the outside, makes it possible to transport heavy loads by a truck directly in to the hall. The supporting structure of the reactor is placed in the center of a 8 x 8 m large and 1 m beep basin at the west side of the hall. The basin was built because of constructional convenience but serves at the same time as an emergency pool for heavy water. Below the ground floor, next to the basin, a separated room is situated, containing a moderator storage tank of 7 m^3 capacity, pumps, pipe system, valves st. The floor in the basement has no sinks, so the room can serve as a collecting basin for heavy water in the event of accident. The three ton crane moving along the reactor hall is supported from the side walls.

2.3. Control room

The control room is 6 x 5 m large. It communicates on one side with the reactor hall trough a iron gate, and on the other with the E-W direction corridor of the building. When the reactor is in operation the iron door is closed and the personal is protected from the direct radiation of the reactor. The room has no direct view on the reactor hall. All cables connecting the control instrumentation and the reactor are going underfloor trough a special tube. In the control room control console, and radiation monitoring instrumentation are located.

2.4. Electrical installation

The electrical installations contain two independent lines:

- main power supply, 220V - 50cps, 3 phase,
- 24 V DC supply from a accumulator battery.

The power supply is obtained from a transformer 5000/220 V located in the basement of the building. The main switchboard and the fuses are in a basement room beneath the transformer station. Each laboratory room, control room and the reactor hall have a local switchboard with fuses.

The 24 V DC supply is used for control rood operation, heavy water pneumatic valve operation as well as the signalization inside the building.

2.5. Ventilation

All laboratory rooms in the building are ventilated by means of a main inlet-outlet ventilation system. The warm or cooled air is blown into the room trough the main air duct . A separate duct is used to suck out exhausted air. The ventilators with the clima camera and heaters are located in the basement. The reactor hall is ventilated by means od two small capacity conventional wall ventilators located on the opposite walls.

3. Reactor

3.1. Description of the reactor core

In order to achieve a completely non-reflected system, the reactor tank is mounted on a platform and placed in the center of a basin with dimensions 8000 x 8000 x 1500 cm^3, in his way the center of the reactor core is at least four meters away from the floor, roof as well as from the sidelong walls of the reactor hall. The aluminium structure supporting the reactor tank is designed for a working load of 15 tom. Four addiational diagonal butteress were added later in order to increase the stability and the working load of the structure.

Since the programme provides the investigation of different kinds of fuel, there are two reactor cores - standard or referent core, and the enriched core.

The standard core consists of natural uranium fuel and heavy water moderator. The natural uranium is manufactured in metalic slugs 25 mm in diameter and 300 mm long. Seven such slugs, placed in 99,8% aluminium tube of dimensions 27/25x2250 mm make one fuel element. The total weight of natural uranium is 3995,0 kg, which corresponds to a total number of 208 fuel elements. There are 7,0 tons of heavy water available as the moderator. At present D_2O concentration is 99.84 %,

The enriched core consists of 2% enriched uranium fuel and heavy water moderator. The metalic uranium is manufactured in tube shape slugs with a wall thickness of 2 mm, canned from the outside and the inside with aluminium ($\sigma_a = 0.237b$; $\lambda_a = 70$ cm; $\lambda_{tr} = 11$ cm). The canning is 1 mm thick. The dimensions of the fuel slugs are 39/35x110 mm. Ten to fiveteen such fuel slugs are placed in 99,8% aluminium tube of dimensions 43/41x2250 mm to make one enriched fuel element. The total weight of enriched uranium is 340 kg.

3.2. Reactor tank

The reactor tank is a cylindrical vessel with a flat bottom. The internal diameter is 199,86 cm, and the height 230 cm. The bottom of the reactor tank is made of 15 mm thick aluminium, while the thickness of the side wall is reduced to 10 mm. An aluminium lid strengthened by radial ridges tightly covers the reactor tank. The lid has a 50 x 1900 mm slot along the diameter which serves for measurements as well as for neutron irradiations inside the reactor core. This slot can be hermetically shut with an easily removable cover.

Flange connections on the reactor tank are provided for :

- heavy water inlet and outlet (bottom)
- pressure egalization (side)
- horizontal channel (side)

Supporting grids for fuel elements are placed at a height of 2150 mm from the bottom. The grids are made of four semicircular aluminium plates. Each plate contains a number of holes which give the possibility to arrange variable lattice configurations.

3.3. Reactor platforms

Two platforms are built around the reactor. These two platforms are supoorted by a separate structure in order to prevent any oscillations of the reactor tank while the personnel is moving on the platforms during preparation of experiments and to make possible the removal of the platforms, should any scattering material around the reactor be objectionable.

3.4. Reactor shielding

Following strictly the conception of a completely bare system, no shields were built around the reactor core inside the hall. However, the walls of the control room, the corridors and the neighboring laboratories are covered with an additional 5o to 3o cm. thick concrete shield.

3.5. Heavy water circulation system

The circulation of the moderator from the storage tank to the reactor tank, and back, is realized through a stailess steel pipe system. A canned roto pumpe is used (Champump 3/4 HP) to pump the moderator into the reactor tank through a tube of 32/28 mm. in diameter. This pump can be run at two speeds which make two pumping speeds possible, i.e.

2,5 cm/min, and
0,8 cm/min

The moderator can be drained by gravity through a stainless steel tube of 5o/45 mm. diameter, or through the pumping circulation system. In this, two dumping speeds are realized, i.e.

11 cm/min,
1,7 cm/min

Pumping or draining of the moderator is regulated by pneumatic valves of 5o mm. i.d. The pneumatic valves are controlled by D.C. magnetic valves connected to the electric battery station.

The air pressure difference, when pumping or draining, between the reactor tank and the storage tank is egualized through an aluminium pipe of 5o/42 mm. in diameter. A scheme of the water circulation system is given on Figs. 4 and 5.-

The storage tank which is of a cylindrical shape with a total capacity of 7 m^3 is made of lo mm. thick aluminium. The tank is situated in a separate room 4 m. below the main floor. The room has no waste pipe so that in case of an accident it may hold the whole quantity of heavy water.

Flange connections on the storage tank are provided for:

- heavy water outlet (bottom)
- heavy water inlet (bottom)
- air pressure egualization (top)

In addition there is a hermetically sealed removable lid.

3.6. Level measuring equipment

For continues moderator measurement one of the safety rods is used. This rod differs mechanically from the control rod in that a separate cog-wheel system with a synchro generator is added. The accuracy of measuring the relative heavy water level is better than ± o.o2 cm.

In addition to the continous water level monitoring equipment there are two stable levelmeters in the reactor tank which serve to regulate the pumping speeds-(fast pumping limitter), and the maximum height of the heavy water in the reactor tank (maximum level limitter).

The fast pumping limitter is placed far below the critical level. Its height is determined with a value for k_e=o.9 for a given system. After reaching this level a contact probe activates a relay which stops the fast pumping, and prevents any further fast pumping.

The maximal weter level limitter is placed above the critical level, Its height is determined with a maximum excess reactivity of 6oo pcm, depending on special requirements, After reaching this level the contact probe scans all safety and control rods and stops the pump.

3.7. Pneumatic gun for Ra-Be source

For automatic inserting of the o.5 C Ra-Be neutron source from the container under the bottom of the reactor tank a pneumatic gun with a magnetic lock is used.

4. Reactor Control system (Bock diagram BSSS, Fig. 2)

4.1. Safety rods

The reactor is equipped with three safety rods and one control rod. Control rod No. 3 serves simultaneously as a follow-up point contact probe by which the heavy water level in the reactor tank can be measured both manually and automatically.

Position of the follow-up level meter and of the control rod are indicated on the control console by synchro position indicators while the other two safety rods are provided only with signal lights for indicating limit positions.

Pumping of heavy water into the reactor tank is possible only if the follow-up level meter is set to automatic operation.

Maximum speed of the level meter and of the control rod is 0.5 cm/sec. Precision of level indication is within ± 0.2 mm.

Safety rods can be widhdrawn only if all safety circuits are closed and if one of the start-up cannels indicates at least 5 pulses/sec. To ensure the presence of this minimum signal a Ra-Be source of 0.5 C is injected pneumatically in a position immediately below the reactor tank where it is locked by an electric magnet.

The control rod can be withdrawn only if the two safety rods are in the upper limit position.

To withdraw the third safety rod (the follow-up level meter) it is necessary that all the safety circuts are closed.

Temperature of the heavy water in the reactor tank is measured by a platinum resistance thermometer which permits an accuracy of ± 0.2 °C.

4.2. Control console (Block diagram BSSS)

The control console of the reactor is equipped with six measuring channels:

- Two pulse channels with BF_3 counters for operation in the subcritical range.
- Two logarithmic DC channels for measurement of power level and period. Power indication from one of these channels is included in the automatic power control loop. Both channels use compensated boron chambers type CCP1N10 with a sensitivity of the order of $1.5.10^{-14}$ A/n/cm^{2}sec.
- Two linear DC channels with compensated boron chambers type CCP1N10 for power level measurement. One of these two channels is used for automatic power control.

Power level is controlled automatically by an on-off regulator with an accuracy of ± 1% and with a period limit of ± 60 sec.

The logarithmic channels cover a range of 10^{-12} to 10^{-6} while the range of the period meter is $\pm \infty$ to ± 10 sec.

The linear channels cover a range from 50 mV to 50 V with a possibility of changing the sensitivity by varying the series resistance in the ratio 1:10 and 1:100.

Functions of the different channels are listed in Table 1.

4.3. Radiation monitoring system

The radiation monitoring system consists of the following channels:

- two channels for fast neutrons (one monitoring the reactor hall and the other the control room)

- three gamma channels for controlling radiation in the hall, the control room and the northern corridor at the point which is closest to the reactor
- four gamma channels for monitoring radiation in laboratories Location of monitoring instrumentsis given on Fig. 1.

4.4. The safety system

When operating the safety system will result in:

a. dropping of all three safety rods
b. dropping of the control rod
c. stopping any further increase in the heavy water level

The safety system is designed on the principle of one of two. There are 12 circuits which will cause the safety system to operate giving also an optical indication of the fault that has caused the scram:

Circuit No.1 - loss of phase PH_1 in the mains supply

Circuit No.2 - loss of phase PH_2 in the mains supply

Circuit No.3 - loss of phase PH_3 in the mains supply

Circuit No.4 - loss of 24 V DC

Circuit No.5 - Point contact probe for maximum heavy water level and radiation monitoring system

Circuit No.6 - Instrument channel No.5 : minimum and maximum switches on the indicating instrument

Circuit No.7 - Instrument channel No.4 : maximum switch on the instrument measuring ionisation chamber current

Circuit No.8 - Instrument channel No.4: period less than 10 sec.; loss of HT supply

Circuit No.9 - Instrument channels 3 or 4: maximum switch on the period recorder ($T < 20$ sec); maximum switch on the power level recorder

Circuit No.1o -Instrument channel 3: maximum switch on the instrument indicating ionisation chamber current

Circuit No.11 -Instrument channel 3: period less than 10 sec; loss of HT supply

Circuit No.12 -Instrument channel 6: maximum and minimum switch of the indicating instrument, maximum switch on the power level recorder

A manual scram button is also included in the safety circuits. Safety circuits of the instrument channels are automatically blocked if the instruments are disconnected from the mains supply.

5. Experimental possibilities

To allow for a broad variety of investigated lattices, a changeable lattice pitch is procured by a system of fuel supporting plates. One plate is fixed at the bottom of the reactor tank and the other about 2o cm bellow the lid, on the top of the tank. The fuel elements are inserted in holes drilled in the plates. The system of holes in the two supporting plates gives the possibility to arange about fire different lattice configurations. At present square lattices are investigated and the existing holes in the plates allowe for arrangement of the following configuratinons

a) main pitch and integer multiples of the main pitch (n.a)

b) Multiples of the main pitch with $\sqrt{2}$ and $n\sqrt{2}$

c) A function of the main pitch of the forme $\sqrt{(na)^2+q^2}$, where a is the main pitch.

With 3 pairs of suporting plates it is possible to arrange the following lattices.

Table

Main pitch (cm)	7		8		9	
$na\sqrt{2}$	9.9.	19.8	11.3	22.7	12.7	25.4
na	14	21	16	24	18	
$\sqrt{(2a)^2 + a^2}$	15.6		17.9		2o.1	

The main adventage of such a system is that it is relatively cheap and suits to very simple construction of the reactor core. Some disadventages are that it takes some time to rearange a new lattice. This time depends on the number of fuel elements. For the enriched cores it is usually less than one hour. To avoid eventual degradation of the heavy water during this operation, prior to opening the lid of the tank, the water is drained to the storage tank. During the operation hot dry air is blown into the reactor tank. A small quantity of heavy water not exceeding loo gr. is usually lost in such an operation.

With sufficient number of fuel elements it is possible to arrange a radialy bare reactor system. In the axial direction the reactor is bare in most cases.

This makes it possible to treat the reactor as a bare system in large number of experiments. By criticality approach bare systems with a buckling as low as $7.6.1o^{-4}$ can be investigated.

It makes no difficulties to arrange a reactor core with radial reflector, or bottom and top axial reflectors. For reactor oscilator work a central reflector which can serve as a thermal neutron pit is usually prepared. The variety of possible configurations of the reactor core and reflectors is very large. This makes it possible to investigate the influences of one or both directional reflectors on reactor parameters.

There exist several facilities for reaching the interior of the reactor core. For neutron flux distribution measurements, dismountable horizontal and vertical channels passing trough the reactor core are provided. The vertical channel is in the central position and can be used either for neutron flux distribution measurement or for sample oscilation in connection with oscilator work. The horizontal channel is at 6o cm from the bottom of the tank and can reach either the center axis, or to pass trough the reactor. For neutron flux distribution measurements these channels are used in connection with various tehniques applied. Normally for all measurements with micro BF_3 or semiconductor counters the measuring devises are moved along the experimental channels. When activation techniques were applied the foil holders are directly inserted in the channels.

For all experiments where the fuel should be reached, there is a slot 7 cm wide on the reactor lid.

The slot is closed with a special cover which can be removed if necessary. An additional opening on the tank lid serves to insert and remove speccialy prepared fuel elements for intracell measurements.

6. Research programme

The research programme prepared for the RB reactor is a part of a general programme in reactor physics, based on the national plans of development of nuclear energy. The detailed description of the experiments planned, and the research programme for the year 1963 is given in references (2,3).

References

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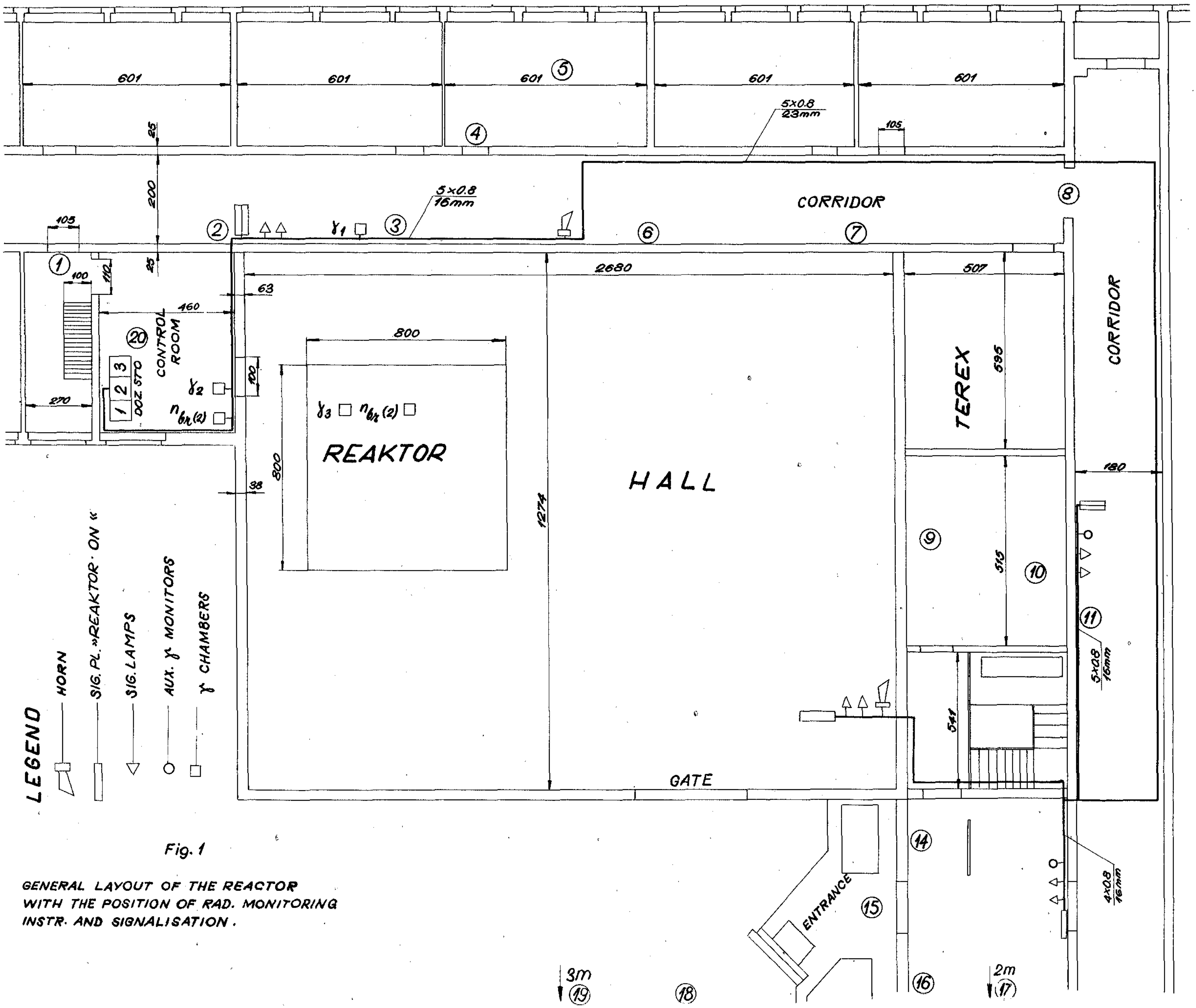
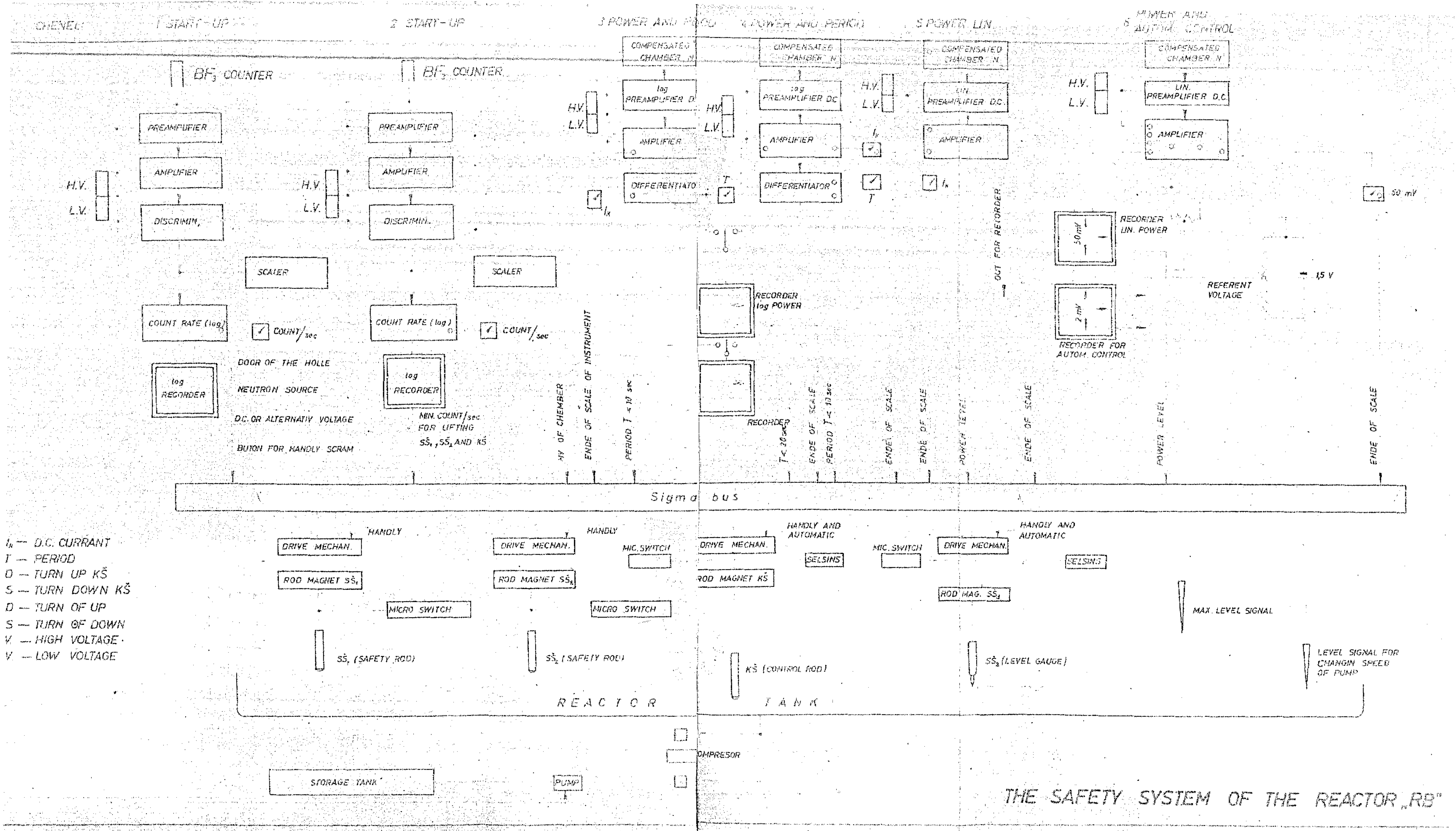


Fig. 1

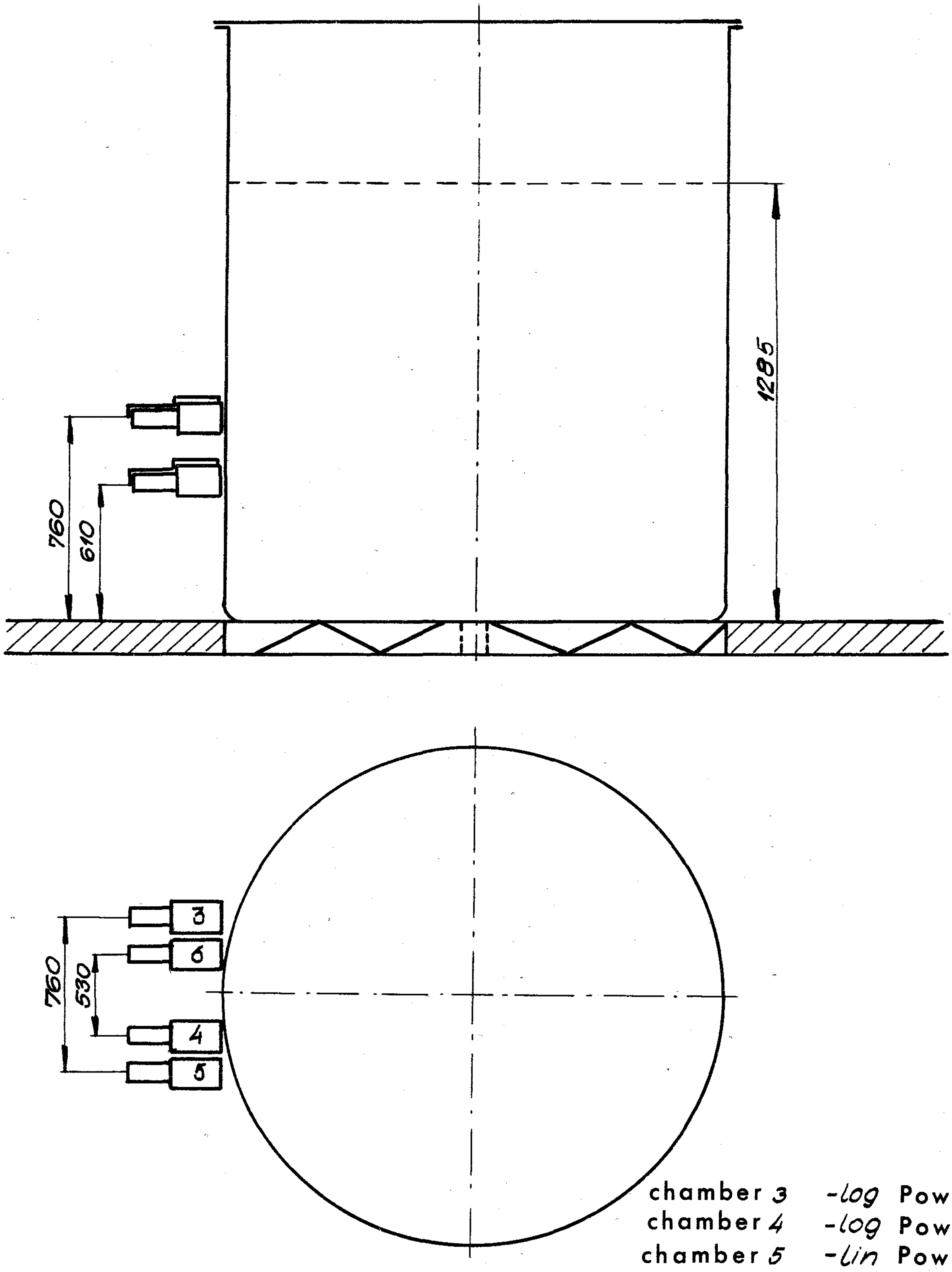
GENERAL LAYOUT OF THE REACTOR WITH THE POSITION OF RAD. MONITORING INSTR. AND SIGNALISATION.



I_k — D.C. CURRANT
T — PERIOD
O — TURN UP KŠ
S — TURN DOWN KŠ
D — TURN OF UP
S — TURN OF DOWN
V. — HIGH VOLTAGE
V. — LOW VOLTAGE

THE SAFETY SYSTEM OF THE REACTOR „RB"

Location of ionisation chambers of the control system



chamber 3 - log Power
chamber 4 - log Power
chamber 5 - lin Power
chamber 6 - lin Power

Fig. 3

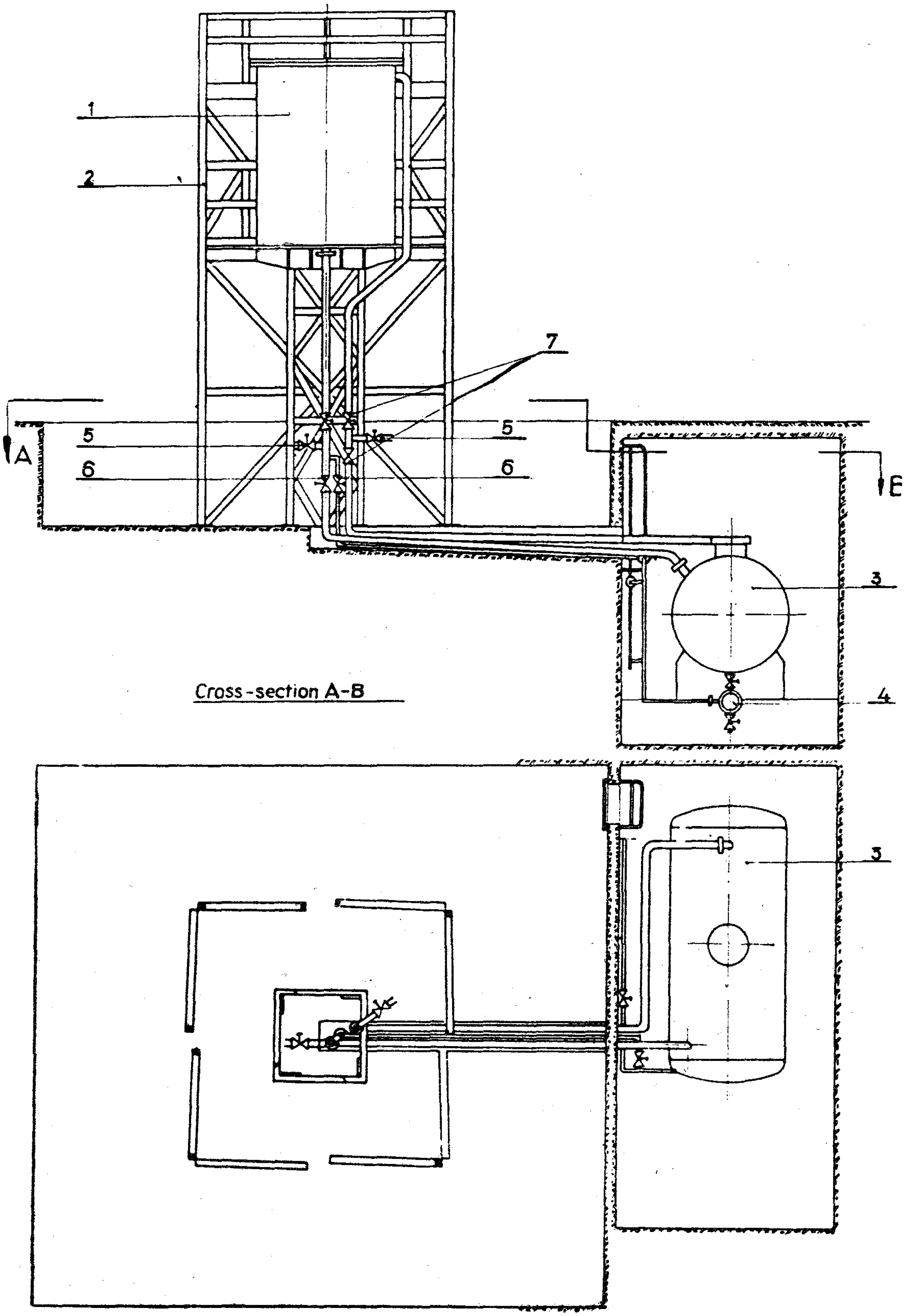


Fig. 4. — Schematic view of the reactor

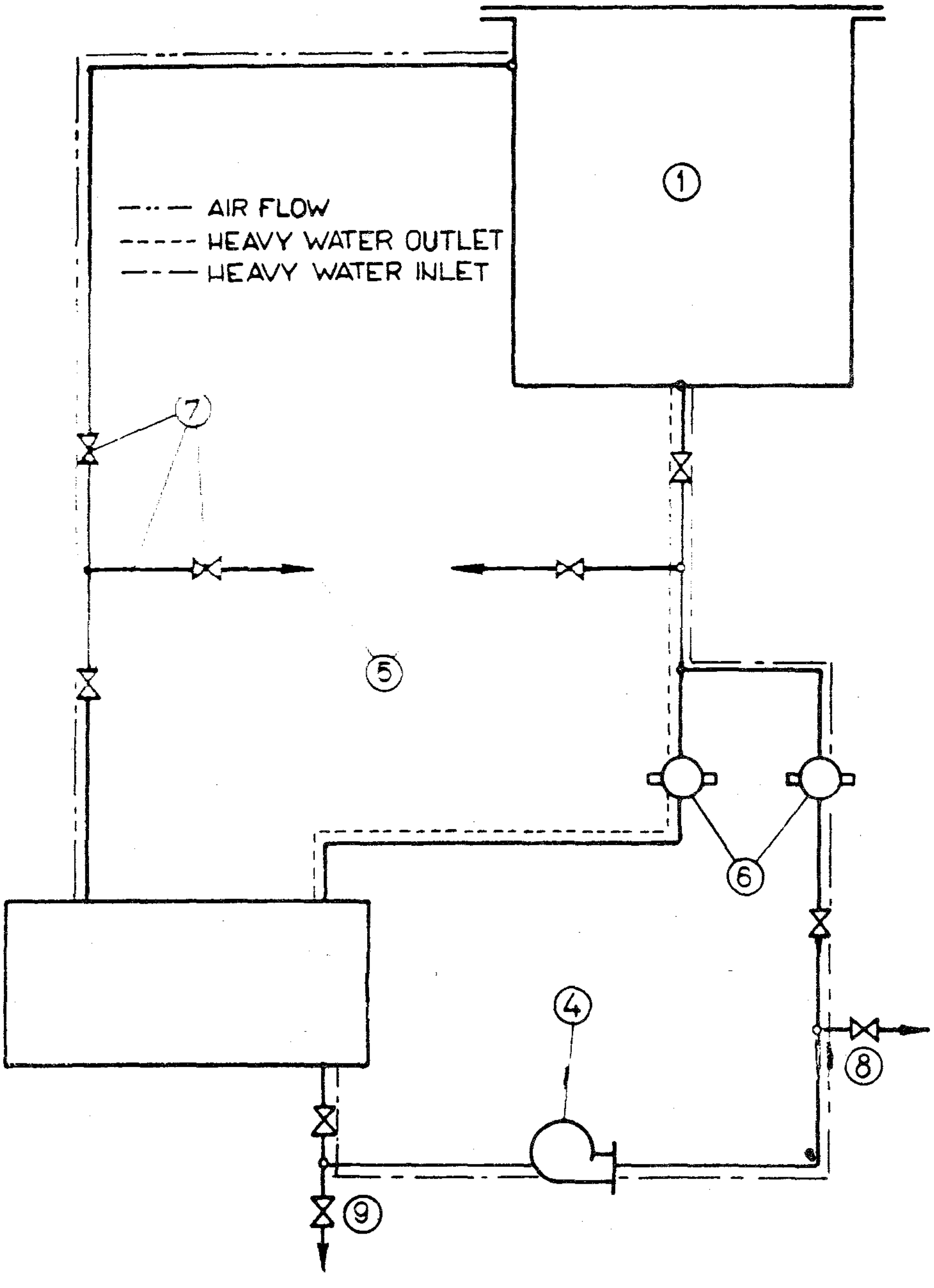


Fig. 5. — Heavy water circulation loop