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ABSTRACT

Dosimetric pellets, made by cold pressing a mixture of $CaSO_4$(Dy) and NaCl powders, of grain size between 85 μm and 185 μm, in the ratio 1 : 2 exhibit a wide scattering in the TL response. Even the same pellet gives different TL responses depending upon the surface facing the detector while making the measurement. Using finer powders of grain size less than 85 μm the observed scattering in the TL response is less than ± 10% from the average for 60% of the pellets. Dosimetric characteristics of these pellets have been investigated and they are found to be suitable for environmental and personnel radiation monitoring with appropriate energy compensating filters. When the pellets, wrapped in a thin aluminium foil, are gamma irradiated there is an electronic build up along the thickness of the pellet as a result of which the rear surface shows 19% higher TL response as compared to that of the front surface. The two surfaces exhibit nearly the same TL response when the pellets are irradiated, under electronic equilibrium condition, between lucite plates. A new irradiation facility is described in which the production of interfering low energy scattered radiation is largely avoided.

1 – INTRODUCTION

In recent times, $CaSO_4$(Dy) TL phosphor has been increasingly in use for radiation monitoring[3,6,8,9] due to its high sensitivity and ease of preparation. If the TL phosphor is used in the loose powder form, some loss of powder and triboluminescence is unavoidable during the read-out process. There has been a continuous search for the design of a dosimeter in which the TL phosphor is used in a fixed geometry form. Of the various designs available, two are particularly more popular. One of them is to use the powder tightly packed and sealed in a glass capillary. Another is to mix the TL phosphor with teflon powder in the ratio 1 : 5 and mould this mixture in the form of thin discs.

It is very important to use a potassium free glass capillary for sealing the TL phosphor, otherwise the dosimeter will not be useful for low dose measurements due to the high self irradiation rate of ^{40}k. The main problems in the use of teflon disc type dosimeters are that, while heating, teflon softens, its optical properties change and finally, it melts at about 300°C. Therefore such dosimeters should be annealed at temperatures less than 300°C for reuse and a special holder must be used during read out and annealing in order to keep the dosimeters flat[2].

Recently a new type of dosimeter has been developed in which NaCl or KCl powder is thoroughly mixed with the TL phosphor in the weight ratio 2 : 1 and the mixture is cold pressed in the form of pellets of diameter 1 cm and thickness 1 mm[7,1]. Some of the difficulties encountered during the use of $CaSO_4$(Dy): NaCl pellets and their possible elimination are investigated and described in this report.

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2 – EXPERIMENTAL

2.1 – Preparation of $CaSO_4$(Dy): NaCl Pellets

In a preliminary step, 15 mg of Dy_2O_3 is dissolved in a few ml of dilute sulphuric acid and the solution is added to 250 ml of concentrated sulphuric acid. In this solution, 8.093 g of $CaCO_3$ is added and dissolved completely by heating up to 200°C. The undissolved portion is filtered out. The sulphuric acid is then slowly evaporated in a fumehood by maintaining the solution at about 350°C. Crystalline material, left behind after complete evaporation of the acid, is washed with distilled water, and dried[10]. Crystals are crushed, sieved and particles between 85 μm and 185 μm size are selected. This particle size is used in all experiments unless otherwise indicated. The powder is annealed at 600°C for 1 hour for optimum TL sensitivity. $CaSO_4$(Dy) powder is mixed with commercially available NaCl powder, in the weight ratio 1 : 2 and sieved between 85 μm and 185 μm particle size. They are thoroughly mixed in a motor driven mixer for one hour. Three pellets of 6 mm in diameter and 1 mm thickness are made simultaneously in a specially designed die using a Perkin Elmer press. A mixture weighting 75 mg is used for each pellet and a pressure of 8000 lb is applied for one minute. Pellets are given a standard thermal annealing treatment at 400°C for one hour before use.

2.2 – Gamma Irradiation and TL Measurements

For gamma irradiation, pellets are placed in a circle of 50 cm radius on a plastic plate. A Co - 60 gamma source of activity 27 mCi was used for irradiation. At this distance, the error in delivering the dose of more than 100 mrad is estimated to be less than ± 1%. After irradiation, TL glow curves were recorded by heating the pellets at a linear rate of 10°C/s in a Harshaw 2000 AB TLD reader unit. TL light output is integrated between the temperatures 170°C and 300°C.

3 – RESULTS AND DISCUSSIONS

3.1 – TL Response of the Pellets

Thirty pellets, after the standard thermal annealing of 400°C were wrapped in aluminium foil and given a gamma dose of 300 mrad. TL glow curves of the pellets were recorded keeping the same surface, I, which faced the gamma source during irradiation, towards the detector (photomultiplier tube).

The average TL response of these pellets was 109.0 nC with a percentual standard deviation of ± 21%, as shown in Table I. Only 13% of the pellets showed a TL response with deviation less than ± 10% from the average (Figure 1), while the maximum deviation observed from the average response was ~40% for 3% of the pellets.

The same group of 30 pellets, after standard thermal annealing received again the same gamma dose of 300 mrad. But at this time the reverse surface, II, was irradiated and read-out. The average TL response in this case shown in Table I, was 107.0 nC with a percentual standard deviation of ± 15%, where 50% of the pellets showed deviations of more than ± 10% from the average response. However in a sample to sample comparison between the TL response of surfaces I and II, there were 7% of the pellets wich gave more than 50% deviation, 53% of them which gave between 10% and 50% deviation and 40% which gave less than 10% deviation. (Figure 2).

Heavy X – irradiation changes the colour of NaCl in the pellet in a non-homogeneous way, leading to the conclusion that the TL phosphor $CaSO_4$(Dy) is not uniformly distributed in the pellet. Since the pellets are translucent, only the light emitted from the upper layers of the pellet reaches the detector during read-out. Therefore the two surfaces behave as two different pellets, indicating that only one of the sides should be irradiated and read-out.

In order to reduce the scattering in the TL response, pellets were made from $CaSO_4$(Dy) and NaCl powder of particle size less than 85 μm after mixing thoroughly. TL glow curves were recorded after standard thermal annealing and 300 mrad gamma dose. Results are given in Table I, for surfaces I and II.

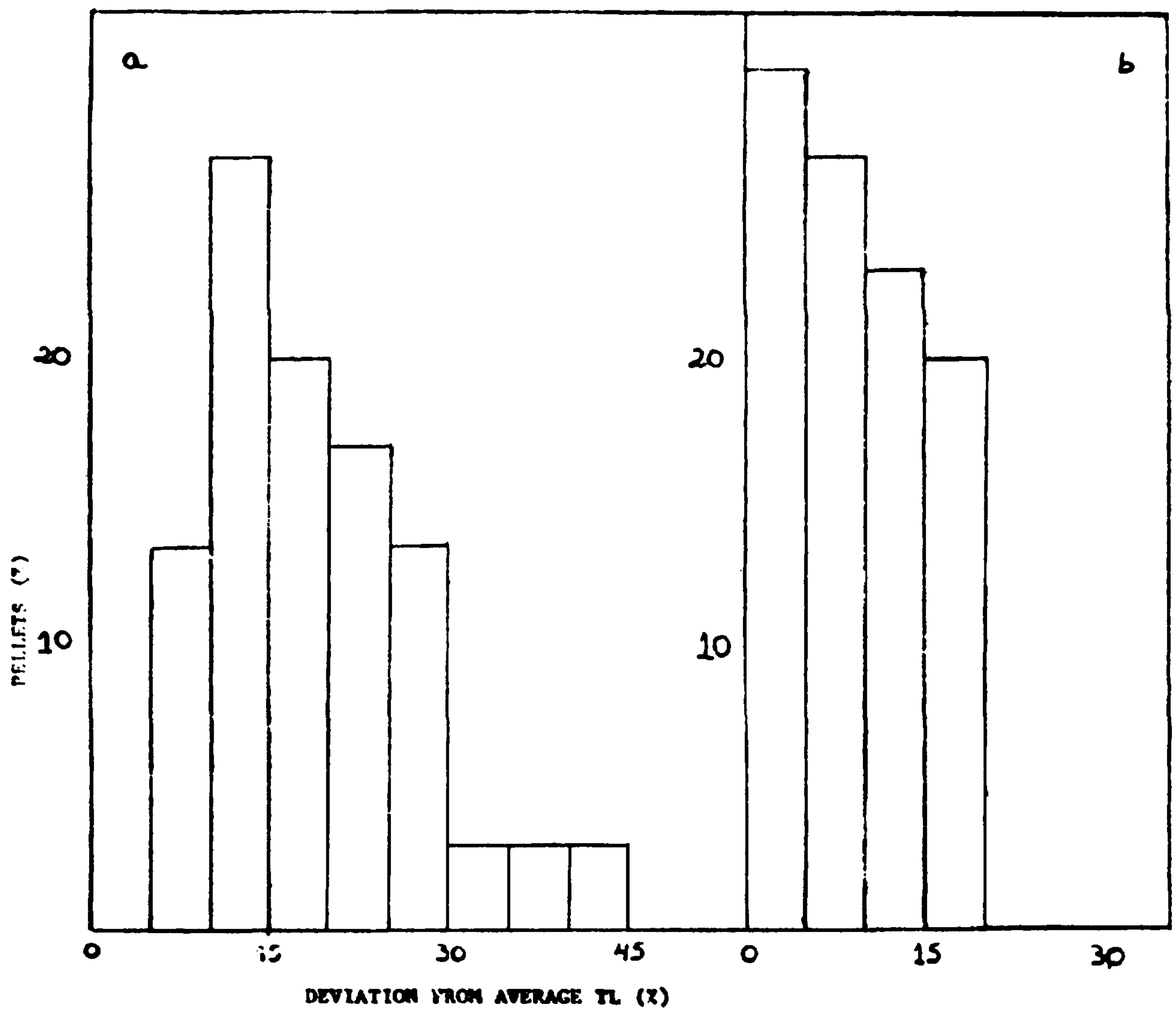

Figure 1 — Histogram relating the percentage of pellets to the deviation from average TL (%). a) grain size between 85 and 185 μm. b) grain size less than 85 μm.

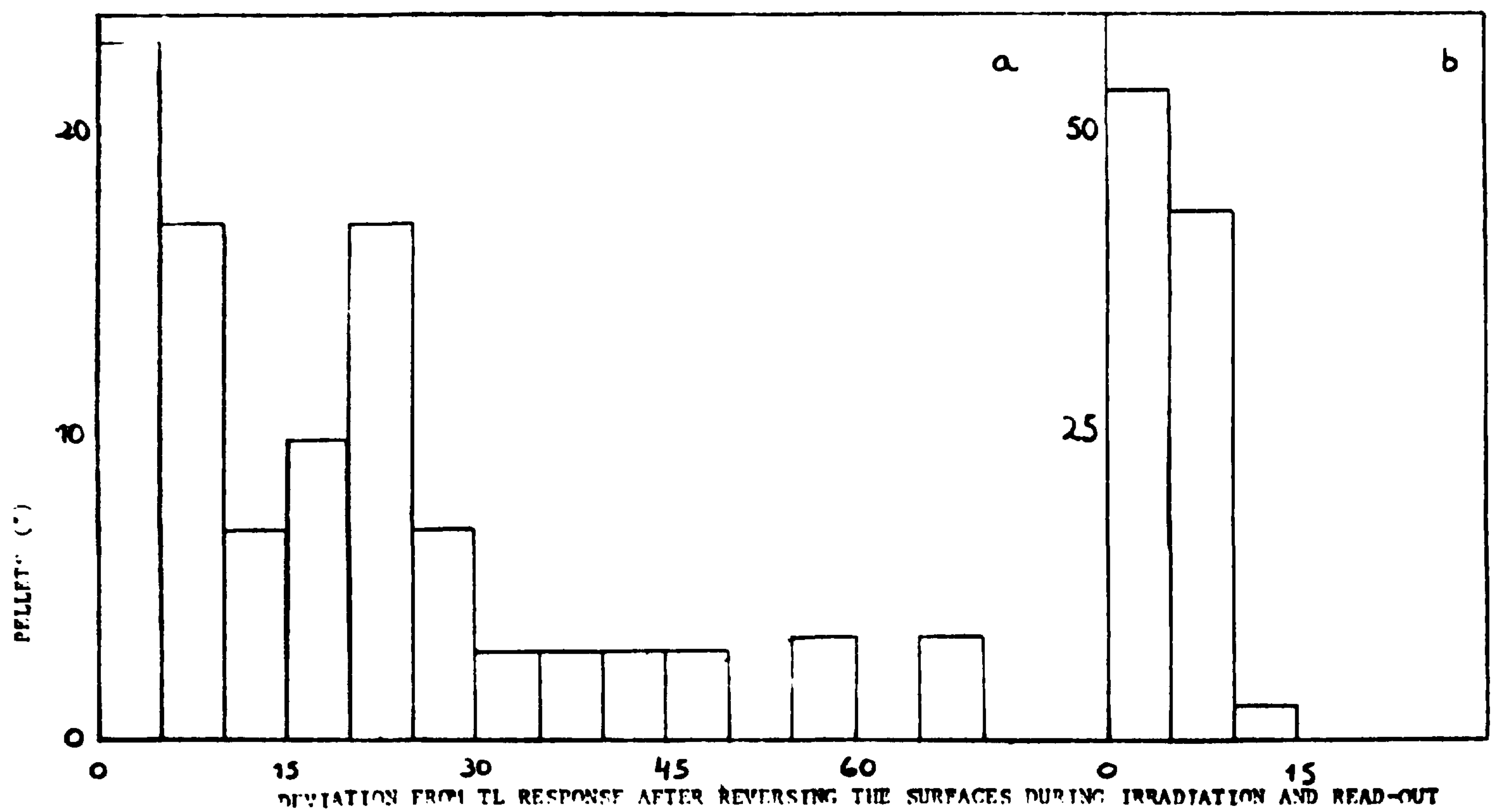

Figure 2 – Histogram relating the percentage of pellets to the deviation from TL response after reversing surfaces during irradiation and read-out: a) grain size between 85 and 185 μm. b) grain size less than 85 μm.

Table I

TL Response of the Pellets

SAMPLE	TREATMENT	AVERAGE	STANDARD DEVIATION	%
30 PELLETS (85-185)μm	300 mrad gamma dose at SURFACE I	109.0	23.2	21
30 PELLETS (85-185)μm	300 mrad gamma dose at SURFACE II	107.0	16.0	15
30 PELLETS < 85 μm	300 mrad gamma dose at SURFACE I	116,8	13,4	11
30 PELLETS < 85 μm	300 mrad gamma dose at SURFACE II	114.0	13.5	12

The average TL response shown by these pellets was 116.8 nC with a standard deviation of ± 11% for surface I and 114.0 nC with a standard deviation of ± 12% for surface II. In this case 97% of the pellets showed a deviation between ± 10%, and 57% of them, less than ± 5% deviation, when comparing surfaces I and II on a sample to sample basis.

For routine dosimetry, it is not pratical to calibrate all the dosimeters used for dose measurements. All the dosimeters should have nearly the same sensitivity to avoid the individual calibration. Since ~60% of the pellets made from fine powder have a TL response within ± 10% of the average response these pellets after selection are suitable for routine dosimetry (Figure I).

3.2 – Electronic Build up Throughout the Thickness of the Pellet

Thirty pellets made from fine powder were given a gamma dose of 300 mrad after a standard thermal annealing and their glow curves were recorded keeping surface I facing both the gamma source during irradiation and the detector during read-out. After read out, these pellets were again annealed and surface I was given the same gamma dose of 300 mrad in the same manner as before. This time the opposite surface II of the pellets faced the detector while recording the glow curves. Results are given in Table II.

When the surface II, which is opposed to the source during gamma irradiation, faces the detector, a TL response 19% higher is obtained. This consistent increase, observed for all the pellets is due to an electronic build up along the thickness of the pellet[5] as a result of which the rear surface receives higher dose as compared to the front surface. In order to avoid this problem, pellets must be irradiated in a electronic equilibrium condition. For This purpose, an experiment was conducted in which the pellets were sandwiched between lucite plates of varying thicknesses from 1 mm to 5 mm and irradiated with gamma rays. From the TL measurements, it was found that a thickness of 3 mm is sufficient to achieve the electronic equilibrium. When irradiating the pellets between the 3 mm lucite plates, the average TL response shown by the two surfaces of the pellets are (76.2 ± 6.6) nC and (71.9 ± 6.6) nC respectively (Table II). The TL response from surface I and II differ only 6% when using the 3 mm lucite plates as opposed to the 19% difference, when these plates are not used. Therefore, irradiation of pellets must always be done between lucite plates of thickness 3 mm each.

3.3 – Radiation Scattering

For irradiation, a Co - 60 gamma source and the pellets were placed on top of a 1 cm thick plastic plate. Gamma radiation interacts with the plastic plate and spectrum of photons of energies from 0 (zero) to about 1 MeV is produced due to the Compton effect[4]. The pellets are thus exposed to these low energy scattered photons in addition to the direct Co - 60 gamma rays. Since $CaSO_4(Dy)$ phosphor has a high effective atomic number the absorption cross section for 40 KeV energy photons is 12 times higher than that for 100 KeV energy photons causing a higher TL response for the former exposure. Therefore, the presence of a small fraction of these low energy radiation during calibration exposure can introduce large errors.

Table II

TL Response of the Pellets Irradiated in Aluminium Foil and between 3 mm Thick Lucite

SAMPLE	TREATMENT	AVERAGE (nC)	STANDARD DEVIATION	%
pellet (< 85 μm)	300 mrad gamma dose at surface I (TL of surface I)	98.1	10.4	11
pellet (< 85 μm)	300 mrad gamma dose at surface I (TL of surface II)	116.8	13.4	12
pellet (< 85 μm) between 3 mm lucite plates	300 mrad gamma dose at surface I (TL of surface I)	76.2	6.6	9
pellet (< 85 μm) between 3 mm lucite plates	300 mrad gamma dose at surface I (TL of surface II)	71.9	6.6	9

The results of Table II show that pellets irradiated in aluminium foil have, on the average 28.7% higher TL response (surface I) than those irradiated between the lucite plates. This could be explained by saying that the lucite prevents the soft radiation from reaching the pellets. In order to find out if this is the case, pellets were irradiated between lead filters of thickness 1 mm which cut off the radiation effect nearly completely up to 50 KeV.

These pellets showed only 5% lower TL response as compared to that obtained with lucite plates and a part of this is due to attenuation of gamma rays in lead filter. Therefore, it may be stated that practically the soft radiation, generated by the interaction of gamma rays with the botton plastic plate, is stopped by the 3 mm thick lucite plate.

Table III gives the results of an experiment in which irradiation of the pellets was done in plastic cassettes. A complete description of these cassettes is given elsewhere[1]. The plastic cassette has one open window and three filters, namely, plastic of thickness 2.3 mm, lead of thickness 1 mm and 0.8 mm thick lead with a central hole of diameter 2 mm[1]. Four pellets were placed, one in each of these four positions after being sealed in a plastic sheet. Four plastic cassettes containing 16 pellets were given a gamma dose of 300 mrad at a distance of 50 cm from the Co - 60 source. The irradiation was first done with the open window and, therefore, surface I, facing the gamma source. After the read-out and standard thermal annealing, these pellets were placed in the same position and the cassettes were again given the gamma dose of 300 mrad with the open window facing 180° away from the source so that surface II faced the source. Pellets at the open window location showed, on the average, 52.9% higher TL response for surface I than surface II. Results of the TL measurements are given in Table III.

In this experiment, the average deviation in TL response due to scattering has increased from 28.1% to 52.9% where the former value was obtained with the aluminium foil but without the plastic cassette, while the latter was obtained with the plastic cassette. This difference is probably because plastic edges of the window produce additional scattering. In order to eliminate or reduce the error due to scattering, a new irradiation arrangement must be employed such that the scattering agent is as far away from the pellets as possible. The design of the plastic cassette should be also modified to avoid radiation scattered from the cassette from reaching the pellets.

3.4 – New Irradiation Facility

Figure 3 shows the design of a new irradiation facility. Source S is enclosed in an aluminium tube of 1 cm diameter and wall thickness of 1.5 mm which is attached to the rod 4 of the same diameter. When not in use, the source rests in a cylindrical lead box 3, of wall thickness 5 cm, fitted in a table of dimensions 70 cm x 70 cm and 20 cm of height. For irradiation, pellets are sandwiched between lucite plates of dimensions 5 cm x 1,5 cm, in batches of 10, and placed in a 5 mm deep circular slot of the annular ring R. The annular ring is held at a height of 10 cm from the bottom aluminium plate 2 with the help of four thin aluminium rods AR. By pulling the string T the source S slides along a tube A of internal diameter 2 cm, until it is stopped by the cap C. Source holder 4 is balanced by the weight W. In this position, source S faces the pellets. Irradiation of the pellets starts as soon as the source is pulled out from tube A.

In this assembly, the only scattering medium near the source S is rod 4 of diameter 1 cm. But it provides a very small surface area for interaction with gamma rays and the irradiation of the samples is as good as in free air. There will be attenuation of the radiation intensity by about 1% because of the 1.5 mm thick aluminium tube surrounding the source, which has to be taken into account for precise dose measurements.

The distance between the source and the samples is 15 cm. This small source sample distance will not introduce any error while giving the dose because in this assembly, the process of raising or lowering the source takes only a fraction of a second.

Table III

TL Response of the Pellets Irradiated in Plastic Cassettes, with Surface I (open window) and Surface II (plastic) Facing the Source

Cassette (nº)	Pellets (nº)	Filters	TL response (nC) I	TL response (nC) II	Deviation between TL response I and II (%)
1	1	Open window (I)/ Plastic (II)	74.7	46.5	60.6
	2	Plastic	68.7	62.6	–
	3	Lead	60.6	62.6	–
	4	Lead with hole	66.7	64.6	–
2	5	Open window (I)/ Plastic (II)	92.9	56.6	64.1
	6	Plastic	60.6	58.6	–
	7	Lead	62.6	62.6	–
	8	Lead with hole	62.6	58.6	–
3	9	Open window (I)/ Plastic (II)	84.8	58.6	44.7
	10	Plastic	64.6	64.6	–
	11	Lead	66.6	70.7	–
	12	Lead with hole	71.7	74.7	–
4	13	Open window (I)/ Plastic (II)	94.9	66.7	42.3
	14	Plastic	64.6	64.6	–
	15	Lead	66.6	70.7	–
	16	Lead with hole	64.6	66.7	–

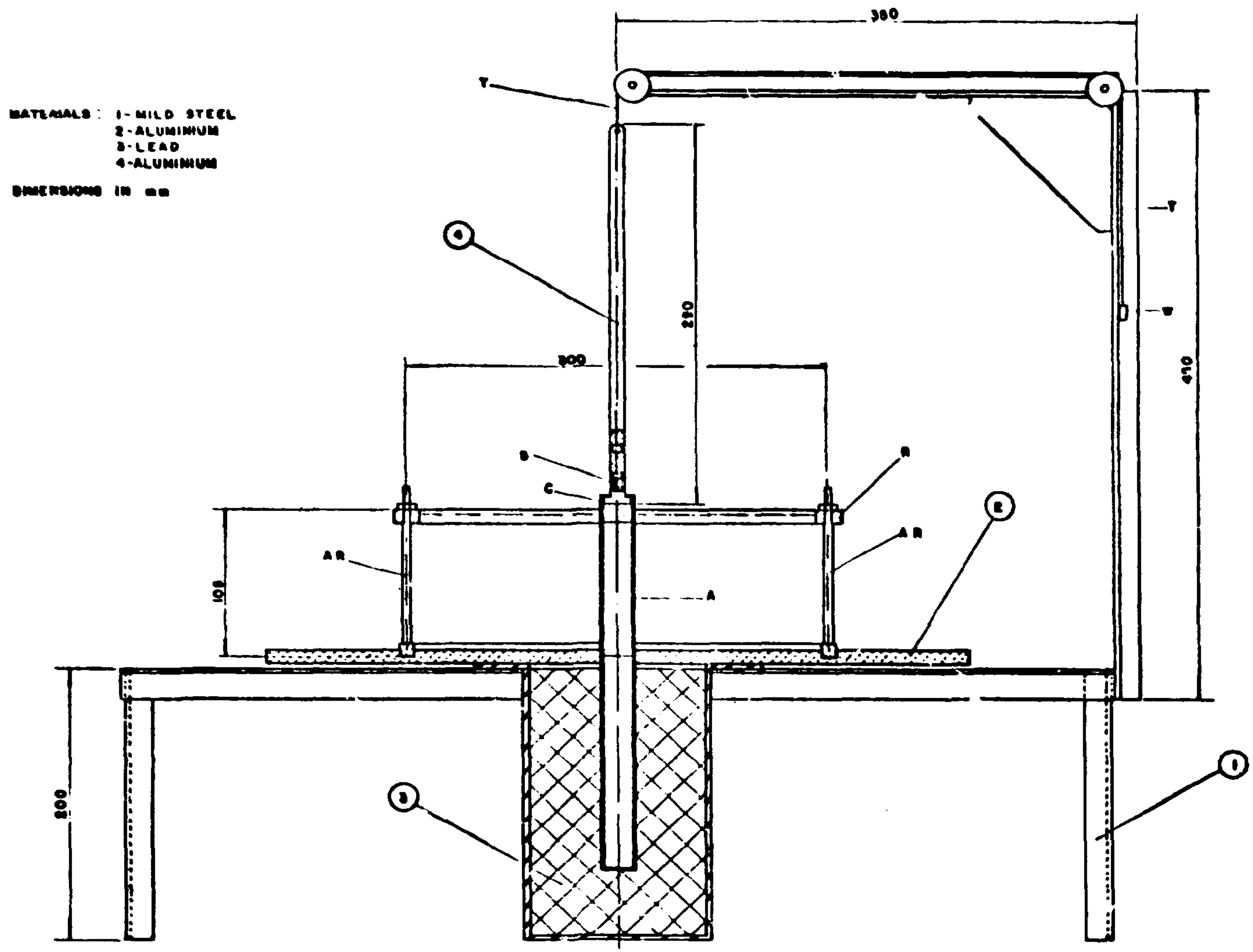

Figure 3 – Irradiation facility.

CONCLUSIONS

In order to reduce the scattering in the TL response of $CaSO_4$(Dy) pellets, they should be made with a powder mixture of particle size less than 85 μm. Since 60% of the pellets made from fine powder have the TL response within ± 10% of the average TL response, these pellets, after selection, are suitable for routine dosimetry. In addition, irradiation of pellets should always be done between lucite plates of thickness 3 mm each. When used in the proposed badge, the pellets can be utilized in personnel and environmental dosimetry of γ and X radiation.

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RESUMO

Amostras produzidas pela compactação a frio de uma mistura de $CaSO_4$:Dy e NaCl, com granulação entre 85 μm e 185 μm na razão de 1 : 2, apresentam um largo espalhamento na resposta TL. As mesmas amostras apresentam diferentes respostas dependendo da superfície voltada para o detector durante a medida TL. Utilizando-se pó fino, de granulação menor que 85 μm, na compactação das amostras, o espalhamento na resposta foi observado como sendo menor que ± 10% da média para 60% das amostras. Quando as amostras são expostas à radiação gama envoltas em folha de alumínio fina, ocorre "build up" eletrônico ao longo da espessura da amostra, como consequência, a superfície posterior apresenta resposta 19% superior em relação à resposta da superfície frontal. As duas superfícies apresentam aproximadamente a mesma resposta quando as amostras são irradiadas sob condições de equilíbrio eletrônico entre placas de lucite de 3 mm de espessura.

Um novo arranjo para irradiação é descrito, no qual é eliminada a ocorrência de espalhamento da radiação.

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