SOME RESULTS OF THE OPERATION OF THE BRAZILIAN SWIMMING POOL REACTOR IEAR-1

ALGUNS RESULTADOS DA OPERAÇÃO DO REATOR BRASILEIRO DE PISCINA IEAR-1

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SOME RESULTS OF THE OPERATION OF THE BRAZILIAN SWIMMING POOL REACTOR IEAR-1

INTRODUCTION

The Brazilian Swimming-pool Reactor has already been described [1] [2] and the first critical experiment performed on September 16th, 1957; six months later, during some operations at high power (1-2.5 and 5 Mw) abnormal levels of activity were detected in the bridge and also abnormal levels of airborne activity[3]. The analysis of these abnormal levels of activity showed that the fuel elements were possibly corroded, with a consequent release of fission products in the water and air. Further tests[5] showed that at least 10 fuel elements had failed and so a new set was ordered.

Before putting the new fuel elements in the water it was decided to empty the front compartment of the pool in order to clean the walls, the suspension frame and the grid plate of any eventual contamination by fission products released from the old set of fuel elements; at the same time it would be possible to install a new return of the primary cooling system. This replacement was needed since the old return of the primary cooling system was producing a severe turbulence, which destroyed the hot water layer that in high power operations is needed to avoid the increase of activity at the water surface due to N^{16} or Na^{24}.

At the beginning of 1959, the front compartment of the pool - was emptied, after the removal of the defective fuel elements to an appropriate rack located in the rear compartment of the pool. The walls and grid plate were then decontaminated and after the new return of primary cooling system was installed, the front compartment was filled with demineralyzed water.

This paper, which is divided in three parts, A, B, and C, presents some results of pre-critical, critical, low power and high power experiments performed from January 1959 to April 1960. Part A describes the tests conducted in order to verify if the defective elements were still releasing fission products in the water, and also the experiments to determine the release and fall times of the safety rods. Part B presents some results of the critical and low power experiments performed to re-calibrate the power measuring instruments and also the calibration curves of the control and safety rods. Finally, part C gives the results of high power operation from 500 kw up to 5 Mw.

PART A: PRE-CRITICAL EXPERIMENTS

RELEASE OF FISSION PRODUCTS FROM FAILED FUEL ELEMENTS

After the removal of the failed fuel elements from the grid plate of the reactor to the storage rack located in the rear compartment, a gate was inserted between the two compartments, allowing the front one to be emptied for the purpose already described.

When the gate was still in position, during the filling of the front compartment, it was decided to investigate if the failed fuel elements were releasing fission products in the water. At the time it was decided to perform such investigation, a reasonable part of the water of the rear compartment had already been mixed with the water of the front compartment. Indeed, the tightness of the gate had been carefully maintained when the first compartment was emptied; but after this compartment started to be filled, no special attention was given to that tightness. Before the series of tests described below were performed, the tightness of the gate was again carefully restored, and the absence of any mixing was checked by decreasing the water level of the first compartment relatively to the rear one and measuring continuously this level difference.

For the detection of fission products, water was sucked by a pump and a by-pass line with two small plastic tubes containing anionic and cationic resins, was installed in the outlet pipe. The flow of water through the resins was controlled by a valve, and adjusted to 10 liters per hour. A schematic drawing of the sampling and radioactive demineralyzer systems is given in figure 1.

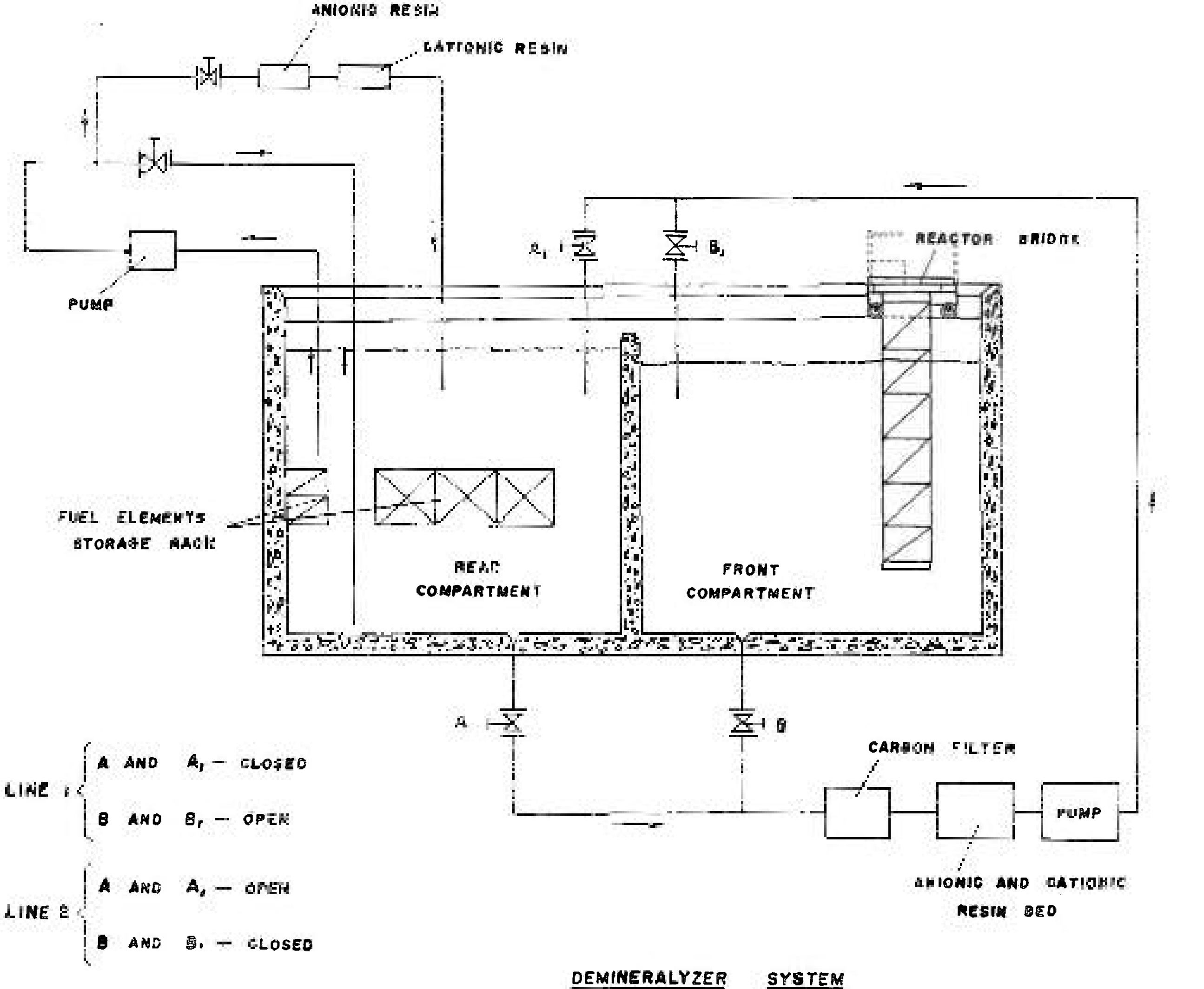


Fig. 1 SCHEMATIC DRAWING OF SAMPLING AND DEMINERALYZER SYSTEMS

After the first experiments, the presence of Cs-137, Cr-51 , Ce-144 and Fe-59 was detected by gamma-spectrometry in the cationic resin; in the anionic resin only appeared again the Cr-51. It was then decided to check the presence of fission products through a quantitative gamma-spectrometric determination of Cs-137, since for this isotope a calibrated source was available.

The results of the experiments carried out to determine the amount of Cs-137 present in the rear compartment and the capacity of the radioactive demineralyzer system to remove such isotope, are presented in table 1.

TABLE 1

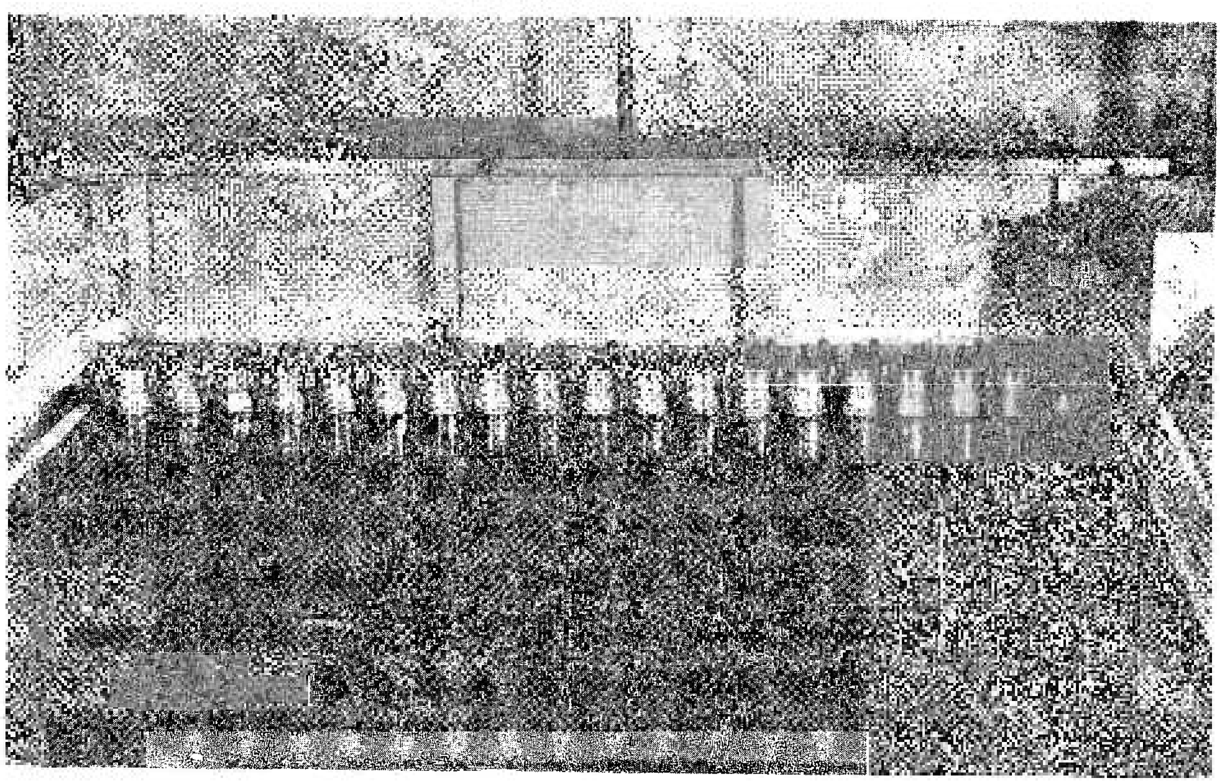
Sample Number	Compartment Sampled	Date of Sampling	Demineralyzer system		Specific Activity of Cs-137 in the water (10^{-8} µc/ml)
			Line 1	Line 2	
4	Rear	Jan.14 to 15	ON	OFF	3.6
5	Rear	15 to 16	ON	OFF	3.6
6	Front	16 to 17	OFF	ON	0.6
7	Rear	17 to 19	ON	OFF	1.5
8	Front	19 to 20	OFF	ON	0.25
9	Rear	20 to 21	ON	OFF	1.9
10	Rear	21 to 22	ON	OFF	3.7
11	Rear	22 to 23	ON	OFF	5.8
12	Front	23 to 24	OFF	ON	0.07
13	Rear	24 to 26	OFF	ON	4.6
14	Rear	29 to 30	ON	OFF	4.3

The comparative analysis of the results of the specific activity of samples numbers 6, 8 and 12 shows that the removal of fission products from the front compartment is effective. On the other hand, the results for samples numbers 5, 7, 9,, 10, 13 and 14 show clearly that the rate of the removal of the fission products in the rear compartment was not sufficient to decrease continuously its specific activity; even after a 48 hours circulation of the water from the rear compartment, its specific activity did not decrease below 4×10^{-8} μc, showing that there was a continuous release of fission products from the defective fuel elements. The rate of this release was so high that the specific activity increased to $5{,}8 \times 10^{-8}$ $\mu c/ml$ when the line 2 of the demineralyzer system had been off for 72 hours.

It was then decided to isolate the defective fuel elements from the pool water, putting them into a set of aluminum tubes immersed in the water.

A photograph of this set of storage tubes is shown in figure 2 and a detailed description of these experiments and of this extra storage rack for defective fuel elements will shortly be published.

Figure 2



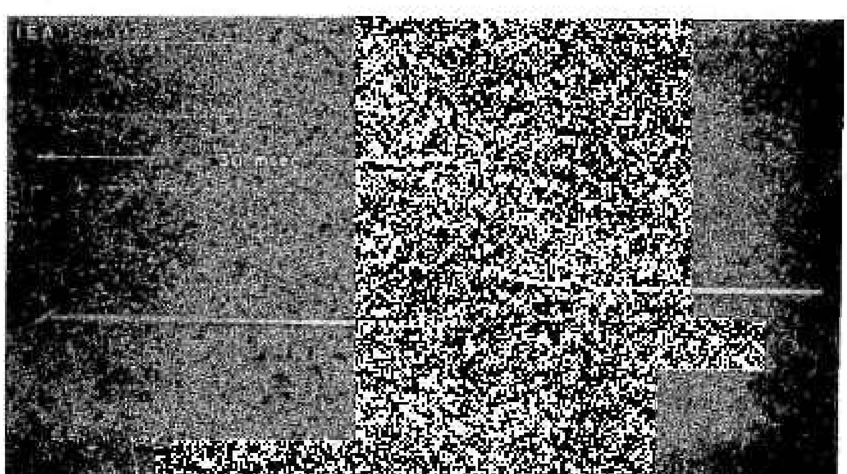
RELEASE AND FALL TIMES OF THE SAFETY RODS

After the partial fuel elements that house the safety and control rods were positioned in the grid plate, a series of measurements were carried out in order to determine the release and fall times of the safety rods.

The release time of a safety rod is defined as the time interval between the appearance of a fast signal (rise time of the order of 1 μsec) at the sigma bus and a measurable separation of the safety rod armature from the electromagnet.

The measurements of the release time of the three safety rods were performed by injecting a square pulse of 1 μsec rise time at the sigma bus of the safety amplifiers and at the beam trigger terminal of a Tektronix oscilloscope. The measurable separation of the safety rod armature from the electromagnet was given by the opening of the clutch switch of the safety rod; when this clutch switch was opened, a second signal was sent to the vertical deflection plates of the oscilloscope. Figure 3 gives a photograph of one of the measurements.

Figure 3



The release time depends, for each safety rod, on the ratio i_m/i_r where i_m is the actual magnet current and i_r the release magnet current, that is, the minimum value of the magnet current that still holds the safety rod. Table 2 gives the release time, in milli-seconds, versus i_m/i_r for the safety rod nº 1; the values obtained for the two other safety rods do not differ appreciably from these ones.

Table 2

Safety Rod nº 1 Magnet Current Ratio $\frac{i_m}{i_r}$	Release Time (msec)
1.30	28.6
1.50	40.8
1.75	58.2
2.00	72.6
2.25	81.8

The release time defined above do not apply for safety rod drops caused by signals that actuate on the slow scram line of the safety system of the reactor. Indeed, the slow scram line actuates a relay that opens the power line of the magnet current circuitry transformer, whereas the fast scram line actuates through the sigma amplifier, directly on the grids of the tubes that supply the magnet currents. The delay time between a signal from one of the safety devices capable of opening the slow scram line, and the rod separation was measured by a method similar to the one already described. Some typical values for this delay time are given in table 3, all of them for - $i_m/i_r = 1.5$, that is, for normal operating value of the magnet currents.

TABLE 3

SAFETY DEVICE	DELAY TIME(msec)
Manual Scram	114
Continuous air monitor scram	121
Basement door opening scram	127
Bridge lock scram	125

Another important parameter for reactor control is the fall time of a safety rod. The fall time of a safety rod is defined as the time elapsed from the opening of the clutch switch to the instant the safety rod reaches its fully inserted position.

The measurement of the fall time for each safety rod as a function of the distance from the fully inserted position, was carried out using the same oscilloscope technique. In this case, the opening of the clutch switch triggered the Tektronix oscilloscope beam. A microphone placed near the grid plate gave the signal that indicated that the safety rod had reached its fully inserted position. The results of the measurements are given in table 4.

TABLE 4

Rod Number	Percent Withdrawn	Fall Time (msec) with circulation (2000 gpm)	Fall Time (msec) without circulation
1	100	405	458
	75	345	376
	50	261	294
	25	167	178
2	100	418	450
	75	348	370
	50	262	288
	25	156	198
3	100	400	445
	75	342	374
	50	262	296
	25	172	204

This table also gives the results of measurements performed with a complete core and forced circulation of the water at a rate of 2000 gpm. Of course, those measurements were performed after the critical experiment that will be described in part B, and were conducted in order to determine the influence of the water forced circulation upon the fall time of the safety rods.

It is interesting to remark that the technique employed permits the verification of any abnormal behaviour of a rod during its fall.

PART B: CRITICAL AND LOW POWER OPERATIONS

CRITICAL EXPERIMENT -

After the completion of the pre-critical experiments and a thoroughly check of the correctness of all the safety and measuring circuits operation, a critical experiment was performed on March 13th, 1959.

The curve of inverse multiplication versus U-235 mass in the core is presented in figure 4, and from its extrapolation, the critical mass of U-235 should be 3568.50 grams.

The total mass of U-235 was 3575.32 grams, in a 5 x 5 array-with six graphite reflectors on the south face of the core (figure 5), and the reactor reached criticality with all safety rods fully withdrawn and the control rod at 56% withdrawal.

LOW POWER EXPERIMENTS

The 5 x 5 loading with minimum U-235 mass used to perform - the critical experiment was evidently not suitable to calibrate the safety or control rods; but its geometry was quite convenient for comparison with the theoretical calculations.

Figure 4

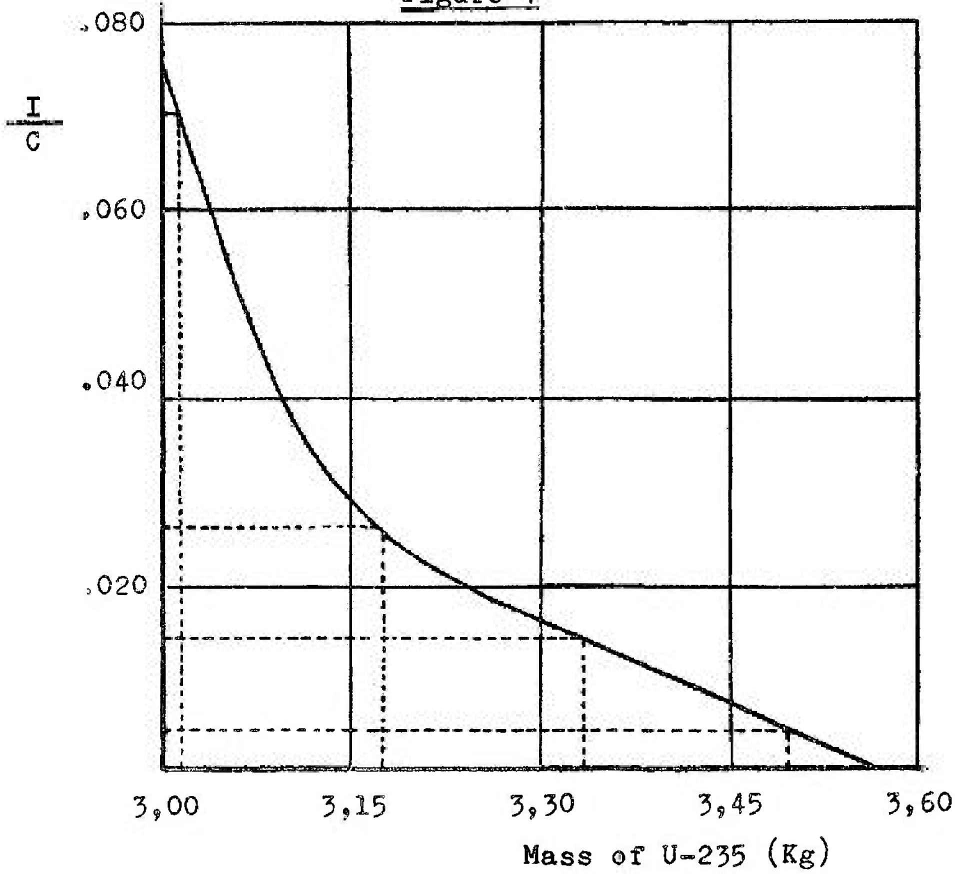
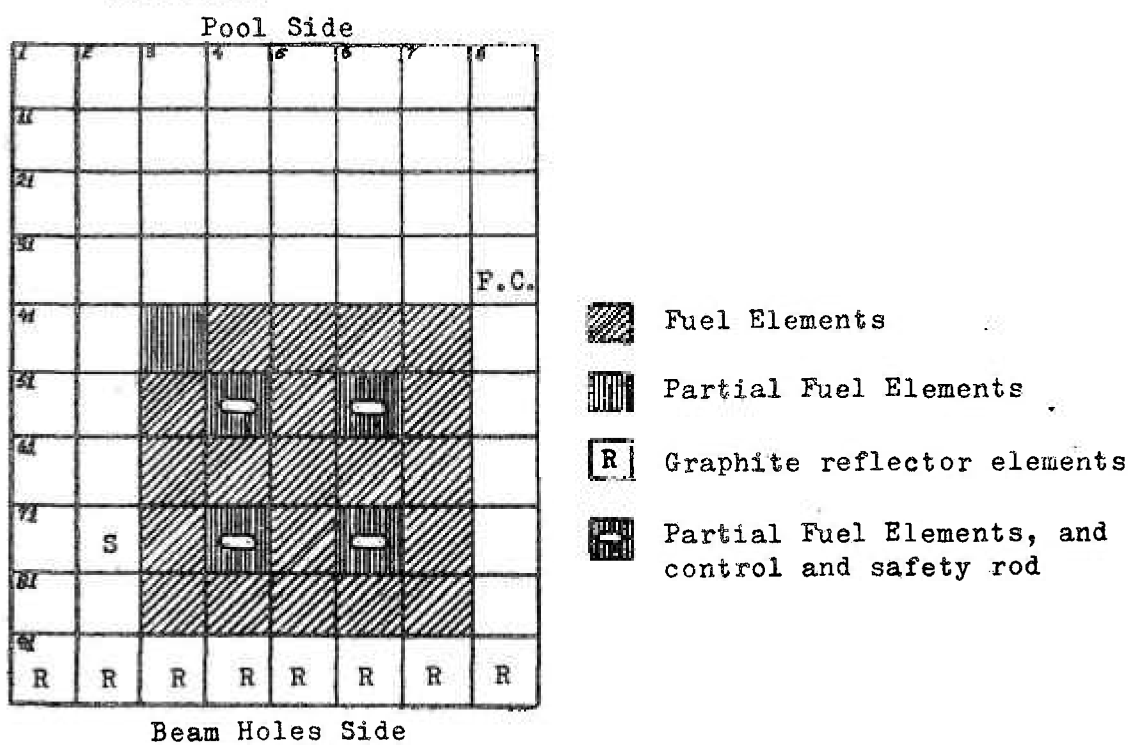


Figure 5



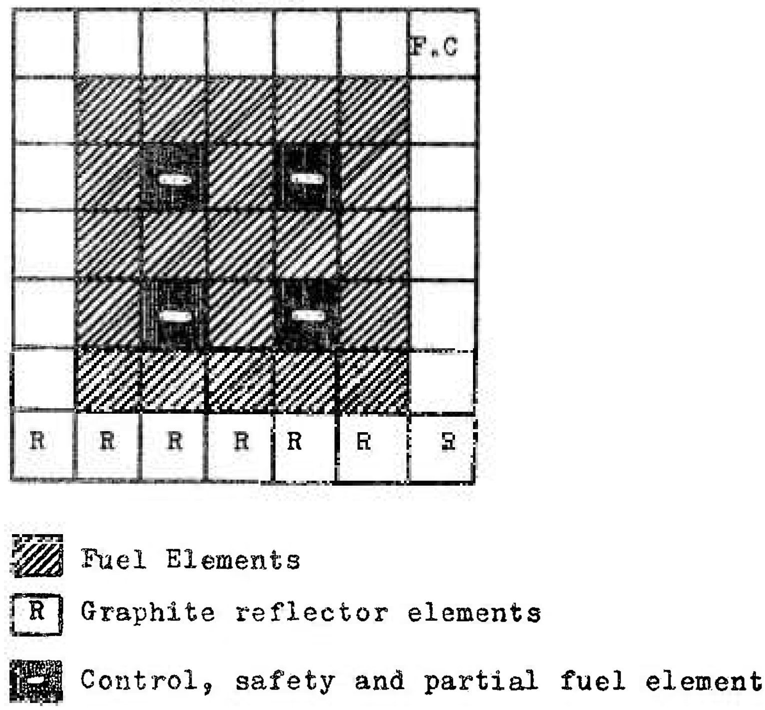
For this reason it was decided to calibrate the power measuring instruments using a loading with the same geometry, but with a reactivity - slightly greater. This loading, numbered 40, is shown in figure 6.

The reactor was then operated at a nominal power level of 50 watts and the standard procedure of gold foil activation was used to get a flux mapping of the core. The results of such flux mapping are presented in table 5 and figure 6.

Table 5

Fuel Element Number	Position	$\overline{\varphi}_{f.elem}/\overline{\varphi}_{core}$	Fuel Element Number	Position	$\overline{\varphi}_{f.elem}/\overline{\varphi}_{core}$
62	43	0.51	52	63	1.30
59	44	0.82	53	67	0.93
58	45	0.91	46	73	0.89
60	46	0.78	75	74	1.22
61	47	0.60	47	75	1.25
54	53	0.72	76	76	1.22
77	54	1.00	48	77	0.89
55	55	1.16	41	83	0.74
74	56	1.01	42	84	0.94
51	57	0.80	43	85	1.10
49	63	0.94	44	86	0.94
50	64	1.30	45	87	0.70
56	65	1.39			

Figure 6



The real power calculated from those data was 18.7 watts, and the compensated ion chambers of the linear level and log N measuring circuits were positioned to give such value for the power level.

Another flux mapping of the core was also made using copper wires, inserted between the plates of the fuel elements. This wire technique was developed by the Nuclear Physics Division of the Institute and a complete description of the experiments will be the object of another paper to be published.

After these flux mappings, the core loading was changed by adding successively three more fuel elements; the total mass of U-235 in the core became then 4055.88 grams. This core loading, numbered 49, has been used since October 13th, 1959, and has enough reactivity to allow the operation of the reactor even at 5 MW.

During some special experiments the core loading has been changed and until March 1960, 11 different loadings have been used.

All the experiments described in this paper were performed with loading number 49. The control and safety rod calibration curves for this loading are given in figures 7 and 8.

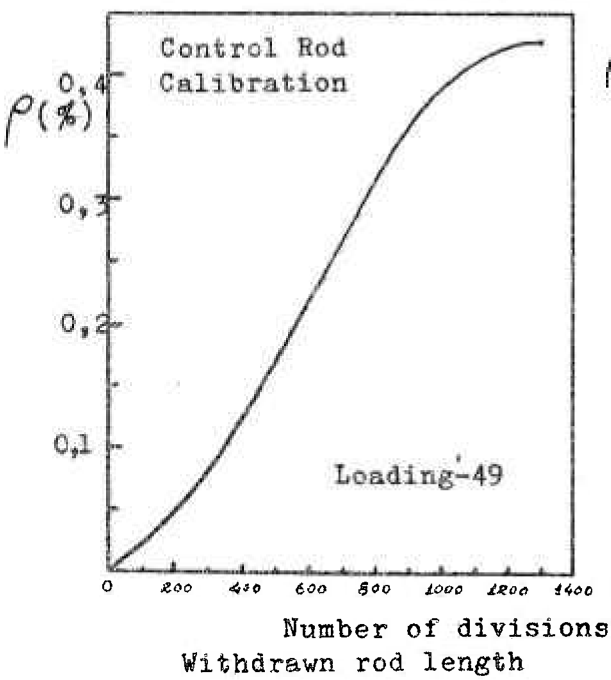


Figure 7

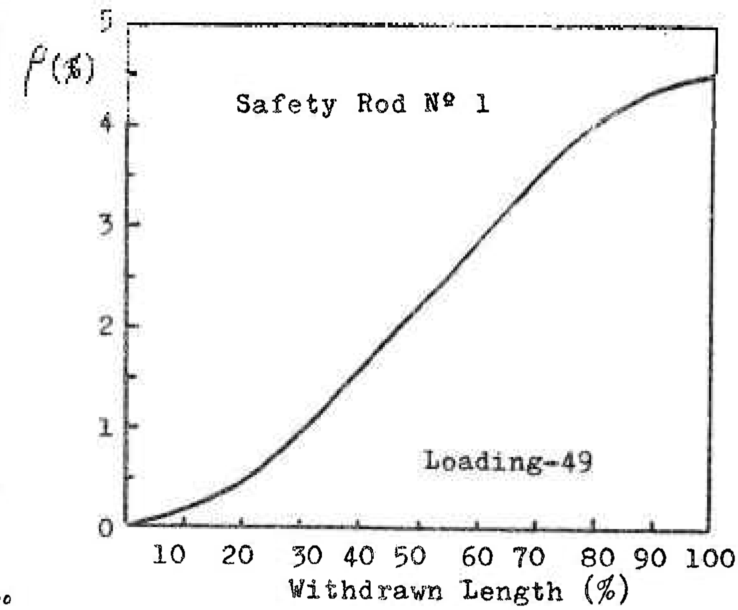


Figure 8

The calibration curve of figure 7 was obtained by the in-hour method. The periods were measured using the fission chamber channel at power levels less than 100 watts, to avoid any influence of the temperature effect. The built in reactivity of the core was quite sufficient to allow a calibration of the control rod from fully inserted to fully withdrawn. The numbers in the abscissa axis of figure 7 refer to divisions of the control rod positioning meter. This meter is operated by a selsyn motor coupled to another one connected to the gear-box of the drive mechanism of the control rod. This measuring system replaced the original one that used a meter and a helipot geared to the drive mechanism, because it was noticed that this one was quite sensitive to voltage fluctuations on the main power line and did not give reproducible readings.

The complete calibration of the safety rods were not possible with loading 49, because there was not sufficient built-in reactivity to allow a full insertion of any safety rod. The curve presented in figure 8 was obtained from 40% to 100% withdrawal by direct inter-calibration with the control rod. From 40% down to 0% the shape is an approximate one, since this part was obtained assuming symmetry in relation to the mid point.

It can be seen from figures 7 and 8 that the total reactivity controlled by the control rod is 0,42% and that the linear part of the curve has a slope of 0.49×10^{-3} %/div. or 1.09×10^{-2} %/cm; for the safety rod nº1, the total reactivity is 4.42% and the slope in the linear region is 0.11%/cm .

The speed of these rods are:

control rod: 16.48 mm/sec

safety rods: 1.752 mm/sec.

As a matter of fact, the high speed of the control rod is necessary in the automatic operation of the reactor when a servo-mechanism, coupled to the linear level recorder, maintains the power level at any preset value from 5 watts up to 5 megawatts.

PART C: HIGH POWER OPERATIONS

OPERATIONS AT 500 kw

After some months of operation at power levels less than 200kw, the reactor power was raised to 500 kw.

For operation in the power level range from 200 kw up to 5 Mw - the core is cooled by forced circulation of the pool water. The primary cooling system is of the closed circuit type and water is forced to circulate through the plates of the fuel elements at a rate of 2400 gpm.

A total of 27 operations at 500 kw power level were performed until May 1960, corresponding to a total energy of 47,500 kwh; those operations were conducted mainly for the production of I-131, Au-198, and neutron-spectrometry experiments.

A quite remarkable result was obtained on 1960, during operation number 20/60.

During that operation, it was noticed that the bulk pool temperature, measured by the thermocouple number 8 located at 5 meters below the water surface, was 11°F above the cooling tower water temperature. Consequently, when the cooling tower fans and the primary and secondary pumps were turned on, the temperature at the bottom of the pool decreased rapidly and when the reactor was critical at low power, there was a temperature difference of 10.8°F between the readings of the thermocouples 8 and 9. Since the thermocouple number 9 was located at a distance of 30 cm below the water surface, this meant that there was a sort of stratification of the pool water, with the upper stratum - at a higher temperature than the lower one.

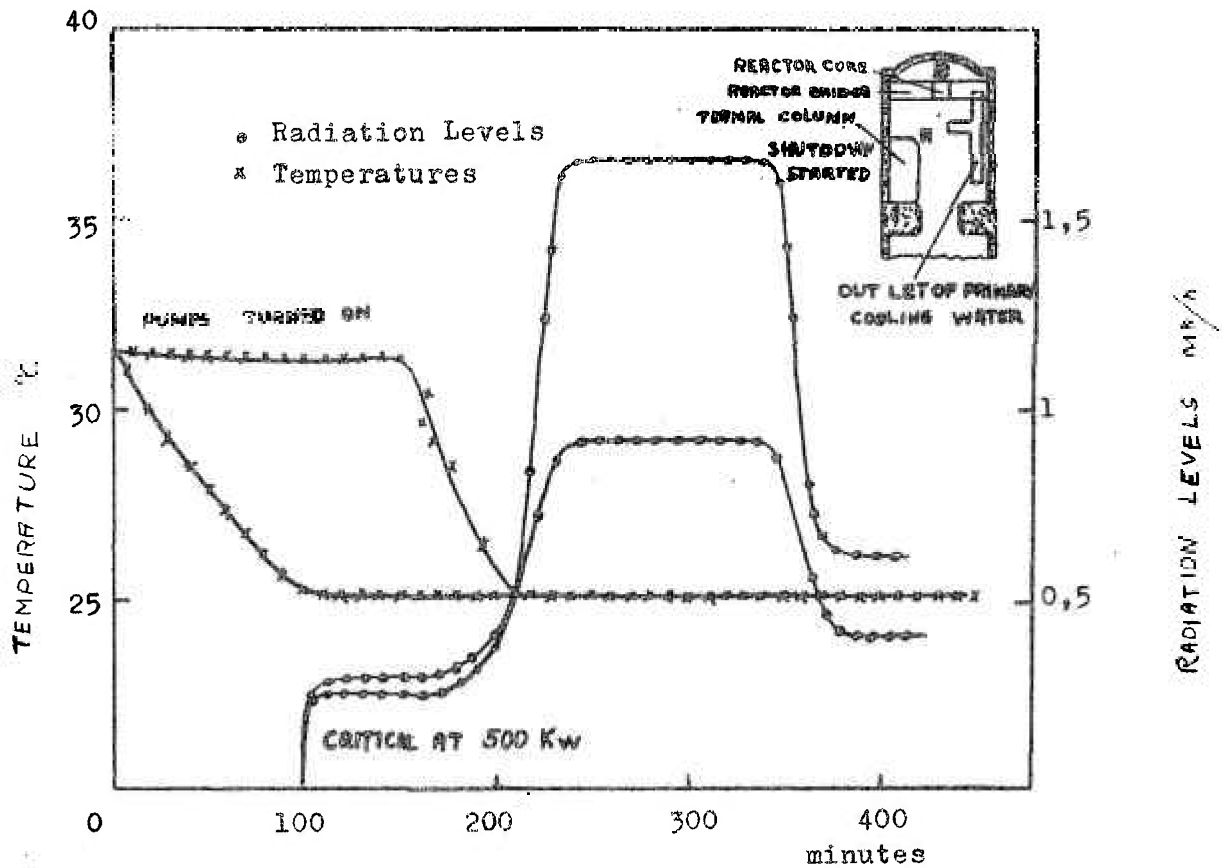
This stratification would certainly be quite effective in reducing the activity level at the surface of the pool, since any radionuclides produced during the operation of the reactor and present in the water, would be confined to the lower water stratum.

This indeed happened: when the reactor power level was raised to 500 kw, the activity levels at the surface of the pool were much smaller than the ones normally found in other operations at the same power level and in which there was no formation of an upper hot water layer(6). After 110 minutes of operation at 500 kw, the temperature of point 9 dropped rapidly, showing that the stratification was being destroyed. This was certainly due to the water turbulence produced even by the new return of the primary cooling - system.

The disappearance of the upper hot water layer allowed the radionuclides present in the water to reach the surface and therefore the activity levels at the pool surface increased rapidly, reaching the values observed in all the previous operations at 500 kw power level(6).

In figure 9 are shown the curves of the temperatures of points 8 and 9 and the pool surface activity levels at the regions A and B.

Figure 9



Region A shows an activity level higher than region B because it is near the region of the pool surface where the water turbulence is greater. This region is located on the vertical of the thermal column edge , near the primary cooling system return outlet. Previous experiments had indeed already shown that practically all the water turbulence is produced on that region.

The results shown in Figure 9 prove quite conclusively that the presence of a hot water layer is really efective in reducing the activity-levels at the surface of the pool; the problem remains, however, of how to maintain this hot water layer or, what is equivalent, of how to avoid any turbulence capable of destroying it.

Further experiments to determine the influence of the thickness of the hot water layer on the pool surface activity levels are being planned for this winter; it is hoped that the heating system available to produce a hot water layer on the surface of the pool will be capable of heating sufficiently the pool water, to reproduce the conditions that were found, by chance, on that operation number 20/60.

OPERATIONS AT 2 AND 5 MW

On March of this year, two operations at high power were performed: one at 2 Mw and another at 5 Mw power level. During both operations an extensive series of measurements were conducted to get some data on the following subjects:

a) activity levels at the surface of the pool;
b) water activity;
c) airborne activities.

In this paper, the results concerning the activity levels at the surface of the pool, will be presented briefly, since a detailed report on this subject and on the water and airborne activities will be presented in this symposium(6).

The operation at 2 Mw was performed onMarch 29th, and the power level was maintained at 2 Mw for 8 hours. The operation proceeded according to the following schedule.

The power level was first raised to 500 kw and the reactor - maintained critical during 9 minutes, in order to re-adjust the position of the high-level safety non-compensated ion chambers.

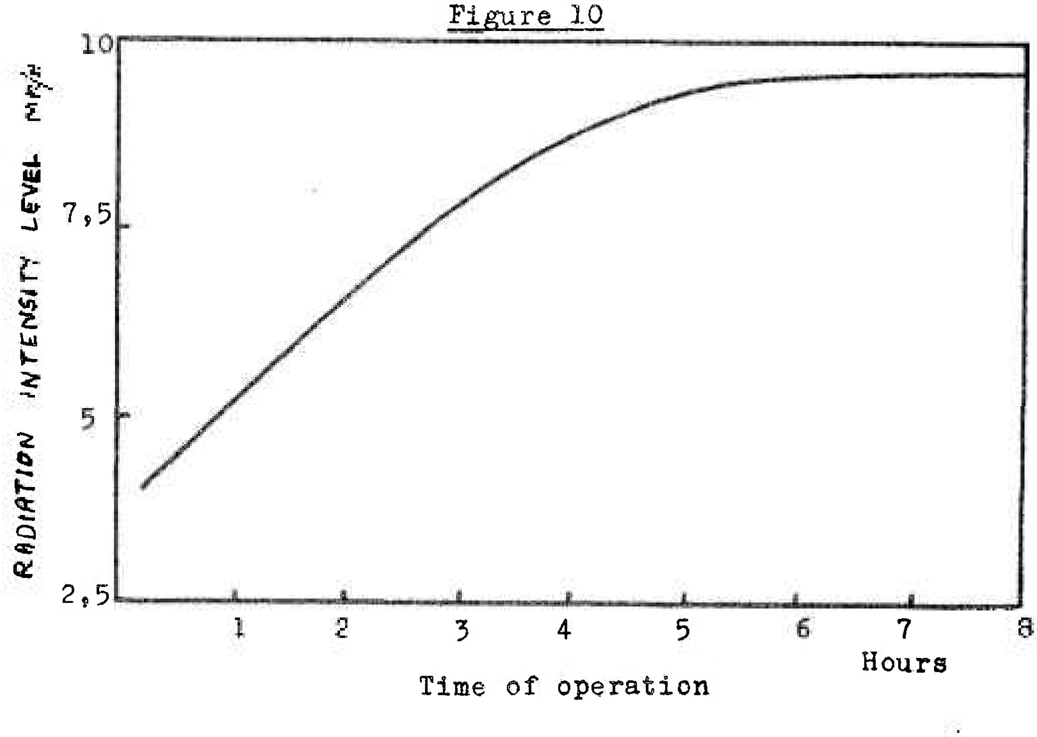
The power was then raised to 1 Mw and this power level maint ined during 20 minutes, for a complete survey of the building, excluding the basement.

Finally the power was raised to 2 Mw, and the operation continued for 8 hours.

The highest activity level observed at the surface of the pool was 10 mr/h, at the region where the turbulence of the water is more pronounced, that is, the region called A in the discussion of the effect of a hot water layer at 500 kw power level operation.

The variation of the activity level at this region, as a function of time of operation, is shown in figure 10.

Figure 10



It can be seen that the activity level was increasing very slightly after 6 hours of operation. This result seems to indicate that the contribution of Na-24 to this activity level must be small, since the half life of this radionuclide is 15 hours. It was not possible to follow the decay of this activity after the shut-down of the reactor, since the instrument used to measure the activity level at this region was not a recording one.

The activity levels at the surface of the pool on two other regions were measured by Jordan monitors and recorded during and after the operation. There was also, for those regions, a quasi-stabilization of the radiation levels at approximately 6 hours after the power level attained 2Mw.

The decay curves of these activities were analyzed and the results are given in the paper by R. Ribeiro Pieroni et al[6].

The temperatures at seven different points were continuously recorded; and the analysis of the results showed that the heat-exchanger - and cooling tower worked properly.

The primary and secondary water flows during the whole operation were 2400 gpm and 1800 gpm, respectively; the calculated thermal power was 1.8 Mw, with no correction for fast neutrons, neutrinos and gamma-rays energy escape.

Regarding the operation at 5 Mw power level, the operation schedule was the following:

a) power raised directly to 2Mw; reactor critical during 23 minutes;

b) power raised to 5Mw; reactor critical during 5 1/2 hours;

c) power decreased to 2Mw; reactor critical during 1 hour.

During the operation at 2Mw, the position of one of the compensated ion-chamber was adjusted to permit the power to be increased to 5 Mw, at 50% of full scale on the recorder of the linear level micro-microammeter channel. At the same time a complete survey of the building was made, excluding the basement.

After the reactor power was stabilized at 5 Mw, an extensive series of measurements of water and air activities was conducted, and the results are presented in the paper by R. Ribeiro Pieroni et al[6].

The maximum activity level observed at the pool surface was 30 mr/h, at the region of maximum water turbulence. The variation of the activity level at this point, as a function of time of operation, could not be obtained due to a fault in the detector. It was possible, neverthless, to see that the time of operation was not enough for this activity level to stabilize, but it increased very slowly, probably due to the gradual build-up of Na-24.

The activities at various points on the building were measured by Jordan monitors and the results are presented in the paper quoted above.

Finally, the analysis of the recorded temperatures showed that for operation at 5 Mw the same water flows used for the operation at 2 Mw were quite satisfactory.

The main results and conclusions obtained during those operations at 2 and 5 Mw were the following:-

a) the activity levels at the working areas on the third floor were quite below the maximum permissible values;
b) the airborne activities observed were all below the MPC;
c) it is not possible to conclude that this situation will be maintained after the equilibrium concentration of Na-24 is reached;
d) the fuel elements are working satisfactorily, even at the maximum power level;
e) operations at 2 and 5 Mw power levels must be conducted during more extended periods of time, in order to be sure that the air and water acti

vity levels and the airborne activity are maintained below the maximum permissible values, even in the absence of a hot water layer;

f) during those more extended operations, it will be most desirable to determine unambiguously the radionuclides responsible for the air and water activities.

Those operations at high power level are being programmed and it is hoped they will be performed during this year.

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