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**PRELIMINARY RESULTS OF 5 Mw OPERATION WITH
THE BRAZILIAN SWIMMING POOL REACTOR**

**RESULTADOS PRELIMINARES DA OPERAÇÃO COM O REATOR DE
PISCINA BRASILEIRO NUM NÍVEL DE POTÊNCIA DE 5 Mw**

*M. D. S. Santos, P. S. Toledo, F. W. Lima, R. R. Pieroni,
C. C. Cardwell, A. Abrão, R. Brenner, E. W. Cybulska, C. R.
Pereira, I. C. Nascimento, A. C. Penteado, E. Wilner
e A. R. Frascino*

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INSTITUTO DE ENERGIA ATÔMICA
Caixa Postal 11049 (Pinheiros)
CIDADE UNIVERSITÁRIA "ARMANDO DE SALLES OLIVEIRA"
SÃO PAULO — BRASIL

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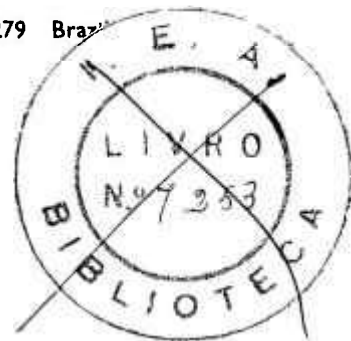
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— Chefe da Divisão de Radiobiologia



Preliminary Results of 5 Mw Operation with the Brazilian Swimming Pool Reactor

By Marcello Damy de Souza Santos,*† Paulo Saraiva de Toledo,*† Fausto Walter Lima,*† Rômulo Ribeiro Pieroni,*† C. C. Cardwell,‡ Alcido Abrão,* Paul Brenner,* Ewa Wanda Cybulska,* Carlos Rodrigues Pereira,* Ivan Cunha Nascimento,* Azor C. Penteadó,* E. Wilner* and A. R. Franscino*

Since there is no published literature on the behaviour of a swimming pool reactor at powers higher than 1 Mw, the first results obtained with the Brazilian research reactor¹ are worth description. In this paper a brief discussion is presented of the methods used for the power calibration of the neutron flux sensing instruments and of the activities measured in air and water.

The reactor installed at the Instituto de Energia Atomica is a swimming pool reactor designed and built by the Babcock & Wilcox Co. in accordance with the specifications furnished by the Comissão de Energia Atomica of the Conselho Nacional de Pesquisas. The reactor is very similar in design to that built by the same company for the University of Michigan. The main differences lie in the alterations which have been introduced in the fuel element design, cooling system and in the pool dimensions, in order to allow a continuous operation at 5 Mw.

The successful operation which was obtained at these high power levels suggests interesting applications for the use of a swimming pool reactor, since neutron fluxes comparable with those available in some materials testing reactors are obtained with the advantage of the use of several lattice arrangements.

When compared with some materials testing reactors of comparable fluxes, the swimming pool reactor offers the disadvantage of providing a smaller useful space for irradiation. This does not constitute a large disadvantage for countries which are starting their activities in the nuclear energy field and is matched by the low costs of installation and operation. From the results obtained it can be concluded that with some minor changes, the reactor can be operated at steady power levels higher than 5 Mw with no foreseen difficulties.

CORE ARRANGEMENT

In order to operate at a steady 5 Mw power level a larger excess reactivity must be provided in the core to take into account the effects due to temperature, xenon and samarium poisoning and the reactivity due to the beam holes. The value of the excess of reactivity can be computed, as far as the poisoning is concerned, either by extrapolating the BSF flux data at 1 Mw or by using the flux data computed with an electro-data computer by a multigroup theory, at the same power, and calculating the expected poisoning at these flux levels.

For a totally water reflected core, in a 5×5 arrangement the expected fluxes at 5 Mw operation are:

	Fast	Thermal
At reactor center	9.0×10^{13} n/cm ² sec	4.0×10^{13} n/cm ² sec
At reactor lattice edge	3.0×10^{13} n/cm ² sec	3.5×10^{13} n/cm ² sec
Peak flux at reflector (water)		4.0×10^{13} n/cm ² sec

With these flux values the estimated excess reactivities required for 5 Mw operation are easily calculated once the flux distribution in the core is known.² In addition to the excess reactivity required to counterbalance the equilibrium xenon poisoning, some excess must be provided for xenon override. Assuming a reactor cycling time of 8 hours in service and 16 hours shutdown on a 5 day per week basis and assuming further that 200 Mwd of operation is desired, the approximate allocation of U²³⁵ would be as shown in Table 1.

In order to provide the required excess reactivity in the core, a 5×6 arrangement was used, with five partial elements, four of which were located in the control and safety bar positions and one at the edge of the lattice. The core arrangement is represented in Fig. 1. A critical experiment was carried out and the critical mass was found to be 3.775 kg of U²³⁵. Once the critical mass was obtained, the last row of fuel elements was gradually loaded in order to have

* Instituto de Energia Atômica, São Paulo.

† On leave of absence from the University of São Paulo.

‡ The Babcock & Wilcox Co., Virginia, U.S.A.

Table 1

Critical mass	3780 g
200 Mwd burn up	200 g
Equilibrium xenon	280 g
Beam experiments	250 g
Temperature coefficient	4 g
Loading total	4514 g

the required excess reactivity; the criticality was then obtained when the safety bars were only half-way inserted, leaving a controllable negative excess reactivity of 3.5%, which was amply sufficient for control purposes.

POWER CALIBRATION

Before a power level of about 100 watts was attained to allow an accurate power calibration by means of a flux determination in the core, a crude calibration of the neutron sensing instrumentation was made by extrapolating the estimated power obtained in the first critical experiment.¹ With such an estimate, flux plots of the thermal neutrons in the core were made and the initial calibration was corrected. Since both the log n amplifier and the linear level micromicroammeter were calibrated against the fission chamber in the startup channel, the procedure which was used to calibrate the fission chamber will be described.

For such a calibration a 5.38 curie Po-Be source of unknown yield was used. The first step, therefore, was to calibrate the neutron yield of the source. For this calibration a comparison was made with a 9.49 millicurie radium-beryllium source which had been

calibrated at the National Bureau of Standards. Since the neutron spectrum of these sources was different, the comparison was studied by using the "averaging effect" of the reactor core.

In order to have a precise power calibration, the flux distribution in the reactor core was studied using gold foils as thermal neutron detectors. The foils used had an area of 0.8 cm² and a thickness corresponding to 80 mg per square centimeter. This thickness was chosen in order to avoid a flux perturbation in the core, and its small value led to small corrections to the flux depression at the gold resonance energy. In order to avoid a possible change in the aluminum-to-water ratio, the foils were placed in recessed holes in a thin lucite strip which could be inserted between the fuel element plates.

The flux determinations were made with practically cold fuel elements; the lucite strips were inserted between the plates under a layer of 1 metre of water by means of a special handling tool. Both the thermal and the epithermal fluxes were measured by using bare and cadmium-covered foils, 0.5 mm thick. The irradiations were made using a 5×6 arrangement as in Fig. 1.

Such an arrangement provided an excess reactivity of 3.5% which was amply sufficient to overcome the effects due to xenon poisoning and to beam holes at the maximum operating power (5 Mw). The measurements were made by irradiating the foils at a nominal power of 200 w during half an hour. The power was raised after a thirty-second period and the reactor was manually scrammed at the end of the irradiation time, a correction for the startup being taken into account in the activity calculations. The induced radioactivity in the foils was measured by means of a Geiger counter system and the absolute counting rate was determined by use of a calibrated beta source UX₁-UX₂ for the determination of the geometry and by applying the corrections due to self-absorption, self-scattering and back-scattering from the support. The results of the absolute beta counting were compared with similar measurements from similar gold foils which were irradiated in a batch and measured at Oak Ridge. In order to have an accurate estimate of the power, the power generated in each fuel element was computed.

The detailed description of the flux measurements will be published elsewhere. A comparison between flux measurements and the temperature differential method gave results which agreed within 10% after a correction was applied to the temperature differential measurements, taking into account the fact that since many fast neutrons and gamma rays escape from the core, the fission energy which is actually converted into core heat is a fraction of the total energy released in the fission process. The flux measurements have shown that the energy scale, calibrated in the rough way described above, was about 20 times higher than what it should be; all the instruments were then recalibrated in order to indicate the precise value of the power level. A comparison between the power scale as obtained by this method

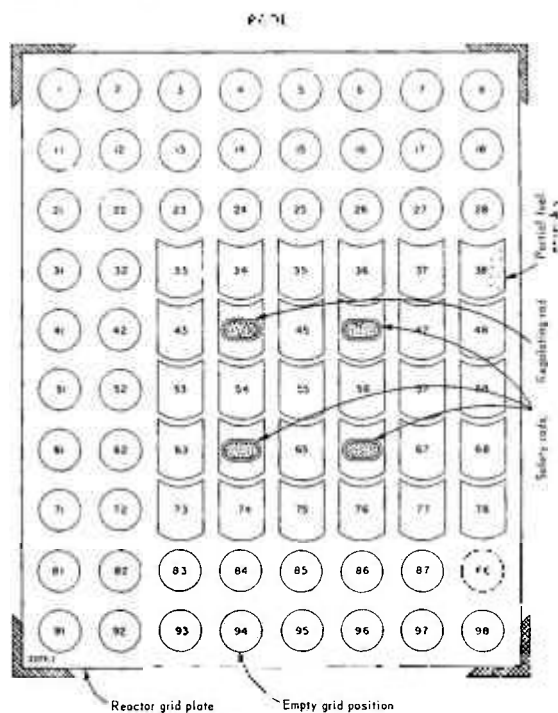


Figure 1. Core arrangement

and the results from two different methods which will be described now has shown very good agreement within the experimental errors.

At higher powers, the energy scale calibration was checked against the calculated power in the core as obtained by differential temperature measurement between the water entering and leaving the core.

In order to measure the temperature of the water entering the core, a thermocouple was hung at about thirty centimeters from the core top; the temperature of the water leaving the core was measured by another thermocouple located at the heat exchanger water inlet. During these experiments the cooling tower was kept in operation in order to maintain constant the temperature of the pool water. The power level was determined by this method at 500, 1000, 2200 and 5000 kw as indicated by the linear level amplifier on the calibration obtained by flux measurements.

Another method of calibration based on the xenon poisoning was used to check the power levels as determined from the experiments which have been already described. This method is described elsewhere³ and has given very good agreement with the flux measurements.

REACTOR BEHAVIOUR AT POWERS ABOVE 1 Mw

In the experiments at power levels higher than 100 kw, forced cooling of the core must be used; an interlock system in the log n recorder will scram the reactor if the primary cooling pump fails.

In these experiments a primary flow of 2200 gpm and a secondary flow of 1500 gpm were used. As the power was gradually raised, special attention was paid to the temperature of the water entering and leaving the core. When a power of 1 Mw was reached the reactor was kept at that level for 5 hours.

The radiation levels in the building and at the pool surface (which are described elsewhere⁴) have shown that the fuel elements were behaving as expected and that the radiation levels were within tolerance levels.

In the experiments at powers of 2.5 and 5 Mw special attention was paid to the linear level channel in order to be able to detect any effect which might be due to a possible bubble formation on the surface of the fuel element plates; as one should expect from straightforward calculations, no such effect was observed and the reactor operated continuously for 5 hours at this power level.

At a 5 Mw power level the fluxes in the centre of the core are 8×10^{13} and 2×10^{14} thermal and fast neutrons per square centimeter per second, respectively.

The measurement of the radiation levels on the pool surface and in the beam hole doors and the measurements of the activities in air and water have shown that operation at such a high power level is possible. Special care must be taken, however, to reduce the activity at the surface of the pool water and in the air, which is due to N^{16} , Na^{24} . Gaseous isotopes produced during the fission process and their descendants can also give rise to a high activity.

A detailed report on the observed activities described in Refs. 4 and 5 shows that the high level of radiation observed in air is due to a large amount of turbulence at the pool surface; this turbulence prevents the formation of a clean hot water cushion on the surface of the pool which should prevent the active atoms from coming to the surface and diffusing into the air.

Such turbulence was due to a faulty design of the heat exchanger. This trouble has been completely eliminated. We have every hope that the reactor will continue to operate satisfactorily at these high temperature levels.

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ERRATA

- Page 541 — first column — 16th line — instead of: 2200
read: 2000
- Page 541 — second column — from the 34th line on — instead of: This trouble has been completely...
read: When this trouble be completely eliminated, we have every hope that the reactor will operate satisfactorily at these high power levels.