ASSESSMENT OF CHARACTERISTICS OF THERMOLUMINESCENCE DOSIMETRY (TLD) SYSTEM USED IN CENTRE FOR ENERGY RESEARCH AND TRAINING (CERT), AHMADU BELLO UNIVERSITY, ZARIA

By

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DECLARATION

I declare that the work in the thesis entitled ‘Assessment of Characteristics of Thermoluminescence Dosimetry (TLD) System used in Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria’ has been performed by me in the Department of Physics under the supervision of Prof. T.C. Akpa and Prof. S.P.Mallam. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university or institution. Information derived from published work of other researchers have been fully acknowledge and referenced.

Bello Aisha Ademoh	_________	_________
Name of student	Signature	Date

CERTIFICATION

This thesis entitled **"ASSESSMENT OF CHARACTERISTICS OF THERMOLUMINESCENCE DOSIMETRY (TLD) SYSTEM USED IN CENTRE FOR ENERGY RESEARCH AND TRAINING (CERT), AHMADU BELLO UNIVERSITY, ZARIA"** by Bello, Aisha Ademoh, meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work first and foremost to Allah in who is the key to all my success, to Sheik Ahmadu Tijjani, Sheik Ibrahim Nyass, Sheik Abayawo Ilorin, My Murshid and my late brother, Muh'd Bashir Bello.

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ABSTRACT

Thermoluminescence dosimetry (TLD) system has been used to estimate the personal dose for external occupationally exposed workers in CERT. The reliability and precision of dose measurements and the accuracy of dose evaluation are important factors for the improvement and achievement of individual monitoring objectives. In this piece of work, evaluation of characteristics of TLD system was investigated at the Centre for Energy Research and Training, Ahmadu Bello University Zaria. Dose sensitivity, dose linearity, residual signal, fading, batch homogeneity, stability of Calibration factor, re-usability over 10 cycles, sensitivity to ambient light, and the influence of environmental conditions were evaluated. Not all investigated properties were found to be within the limits defined by IEC standard. These results are discussed in order to demonstrate the degree of accuracy achieved and the need for its improvement where necessary.

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CHAPTER 1 INTRODUCTION

1.1 Thermoluminescence Detectors in Dosimetry

Dosimetry is the quantitative assessment of ionizing radiation absorbed in matter and tissue. There are several techniques for detecting and measurement of dose and dose rate to an individual. These include thermoluminescent dosimetry, film dosimetry, and ionization (pocket) meter. Although active devices such as area monitors and electronic personal dosimeters are often used within a facility, passive systems such as thermoluminescent dosimeters and film batches are usually preferred for personnel applications because of their ease of deployment and the minimal maintenance required.

Personnel dosimeters are devices worn by individuals to measure radiation exposure. Three types of commonly used personnel dosimeters are: pocket meters, film badges, and thermoluminescent dosimeter (TLD) badges. Pocket meters are generally based on an air wall ionization chamber and can either be of the "direct reading" type, where the dose may be read from a scale or other indicator on the device, or the "indirect reading" type, where an instrument is needed to read the dose. Film badges consist of one or more small sheets of photographic film enclosed in a light-tight container that may be affixed to clothing. It is useful over a dose range of about 0.1mGy to 18mGy of gamma rays; it is also sensitive to beta radiation whose maximum energy exceeds about 400 keV, for about 0.5mGy to 10Gy. Using appropriate film and techniques, thermal neutron doses of 0.05mGy to 5Gy, and fast neutron doses from about 0.04mGy to 0.1Gy may be measured. Films used in film batch dosimeters are highly energy dependent in the low energy range, from about 0.2MeV gamma-radiation downward (Herman, 1992).

Thermoluminescent dosimeter badges contain thermoluminescent crystals that absorb and store energy when exposed to radiation, and emit light when heated. The light output is proportional to the radiation dose. The dose is read by heating the TLD crystal in a device equipped to detect the emitted light. Thermoluminescent dosimeters respond quantitatively to x-rays, gamma rays, beta rays, electrons, and protons over a range that extends from about 0.1mGy to 100Gy. Some TLDs such as LiF phosphors are approximately tissue equivalent with effective atomic number 8.1 compared to that of tissue 7.4. Their response is almost energy independent from about 100keV to 1.3keV gamma rays with increase sensitivity below 100keV (Herman, 1992).

The variety of materials used in TLDs and their different physical forms allow the determination of different radiation qualities over a wide range of absorbed dose. This makes TL dosimeters useful in radiation protection where dose levels of microgray are monitored as well as in radiotherapy where doses up to several Gray are to be measured. The major advantages of TL detectors are their small physical size and that no cables or auxiliary equipment is required during the dose assessment. Therefore TLD is a good method for point dose measurements in phantoms as well as for in vivo dosimetry on patients during radiotherapy treatment. As an integrative dosimetric technique, it can be applied to personal dosimetry and it lends itself to the determination of dose distributions due to multiple or moving radiation sources (examples conformal and dynamic radiotherapy, computed tomography). In addition, TL dosimeters are easy to transport, and they can be mailed. This makes them well suited for intercomparison of doses delivered in different institutions. Compared to photographic film dosimeters (film badges), TLDs are more sensitive, reusable with only a gradual change in efficiency and calibration and therefore, more economical, often more nearly tissue-equivalent (LiF), can measure deep and shallow doses, and are less subject to fading with time. Thermoluminescent dosimeters are insensitive to most of the environmental agents (humidity, pressure, atmospheric composition), their evaluation is easily automated and can be used for many forms of radiation, including mixed fields (β, γ and n) or even non-ionizing radiation (UV and visible).

Not all type of thermoluminescent dosimeters can satisfy all the above requirements. Some are best used at low energy range while others at high energy range, their sensitivity could also vary thus the problem of selecting TLD depends on the task they are used for.

Since Daniel *et al.,*(1953) suggested that thermoluminescence (TL) should be applied for radiation dosimetry purposes a lot of efforts have been made in the scientific community to explain the mechanism of thermoluminescence, as well as to improve its application for personal, environmental, industrial and clinical dosimetry.

1.2 Statement of Research Problem

Personnel who work in environments, in which exposure to either x-rays or nuclear radiation is possible, are periodically monitored to determine if the radiation levels to which they have been exposed fall within established safety limits. In addition, environmental monitoring of radiation, as for example, ambient radiation levels in the vicinity of nuclear plants, or background radiation resulting from naturally occurring sources, also require continuous monitoring over a period of time. Monitoring of cumulative exposure to radiation is generally provided by an integrating dose meter. Such monitoring is mandated by various regulatory organizations for personnel working in nuclear plants, radiology departments of hospitals, or in laboratories which utilize x-ray or nuclear radiation sources for experimental purposes. In the Centre for Energy

Research and Training (CERT), thermoluminescent dosimeters are used to monitor personnel radiation exposure. The facility includes a manual TLD reader for evaluation of absorbed doses and an irradiator for calibration. Some environmental researches may be carried out using these facilities and external groups using radiation in one way or the other are also monitored.

There are characteristics unique about these passive detectors that make them suitable for use and re-use even after a long period of time. There is yet no established data on the characteristics of TL detectors used in CERT. Despite the suitability of these TL detectors, different difficulties may be associated with its application.

It may be possible that some of the chips are not as sensitive as the others, changes in the properties of the chips due to its heating in the readout phase, including a sensitization due to the combined effect of irradiation and heating and non-linear dose dependence observed in some potential dosimetric materials such as LiF. Damage could have occurred due to environmental conditions. There could be gradual fading due to the relative long time they have been acquired.

Data on the characteristics of these detectors is therefore necessary to determine their suitability and to ascertain compliance with international electrotechnical committee (IEC) standards.

1.3 Aim and Objectives

The aim of this work is to check the level of performance of TL detectors in order to obtain results that could be used for better service delivery for dosimetry in Nigeria. Based on this, the objectives of this work is to:

i. Evaluate the characteristics of TL detectors such as, batch homogeneity, reproducibility, dose sensitivity, dose linearity, residual signal, sensitivity to ambient light, the influence of other environmental condition and fading used in Centre for Energy Research and Training, ABU Zaria
ii. Characterize and compare results from different TLD batches
iii. Compare the results with the limits provided by International Electrotechnical Committee (IEC).

1.4 Justification

Radiation is hazardous to man, and also advantageous if proper safety cautions are taken. This implies that man must work around radiations in other to exploit these advantages. For a TL detector to be useful, it must exhibit several desirable characteristics. The selected system needs an adequate performance test even in case of commercial detectors where manufacturer's performance recommendations are provided.

It is important to have data on the characteristics of TL detectors to reduce the possibility of variation in dosimeter characteristics during usage. This goes a long way to ensure proper assessment of the dose it has accumulated, thus enhancing the safety of the patient, personnel, the environment and the populace at large.

The results obtained in this work will be used in CERT and other institutions that use these detectors. Comparison of the data obtained with those of similar institution in the country will indicate best practice and compliance with safety standards.

This is a pioneer work; data obtained from this work will serve as significant contribution to literature and a basis for further work.

CHAPTER 2 LITERATURE REVIEW

2.1 Thermoluminescence (TL)

Thermoluminescence (TL) or thermally stimulated luminescence is the emission of light during heating of a solid sample (insulator or semiconductor), previously excited by radiation. The TL material absorbs energy during exposure to radiation (ionizing, visible light, and UV) and stores this energy until heated. The intensity of emitted light as a function of temperature (or time) is the thermoluminescence glow curve (fig.2.1). The glow peaks are a function of various energy traps (Furetta and Weng, 1998).

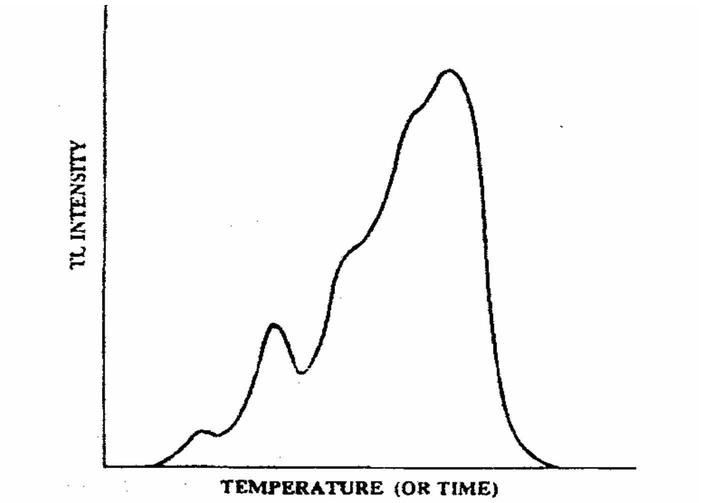

Fig. 2. 1. Example of a glow-curve. At each peak corresponds a well defined trap

Thermoluminescence (TL) phosphors generally exhibit glow curves with one or more peaks when the charge carriers are released. The glow curve is characteristic of the different trap levels that lie in the band gap of the material. The traps are characterized by certain physical parameters that include trap depth (*E*) and frequency factor (*s*).

2.2 Role of Lattice Imperfection in Luminescence

In the field of semiconductors and luminescence, lattice imperfections determine the properties of the solid to a considerable extent (Haug, 1972). A real crystal has defects of different kinds.

Intrinsic defects are lattices imperfections that are caused by the thermal motion of the lattice particles. Because of this motion, lattice particle occasionally leave their lattice site, so that vacancies are left behind as imperfections or interstitials. Intrinsic defects are always present in the lattice because they are purely thermal in origin; they belong to the crystal equilibrium state. The number of defects is small compare to the number of lattice particles (Haug, 1972).

Far more important than intrinsic defect are impurity atoms that are built into the crystal. They can be introduced into the crystal in more or less defined amounts and the defect content thus varied over a wide range. Their action is of decisive significance for the properties of phosphors. Impurity atoms may take up both interstitial sites and lattice sites.

Ionizing radiation produces further defects in TL materials. These defects are called color centres which are absorption centers, coloring ionic crystals. Regardless of type, the presence of imperfections, introduce new energy levels into the normal lattice energy band. It is possible that some of the energy levels constitute metastable states and are able to trap electrons or holes for some extended period of time. Thus during irradiation, electrons and holes created by ionization are trapped on defects or electrons can recombine with trapped holes and vice versa. After irradiation is ended, the produced charged traps can follow different mechanisms. One is the thermal decay of the charged traps and some times growth of one center at the expense of the other: if charges are released from one type of trap, all or part of them may be retrapped by another trap as observed in some TL materials (Furetta and Weng, 1998).

2.3 Principles of Thermoluminescence

The theoretical explanation of thermoluminescence is based on the electron band theory. Upon irradiation of some solids with ionizing radiation, pairs of charge carriers (electrons and holes) are formed, which can move freely within the conduction band and the valence band respectively, fig. 2.2. The charge carriers can be caught in traps with a certain probability depending on the amount of energy, E, applied to the crystal to produce electrons in shallow traps or deep traps (Ogundare *et al.,* 2006).

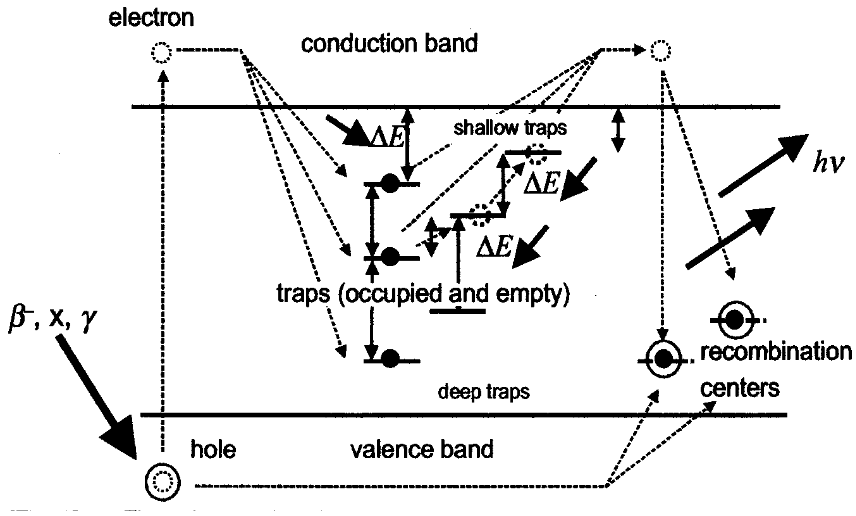

Fig.2.2 The scheme of luminescence excitation and emission in TL materials

The traps are energy states within the energy band usually in the forbidden gap which are produced by lattice defects or impurities. Figure 2.2 show the various things that happen in a crystal when irradiated with ionizing radiation. When TL materials are exposed to ionizing radiation at room or at low temperature, electrons are released from the valence band to the conduction band. This leaves a hole in the valence band. Both types of carriers become mobile in their respective bands until they recombine or until they are trapped in lattice imperfections in the crystalline solids (shallow and deep traps). These lattice imperfections play a very crucial role in the TL process. The trapped electrons may remain for a long period when the crystals are stored at room temperature. They are released if sufficient energy is given to the electron when the crystal is heated.

The probability p of liberation of a charge carrier from trap by thermal excitation is:

$$p \propto e^{-E/KT} \qquad 2.01$$

$$p = s.e^{-E/KT}$$

where E - Thermal activation energy

K - Boltzmann constant

T - Temperature

s - Frequency factor

The released charge carriers can be captured again by traps or recombine in luminescent centers (recombination centers). The wavelength λ of the emitted TL light is proportional to the energy difference ΔE between the trap and the luminescent centers (Ogundare *et al.,* 2006).

$$\lambda = \frac{hc}{\Delta E} \qquad 2.02$$

where h is Planck constant and c is the velocity of light.

The lifetime, τ of the charge carrier in the metastable state at temperature, T is given by

$$\tau = p^{-1}$$

The intensity I of the luminescence is time dependent.

$$I(t) = I_0 \exp(-pt) \tag{2.03}$$

$$I(t) = I_0 \exp\left[-s.\exp\left(-E/_{kT}\right)t\right] \tag{2.04}$$

I_0 is the initial intensity at time $t = t_0$

A simplifying assumption of only one kind of traps present (with the energy depth E) and of recombination of all released charge carriers leads to first-order kinetics as was used by Randall and Wilkin (Furetta and Weng, 1998). Here, the TL intensity is proportional to the rate of release of electrons from the traps, that is,

$$I(t)\alpha \frac{dn}{dt} = -a.p.n = -a.n.s.e^{\left(-E/_{kT}\right)} \tag{2.05}$$

s is the frequency factor "attempt to escape" (s^{-1}) [trap characteristic]

n is the trapped electron concentration at time t and a is a constant. The typical shape of a glow curve (I vs T) can be deduced by solving this differential equation and with a constant heating rate of $\beta = \frac{dT}{dt}$, the following equation for the TL intensity is obtained (Ogundare *et al.,* 2006).

$$I(T) = n_0 e^{-\left(E/_{KT}\right)} e^{\left[-s/_{\beta} \int_{T_0}^{T} e^{-\left(E/_{KT}\right)} dT\right]} \tag{2.06}$$

$n_0 =$ Number of trapped electrons at time $t = 0$

Taking the derivative of $\log I$ with T at maximum temperature, T_M we have the expression

$$\frac{\beta E}{KT_M{}^2} = s.e^{\left(-E/_{KT_M}\right)} \tag{2.07}$$

The integral light sum, S is given by (Furetta and Weng, 1998).

$$S = \int_0^\infty I(t) = -c\int_0^\infty \frac{dn}{dt}dt = -c\int_{n_o}^0 dn = cn_o, \qquad 2.08$$

Here, S is proportional to n_0 and is independent of the heating cycle. If n_0 is proportional to radiation dose, then S is also proportional to the radiation dose. This is a very useful relation in radiation dosimetry (Furetta and Weng, 1998).

When released carriers are captured in traps again, kinetics of higher order may be applied. A second order kinetics could be used to describe a situation in which retrapping is predominant, the TL intensity can be expressed as (Furetta and Weng, 1998)

$$I(t) = \frac{dn}{dt} = -n^2 s' e^{-E/KT} \qquad 2.09$$

and at constant heating rate,

$$I(T) = -\frac{dn}{dt} = n_0 s' e^{-E/KT}[1 + \frac{s' n_0}{\beta}\int_0^T e^{-\frac{E}{KT}} dT]^{-2} \qquad 2.10$$

$s' = s/N$ ……pre-exponential factor, N (cm^{-1}) is the trap concentration.

When one trapping state and one type of recombination centre are involved, three sets of differential equations could be used to explain thermoluminescence which leads to the general one trap equation (GOT). The intensity of the (TL) is given as (Furetta and Weng, 1998)

$$I = nse^{-E/KT}[1 - \frac{\sigma(N-n)}{\sigma(N-n)+m}] \qquad 2.11$$

$\sigma =$ Retrapping-recombination ratio

m -Concentration of recombination centers (holes in centre)

n - trapped electron concentration at time t

s - Pre-exponential (attempt to escape) frequency

σ_{r1} - Cross-section for electron retrapping

σ_r - Cross-section for electron hole recombination resulting in light emission

$\sigma = \frac{\sigma_{r1}}{\sigma_r}$ - retrapping/recombination cross-section ratio

Other forms (order) of kinetics exists like the zero order, mixed first and second order kinetics and general order kinetics (Furetta and Weng, 1998). In practice, traps with different structure and energy difference occur, as well as retrapping between the different types.

The assumption of only one type of hole traps for all different types of electron traps leads to the general equation for interacting kinetics of j different type of interacting electron traps (Ogundare *et al.,* 2006).

$$\frac{dn_i}{dt} = -n_i s_i e^{-E_i/KT} + (\sum_{i=1}^{j} n_i s_i e^{-E_i/KT})[\frac{\sigma_i(N_i - n_i)}{n_r + \sum_{i=1}^{j}\sigma_i(N_i - n_i)}] \qquad 2.12$$

Where $i = 1,2,3,.......j$, $\sigma_i = \frac{\sigma_{ti}}{\sigma_r}$

$\sum_{i=1}^{j} n_{i0} = n_r$ and

$$I(t) = -\frac{dn_r}{dt} = -\sum_{i=1}^{j}\frac{dn_i}{dt}$$

The first term in equation 2.12 describes the thermal untrapping from the ith type of trap, the first term in bracket gives the total charge concentration in the conduction band at time t and the second term in square bracket is the fraction of conduction band electrons retrapped on the ith type of electron traps. The electrons in the conduction band that are not retrapped will recombine with holes to produce the TL light (Furetta and Weng, 1998).

All these theories are models which can describe the shape of the TL glow curve that is the intensity of the TL as a function of temperature, I(T) as well as the influence of charge concentration, heating rate and trap depth on the glow curve. This gives a better knowledge of characteristics of TL materials. (Ranogajec-Komor, 2003).

The production of TL in dosimetric materials is a complex, multistage process involving the transfer of charge and energy between different defect states within the crystal. The final measured TL intensity is the net result of the reaction between photons or nuclear particles of the irradiation field, the type, number and distribution of the defects present within the crystal at the time of irradiation and heating, the nature of the irradiated crystal and other factors such as the irradiation rate, temperature, and energy of the absorbed particles.

2.4 Thermoluminescent Dosimetric (TLD) System

The possible application of the TLD depends on the characteristics of the complete TL system which consists of the detector, the TL reader and the measurement cycle including the mathematical evaluation of the results.

2.4.1 *TL Detectors*

TL detectors are natural or synthetic materials, which emit light whose intensity is proportional to the dose of irradiation when heated after having been exposed to radiation. They are actually phosphors with accumulation, where the active centers are relatively stable at ambient temperatures (Stochioiu *et al.,* 2004)

Nowadays a lot of TL phosphors are well-known which fulfils the requirements (wide dose range, less fading, response to very low energy and higher sensitivity) for various practical dosimetry applications. The most commonly used TL phosphors with decisive amount of dopants are lithium fluoride, calcium fluoride, lithium borate and calcium sulphate. They are usually manufactured in the form of chips, pellets, small rods or powder which is encapsulated for irradiation (Ranogajec-Komor, 2003).

In most literature, their commercial names are often cited. TLD-100 stands for the detector LiF: Mg,Ti from natural Li, while TLD-600 and TLD-700 are produced from enriched ^{6}Li and ^{7}Li isotopes, respectively. Sintered pellets of the same chemical composition from natural LiF are referred under the trade name MTS-N (www.tld.com.pl). Also LiF:Mg,Cu,P (TLD-100H20), ^{7}LiF:Mg,Cu,P (TLD-700H20), CaF_2:Dy (TLD-200), CaF_2:Tm (TLD-300); CaF_2:Mn (TLD-400), Al_2O_3:C (TLD-500), and $CaSO_4$:Dy (TLD-900), sintered pellets LiB_4O_7 detectors with different dopants, MgB_4O_7:Dy/Tm, $KMgF_3$:Pb/Cr/Ag and a new high sensitive LiF:Mg,Cu,Na,Si TL phosphor with a low residual signal, good thermal stability and high sensitivity are one of the most advanced application for TL detectors. El-Faramawy e*t al*., (2000) developed a promising copper doped LiB_4O_7 with low fading and a wide linear dose range (Karikmae, 2004).

These detectors are produced by different laboratories sometimes under different commercial names. The basic routine dosimetry tasks in personnel dosimetry and environmental monitoring can readily be solved with an appropriate selection of commercially available detectors (Karikmae, 2004). However, there has been no ideal TL dosimeter for all tasks so far. Therefore, permanent efforts are made in the scientific community to develop a new "ideal" TL detector (Ranogajec-Komor, 2003).

2.4.2 *Tl Reader*

A basic TLD reader system consists of a planchet for placing and heating the TLDs, a photomultiplier tube (PMT) to detect the thermoluminescence light emission and convert it into an electrical signal linearly proportional to the detected photon fluence and an electrometer for recording the PMT signal as a charge or current. A schematic diagram of a TLD reader is shown in Fig. 2.3. The reading process is based on the heating of the TL material from ambient temperature up to 300 - 400ºC (Furetta and Weng, 1998), while the emitted light is collected and measured quantitatively.

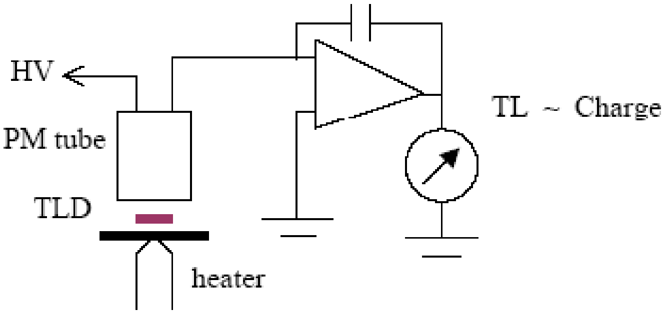

Fig.2.3: Schematic diagram of a TLD reader

Most laboratories use commercially available manual or automatic readers. For routine personal and environmental monitoring, the automatic reader has the advantage because it can evaluate a large number of TL detectors with minimal man-power. On the other hand, for research purposes the manual reader is a better choice, because it gives room for variation of experimental parameters. Several laboratories developed their own readers to fulfill special tasks or requirements (Ranogajec-Komor, 2003).

Some examples of TLD readers are the Harshaw 8800 card reader, an automated system in which up to 1400 cards can be loaded at a time and read automatically, a manual type Harshaw TLD reader (Model 4500), the Model 6600 automatic reader is capable of reading 200 cards with a single loading, and a Victoreen 2800M planchet-type reader. The LTM manual reader is designed to measure accumulated dose signal from any TLD material and the PCL3 is an automatic reader that can evaluate up to 80 detectors in one cycle produced by FIMEL Company, France. Model 680 Solaro dual-channel TLD reader produced by Vinten Instrument Limited is also a type of manual reader (Rathbone, 2006).

2.4.3 *Tl Measurement Cycle*

All steps of the measurement cycle, such as annealing, packaging and storage, irradiation, readout and mathematical evaluation, influence the characteristics and uncertainties of the dosimeter system (Furetta and Weng, 1998).

Annealing is a thermal treatment of TL dosimeters, carried out in an oven or in a furnace. It consist of heating up the samples to a predetermined temperature, keeping them at that temperature for a predetermined period of time and then cooling down the samples to room temperature. The annealing procedures could also be carried out in the reader. This is used only if the dose received by the dosimeters is lower than 10 to 20mGy (Furetta and Weng, 1998). High temperature annealing is needed in order to maintain the characteristics of a TL detector (shape of the glow curve, TL sensitivity, background signal) after repeated irradiations. The influences of variations in the heating and cooling rate, as well as the annealing temperature on the glow curve shape are usually significant. This means that for standardizations of the sensitivity that is the

TL response, all detectors from a batch have to be annealed identically. As a consequence the annealing empties all the traps, that is the TL signal will be reset to zero. At the same time the thermodynamic defect equilibrium is also reestablished during the annealing. Intensive research of the heat treatment effect on the properties of LiF:Mg,Ti dosimeters from the early beginning till today shows the importance of annealing (Yazici and Ozturk, 2003).

The mode of package and storage influences the results of dosimetric measurements. The TL detector becomes a TL dosimeter after placing it in an adequate holder which enables electronic equilibrium during irradiation. Different types of holder design from different manufacturers' exist, for instance the Harshaw Model 8805 dosimeter consists of two major components: (1) the card containing four thermoluminescent (TL) elements, and (2) the card holder made of acrylonitrile butadine styrene (ABS) plastic. The holder consists of front and back pieces that fit together, holding the card inside (Rathbone, 2005). The holder or badge are made of thick plastics and contains various filters to modify the amount of radiation reaching the TL elements, Aluminium filters will reduce the photon radiation reaching the TLD card for energies of less than 60 keV and copper filters will significantly reduce the photon radiation reaching the TLD card for energies of less than 150 keV (Radiation safety manual, Appendix v). Another filter commonly used is PTFE (Polytetraflouroethylene) also called Teflon. Shielding the elements with filters of various materials and thickness make it possible to quantify the exposure and to qualify the type of radiation to which the dosimeter has been exposed.

The dosimeters are kept away from heat and radiation sources during storage by storing them in a low background area. In long-term field irradiation and during international postal transport, the package serves also to protect the dosimeter against UV/sunlight, humidity and mechanical damage against extreme climatic condition.

As TL dosimetry is not an absolute method, calibration with well-known and well defined radiation sources is needed. The most commonly used sources are: ^{60}Co, ^{137}Cs, and ^{226}Ra. Commercially available irradiators usually contain a ^{90}Sr/^{90}Y source (Furetta and Weng, 1998). Such irradiators can satisfy routine tasks; however, for exact measurements they have to be calibrated by a calibration source (Ranogajec-Komor, 2003).

During the readout (process of heating the detector to obtain the glow curve) the following parameters have to be optimized in a performance test: temperature and time of preheat, heating rate, temperature and time of readout. Preheat (sometimes called post-irradiation annealing) is used to eliminate the low temperature peaks of the glow curve (Furetta and Weng, 1998) The choice of an adequate temperature-time profile during pre- and post-irradiation annealing as well as during the readout is important because these parameters influence the glow curve structure and the sensitivity of the TL detector.

It was observed that the kinetic parameters E and s (equation 2.1) are strongly dependent on the cooling rate of the pre-irradiation, the high temperature annealing and the heating rate during the readout (Ogundare *et al.,* 2006). Yossian and Horowitz showed theoretically and experimentally that the glow peaks of the TLD-100 undergo an important modification following post-irradiation annealing at 165 ºC and that this modification depends on the preheat time (Ranogajec-Komor, 2003). In practice, mostly a heating rate of 10ºC/s is adequate while for glow curve structure studies lower heating rates are advisable. At the Rudjer Boskovic Institute, Zagreb preheat at 100 ºC for 20 minutes was found to be very useful for fading correction for all kinds of LiF, CaF_2:Mn and Al_2O_3:C detectors (Miljanic *et al.*, 2002).

2.4.4 *Mathematical Evaluation of Dose*

A mathematical evaluation enables the determination of the evaluated dose value D_e from the TL readout value (TL response, M) using the evaluation factor F_e:

$$D_e = F_e \times M \qquad 2.13$$

The TL response can be represented either by the maximum intensity (height of the peak) or by the area under the TL curve. The peak area method is more frequently used (Furetta and Weng, 1998). F_e involves the calibration factor, F_c which is given as:

$$F_c = \frac{D_c}{\overline{M} - \overline{M}_0} \qquad 2.14$$

$\overline{M}$ is the mean TL signal of TLDs irradiated by a calibration dose, D_c, and $\overline{M}_0$ is the mean TL signal of unirradiated control detectors. F_e contains the algorithm for the calculation in terms of the dose of interest and the combination of results obtained for more than one detector. F_e also enables corrections to be made that become necessary due to background, individual sensitivity of the detectors, fading, non-linearity and energy dependence(Furetta and Weng, 1998).

2.5 The Main Characteristics of The TLD System

2.5.1 *Batch Homogeneity*

A batch of TLD is a set of TLDs produced at the same time and with the same characteristics The homogeneity of a batch represents the performance criterion according to which the value of the dosimetric response for every detector in a batch must not be different from the value of the dosimetric response of any detector in the batch, with more than 30% for a 10 mGy dose (Stochioiu *et al.,* 2004). The standard deviation of the mean value of all dosimeters in a batch or the difference of TL response of any two detectors in a batch is used to show the uniformity of the batch (Ranogajec-Komor, 2003).

Determining the uniformity of a batch is the first test to know the characteristics of a new TLD batch (Furetta and Weng, 1998). This method is mostly used to screen newly received batch of TL dosimeters and at periodic intervals using a defined limit. The samples are screened by irradiating them uniformly with a known dose from a calibrated source of radiation having a good beam quality. Any sample outside the specified tolerance limit is rejected. It has been observed that large precision errors are associated with this method and could be dangerous when used for clinical purposes (Furetta and Weng, 1998). Also replacement of the rejected samples coming from a different batch could introduce error in the whole procedure.

In accordance with International Electrotechnical Committee (IEC) recommendation on batch homogeneity, the uniformity index $\Delta_{\max}$ for a given batch can be defined as (Furetta and Weng, 1998).

$$\Delta_{\max} = \frac{(M - M_0)_{\max} - (M - M_0)_{\min}}{(M - M_0)_{\min}} \times 100 \leq 30 \qquad 2.15$$

M_0 is the background reading

M is the TL response value

$(M - M_0)_{\max}$ is the maximum value of TL reading corrected for background

$(M - M_0)_{\min}$ is the minimum value of TL reading corrected for background

Another procedure not included in the official recommendation is to get the average value, $\overline{M}$ of all the reading corrected for background and evaluate the quantities

$$\overline{M} - \sigma_p \text{ and } \overline{M} + \sigma_p \qquad 2.16$$

where σ_p is the predetermined standard deviation

All the dosimeters which exhibit a net TL response outside this range are rejected (Furetta and Weng, 1998). Since it is not too easy to replace rejected samples, calculations are made in order to correct for the response of the defected samples.

2.5.2 *Dose Linearity*

A good characteristic that any TL material should have in order to be useful for dosimetric application is a linear relationship between the TL response, M and the absorbed dose, D. It has been observed in some materials that beyond a certain dose range a non-linearity sets in, thus the non-linear behaviour has to be corrected for (Furetta and Weng, 1998). The linearity range and non-linearity behaviour depend on the type of material, its physical characteristics and on the reader. In general, the equation for linearity according to the first-order relationship is given as

$$M - M_0 = \frac{1}{F_c} D \qquad 2.17$$

$M - M_0$ is the net TL reading corrected for background measured in readers unit

$\frac{1}{F_c}$ is the absolute sensitivity of the dosimeter measured in dose per reader unit.

Various methods have been recommended for checking the linearity of the data found experimentally. These are the graphical method, IEC, IAEA, regression analysis and analysis of variance methods (Furetta and Weng, 1998).

According to IEC technical recommendation, the average value of the TL response, m_i converted in evaluated dose, $\overline{E}$ of irradiated TLDs with the relative standard error, σ_i compared to the conventional true dose, D_i be kept within the limit (Furetta and Weng, 1998) of equation 2.18.

$$0.90 \leq \frac{\overline{E} \pm I}{D_i} \leq 1.10 \qquad 2.18$$

where $I = \frac{t_{n_j - 1} \times \sigma_i}{\sqrt{n_j}}$ and $t_{n_j - 1} = \frac{\left(\overline{M}_i - D_i\right)\sqrt{n_j - 1}}{\sigma_i}$

$t_{n_j - 1}$ is the value of the student t distribution for $n - 1$ number of detectors for each radiation dose.

The linearity of MTS-N type LiF:Mg,Ti, MgB_4O_7:Dy and CaF_2:Mn detectors was measured in “low” and “high” dose range ($50mGy - 5Gy$), the values of linear fitting for all the detectors were close to 1.00 (0.99-1.00). For the same detectors in the dose range of 0.1-5 mGy the linearity expressed as the standard deviation of the calibration factors was found to be 15.3%, 9% and 7.4% for MTS-N type LiF:Mg,Ti, MgB_4O_7:Dy and CaF_2:Mn, respectively (Ranogajec-Komor, 2003).

2.5.3 *Energy Response*

The response of a dosimetry system is generally a function of radiation beam quality (energy). Ideally, the energy response should be flat that is the system calibration should be independent of energy over a certain range of radiation qualities. As no TL detector response is equivalent for all radiation beam qualities, the energy dependence is an important characteristic of a TL system (Izewska and Rajan, 2004).

In environmental monitoring, personnel dosimetry and especially clinical application of TLDs, the energy range of interest is very wide. Determination of the energy dependence is required in most standard and performance tests. For environmental dosimeter systems, the IEC Standard requires that in the energy range 30 keV to 80 keV the evaluated value should not exceed the conventional true value by more than a factor of 2 and in the range of 80 keV to 3 MeV the difference cannot be more than 30 % (Ranogajec-Komor, 2003).

The energy response depends first of all on the effective atomic number (Z_{eff}) of the detector (Furetta and Weng, 1998). Miljanic *et al.,* (2002) showed experimentally, that dosimeters based on Li have the lowest, those based on Al a higher, and those based on Ca the highest energy dependence. On the other hand, it was shown that the energy absorption characteristics of TLDs depend not only on the effective atomic number of the respective TLD, but are influenced by the added dopant as well (Miljanic *et al.,* 2002). Fairbanks and Dewerd found that LiF:Mg,Ti TLD's obtained from three manufacturers showed similar characteristics in energy response and linearity, the sensitivity, however, varied among the three groups by as much as 40% (Ranogajec-Komor, 2003).

The photon energy response of various LiF:Mg,Ti (TLD-100, TLD-700, MTS-N) was compared to that of various LiF:Mg,Cu,P (TLD-700H, MCP-N, GR-200) (Ranogajec-

Komor, 2003). The doses measured by the high sensitivity LiF:Mg,Cu,P were lower than the nominal doses for the energies of 80-160 keV. At 40.5 keV LiF:Mg,Cu,P shows over-response of 24%, while the LiF:Mg,Ti detectors (MTSN and TLD-700) have an over-response of up to 50%. The energy response at about 100 keV of the new LiF:Mg,Cu,Na,Si detectors shows a decrease, similar to that in LiF:Mg,Cu,P. For lower energies the response is higher than that for LiF:Mg,Cu,P, due to the presence of high-Z elements Na, Cu, and Si (Ranogajec-Komor, 2003).

2.5.4 *Reproducibility*

This term is related to the precision of TL measurement and is always associated with the random uncertainties which are characterized by the standard deviation, σ of the repeated measurement.

In order to perform the reproducibility study for TL measurement, a single dosimeter could be used for repeated measurement or several dosimeters of the same type and the same dose. The total standard deviation σ_T for a single dosimeter used for repeated measurement is given as (Furetta and Weng, 1998).

$$\sigma_T = \sqrt{(\sigma_S . D)^2 + {\sigma_B}^2} \qquad 2.19$$

σ_S is the relative standard deviation of the TL response in readers unit

σ_B is the absolute standard deviation of unirradiated phosphors in mGy

D is the delivered dose in mGy

A more accurate way is to anneal, irradiate, and readout several identical dosimeters with equal amount of dose and evaluate the percentage coefficient of variation, %CV due to the reader, system and the detector. The %CV of the detector is given as (Furetta and Weng, 1998).

$$DVI = \sqrt{(SVI)^2 - (RVI)^2} \qquad 2.20$$

SVI = $\%CV_S$ is the system variability index

RVI= $\%CV_R$ is the reader variability index

DVI= %CV is the detector variability index

According to the IEC Standard, the reproducibility expressed as the coefficient of the variation of the evaluated dose value shall not exceed 7.5% for each dosimeter separately and n dosimeters collectively, for a given dose. This requirement was highly fulfilled in a standard test program carried out for TLD systems applying TLD-100, LiF:Mg,Cu,P, Al_2O_3:C and CaF_2:Mn detectors (Ranogajec-Komor, 2003).

2.5.5 *Dose Sensitivity*

Dose sensitivity, S_i defined as conversion factor from the collected charge (in nC) to dose (in mSv), is a highly non-universal parameter (Bilski and Budzanowski**,** 2005). The general definition of sensitivity factor, S_i for the ith dosimeter in a batch is given as

$$S_i = \frac{\overline{M}}{M_i - M_{0i}} \qquad 2.21$$

$M_i - M_{0i}$ is the net TL response corrected for background

$\overline{M}$ is the average net reading in the batch

The sensitivity factor is used as a dividing or multiplying factor of the net reading to correct the dosimeter response at any delivered dose (Furetta and Weng, 1998). Dose sensitivity depends on many factors, such as the chemical composition of the detector material, the concentration and types of the activators, the physical form of the detector, the type of the reader and its setting (Ranogajec-Komor and Osvay, 1986).

Detectors are produced in batches, and different batches of detectors usually have different responses. For most practical application, especially in applications where a higher order of precision is required, TL detectors have to be highly sensitive so as to be able to measure very low doses. New, high sensitive TLD systems based on Al_2O_3:C, LiF:Mg,Cu,P and LiF:Mg,Cu,Na,Si are being developed and characterized permanently for very low dose monitoring applications (Ranogajec-Komor, 2003). It has been advised to identify and eliminate all elements having S_i that are not within 20% of unity and the elements with percentage coefficient of variation greater than 5% (Furetta and Weng, 1998).

2.5.6 *Residual Signal*

Residual signal is a signal remaining in the TL detector after the readout. If the level of stored energy from previous irradiations is significant with respect to succeeding doses, the residual energy must be reduced further before the detector can be re-used; this restores the sensitivity of the detectors. Residual signal reduction can be achieved by a high temperature anneal (external annealing in oven). In some cases an internal anneal in reader can be performed but this depends on the type of detector and on the nature of the application. The value of the residual signal can be determined by the subsequent readout of the detectors without prior irradiation and usually without additional external annealing.

Investigation of some selected dosimetric properties of MCP-7 detectors with various thicknesses by Bilski and Budzanowski, (2005) showed the residual dose to be about 1% and 0.8% of the original signal in the second readout value and about 0.5% 0f the initial signal during the third readout.

2.5.7 Fading

One of the important dosimetric characteristics of a TL material is fading, that is the loss of signal during storage or the stability of dosimeters under various climatic conditions as a function of time. Fading is an intrinsic effect of a TL material and encapsulation of TL elements into a dosimetric card has no influence (Bilski and Budzanowski, 2005).

The problem of fading of MCP-N (LiF:Mg,Cu,P) detectors was thoroughly studied within a project focused on application of this material in environmental dosimetry. Results of measurements, which were performed using MCP-N detectors produced by TLD Niewiadomski Company, showed that fading was 5% per year at the temperature 33ºC, and is lower for room temperatures. (Bilski and Budzanowski, 2005). According to the manufacturers of Harshaw TLDs, fading varies from 5%/yr (LiF:Mg,Ti and LiF:Mg,Cu,P) to 2% in one month (CaSO4:Dy) at room temperature.

Fading is very important mostly in environmental monitoring since long-term exposures are the object of the investigations. Fading characteristics of newly developed TL materials are always investigated under different conditions (temperature, humidity, light effects). The fading depends on the chemical composition of the detector and the dopants, the crystal structure, the thermal treatment during evaluation (pre-irradiation annealing, post-irradiation annealing/preheat, and heating rate), the climatic and light conditions during exposure. The fading correction can be carried out in different ways. One possibility is 24 hours storage before reading of calibration and field detectors, because the shorter the time between irradiation and readout is, the faster the fading becomes. In most cases the fading curves decrease exponentially in the first 24 (sometimes 48) hours and become linear later on (Ranogajec-Komor, 2003).

According to the IEC Standard the fading has to be within 5% and 10% for 30 and 90 days, respectively under standard test conditions, while it can be 20% for 30 days storage at 50 ºC and 65% relative humidity or at 20 ºC and 90% relative humidity (Ranogajec-Komor, 2003).

Fading can be caused by various effects such as temperature effect, self dose effect, background irradiation, accidental exposure and so on. The amount of signal loss per hour, that is the isothermal decay constant, λ is given as (Furetta and Weng, 1998).

$$\lambda = \frac{1}{t_a} \ln \frac{\overline{M}_B - \overline{M}_C}{\overline{M}_A - \overline{M}_C} (h^{-1}) \qquad 2.2$$

Where $\overline{M}_a, \overline{M}_b, \overline{M}_c$ are are the mean TL response from various groups in a batch, and t_a is the storage period.

The time effect of fading of MCP-N detectors was studied by Bilski and Budzanowski, (2005). They stored the irradiated detectors in a lead container and read them at an increased level of time. Their results showed that there was no significant loss of signal after storage for several months.

2.5.8 Sensitivity to Ambient Light

Thermoluminescent detectors should measure the integral dose of the ionizing radiation but not the integral dose of daylight. The effect of daylight decreases the accuracy of measurements and the sensitivity of TLDs. The IEC-1066 Standard restricts the light sensitivity of TLD. According to this document, the $Li_2B_4O_7$:Mn,Si detectors should not exceed a false dose of 1 mSv when irradiated for 24 h under normal conditions by a luminous energy flux of 1000 W/m^2 in the spectral range 295–769 nm (Danilkin *et al.*, 2006).

There are two effects observed for thermoluminescent detectors related to the exposure to ambient light:

a) Effect on zero point, that is the increase of TLD background signal, observed in the non-irradiated detectors

This effect is connected with the excitation and trapping of charge carriers at shallow and thermally unstable traps. The effect can take place in TLD material and in the materials of the holder. This signal is usually removed during the pre-heat at temperatures much below the main dosimetric peak (Bilski and Budzanowski, 2005). Thermoluminescent sensitivity depends on the impurity content (concentration and chemical composition of the activators), the preparation conditions and is also influenced by the grain size.

b) Effect on response, that is the decrease of TLD signal after exposure to light of irradiated detectors

The decrease of TLD signal after exposure to ambient light is due to bleaching that is removing the charge from some high-temperature traps after exposure to light, essentially to light with some contribution of UV component.

The sensitivity of MCP-N detectors to light was investigated by Duggan *et al.*, (2000). The MCP-N detectors were irradiated with 10 mGy of 137 Cs γ-rays and exposed 2 weeks at ambient light (direct sunlight without glass protection). The other group of irradiated MCP-N detectors was exposed for the arc lamps (Rofin system with a 200 W Hg arc lamp) for the time ranging from 5 min to 2 weeks. Approximately 50% loss of signal for MCP-N detectors was observed after 2 weeks exposure on the direct sunlight (summer-time, Poland). Approximately half the thermoluminescence signal was lost after 1 day exposure under the arc lamp. LiF:Mg,Ti (GR-100) and LiF:Mg,Cu,P(GR-200) detectors were found more sensitive to light and were loosing 50% of TL signal after 5 hour arc lamp exposure (Bilski and Budzanowski, 2005).

According to the IEC Standard, referring to routine environmental applications, the evaluated value of TLDs shall not differ by more than 10% after one week exposure to daylight ($1000Wm^{-2}$) from the evaluated value of a dosimeter kept in the dark (Ranogajec-Komor, 2003).

2.5.9 Sensitivity to other Environmental Conditions

The specification for dosimetric cards requires that response should not change by more than 20% after 48 hours storage at temperature ranging from $-10°C$ to $+40°C$ and relative humidity ranging from 40% to 90%. The influence of environmental conditions on the response of TLD-EC cards was investigated by Bilski and Budzanowski, (2005). Their result shows that storage at temperatures $+40°C$ for 48 hours lead to decrease of TL signal 0.2 to 0.5%, and in $-20°C$ up to 4.5%. Stability of MCP response in temperatures ranging from $-20°C$ to $+50°C$ was also studied by Saez-Vergara *et al.,* (1999). They found an excellent stability of the main peak (within a few percent) at all temperature over three months period (Bilski and Budzanowski, 2005)).

Influence of humidity on the response was not tested in a systematic manner. However, they reported that the twenty years long experience with using MCP detectors in laboratories of the Institute of Nuclear Physics, during which period various climatic conditions were present, enables them to draw conclusion that humidity has negligible influence on these detectors. This conclusion was further supported by lack of any reports or remarks on such effects from any of users of MCP-7 detectors, which are in use on all continents (Bilski and Budzanowski , 2005). According to IEC1066, the stability of dosimeter under various climatic conditions should be tested after storage (i) under standard test conditions (30 and 90 days), (ii) storage at 50ºC and 65% relative humidity (30 days) and (iii) storage at 20ºC , 90% humidity (30 days). (Bilski and Budzanowski, 2005).

CHAPTER 3 EXPERIMENTAL MEASUREMENT

3.1 Introduction

This chapter will give a general description of the materials used in the course of this work , the procedures used in determining some selected dosimetric properties of the detectors used such as reproducibility test, batch homogeneity, dose sensitivity, stability of calibration factor, dose linearity, fading, effect of residual signal, and influence of environmental conditions, are also included in this chapter.

The energy response of the detectors were not determined because the detectors were calibrated using only $^{90}Sr/^{90}Yr$. All annealing were carried out in the TLD reader, no external annealing was performed and resultant TL reading is an average of readings from detectors in position 2 and 4.

3.2 Materials

3.2.1 *Four Detector Cards*

All the TLDs used in this work were obtained from Centre for Energy Research and Trainig (CERT), Ahmadu Bello University, Zaria Several examples of the cards are presented in Fig. 3.1. Up to four TLD detectors, in form of discs with typical disc size 0.4mm in thickness and 12.7mm in diameter can be placed in the card.

All investigations were performed with 3 batches of TLD cards consisting of 10 TLD cards each. Group one (55101 series) contains two LiF detectors (0.4mm in thickness) in position 2 and 4 respectively, group two (6400 series) contains two $CaSO_4$ detectors, and group three (57100 series) contains $CaSO_4$ (0.4mm in thickness) in position 2 and 4.

3.2.2 *TLD Reader*

All cards were evaluated on Solaro Dual-Channel TLD reader model 680 produced by Vinten Instrument Limited in Health Physics Section, CERT. (fig. 3.2). For readouts no nitrogen gas was applied. The following Time Temperature Profile (TTP) was applied for readout of the TLDs:

55101 Series (Table 4)	**6400 and 57100 Series (Table 10)**
- Preheating: 160ºC, 10 s	- Preheating: 180ºC, 12 s
- Heating (linear): 25ºC/s up to 260ºC	-Heating (linear):25ºC/s - 300ºC
- Acquisition time: 16 s	- Acquisition time: 10 s
- Annealing: 300ºC, 16 s	- Annealing: 300ºC, 20 s

Standard voltage applied during the readout was 250V for all two photomultipliers. Sets of 30 TLD cards were stored in a plastic container and were kept at room temperature in a dark area when not in use.

3.2.3 *Irradiation Facility*

The exposure was performed with the calibrated internal $^{90}Sr/^{90}Yr$ irradiator type 623 used in CERT, with source activity of 27.35MBq on 19/09/2007, fig. 3.3. This covers a dose range of approximately 0.011mGy/s to 20mGy/h. Up to 10 TL cards can be placed on the turn table 1cm between the upper and lower source location to attain electron equilibrium during irradiation.

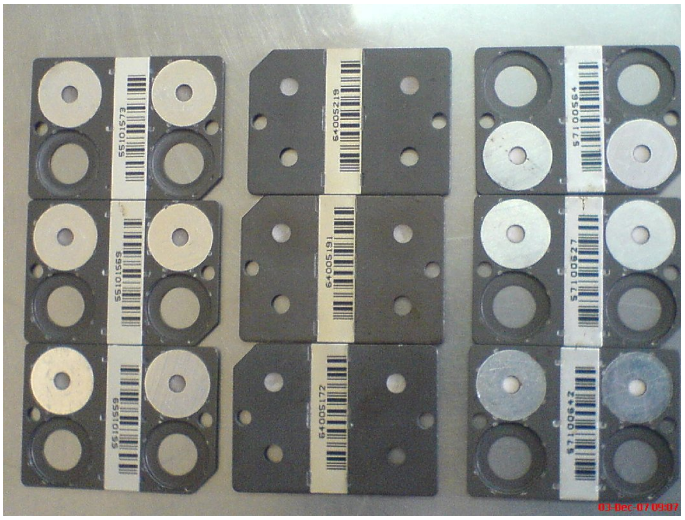

Fig. 3.1 TLD cards with detectors in positions 2 and 4

Fig. 3.2 Solaro dual channel reader

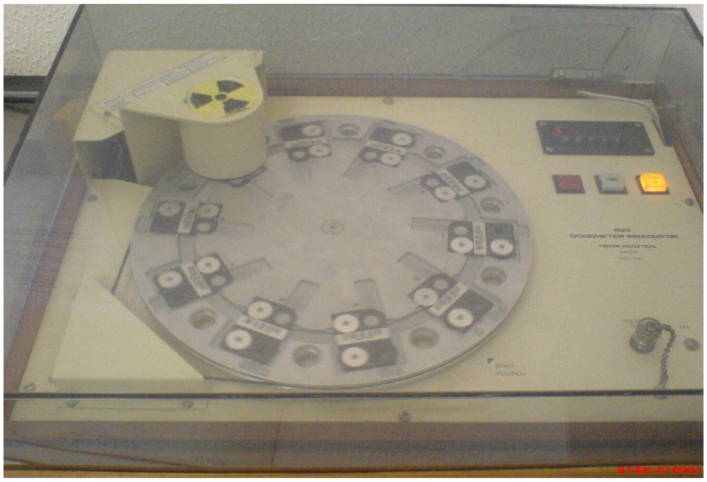

Fig. 3.3 Type 623 Dosimeter Irradiator with Sr/Yr-90 source

3.3 Methods

3.3.1 *Batch Homogeneity*

The 30 TLD cards available for this study where annealed according to their time temperature profile (TTP). The samples were then irradiated with 5mGy from β source irradiator and readout to obtain the TL response, M_i. The samples were re-annealed and read out without irradiation to obtain the zero dose reading, M_{0i} from which the net TL response $M_{i,net}$ was obtained.

$$M_{i,net} = M_i - M_{0i} \qquad\qquad i = 1,2, \ldots,N$$

In determining how homogeneous a batch was, equation 3.01 (Furreta and Weng, 1998) was used to calculate the uniformity index, $\Delta_{\max}$ as

$$\Delta_{\max} = \frac{(M - M_0)_{\max} - (M - M_0)_{\min}}{(M - M_0)_{\min}} \times 100 \le 30 \qquad\qquad 3.01$$

$(M - M_0)_{\max}$ is the maximum value of $M_{i,net}$

$(M - M_0)_{\min}$ is the minimum value of $M_{i,net}$

Equation 3.01 represents the tolerance level above which the result is unacceptable.

3.3.2 *Reproducibility Test*

All the cards were annealed, irradiated with a test dose (2mGy) and read. The same procedure was repeated 10 times and the standard deviation σ_r for the detectors in each cycle and their respective percentage coefficient of variation, $\%CV_r$ was determined. Also the standard deviation σ_c and percentage coefficient of variation, $\%CV_c$ of each detector in all the cycle was determined. The stability of the detector over 10 cycles of readings was determined by calculating the detector variability index, DVI using the formula (Furreta and Weng, 1998).

$$DVI = \sqrt{(SVI)^2 - (RVI)^2} \qquad 3.02$$

$SVI = \frac{\sigma_c}{\%CV_c} \times 100$ is the system variability index

$RVI = \frac{\sigma_r}{\%CV_r} \times 100$ is the reader variability index

Also, the average TL response in each cycle was plotted against the number of cycles to show the deviations in TL response over repeated re-uses with respect to their response in the first cycle.

3.3.3 *Sensitivity Factor (Individual Correction Factor)*

Each batch containing 10 TLD cards were annealed, read out for intrinsic background, M_{0i} and irradiated with a test dose (5mGy). They were read out in only one session to obtain TL response, M_i and the average net TL response was calculated using equation 3.03

$$\overline{M}_1 = \frac{1}{10}\sum_{i=1}^{10}(M_i - M_{0i}) \qquad 3.03$$

The above procedures was repeated five times to calculate $\overline{M}_2, \overline{M}_3, \overline{M}_4, \overline{M}_5$ for the evaluation of

$\overline{\overline{M}} = \sum_{j=1}^{5}\frac{\overline{M}_j}{5}$, j is the number of irradiation performed for the samples. The average response for each sample was evaluated as $\overline{M} = \sum_{j=1}^{5}\frac{M_{ijnet}}{5}$.

The relative sensitivity for each TLD was calculated as

$$S_i = \frac{\overline{\overline{M}}}{\overline{M}_i} \qquad 3.04$$

3.3.4 Calibration Factor

The calibration factor for each detector was determined by annealing, reading out and irradiating the cards with a calibration dose, D_c (5mGy) and calculating their sensitivity factor, S_i using equation 3.05. The equation for the calibration factor is given in 3.06 (Furreta and Weng, 1998).

$$S_i = \frac{\overline{M}}{M_i - M_{oi}} \qquad 3.05$$

$$F_c = \frac{D_c}{\frac{1}{m}\sum_{i=1}^{m} M_{i.net}.S_i} \qquad 3.06$$

$M_{i.net}$ is the net TL response corrected by background reading of the TL cards.

The individual calibration factor, $F_{c,i}$ for each card was evaluated as

$$F_{c,i} = S_i \times F_c \qquad 3.07$$

3.3.5 Stability of Calibration Factor

TLD cards whose calibration factors, F_c and individual sensitivity factor, S_i were previously determined were annealed, irradiated with a calibration dose, D_c and read out. A new calibration factor, F_c' was determined and the stability factor, F_{st} was calculated as

$$F_{st} = \frac{F_c}{F_c'} \qquad 3.08$$

Differences within 1-2% among the F values confirms a very good stability for both the reader and the irradiation facility (Furreta and Weng, 1998).This procedure was repeated each week for five weeks and at the end of each week a new calibration factor was obtained and compared with the first week's calibration factor to verify its stability.

3.3.6 Dose Linearity

This was done by dividing each batch containing 9 TLD cards into 3 subgroups containing 3 cards each with each subgroup irradiated at different dose levels. All the cards were read in one session and the readings corrected for intrinsic background and sensitivity factor. For each sub group, the average value of TL response was calculated as

$$\overline{M}_i = \sum_{j=1}^{3} \frac{M_j}{3} \qquad 3.09$$

$\overline{M}_i$ is the average value of the ith group and M_j is the reading of the jth TLD card corrected for background and sensitivity factor. The average evaluated responses, $\overline{E}_i$ and the conventional true dose, D_i were compared at each dose level using the IEC recommended equation (Furreta and Weng, 1998) to verify the linearity of the dose responses.

$$0.90 \le \frac{\overline{E}_i \pm I_i(\overline{m}_i)}{D_i} \le 1.10 \qquad 3.10$$

D_i is the delivered dose, $\overline{E}_i$ is the average evaluated dose calculated using a determined calibration factor for each sub-group, σ_i is the standard deviation, and t_{n_j-1} is the value of the student-t distribution for $n_j - 1$ degree of freedom.

3.3.7 *Residual Signal*

To test for residual signal, 10 TLD cards were exposed to doses between 0.25 to 2.5mGy with an increment of 0.25mSv for each card and read out with the standard TTP. Immediately afterwards all cards were re-read five times without irradiation to measure the residual signal left in the TL detectors.

3.3.8 *Sensitivity to Ambient Light*

Light sensitivity was tested in following way. Two groups of 5 cards each were annealed in the reader. Five of them were left directly under laboratory light, without cover and the remaining five stored in darkness. After 24 hours the cards were read out using their TTP. The results are as presented in Table 4.10 to show the increment in TL cards background signal.

3.3.9 *Sensitivity to other Environmental Conditions*

To test the influence of environmental conditions on the response of TLDs, each card in a batch was prepared by annealing in the Solaro reader using their standard TTP and exposed to a dose of 5 mGy. Then, they were stored in an oven at $+38°C$ and read out after 24 hours. The same procedure was repeated storing the cards in a freezer at temperature of $-20°C$ and at room temperature.

3.3.10 *Thermal Fading*

Nine TLDs from a batch were divided into three sub-groups (A, B, and C) of 3 TLDs each and annealed. Group A was irradiated with a test dose of 2 mGy and stored inside a lead container together with annealed ones (groups B and C) but not irradiated. At the end of the storage period, t_a (2 weeks) group B was irradiated with the same test dose of group A and all the three groups were read. The isothermal decay constant, λ was evaluated using equation 3.11 (Furreta and Weng, 1998).

$$\lambda = \frac{1}{t_a} \ln \frac{\overline{M}_B - \overline{M}_C}{\overline{M}_A - \overline{M}_C} \, (\mathrm{h}^{-1}) \qquad 3.11$$

$\overline{M}_A, \overline{M}_B, \overline{M}_C$ are the TL response corrected by background and sensitivity factor for the three groups.

The time effect of fading was studied by annealing and irradiating the TLDs with a test dose of 3 mGy, each card was stored in a lead container at room temperature. At the end of every 24hr, three cards from each batch were read out and the process continued until all the cards were read with an increasing level of time. A graph of the TL intensity versus the time elapsed was then plotted to show the possible decrease of TL response.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Batch Homogeneity

The uniformity of TL responses in a given batch which is obtained from their uniformity index (IEC technical recommendation) is shown in Tables 4.1-4.3. The tables indicate the list of net values of TL response corrected for individual background readings. Readings with uniformity index larger than 30 are tagged with reject while those less than or equal to 30, are tagged with accept.

Table 4.1 Homogeneity Test for 55101 Series TLD Cards

DOS NO	M_i	M_{oi}	M_i-M_{oi}	Δ_{max}	IEC
4	5.10	0.05	5.05	16.14	Accept
9	5.33	0.02	5.31	9.04	Accept
3	5.45	0.04	5.41	6.93	Accept
7	5.60	0.03	5.57	3.23	Accept
10	5.68	0.02	5.67	0.97	Accept
5	5.76	0.04	5.72	0.97	Accept
1	5.80	0.05	5.75	3.23	Accept
2	5.82	0.03	5.79	6.93	Accept
8	5.83	0.04	5.79	9.04	Accept
6	5.90	0.03	5.87	16.14	Accept
STDEV			**± 0.26**		

Table 4.2 Homogeneity Test for 6400 Series TLD Cards

DOS NO	M_i	M_{oi}	M_i-M_{oi}	Δ_{max}	IEC
1	4.84	0.04	4.80	83.85	Reject
4	5.03	0.02	5.01	71.13	Reject
6	5.35	0.03	5.33	26.38	Accept
3	5.37	0.01	5.36	10.45	Accept
7	5.43	0.02	5.42	1.29	Accept
5	5.51	0.02	5.49	1.29	Accept
2	5.95	0.03	5.92	10.45	Accept
10	6.84	0.11	6.73	26.38	Accept
8	8.61	0.04	8.57	71.13	Reject
9	8.88	0.05	8.83	83.85	Reject
STDEV			**± 1.45**		

Applying equation 3.1 to calculate the uniformity index, Δ_{max} of TLD cards, responses from 55101 TLD cards satisfy the homogeneity test with 100% degree of acceptance

Some response from 6400 series TLD cards are abnormal and do not satisfy the homogeneity test, with a total of 60% accept. The anomalies observed could be probably due to accumulated dirt in some of the chips or they may probably have been exposed to high doses in previous uses.

Table 4.3 Homogeneity Test for 57100 Series TLD Cards

DOS NO	M_i	M_{oi}	M_i-M_{oi}	Δ_{max}	IEC
4	4.58	0.13	4.45	70.19	Reject
5	4.68	0.05	4.63	57.51	Reject
6	4.81	0.07	4.75	50.68	Reject
7	5.08	0.06	5.02	35.19	Reject
9	5.96	0.15	5.82	3.78	Accept
8	6.14	0.11	6.04	3.78	Accept
1	6.90	0.12	6.78	35.19	Reject
2	7.25	0.10	7.15	50.68	Reject
10	7.39	0.11	7.29	57.51	Reject
3	7.66	0.10	7.57	70.19	Reject
STDEV			**± 1.20**		

Most responses from 57100 series TLD cards do not satisfy the test with 80% reject and only 20% accept. This may be due to scratches observed in some of the cards, the nature and manner in which they were previously handled and the doses they've been exposed to previously.

Among the readings, the responses from 6400 and 57100 series are abnormal and out of range as indicated by the test and are supposed to be rejected but the TL cards are limited thus they are used for further analysis by correcting their responses using their individual correction factor.

It is to be noted that this test is usually applied to a very large number of TLDs in a batch, the results in Table 4.1-4.3 are only an indication of how this test can be applied to a set of cards

4.2 Reproducibility Test

Table 4.4 shows variation of the whole TL system for evaluated TL responses over 10 cycles of readings corrected for background and sensitivity factors. For each detector repeatedly irradiated 10 times with a test dose of 2mGy, the standard deviation and the percentage coefficient of variation is shown and also the standard deviation and the %CV of the mean response of all the detectors used in each cycle of reading is shown in appendix 1-3.

The .deviation in TL responses due to the whole system which comprises of the TLDs, the reader and the irradiation facility expressed as system variability index, SVI, the contribution of reader and its components to the deviations observed in TL response expressed as reader variability index, RVI and the deviation due to the detector alone expressed as detector variability index, DVI calculated from appendix1-3 for the three batches is shown in Table 4.4.

Table 4.4 System, reader, and detector variability index of TL readings over repeated re-uses

Batch	SVI	RVI	DVI
55101	13.01	10.48	7.72
6400	14.41	9.49	10.85
57100	28.16	26.56	9.35

From the readings, the highest amount of variation is generally from the whole system which is due to combination of instability of the reader, the detector and fluctuations of background readings from the environment and the reader. The variation of the response from 55101 series is the least as seen from individual percentage coefficient of variation and from the collective coefficient of variation of the batch as compared to 6400 and 5700 series (appendix 1-3), this may be because of the close sensitivity of this detectors and also the uniformity of the batch as obtained in homogeneity test. It can also be seen that as the readings are generated, there are more fluctuations in the system. The variation in the reader may be partly due to accumulated background signals (photomultipliers noise) as readings are been generated, the internal reference light source stability, which have a major influence on the accuracy and stability of the system and also due to lack of Nitrogen purge to minimize thermoluminescence background signal.

Figure 4.2 shows the average responses in each cycle against the cycle number. The only observed decrease of the response is an abrupt change which occurred in 57100 series at cycle no 4. This seems to be a reader effect as can be seen from the calculated RVI, because after this cycle the response is quite stable.

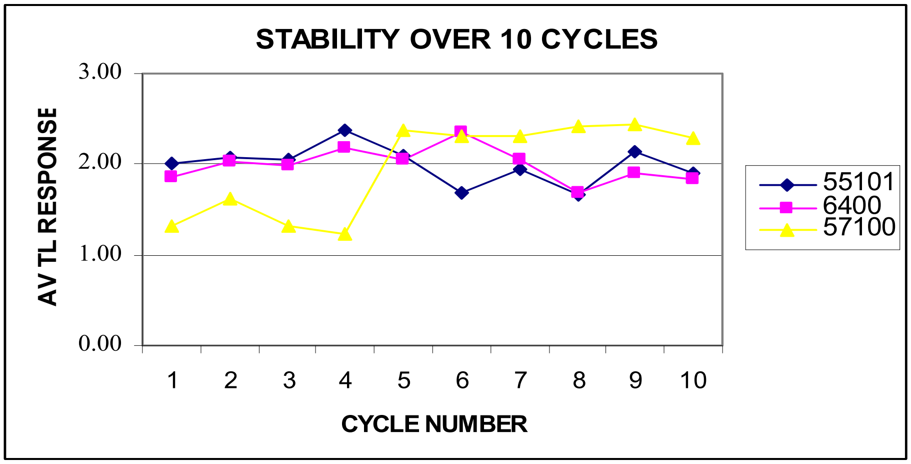

Fig. 4.2. Response of TLD cards over repeated re-uses, with respect to the first measurement.

4.3 Dose Sensitivity (Individual Correction Factor)

Table 4.5 gives the correction factors of the cards used. The values were obtained using equations in sub section 3.3. Each point is an average of five readings. From the distribution of the sensitivity factors, it is obvious that some of the cards are defective.

The acceptable range is from 0.80 to 1.20 (Furetta and Weng, 1998) this is shown in figure 4.3. Here cards from 55101 series made of LiF chip falls within the acceptable limits.

Table 4.5 Individual correction factors.

DOS NO	S_i (55101)	S_i (6400)	S_i (57100)
1	0.94	1.26	0.82
2	0.96	1.08	0.80
3	1.02	1.12	0.83
4	1.01	1.17	1.35
5	1.03	1.10	1.26
6	0.93	1.11	1.30
7	1.04	1.18	1.20
8	0.96	0.74	0.93
9	1.17	0.71	1.05
10	1.00	0.90	0.86
$\overline{\overline{M}}$	**1.00**	**1.04**	**1.06**
σ	**± 0.07**	**± 0.19**	**± 0.22**

This result is in line with previous results. Cards number 8 and 9 from 6400 series and cards number 4, 5, and 6 from 57100 series are out of range. This may be due to the amount of dose they were subjected to or the instability of the reader. From the table, an over response from cards 8 and 9 in 6400 series shows that this detectors are probably damaged.

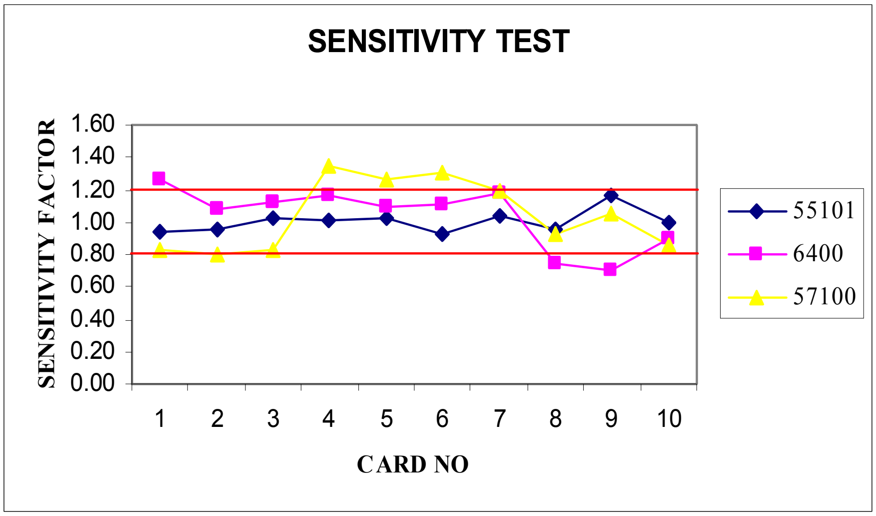

Fig. 4.3 Comparison of S_i factors from various batches.

4.4 Calibration Factor and Stability of Calibration Factor

This is a translation factor that converts TL emission from the detectors to the dose received by the detectors. Table 4.6-4.8 shows the behaviour of stability factor over 6 weeks. Each value is an average of 10 readings corrected for individual background and sensitivity factor.

Table 4.6 Stability of Calibration factor over 6 weeks for 55101 TLD Cards

55101	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6
F_c	0.92	0.91	0.98	0.88	0.89	0.89
F_{st}	1.00	0.99	1.07	0.95	0.97	0.97

A difference of 1%-5% among the F_{st} values of 55101 series indicates an average stability of the detectors and the irradiation system. Though there is an observed fluctuation in week three, this could be a reader effect or fluctuations in background signals.

Table 4.7 Stability of Calibration factor over 6 weeks for 6400 TLD Cards

6400	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6
F_c	0.98	0.79	0.91	0.78	1.00	0.78
F_{st}	1.00	0.80	0.92	0.79	1.02	0.79

Table 4.8 Stability of Calibration Factor over 6 weeks for 57100 TLD Cards

57100	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6
F_c	1.16	0.89	0.92	0.94	0.77	0.81
F_{st}	1.00	0.77	0.79	0.81	0.66	0.70

The F_{st} values are obtained by considering the first calibration factor determined at the beginning, as a normalization factor.

What could be the cause of variations observed in 6400 and 57100 series? It has been observed that the response of the dosimeters depends on their individual sensitivity factor and also the responses vary from one session of reading to the other. This is because in-between the first calibration factor and subsequent ones, the instability in the reader electronic, example due to environmental variations, and/or different period of switch-off/switch-on of the reader, is not taken into consideration. Thus, the variation observed in the calibration factors. It has been advised that at the beginning of each session of readings a new calibration factor should be determined (Furetta and Weng, 1998).

4.5 Dose Linearity

Table 4.9 shows the dose response studies performed for doses between 0.1mGy to 7mGy.

Table 4.9. Evaluation of the linearity of response of TLD cards

	55101 SERIES			**6400 SERIES**			**57100 SERIES**		
D_i	E_i	I_i	$(\overline{E}_i \pm I_i)/D_i$	E_i	I_i	$(\overline{E}_i \pm I_i)/D_i$	E_i	I_i	$(\overline{E}_i \pm I_i)/D_i$
0.10	0.10	4.30E-05	1.00	0.10	0.0004	1.00	0.10	-0.0001	1.00
0.20	0.20	3.75E-04	1.00	0.20	0.0001	1.00	0.20	-0.0010	0.98
0.30	0.30	1.09E-03	1.00	0.30	0.0054	1.02	0.30	0.0012	1.00
0.40	0.40	7.93E-04	1.00	0.40	-0.0002	1.00	0.40	0.0068	1.02
0.50	0.50	2.06E-03	1.00	0.50	-0.0005	1.00	0.50	0.0002	1.00
1.00	0.10	-4.10E-03	1.00	1.00	0.0679	1.07	1.00	0.1564	1.16
2.00	2.00	-3.03E-03	1.00	2.00	-0.0028	1.00	2.00	0.1026	1.05
3.00	3.00	3.56E-02	1.01	3.00	0.1102	1.04	3.00	-0.0338	0.99
4.00	4.00	1.04E-01	1.03	4.01	1.2125	1.31	4.00	0.0361	1.01
5.00	5.00	-1.92E-02	1.00	5.00	-0.0208	1.00	4.10	0.0010	1.00
6.00	6.00	-1.40E-02	1.00	5.10	-0.136	0.98	6.00	-0.1712	0.97
7.00	7.00	-2.74E-02	1.00	7.02	6.3549	1.91	7.00	0.1506	1.02
STANDARD DEVIATION			± 0.01			± 0.27			± 0.05

According to the IEC1066 recommendation the measured response shall not vary from the conventional true value, D, by not more than 10%. The results are presented below.

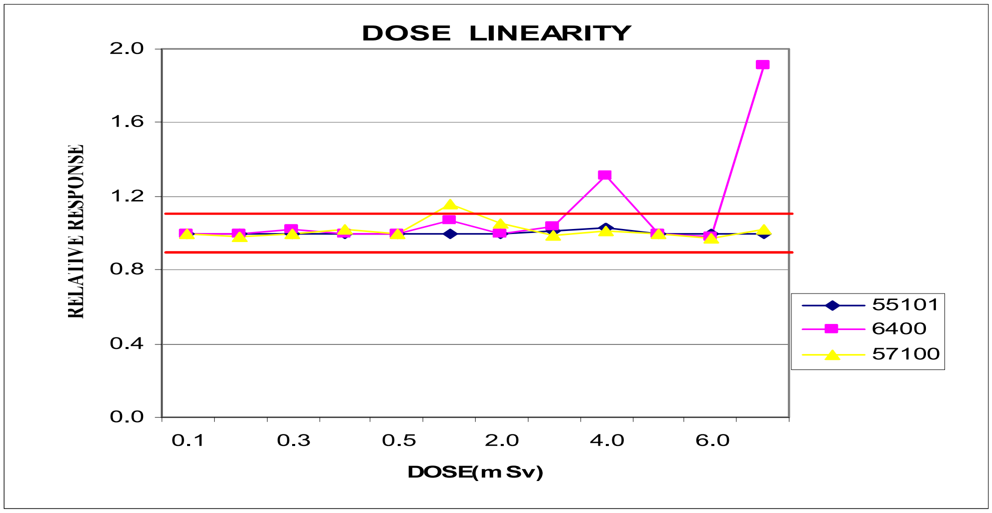

Fig. 4.4 Dose response of TL detectors

Responses from 55101 series are linear. This is also verifying the results obtained in their homogeneity and sensitivity test. Variations found in 6400 and 57100 series are probably due to damage of some of the detectors.

4.6 Effect of Residual Signal

Residual signal is a signal remaining in the TL detector after the readout. The value of the residual signal is determined by the subsequent read outs of the detector without prior irradiation. Figure 4.6-4.8 shows the plot of residual signal for various doses measured within five consecutive re-reads following initial readout of exposed detectors.

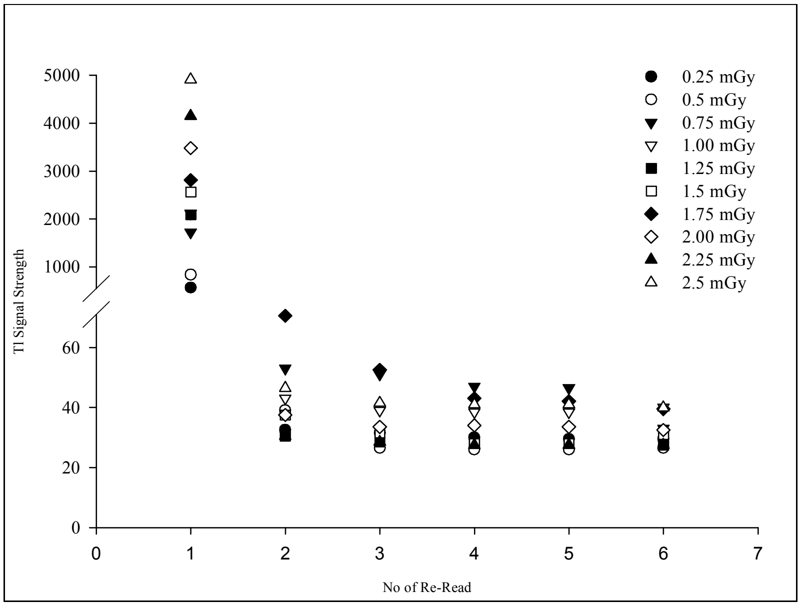

Fig 4.5 Residual signal curve for 55101 series TLD Cards

The residual signal after the first readout is at the level of 5% to 8% of the initial signal. The next readouts, which can be treated as a simplified annealing, slightly reduces the signal below the first readout and become constant after the second readout as observed in 55101 and 6400 series. This is usually performed if the signal exceeds a set limit. In 57100 series; most of the TL responses were constant after the second and third readout with a slight increase and decrease in response of some detectors. For low dose irradiation, the measured signal includes also the non-radiation background.

Figure 4.6 shows the TL signal strength of 55101 TLD cards as the cards are repeatedly re-read when exposed to different level of dose. For each given dose, the signal tends to be stable after the second read out and remains almost constant after the third readout with an overlap of the responses as the number of re-reads increases. There also seems to be a decrease in TL signal as the dose increases.

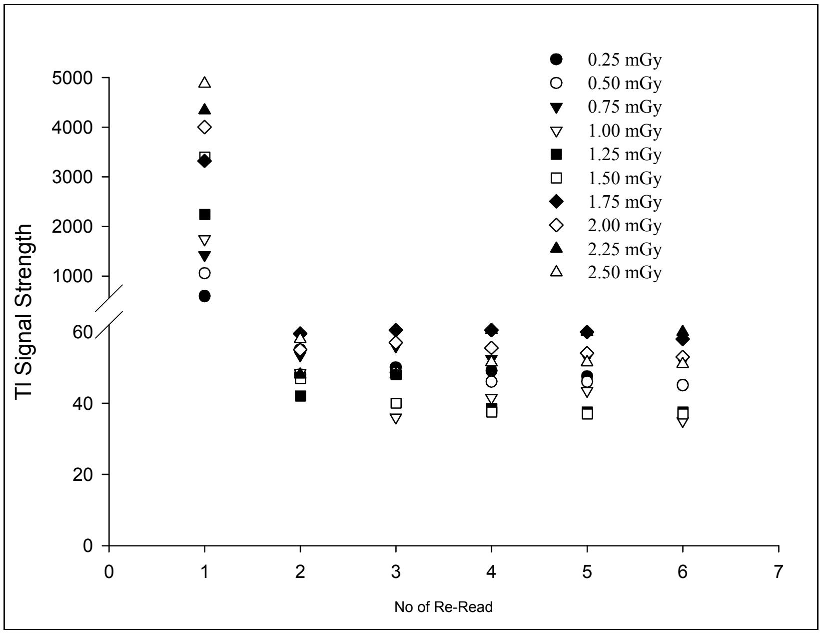

Fig 4.6 Residual signal curve for 6400 series TLD Cards

The signals observed in 6400 series are reduced to about 8% of the initial signal in the second readout and remains almost constant after these. Although, there are slight increases in response with the number of re-reads, this may be due to increase of background signal in the reader.

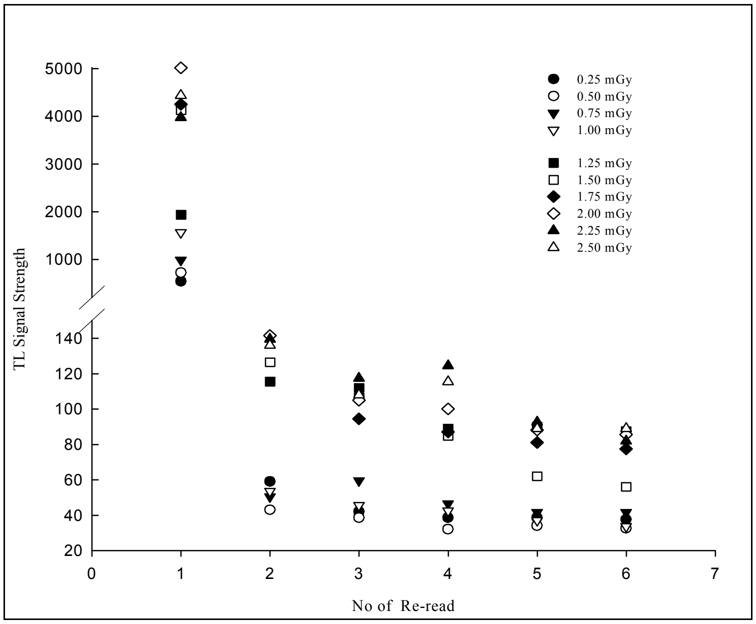

Fig 4.7 Residual signal curve for 57100 series TLD Cards

In 57100 series, the response of the cards decreases to about 5% of the original signal in the second read out. The residual signal is almost constant after the second read out with a gradual decrease of TL signal as the number of re-read increase.

4.7 Effect of Ambient Light

Table 4.10 shows the response of non-irradiated TLD cards when stored in darkness for 24 hours compared to their response when exposed to normal laboratory light.

Table 4.10 Effect of ambient light after 24 hrs exposure of non-irradiated cards

	DARK (mSv)			NORMAL LAB LIGHT (mSv)		
BATCHES	**BKG DOSE**	**FINAL**	**DIFFERENCE**	**BKG DOSE**	**FINAL**	**DIFFERENCE**
55101	0.038	0.047	0.009	0.030	0.095	0.065
6400	0.042	0.049	0.007	0.058	0.199	0.141
57100	0.048	0.056	0.008	0.050	0.086	0.036

Comparing their differences, an increment in TL background signal after exposure to normal laboratory light was found to be 14%, 5%, and 22% for 55101, 6400, and 57100 detectors respectively. The increase of TLD background signals, observed in the non-irradiated detectors after exposure to laboratory light, is connected with the excitation and trapping of charge carriers at shallow and thermally unstable traps. The effect can take place in TLD materials and in the materials of the holder. This signal is usually removed during the pre-heat at temperatures much below the main dosimetric peak.

4.8 Sensitivity to other Environmental conditions

Table 4.11 shows the evaluated responses of the TLD cards when stored in freezer, at room temperature, and in oven. Each value is an average of readings corrected for background and sensitivity factor. Stability of response with temperatures ranging from

$-20°C$ to $+30°C$ indicates an excellent stability of the response (within a few percent) over 24 hours.

Table 4.11: Evaluated response of TLD cards stored 24 hours at different temperatures

TEMP.	55101 SERIES	6400 SERIES	57100 SERIES
-20	4.999	5.000	5.000
20	5.001	5.016	5.003
38	5.000	5.014	4.990

.

According to IEC1066, the stability of dosimeter under various climatic conditions should be tested after storage (i) under standard test conditions (30 and 90 days), (ii) storage at 50ºC and 65% relative humidity (30 days) and (iii) storage at 20ºC , 90% humidity (30 days).

4.9 Time Effect of Fading

Fading, which is an intrinsic effect of the TL material, was tested over a period of 288 hours. Figure 4.9 shows the response of TLD cards over a period of 288 hours for each batch. At each point is an average of 3 readings corrected for individual background and sensitivity factor. The relative TL response of the detectors, irradiated with β-rays (3mSv) versus time elapsed from irradiation is shown below.

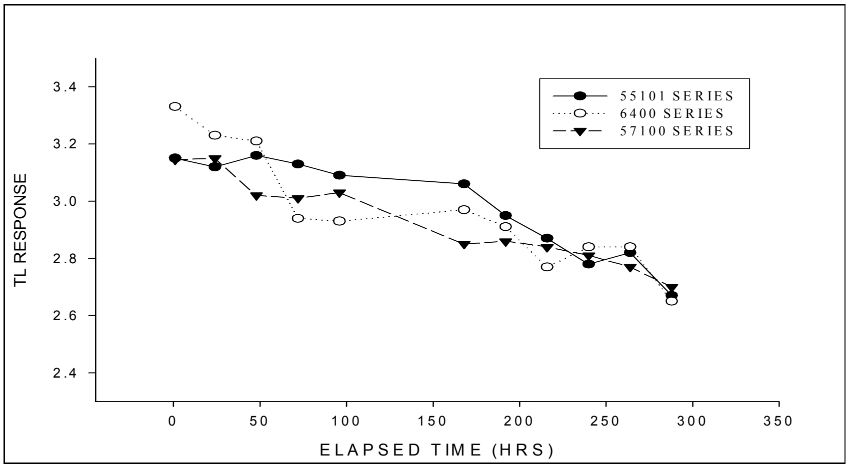

Figure 4.8 Time effect of fading

Though there are fluctuations in the reading which could be due to influence of other factors such as instability of the reader and influence of natural background radiation, the most important conclusion from this study is that the main response did not vary by more than a few percent. Time period of all these investigations was limited to 288 hours; although the time could be extended to periods of 1-3 months. It has been observed that even if TLDs are stored for longer time at room temperature, effects of fading will be negligible (Bilski and Budzanowski, 2005).

Table 4.14. Isothermal decay constant of cards stored for 2 weeks.

	TL SIGNAL (55101)	**TL SIGNAL (6400)**	**TL SIGNAL (57100)**
GROUPA	2.197	2.120	1.967
GROUP B	2.278	3.120	2.194
GROUP C	0.035	0.027	0.007
λ	**0.0001**	**0.0012**	**0.0003**

From the isothermal decay constant calculated using equation 3.11, the effect of fading is negligible for the period which these detectors where stored. Table 4.14 shows these constants calculated for each batch. The rate at which 55101 detectors decay is less than those of 6400 and 57100 series, this is further confirming the stability of these detectors as seen from previous tests.

Within the time frame of the investigation, detectors from 55101 batch fades by 0.01%, from 6400 series, 0.12%, and from 57100 series, 0.03%.

CHAPTER 5 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary of characteristics of TLD System used in CERT

Selected properties of TLD system, which are of relevance for personnel dosimetry, were evaluated on the basis of their usage in Centre for Energy Research and Training, (CERT) ABU Zaria. The cards, produced by Vinten Instrument Limited were evaluated on the Solaro reader Model 680 and irradiated using Sr/Yr-90 source. The cards were equipped with 2 high sensitive (LiF) detectors in batch 55101 and $CaSO_4$ detectors in batches 6400 and 57100 respectively.

Batch homogeneity: 55101 batch is within limits provided by IEC, some detectors from 6400 series and 57100 series did not satisfy the homogeneity test and thus are supposed to be rejected. The variations observed in these sets may be due to damage in the detector materials during usage or as a result of accumulated dirt on the surface of the chips.

Dose sensitivity_was found to depend on the stability of the TLD reader and the type of detector used and varied from 0.93 to 1.17 for 55101 series, 0.71 to 1.26 for 6400 series and 0.80 to 1.35 for 57100 series. With the tolerance of 0.8 to 1.20, detector from 55101 series are more sensitive than those of other batches.

The linearity response_in the dose range between 0.1 mSv and 7 mSv for 55101 series was within 1.00 ± 0.01, which fulfills the IEC requirements with 10% along the band of linearity. 0.98 to 1.91 ± 0.27, 0.97 to 1.16 ± 0.05 for 6400 and 57100 series respectively, with some response from the detectors in these batches not fulfilling the IEC requirements.

The residual dose_was found to be about 3% to 8% of the original signal after the first read out and decreases to a constant level of about 1.36%, 1.83% and 2.76% of the initial signal after the second read out in 55101, 6400, and 57100 series respectively.. At lower doses, it is noted that the residual signal is high due to the effect of reader background noise and natural background radiation.

Fading was found to be negligible over a period of 288 hours. The isothermal decay constant which indicates the rate of fading was found to be 0.01%, 0.12%, and 0.03% for 55101, 6400, and 57100 series respectively when stored at room temperature for two weeks. According to the IEC Standard the fading should be within 5% and 10% for 30 and 90 days, respectively under standard test conditions

The effect of laboratory light on background dose that is the increase of TLD background signal, observed in the non-irradiated detectors, after indoor exposure were found to be 0.056mSv (14%), 0.134mSv (5%), and 0.028mSv (22%) of the background signal for 55101, 6400, and 57100 detectors respectively when exposed for 24 hours under normal laboratory light.

Influence of environmental conditions:_storage at temperatures +38ºC for 24 hours with a test dose of 5mGy lead to increase of TL signal by 0.3% in 55101 series, decrease by 0.3%, and 1.3% in 6400 and 57100 series respectively. In -20 ºC, decreases of TL signal up to 0.2%, 1.6%, and 0.3% for 55101, 6400, and 57100 series respectively was observed.

Stability after 10 readouts, the change of TL signal fluctuates for all the series with the least variation observed in 55101 series. None of the detectors satisfies the IEC recommendation which requires that the percentage coefficient of variation for each detector separately and n detector collectively should not be greater than 7.5%. Part of this effect could be attributed to the TLD reader instability and due to non-availability of Nitrogen gas in the system.

Stability of calibration factor: a difference of 1-5% among the F_c values indicates an average stability of the calibration factor except in 57100 series. This could be due to the reader effect.

Table 5.1 shows the summary of the result of tested parameters compared to the required standard. From the table, not all the requirements where met. Detectors in 55101 series satisfy most of the requirements

Table 5.1 summaries of results showing the main technical-functional parameters of the TL system

PARAMETER	**55101**	**6400**	**57100**	**REQUIRED**
BATCH UNIFORMITY	16.14%	83.85%	70.19%	≤30%
STABILITY OVER 10 CYCLES OF READINGS	7.72% ± 3.30	10.85% ± 4.25	9.35% ± 2.79	≤7.5%
MEAN DOSE SENSITIVITY	1.00 ± 0.07	1.04 ± 0.19	1.06 ± 0.99	20% (0.80-1.20)
STABILITY OF CALIBRATION FACTOR A (6WKS)	0.99 ± 0.04	0.89 ± 0.11	0.79 ± 0.12	1.00 (1-2%)
DOSE LINEARITY (0.1-7mSv)	1.00-1.03	1.00-1.91	0.98-1.16	10% (0.9-1.1)
AVERAGE RESIDUAL SIGNAL	1.44% (2nd read) 1.36% (3rd read)	1.88% (2nd read) 1.83% (3rd read)	3.01% (2nd read) 2.76% (3rd read)	1-2% (2nd read) 0.5% (3rd read)
SENSITIVITY TO AMBIENT LIGHT	14%	5%	22%	
EFFECT OF ENVIRONMENTAL CONDITIONS	0.3% $(+38^{\circ}C)$ 0.2% $(-20^{\circ}C)$	0.3% $(+38^{\circ}C)$ 1.6% $(-20^{\circ}C)$	1.3% $(+38^{\circ}C)$ 0.3% $(-20^{\circ}C)$	≤ 20% (48 hours) from $-10^{\circ}C$ to $+40^{\circ}C$
FADING/Hr (2 wks)	0.01%	0.12%	0.03%	5% (30 days)

5.2 Conclusion

The investigations of TLD dosimetric cards with LiF detectors proved their superior properties for dose estimation compared to $CaSO_4$ detectors. This has been attributed to the tissue-equivalence of these detectors. LiF detectors have higher stability and sensitivity to TL response, higher linear dose response, and lower percentage coefficient of variation. Although variations in 55101 series detectors are the least, there were observed variations in the whole system during several re-uses, fluctuations in the calibration factors in each week, and some batches were not homogeneous.

5.3 Constraints

Characterization in these work are limited only to those properties the available and functional equipment could permit the researcher to measure. The determination of some properties at higher doses could not be determined, due to lack of Nitrogen gas and malfunction of the external anneal oven. Also the low memory of the system (30mbytes) and lack of printer attached to the system could not allow the user to store large amount of data nor print out glow curves as data's are being generated.

5.4 Recommendations

This work gives an insight to some methods of testing the level of performance of TLDs used by personnel in CERT in order to be able to compare the results obtained to a given standard since these detectors are used in many health related organizations in our country. As a result,

1 There is need to have an established standard of performance for all the TLDs used in the establishment for proper comparison at later times in order to know the capability of these detector.

2 The present level of performance for other types of detectors used in CERT could also be determined to make comparisons between the various types of detectors at our local level and improve on those that are not up to standard.

3 It will be of good advantage to the researchers and the institution to have a functional annealing oven in order to be able to perform experiments at higher doses.

4 A more detailed work could be done if an automatic reader, a computer with a higher memory capacity and latest version of operating system, also an irradiator that can be preset using a remote control is used in this project.

5 The experiments could also be carried out for a longer period of time in order to know the frequency of variations of their characteristics

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APPENDIX 1 (55101 series response over 10 cycles of reading)

55101
CYCLE NUMBER

NO	1	2	3	4	5	6	7	8	9	10	AV	σ_c	%CV_c
1	1.95	2.10	2.14	2.33	2.11	1.77	1.97	1.71	2.11	1.75	2.00	0.20	10.14
2	2.08	2.18	2.01	2.27	2.20	1.77	1.99	1.63	2.11	1.70	1.99	0.22	11.15
3	2.06	2.00	2.13	2.42	2.08	1.72	1.99	1.70	2.15	1.70	1.99	0.23	11.61
4	2.03	1.87	2.15	2.35	2.10	1.74	1.98	1.67	2.22	1.83	1.99	0.22	11.00
5	2.13	2.04	2.12	2.38	2.16	1.63	2.01	1.75	2.14	1.54	1.99	0.27	13.35
6	1.89	2.01	1.91	2.50	2.25	1.78	1.99	1.56	2.25	1.79	1.99	0.28	13.93
7	2.07	2.14	2.22	2.20	2.01	1.69	1.92	1.85	1.99	1.87	2.00	0.17	8.47
8	2.05	2.07	2.08	2.53	2.19	1.53	1.90	1.73	2.07	1.74	1.99	0.28	14.09
9	1.86	2.04	2.19	2.31	2.13	1.57	1.67	1.47	2.13	2.49	1.99	0.33	16.81
10	1.96	2.21	1.52	2.44	1.69	1.58	1.95	1.69	2.09	2.72	1.98	0.39	19.59
AV	2.01	2.07	2.05	2.37	2.09	1.68	1.94	1.67	2.13	1.91			
σ_r	0.09	0.10	0.21	0.10	0.16	0.09	0.10	0.10	0.07	0.38			
%CV_r	4.45	4.76	10.08	4.33	7.59	5.50	5.19	6.23	3.51	19.77			
SVI	13.01												
RVI	10.48												
DVI	7.72												

APPENDIX 2 (6400 series response over 10 cycles of reading)

6400
CYCLE NUMBER

NO	1	2	3	4	5	6	7	8	9	10	AV	σ_c	%CV_c
1	1.74	2.00	1.62	2.05	1.71	3.00	2.13	1.39	2.48	1.65	1.98	0.48	24.07
2	1.88	2.16	1.89	2.40	2.15	2.44	1.91	1.63	1.58	1.85	1.99	0.29	14.80
3	1.78	2.05	1.85	2.17	1.97	2.49	1.98	1.70	2.14	1.81	1.99	0.24	11.80
4	1.71	2.01	2.04	2.22	2.01	2.35	2.26	1.45	1.99	1.88	1.99	0.27	13.32
5	1.82	1.67	2.20	2.26	2.27	2.37	1.95	1.51	1.81	2.02	1.99	0.29	14.47
6	1.61	1.81	1.79	2.41	2.19	2.83	1.88	1.71	1.79	1.84	1.99	0.38	19.15
7	1.95	2.22	2.07	2.00	1.85	2.55	1.72	1.84	2.02	1.71	1.99	0.25	12.58
8	2.03	2.17	2.28	2.16	2.06	1.80	2.14	1.89	1.35	2.02	1.99	0.26	13.26
9	1.99	1.98	2.24	2.16	2.12	1.98	2.31	1.77	1.70	1.71	1.99	0.22	10.90
10	1.98	2.10	1.84	1.95	2.15	1.70	2.31	2.01	2.17	1.75	2.00	0.19	9.75
AV	1.85	2.02	1.98	2.18	2.05	2.35	2.06	1.69	1.90	1.83			
σ_r	0.13	0.16	0.21	0.15	0.16	0.40	0.19	0.19	0.31	0.12			
%CV_r	7.14	7.98	10.48	6.72	7.89	16.95	9.30	11.16	16.24	6.58			
SVI	14.41												
RVI	9.49												
DVI	10.85												

APPENDIX 3 (57100 series response over 10 cycles of reading)

	57100 CYCLE NUMBER												
NO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**	σ_c	**%CV$_c$**
1	1.40	1.41	1.41	1.24	2.32	2.45	2.32	2.36	2.36	2.36	1.96	0.52	26.33
2	1.32	1.46	1.33	1.25	2.36	2.31	2.35	2.36	2.43	2.44	1.96	0.54	27.33
3	1.42	1.45	1.30	1.33	2.30	2.40	2.14	2.52	2.36	2.41	1.96	0.52	26.31
4	1.28	1.51	1.29	1.21	2.38	2.28	2.33	2.24	2.57	2.47	1.96	0.56	28.42
5	1.21	1.69	1.48	1.40	2.28	2.15	2.23	2.46	2.47	2.32	1.97	0.47	24.11
6	1.18	1.38	1.35	1.25	2.41	2.15	2.27	2.62	2.55	2.36	1.95	0.59	30.13
7	1.22	1.22	1.37	1.21	2.47	2.46	2.31	2.41	2.46	2.33	1.95	0.60	30.74
8	1.34	1.22	1.00	1.21	2.46	2.55	2.33	2.54	2.53	2.18	1.94	0.65	33.76
9	1.35	2.32	1.22	1.16	2.30	2.06	2.47	2.40	2.27	2.04	1.96	0.51	26.15
10	1.36	2.56	1.38	0.92	2.47	2.14	2.36	2.16	2.28	1.86	1.95	0.55	28.31
AV	1.31	1.62	1.32	1.22	2.38	2.30	2.31	2.41	2.43	2.28			
σ_r	0.08	0.46	0.13	0.13	0.07	0.17	0.09	0.14	0.11	0.19			
%CV$_r$	6.34	28.09	10.01	10.30	3.14	7.25	3.79	5.85	4.47	8.45			
SVI	28.16												
RVI	26.56												
DVI	9.35												