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Construction and Startup of the First Argentine Reactor (RA-1)

By Fidel Alsina Fuertes and Otto O. M. Gamba *

When the CNEA authorities, on 9 April 1957, decided to build an experimental reactor, the reasons for the decision were essentially the following:

(*a*) In its seven years of existence, the agency has trained a group of scientists and technicians who were sufficiently specialized in reactors to be in need of such a reactor for further training and to gain experience in its operation and working details.

(*b*) The CNEA operates a pilot plant for the production of metallic uranium from Argentine minerals in the vicinity of Buenos Aires. This plant produces small amounts of metallic uranium, and it is very desirable that tests of this uranium be carried out in a reactor, for the purpose of purity control.

(*c*) It also was convenient to have a powerful source of neutrons for general scientific experimentation, such as the determination of the nuclear constants of materials, activation analyses, neutron physics and exponential experiments.

(*d*) The production of radioisotopes, even on a small scale, would permit scientific investigators and industry to adapt themselves to their use, thus offering many advantages in a short period of time.

More than one choice of reactor type was possible. The decision was made with due allowance for various considerations. While it is true that it would have been worthwhile to make a reactor using natural uranium processed in the country, this would have entailed greater expense. Since this country has an agreement with the United States regarding the rental of certain quantities of 20% enriched uranium, it was decided to use a reactor which would use enriched fuel. Allowing for price and efficiency, a very attractive solution would have been a pool-type reactor having a heat power of a few megawatts, which could have been acquired from a specialized manufacturer. However, a smaller (and simpler) reactor was chosen because, while it was true that some useful possibilities were sacrificed, the construction time was cut down, and the reactor was in fact built by the personnel of the CNEA, who thereby gained much valuable experience. Costs were also reduced. For these reasons, the " Argonaut " type, which is a training reactor used by the Argonne National Laboratory of the USA, easy to make, economical and sufficiently versatile for all kinds of measurements, was chosen.

The location chosen was on the outskirts of Buenos Aires, 7 kilometers from the central laboratories of the CNEA, and some 300 meters from the nearest inhabited houses. Transportation and utilities provided are very good.

The name chosen was RA-1, which stands for " Argentine Reactor No. 1 ".

DESCRIPTION

In view of the similarity between the RA-1, Fig. 1, and the " Argonaut " described in papers ANL-5552 [1] and ANL-5647, [2] this will be a brief description, detailed only in the parts that constitute modifications of the " Argonaut ".

RA-1 is a thermal neutron reactor which uses 20% enriched uranium as a fuel. It is H_2O cooled, graphite moderated and equipped with a concrete shield. The core, made up of uranium oxide plates canned or jacketed in aluminum, is located in an annular zone, and the fuel can be variously arranged in accordance with the desired flux distribution. The experimental facilities are two lateral irradiation channels, a thermal column and various vertical channels. Furthermore, since the shielding is removable, all the internal parts are easily reached. The general arrangement can be seen in Figs. 1 and 2.

Core and reflector. It is the central part of the reactor and forms a square zone, in the center of which there are two vertical, concentric, cylindrical tanks made of aluminum. The measurements are approximately 1.20 meters in height and 0.90 meters in diameter.

The central cylinder is full of graphite, and provided with vertical channels for irradiation purposes. The most important is the central hole, into which, normally, neutron sources are inserted for startup. In addition, there are 7 holes arranged in various radial directions from the axis. All, normally, are filled with special graphite.

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* Comisión Nacional de Energía Atómica.

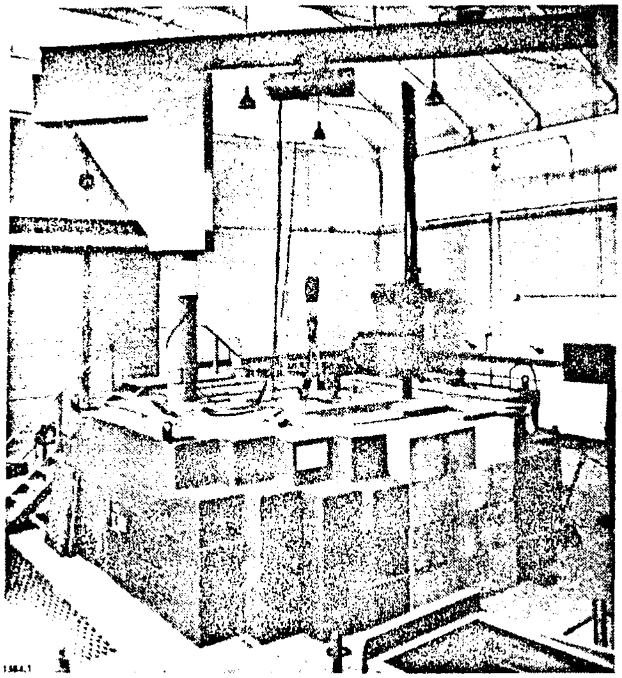


Figure 1. View of RA-1

In the annular area, between the two tanks, the fuel plates are arranged in groups, in aluminum cans. These cans rest against a special support arranged in the bottom of the outside tank. The fuel cans, which are of various forms, can be arranged in groups.

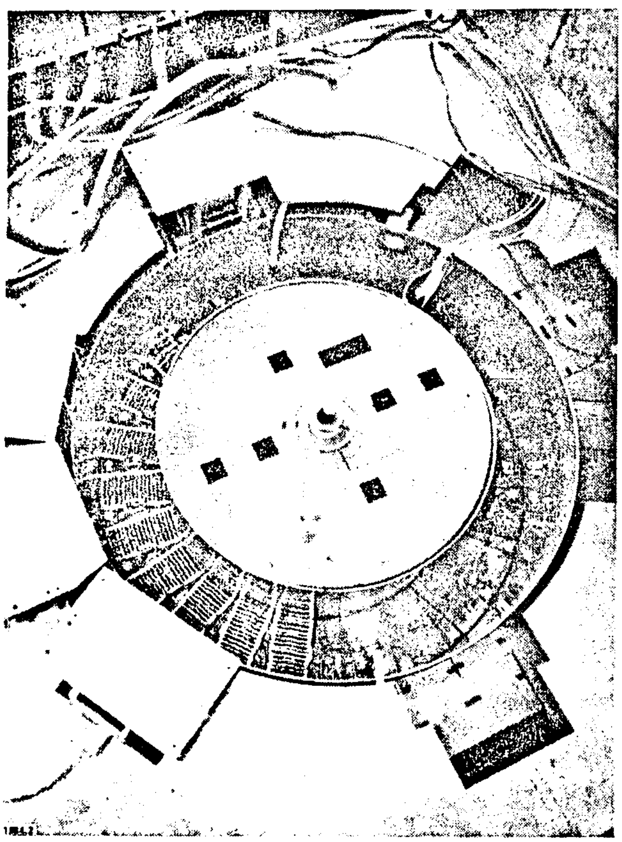


Figure 2. Core of RA-1

For example, they can be used to form a complete circle, single sector, two sectors, or other arrangements, according to the distribution of the fuel in the 360 degrees of the annular zone. The rest of the zone is filled with a rectangular graphite box and, between these parts and the fuel cans, we find triangular parts (wedges) of graphite. During reactor operation the whole area between both cylindrical tanks is full of H_2O, which acts as a coolant and moderator. Around the outer tank we find a graphite reflector which forms a container 1.56 m × 1.56 m × 1.20 m, approximately, with an extension in the form of a thermal column. Opposite the thermal column there is a water tank for large volume irradiation and shield measurements. However, in order to lend greater attention to the design of these

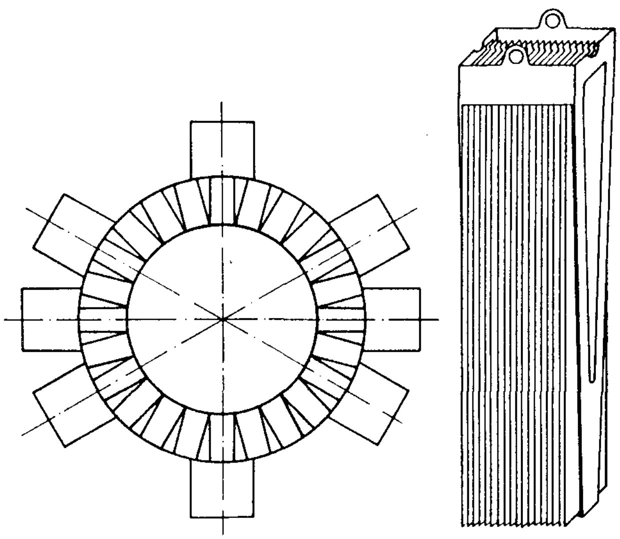


Figure 3. Fuel element rack and location diagram

parts prior to making a study of the experiments to be conducted, no irradiation tank was built and, of the thermal column, only a part 0.40 meter in length was constructed, the rest being sealed up with a shield made of concrete blocks. The graphite reflector also houses the control elements (cadmium plates) and detecting instruments (chambers and counters).

The graphite, of nuclear quality, was bought abroad in the form of rods 100×100×800 mm and 100×100×400 mm, and machining was performed in the shops of the CNEA.

Fuel elements. Uranium oxide, 20% enriched, is jacketed in aluminum in the form of plates approx. 600 × 72 × 2.2 mm. The outside of these plates is pure aluminum and the inside is a mixture of aluminum and uranium oxide. The fuel elements were manufactured from the U_3O_8 powder acquired in the US by the personnel of the Metallurgical Division of the Nuclear Reactor Department of the CNEA. The method used was the extrusion of an aluminum cylinder containing a mixture of aluminum powder and uranium oxide. The details of the operation were worked out with samples of natural uranium oxide from Argentina. The metallurgical process for the manufacture of fuel elements is described in greater detail in another paper presented to this Conference. Each plate contains 7 to 30 grams of U^{235}.

The fuel plates were arranged in special cans, 17 plates per can. The design of these cans was guided by the idea of having the amount of aluminum incorporated in the core area as small as possible. Between each pair of fuel plates there is a layer of water about 6 mm thick. The fuel cans are held in position by concentric tanks that guard them laterally, and by a lower support, also made of aluminum, that bears on the bottom of the outside tank.

The remaining part of the annular area, between the two tanks of the core, is filled with rectangular graphite parts and triangular parts (wedges) of the same height as the fuel can, and resting against the same lower support which carries these cans. These graphite parts are covered with a coat of varnish of the "Glasscote" type, to avoid contact of the graphite with the water. Special care has been taken to have all the rectangular graphite parts mutually interchangeable, and also interchangeable with the fuel can. In practice, however, small distortions of the tanks made it preferable to number these parts, so that each one should have an exactly defined place, those corresponding to the places where the fuel cans are located being left temporarily unused.

Shield. The lateral shield is made up of removable concrete blocks, the shape and size of which vary, as shown on the diagram. The thickness of the shield ranges from 1.40 m to 1.80 m (Fig. 4).

The upper shield, above the core, is a cover made of several square-shaped parts, 1.56 m by 1.56 m and 0.40 m thick. It consists of a sort of steel case, filled with baryta concrete, and rests on a structure made of 4 concrete columns and a frame made of aluminum beams. The circular central part of the cover can be removed, and this uncovers the tanks of the core. In the central part of the cover are two small plugs which can be removed; one is circular and central and the other is radial and elongated, so that smaller parts can be placed in the core without uncovering a large surface.

Water circulation system. When the reactor is not functioning, water from the reactor passes to a tank under the level of the floor in a ditch at the side of the reactor (Fig. 5). In order to start up the reactor, it is necessary to pump the water from the discharge tank into the reactor core. There is a heat exchanger, which can function by means of a thermo-siphon or by forced circulation with the pump, and return to the discharge tank. An electrical heater makes it possible to operate at a constant temperature (higher than the ambient temperature), when the heat of fission is inadequate to achieve the desired result.

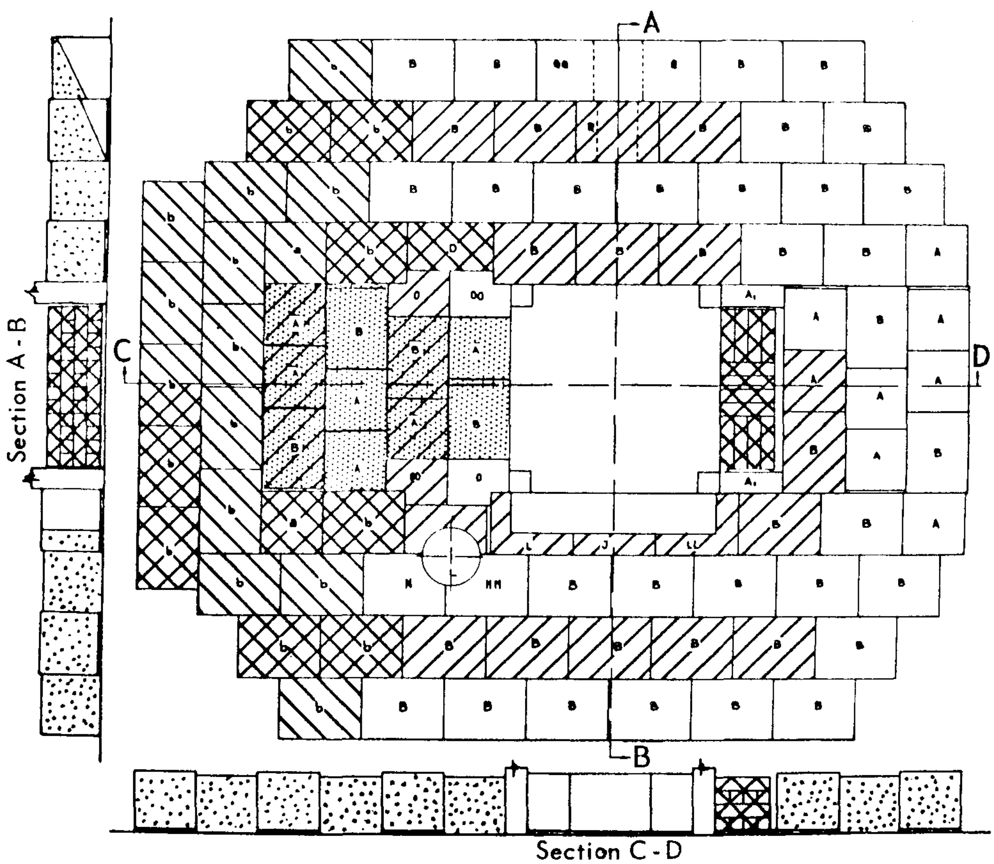


Figure 4, Arrangement of shielding

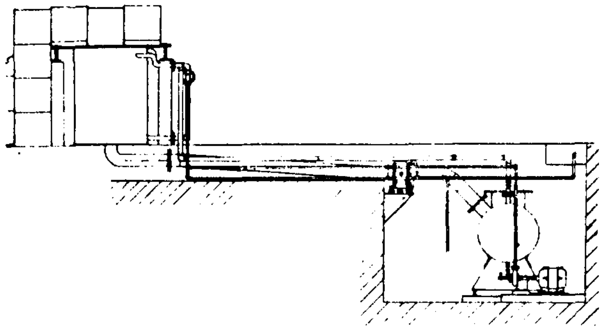


Figure 5. Water circulation system

As a safety measure, the water discharge valve opens automatically each time the reactor cuts off. The H_2O used is demineralized in the conventional way.

Nitrogen system. Should there be an emergency stoppage, the removal of the water from the core brings about a reduction in the reactivity, owing to a decrease in the moderating effect. Since the discharge of the water takes some time, there is a system which, in case of a scram, injects nitrogen into the water of the core. The bubbles between the fuel plates cause an immediate drop in the reactivity, due to reduction in the amount of moderating water.

Control (electromechanical part). The control system of the RA-1 is similar to that of the " Argonaut ", with a few variations. All electronic devices control a series of contacts that must be closed to permit functioning of the relay that energizes the whole control system. This type of wiring is essentially safe; in all cases of accidents (breakdown in the electronic equipment, drop in voltage, etc.) the main relay will be open, which brings all the control devices to the safest position.

Energizing the main relay makes it possible, as a first operation, to pull out the safety plates. This is a precautionary measure in order to have a certain amount of negative reactivity in reserve during the operations that follow. In the upper position the plates close contacts arranged in series, which make it possible to continue the following operation, which is the closing of the automatic discharge valve. The next operation is to pump water to the reactor. Once the reactor core is filled, a relay is energized by means of a float which makes it possible to move the control plates which bring the reactor to criticality.

The fundamental modifications used for the RA-1 are:

(1) The use of ac motors to operate the safety and control plates, which makes it possible to simplify the wiring to the point that two push-buttons are used

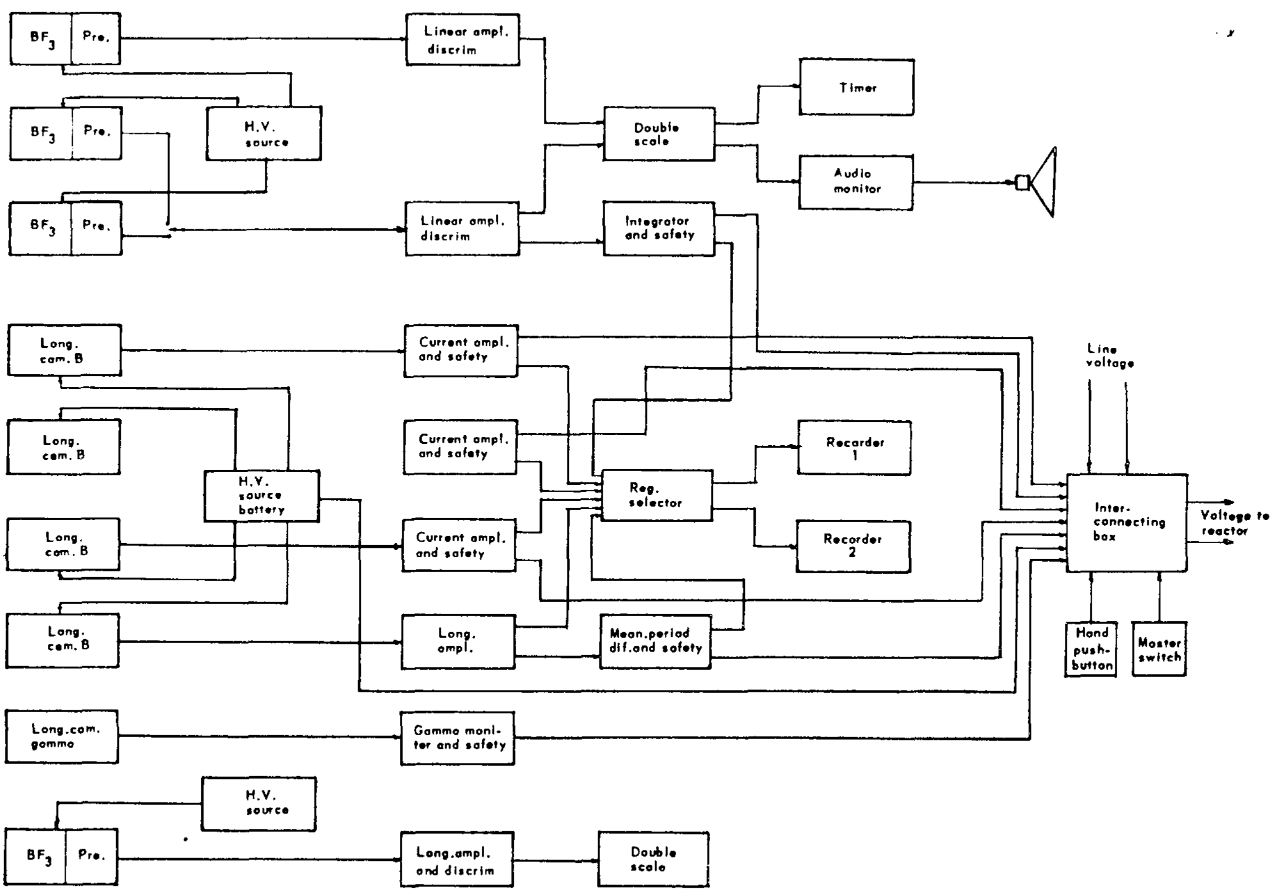


Figure 6. Electronic control diagram

for reactor operation: one marked " increased reactivity ", which pulls out the safety plates, closes the the discharge valves, pumps the water and withdraws the control rods; a second, marked " decreased reactivity ", used to insert the control rods.

(2) A new wiring schematic for the temperature control part of the reactor, giving a wider range of possibilities for cooling and heating the moderator, so that tests can be carried out with great temperature stability.

Unlike the " Argonaut ", the RA-1 allows the pumping out of the water and the opening of the natural convection valve at the same time as a variable thermal control device opens the cooling valves, and connects the heaters in order to maintain the reactor temperature within narrow margins.

Control plates. Control is achieved by means of cadmium plates, which hang from steel bands running over an aluminum pulley. An electromagnetic clutch provided between the pulley and drive motor allows a plate to move only when it is energized and, in addition, maintains it in the upper position, owing to the irreversibility of the gear train. Should the clutch be de-energized, the action of the band, which acts as a spring, and the force of gravity cause the plates to drop.

There is a hydraulic damper to prevent this fall from being too sudden and in addition a potentiometric device follows the pulley in its rotation, in order to post the position of the plate on the control console.

Control (electronic part). The electronic control circuits provide for stopping the reactor by means of relays which act on the control systems when one of several possible events takes place: (1) a safety circuit covers a preset percentage of the scale of its instruments; (2) the period drops to less than 10 seconds; (3) any one of the cut-off push-buttons is activated;

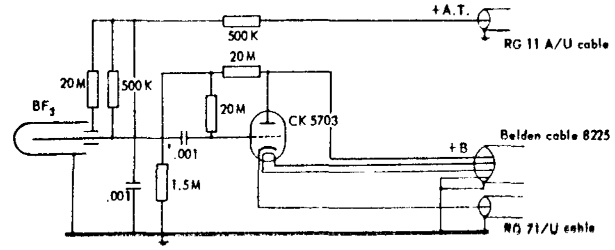


Figure 7. Preamplifier circuit

(4) there is an electrical power failure; (5) a breakdown takes place in a safety circuit; (6) radiation level in the reactor room is greater than the biological tolerance of the personnel.

The block diagram of Fig. 6 shows the arrangement of all the control circuits with their interconnections, and their connection to an interconnecting box which, by acting on the line voltage, actuates the control and safety rods, the nitrogen system and the water drainage valve.

The circuits of the various parts of this block diagram are similar to those of the " Argonaut " of the Argonne Laboratory, with a few important exceptions: (1) preamplifying circuits of the ionization chambers, proportional to BF_3; (2) linear amplifying circuits; (3) high-voltage source for the ionization chambers; (4) double scaler; (5) recording selector; (6) movable neutron monitor.

For startup, use is made of some neutron source consisting of radium and beryllium, the multiplication control circuit having first been eliminated (source multiplication interlock), which is one of the possible causes of shutdown in the US design.

The preamplifier and linear amplifier circuits are shown in Figs. 7 and 8, respectively. The preamplifier adopted has the advantage of having a very low input capacitance through which output pulses of 40 to 100 mv are obtained, which penetrate directly

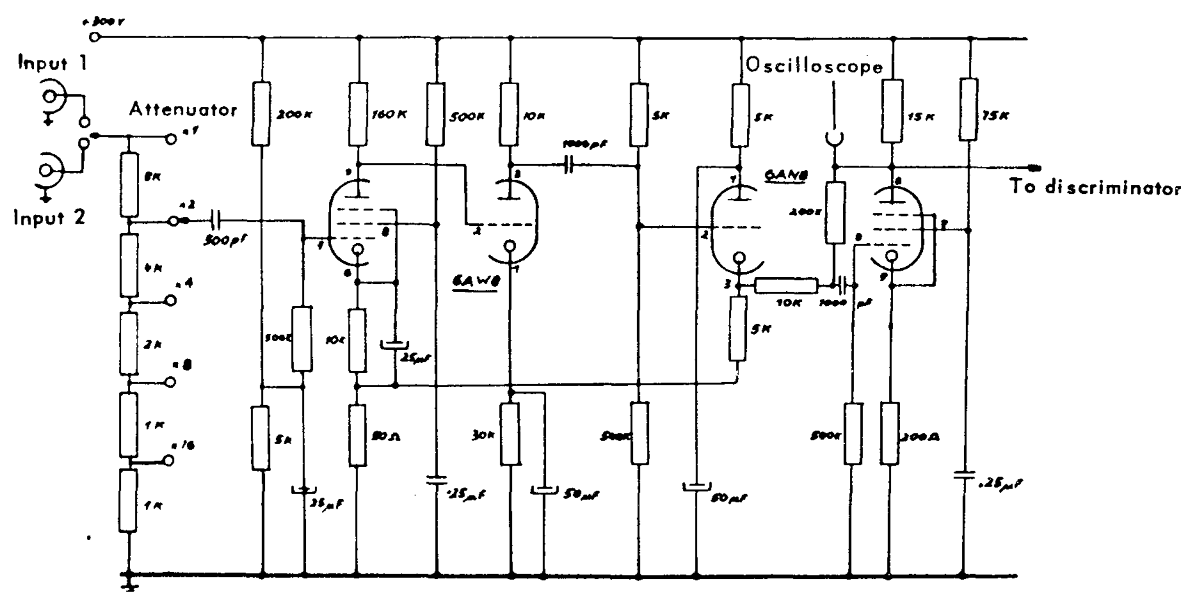


Figure 8. Amplifier circuit

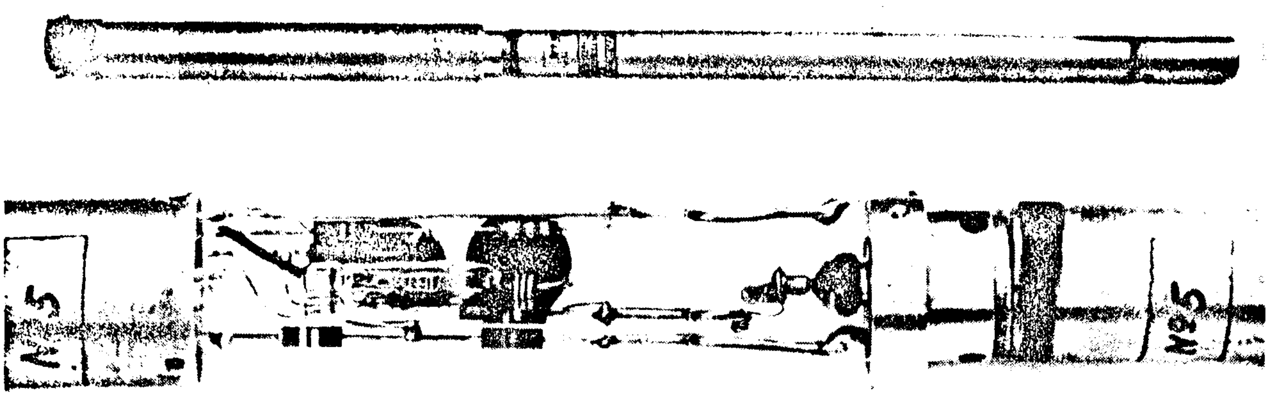


Figure 9. Interchangeable elements

into the amplifier through coaxial cables of the RG71/V type. Such cables of a length up to 20 meters have been used, and no drawbacks were noted. The cathode resistance of the preamplifier is included in the amplifier and, in addition, acts as the attenuator for the latter.

In addition to the advantages mentioned, the extreme simplicity and ease of assembly of the interchangeable elements can be appreciated by reference to Fig. 9.

The linear amplifier (Fig. 8) has a gain of 1000, with a band of about 600 kc width, which is more than is needed for the intended use.

It is linear up to output voltages of 60 v, and it does not block out with such strong signals as might saturate it.

This equipment also includes a discriminator and a pulse shaper (Fig. 10). There are two outlets with cathode followers. The assembly, made up of the preamplifier, amplifier and other elements, has a large discriminating plateau in the vicinity of 6V, P2 control (Fig. 10), which guarantees, at all times, that the measurements will be constant.

The total number of tubes in the amplifier and auxiliary circuits is only 5, excluding the power supply, which is stabilized in the conventional fashion.

As regards the high-voltage source of the cameras, it has been thought preferable to use dry batteries that combine consistency, reliability and good adjustment with ease of replacement.

The double scaler has been made with EIT tubes in keeping with conventional circuits, which use these tubes. They can function simultaneously, or each one individually.

In addition, there is a recording selector panel with which it is possible to connect two recorders

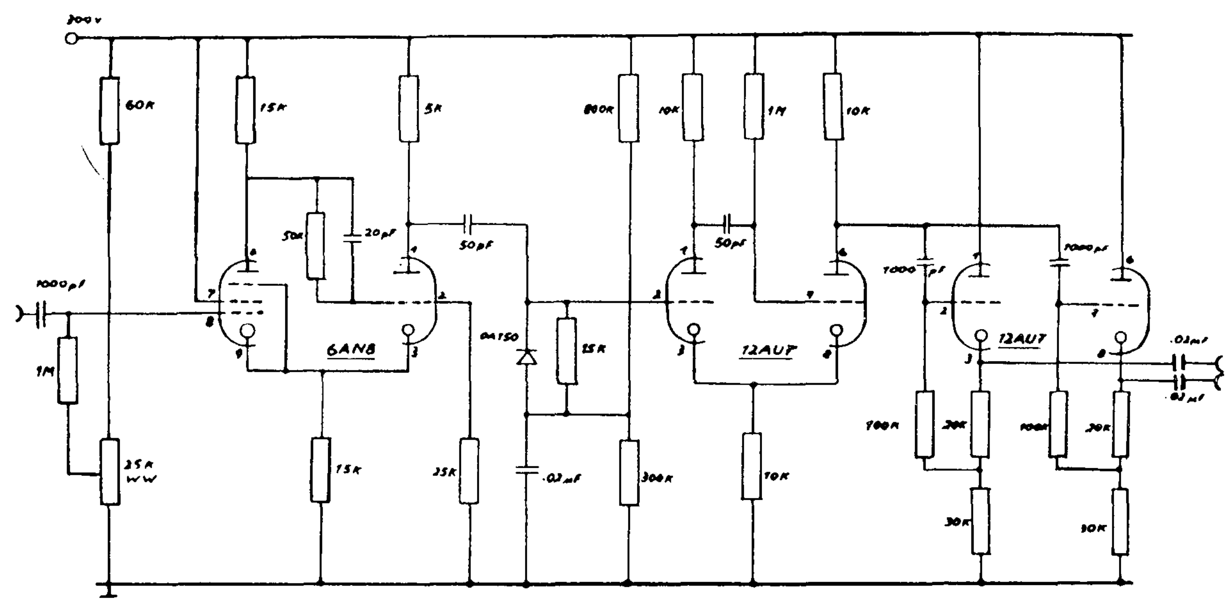


Figure 10. Discriminator and wave shaper

to any two of the six outlets to be recorded (but not the same outlet for the two recorders).

Furthermore, a movable neutron detector has been provided, built around a proportional counter inside the paraffin block, and functioning with the same circuits as those of the reactor proper.

All these devices were made in the Electronics Department of the CNEA.

Starting source. Use is made of a source of neutrons made up of Ra–Be, of 50 mc, giving approximately 5×10^5 neutrons, which the CNEA already had for experimental purposes. Owing to the lack of intensity of this source, it is necessary to place it where it can be most effective. This is done by inserting it into one of the vertical holes used for core irradiation.

Experimental facilities. The core is equipped, in the central graphite cylinder, with a circular-cross-section vertical hole and seven rectangular ones, in which the samples to be irradiated can be inserted.

Two faces of the reactor are equipped with various irradiation tubes, which penetrate to the tank. By removing graphite blocks from the thermal column, more irradiation possibilities are obtained.

The shielding, made up of loose concrete blocks, gives access to the graphite reflector, so that any samples, equipment, or instruments can be placed in this reflector.

It has been stated before that until such time as the water tank for irradiation and measurements has been built, there will be an extension of the reflector, on the side opposite the thermal column.

Plant and ancillary facilities. The building is a large room, 17×17 m and 7 m free height. It is of simple construction, with brick walls and a prefabricated tile roof of light concrete.

In view of the need for ground excavation to give an adequate foundation to the reactor, a free basement has been left under it which communicates with the ditch near the discharge tank, as well as the water pumps and other mechanical devices.

A rotary-arm 3-ton crane makes it possible to move heavy parts. It reaches over the reactor and adjacent parts of the room. Deep holes with concrete covers are left in the ground, for the storing of activated materials. Three of these holes are on the side of the reactor within reach of the crane.

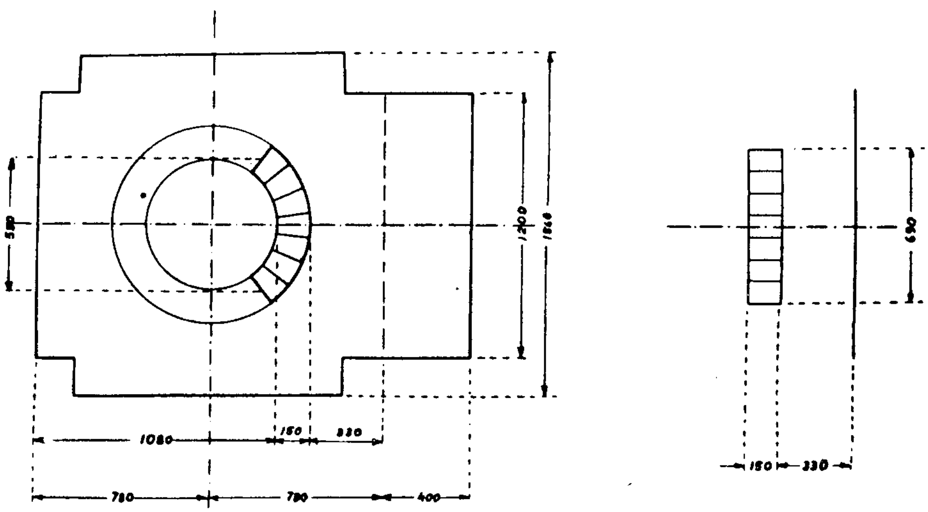
Channels were also left in the flooring for electrical cables and tubing.

COMPUTATIONS

Since, on the whole, we followed the design of the "Argonaut" reactor of the Argonne National Laboratory, it was not necessary first to compute the nuclear characteristics of RA-1. Before it was built, however, a recomputation of the critical mass and other characteristics was made in order to know the influence of various factors, such as the presence of impurities in the structural materials, and U^{235} concentration of the fuel elements. We base these calculations on papers referring to the "Argonaut".[3–5] All the computations were made with the fuel disposed in a single sector of the annular zone ("one-slab geometry").

Critical Mass Computation

This was performed on the basis of a two-group diffusion method. Pre-fixed data were the general geometric arrangement, the dimensions of the fuel plates and the uranium–aluminum ratio of these plates. This last datum was determined by the Metallurgical Section Staff on the basis of earlier tests. In accordance with these data, the constants of interest in the core area were set, the criticality condition being determined for a variation of the dimensions (volume) of the core.



a   b

Figure 11. Real schematic (a) and simplified schematic (b) of the RA-1 core

Simplifying hypotheses on which the computation rested were the following: (*a*) Even though the effective arrangement was that indicated in Fig. 11a, the computation geometry was that applicable to Fig. 11b. (*b*) The area of the core was considered a homogeneous mixture of uranium, H_2O, aluminum, and graphite, in the following proportions:

$$\frac{U_3O_8\ \text{vol.}}{\text{Total vol.}} = 0.0261 \qquad \frac{H_2O\ \text{vol.}}{\text{Total vol.}} = 0.5998$$

$$\frac{\text{Al vol.}}{\text{Total vol.}} = 0.1887 \qquad \frac{\text{C vol.}}{\text{Total vol.}} = 0.1854.$$

(*c*) In the azimuthal direction (" length " of the fuel sector), the reflector was taken as infinite in both directions, as well as in the radial direction toward the center. In the radial direction, toward the outside reflector, consideration was given to a 34-cm reflector, although, at the last minute, it was decided to add a part of a thermal column, 40 cm, which therefore was not allowed for in the computation. Vertically, we considered a water reflector, taking 7.5 cm on each side for the value of the economy due to the reflector.

Computation method. The variations in the volume of the area of the nucleus can be achieved by varying the radial thickness (or again, by varying the number of fuel plates present in any can), or the azimuthal dimension (angle covered by the fuel sector, which is equivalent to varying the number of fuel element cans).

The computation method consisted of setting up the solutions of the general equations of the two-group theory for the three zones (finite reflector, core, infinite reflector), and writing the contour conditions for them, from which the compatibility condition is the zeroing of the determinant. This determinant is in principle of the 8th order, but simple algebraic transformations reduce it to one of the 4th order. In order to find the point for which the criticality condition is fulfilled, a direct tracing was made of the value of the determinant as a function of the U^{235} mass, which was done for :

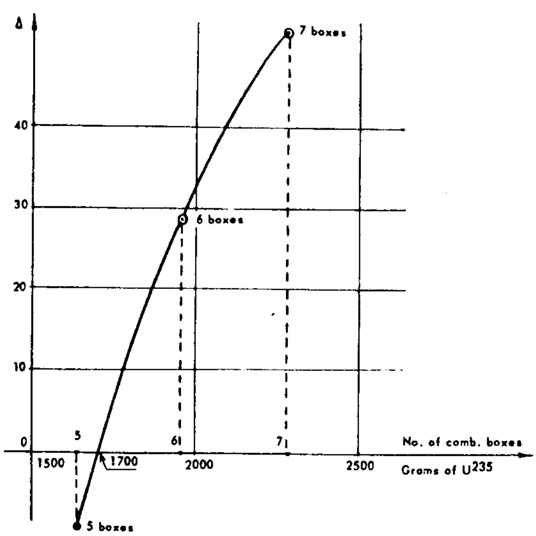


Figure 12. Determination of the critical mass by azimuthal variation

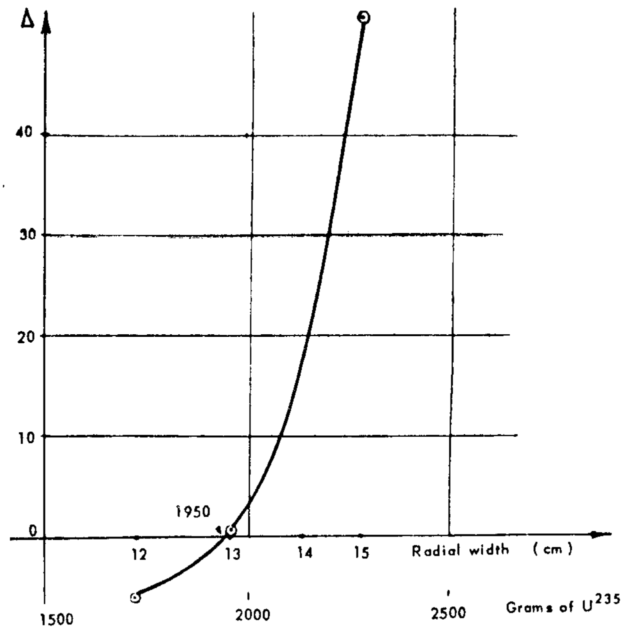


Figure 13. Determination of the critical mass by radial variation (width of seven cases more or less equalling 70 centimeters)

(*a*) *Azimuthal variation.* Having set the width of the core the length was varied, that is the number of fuel cans. The economy for each reflector in the azimuthal direction was computed by the one-group theory, allowing for the variation of this economy when the number of cans also varies. This gave the critical mass of 1700 g (Fig. 12).

(*b*) *Radial variation.* Once the number of fuel element cans was set, the radial thickness of the core was varied. The economy due to the reflector is that already obtained for this number of cans. The critical mass obtained by the method is 1950 g (Fig. 13). Since the value of the experimentally determined critical mass is some 2200 g, it will be seen that this method gives a better result than the earlier one.

Value of constants. The thermal neutron cross sections were obtained from BNL-325, except that applicable to graphite, for which the datum recommended by the manufacturer was accepted. The constants of the fast neutron group were taken from ANL-5710.

Error computation. In order to determine the influence of the uncertainties in the initial data on the value of the critical mass found, the computation of error propagation was expressed mathematically. Through the application of formulas of differential calculus and with the numerical values of the computation already made, the influence of possible errors in the computation was determined for small errors in the computation constants.

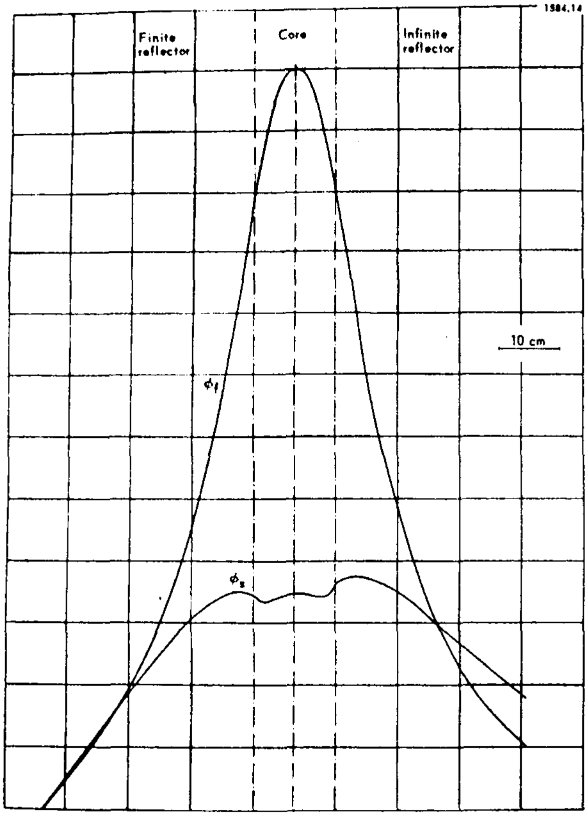


Figure 14. Radial distribution of flux

Below are given the values considered:

Reflector

$\Delta M/\Delta\tau = 0.3$ g/cm² (M = critical mass, τ = Fermi age of the graphite = 364 cm²)

$\Delta M/\Delta L = 1.5$ g/m (L = diffusion length = 52 cm)

$\Delta M/\Delta D_f = 1000$ g/cm (D_f = diffusion coefficient (fast) = 1.1 cm)

$\Delta M/\Delta D_s = 500$ g/cm (D_s = diffusion coefficient (thermal) = 0.84 cm)

Fuel

$\Delta M/\Delta\tau = 26$ g/cm² (τ = Fermi age = 60 cm²)

$\Delta M/\Delta L = 24{,}000$ g/cm (L = diffusion length = 1.87 cm)

$\Delta M/\Delta k = 3000$ g (k = multiplication constant = 1.66)

$\Delta M/\Delta D_f = 1000$ g/cm (D_f = diffusion coefficient (fast) = 1.25 cm)

$\Delta M/\Delta D_s = 15{,}000$ g/cm (D_s = diffusion coefficient (thermal) = 0.25 cm)

Computation of Flux Distribution

Once the critical mass was obtained, the system of equations was solved, giving the value of the coefficients shown in an analytical expression of the flux. This gave the expressions of the thermal and fast fluxes given on Fig. 14.

Computation of the Added Flux and of Neutron Mean Life

In order to be able to evaluate some constants by means of perturbation calculations the flux distribution, which is appended, was also determined analytically, according to the two-group theory. The method, which is similar to the computation of the real flux, resulted in the curves shown in Fig. 15.

With the additional flux so obtained, the value of the mean life of the neutrons was calculated by means of the formula:

$$l = \frac{\int \left(\frac{\phi_f^\dagger \phi_f}{v_f} + \frac{\phi_s^\dagger \phi_s}{v_s} \right) dv}{\int D \Sigma_{fs} \phi_f^\dagger \phi_s dv}$$

where ϕ_f, ϕ_s, $\phi_f^\dagger$ and $\phi_s^\dagger$ are the fast and thermal real fluxes, respectively, v_f, v_s the velocity of fast and thermal neutrons; D the number of neutrons produced by thermal fission and Σ_{fs} the microscopic fission cross section of thermal neutrons. The value obtained was 1.50×10^{-4} seconds.

EXPERIMENTAL DETERMINATIONS

The determination of the critical mass of RA-1 was done in the usual way, but since we were dealing with the reactor for the first time some special precautions were taken. For this experiment,

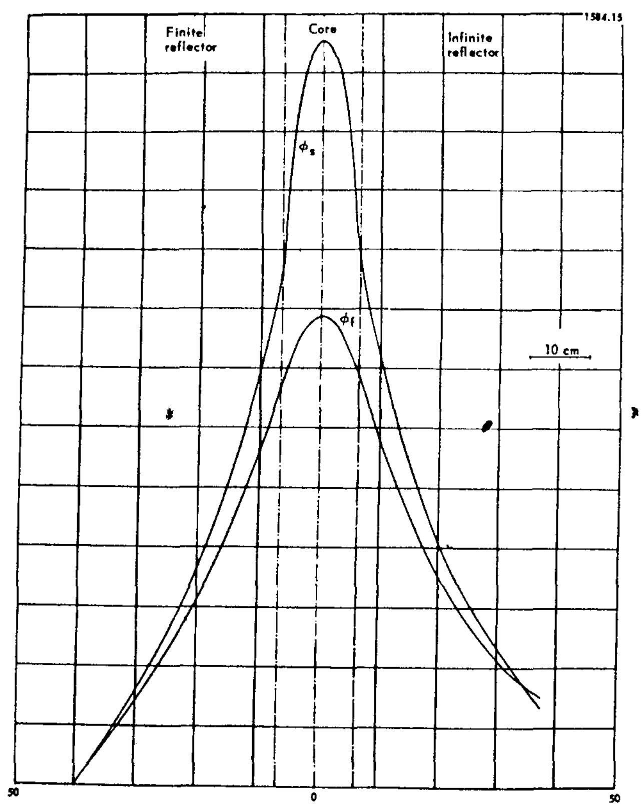


Figure 15. Radial distribution of additional flux

use was made of a Ra-Be source of 5×10^5 neutrons per second. The measurements were made with three BF_3 counters located at different distances from the reacting core and as far as possible from the source. In addition, a pulse integrator was used which could be connected to any one of the tubes, the output of which was fed to a recorder. During the experiment the ionization chambers and the period measuring device are connected also.

The safety devices consisted of those usually found in a reactor: (1) automatic high-level release in the integrator; (2) automatic high-level release in the BF_3 chambers; (3) automatic release for very short periods, $T = 10$ seconds. The operation of any one of these devices was sufficient to cause the drop of all the control and safety rods (four in all) in approximately one-third of a second.

The manual shutdown push button was added to this. It has exactly the same effect as the manual device used for opening the discharge valve (the operation of which, in the finally installed facility, is automatic). Aside from these elements a Cd plate was installed especially for the critical test, and manually operated.

The alarm device was represented by an ionization chamber equipped with a bell that rang when γ radiation of the medium reached a preset level.

The safety team (two persons) constantly watched the neutron and gamma radiation levels during the whole experiment. During the tests, all safety and control devices are continually verified. The tests for the determination of the critical mass and verification of the safety and control devices required some 36 hours of continuous work. The critical point was reached in 8 hours.

The determination of the critical mass was achieved by placing a first load of 700 grams of U^{235} in the reactor. The theoretically computed critical mass was 1960 grams for the arrangement of the uranium in a block, which was adopted as being the minimum critical mass. The load was arranged as a ring about the outer edge of the annular area. It was then possible to make use of the efficiency of the control and safety plates. The rest of the case was filled with lucite plates, in order to avoid possible positive vacuum coefficients.

Filling with water was in five stages, taking, for each water level, the number of counts (N) in each tube and drawing the $1/N$ curve as a function of the height. This operation was repeated systematically for each load. The purpose of the test was to keep the reactor from growing critical when the water level was reached with the control rods, which would have caused a rapid increase of the flux, since the reactivity is very sensitive to small variations of the water level.

The counts having been made with the control plates inside and outside, the reactor was shut down and emptied, and a new load was added, as determined by the manner in which the $1/N$ curve shaped up as a function of mass M (or $1/M^2$).

The following is the order of operations:

1. Arrange the fuel elements in the annular space.
2. Raise the safety plates and make a count.
3. Close the discharge valves and bring the water level to 40 cm, taking the number of counts.
4. Raise the water level in 20-cm steps and take the number of counts at each level when the recorder indicates that the flow has been stabilized.
5. Represent $1/N$ as a function of the water level and extrapolate for $1/N = 0$.
6. If the extrapolation point falls at a level greater than 1.20 meters (full tank), complete the filling and take the number of counts.
7. Remove the control plates and take the number of counts.
8. Shut down the reactor, using different methods in each instance, for the purpose of verification.
9. Decide the next load on the basis of the $1/N$ curves, as a function of mass M. Two curves are drawn for each counter, one with the control plates inserted, and the other with the plates out. The load added will be such that the total mass will be less than the smallest extrapolated critical mass in all instances.

Seven loads were tested in each case. The extrapolated critical mass was 2340 grams with the control plates inserted and 2200 grams with the control plates pulled out.

Flux Distribution

The first measurements were carried out by activation of small manganese plates. The radial profile of the flux was determined in the central cylinder (internal reflector), the vertical profile of the flux inside the core, and the vertical profile inside the central reflector. In the outside reflector, no determination was made of the flux, since this zone is less accessible and this is where we find the detection instruments and the control plates. Figures 16, 17 and 18 show the results obtained.

Comparison of Experimental and Theoretical Results

Agreement between the experimental results and those computed can be considered satisfactory, allowing for the influence of the factors which may not

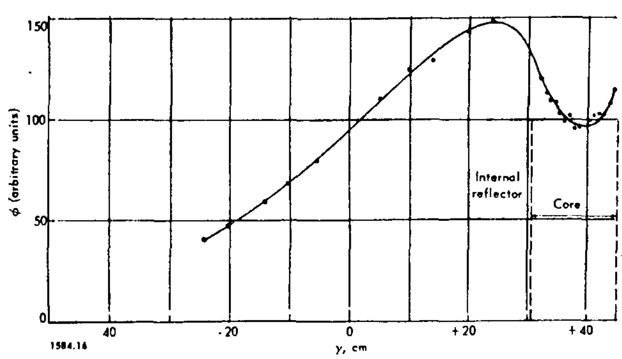


Figure 16. Radial flux distribution (experimental). Thermal flux along the diameter (axis of symmetry)

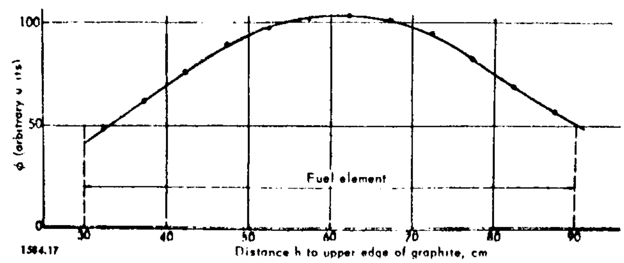


Figure 17. Distribution of the vertical flux in the core (experimental). Thermal flux along a fuel element

have been allowed for in the computation. The most important discrepancies observed are the following:

(*a*) The computed critical mass is markedly smaller than that actually obtained. This underestimate of the critical mass seems to be inherent in the method, since it is also observed in the case of the " Argonaut ". It is necessary to point out that in this computation the distribution of U^{235} is supposed to be homogeneous. This was in fact achieved since, in order to reduce the critical mass to the utmost, the core was charged in such a way that the plates having the largest uranium contents were placed in the central zone. If such a precaution had not been taken, the recovered mass would have been much greater. In an experiment carried out with another distribution of fuel, a critical mass of the order of 2650 g U^{235} was obtained, which clearly proves the great influence of the lack of homogeneity of the fuel concentration in the volume of the core.

(*b*) The radial flux curve of the core, obtained by computation, shows a maximum with a positive curvature in the center, which is not shown on the experimental curve. It is likely that the depression which the experimental curve shows at the center of the core is due to a greater concentration of U^{235}, since the central plates, as already indicated, are richer in uranium.

(*c*) The maximum of the flux curve in the graphite reflector, with respect to the value in the core, is greater in the experimental curve than in the theoretical one. This may be due to various causes. The depression of the flux in the core, due to the non-homogeneous distribution of the uranium, acts in that direction. The curvature of the core (which instead of being parallelepipedal is a sector of the annular zone) also may have a certain neutron concentration effect in the zone of the internal reflector. Finally, it may be of some importance that there is a different spectral distribution of the neutron energy. In the graphite, the mean energy of the neutrons absorbed by the manganese sheets must be less than the mean energy in the core, and since absorption follows approximately the $1/v$ law the flux in the core is measured with less yield than the flux in the reflector.

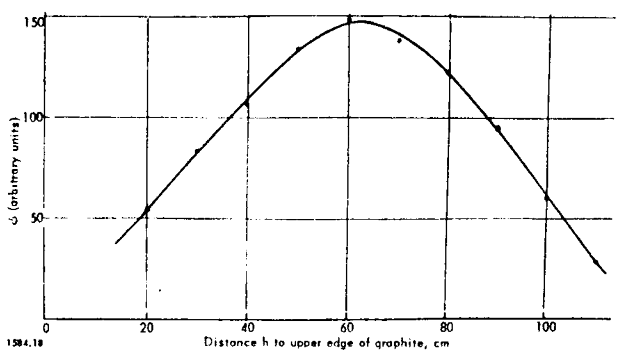


Figure 18. Vertical flux distribution in the reflector (experimental). Thermal flux along a fuel element

CURRENT FUNCTIONS AND CONSTRUCTION EXPERIENCE

Current Functions

The RA-1 is meant essentially for the following: (*a*) training of personnel, (*b*) measuring of cross sections and nuclear parameters, (*c*) shielding tests, (*d*) studies of various load symmetries.

A small amount of radioisotopes may be produced, over and above those that have a short half-life. However, prolonged irradiation has the double drawback of leaving the core active, which makes subsequent experimentation more difficult, and does require constant personal attention, since it still does not have automatic power control, which is now being studied.

RA-2 Project

Since we are dealing with the first reactor built in Argentina, experience acquired in its construction has been of considerable value. Not only have we trained personnel in machining graphite, in making control installations, shields, pipes, etc., but we have gained organizational experience which will be needed for similar projects.

Apart from the installations that have been made by private industry, we have given various firms an opportunity to acquire experience in these new techniques.

Although the designs were made in Argentina, they were based on the Argonne National Laboratory plans for the "Argonaut" and for reasons of time we limited ourselves to modifications in the details.

In consequence, during the building of the reactor some modifications in design arose, which were not incorporated in the RA-1 in order not to hold back the work. All the observations collected were accumulated in order to be used in a new design incorporating the structural modifications considered desirable both through discussion of the plans and through experience with the reactor already built and functioning.

As a result of these modifications, a reactor project was drawn up, similar to the RA-1 as regards its purposes and characteristics, but simplified as to its structural details, to make it more economical, and equipped with a few experimental facilities which are not available on the RA-1.

For instance, the inside thermal column is square instead of round, to reduce the machining of graphite, and it is filled with graphite blocks which can readily be removed, making it possible to obtain irradiation channels where required.

The demineralized water tank has been placed under the reactor in a basement, in order to reduce the length of the piping. In addition, the total amount of water has been reduced, so that the tank is smaller and more economical and it is easy to control the temperature of the moderator by heating or cooling. In this fashion the determination of the temperature coefficient can be made more accurate and simple.

The central thermal column may be extended until its upper surface is at the level of the shield, which makes it easier to install structures on the reactor for exponential experiments.

The design of the control rod has been simplified, as well as the arrangement of the fuel elements and the collar on the reactor.

It is felt that RA-2, which incorporates in its design all the experience obtained with the "Argonaut" and with RA-1, as well as the main characteristics of other reactors of the same type, is at the present time a more economical and versatile reactor for the objective for which it is designed than those used as a model.

Various parts will be tested in the RA-1, and subcritical tests will be conducted on the distribution of the proposed load.

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