THERMOLUMINESCENT DOSIMETRY[1]

11pp

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Luminescence is the emission of light without the application of heat energy sufficient to cause incandescence. Luminescent light is often called cold light. Many solids which display energy storage properties are also luminescent and these may be applied to the dosimetry of directly and indirectly ionizing radiation. The phenomenon of RPL[1] and TL[2] are the basis for two complementary dosimeter systems. TL is the emission of light on the gentle warming of an excited phosphor. The absorption of ionizing radiation by the TL phosphor produces free electrons and holes some of which are trapped at impurities or other imperfections where they are bound until sufficient energy is imparted to free them. Upon release, the electrons return to a lower energy state and emit radiant energy in the form of visible light the brightness and total emission of which is proportional to the number of trapped electrons. The number of trapped electrons is, in turn, proportional to the dose. Since ionizing radiation excites the TL phosphors and thermal stimulation produces light emission, the combined sequential phenomena may be termed radiothermoluminescence, a term which will be denoted by the capital letters RTL.

TL materials are numerous and have been observed and studied for centuries. Boyle recorded the TL of certain diamonds in 1663 and the

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1 - Radiophotoluminescence

2 - Thermoluminescence

physician to the Elector, Freiedrich Wilhelm, Johann Elsholtz, published a text in 1681[3] describing the TL mineral fluor spar. Some of the TL materials studied in recent years with respect to dosimetry are fused Al_2O_3 natural and synthetic fluorite containing Mn as an activator, ($Ca\ F_2$:Mn) and natural and synthetic Li F. Natural implies use of the compound as found in nature after suitable refinement while synthetic indicates the laboratory preparation of the material under controlled conditions from the elemental constitutents. We are investigating only the applicability of synthetic $Ca\ F_2$:Mn and Li F to medical and radiobiological dosimetry.

The sensitivity, range and size of these two phosphors indicates their suitability to in-vivo dosimetry which we define as follows: "In-vivo dosimetry is the ability to implant one or more dosimeters at a site or sites of interest to the clinician without undue risk to the patient using accepted trocar or catheter techniques. Furthermore, the dosimeters must be easily removed and must also be capable of re-insertion." If these requirements are to be met, the dosimeter must not measure more than 0.089 inches in outside diameter and, if not spherical, should be less than one-half inch in length. Present TL dosimeters, in which the phosphor is glass encapsulated, measure 10 mm by 1.0 mm O.D. Since the length can be reduced, TL phosphors are applicable to in-vivo dosimetry.

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3 - De Phosphoris Observations

The dimensions just cited do not include any allowance for a metal shield which may be necessary to correct energy dependence.

TL phosphors are sensitive. Present estimated range is 0.01 mr to 250,000 r. It is this fact which makes these dosimeters attractive to nuclear medicine. Their range encompasses the dose range of interest. Suitable shielded TL dosimeters may be implanted in the organ or organs concentrating gamma-emitting radioisotopes administered diagnostically or therapeutically in the surrounding host and in proximate and remote radiation sensitive organs.

RTL dosimeters are read or stimulated by heating at a constant rate and either tracing using a strip chart recorder, a time history of intensity, or electronically integrating the total light emission. The former approach yields a glow curve, the peak amplitude of which may be correlated with dose. The area under the glow curve which may be obtained by electronically integrating the phosphorescence may also be correlated with dose. Integration of the light signal is the basis for several reader designs. The first slide is a block diagram of our experimental reader system. (Discuss slide and make the following comments)

> The system is comprised of a fluorimeter which is a light-tight box in which the TL dosimeters may be inserted one at a time and subjected to gentle direct or indirect electrical heating for 20 to 30 seconds by applying a current of 15 to 20

amperes. Upon heating, the phosphor emits blue-green light which is detected by a PMT. Interposed between the PMT and phosphor is a blue-green by-pass filter and an IR filter. The output of the PMT is fed to a current amplifier integrator or a strip chart recorder. Both read-out devices are shown connected in ~~parallel~~ series in our schematic. The dual read-out mode is peculiar to our experimental requirements and is not envisioned for clinical use. (Remove first slide.)

A glow curve resembles the spectrum for an isotope emitting a single gamma ray. The spectrum of Au-198 is an excellent analog. When heat is applied, a weak luminescence is produced due to relatively wealky trapped electrons which are liberated. As heating increases, so does the liberation rate until a maximum is reached beyond which intensity falls off due to trap depletion. The act of reading destroys the reading. RTL dosimeters are re-usable but not cummulative devices. Both Li F and Ca F_2:Mn are high-temperature phosphors, that is, there should be no danger of low dose erasure at room or body temperatures. Ca_2 F:Mn exhibits a single peak glow curve at 240°C. This corresponds to a relatively deep, stable trap depth of about 1 ev.

The reading of low doses requires a satisfactory signal to noise ratio. Since heat is applied in the vicinity of the PMT, dark current may be a problem. Cooling without condensation is one solution.

Another is the use of end cathode, Venetian blind, tri-alkli-halide, PMT having an S-11 response. Such tubes have the desired spectral response, sensitivity and an estimated dark current of 10^{-10} amperes at room temperature.

RTL phosphors may be exposed loose if encapsulated within a transparent housing, bound to a surface or embedded in a glassy matrix. The use of a loose phosphor is attractive from the fabrication viewpoint, but it does introduce problems. An effect due to mechanical disturbance may take place and produce a spurious TL. This phenomena is called tribothermoluminescence. Under certain conditions, unexposed phosphors could, upon heating, give rise to a glow curve equivalent to an exposure of 300 mr. Fixation by any suitable means appears to be the solution to this problem. If a glassy matrix or capsule is used, the remote possibility exists that any required metallic shielding may be incorperated into the glass envelope, thereby eliminating the need for a separate metallic shield.

Range, while excellent, may present a reader design problem. This arises from a combination of circumstances. If only one dosimeter is read and the exposure unknown, the reading may be lost if the wrong range of a multi-range instrument is selected. The reading may be off-scale or the signal so low it is not detected, or lost in the noise. One way to overcome this is to design a single range reader covering ten decades of response. This is a formidable specification. There are several possible approaches, all of which are based on the assumption that a suitable PMT can be found which will see 0.01 mr as well as 250,000 r without swamping. We are considering five possibilities:

1) light attenuation;
2) sampling;
3) compression-amplification;
4) storage transfer;
5) data storage.

A set of medium-density optical filters may be automatically interposed between the phosphor and PMT. Interposition will be actuated by the rise time of the signal. If a given integrated current is recorded before a predetermined time, a filter will be automatically interposed.

Sampling requires the use of an electronic sampling device which rapidly and repeatedly samples the signal and, when read-out is completed, reconstructs the signal and indicates exposure.

A compression-amplifier may be used to compress the signal as the amplitude increases. Some signal will be lost which must be regenerated post read-out and fed into the integrator.

Storage transfer requires the use of low-leakage capacitors. The signal charges the capacitor and, when fully charged, the capacitor is discharged and the output fed to the integrator. This is a cyclic procedure and, if transfer is effected in microseconds, signal loss should be held to a minimum.

A memory device approach might be based on the recording of the signal on a magnetic tape. The tape would store the signal which could be repeatedly fed to the integrator until a suitable range is found.

In addition to the problems of reader design and RTL housing, we are conducting simultaneous programs in radiological physics and clinical applications designed to establish performance characteristics and applications. The following areas are currently under study:

1) range verification;

2) response at body temperature;

3) fading at 98°F;

4) linearity;

5) energy dependence and shielding requirements, including shield design;

6) calibration procedures.

The experience of other investigators and preliminary results are encouraging. We are confident that the RTL dosimeter will prove as acceptable as the RPL dosimeter. If this proves to be true, then I trust we may report at some future meeting of this society the following RTL dosimeter characteristics:

Accuracy	-	±10% or slightly better;
Confidence Limit	-	99.9%;
Range	-	100 mr to 250,000 r, possibly as low as 0.01 mr.

Thank you.

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A Preliminary Study of Thermoluminescent Dosimetry[1]

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A miniature solid state dosimeter based on the phenomenon of thermoluminescence (1) is presently being investigated in our laboratory for introduction into an *in vivo* dosimetry system, previously described by the authors (1, 3, 4). The radiation-sensitive element is a manganese-activated calcium fluoride phosphor. Development of this phosphor was carried on at the U. S. Naval Research Laboratory by Schulman *et al.* (2).

The dosimeter we are using is in the form of a needle, 10 mm. long and less than 1 mm. in outside diameter. It is sealed within a glass tube and read by heating at a constant rate. Heating liberates electrons which were trapped during irradiation, and these electrons attempt to return to their ground state by emitting energy in the form of blue-green light. A graph of fluorescent intensity *vs.* time, generated at a constant heating rate, is called a "glow curve." Either the area under the glow curve, or its peak, may be used to read the dosimeters; we prefer to use the former. This area may be measured by electronically integrating the current output while the glow curve is traced. The most difficult problem in developing the reader system has proved to be the mounting of the photomultiplier assembly in the area of the heating circuit.

The dosimeter is a relative device. It is calibrated by exposing a large number of dosimeters to different radiation modalities. Since the response is linear, the area under the glow curve increases as the exposure increases. A calibration factor having the dimensions of roentgens per unit area may thus be determined. The act of reading destroys the electron traps. Hence, this dosimeter cannot provide a permanent exposure record nor can it be used as a cumulative device. This fact plus its sensitivity and range distinguish it from the radiophotoluminescent dosimeter (3, 4).

The range of the thermoluminescent dosimeter is estimated to be from 10^{-5} to 10^{5} r, a span of ten decades. Like the radiophotoluminescent dosimeter (3), it is energy dependent and corrective shielding is required. The shielded and unshielded dosimeters will be subjected to x-rays from 260 kv to 1 Mv, cobalt 60, radium, and iridium 192 in air, and at various positions in depth of phantoms with varying portal sizes to determine the effect of energy on response. When satisfactory shields have been evolved, exposures will be made in animals. Thermoluminescent dosimeters developed to date have been of the large bulb type. Our work deals solely with miniature dosimeters similar to those being used in Discoverer satellites. Our objective is the development of a second generation of implant dosimeters for radiation dosage verification (4) and inhomogeneity studies with radiation therapy equipment as well as with diagnostic x-rays in specific anatomic areas, while patients undergo various examinations. The thermoluminescent dosimeter is intended to complement, not to supplant, the radiophotoluminescent dosimeter. Figure 1 presents a block diagram of our basic reader. Figure 2 shows the thermoluminescent dosimeter with a plastic sleeve. At this time we are evaluating an Elcor model A309A current indicator and integrator to determine its suitability as the digital read-out integrator.

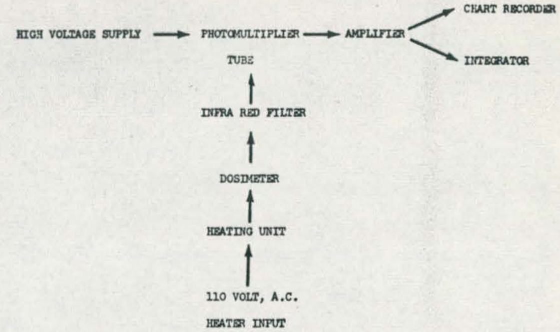

Fig. 1. Block diagram of thermoluminescent reader.

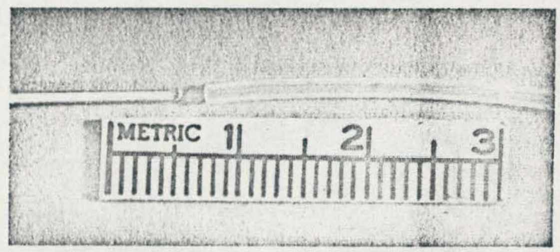

Fig. 2. Thermoluminescent dosimeter with plastic sleeve.

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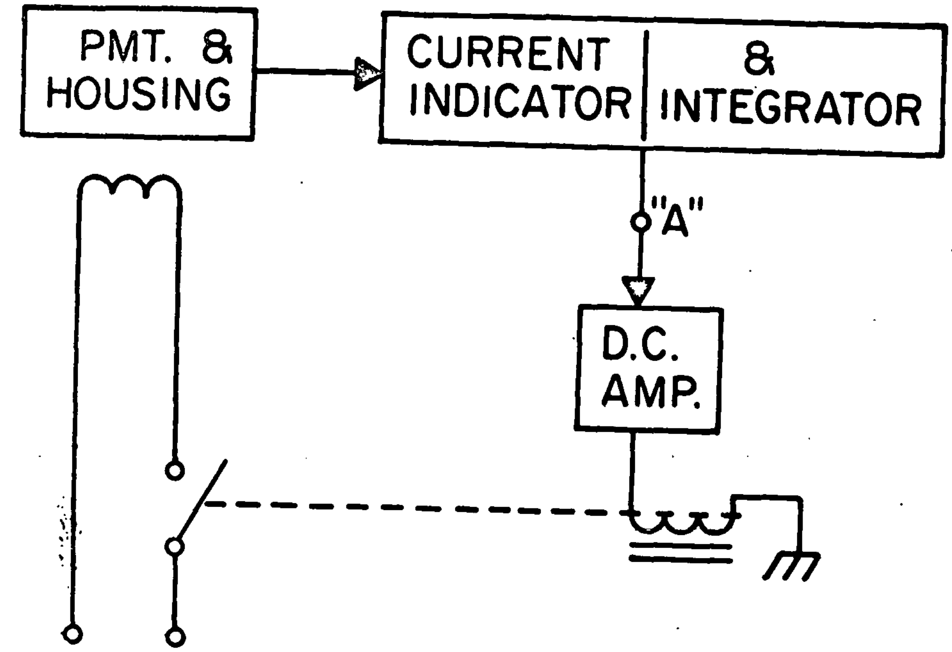
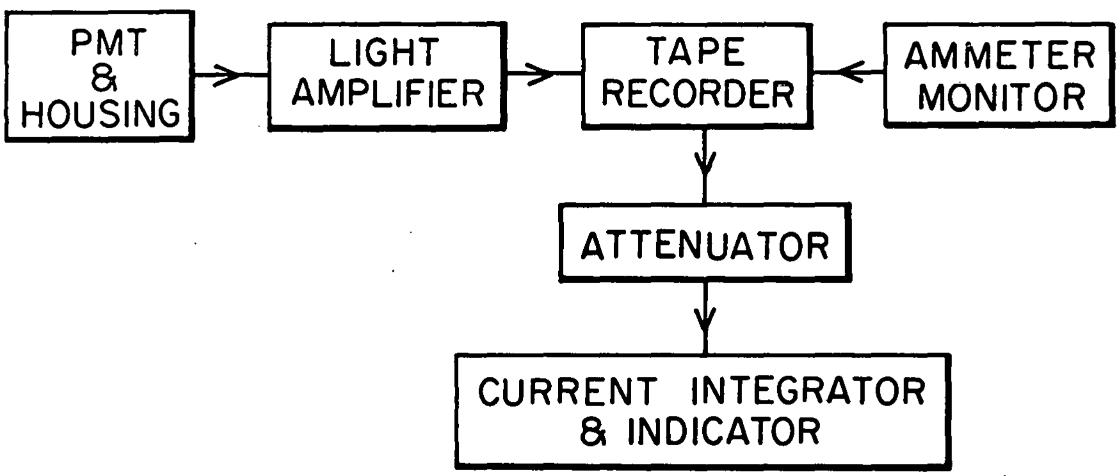
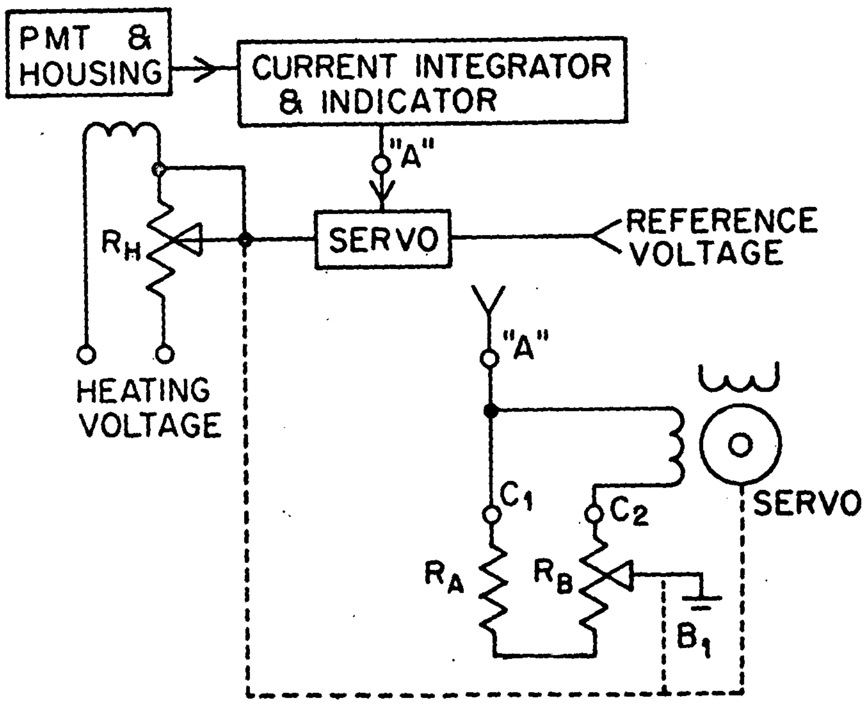


RELAY OPERATED HEATING RATE CONTROL



MEMORY TYPE OF DOSIMETRY READ-OUT



SERVO SYSTEM FOR CONTROL OF HEATING RATE