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THE IN-PILE DOSIMETRY OF MIXED RADIATIONS IN THE CORE OF TRIGA MARK III NUCLEAR REACTOR AT ININ-MEXICO

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ABSTRACT

Two isothermic calorimeters, one containing graphite and the other aluminum, were used to measure ionizing radiation doses received in three experimental positions of a TRIGA Mark III reactor core. The dose rates in the positions studied were found to be the following: Central Thimble (CT): (12.8 ± 0.3) x 10^5 Gy/h, 64% γ: 36% n_f; In-Core Isotope Production Facility (I-CIPF): (5.0 ± 0.1) x 10^5 Gy/h, 76%γ: 24% n_f; In-Pool Isotope Production Facility (I-PIPF): (2.0 ± 0.1) x 10^5 Gy/h, 80%γ: 20% n_f.

The solid oxalic acid dosimetric technique was also utilized. Radiolytic decomposition constant (a) values observed in the experimental positions were the following: $a_{CT} = 17.64 \pm 0.01$ MGy; $a_{I\text{-}CIPF} = 17.4 \pm 0.4$ MGy; $a_{I\text{-}PIPF} = 17.6 \pm 0.4$ MGy.

RESUMEN

Se determinaron las dosis de radiación ionizante en tres posiciones experimentales del Reactor Nuclear TRIGA MARK III del Centro Nuclear de México, mediante el uso de un par de calorímetros isotérmicos; uno de ellos con muestra de grafito y el otro con muestra de aluminio. Se encontró que en las posiciones experimentales estudiadas las razones de dosis son las siguientes: Dedal Central (DC): (12.8 ± 0.3) x 10^5 Gy/h, 64% γ/36% n_r; Tubo Seco (TS): (5.0 ± 0.1) x 10^5 Gy/h, 76% γ/24% n_r; Sistema de Irradiación Fijo de Cápsulas (SIFCA): (2.0 ± 0.1) x 10^5 Gy/h, 80% γ/20: n_r.

Se estableció también la técnica del dosímetro de ácido oxálico sólido, los valores encontrados de las constantes de descomposición radiolítica en las posiciones experimentales fueron las siguientes:
a_{DC} = 17.64 ± 0.01 MGy; a_{TS} = 17.45 ± 0.40 MGy; a_{SIFCA} = 17.56 ± 0.38 MGy.

INTRODUCTION

The movable-core TRIGA MARK III reactor is a light water cooled and reflected pool type reactor, using fuel moderator elements in which a zirconium hydride moderator is homogeneously combined with 20% enriched uranium fuel$^{(1)}$.

In Fig. 1 which presents a cross sectional diagram of the reactor core the experimental positions which were occupied in the present experiments are also shown.

Under normal conditions 1MW power, the neutron flux in the experimental positions were the following$^{(2)}$:

Position	$\phi\ n_f (n/cm^2\ s)$	$\phi\ n_t (n/cm^2\ s)$
Central Thimble (CT)	3.5×10^{13}	3.7×10^{13}
In-Core Isotope Production Facility (I-CIPF)	1.1387×10^{13}	1.3211×10^{13}
In-Pool Isotope Production Facility (I-PIPF)	4.5049×10^{12}	9.1633×10^{12}

The aim of the present investigation was to determine the dose rate from various experimental positions within the core of the reactor. For this purpose two isothermic calorimeters were constructed; one containing graphite and the other an aluminum sample. The graphite calorimeter was used to asses the global absorbed dose of radiation (*i.e.*, fast neutrons and gamma radiation) while the aluminum calorimeter served to assess the amount of gamma radiation.

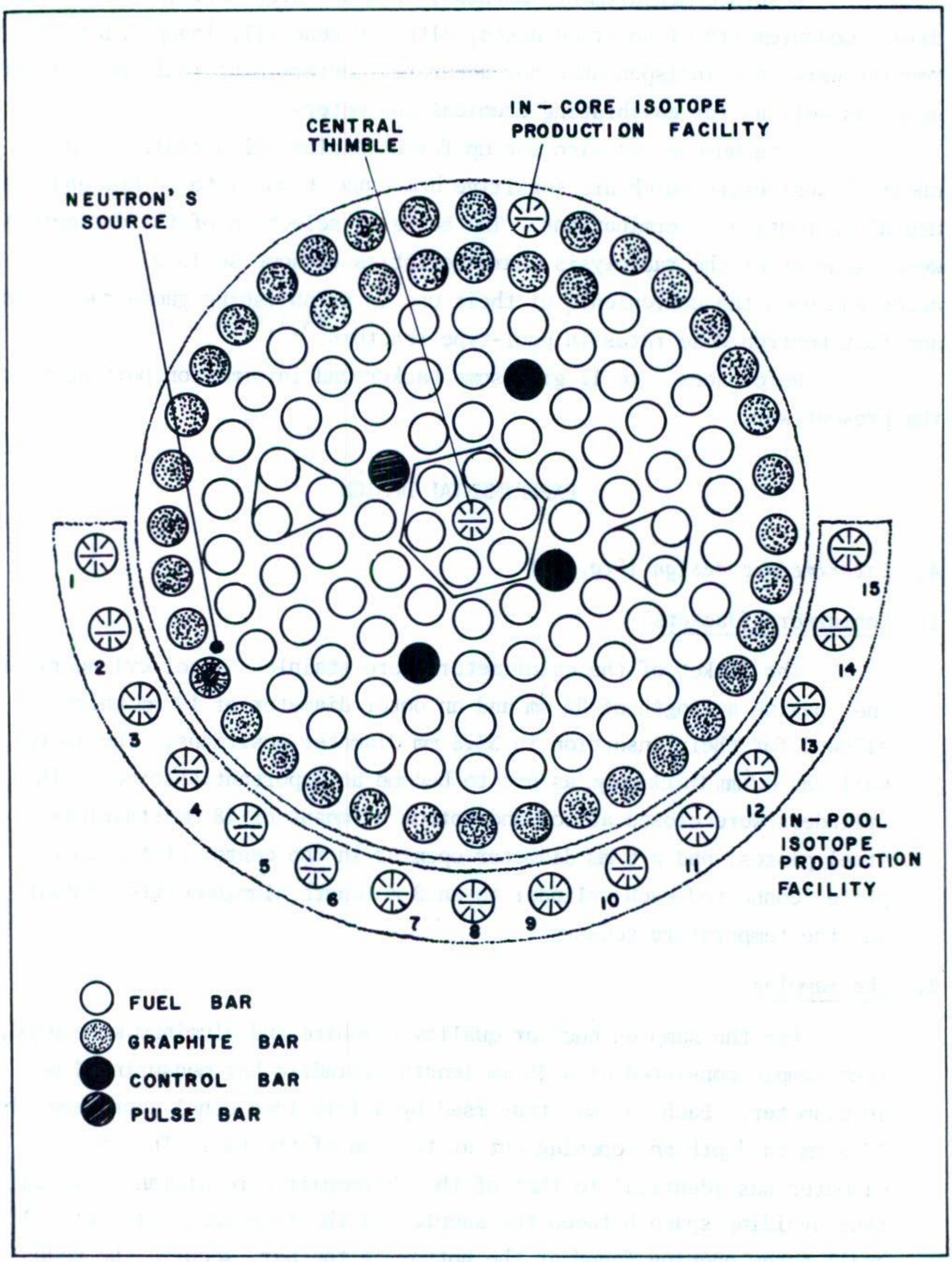


Fig. 1. Cross sectional diagram of the TRIGA MARK III reactor core.

Absolute measurements methods, such as calorimetry, which involves direct measurements of absorbed doses, although generally inappropiate for routine work, are indispensable for accurately determining ionizing radiation doses as well as for calibrating chemical dosimeters.

A technique was also set up for utilizing solid oxalic acid chemical dosimeters which are sensitive in a range from 1 to 10 MGy and are useful in routine determinations. The basis of selection of the dosimeters were studies of the radiolysis characteristics of some solid dicarboxilic acids and upon the convenience of their use in establishing gamma radiation and fast neutron dose rates in pool-type reactors(3,4,5,6).

References 7 to 12 give some background information pertinent to the present work.

EXPERIMENTAL DESIGN

A. *Calorimetric design (Fig. 2)*

1. Containers (Jackets)

The jacket of the calorimeters were stainless steel cylinders each one having a length of 82 mm and an outer diameter of 19 mm which allowed for their insertion in 33.8 mm diameter positions. The jacket wall was 0.5mm thick only, as not to become an important absorber. The cylinders were closed at top and bottom by means of 18 mm stainless steel plates, and a 6 mm diameter opening in the center of the upper plate, connected each cylinder to an 8 m length aluminum tube containing the temperature sensors.

2. The Samples

For the samples nuclear quality graphite and aluminum were used. Each sample consisted of a 35 mm length cylindric bar measuring 4 mm in diameter. Each bar was traversed by a 1/16 inch canal approximately 17.5 mm in depth and opening out at the top of the bar. The canal diameter was identical to that of the thermopair wire aislant covering thus avoiding space between the sample and the thermopair aislant. A small screw opening found at the bottom of the bar, secured the pedestal holding the sample. The aluminum bar mass was 0.98975 g and that of the graphite 0.56875 g.

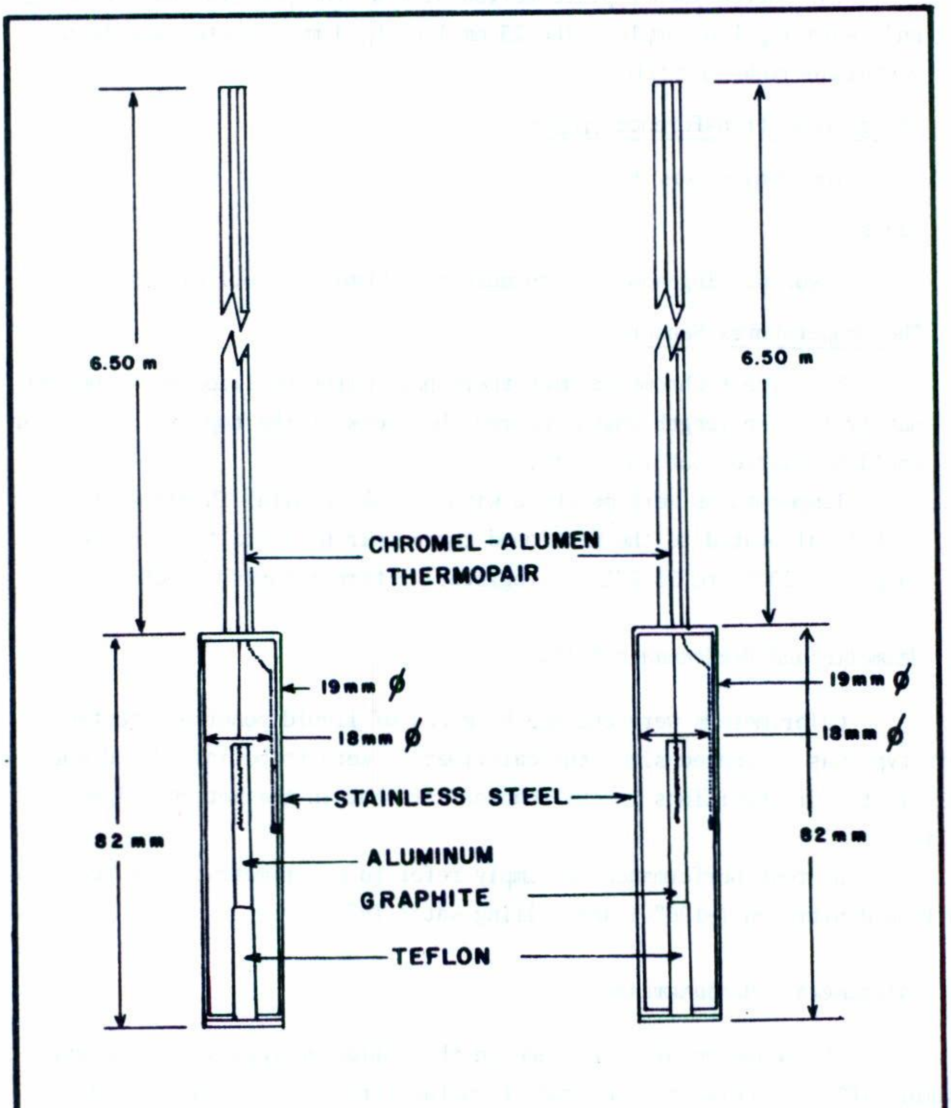


Fig. 2. Calorimetric design.

3. The Sample Pedestal

The bottom jacket plate served also as the pedestal base holding and isolating the sample. The 23 mm length, 4 mm diameter sample pedestal was made of teflon.

4. The gaseous transference medium

The medium was air.

5. Seals

Argon welding was used to unit the stainless steel pieces.

6. The Temperatures Sensors

The type-K chromel-alumen thermopair wires utilized were approximately 10 m in length which ensured that work at the top of the reactor could be carried out in safety.

Temperatures were measured with a Fluke Digital Thermometer model 2100 A calibrated to the mentioned thermopair having a temperature range of -200°C to 1370°C and registering temperatures directly in °C.

B. *Hermetic and Performance Tests*

Calorimeters were checked by means of liquid penetrant testing. This type was indicated since the calorimeters were to be introduced not only in the dry positions in the reactor core but in the wet positions as well.

By test performance we simply refer to calorimetric test behavior in liquid nitrogen (-196°C) and boiling water (92°C).

C. *Calorimetric Measurements*

The measurements were made in the following positions: Central Thimble (CT), In-Core Isotope Production Facility (I-CIPF) and 7,8 and 9 positions in In-Pool Isotope Production Facility (I-PIPF). Introduction of the calorimeters in wet positions could be effected without applying weights by exerting slight pressure on the support bar of the calorimeters. Measurements of two distinct positions were routinely made as a part of each experiment. From before reactor start-up and once connected the thermopairs to the digital thermometer, the calorimeters remained undisturbed in their experimental positions from which measurements were to be taken. Each one of thermometer channel outlets was used to register the temperatures of the graphite and of aluminum samples and another two to register the temperatures corresponding to the graphite and aluminum calorimeter jackets or reference temperatures. Initially the temperatures registered at each channel opening had to be identical. Once started-up the reactor was allowed to reach criticality at 1MW of power. During each minute the temperature was recorded for both the sample and the reference up to that point in time where no variations in temperature was recorded. This point was designated as equilibrium temperature (t_e).

To obtain the parameter denominated as pseudoperiod, temperature changes have to be measured during the cooling of the calorimeters outside the field of radiation. Earlier, J.F. Lugo(7) set up an experimental design in which an aluminum calorimeter, identical to that of the present experiments, which was suitable for determining the pseudoperiod value. However to use this value it was first necessary to verify similar cooling behavior for the aluminum and graphite calorimeters. This was accomplished within a radiation field.

The formula used for the calculations was(13)

$$\frac{P}{M_m} = C_e \ (t_e - t)/T_o \quad ,$$

where:

P - energy amount absorbed by each sample, cal/min

M_m - sample mass, g

C_e - specific heat of the sample at t_e, cal/°K mol

t_e - equilibrum temperature, °K

t - reference temperature, °K

T - pseudoperiod equal to 3.5 min^{-1}

D. Dosimeter of Solid Oxalic Acid

1. Equipment, Materials, Reagents

For the experiments the analytical grade dihydrated-oxalic acid used did not require further purification. The crystals were pulverized in an agata mortar, and of the grains resulting, only those between mesh 50-60 were used.

The amount of water of crystallization per number of molecules was checked by Karl Fischer technique. The experimental design used for situating the samples inside the reactor core is shown in Fig. 3.

The analytical weight scale was a Mettler model H.51 of a capacity of 160 ± 0.00001 g whose quality as given on the manufacter's label was previously checked for accuracy.

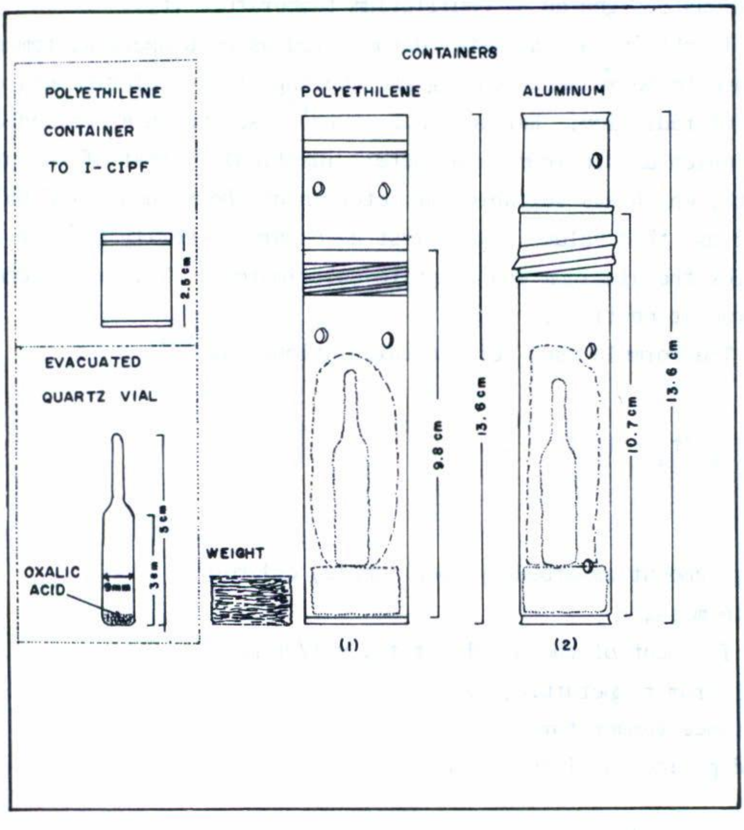


Fig. 3. Experimental design used for situating the solid oxalic acid samples inside the reactor core positions:

(1): I-PIPF (2): CT and I-CIPF.

2. Dosimeter Application

The samples of 0.15 to 0.25 g were placed in differents experimental arrangements depending on the positions in which measurements were to be made.

Irradiation times were the following: CT, 2 hours; I-CPIF: 3 hours; I PIPF: 5 hours and 7 hours. Based on the dose rate in each position and the useful doses interval of the oxalic acid dosimeter.

After irradiation the samples were stored at the temperature of 80°C until weight was stabilized (80 hours). Calculations for a_r were based on the following formula$^{(5)}$:

$$a_r = \frac{D}{\log \frac{m_o}{\overset{*}{m}}} \quad ,$$

where:

D - absorbed dose, Gy

m_o - initial sample mass, g

$\overset{*}{m}$ - final mass of the sample, corrected, g, = 1.4 x the final mass

a_r - radiolytic decomposition constant inside the reactor; r can be CT, I-CIPF or I-PIPF.

Radiolytic decomposition yield G_o of oxalic acid was calculated by means of the following formula$^{(3)}$:

$$G_o = 100\ A\ k \quad ,$$

where:

A is the Avogadro's number and

$$k = \frac{2.303}{a_r} \quad \frac{g\ mol}{eV}$$

RESULTS AND DISCUSSION

A. *Calorimetric Determinations*

Table I provides the data obtained from the calorimeters located in different experimental positions in the reactor core. As is to be ob-

TABLE I

CALORIMETER	POSITION	INITIAL TEMPERATURES, °C	EQUILIBRIUM TEMPERATURES, °C	
			REFERENCE	SAMPLE
ALUMINUM	CT	17.9	78.4	131.7
"	"	18.7	79.8	128.4
"	I-CIPF	17.1	45.0	68.9
"	"	17.7	39.7	63.7
"	I-PIPF # 7	14.8	26.0	36.9
"	I-PIPF # 8	16.7	27.4	37.7
GRAPHITE	CT	17.5	80.9	129.5
"	"	17.6	92.1	122.4
"	I-CIPF	17.6	55.3	70.4
"	"	18.2	53.4	68.5
"	I-PIPF # 7	16.5	22.9	27.9
"	I PIPF # 8	14.6	20.0	27.0

served the highest temperatures measured are there in the CT and the lowest those of positions furthest from the core; I-PIPF. In the case of the latter the reference temperature was only a few degrees higher than the initial temperatures, whereas in the I-CIPF the temperature reached 50°C approximately and up to 80°C in the CT. In Table II are given the dose rate results and the gamma and fast neutron effects. The highest dose ratio were recorded in the CT position: 12.8 x 10^5 Gy/h of the global dose and 8.2 x 10^5 Gy/h from gamma radiation. The γ:n_f ratio was 64:36 in this position. In the I-CIPF the global dose ratio was 5.0 x 10^5 Gy/h and the dose ratio for gamma radiation was 3.8 x 10^5 Gy/h, the γ: n_f ratio was 76:24. In the I-PIPF the global dose ratio found was 2.0 x 10^5 Gy/h and 1.62 x 10^5 Gy/h from gamma radiation, the ratio γ:n_f was 80:20. The further away the experimental position are found from the centre of the core the less the radiation dose effects due to fast neutrons. The value obtained in the present experiments in the I-CIPF with a aluminum calorimeter was similar as that J.F. Lugo obtained with an identical calorimeter in a adjacent I-CIPF position(7).

With respect to absorbed dose rates measured in other research reactors and the maximum value obtained in the present study: 3.6 mW/g (1.28 MGy/h), is within the maximum reported in reference 13:BEPO Reactor, 6.5 MW = 3 mW/g and NRX Reactor 40 MW = 300 mW/g, etc.

B. *Oxalic Acid Dosimeter*

Table III presents the experimental results obtained with oxalic acid dosimeters. All the experiments were performed with a dosis equal to or above 1 MGy which is the lower limit of oxalic dosimeter.

The values of the radiolytic decomposition constant (a) in the three positions are very similar: a_{CT} = 17.63 MGy, $a_{I\text{-}CIPF}$ = 17.4 MGy and $a_{I\text{-}PIPF}$ = 17.6 MGy.

Figure 4 illustrate the behavior of the dihydrated oxalic acid dosimeter as a function of total absorbed dose. The experimental values confirm the existence of a proportional relationship between radiolytic decomposition and total absorbed dose.

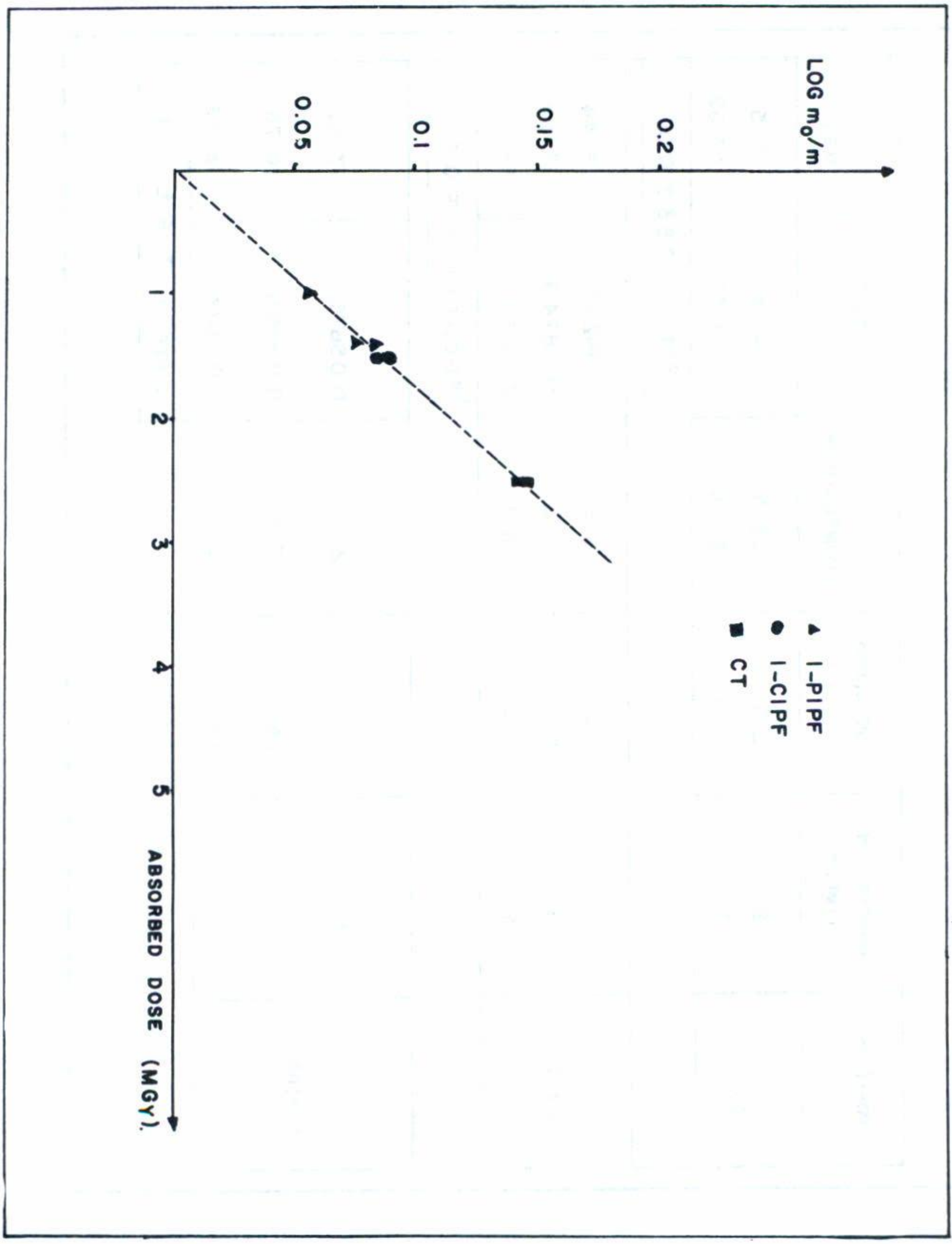
As can be observed from Table IV the two different types of reactors give dosimetric values that are quite similar. However, it is

TABLE II

POSITION	CALORIMETER	GLOBAL DOSE RATE, GY/h	DOSE RATE FROM GAMMA RADIATION RADIATION, GY/h	% EFFECT	
				γ	n_f
CT	GRAPHITE	$(12.8 \pm 0.3) \times 10^5$		64	36
	ALUMINUM		$(8.2 \pm 0.3) \times 10^5$		
I-CIPF	GRAPHITE	$(5.0 \pm 0.1) \times 10^5$		76	24
	ALUMINUM		$(3.8 \pm 0.1) \times 10^5$		
I-PIPF	GRAPHITE	$(2.0 \pm 0.1) \times 10^5$		80	20
	ALUMINUM		$(1.62 \pm 0.06) \times 10^5$		

TABLE III

POSITION	IRRADIATION TIME, h.	DOSE, MGy	% DECOMPOSITION	LOG m_0/m^*	MGy
CT	2	2.5	28.3	0.14448	17.75
	2	2.5	28.6	0.14636	17.52
				^{a}CT = 17.63 ± 0.01	
I-CIPF	3	1.52	19.2	0.09248	16.44
	3	1.52	18.2	0.08748	17.38
	3	1.52	18.1	0.08383	18.13
				^{a}I-CIPF = 17.4 ± 0.4	
I-PIPF	5	1.0	12.2	0.05675	17.62
	7	1.4	17.5	0.08365	16.78
	7	1.4	15.7	0.07676	18.29
				I-PIPF = 17.6 ± 0.4	


LOG m_o/m
0.2
0.15
0.1
0.05
1
2
3
4
5
ABSORBED DOSE (MGY)
▲ I-PIPF
● I-CIPF
■ CT

extremely important when considering these results to evaluate the dosimetric characteristics particular to each case, taking into account the specific conditions of use. Also presented in Table IV are the results obtained with dosimeters exposed to sources of gamma radiation, which when compared to those exposed in a mixed radiation reactor field give values which are notoriously different in the case of the TRIGA MARK III reactor used in the present study it is to be recommended periodic verification of the dose ratios obtained in experimental positions.

TABLE IV

REFERENCE	TYPE OF REACTOR (COMPOSITION OF RADIATION $\gamma : n_F$)	G	a (MG$_Y$)
This WORK	TRIGA MARK-III (64-80: 36-20)	10.0	17.5±0.38
5	HEAVY WATER (70: 30)	8.5	21.1±1.5
8	TRIGA MARK-III (? : ?)	6.4	25±0.21
10	γ RADIATION	6.5	27.2 ± 5.7
9	γ RADIATION	6.9	24.9± 0.18

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