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CENTRO DE OPERAÇÃO E UTILIZAÇÃO DO REATOR DE PESQUISA – IEAR-1
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FLUX MEASUREMENTS OF THERMAL AND FAST NEUTRONS AT LOCATIONS AVAILABLE FOR SAMPLE IRRADIATION IN THE IEAR-1 FACILITY

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ABSTRACT

The value of fast and thermal neutron flux at several points that are offered for irradiation of samples in the IEAR-1 reactor are reported.

The measurements were made by the activation foil technique and it was employed gold for the determination of thermal neutron flux and aluminum for fast neutron

INTRODUCTION

Over the past three years, as a result of several investigations performed at the request of various users of the IEAR-1 facility, a significant amount of data has been accumulated on the value of fast and thermal neutrons flux at the several points that are offered for irradiation of samples. The major purpose of this paper is to make these data available to all current and potential users in the hope that this will help in the evaluation of the results that are currently being obtained and for easier planning of future utilization of the facility.

We will start with a description of the experimental procedure that we have used and will then report the data obtained in chronological order; this will allow for an appropriate correlation with the performance record of the reactor.

EXPERIMENTAL PROCEDURE

Measurements were made according to the foil activation method following the principles outlined in refs. 1 and 2.

Thin gold foil was used to determine thermal neutrons fluxes, while for fast neutrons aluminum was employed in the majority of cases; on one occasion iron was chosen together with aluminum in order to allow for a comparison of the results.

Since there are some significant differences between the procedure used with thermal neutrons and the one for fast neutrons, we will give details about the two cases separately.

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a) Measures of Thermal Neutrons Flux

In this case we used thin foils of a gold alloy containing 0.13% gold prepared from wires obtained from Reactor Experiments Inc. The effective thickness of gold was calculated to be 40 $\mu g/cm^2$. Each foil had an area of approximately 2 mm^2 and a total mass varying between 0.5 and 1.0 mg.

In order to eliminate the activation contribution of epithermal neutrons, the gold foils were irradiated in pairs one of which was encapsulated in a small Cadmium container with wall thickness of 1 mm. The pairs, mounted in aluminum frames, were positioned for irradiation at the points under study.

After irradiation, a set of five foils was chosen as standard and both an absolute activity measurement using a $4\pi\beta$-γ coincidence system and a relative gamma measurement with a NaI detector were performed.

The error calculated for the calibration of the standards with the beta-gamma coincidence method was less than 0.5%. Relative measurements on the rest of the samples had an estimated error of 1%.

For the actual calculations of the value of the neutron flux (see refs.) a Maxwell distribution of the velocities was assumed at the temperature of 36°C which was measured in the core of the reactor and a value of 98.8 barns for σ_0 was used.

b) Measures of Fast Neutrons Flux

Aluminum foils of 5 mm in diameter and with a mass of approximately 10 mg were irradiated. The reaction used was: $^{27}Al(n,\alpha)^{24}Na$. The unavoidable presence of ^{55}Mn impurities in the aluminum together with the high cross section of ^{55}Mn for thermal neutrons required that the foils be encapsulated in Cadmium containers. Even with this precaution the creation of ^{56}Mn by fast neutrons required a 15 hours waiting period before the actual measurement on ^{24}Na could be performed.

Also in this case a standardization procedure of a set of samples and relative measurements on the rest was employed with errors comparable to the ones obtained in the case of thermal neutrons.

For the flux calculation a cross section averaged over the Watt fission spectrum equal to 0.705 barns was used (ref. 1).

Since the cross section of ^{54}Fe for fast neutrons seems to offer a better opportunity for a more accurate measurement, a few Iron foils were irradiated and the reaction $^{54}Fe(n,p)^{54}Mn$ was exploited in order to obtain further data. Only relative measurements were taken in this case using a standard supplied by the IAEA. The difficulty in obtaining good Iron samples and the problems connected with activity measures were the major reason for choosing Aluminum for routine investigation.

EXPERIMENTAL RESULTS

A first series of data on thermal flux was obtained during the period April-September 1973 and is reported in Table I.

Table I

(All data of 1973)

Location EIFS 35 A

Shelf	Thermal Flux	Cadmium Ratio (Gold)	Day
2	–	–	22/06/73
3	$1.21\ 10^{13}\ n/cm^2 \times s.$	2.1	
4	–	–	
5	$1.35\ 10^{13}\ n/cm^2 \times s.$	2.7	
6	$1.03\ 10^{13}\ n/cm^2 \times s.$	2.1	
7	$0.87\ 10^{13}\ n/cm^2 \times s.$	2.1	
8	$0.80\ 10^{13}\ n/cm^2 \times s.$	1.5	24/04/73
9	$0.86\ 10^{13}\ n/cm^2 \times s.$	2.5	24/04/73

Location EIFS 27

Shelf	Thermal Flux	Cadmium Ratio (Gold)	Day
2	$4.8\ 10^{12}\ n/cm^2 \times s.$	4.3	22/05/73
3	$5.1\ 10^{12}\ n/cm^2 \times s.$	3.9	
4	$5.3\ 10^{12}\ n/cm^2 \times s.$	3.9	
5	$5.3\ 10^{12}\ n/cm^2 \times s.$	4.1	
6	$5.4\ 10^{12}\ n/cm^2 \times s.$	3.6	26/08/73
7	$6.2\ 10^{12}\ n/cm^2 \times s.$	–	
8	$4.2\ 10^{12}\ n/cm^2 \times s.$	3.6	
9	$3.1\ 10^{12}\ n/cm^2 \times s.$	3.6	

Location EIFS 51

Shelf	Thermal Flux	Cadmium Ratio (Gold)	Day
3	$7.6\ 10^{12}\ n/cm^2 \times s.$	3.3	26/08/73
4	$9.8\ 10^{12}\ n/cm^2 \times s.$	4.0	
5	$9.7\ 10^{12}\ n/cm^2 \times s.$	4.1	
6	$9.0\ 10^{12}\ n/cm^2 \times s.$	4.0	
7	$7.0\ 10^{12}\ n/cm^2 \times s.$	3.8	

Location EIFS 35 C

Shelf	Thermal Flux	Cadmium Ratio (Gold)	Day
2	$1.14\ 10^{13}\ n/cm^2 \times s.$	2.7	28/08/73
3	$1.18\ 10^{13}\ n/cm^2 \times s.$	2.6	
4	$1.15\ 10^{13}\ n/cm^2 \times s.$	2.5	
5	$1.14\ 10^{13}\ n/cm^2 \times s.$	2.5	
6	$1.02\ 10^{13}\ n/cm^2 \times s.$	2.4	
7	$0.85\ 10^{13}\ n/cm^2 \times s.$	2.3	
8	$0.64\ 10^{13}\ n/cm^2 \times s.$	2.2	
9	$0.62\ 10^{13}\ n/cm^2 \times s.$	2.6	

Location EIFS 13

Shelf	Thermal Flux	Cadmium Ratio (Gold)	Day
2	$2.16\ 10^{12}\ n/cm^2 \times s.$	5.7	12/09/73
3	$2.90\ 10^{12}\ n/cm^2 \times s.$	4.5	
4	$2.97\ 10^{12}\ n/cm^2 \times s.$	4.4	
5	$3.28\ 10^{12}\ n/cm^2 \times s.$	4.7	
6	$2.89\ 10^{12}\ n/cm^2 \times s.$	3.9	
7	$2.52\ 10^{12}\ n/cm^2 \times s.$	4.3	
8	$1.96\ 10^{12}\ n/cm^2 \times s.$	4.3	
9	$1.84\ 10^{12}\ n/cm^2 \times s.$	4.5	

The irradiations were done by loading the foils on the available shelves at the different locations. The average distance between the shelves was 5.5 cm. These activations were performed on different days for each location over an extended period of time and because of the flux variations due to fuel burn up and other fluctuations (see below) they cannot offer a coherent picture of the overall flux distribution. However they do show the flux variations in the vertical direction at the various locations. Figure 1 gives a graphical presentation of a typical flux distribution as measured at location 35c (see Figure 2).

Considering all the possible sources of error affecting these data, we estimated that these flux values are correct within approximately 5%.

On June 3, 1975 a special reactor run was made in order to allow for the simultaneous irradiation of foils at the 12 different locations reported in Figure 2 which shows a schematic of the geometry of IEAR-1 together with the core configuration in use on that date.

On this occasion a set of foils (Gold, Gold with Cadmium shield and Aluminum with Cadmium shield) was loaded on the same shelves used during the previous measurements and at several other locations. The results obtained are presented in Table II and they give a better picture of the total flux distribution that can be expected at the various locations and within each location during a particular run.

A flux profile for both thermal and fast neutrons together with the relative Cadmium ratios as obtained in position 35c is shown in Figure 3.

The total absolute error estimated in the determination of thermal flux values is of 5%. In the case of fast neutrons an estimate of the error is difficult due to the uncertainty of the value for the average cross section over the fission spectrum found in the literature. In order to better evaluate the importance of this parameter, a measurement was made using iron foils (see above) at location 23 shelf 5. The flux value obtained in this measurement was of 8.0×10^{11} n/cm^2/sec. to be compared with the value of 9.0×10^{11} n/cm^2/sec. obtained using aluminum at the same location. This result seems to indicate that the data in Table II could be affected by a systematic error as large as 11% while the sum of all other errors is estimated to be approximately 5%.

A final series of measurements were made during the month of July 1975 with the aim to determine the flux variations that a user could expect at one location over a short period of time (daily fluctuations). As revealed by the data of Table III and the plot of Figure 4, these fluctuations were found to have values up to 17% of the flux intensity for thermal neutrons. Even though also in this case the total absolute error could be quite large, the relative error (which is of interest here) did not exceed 2%.

CONCLUSION

We realize that the data reported in this paper are quite fragmentary and insufficient to give an exhaustive description of the flux distribution within IEAR-1, but we feel that they could serve as groundwork for further investigation and give an orientation to the users.

In particular we would like to point out two interesting results: a) The value of the thermal neutron flux can vary by 60% depending on shelf choice at a given location; b) The daily fluctuations of the same with time can be of the order of 17%.

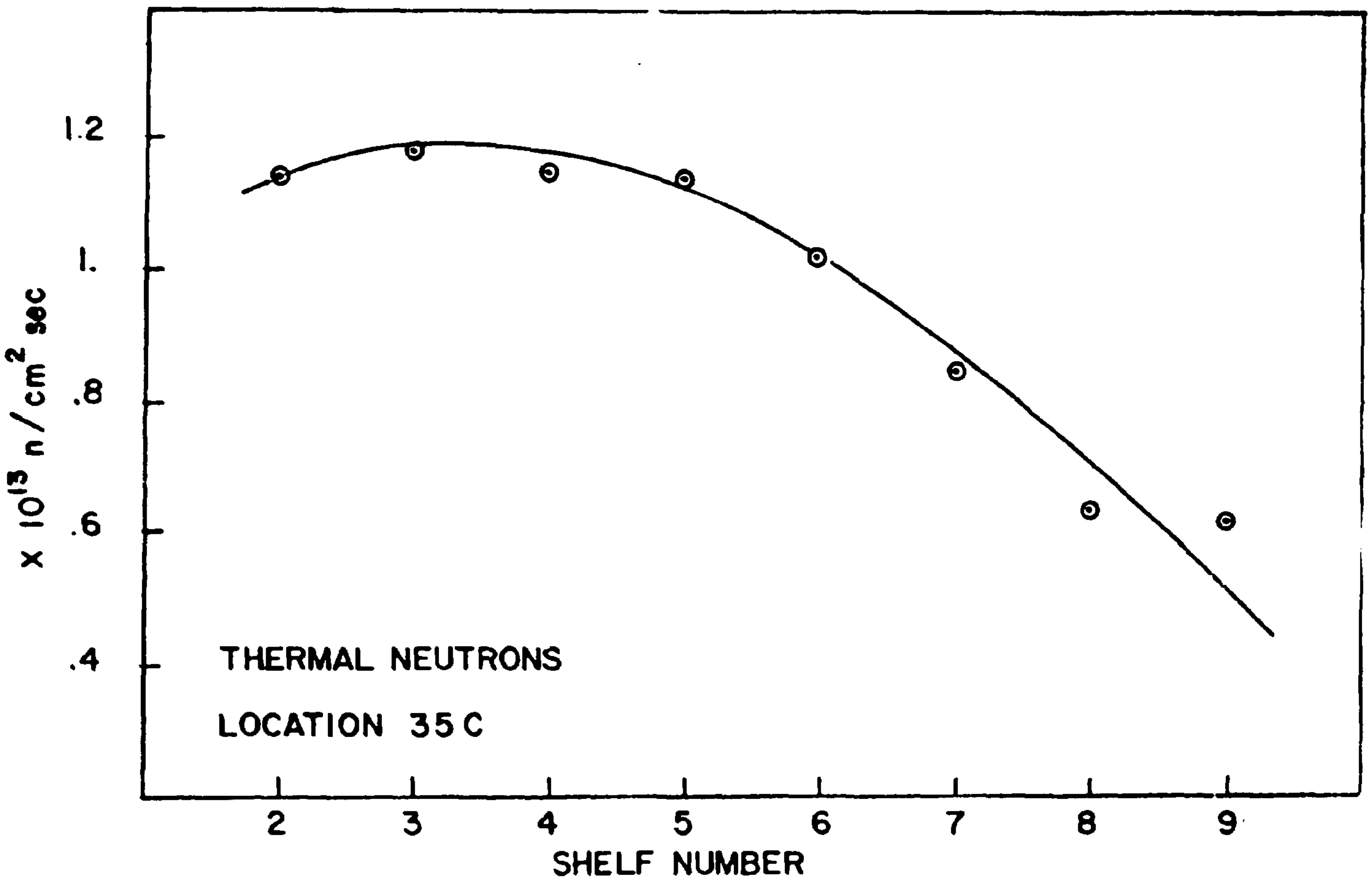

Figure 1 — Plot relative to 1973 data (35c).

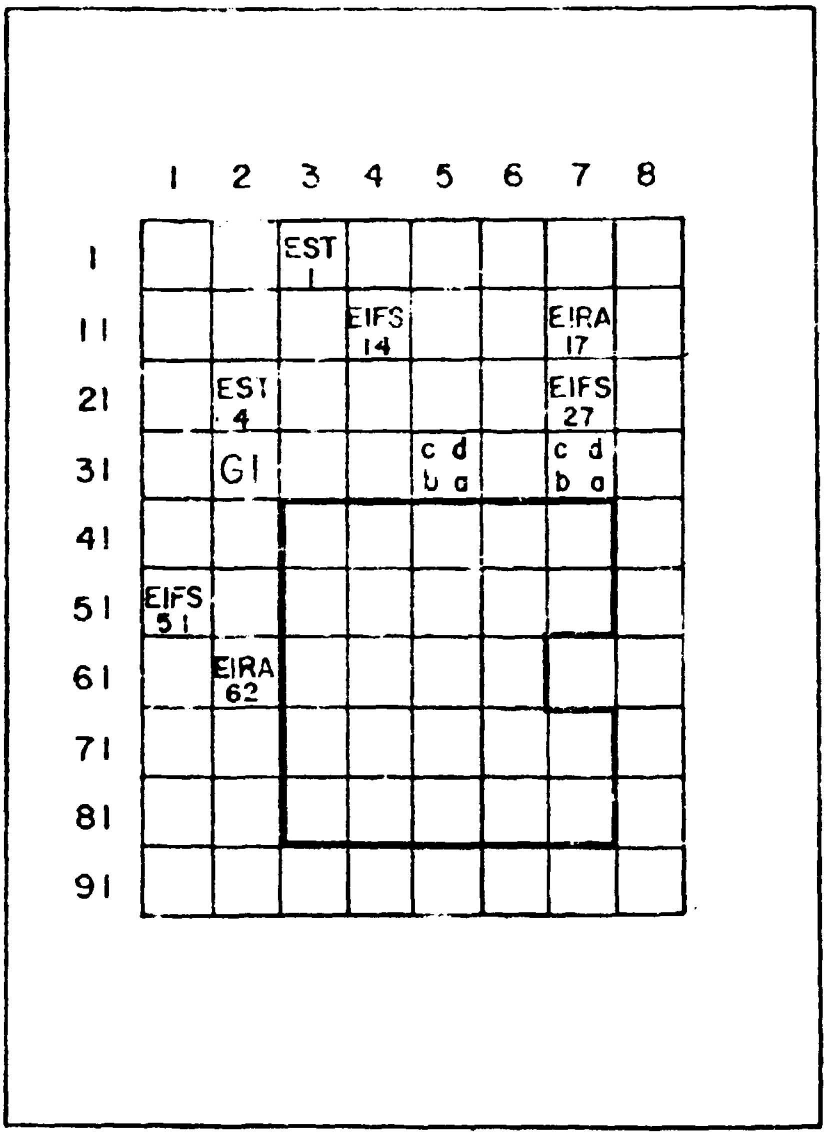

Figure 2 – Schematic of IEAR-1.

Table II

(All data of 1975)

Location	Shelf	Thermal Flux (n/cm^2/sec.)	Error	Cadmium Ratio (Gold)	Error	Fast Flux (n/cm^2/sec.)	Error
35a	2	1.46 10^{13}	2%	2.24	3%	7.36 10^{12}	2%
35a	3	1.59 10^{13}	2%	2.23	3%	8.19 10^{12}	2%
35a	4	1.66 10^{13}	2%	2.27	3%	7.97 10^{12}	2%
35a	5	1.60 10^{13}	2%	2.29	3%	7.70 10^{12}	2%
35a	6	1.44 10^{13}	2%	2.29	3%	7.09 10^{12}	2%
35a	7	1.20 10^{13}	2%	2.28	3%	5.97 10^{12}	2%
35a	8	1.06 10^{13}	2%	2.45	3%	4.78 10^{12}	2%
35C	2	1.27 10^{13}	2%	2.70	3%	3.69 10^{12}	2%
35C	3	1.42 10^{13}	2%	2.69	3%	4.19 10^{12}	2%
35C	4	1.47 10^{13}	2%	2.74	3%	4.24 10^{12}	2%
35C	5	1.44 10^{13}	2%	2.75	3%	4.04 10^{12}	2%
35C	6	–	–	–	–	3.74 10^{12}	2%
35C	7	1.21 10^{13}	2%	2.95	3%	3.25 10^{12}	2%
35C	8	0.98 10^{13}	2%	3.01	3%	2.54 10^{12}	2%
37a	1	0.94 10^{13}	2%	2.86	3%	3.15 10^{12}	2%
37b	1	1.16 10^{13}	2%	2.50	3%	4.66 10^{12}	2%
EIRA 62	1	2.22 10^{13}	2%	2.62	3%	7.26 10^{12}	2%
EIRA 62	2	2.11 10^{13}	2%	2.41	3%	7.87 10^{12}	2%
EIRA 62	3	2.14 10^{13}	2%	2.63	3%	6.73 10^{12}	2%
EIRA 62	4	1.73 10^{13}	2%	2.46	3%	6.07 10^{12}	2%
EIFS 27	2	5.15 10^{12}	2%	4.70	3%	0.89 10^{12}	2%
EIFS 27	3	5.57 10^{12}	2%	4.34	3%	1.01 10^{12}	2%
EIFS 27	4	5.67 10^{12}	2%	4.54	3%	0.96 10^{12}	2%
EIFS 27	5	–	2%	–	3%	0.94 10^{12}	2%
EIFS 27	6	5.48 10^{12}	2%	4.61	3%	0.93 10^{12}	2%
EIFS 27	7	5.20 10^{12}	2%	5.31	3%	0.78 10^{12}	2%
EIFS 27	8	3.99 10^{12}	2%	5.17	3%	0.62 10^{12}	2%
EIRA 17	1	2.60 10^{12}	2%	5.36	3%	3.29 10^{11}	2%
EIRA 17	2	2.40 10^{12}	2%	4.81	3%	3.65 10^{11}	2%
EIRA 17	3	2.63 10^{12}	2%	4.69	3%	3.76 10^{11}	2%
EIFS 14	2	1.04 10^{13}	2%	11.6	3%	5.66 10^{11}	2%
EIFS 14	4	0.47 10^{13}	2%	5.15	3%	6.04 10^{11}	2%
EIFS 14	6	0.13 10^{13}	2%	2.14	3%	5.52 10^{11}	2%
EIFS 51	1	8,37 10^{13}	2%	4.04	3%	1.47 10^{12}	2%
GI	Fundo	8.23 10^{12}	2%	5.07	3%	1.70 10^{12}	2%
GI	10 cm	–	2%	–	3%	1.18 10^{12}	2%
Estação 4	1ª irradiação	4.4 10^{12}	4%	4.8	5%	7.5 10^{11}	4%
	2ª irradiação	–	–	–	–	10.4 10^{11}	4%
Estação 1	1ª irradiação	3.1 10^{11}	4%	3.2	5%	2.1 10^{11}	4%
	2ª irradiação	6.2 10^{11}	4%	5.8	5%	2.1 10^{11}	4%

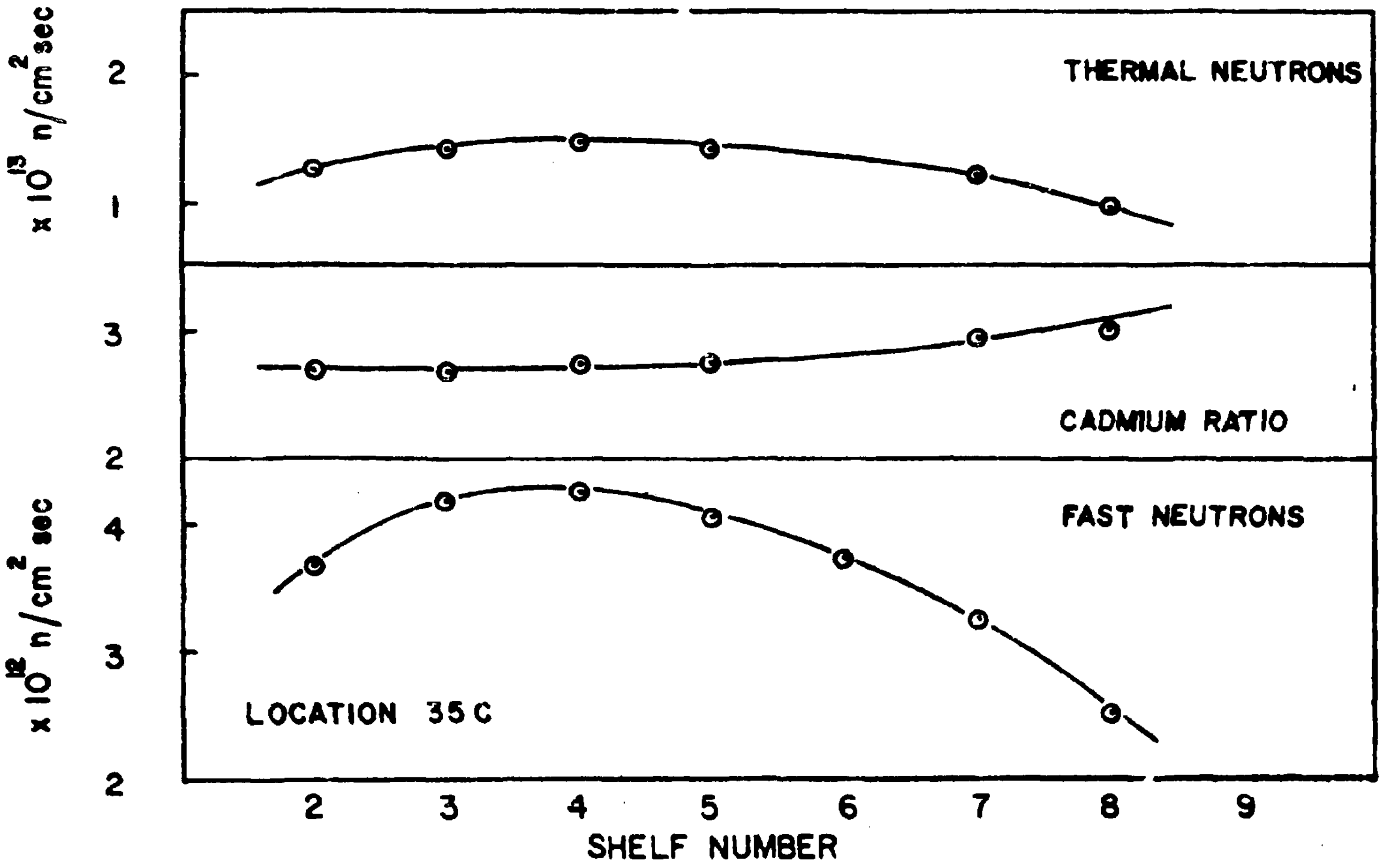

Figure 3 — Plot of 1975 data (35c).

Table III

Data on Flux Variations

Location EIFS 13				
Day (1975)	Shelf	Thermal Flux (n/cm^2/sec.)	Cadmium Ratio (Gold)	Fast Flux (n/cm^2/sec.)
07/05	4	$3.06\ 10^{12}$	6.0	–
08/05	4	$3.13\ 10^{12}$	5.5	$4.0\ 10^{11}$
09/05	4	$2.86\ 10^{12}$	5.7	$4.5\ 10^{11}$
12/05	4	$3.10\ 10^{12}$	6.1	$4.1\ 10^{11}$
13/06	4	$2.90\ 10^{12}$	6.5	$3.6\ 10^{11}$
01/07	4	$3.44\ 10^{12}$	5.7	$4.87\ 10^{11}$
01/07	5	$3.06\ 10^{12}$	5.5	$4.34\ 10^{11}$
01/07	6	$2.24\ 10^{12}$	5.2	$3.71\ 10^{11}$
02/07	4	$2.88\ 10^{12}$	6.2	$3.96\ 10^{11}$
02/07	5	$2.50\ 10^{12}$	5.3	$3.88\ 10^{11}$
02/07	6	$2.33\ 10^{12}$	5.6	$3.38\ 10^{11}$
03/07	4	$3.30\ 10^{12}$	5.9	$4.43\ 10^{11}$
03/07	5	$2.98\ 10^{12}$	5.6	$4.33\ 10^{11}$
03/07	6	$2.65\ 10^{12}$	5.8	$3.83\ 10^{11}$
04/07	4	$3.11\ 10^{12}$	5.6	–
04/07	5	$2.59\ 10^{12}$	6.0	–
04/07	6	$3.31\ 10^{12}$	6.5	–
21/07	4	$3.20\ 10^{12}$	5.9	$4.27\ 10^{11}$
21/07	5	$3.17\ 10^{12}$	5.5	$4.33\ 10^{11}$
21/07	6	$2.67\ 10^{12}$	5.6	$3.80\ 10^{11}$
22/07	4	$3.17\ 10^{12}$	5.7	$4.23\ 10^{11}$
22/07	5	$3.27\ 10^{12}$	5.7	$4.25\ 10^{11}$
22/07	6	$2.89\ 10^{12}$	6.4	$3.51\ 10^{11}$
23/07	4	$3.22\ 10^{12}$	6.2	$4.05\ 10^{11}$
23/07	5	$3.41\ 10^{12}$	6.7	$3.91\ 10^{11}$
23/07	6	$2.69\ 10^{12}$	5.9	$3.58\ 10^{11}$
24/07	4	$2.90\ 10^{12}$	5.6	$3.99\ 10^{11}$
24/07	5	$2.70\ 10^{12}$	5.6	$3.82\ 10^{11}$
24/07	6	$2.56\ 10^{12}$	5.8	$3.44\ 10^{11}$
25/07	4	$2.96\ 10^{12}$	5.8	$4.22\ 10^{11}$
25/07	5	$2.76\ 10^{12}$	5.6	$4.08\ 10^{11}$
25/07	6	–	–	$3.76\ 10^{11}$

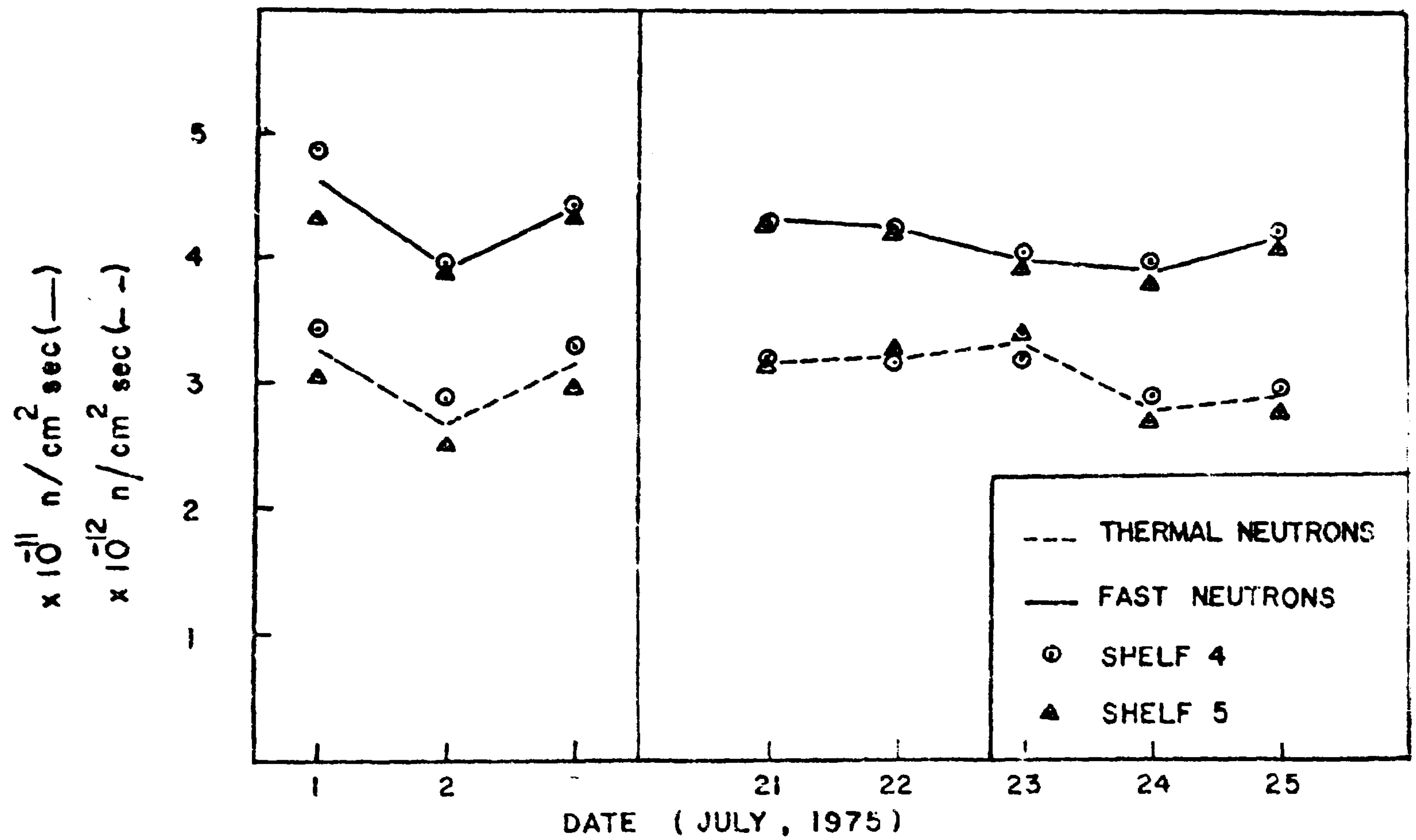

Figure 4 — Plot of time variations.

RESUMO

São apresentados os valores de fluxo rápido e térmico, em vários locais que são oferecidos para irradiação de amostras no reator IEAR-1.

As medidas foram feitas pela técnica de ativação de folhas e foi empregado ouro para a determinação do fluxo de nêutrons térmicos e alumínio para nêutrons rápidos.

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