OPERATIONAL EXPERIENCE AND UTILIZATION OF THE BRAZILIAN 5 MWth SWIMMING POOL REACTOR

EXPERIÊNCIA RELATIVA À OPERAÇÃO E UTILIZAÇÃO DO REATOR BRASILEIRO, TIPO PISCINA DE 5 MWth

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ABSTRACT

In this paper some aspects related with the operation and utilization of the Brazilian 5 MWth Swimming Pool Reactor are presented.

The first part, after a brief description of the reactor and associated irradiation and experimental facilities, gives some operational data such as: energy consumption, number of operations, radiation levels, temperature values, etc., obtained in high power operation, from 500 kw up to 5 MWth.

In the second part are described some of the difficulties encountered during the routine reactor operation. Special emphasis is given to the fuel element corrosion problem and to the pool surface activity levels at 5 MWth power operation.

The third part contains a general description of the utilization of the reactor, specially in the production of isotopes, use of neutron beams and training of personnel.

Finally the overall organization of the Reactor Operation Section of the Reactor Physics Division is presented including its relationship with other Divisions of the Institute of Atomic Energy.

REACTOR DESCRIPTION

The IEAR-1 reactor installed at the Institute of Atomic Energy (1) is a swimming pool reactor, designed and built by the Babcock & Wilcox Co., to operate continuously at 5 MW. The fuel elements are of the MTR type, with 19 plates, with uranium enriched at 20%. Each normal fuel element contains about 160g of U^{235} and the partial ones, for the control and safety rods, about 76g.

The reactor can be operated at two different positions. In the main core position, the grid plate is located above the header of the primary coolant loop, and the flow rate through the core is 2600 gpm. The second position is in front of a thermal column, made up of graphite blocks placed inside a rectangular steel box of 1.80 by 2.40 meters, and provided with six channels of removable graphite blocks. The thermal column is shielded by a 16 ton door 12 3/4 inches thick (consisting of 11 inches of steel plates, 1 inch lead and 1/4 inch boral plates). The maximum operating power at this position is about 100 kw; at this power level the reactor does not require forced cooling and the graphite blocks temperature due to radiation heating is reasonable.

The pool is divided into two interconnected compartments. One compartment is provided with a storage rack for spent fuel elements, whereas in the other one the reactor core can be operated either in the main position or in the thermal column position. Both compartments are separated by a movable aluminum gate, so that the core can be stored in the back compartment, whenever repairs in the main pool part are needed.

59 different core loadings and the effect of graphite reflectors have been studied. For the radioisotopes production operation, however, the core loading is one with 24 normal fuel elements and 4 partial ones for the single control and three safety rods. Fig. 1 presents some of the arrangements, the total U^{235} mass, and the approximate excess of reactivity.

The nuclear instrumentation is composed of:

1) One fission chamber for the start up channel;
2) Two compensated ion chambers for the Log N and Linear Level channels;
3) Two non-compensated ion chambers for the safety channels;
4) One neutron thermopile.

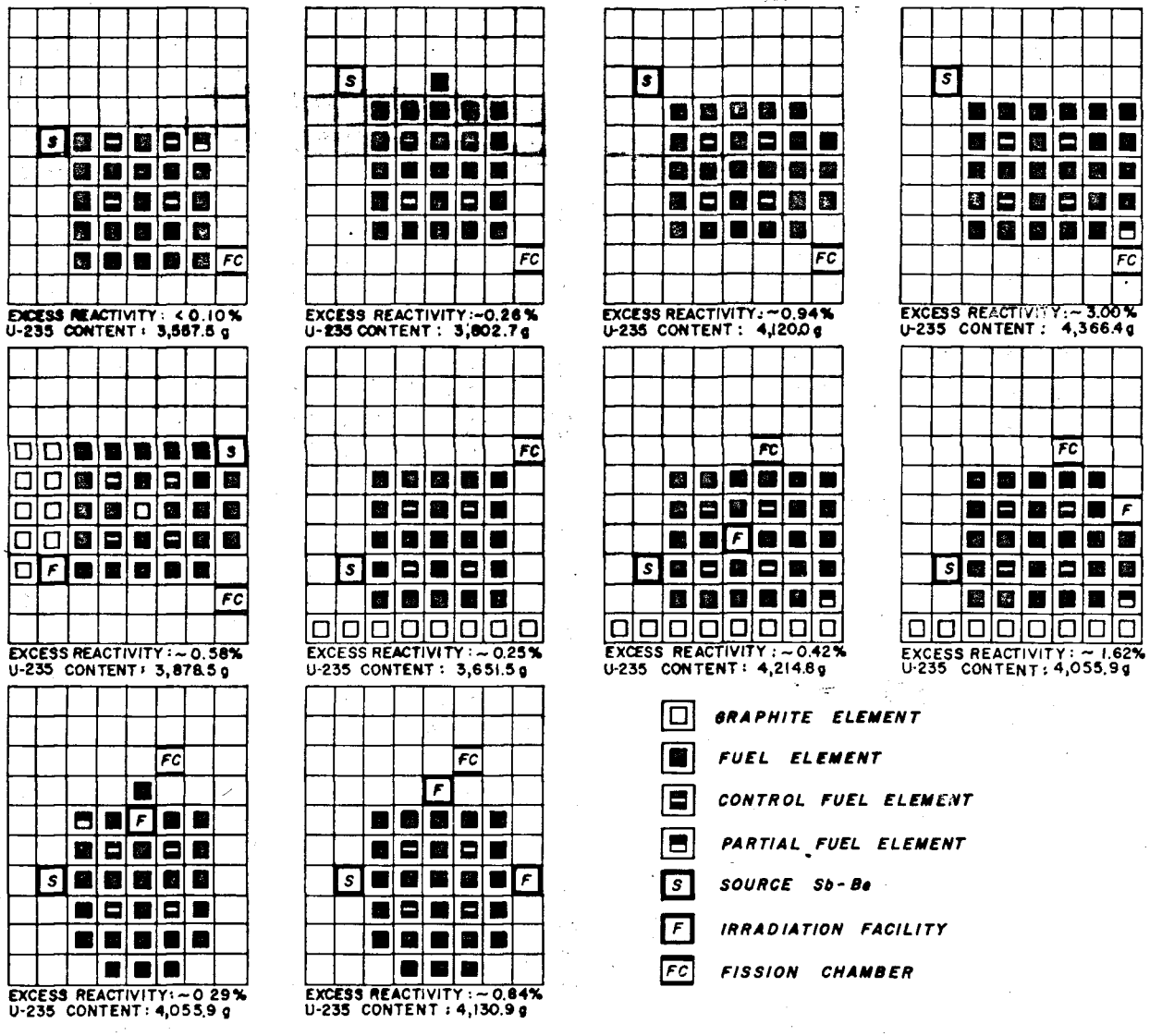

S
FC
EXCESS REACTIVITY : < 0.10 %
U-235 CONTENT : 3,567.5 g
EXCESS REACTIVITY : ~0.26 %
U-235 CONTENT : 3,802.7 g
EXCESS REACTIVITY : ~0.94 %
U-235 CONTENT : 4,120.0 g
EXCESS REACTIVITY : ~3.00 %
U-235 CONTENT : 4,366.4 g
F
EXCESS REACTIVITY : ~0.58 %
U-235 CONTENT : 3,878.5 g
EXCESS REACTIVITY : ~0.25 %
U-235 CONTENT : 3,651.5 g
EXCESS REACTIVITY : ~0.42 %
U-235 CONTENT : 4,214.8 g
EXCESS REACTIVITY : ~1.62 %
U-235 CONTENT : 4,055.9 g
EXCESS REACTIVITY : ~0.29 %
U-235 CONTENT : 4,055.9 g
EXCESS REACTIVITY : ~0.64 %
U-235 CONTENT : 4,130.9 g
GRAPHITE ELEMENT
FUEL ELEMENT
CONTROL FUEL ELEMENT
PARTIAL FUEL ELEMENT
SOURCE Sb-Be
IRRADIATION FACILITY
FISSION CHAMBER

FIG. 1

Two ion chambers (Remote Area Monitoring System) located at the basement near the heat exchanger, act as a reliable reactor power monitor due mainly to the N^{16} activation.

The irradiation and experimental facilities, such as the beam holes, are available at the two core positions.

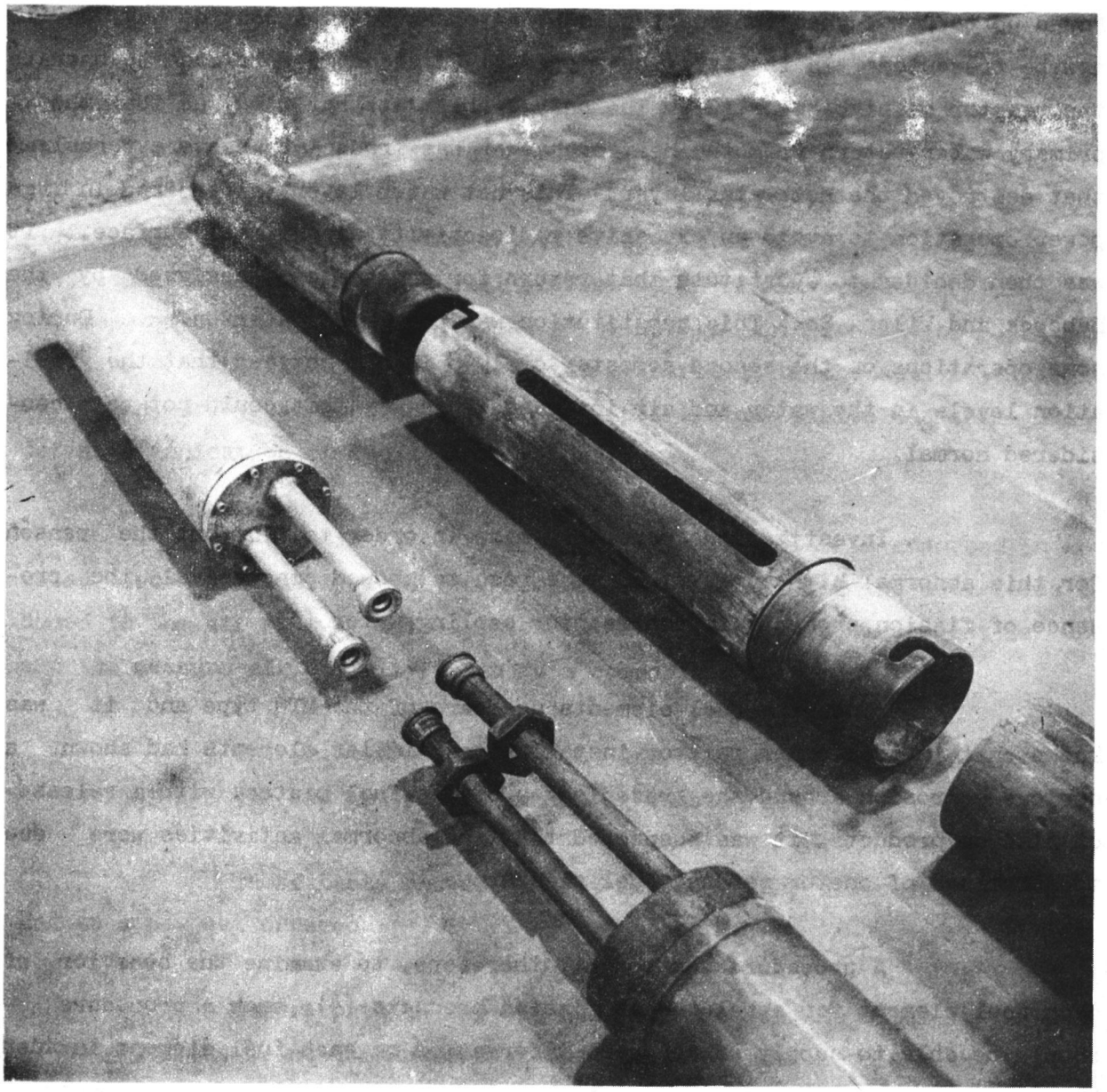
In front of the thermal column position are located two six-inches beam holes. At the main core position there are six six-inches, two eight-inches beam holes, and two six-inches through tubes. Each beam hole can acommodate three different types of plugs and in fig. 2 are shown the photographs of two of them.

1) Sample plugs, inside which it is possible to irradiate huge samples near the core;
2) Electrical plugs for experiments requiring fluid pipes or wires;
3) Colimating plug which allows the withdrawal of a neutron beam of 1 1/2 inch diameter.

Adjacent to the reactor core are located the terminals of a pneumatic rabbit system with three sending and receiving stations.

One of the advantages of the open pool research reactor is the easy access to the core or grid plate, and almost all of the irradiations are performed locating sample holders at the grid plate.

The pool water volume is about 272 m^3. The specific resistivity is maintained on the range of 1 M Ω-cm, and the pH between 5.5 and 6.2. The flow rate through the demineralizing water system is about 18 gpm, 24 hours a day.



OPERATIONAL EXPERIENCE AND DIFFICULTIES ENCOUNTERED DURING ROUTINE OPERATIONS

The reactor went critical for the first time on September 16, 1957. A brief chronological description of the main problems and difficulties found up to date, when the reactor is being operated in a routine way, will now be presented: In the first quarter of 1958 attempts were made to operate the reactor on high power (2). The only problem at that time was that the primary water return from the heat exchanger was producing a severe turbulence that destroyed the hot water layer. This hot water layer is required in high power operation to avoid an excessive radioactivity at the pool surface. It was then decided to substitute that return for another one, designed by the Babcock and Wilcox Co. This substitution was performed later on. During some operations on the second semester of 1958 it was noticed that the radiation levels in the water and air increased in a way that could not be considered normal.

Investigations were then made in order to find out the reason for this abnormal high activity and the results showed conclusively the presence of fission products in the reactor cooling water (3).

Since the fuel elements used are of the MTR type and it was known that in some other reactor installations similar elements had shown a serious corrosion around the brazed edges of the fuel plates, with a release of fission products, it was suspected that the abnormal activities were due to a failure of one or several fuel elements.

A procedure was sought, therefore, to examine the behavior of each fuel element for a release of fission products (4); such a procedure should be able to supply unambiguous information on each fuel element in order to provide a well established rejection criterion for failed fuel elements.

All the known methods used in the detection of cladding fail-

ures in swimming pool reactor fuel elements were only able to give an indic - ation that a failure had occurred; there was no way, however, to identify the elements responsible for the release of fission products except by comparison of the behavior of each suspected element when inserted in a new core.

A method was then developed to allow an unambiguous identification of a failed fuel element, even when one or more fuel elements of the reactor core were releasing fission products as well.

Essentially, the method developed at the Atomic Energy Institute consists in submitting a fuel element to the leakage neutron flux from the reactor operating at about 10 kw power level. This is done by placing the said element close to the core; the measurement of the activity carried out by an air stream bubbled through the fuel element plates can then give a definite indication of a cladding failure.

The activity carried out by the air stream is adsorbed in activated carbon and easily measured. In order to account for the activities induced in the air or due to impurities in water, a dummy fuel element is used and the measure air activity taken as a compariscn standard.

The procedure is efficient and simple and some improvements on the safety aspects and automation are being considered.

Those tests showed that at least 10 fuel elements had failed and so a new set 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 the new return of the primary cooling system.

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. After the removal of the failed fuel elements a gate was inserted between the two compartments, allowing the front one to be emptied for the purposes already described.

When the gate was still in position, during the filling of the front compartment, it was decided to investigate (5) if the failed fuel elements were releasing fission products in the water. At this time 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 demineralizing system is given in figure 3.

After the first experiment, 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 demineralizing system to remove such isotope, are presented in Table I.

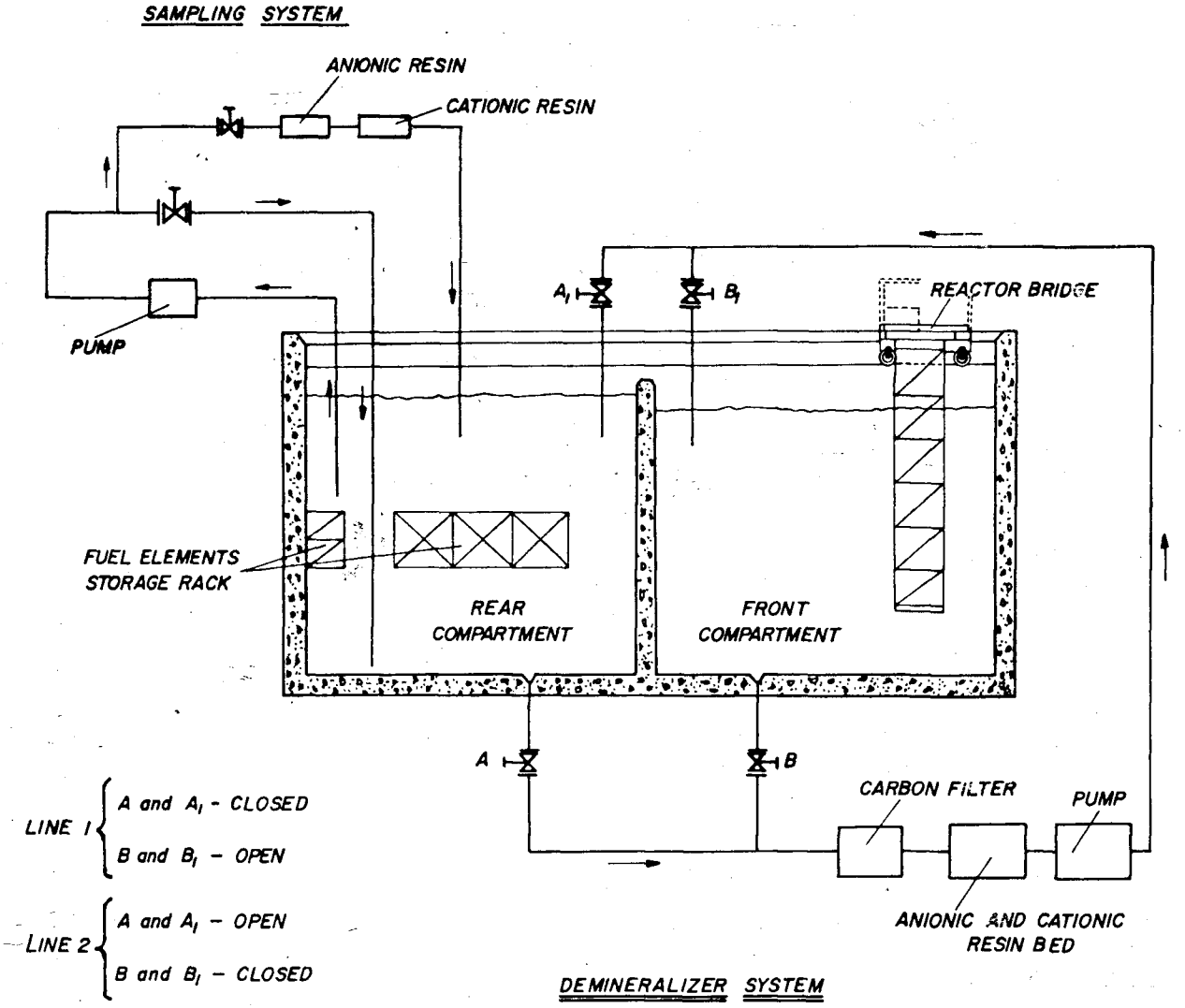

SAMPLING SYSTEM
ANIONIC RESIN
CATIONIC RESIN
PUMP
A1
B1
REACTOR BRIDGE
FUEL ELEMENTS
STORAGE RACK
REAR
COMPARTMENT
FRONT
COMPARTMENT
A
B
CARBON FILTER
PUMP
ANIONIC AND CATIONIC
RESIN BED
LINE 1
A and A1 - CLOSED
B and B1 - OPEN
LINE 2
A and A1 - OPEN
B and B1 - CLOSED
DEMINERALIZER SYSTEM

FIG. 3

TABLE I

Sample Number	Compartment Sampled	Date of Sampling January	Demineralizer System		Specific Activity of Cs^{137} in the water(10^{-8} μc/ml)
			Line 1	Line 2	
4	Rear	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 $5,8 \times 10^{-8}$ μc/ml when the line 2 of the demineralizing 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 tube immersed in the water.

After the required tests, the reactor was brought critical again and

calibrations and other determinations performed. Within a few months the reactor power was gradually raised up to 500 kw. The operations at this power level were required mainly for isotope production and beam experiments.

During one of those operations 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, then the cooling tower fans and the primary and secondary pumps were turned on, the temperature at the bottom of the pool decreased rapidly. 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. After 110 minutes 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 with 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. Therefore the activity levels at the pool surface increased rapidly, reaching the values observed in all the previous operations at 500 kw power level.

In figure 4 are shown the curves of the temperatures of points 8 and 9 and the pool surface activity levels at the regions A and B.

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 direction of the thermal column south 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 Fig. 4 prove quite conclusively that the presence of a hot water layer is really effective in reducing the activity levels at the surface of the pool; the problem was then of how to maintain this hot water layer or, what is equivalent, how to avoid any turbulence capable of destroying it.

In order to solve this problem it was decided to install a plastic layer at about 3 feet below the water surface, in order to help to maintain the stratification. This was done at the end of 1960 when the reactor had to be shut down for a few weeks, to reinforce the tubes of the heat exchanger that presented a severe vibration at the normal flow rates.

Further tests showed that with the water warmed (through a 40 kw heater in the make up water line) and with the plastic layer (fig. 5) the radiation levels at the surface of the pool decreased by a factor of about 8, with the value of 1.8 mr/hr for the gamma-ray dose rate at 2 MW power level.

It will be interesting to point out some date on the 3rd floor activity levels throughout those events. These data are presented in table II.

The energy dissipation during the last years is presented in figure 6.

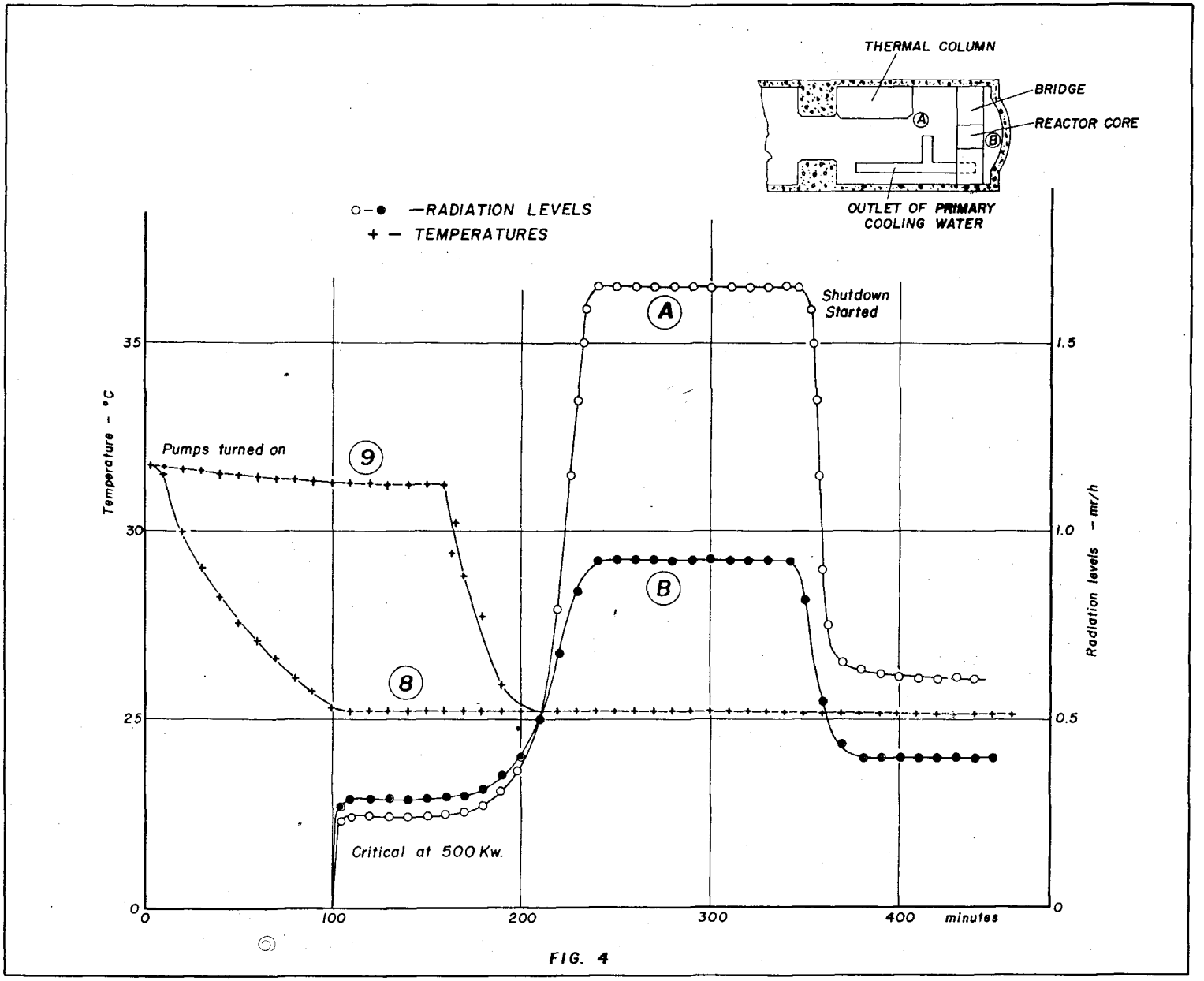
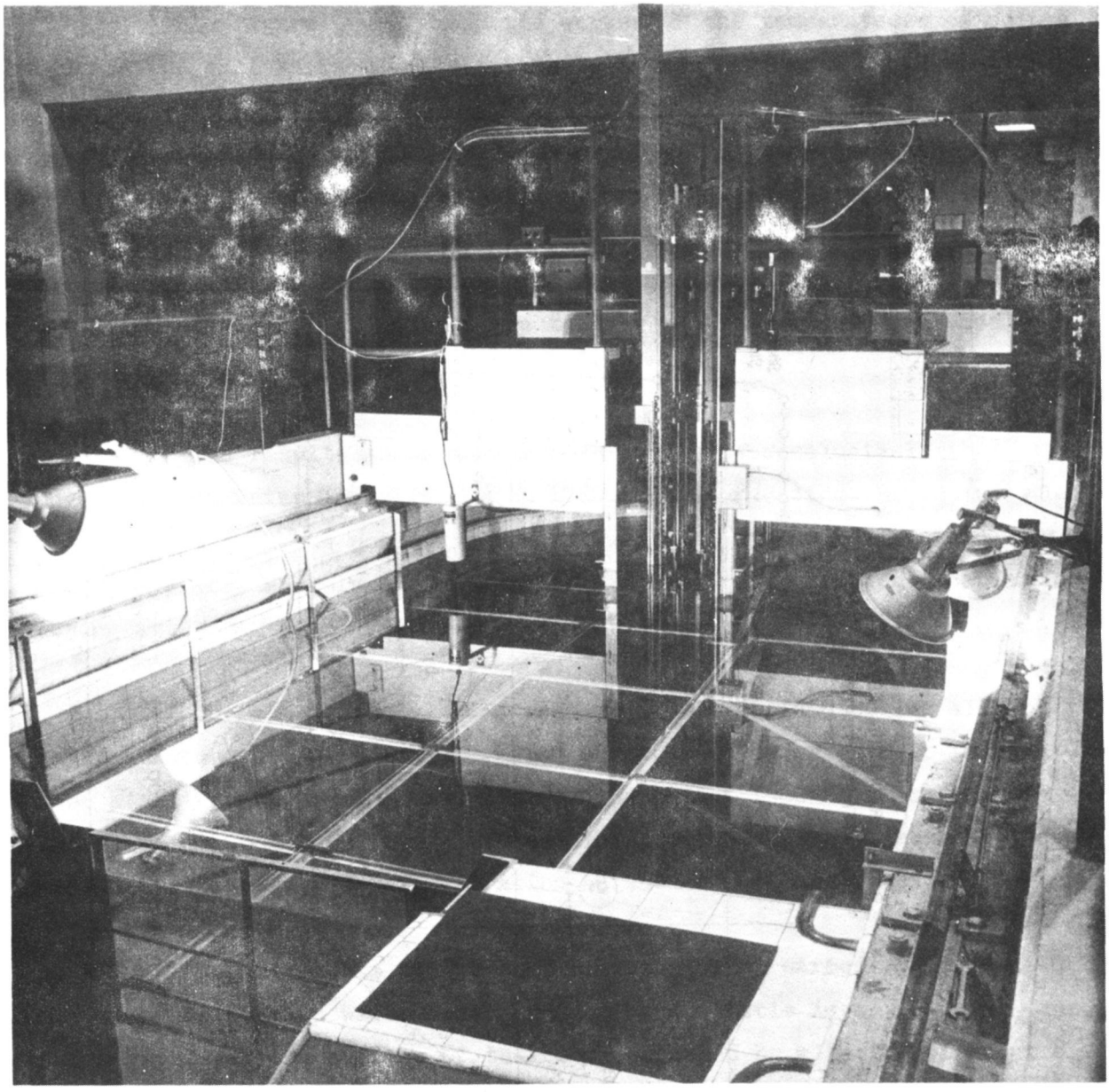

THERMAL COLUMN
BRIDGE
REACTOR CORE
A
B
OUTLET OF PRIMARY COOLING WATER
o-● —RADIATION LEVELS
+ — TEMPERATURES
Shutdown Started
A
35
1.5
Pumps turned on
9
Temperature - °C
30
1.0
B
8
25
0.5
Critical at 500 Kw.
0
0
100
200
300
400
minutes
Radiation levels - mr/h

FIG. 4



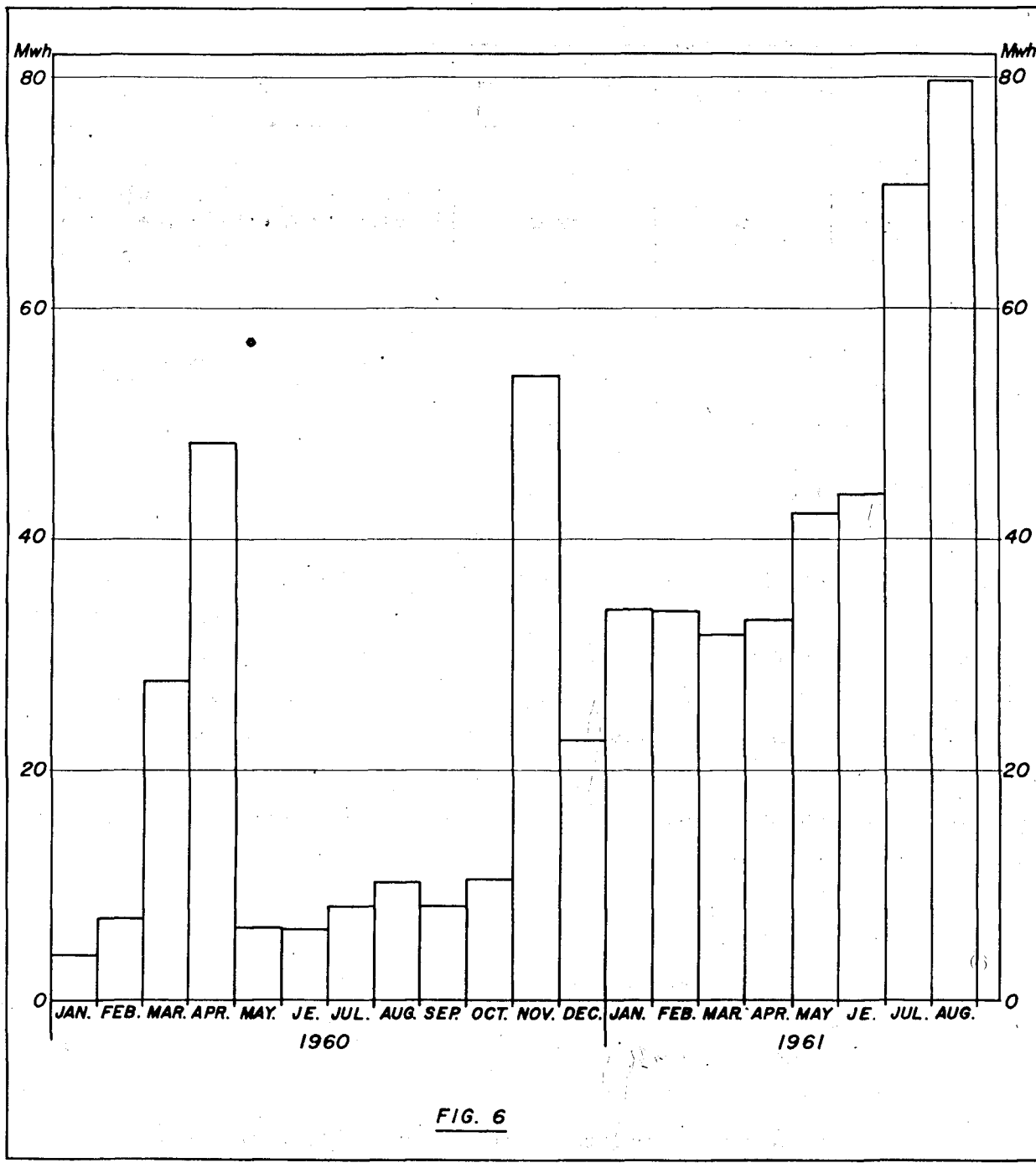

Mwh
80
60
40
20
0
JAN. FEB. MAR. APR. MAY. JE. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JE. JUL. AUG.
1960
1961

FIG. 6

TABLE II

Date	Power Level	Dose rate at the water surface	Remarks
Feb. 1958	1 Mw	10 mr/hr	First high power operation with the first set of fuel elements.
Apr. 1958	1 Mw	60 mr/hr	Fission products in the pool water due to defective fuel elements.
Nov. 1960	500 Kw	3.5 mr/hr	New set of fuel elements and new primary water return.
Jul. 1961	2 Mw	1.8 mr/hr	Same as above but with the plastic layer and hot water cushion.

REACTOR UTILIZATION

The reactor operations schedule has been programmed has been programmed considering often conflicting demands such as isotope production , training, and some other experiments concerning operational behavior. Therefore the operations time and power have been variable, depending on the demands. At the moment (2nd semester 1961) a considerable increase on the isotope production and two other neutron beam experiments are being planned. Consequently, the operations will be more frequent from now on. The principal uses of the reactor have been:

a) Radioisotopes production;
b) Neutron beam experiments;
c) Training;
d) Activation analysis.

During those operations all the possible operational data were gathered. Neverthless, special operations had to be run for this purpose.The reactor core or the spent fuel elements have been used sometimes as a gamma source, to irradiate different types of seeds, grains and other biological -

materials mainly for agricultural researches. The reactor has also been used for radiation damage studies.

a) Radioisotopes Production

Most of the isotope production is concentrated on the I^{131}, P^{32} and Au^{198}, although several other isotopes for special purposes have been produced as well. A great part of this production is distributed among several research institutions or hospitals in Brazil.

The I^{131} and P^{32} are produced by the irradiation of telluric acid and magnesium sulphate respectively.

As mentioned before, there are plans to increase considerably the production of I^{131} (up to 300 mc weekly) and P^{32} (up to 100 mc weekly).

The production of new isotopes such as Cr^{51}, colloidal gold, Co^{60} needles and capsules, Na^{24}, and others, is being considered.

Almost all samples have been irradiated in different types of sample holders located on the grid plates; the pneumatic rabbits have also been used especially for the production of tracer quantities for radiochemistry research.

One of the irradiation facilities located at the grid plate is a vertical aluminum tube 3 inch diameter, and it is used for low power irradiation and for danger coefficient experiments.

Another irradiation facility used mainly for fast neutron irradiations is an aluminum box with external dimensions similar to the fuel elements. To assure the tightness of the cover a polyethylene gasket is used. After irradiation this element has to be withdrawn from the pool, placed

in a special shield, and then opened to remove the internal aluminum tubes - that contain the samples.

The sample tubes of telluric acid were irradiated inside one of those aluminum boxes, when the reactor power was 500 kw. When the power raised to 2 MW the samples melted, due to excessive heating. Indeed, the heat transfer characteristics of the system were very poor, due to the air gap that existed between the sample aluminum tube and the outer aluminum box. A water-cooled irradiation facility was then designed to irradiate telluric acid and other samples. Since the swimming pool of the IEAR-1 reactor contains 272 m^3 of water, it was desirable to avoid any possible contamination of the whole pool water in case of rupture of one sample tube. In this water-cooled facility, deionised water enters the facility from the top, reaches the bottom and then is directed to the sump through a metal tube welded in a flange located 2.5 m above the grid plate. The activity of the water coming from the facility can be monitored before it reaches the sump. If the monitor indicates contamination, the water is diverted to a retention tank available at the basement of the reactor building. In order to remove the samples the flange is easily opened manually from the outside of the water surface and the inner sample tubes are transferred to a transport shield placed below the water surface.

b) Neutron Beam Experiment

The Division of Nuclear Physics has used one or more of the experimental beam ports during a large fraction of the total operating time of the reactor. A crystal neutron spectrometer was built in 1959 at the Institute's workshop and is capable of an accuracy of about 3' in the Bragg angle. With the crystals commercially available, this instrument is capable of significant measurement from .01 to 10 electron volts when highest resolution is not necessary.

At the beginning, the spectrometer was used to study locally - available natural calcite crystal in order to select those which reflectivity and inherent resolution were appropriate for particular experiments. Those calcite crystals and a synthetically produced sodium chloride crystal of good quality, have been used extensively up to now. There are plans to obtain lithium fluoride and beryllium crystals, in order to improve the resolution at neutron energies from 1 to 10 electron volts.

Up to June, 1961, some experiments were performed to determine the effect of moderator temperature on the neutron spectrum. Measurements of total cross section were also made to determine the relative purity of reactor materials, such as graphite.

Actually the spectrometer is being specifically adapted for measurements of the cross sections of some rare earth elements. These elements are important in reactor design and nuclear theory as well, and sufficiently pure samples of Pr, Yb, Tb, Ho, Er, Tm, Lu, and Hf are locally available. Those measurements are important since their neutron cross section - either have not been measured in the low energy region, or the several existing measurements do not agree.

A gamma-ray spectrometer, consisting of NaI and plastic scintillators and a multi-channel analyzer, will be used together with the crystal neutron spectrometer to investigate resonance neutron capture gamma-rays, in some of these rare earth elements.

A high transmission mechanical velocity selector is being built and can be used together with the crystal neutron spectrometer to eliminate "order contamination" of the monochromatic beam. Alone it can be used to make some low energy neutron spectrum measurements in important moderators.

c) Training

The Institute, in collaboration with the Polytechnical School, of the University of São Paulo, gives a course on the Nuclear Engineering - specialization. This course as well as other given in this country, uses the reactor for experiments on nuclear and reactor physics.

Among these experiments, we can quote: critical loading, rods calibration, power effect, measurements of reactivity changes, total cross sections by transmission using a crystal spectrometer, and delayed neutrons studies.

A training of a large number of operators and engineers is made concomitantly with the operations performed in order to get data on the reactor performance. Among these experiments, special care is given to the thermal flux plot. This is done for each new core loading that will be used on high power operations; gold foils, bare and cadmium covered, are used as neutron detectors.

In this way a flux dependent term on the burn up factor for the fuel elements is obtained and at the same time the reactor power calibration is checked. This nuclear calibration is also cross-checked with the one obtained from heat balances at higher power. The linearity of the power measuring instrument is checked also with foils activation from a few kw up to 2 MW.

d) Activation Analysis

The facility most used for activation analysis is the pneumatic tubes system specially for short time irradiations.

The samples are enclosed in polyethylene vials and placed in the aluminum carriers (rabbits) to be sent near to the reactor core.

For samples that require longer irradiation time a vertical aluminum tube placed on the grid plate can be used. In this case a rotor of variable speed is adapted in order to rotate a rack which contains the sample and the standard tubes located symetrically with respect to the vertical axis.

This facility can be used either with or without water.

Some of the analysis performed or under study are: activation of gold and uranium ores and subsequent identification and determination of Au^{198} and Np^{239}; identification of some elements in graphite ash, such as sodium; identification of elements in water residues, for instance the determination of sodium and uranium in the reactor pool water; identification and determination of rare earths in very pure uranium salts.

ORGANIZATION OF REACTOR OPERATION

The Reactor Operations Section of the Reactor Physics Division is responsible for the operation and maintenance of the reactor. The reactor staff consists of one supervisor, an assistant supervisor, two trainee engineers, three reactor operator technicians and two nuclear instrumentation maintenance technicians. In order to perform maintenance services this Section has a small mechanical shop and an electronic laboratory.

The water treatment is in charge of the Radiochemistry Division, which reports to this Section the values of the pH and the specific resistivity of the pool water.

The Institute has also a Radiological Protection Service, which is responsible for the health physics or radiation hygiene, not only for the reactor but for all laboratories where radioisotopes are used or prepared as well as for the nuclear particle accelerator. The Radiological Protection Service reports to the Reactor Operations Section the radiation levels inside the reactor building, whenever the reactor is in operation.

All applications for irradiations and experiments are made to this Section, through the heads of the Divisions. For simple irradiations,the supervisor and his staff discuss the requirements directly with the applicant. For complex experiments or irradiations that require special care, the hazards and safety aspects are discussed by a Committee. Usually the members of this Committee are: The applicant, the head of the applicant's Division, the reactor supervisor and assistant, and the head of Radiological Protection Service.

The Reactor Operations Section is also responsible for the maintenance of the experimental and irradiation facilities as well as for handling of irradiated materials until these are placed into the transfer shields.

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