



**THE CONSTRUCTION OF THERMOLUMINESCENCE
EQUIPMENT**

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จาก
บัณฑิตวิทยาลัย มหาวิทยาลัยมหิดล

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The purpose of this research is to build thermoluminescence (TL) equipment employing analogue electronic controls for use in dating tektites. The ramp generator provided control signals for heating rates in the range 5-30 °C/s.

The equipment was then used to date tektites from Ubon Ratchathani Province, Northeastern Thailand. The samples included layered and splash tektite, which were broken into small pieces with a grain size less than 0.075 mm. The grains were washed with water until a clean powder sample was obtained. The naturally absorbed dose of these samples was then estimated using the TL techniques. The paleodoses of layered and splash tektites were found to be 3300 ± 178 Gy and 2775 ± 416 Gy, respectively. The annual dose estimated using the gamma ray spectrometry was 5.11 ± 0.51 mGy/yr. Tektite ages were estimated to be 0.65 ± 0.16 and 0.54 ± 0.10 million years for layered and splash tektite, respectively.

The performance tests showed that this equipment gave TL readings in fair agreement with the commercially available TL equipment.

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ในการวิจัยนี้ได้ทำการสร้างเครื่องมือวัด TL แบบแอนนูลอก มีวงจรกำเนิดสัญญาณแรมป์ควบคุมอัตราการให้ความร้อนในช่วง 5-30 องศาเซลเซียสต่อวินาที

ได้ใช้เครื่องมือที่สร้างขึ้นในการหาอายุของเทคไทต์บริเวณจังหวัดอุบลราชธานี ภาคตะวันออกเฉียงเหนือของประเทศไทย โดยขึ้นตัวอย่างเป็นเทคไทต์ชนิด layered และ splash ขึ้นตัวอย่างถูกบดจนได้ขนาดเล็กลงกว่า 0.075 ไมครอน ล้างทำความสะอาดตัวอย่างด้วยน้ำ นำไปอ่านการสะสมปริมาณรังสีจากธรรมชาติโดยอาศัยเทคนิค TL พบว่าปริมาณการสะสมรังสีของเทคไทต์ชนิด layered ได้ 3300 ± 178 เกร และเทคไทต์ชนิด splash ได้ 2775 ± 416 เกร ทำการวัดอัตราการรับรังสีจากสิ่งแวดล้อมของเทคไทต์โดยใช้ gamma ray spectrometry มีค่าเท่ากับ 5.11 ± 0.5 มิลลิเกรต่อปี นำไปคำนวณหาอายุของเทคไทต์ชนิด layered ได้เท่ากับ 0.65 ± 0.16 ล้านปี และเทคไทต์ชนิด splash ได้เท่ากับ 0.54 ± 0.10 ล้านปี

จากการทดสอบสมรรถนะของเครื่องนี้ พบว่าให้ผลเป็นที่น่าพอใจเมื่อเทียบกับเครื่องมือ TL ที่ใช้อยู่ทั่วไป

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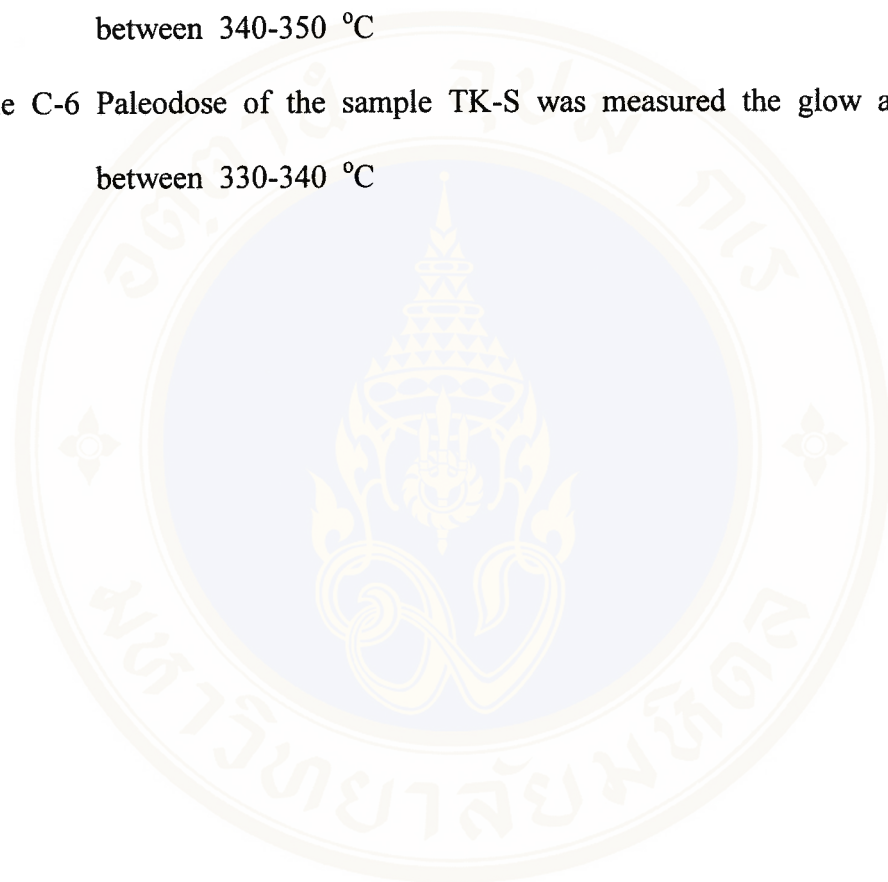
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CHAPTER I

INTRODUCTION

1.1 Reasons and Importance of the Present Study

There are many methods of nuclear techniques for measurement of nuclear radiation dosage and one of the most significant techniques is Thermoluminescence (TL). Extensive research in TL studies has gained interest because of its various applications in safety and personnel monitoring of people working with reactors, particle accelerators, X-ray machines, nuclear power plants and radiation source. TL phenomenon can be used to determine the ages of archaeological samples such as an ancient pottery (1), ceramic, geological samples such as a lava flow, fault (2). TL has also been used in the study of lunar materials and meteorites (3).

Thermoluminescence is the light emission occurring during heating of a sample that has already absorbed some energy from radiation. The emitted light falls upon the photomultiplier tube of suitable wavelength response. The signal from photomultiplier tube is amplified by the electrometer device and plotted against the temperature of the sample to produce the glow curve. Occurrence of TL is basically governed by the same principles as those of all luminescence processes and is merely one of a large family of luminescence phenomena that are named after the type of radiation used to excite the emission such as photoluminescence, radioluminescence, electroluminescence, and others (4).

The theory of TL was first suggested by Urbach (3) in 1930. He also suggested the graph which traces the variation of the TL intensity with increasing temperature is known as the glow curves of sample. The theory for the calculation of model glow curves was given in 1945 by Randall and Wilkins (3). In 1953, Daniels (3) and colleagues were the first to propose TL as a research tool in radiation dosimetry. They also suggested the determination of natural TL from rocks, which further led to the development of technique for geological and archaeological dating. Until 1962 work was intermittent and devoted to the development of equipment for the rapid heating of powdered sample (6). In fact TL equipment can be designed from the very simple to the extremely sophisticated. The nucleus of all the various designs is a light detection system, a heating control unit and a recording signal system. The designs of each of these components are varied depending on designers.

There has been considerable debate on the need for a linear heating rate, some designer required a linear heating rate but some designer suggested that the heating rate need not necessarily be linear, but it must be very reproducible (7). In this research, the TL equipment emphasize the need for an accurate linear heating rate. For this reason, the glow curves routinely obtained are reproducible.

It is possible to buy the TL equipment but it is usually expensive and requires some adaptation before it can be used conveniently with a particular field. Thereby, We built our own equipment with inexpensive and simple

components. Although, the computer is gaining popularity to controlled TL equipment but we preferred a analogue control less costly.

TL-dating method is based on the phenomenon of natural ionizing radiation inducing free electrons in a mineral that can be trapped in defects of the mineral's crystal lattice structure. These trapped electrons escape and release some energy as TL when heated. In this research, the terrestrial ages of tektites are to be determined. Tektites are pieces of natural glass. It was found in northeastern Thailand (8). Since tektites are made of a glassy material which were once melted at a high temperature, the clock were then set to zero. The amount of TL is proportional to the time that has elapsed. For this reason, the TL technique can be used to establish the terrestrial age.

1.2 Objective

1. To study the TL equipment.
2. To construct the equipment for the measurement of TL.

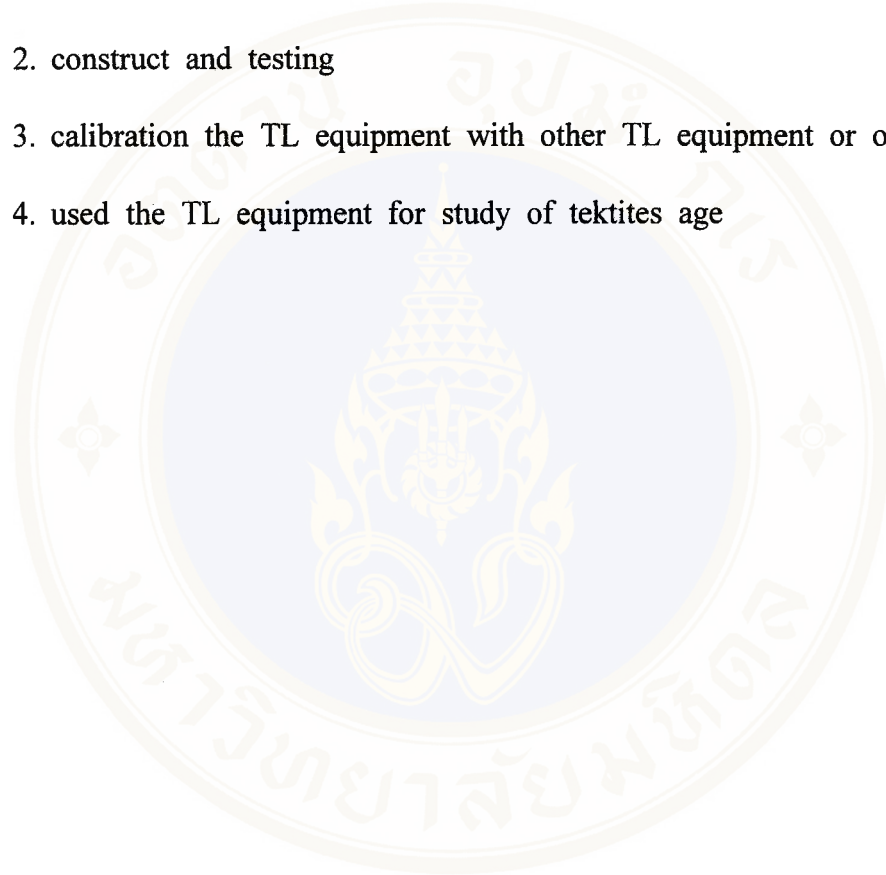
1.3 Scope of the Study

1. design and construct the equipment for TL measurement
2. testing
3. calibration with other TL equipment or other samples

1.4 Step of the Study

This research is an experimental study of the equipment for TL measurement. In experimental study divided into four part that are:

1. design the equipment for TL measurement
2. construct and testing
3. calibration the TL equipment with other TL equipment or other samples
4. used the TL equipment for study of tektites age



CHAPTER II

THEORETICAL ASPECT

2.1 The Principle of Thermoluminescence

2.1.1 Simple Model of Thermoluminescence (4,9)

Figure 2-1 is an energy level diagram of the crystal which exhibits TL.

The irradiation of crystal by nuclear radiations raise electrons from the valence band to the conduction band and leave a holes in the valence band. These electrons and holes move through the crystal until they recombine or until they are trapped in the metastable states as represented in figure 2-1a. These metastable states are due to a defects in the crystal lattice or impurity sites. When the crystal is heated, sufficient energy may be give to the electron to escape from their trap and raise it the conduction band as shows in figure 2-1b. If this electron recombines with the trapped hole at the recombination centre and thus a light is emitted, then the process is called thermoluminescence (TL).

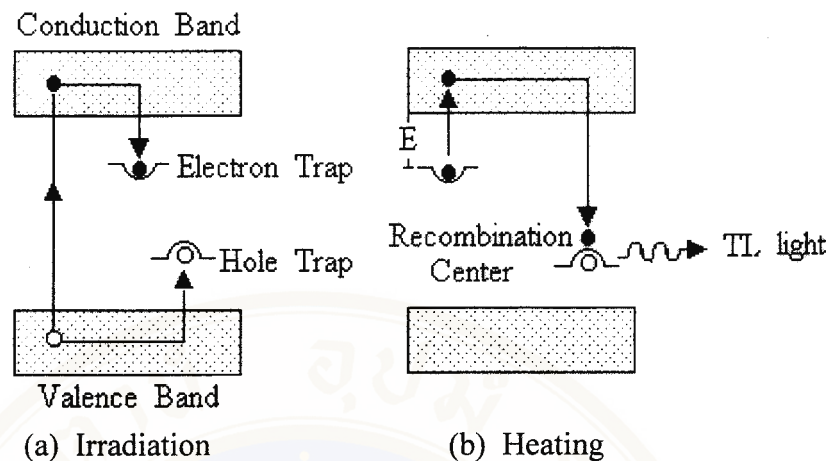


Figure 2-1. Schematic energy level diagram of the crystal which exhibits TL due to radiation.

2.1.2 Determination of Trap Depths (9, 10)

Randall and Wilkins (3) developed a simple first order kinetics model for thermoluminescence. This method can be used to determine trap depths. Each peak in the curve of TL intensity versus temperature so called the glow curve is related to a trap with a trap of energy depth E and a frequency factor s . On heating, the electrons in the crystal are thermally excited and released from the traps. Those electrons that go to the recombination centres will cause thermoluminescence.

The probability per unit time of the release of an electron from the trap of depth E at some absolute temperature T is given by Equation 1.

$$\lambda = s \cdot e^{(-E/kT)} \quad (1)$$

Where k is Boltzmann's constant $= 0.862 \times 10^{-4}$ eV/K

However, the probability λ is related to the average residence time of electrons in a given type of trap as $\tau = 1/\lambda$. The TL intensity $I(t)$ at any

time during heating is proportional to the rate of release of electrons from the trap and is given by the first – order kinetics equation as equation 2.

$$I = c \left| \frac{dn}{dt} \right| = -c \frac{dn}{dt} \tag{2}$$

$$\frac{dn}{dt} = -\lambda n$$

$$\frac{1}{n} \frac{dn}{dt} = -\lambda$$

$$\frac{1}{n} \frac{dn}{dt} \delta t = -\lambda \delta t = -\lambda \left(\frac{dt}{dT} \right) \delta T = -\frac{\lambda}{\beta} \delta T$$

$$\int \frac{1}{n} \frac{dn}{dt} dt = - \int \frac{\lambda}{\beta} dT$$

$$\int_{n_0}^n \frac{1}{n} dn = - \int_{T_0}^T \frac{s}{\beta} \cdot e^{(-E/kT)} dT = - \int_{T_0}^T \frac{s}{\beta} \cdot e^{(-E/kT')} dT'$$

$$\ln \frac{n}{n_0} = - \int_{T_0}^T \frac{s}{\beta} \cdot e^{(-E/kT')} dT'$$

$$n = n_0 \cdot e^{- \int_{T_0}^T \frac{s}{\beta} \cdot e^{(-E/kT')} dT'}$$

$$I = cn_0 s \cdot e^{(-E/kT)} \cdot e^{- \int_{T_0}^T \frac{s}{\beta} \cdot e^{(-E/kT')} dT'} \tag{3}$$

Where n is the number of trapped electrons

n_0 is the initial number of trapped electrons

c is a constant

β is the heating rate = dT/dt

Equation 3 is the basis of the determination of the trap of depth E.

2.2 Apparatus for the Measurement of Thermoluminescence

2.2.1 Basic Components

Equipment for the study and quantification of the TL from a samples are suggested in many reports. In general, the basic components of TL equipment are composed a heating system, a light detection system and a signal recording system. A schematic diagram of basic TL equipment is shown in figure 2-2.

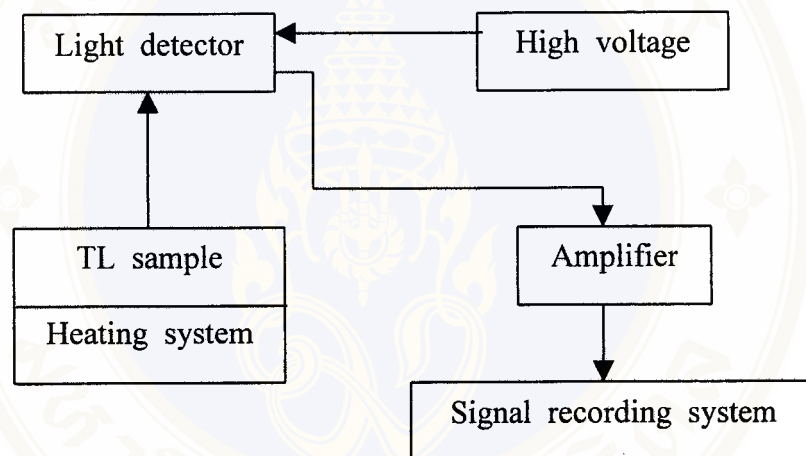


Figure 2-2. Basic components of a TL equipment.

2.2.2 Heating the Samples

The method of reading a TL sample is simple. In a relatively short time the sample is heated from the ambient temperature to some final temperature such as 500 °C for TL-dating (1,2). The emitted light is measured quantitatively, usually ranging from a few seconds to a few minutes.

There are several methods of heating the sample such as ultrasonic heating and infrared heating. These methods are not used in any commercial TL

instrument because they are complex . An advantage of these methods of heating is that the rapid and uniform heating causes an increase in sensitivity of the material (9). However, planchet heating , gas heating, microwave heating and laser heating are used in heating the sample.

1. Planchet Heating (9, 10)

Planchet heating or ohmic heating can be heated indirectly with electricity. It generally acts as the heater element itself. There are two general methods used to heat the sample, placing directly the samples to a heating element and putting the samples in a pan or planchette. The heated pan or planchette is used in many commercial TL instruments such as HARSHAW 3500 QS. Since many of the commercial TL instruments use the heated pan or planchette method, the effects of the pan are important to consider. Cameron (9) concluded that the component of a pan or planchette may affect the results of a TL measurement such as its reflectivity, its mass and its reflectivity, its mass and its surface area.

2. Hot Gas Heating (10)

The hot gas heating method is not used in any commercial equipment because this method is only suitable for solid forms of TL samples and is not possible with loose powder. Some TL instruments have been built utilizing heated nitrogen as the heat transfer medium. The heating is very rapid and is particularly suited to automated TL equipment such as Studsvik automatic TLD reader 1313B and TNO automatic TLD system.

3. Microwave Heating (10, 11)

Microwave or RF heating is the heating of graphite or other suitable materials in which the TL sample is placed. The graphite is heated by the induced current produced by a microwave induction heating coil.

Disadvantages of microwave heating are the large amount of microwave power needed and the difficulties of controlling the heating cycle.

4. Laser Heating

Laser heating is one type of optical heating. The laser heating technique yields a dramatic increase of the heating rate up to 2.0×10^4 °C/s and thus increases the sensitivity of TL samples (10). Disadvantage of laser heating are the high cost and complexity of the readout system, need for precise adjustment of the beam and positioning of TL samples, difficulty in obtaining the temperature profile of the laser heated TL sample due to its very rapid heating and so it is suitable only for thin TL samples.

2.2.3 The Light Detecting

The technique of light detection is not specific to TL samples because these samples are different wavelength. The general task of light detecting system is convert the light emitted by the TL samples into an electronic signal such as charge, current and voltage, which can be measured and used to activate output devices such as printers, chart recorders and computers.

1. Photomultiplier Tube (PMT)

Until recently, all commercial instruments used a photomultiplier tube to detect the emitted TL. McKEEVER (6) suggested most photomultiplier tubes used in TL applications have 11 or 13 dynode stages and 52 mm diameter and windows. Typical cathode sensitivities are 70-100 $\mu\text{A}/\text{lumen}$ and the anode sensitivity is typically 2000 A/lumen . Thus, gains of $10^6 - 10^7$ are often achieved. A 1% variation in supply voltage would produce a 10% variation in output current of the photomultiplier (12).

The anode current is simply amplified by a suitable d.c. picoammeter, the output of which is displayed on a chart recorder or a computer for data analysis. The most common photocathode types are the alkalis namely KCs, RbCs or KNaSb. The alkalis have a sharp response peaking at $\sim 420 \text{ nm}$ (6) This conveniently corresponds with the maximum emission wavelength of many TL samples (4) So that, the choice of the spectral response of the photocathode is indicated by the spectra of the TL sample to be measured. Figure 2-3 gives an example of photomultiplier tubes with various spectral responses. The characteristics of a photomultiplier tubes listed in the manufacturer's literature are typical values. The individual tubes may vary considerably from the listed value.

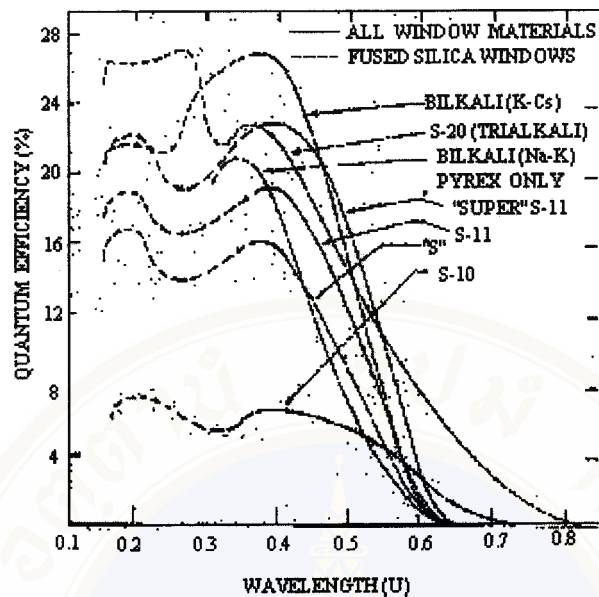


Figure 2-3. Spectral responses of different types of photocathodes used in PMT
(Courtesy of EMI Electronics Ltd.)

2. Filters

TL spectra are usually in the visible region and the undesired infrared emission can be preferentially absorbed by using a filter. All filters have some attenuation of the TL signal. Figure 2-5 shows the transmission characteristics of O.B.-10 filter. Zimmerman (3) discussed that the important TL information for dating is obtained at temperatures between about 300 – 500 °C. At these high temperatures, a great deal of blackbody radiation comes from the heater and the sample. This is reduced by means of a filter.

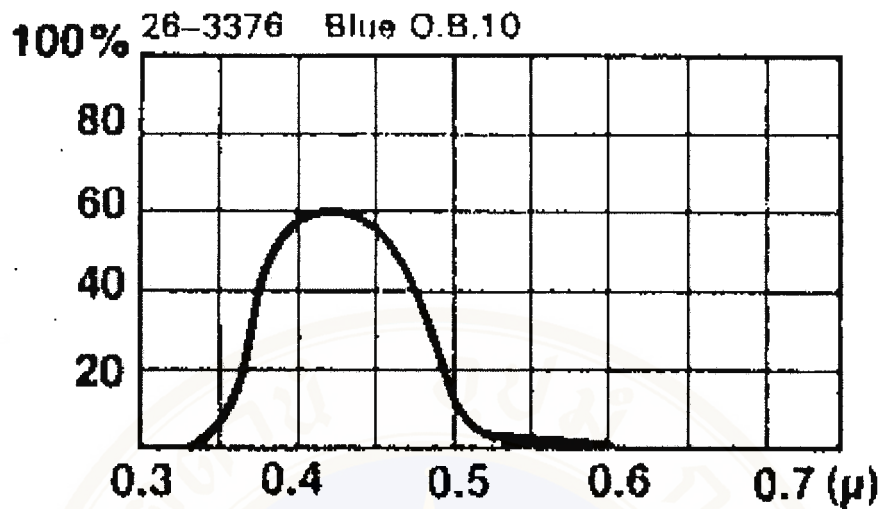


Figure 2-4. Absorption characteristics of O.B.-10 filter .

2.2.4 Recording Glow Curves

Glow curve is the graph of TL intensity as a function either of temperature or of time. Cameron (9) found that the factors may affect the shape of a glow curve such as the heating rate and its uniformity ; the size, shape and thermal conductivity of the sample; the recording instrument used; the level of irradiation and annealing history of the sample. If the heating rate is uniform, these curves are very similar. Changes in the heating rate have several effects on the glow curve as presented in figure 2-5.

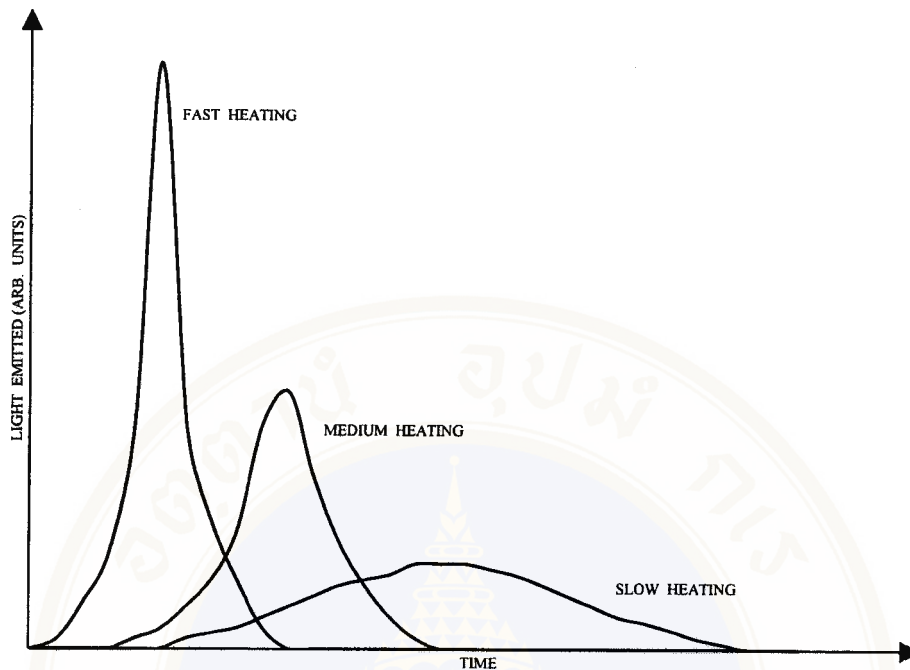


Figure 2-5. The effect of heating rate on the glow curve (9).

The part of the sample, which is in contact with the heating strip heats up first and other parts of the sample heated as the heat is conducted. It is obvious that the size, shape and conductivity of the sample affect the shape of the glow curve. In a thick sample, the portion furthest from the heat may lag in temperature so that it is emitting a low temperature glow peak. The hottest position is emitting a high temperature glow peak.

The shape of the glow curve occurs at different irradiation radiation levels as shows in figure 2-6. Similar changes were observed in tektites and other TL samples in this research.

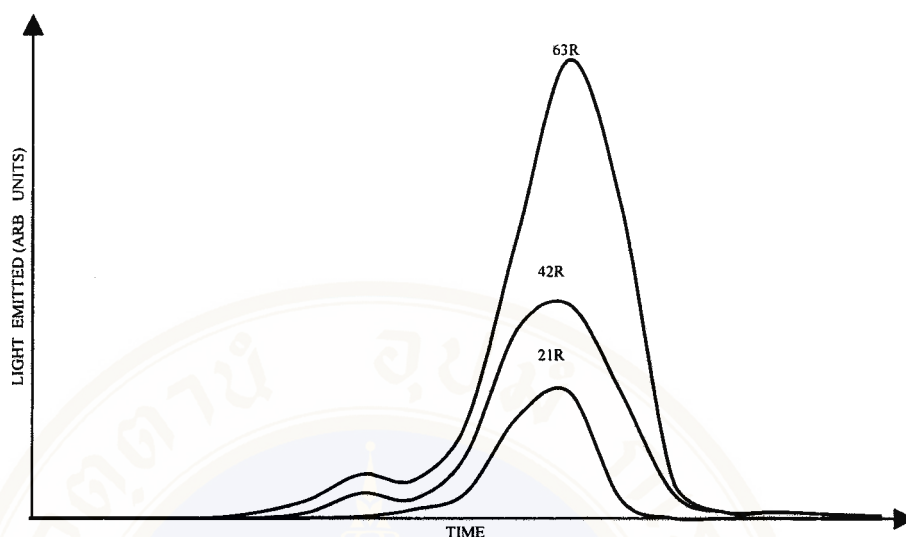


Figure 2-6. Changes in the glow curve structure of LiF at three different irradiation (14).

The type and characteristics of the recording instrument used may affect the glow curve. Glow curves may be recorded in a variety of ways. McDougall (11) discussed the simple method sketched in figure 2-7. It is to generate glow curves on a chart recorder which is connected to an electrometer amplifier. With this method the automatic (15) or manual operation (12) can be used.

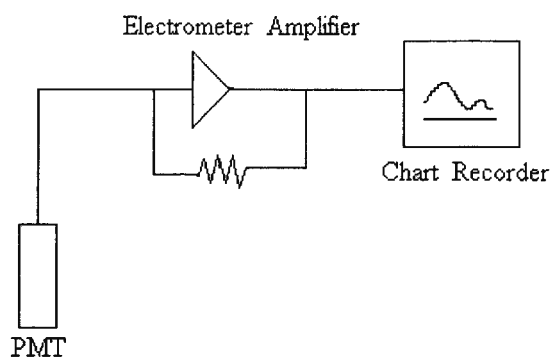


Figure 2-7. Simple method for generating glow curves.

2.3 Application of Thermoluminescence Dating in Tektites

2.3.1 The Origin and the Distribution of Tektites in Thailand (16,18)

There has been a debate about the origin of tektites, namely tektites are the product of the extraterrestrial material or terrestrial material until scientists took the rocks and minerals on the moon, the sediment, rocks and soil on the earth and terrestrial meteorites to analysis for their chemical composition. It is concluded that the chemical composition of tektites is similar to the chemical composition of the earth's surface.

It is now commonly accepted that tektites were formed by the impact melting of sediment and rocks on the earth's surface during meteorite collision. Massive explosions sent showers of tektites to the sky. Later they fell and steadily dried.

The distribution of tektites on the earth's surface is divided into four regions as listed in the table 2-1. Tektites are named after the countries where they are found.

Table 2-1. Tektite names and localities (17).

Region	Names and Localities
Australasian	Indochinites(Indochina, Laos, Veitnam and Cambodia) Philipinites and rizalites (Philippines and its Rizal Province) Javaites (Java), Billitonites (Billiton), Australites (Australia and Tasmania) and Thailandites (Thailand)
Ivory Coast	Ivory Coast Tektites
Czechoslovakia	Moldavites (Bohemia and Moravia)
North America	Bediasites (Texas) and Georgia tektites

Thailandites are richest in the northeastern regions such as Ban Huai Sai, Buntharik in Ubon Ratchathani and Sri Saket Province etc.

2.3.2 The Shapes and the Chemical Composition of Tektites

Fiske, et al (8) described that two types of tektites are found in Thailand, namely the layered or Muong Nong and the splash-form tektites.

1. Layered Tektites

Layered tektites are also called Muong Nong tektites because the first ones were found in the village of Muong Nong in Laos (16). Layered tektites are made up of thin layers or are layered in structure and inhomogeneous. Dark and brown layer alternate. These tektites contain a lot of bubbles. The shape of layered tektites is elliptical due to flow phenomena (16). Bunopas (18) argued that layered tektites in or near Hainan, Indochina and Thailand can be

found up to 12.8 kg or even 24 kg. The world's largest layered tektites are shown in the House of Gems, Thailand. It weighs 24 kg.

2. Splash-form tektites

Splash tektites are found in various shapes such as spheres, drops, dumbbells, etc. Those shapes indicated that the melt solidified during rotation. Splash tektites are usually small with weights of less than 0.3-0.5 kg (16).



Figure 2-8 . Layered and Splash tektites from northeastern Thailand (16).

Both tektite are morphologically and compositionally distinct. In the table 2-2, Schnetzler (19) summarized the chemical composition of tektites in northeastern Thailand.

Table 2-2. Main elements in tektites from northeast Thailand.

Average values (% weight)	SiO ₂	Al ₂ O ₃	FeO	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂
Layered tektite (75 samples)	76.25	11.10	4.10	1.63	1.67	1.40	2.47	0.68
Splash tektite (112 samples)	73.20	12.84	4.73	2.15	2.23	1.32	2.39	0.75

2.3.3 Determination of the Terrestrial Age of Tektites

2.3.3.1 Age Equation

The relationship between TL intensity and absorbed radiation dose had been established for the use of TL as a means of age determination. This technique has an age range of 1,000 to 500,000 years (20). The assessment of the terrestrial age of tektites can be calculated by the equation 4.

$$\text{Age in year} = \frac{\text{Paleodose}}{\text{Annual dose}} \quad (4)$$

The paleodose is usually expressed in terms of the gray;Gy. The annual dose is then in units of miligray per year;mGy/yr.

2.3.3.2 Evaluation of Paleodose (1,5)

Paleodose or the natural radiation dose is the TL emitted by the unirradiated, which accumulated over the burial period of the sample. The paleodose is denoted by PD and is evaluated by comparing the signal because the natural radiation dose of the sample with the increase of TL signal induced by known amounts of additional radiation. By extrapolating the growth curve of the TL backwards to the dose axis, the amount of the natural dose accumulated since the initializing event until the TL read-out can be obtained. In general, the growth curves are not straight line (5).

In TL dating, the emitted TL at low temperatures is not considered because it is unstable. In natural samples, TL at low temperatures has decayed away during the burial because the half-lives of trap levels are short. In contrast, irradiated samples emit this low temperature TL because the interval between irradiation and measurement is too short for decay. This difference is the basis of the plateau test. The plateau must be determined before the paleodose evaluation. TL signals are then integrated in the plateau region previously determined.

2.3.3.3 Evaluation of Annual Dose

The annual dose or dose-rate has been evaluated from the equation 5, derived by Aitken (1,5).

$$AD = k(2.783U+0.738Th)/(1+1.50W) + (0.1462U+0.0286Th+0.6893K)/(1+1.25W) + (0.1148U+0.0514Th+0.2069K)/(1+1.14W) + 0.15 \text{ mGy/yr} \quad (5)$$

where, U is the concentration of uranium in ppm.

Th is the concentration of thorium in ppm

K is the concentration of potassium oxide in %

k is the efficiency of alpha particles in producing TL

W is the water content (% / 100)

This equation is based on the assumption that there is no radon loss and that the average value for the efficiency of alpha particles in producing TL is 0.15 (3,5) and also that the cosmic radiation is quoted by background dose rate is 0.15 mGy/yr (5).

The main contributors to the dose are isotopes of uranium, thorium and potassium, namely uranium-238, thorium-232 and potassium-40. Smaller amounts of uranium-235, rubidium-87 and cosmic radiation are also present. The decay chains for the main radioactive isotopes are given in the table 2-3 and 2-4. When nuclei of uranium, thorium and potassium decay, alpha particles, beta particles and gamma radiation are emitted. Thus, an individual sample grain will receive most of its internal annual dose from alpha and beta particles and the external annual dose from the surroundings as gamma and cosmic radiation.

Table 2-3. Radioactive decay schemes of potassium and rubidium (5)

Potassium-40 (natural abundance 0.0117%)	Rubidium-87 (natural abundance 27.8%)
<p>potassium-40 (half-life: 1.25×10^9 years)</p> <p>γ(1.46 MeV) β(1.36 MeV)</p> <p>argon-40 (stable) calcium-40 (stable)</p>	<p>rubidium-87 (half-life: 48×10^9 years)</p> <p>β(0.27 MeV)</p> <p>strontium-87 (stable)</p>

Table 2-4. Radioactive decay schemes of thorium and uranium (5)

Thorium series		Uranium series	
Nuclide	Half-life	Nuclide	Half-life
thorium-232	14.0×10^9 yr	uranium-238	4.47×10^9 yr
↓ 1α		↓ 1α,2β	
radium-228	6.7 yr	uranium-234	245×10^3 yr
↓ 1α,2β		↓ 1α	
radium-224	3.6 d	thorium-230	75×10^3 yr
↓ 1α		↓ 1α	
radon-220	55 sec	radium-226	1600 yr
↓ 2α,2β		↓ 1α	
polonium-216	0.16 sec	radon-222	3.82 d
↓		↓ 3α,2β	
↓		lead-210	22 yr
↓		↓ 2β	
↓		polonium-210	138 d
↓		↓ 1α	
lead-208	stable	lead-206	stable

In principle there are several methods by which the uranium, thorium and potassium contents can be determined such as thermoluminescence dosimetry (TLD), neutron activation analysis, gamma ray spectrometry, etc.

CHAPTER III

Design and Construction of the Equipment for Thermoluminescence Measurement

3.1 Component of the Equipment

The designing of each component of apparatus for measurement of TL varies depending on individual designer and application. A new TL equipment in this research was built with the following objectives

1. It should be simple in construction and operation.
2. It should have a variable heating rate.
3. It should accept a variety of sample sizes form.

A schematic diagram and a photograph of the equipment in this research are presented in figure 3-1 and 3-2, respectively.

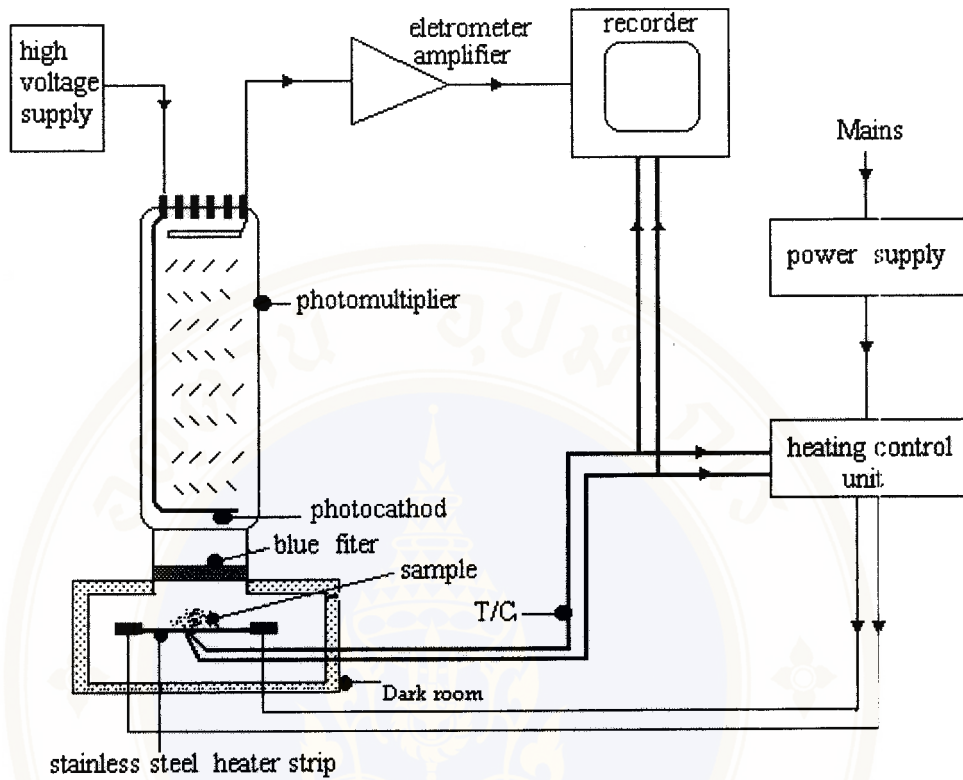


Figure 3-1. Schematic diagram of the TL equipment.

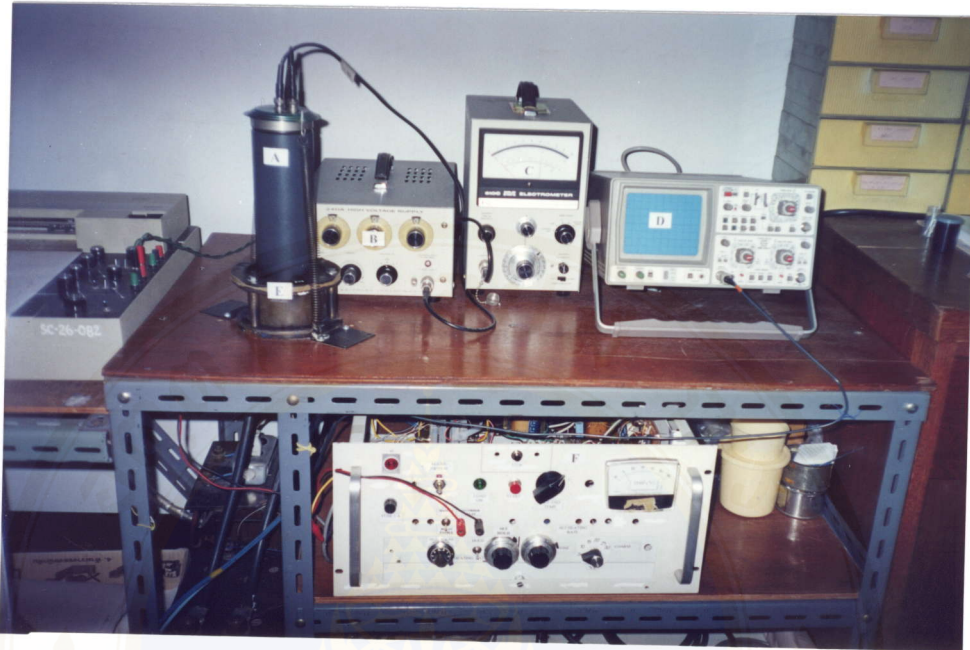


Figure 3-2 The component of the TL equipment (A) photomultiplier tube
(B) high voltage supply (C) electrometer (D) oscilloscope
(E) sample chamber (F) heating control unit (G) recorder.

The TL equipment consists the three mains units such as heating unit, light detection unit and signal recording unit.

3.2 Heating Unit

There are several methods of providing heating mechanism in TL equipment such as ohmic heating, microwave heating, laser heating, hot gas heating and projection lamp heating (21).

In this instrument, the sample was heated by an ohmic heating. This heating method is used in most commercial TL equipment (12,15). Cameron (9) is

described two means of ohmic heating. Firstly way, the sample is placed on a pan or tray and can be heated by the passage of a current through the pan. Secondly, the sample in the pan can be heated by bringing it into contact with an electrically heated element. The heating element referred to has low thermal inertia. The low thermal inertia also enables reasonably high heating rate such as $10\text{ }^{\circ}\text{C/s}$ to be used and also facilitates the rapid cooling of the heater. However in this research, the sample is placed directly on a heating strip as shown in figure 3-3. An advantage of this method of heating is that more rapid and more uniform heating is readily achievable.



Figure 3-3. A sample on a heating strip.

3.2.1 The Operation of the Electronic Network of the Heating Control Unit

In the study of thermoluminescence, the usual mode of operation requires a linear temperature rise in time because the obtained glow curves are then smooth (15). The required rate of temperature rise and the final temperature are set by user. In this research, the linear heating controller comprises five basic circuits as presented schematically in figure 3-4 and the main circuit is shown in figure 3-5. On operating the "START" switch, the voltage output of ramp generator was generated and fed to an inverting amplifier. The voltage output of the inverting amplifier was compared with the voltage of the thermocouple by the comparator circuit. The difference signal is used in driving the heater circuit via the non-inverting amplifier in the thyristor firing circuit.

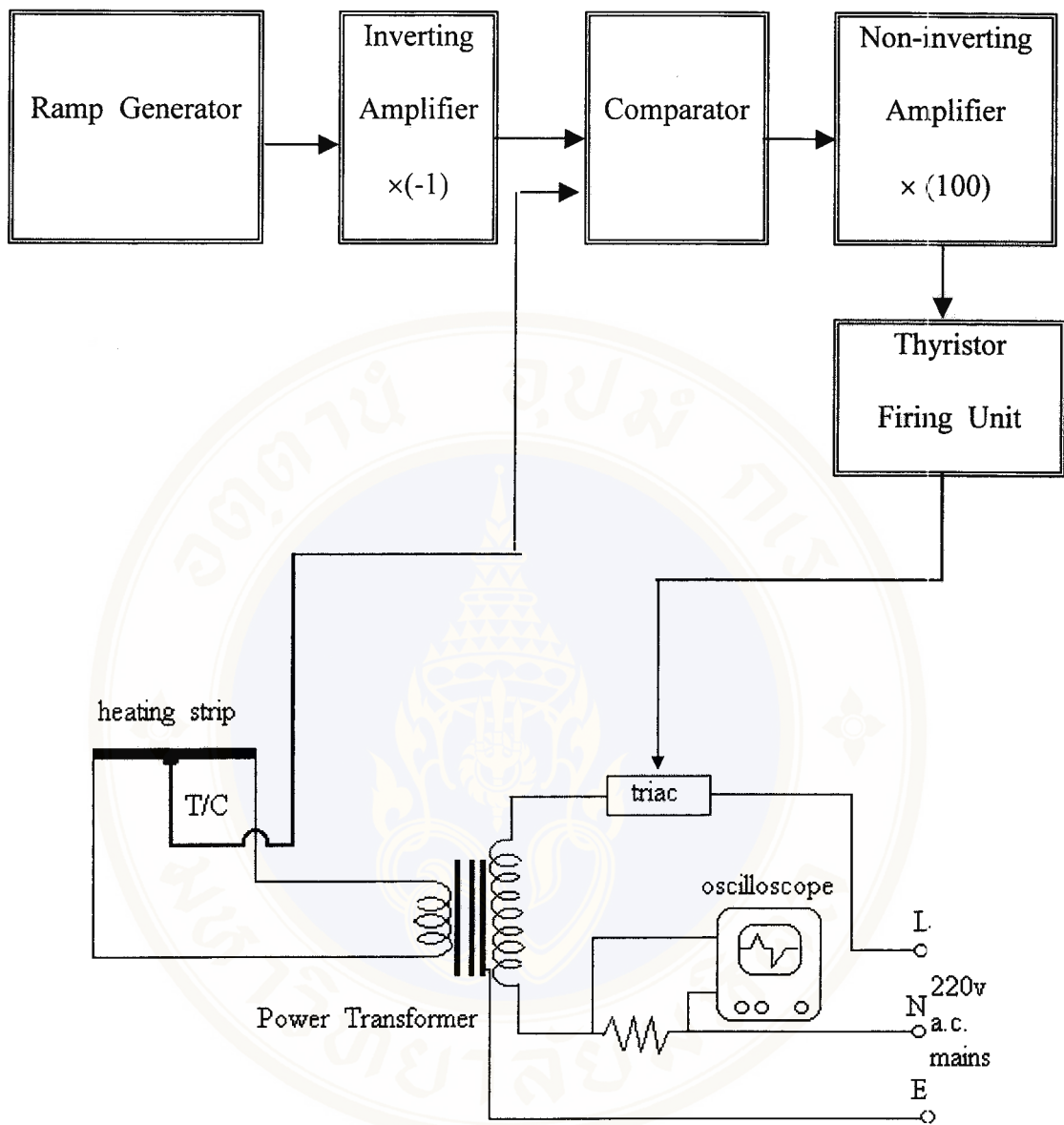


Figure 3-4. Block diagram of linear heating control unit comprises the ramp generator circuit, inverting amplifier circuit, comparator circuit, non-inverting amplifier circuit and thyristor firing circuit.

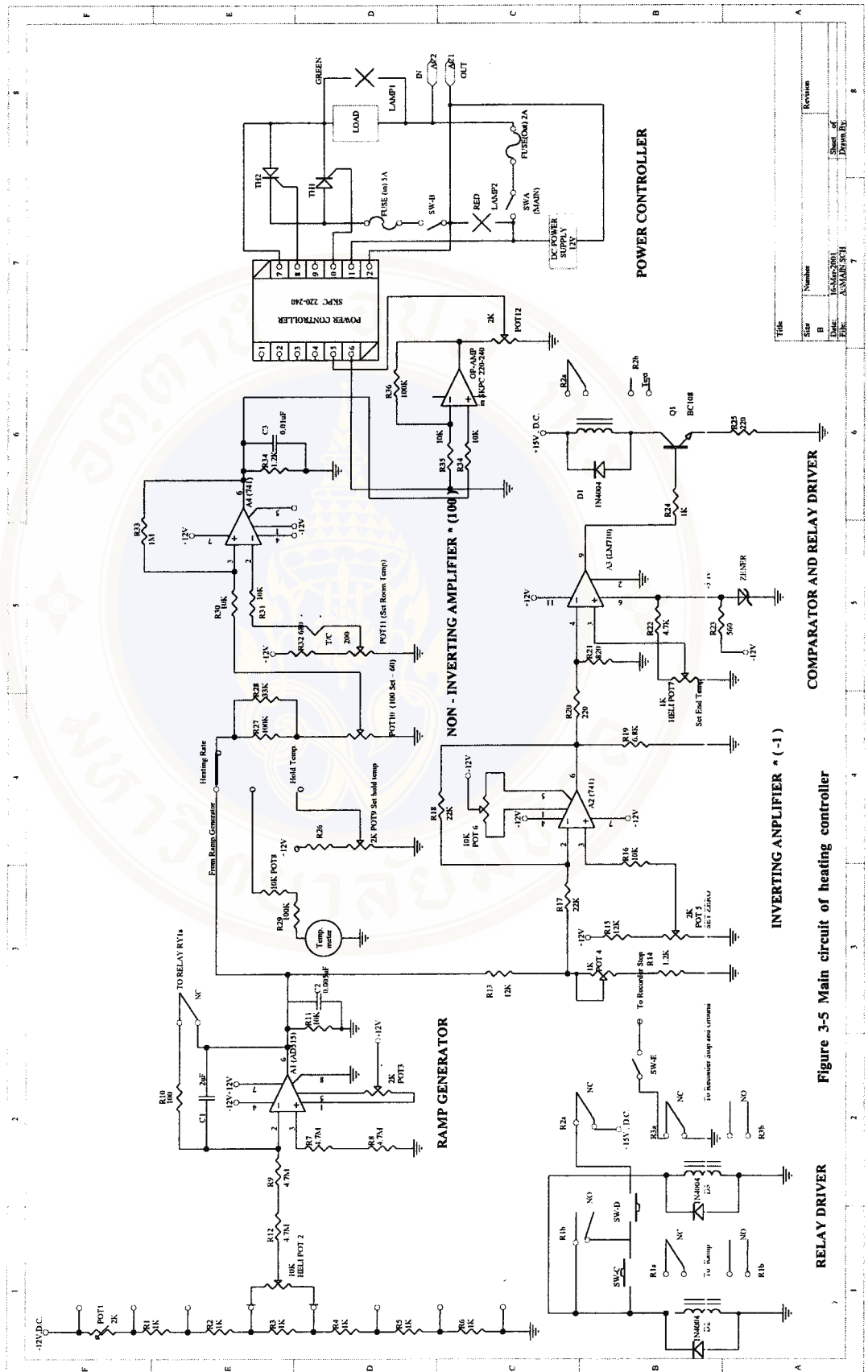


Figure 3-5 Main circuit of heating controller

3.2.1.1 Ramp Generator Circuit

Ramp voltage generator circuit in figure 3-6 is the integrator circuit. The stabilized -12 V provides a -10 V reference voltage through by the potentiometer POT 1 and the resistor R₁-R₆. The selector switch and HELIPOT 2 together will set the heating rate at any values within range 5-30 °C/s. On operating the “START” switch SW-C, the relay R_{1b} will open. The integrator circuit A₁ will now begin to generate a ramp voltage. The fixed input voltage causes the capacitor C₁ to charge by a constant current. The voltage drop across the capacitor C₁ is the ramp output. This output will continue to rise linearly.

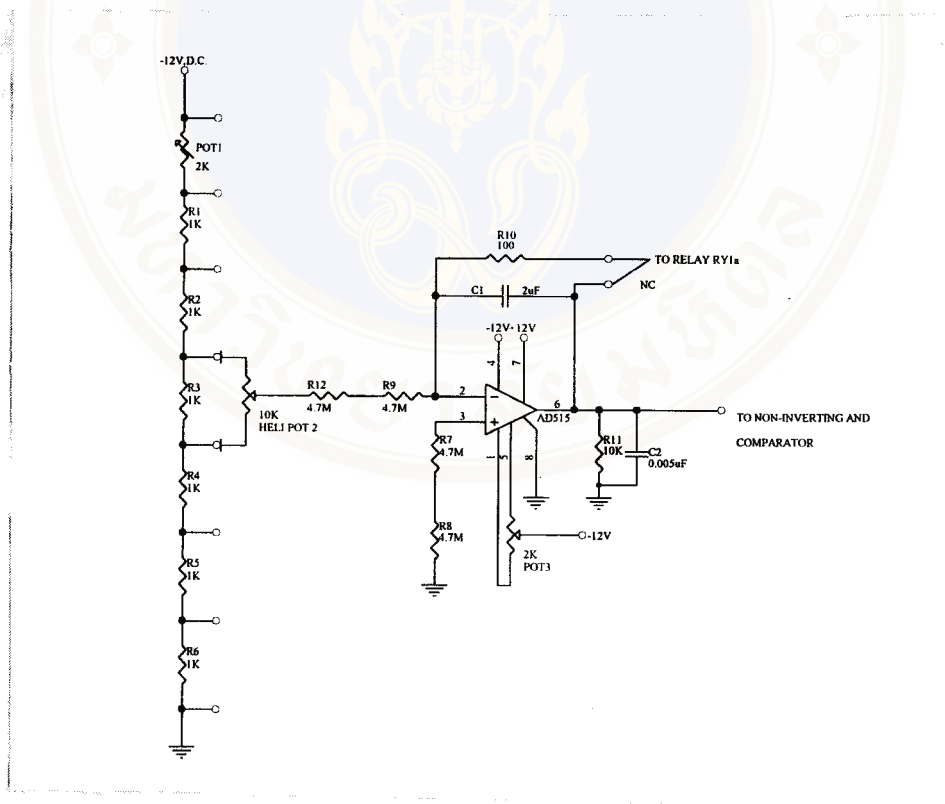
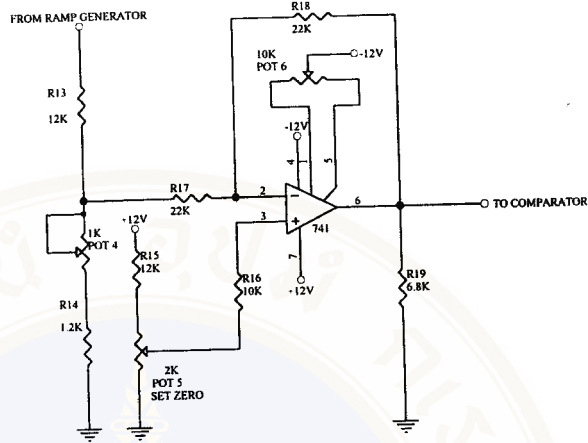


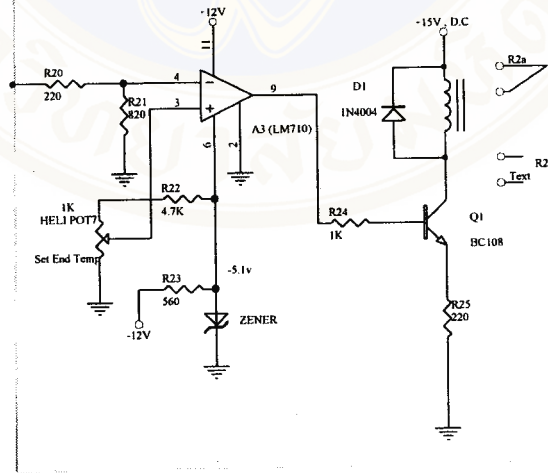
Figure 3-6. Ramp generator circuit.

3.2.1.2 Inverting Amplifier and Comparator Circuit

Inverting amplifier and comparator circuits are shown in figure 3-7. The voltage output of the integrator circuit A_1 is fed to a DC inverting amplifier A_2 with a gain of about 1. The voltage output from A_2 of about -10V is fed to the inverting input of a $\mu A710$ operational amplifier A_3 . The signal between of the both input terminals of A_3 were compared. If the voltage output from A_2 is equal to or more negative than the reference voltage which provided by HELIPOT 7, the output from A_3 will be positive and is applied to the base of a silicon npn transistor Q_1 via R_{24} resistor. Q_1 will be driven to saturation and the relay R_{2a} operates. The capacitor C_1 is then instantaneously discharged and the ramp voltage drops to zero. But if the voltage output from A_2 less negative than the reference voltage, the transistor Q_1 will not conduct. The capacitor C_1 will be ready to charge again. Diode D_1 - D_3 are used to prevent induced electromotive force of the relay coils from damaging the circuit.



Inverting Amplifier

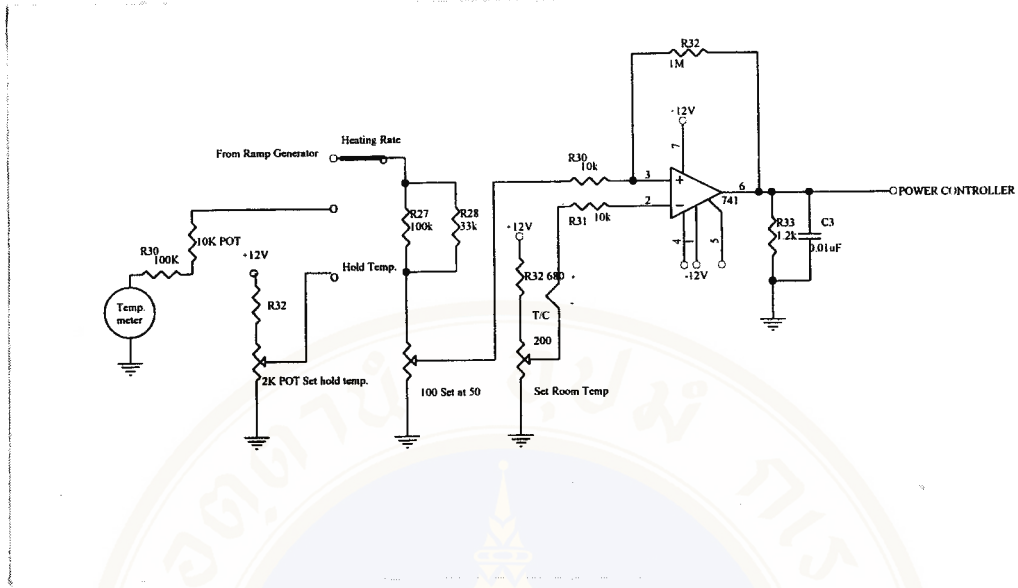


Comparator

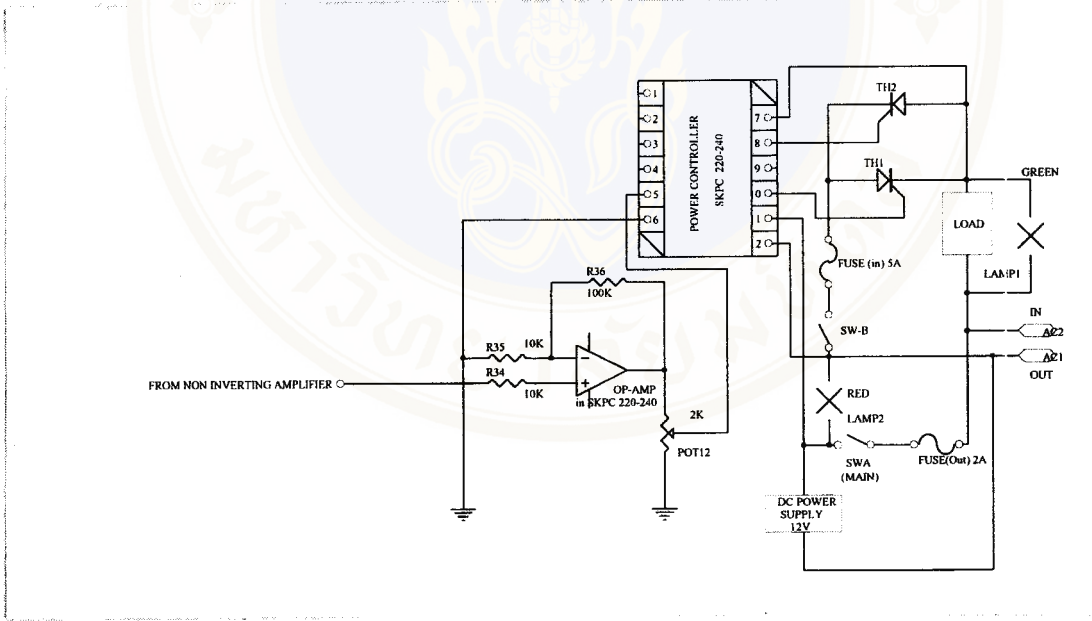
Figure 3-7. Inverting amplifier and comparator circuits

3.2.1.3 Non-inverting Amplifier and Thyristor Firing Circuit

Figure 3-8 is a schematic diagram of the non-inverting amplifier and thyristor firing circuit. This circuit will run when the switch SW-F is closed. The ramp output proceed via the resistor R_{30} to the non-inverting input of the 741 operational amplifier A_4 . In this circuit, a chromel-alumel thermocouple is connected to the inverting input of A_4 . The power controller will fire the thyristor when the output from A_4 is positive, thereby the strip temperature will rise. The heating will stop as soon as the ramp voltage drops to zero or A_4 output is negative. The integration can be brought to a sudden stop by pushing the STOP bottom, the switch SW-D. In this circuit, thyristors TH_1 and TH_2 must be mounted on heavy aluminum heat sinks.



Non-inverting amplifier



Thyristor firing

Figure 3-8. Non-inverting amplifier and Thyristor firing circuit

3.2.2 The Actual Heating Control Unit.

The electronic circuits was built, tested, and calibrated, as described in the following.

3.2.2.1 Apparatus

1. Bryans 28000 recorder
2. EMI 9502B photomultiplier tube
3. oscilloscope
4. high voltage supply
5. electrometer amplifier
6. low voltage AC supply

3.2.2.2 Ramp Generator Circuit

Figure 3-11a is a set up for testing the ramp generator. A constant voltage of -11.8 V was fed to the inverting input of A_1 . The capacitor C_1 was charged by a constant current of about 1.26 μ A. The voltage across the capacitor C_1 is the ramp voltage V_{01} . The output V_{01} grew linearly in time (see figure 3-11b). This output could be instantaneously reset to zero by closing the switch SW and thus discharging C. When the switch SW was re-open the ramp voltage resumed.

The voltage across the capacitor C_1 is equal to the output of ramp generator V_{O1} . The output V_{O1} will continue to linearly charge positive by proportional to time, as indicated in figure 3-9b. This output may be instantaneously reset to zero by closing the switch SW, because the capacitor C_1 was suddenly discharged. If the switch SW was open, the capacitor will charge again.

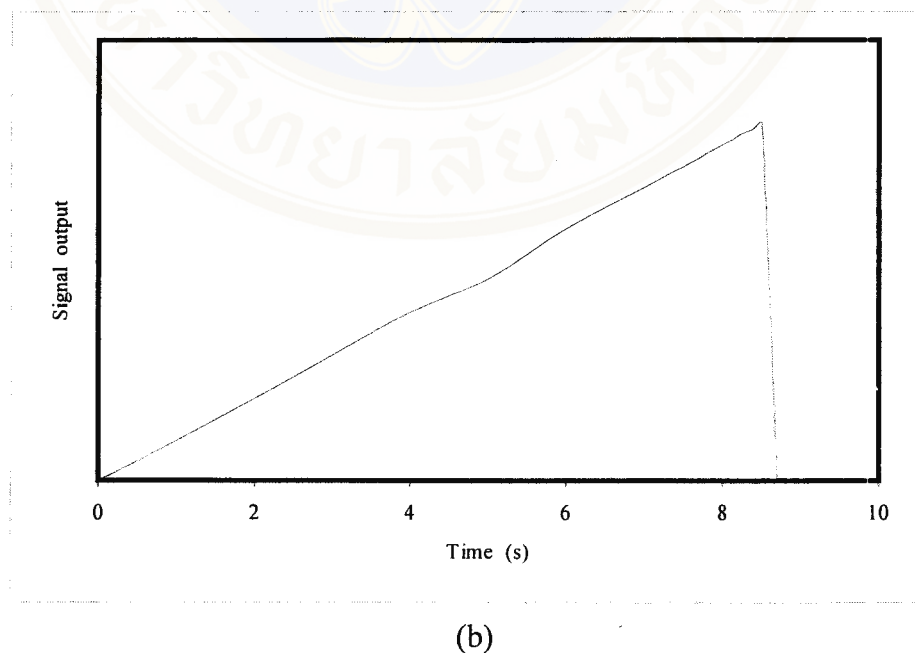
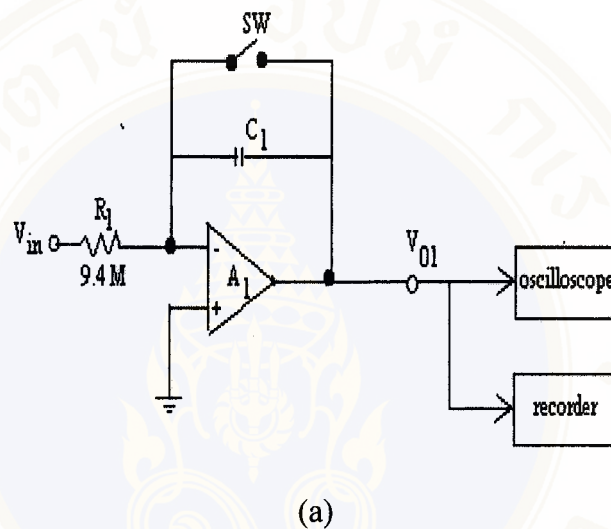


Figure 3-9. Signal output from the integrator circuit at a fixed input voltage.

The ramp voltage was given by

$$\frac{dV_o}{dt} = -\frac{1}{RC} \int V_i dt = +\frac{11 \cdot 8}{RC} t$$

$$\frac{V_o}{t} = \frac{11 \cdot 8}{RC} = 1.26 \text{ Volts/sec.}$$

For $R = 9.4 \text{ M}\Omega$, $C = 1.0 \text{ }\mu\text{F}$.

The measurement showed that $V_o/t = 1.28 \text{ volts/sec.}$ which is well within the calculated value of 1.25 volts/sec.

3.2.2.3 Inverting Amplifier Circuit

The Inverting amplifier circuit made use of the series 741 operational amplifier (2C) Its gains in 1. (see Table 3-1)

Table 3-1 Inverting amplifier.

Input voltage V_i (V)	Output voltage V_o (V)
0.2	-0.2
0.4	-0.4
-0.2	0.2
-0.4	0.4

3.2.2.4 Coparator Circuit

The circuit used a special purpose 710 op. Reference voltage; V_{ref} was set at approximate by 20 mV corresponding to 500 °C. Testing of the comparator circuit is shown in figure 3-10. The results of testing are listed in table 3-2 and figure 3-11.

Table 3-2. Data of the testing of comparator circuit.

V_{ref} (V)	V_{bat} (V)	V_{ref} (V)	V_{bat} (V)
0	0	0.50	0.71
0.05	0.12	0.55	0.79
0.10	0.17	0.60	0.84
0.15	0.24	0.65	0.89
0.20	0.29	0.70	0.96
0.25	0.36	0.75	1.03
0.30	0.45	0.80	1.09
0.35	0.51	0.85	1.16
0.40	0.58	0.90	1.26
0.45	0.66	0.95	1.35

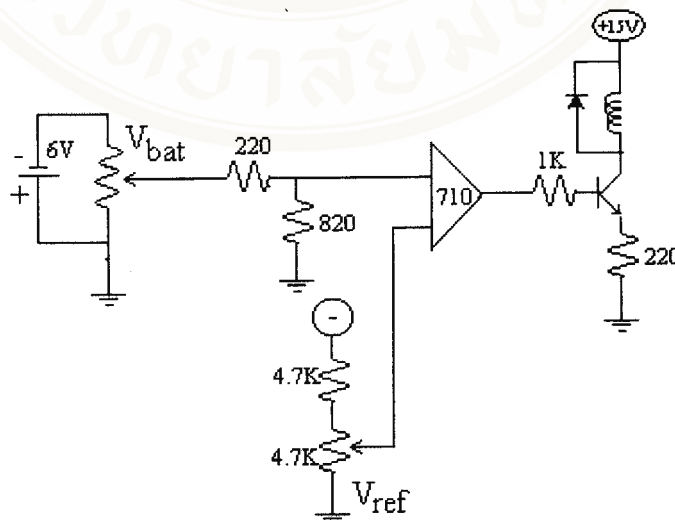


Figure 3-10. Testing of comparator circuit.

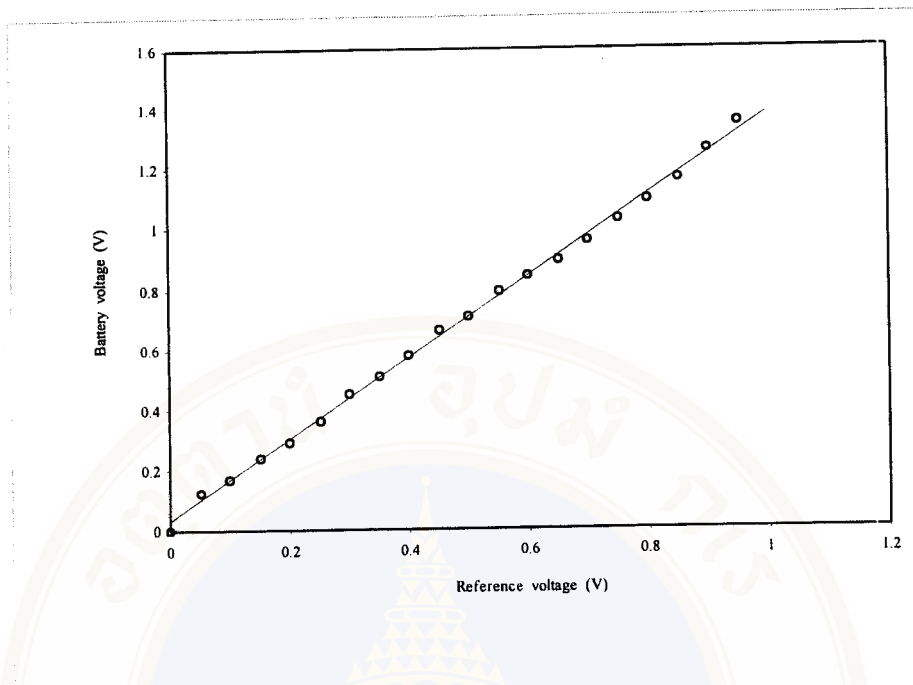


Figure 3-11. The results of the testing of the comparator circuit

3.2.2.5 Non-Inverting Amplifier and Thyristor Firing Circuit.

The first circuit in figure 3-8 is non-inverting amplifier with a gain of about 100 times. Table 3-3 shows the input/output from this circuit.

Table 3-3. Non-inverting amplifier with a gain of about 100 times.

V_{input} (V)	V_{output} (V)
0.1	10
0.2	20
0.3	30
-0.1	-10
-0.2	-20

In this circuit, the room temperature compensation can be adjusted with a $200\ \Omega$ potentiometer and it was set approximately $60\ \Omega$. The room temperature compensation network was calibrated and set at $22.5\ ^\circ\text{C}$ which corresponded to $0.9\ \text{mV}$ at the output of the potentiometer (see figure 3-12).

The heating control unit was also calibrated for its operation when the switch SW-F was set at "HOLD" position where the temperature of the strip was kept steady. In this mode of operation the integration was disabled.

Table 3-4. Calibration of the HOLD operation.

Set Hold values (V)	Measured values	
	SW-F at Hold	SW-F at Heating rate
2	2.0	2.0
4	4.0	3.9
6	6.1	6.2
8	8.2	8.1
10	10.0	10.0

3.2.3 The Temperature Calibration for the in Heating Cycle

In a normal heating cycle, the strip temperature started at about $25\ ^\circ\text{C}$ and went up to $500\ ^\circ\text{C}$. We calibrated the equipment by "trial and error" method working at the initial temperatures of $0\ ^\circ\text{C}$ and also of $25\ ^\circ\text{C}$ and adjusting various control parameters for consistency. Besides, we also checked for the

validity of the calibration by checking the boiling of drops of water on the strip; they boiled at ~100 °C, within measurement errors.

Table 3-5. The results of the temperature calibration for the heating cycle.

Initial temperature at 0 °C						
Signal output from a vertical-axis of graph ; figure 3-12(mV)					Final temperature (°C)	
Calculated value	Measured value			Mean	Calculated value	Measured value
20	20	20.1	20.1	20.07	500	502
Set initial temperature at 25 °C						
19	19.2	19.2	19.1	19.17	475	479

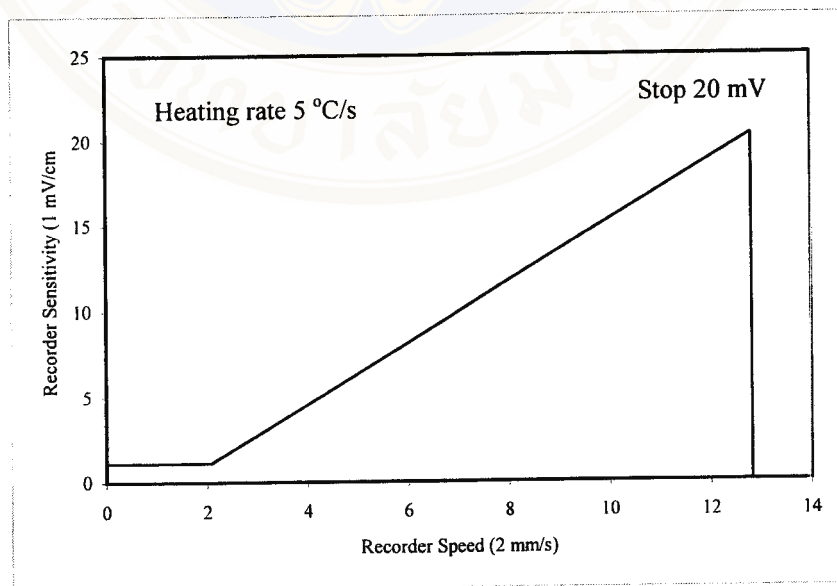


Figure 3-12. The graph of the signal output in a heating cycle.

3.3 Light Detection Unit

3.3.1 Choices of Photomultiplier Tube and Filter

In the study of radioactivity, there are many types of detectors that can be used for measuring exposure to nuclear radiation. In this research, the signal of the emitted light was measured using a EMI 9502B photomultiplier tube (PMT) because of its extremely light sensitivity. Most TL samples display a blue-green (4,5) which is in the region of peak sensitivity for the PMT. The TL light was detected by photomultiplier tube, the signal was then amplified by an electrometer amplifier with a gain range 10^1 - 10^{11} amp and was plotted as a function of temperature on potentiometric chart recorder. For dating, the TL spectra was measured in the visible region. The blue - green filter, having high transmission in the blue green region, was used to eliminate signal due to blackbody radiation from the heater and sample. The choice of PMT and colour filter proved satisfactory.

3.3.2 Sample Chamber and Heater

In this research, the chambers was of cylindrical form with heating strip in the middle. The chamber was completely light tight. An aluminum reflecting light guide was positioned over the strip just above the sample area. Immediately on top of the light guide was placed the blue-green filter. At some distance above the filter was mounted vertically the end-window PMT. The

PMT assembly could be lifted away from the top of the heating chamber in order to facilitate the removal and replacement of the samples.

The stainless steel heating strip was powered by a high current low voltage transformer which was in turn controlled through the thyristor firing unit. The thermocouple wires was spot-welded to the strip just under the sample position. The thermocouple used was of the chromel-alumel type whose output voltages were 1 mV at 25 °C and 20 mV at 500 °C.

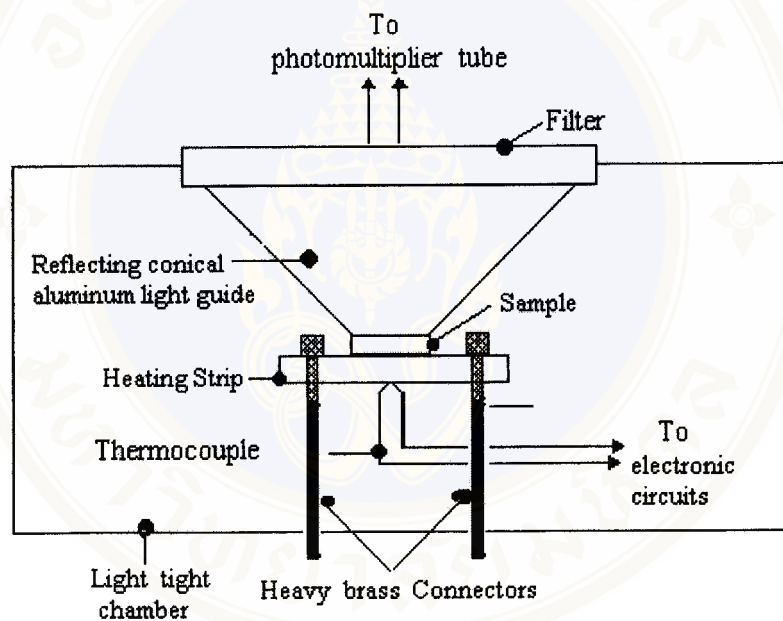


Figure 3-13 Schematic for a sample chamber was mounted in the dark room.

3.4 Signal Recording Unit

The light output from the photomultiplier was amplified with the electrometer amplifier and fed to the Y-axis of recorder. This output was proportional to the thermoluminescence signal. The temperature was measured by a chromel-alumel thermocouple and could be fed to the X-axis of the recorder. The internal TIMEBASE of the recorder may be used in place of the thermocouple output. Typical “glow curves” taken with the equipment are shown in figure 3-14.

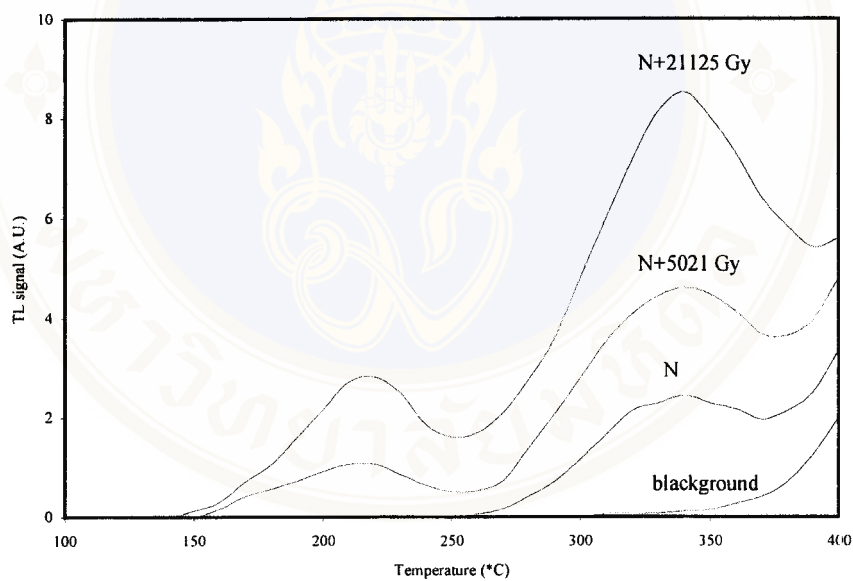


Figure 3-14. Glow curves of the layered tektite from Ubon Ratchathani Province, Thailand.

CHAPTER IV

THE CALIBRATION OF THE TL EQUIPMENT

The calibration was divided into the following two stages:

- 4.1 Calibration of the heating rates
- 4.2 Calibration of the pen-recorder and synchronization.

4.1 Calibration of the Heating Rates

4.1.1 Observation the Water Boiling on a Heating Strip

A water drop was placed on a heating strip, and it boiled when the voltage ramp reached ~2.0 volts for which was taken to correspond to a temperature of ~100 °C and was regarded as a check point.

4.1.2 Tests Run with other Thermoluminescence Equipment and TL Samples

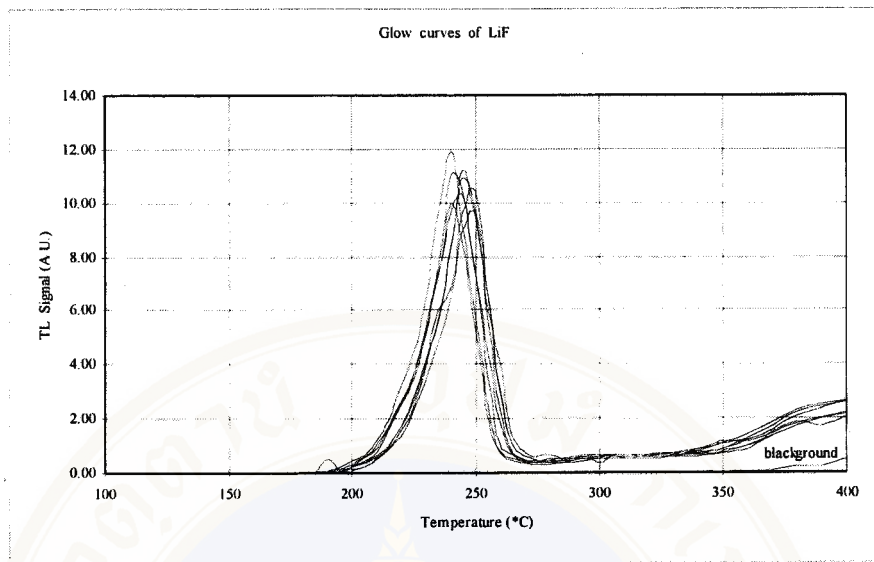
The glow curves of standard TL dosimeter discs of LiF were taken and compared with those obtained using the commercial instrument in the Research Laboratory of the Department of Mineral Resources and the Department of Medical Science (Model QS 3500-HARSHAW). In this research, we will refer to our equipment by “MU”, the equipment in the Department of Mineral Resources by “DMR” and the Model QS 3500-HARSHAW) by “QS-3500”.

We used LiF. LiF was used in the form of disc, diameter of about 0.5 cm. Experimental study of TL glow structure of LiF was divided into two steps.

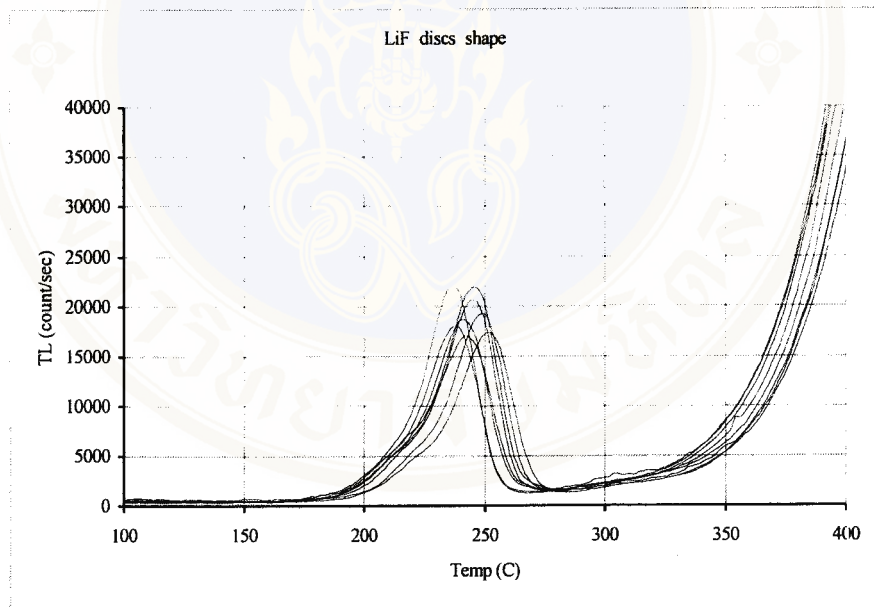
1. study of TL glow structure of LiF and the TL samples.
2. study of TL glow structure of an artificial doses imparted to LiF.

4.1.2.1 TL Glow Structure of LiF and the TL samples

Glow curves of ten selected LiF samples and of three a variety of natural TL samples were taken from two different pieces of equipment “MU”, “DMR”. Figure 4-1 shows typical glow curves of LiF, similar glow structures have been obtained in figure 4-1a and 4-1b. The average values of temperature of the main peak are 246 ± 1 °C and 245 °C for equipment No. “MU” and “DMR”, respectively. In figure 4-2 are shown a typical glow curves of the samples and summarized in table 4-1. These curves obtained after subtraction of background by a second run of the sample.

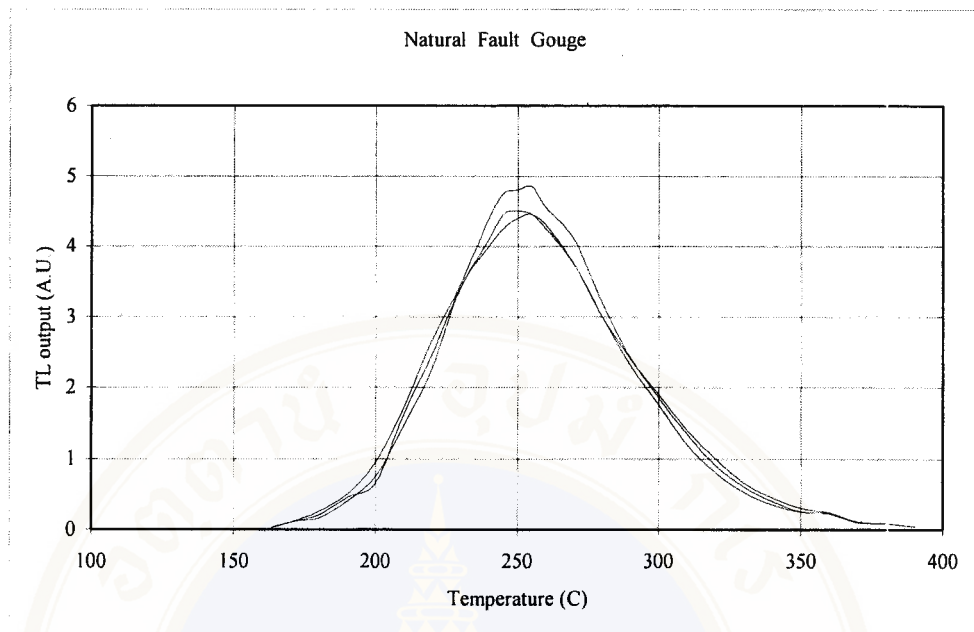


(a)

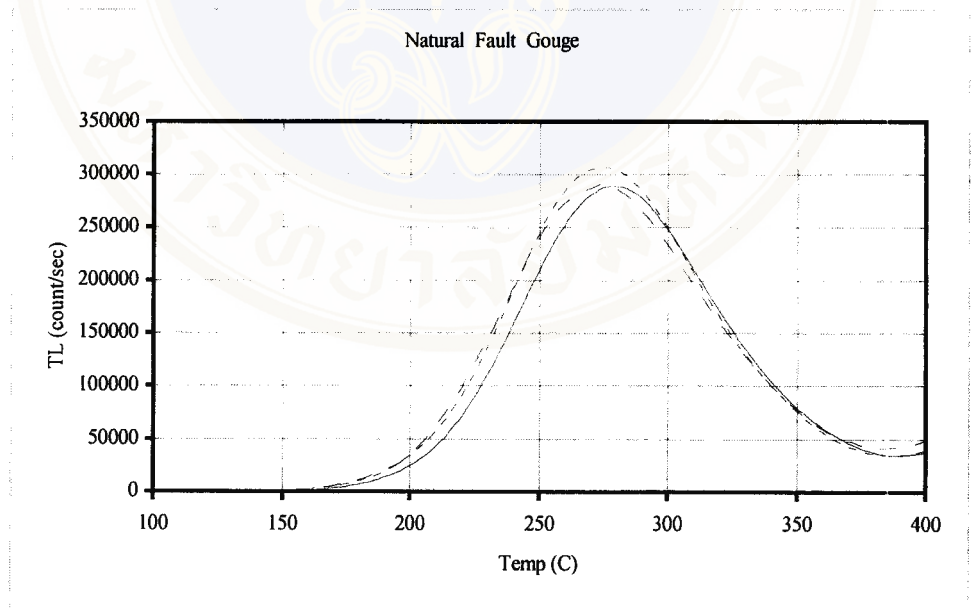


(b)

Figure 4-1. The glow curves of LiF (a) taken from “MU” (b) taken from “DMR”



(a)



(b)

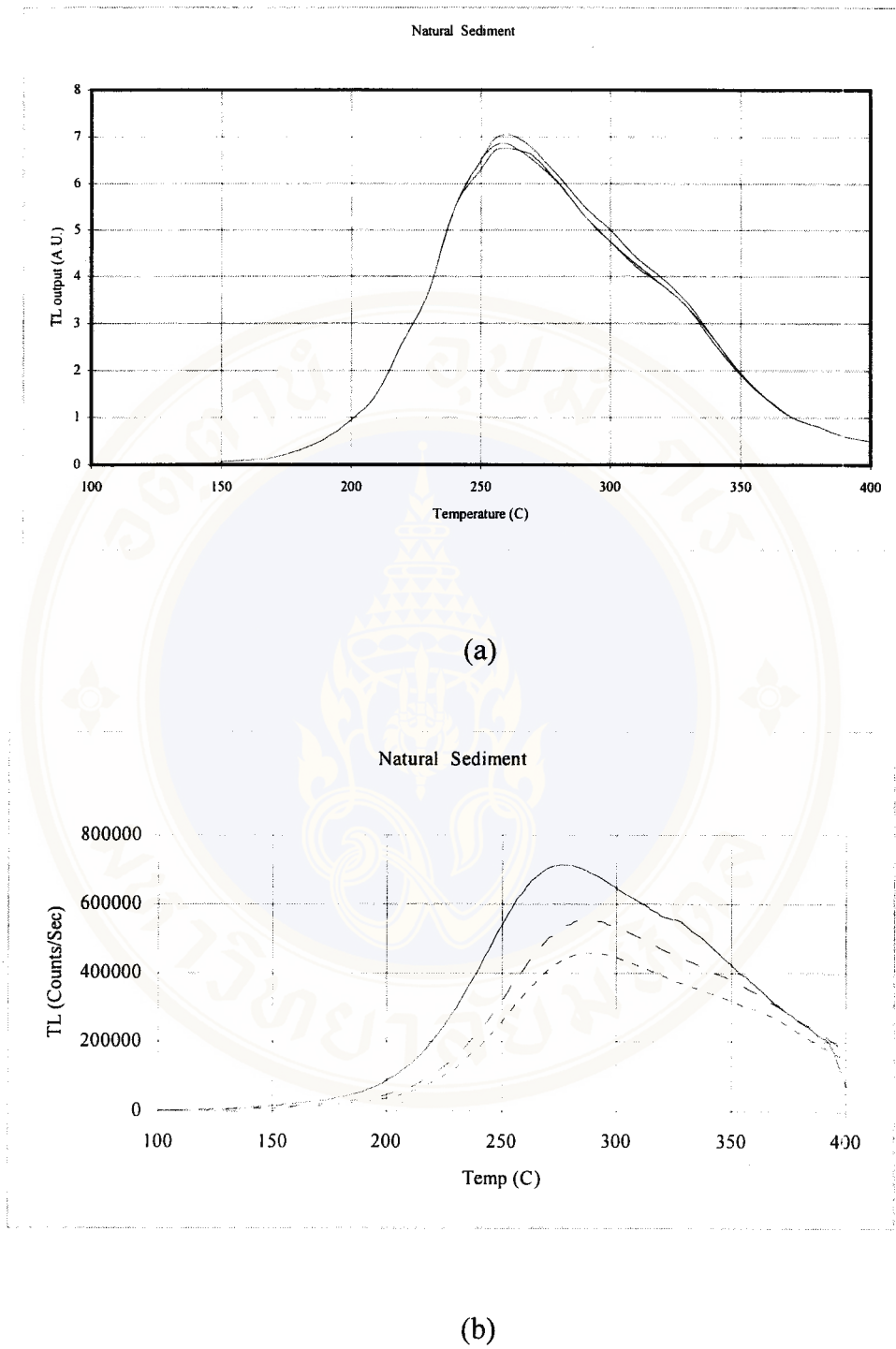


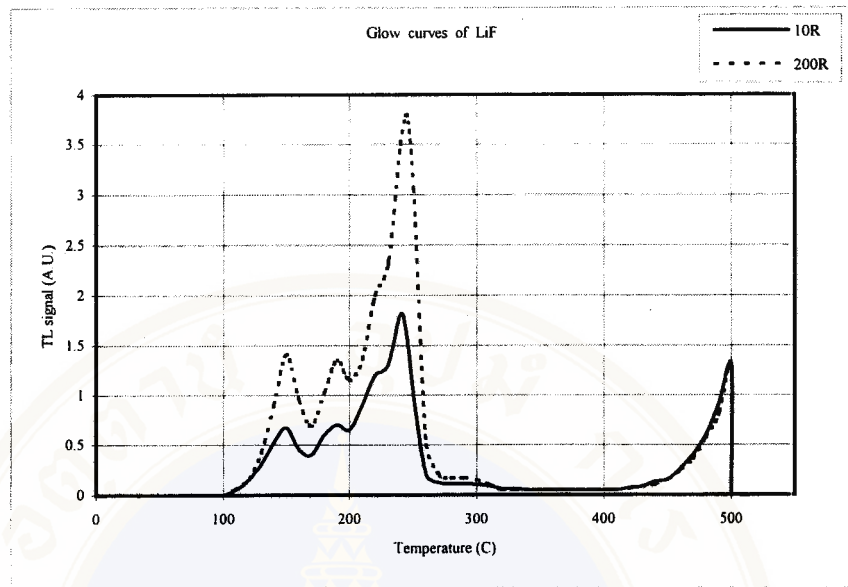
Figure 4-2. Typical glow curves of TL samples, (a) the glow curves obtained from “MU” and (b) the glow curves obtained from “DMR”.

Table 4-1. Summarization the gained results of a TL sample from run with a different equipment that containing 1 peak.

Natural Sample	Peak temperature (°C)	
	TL equipment No. "MU"	TL equipment No. "DMR"
Fault gouge	255±2	275
Sediment	260±1	278
LiF	246±1	245

4.1.2.2 TL Glow Structure of an Artificial Doses Imparted to LiF

LiF discs were annealed at 500oC for 100 sec. These LiF were irradiated for a 32.67 R/min from Co-60 source which had been calibrated for γ -ray doses. The artificial doses range between 10R and 200R. A typical TL glow structure contains 4 peaks as shown in figure 4-2.



(a)

(b)

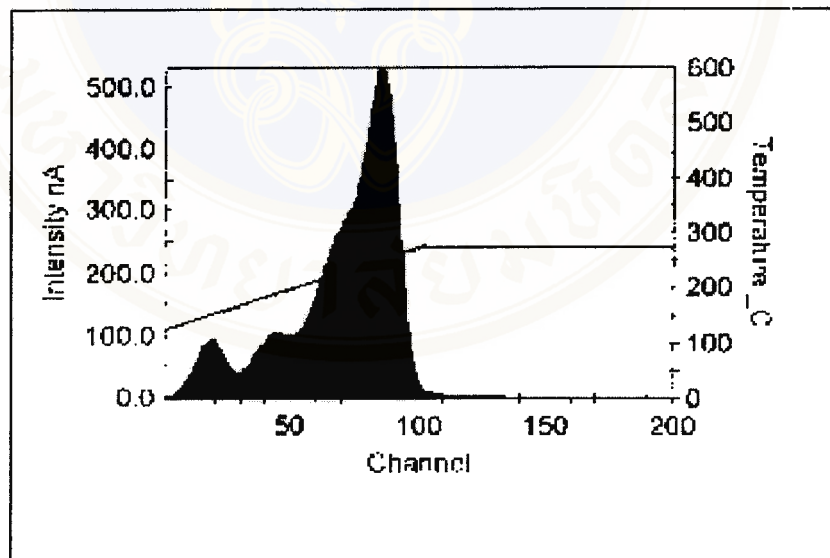


Figure 4-3. The typical glow curves of an artificial doses imparted to LiF

(a) taken from "MU" (b) taken from "QS3500".

Table 4-2 summarizes the results obtained. Peak positions are shown in degrees Celsius. The average values of peak temperature were given together with their error estimates. The third peak is doubtful.

Table 4-2. Summarization of glow peak structure of LiF.

Dose (R)	Peak temperature ($^{\circ}\text{C}$)					
	TL equipment No. "MU"			TL equipment No. "QS 3500"		
	1	2	4	1	2	4
10	148 \pm 2	187 \pm 2	240 \pm 3	156	189	244
50	150 \pm 2	188 \pm 2	243 \pm 3	153	185	240
100	152 \pm 2	190 \pm 2	243 \pm 3	156	200	244
200	150 \pm 2	187 \pm 2	242 \pm 3	154	185	240
Average	150 \pm 2	188 \pm 2	242 \pm 3	155	200	242

4.2 The Calibration of the Pen-Recorder and Synchronization

In this investigation the heating rate can be changed. The heating rates and the pen-recorder speeds were checked and adjusted for synchronization. The results were consistent.

The results are summarized in table 4-3. The values of distance traveled by paper and time required are the weighted mean from ten runs together with their errors.

Table 4-3. The results for different heating rates.

Setting Heating Rate (oC/s)	Experimental values		Calculated values	
	Distance Recorder (cm)	Time Recorder (s)	Distance Recorder (cm)	Time Recorder(s)
5	20.2±0.07	101±0.8	20.0	100
10	9.9±0.07	49±0.3	10.0	50
15	6.5±0.03	32±0.5	6.6	33
20	4.9±0.06	25±0.8	5.0	25
25	3.9±0.05	20±0.6	4.0	20

CHAPTER V

THERMOLUMINESCENCE DATING IN TEKTITES

Tektites are pieces of a natural glass, usually black color but sometimes green, brown or gray tone. The distribution of tektites occurs only in restricted regions. The ages of tektites in each regions are different, as shown in Table 5-1.

Table 5-1. K/Ar and fission-track ages of tektites strewn fields.

Materials	K/Ar ($\times 10^6$ years)	Fission-track ($\times 10^6$ years)
Australites	0.72 ± 0.06	0.70 ± 0.10
Indochinites	0.73 ± 0.06	-
Philippinites	0.70 ± 0.04	-
Thailandites	0.72 ± 0.06	0.70 ± 0.04
Moldavites	14.70 ± 0.70	14.10 ± 0.60
North American tektites	34.20	36.40 ± 1.50

Since the age of tektites are a very interesting and controversial subject. There are several methods for dating the terrestrial age of tektites such as K/Ar measurements and fission-track analysis. O'Keefe (23) concluded that the terrestrial age of tektites estimated from K/Ar measurements and from fission-track

analysis are as listed in Table 5-1. Since the thermoluminescence dating is one method which has been applied to tektites. Durrani (24) estimated the terrestrial age of thailandites to be about 0.56×10^6 years for annual dose of about 5.51 mGy/yr by means of TL dating. He concluded that the age obtained by this method is in fair agreement with the K/Ar and fission-track ages of thailandites.

In this research, the thermoluminescence apparatus was constructed for measurement of the terrestrial age of tektite from Ubon Ratchathani Province, Thailand.

1. Layered tektite is labeled the sample number by TK-L
2. Splash tektite is labeled the sample number by TK-S

5.1 Sample Preparation

1. Samples No. TK-L and TK-S were crushed using a wooden mortar to a grain size less than 200 mesh (0.075 mm) by sieving.

2. A crushed samples No. TK-L and TK-S weighing 7.44 g and 8.33 g respectively were weighed for water content.

3. Samples were washed in water and were later dried in the oven for about 24 hr. at 55 °C.

4. Samples were put in capsules and then exposed to a Co-60 source. A Co-60 source was employed as the gamma ray source, with the activity of 8.8 kilocurie. Irradiation dose rate were about 2 Gy/sec.

5.2 TL Measurement

The constructed TL apparatus employed for the measurement of both natural (N) and irradiated samples (N+ γ) of No. TK-L and TK-S. This equipment consists of a dark chamber containing a heating strip that can be heated up at a uniform rate under the control of a heating control unit. The operating conditions employed are

- Weight of sample ; 5 mg
- Heating rate ; 5 °C/s
- Amplifier current ; 10^{-10} Amp.
- Recorder speed ; 2 mm/s
- Recorder sensitivity ; 2.5 V/cm
- Blue-Green filter ; O.B.-10

The temperature of the sample was measured by means of a thermocouple spot-welded directly underneath the heating strip. The sample powder was spread uniformly over an area about 0.2 cm² located at the center of the strip and surrounded by an aluminum reflecting cone. The top of the Al cone was covered by a blue-green filter. When the sample was heated, the TL output was measured by PMT. The PMT signal was amplified by an electrometer device whose output was connected to the Y-axis of a chart recorder while the temperature was recorded along X-axis of the same recorder. TL signal versus temperature curve was thus obtained.

The heating cycle extended from ~25 °C to ~500 °C. All heating was performed in a normal air. After completing the first heating cycle, a second cycle was measured a few minutes later. This second run enabled us to subtract

the black-ground and blackbody radiation contributions. Figure 5-1 show typical glow curves for the sample No. TK- L and TK-S. Curve 1, 2, 3, 4 and 5 is the natural TL, the natural TL plus a 5021 Gy, 10245 Gy, 15458 Gy and 21125 Gy, respectively.



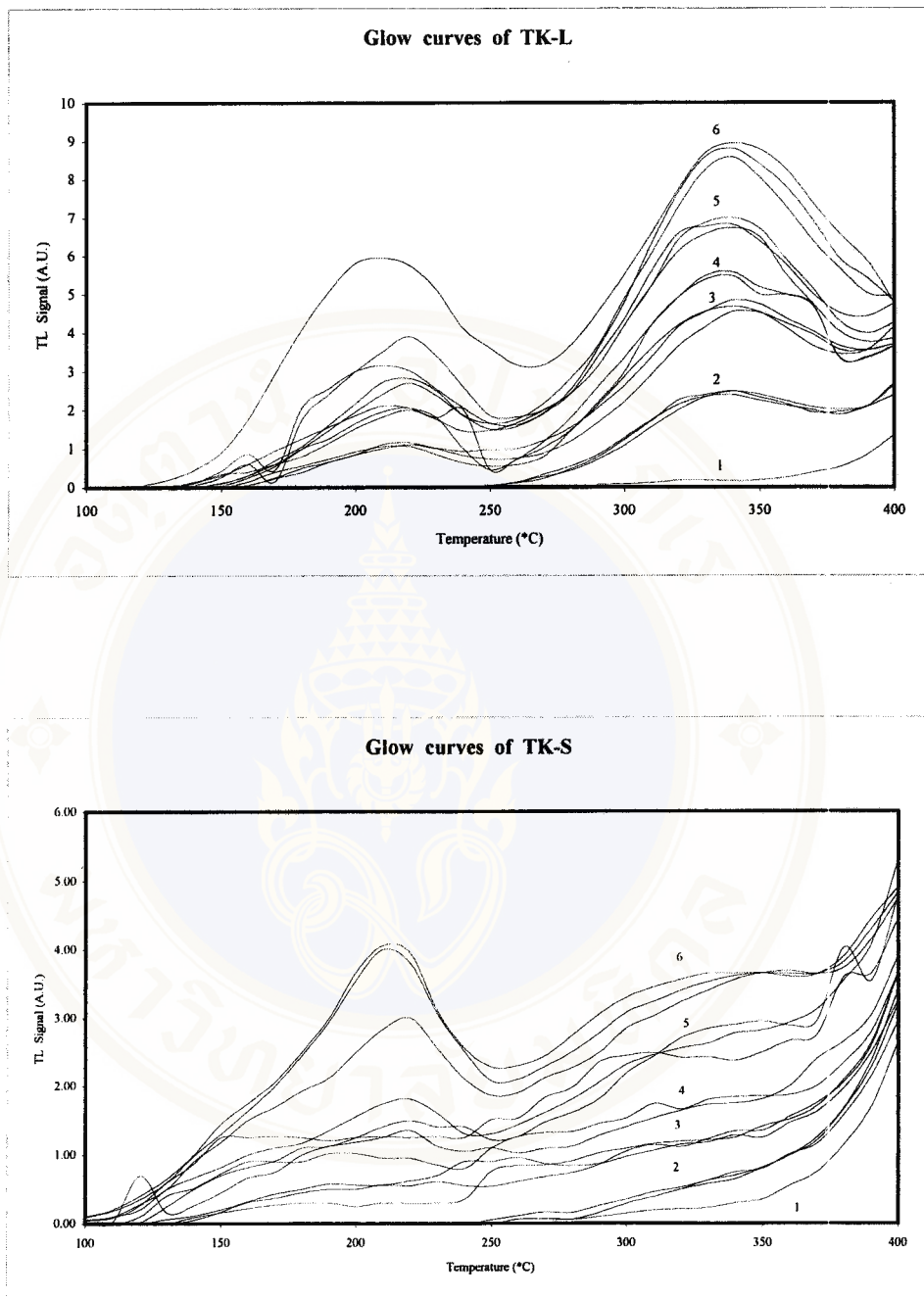


Figure 5-1. TL glow curves of sample No. TK-L and TK-S (1 = background ,
 2 = natural;N , 3 = N+5021 Gy , 4 = N+10245 Gy , 5 = N+15458 Gy and
 6 = N+21125 Gy)

5.3 Determination of the TL Age

The TL age of tektites were evaluated by the equation 4. After a natural samples (N) and irradiated natural samples (N+irradiation dose) were read for TL signals. The obtained glow curves were subjected to the plateau test as indicated in Figure 5-2. In this figure, the vertical axis is the ratios of peak height of natural to irradiated samples

The determination of paleodose used high temperature peak glow area of TL glow curve. On examining the glow area between 340 – 350 °C for sample No. TK-L and 330-340 °C for sample No. TK-S natural doses were estimated to be 3300 ± 178 Gy and 2775 ± 416 Gy, respectively. Figure 5-3 shows the TL growth curves of the sample No. TK-L and TK-S. In this figure, the vertical axis is the ratio of glow area of irradiated to natural samples.

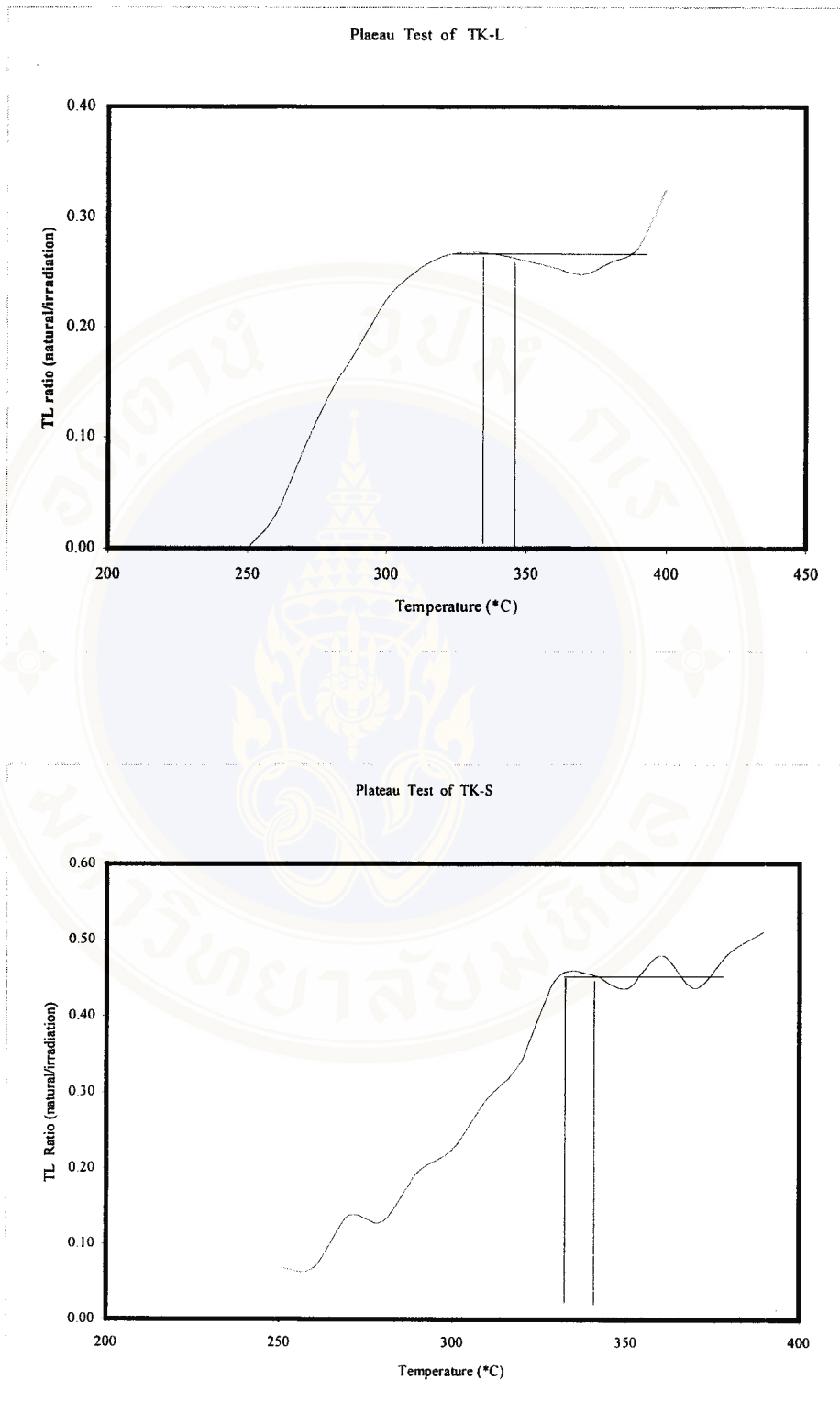


Figure 5-2. Plateau test of sample NO. TK-L and TK-S.

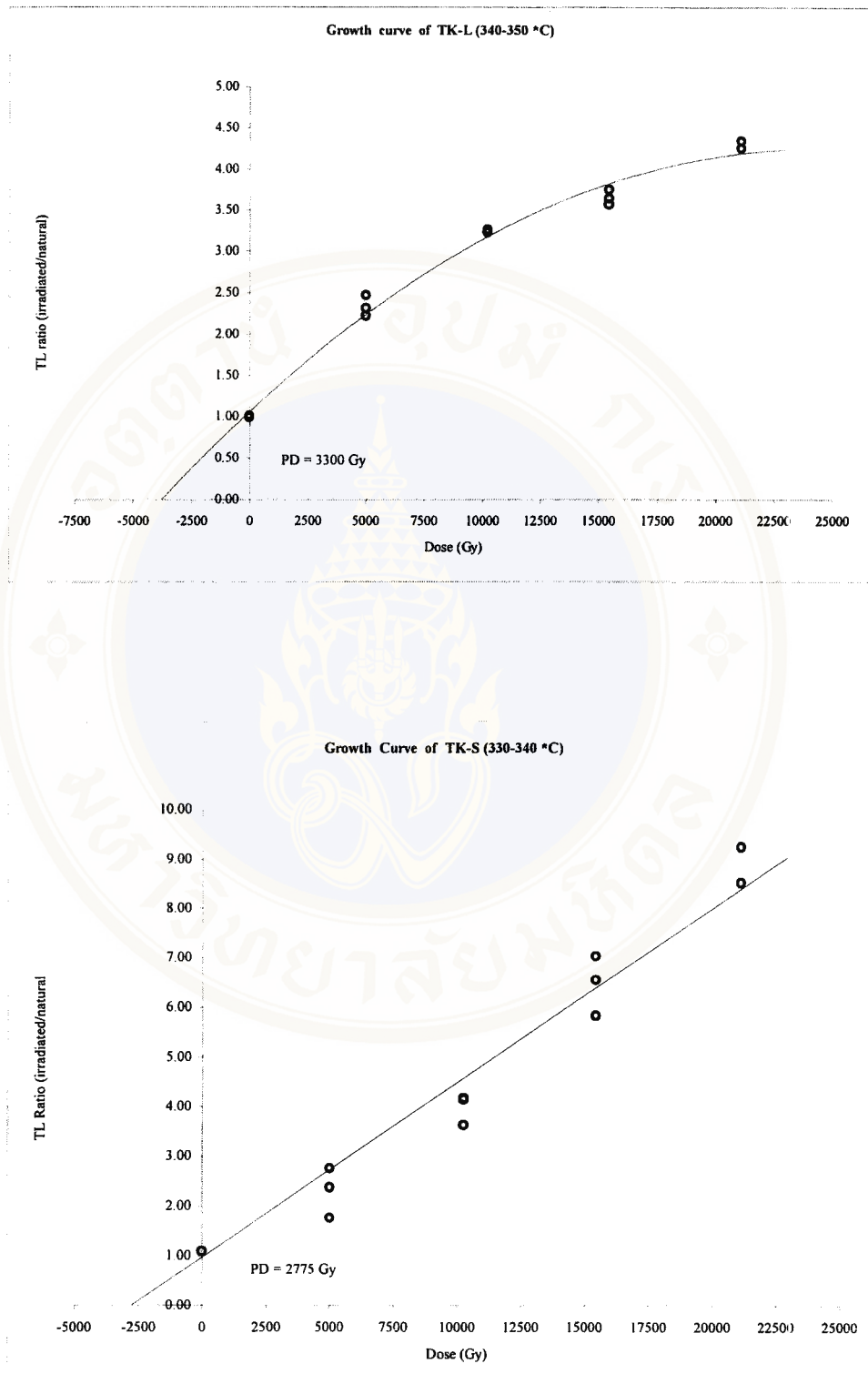
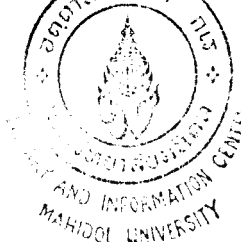


Figure 5-3. TL growth curve of the sample No. TK-L and TK-S.



The annual dose was evaluated from the uranium (U), thorium (Th) and potassium (K) content by using Bell's conversion factor and Aitken (5). In this research, these radioelement contents were measured by gamma ray spectrometry at Akita University Japan, as shown in Table 5-2. This table shows the annual doses for the known values of U, Th and K contents.

Alternatively, the U, Th and K contents can be carried out by using X-ray fluorescence and neutron activation analysis (8).

Table 5-2. The U, Th and K content of tektites from northeastern Thailand and annual dose values.

Techniques	Concentrations of the radioelement			Annual dose (mGy/yr)
	U (ppm)	Th (ppm)	K (%)	
X-ray fluorescence	2.3±0.4	12.7±0.6	1.28±0.02	4.73
neutron activation analysis	2.6±0.3	15.0±2.0	2.42±0.65	6.23
Gamma ray spectrometry	2.41	10.84	2.06	5.11±0.51

In this research, an annual dose were calculated by the equation (5) to be about 5.11±0.51 mGy/yr for the water content of about 8.93% for the sample tektites. The water content was evaluated from the ratios of weight of water to dry weight. The above calculation was carried out on the assumption that there was no radon loss and used the average value for the efficiency of alpha

particle in producing TL as 0.15 (3,5) and the cosmic radiation as 0.15 mGy/yr (1,3,5). The results of TL age of tektites are shown in Table 5-3.

Table 5-3 . TL - dating results of tektites.

Sample No.	Annual dose (mGy/yr.)	Paleodose (Gy)	TL age ($\times 10^6$ yr.)
TK-L	5.11 \pm 0.51	3300 \pm 178	0.65 \pm 0.16
TK-S		2775 \pm 416	0.54 \pm 0.10

CHAPTER VI

DISCUSSION AND CONCLUSION

The work was sub-divided into two parts. Part I was the construction of the TL equipment. Part II was to use it in the measurement of the terrestrial age of tektites.

6.1 TL Equipment

A home-made TL equipment was designed and constructed. It had a variable heating rate and, could accommodate samples of various forms and sizes, down to 1 cm in diameter. The equipment used separate high voltage supply, electrometer and recorder. The heating covered the range of ~ 25 °C to ~ 500 °C and the heating was performed in a normal air. After completing the first heating run, a second run followed few minutes later. This second run enabled us to subtract the black-ground and blackbody radiation from the first run. Representative glow curves from various samples are shown in figure 4-3 and 5-1. These curves were reproducible.

The 9502B photomultiplier tube used in the equipment had low dark current. The photomultiplier tube was positioned close to the sample in order to collect as much light as possible. Blue-green filter was used to suppress signals due to blackbody radiation from heater and sample.

The heating control circuits was adjusted until its properly work. The controller performed satisfactorily. The equipment compared very well with the commercial model used by other groups of researchers.

This equipment was then employed for the measurement of TL in tektites as described in chapter V. The dating results obtained were in agreement with the known geological ages using K/Ar measurement and fission track analysis.

6.2 The Terrestrial Age of Tektites

TL-dating method is based on the phenomenon that natural ionizing radiations can cause electrons to be trapped in trapping sites due to defects of the mineral's crystal lattice. These trapped electrons can be freed by heating, and subsequent de-excitation gives rise to TL emission. Tektites are pieces of natural glass. It was found in northeastern Thailand (8). Since tektites are made of a glassy material, which were once melted at a high temperature, the clock were then set to zero. The amount of TL is proportional to the time that has elapsed. For this reason, the TL technique can be used to establish the terrestrial age. The TL age of tektites were evaluated by the ratios of the paleodose to the annual dose.

To evaluate the annual dose, the concentration of uranium, thorium and potassium in the tektites was determined by gamma spectrometry. The cosmic radiation contribution of about 0.15 mGy/yr was quoted by Aithen (5). An annual dose was calculated to be about 5.11 ± 0.51 mGy/yr. This value is in good agreement with the value 5.51 mGy/yr obtained by Darrani (24) and 4.73 and 6.03 mGy/yr obtained by a direct measurement at the burial site (8).

Paleodose was evaluated from the growth curve by extrapolating the growth curve of the TL backwards to the dose axis. The amount of the natural dose accumulated since the initializing event until the TL readout can be obtained as the paleodose. The paleodose values 3300 ± 178 Gy and 2775 ± 416 Gy for layered and splash tektites, respectively. The estimated the terrestrial ages of layered and splash tektites were found to be about 0.65 ± 0.16 million years and 0.54 ± 0.10 million years, respectively.

The results of TL ages of tektites obtained by TL-dating technique were in fair agreement with the K/Ar and fission track ages of Australasian region (23). A number of problems for age determination may be mentioned, namely, the impurity in the powder sample causing serious TL, lack of knowledge of annealing history of the samples, the accurate value of TL producing efficiency of alpha particles, nonlinearly of the dose response curves, lack of accuracy of the estimation of the annual dose due to lack of precise determination of the internal and external radiation dose-rates. A more careful analysis of individual glow peaks by employing narrow band optical filters and the calibration of the laboratory irradiation are required.

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APPENDIX A

Thermoluminescence of Tektites

Heating rate	:	5 °C/s
Recorder speed	:	2 mm/s
Recorder sensitivity	:	5 V/cm
High voltage	:	1000 V
Filter	:	O.B. 10
Powder grain sizes	:	less than 0.075 mm
Sample amount	:	5.0±0.05 mg

Description	:	
1	:	background
2	:	“natural, N”
3	:	N+5021 Gy
4	:	N+10245 Gy
5	:	N+15458 Gy
6	:	N+21125 Gy

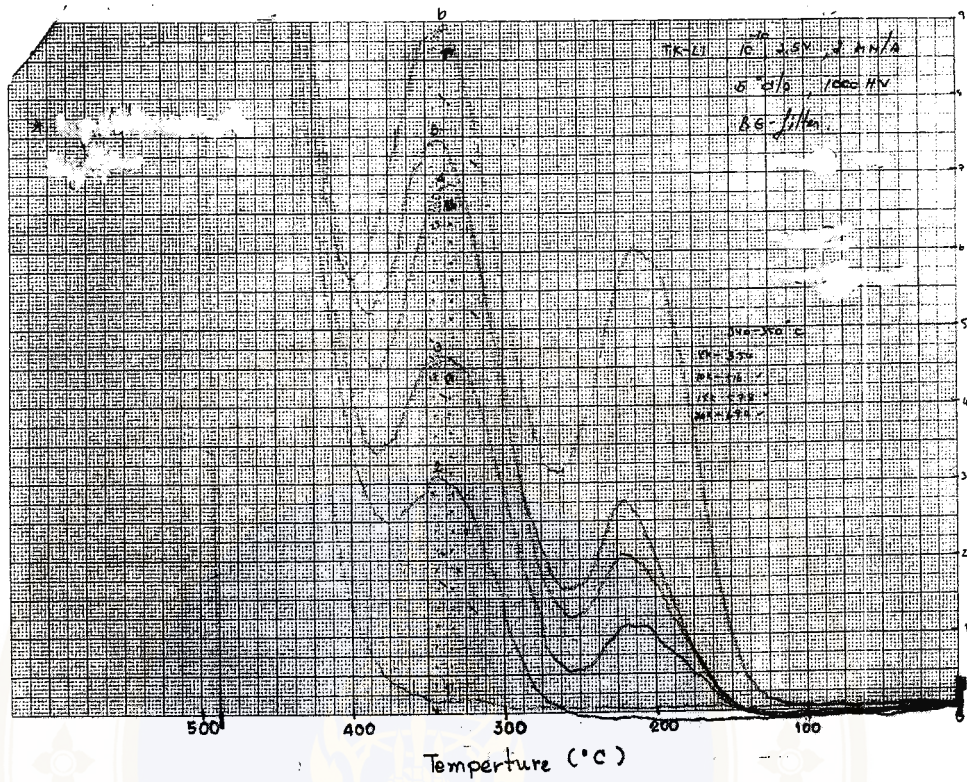


Figure A-1. The original of glow curves of sample NO. TK-S

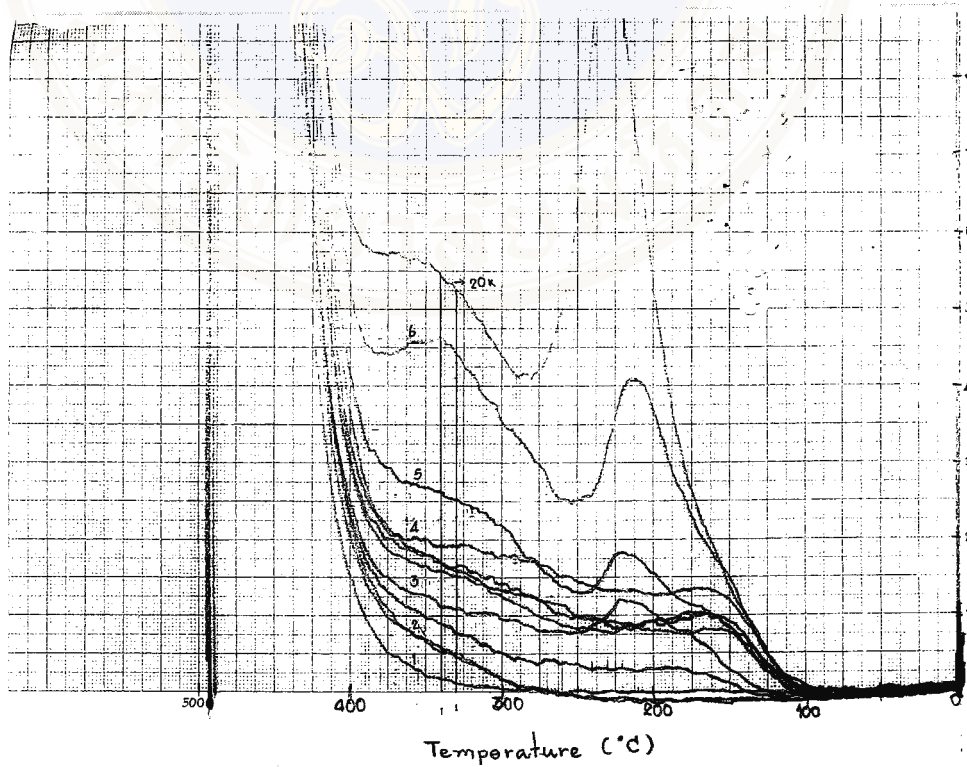
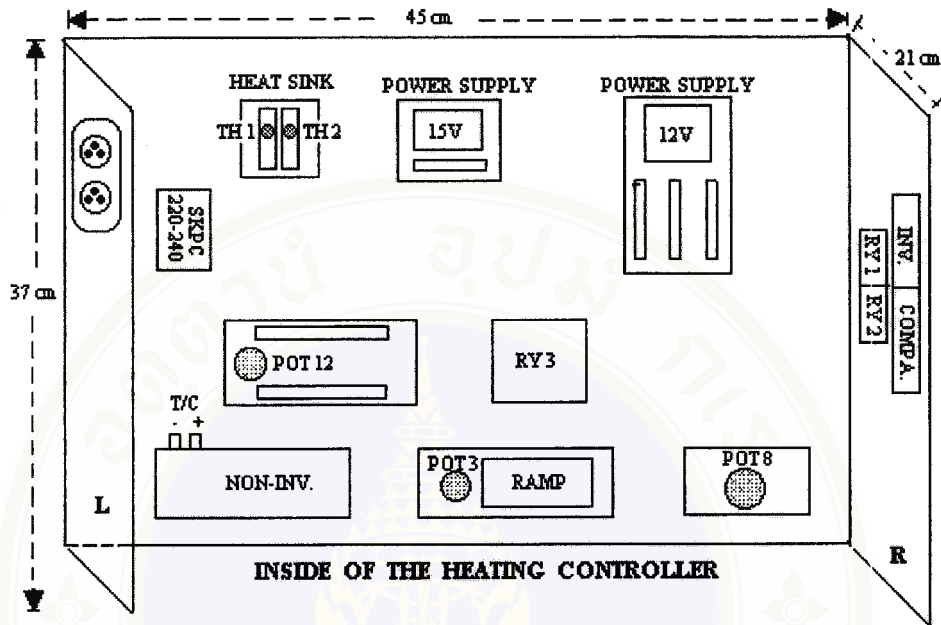
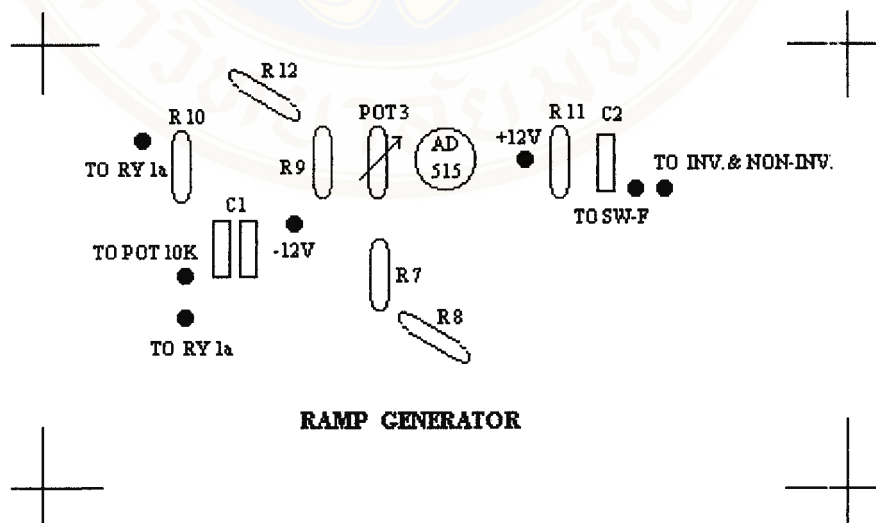


Figure A-2. The original of glow curves of sample NO. TK-L

APPENDIX B



(a)



(b)

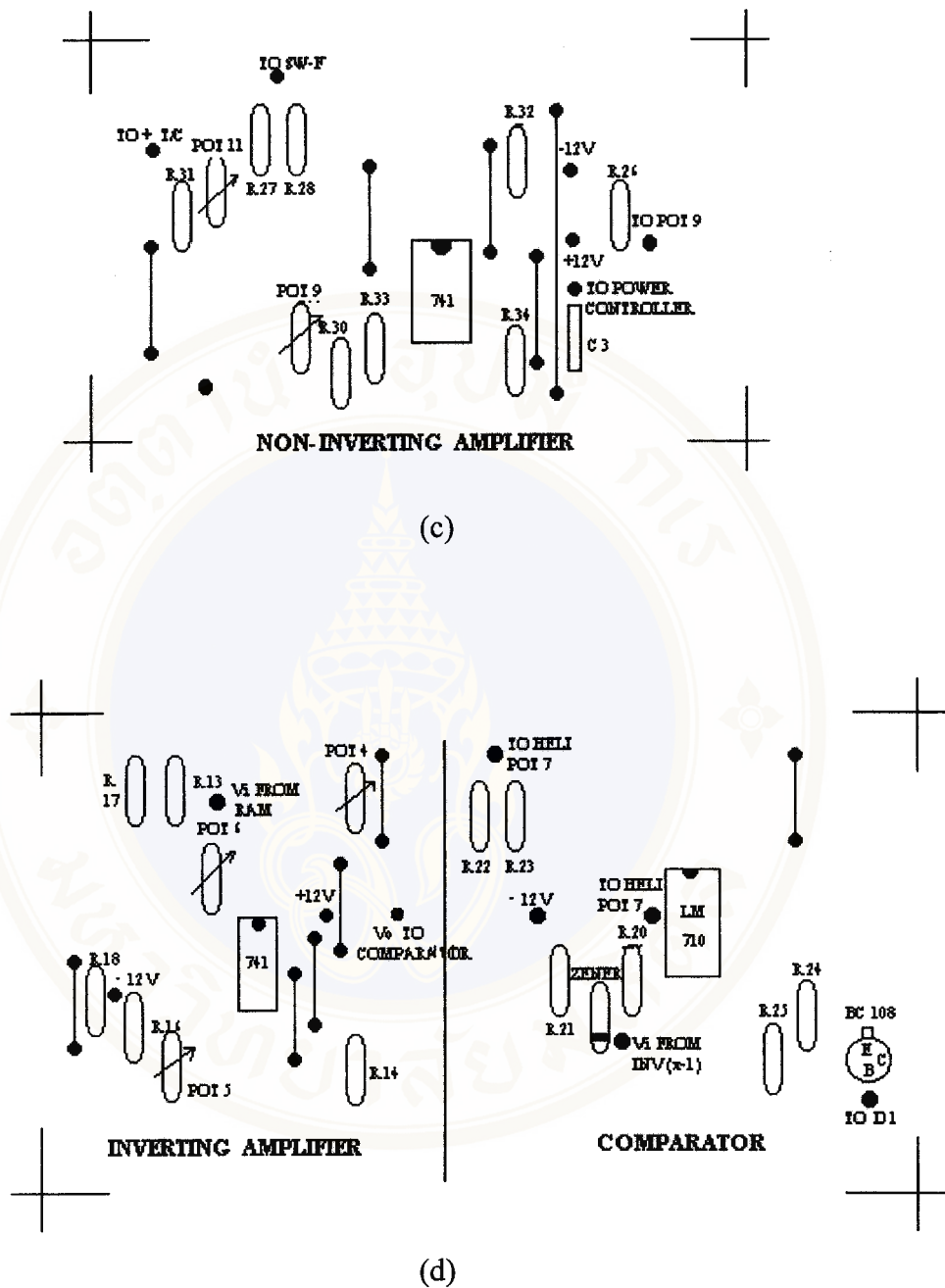


Figure B-1. The characteristic of the heating controller in this research

(a) the position of each component inside of the heating

controller (b-d) the position of the electronic device in circuits.



**Precision, Low-Power
FET-Input Electrometer Op Amp
AD515**

PRELIMINARY TECHNICAL DATA

FEATURES

Ultra Low Bias Current : 0.075 pA max (AD515L)
0.150 pA max (AD515K)
0.300 pA max (AD515J)

Low Power : 1.2 mA max Quiescent Current
(0.8 mA typ)

Low Offset Voltage : 1.0 mV max (AD515 K&L)

Low Drift : 15 μ V/ $^{\circ}$ C max (AD515K)

Low Noise : 4 μ V p-p, 0.1 to 10 Hz

PRODUCT DESCRIPTION

The AD515 series of FET-input operational amplifiers are second generation electrometer designs offering the lower input bias currents available in any standard operational amplifier. The AD515 also delivers laser-trimmed offset voltage, low drift, low noise and low power, a combination of features not previously available in ultra-low bias current circuits. All devices are internally compensated, free of latch-up, and short circuit protected.

The AD515 delivers a new level of versatility and precision to a wide variety of electrometer and high impedance buffer measurement situation, including photo-current detection, vacuum ion-gauge measurement, long term precision integration, and low drift sample/hold application. The device is also an excellent choice for all forms of biomedical instrumentation such as pH/pIon sensitive electrodes, very low current oxygen sensors, and high impedance biological microprobes. In addition, the low cost and pin compatibility of the AD515 with standard FET op amps will allow designers to upgrade the performance of present systems at little or no additional cost. The 10^{15} ohm common mode input impedance, resulting from a solid bootstrap input stage, insures that the input bias current is essentially independent of common mode voltage.

SPECIFICATIONS (typical @ +25 °C with $V_s = \pm 15\text{VDC}$, unless otherwise specified)

MODEL	AD515J	AD515K	AD515L
OPEN LOOP GAIN $V_{out} = \pm 10\text{V}$, $R_L \geq 2\text{k}\Omega$ $R_L \geq 10\text{k}\Omega$ $T_A = \text{min to max}$, $R_L \geq 2\text{k}\Omega$	20,000V/V min 40,000V/V min 15,000V/V min	40,000V/V min 10,000V/V min 40,000V/V min	25,000V/V min 50,000V/V min 25,000V/V min
OUTPUT CHARACTERISTICS Voltage @ $R_L = 2\text{k}\Omega$, $T_A = \text{min to max}$ @ $R_L = 2\text{k}\Omega$, $T_A = \text{min to max}$ Load Capacitance Shot Circuit Current	$\pm 10\text{V}$ min ($\pm 12\text{V}$ typ) $\pm 12\text{V}$ min ($\pm 13\text{V}$ typ) 100pF 10mA min (25mA)	*	*
FREQUENCY RESPONSE Unity Gain, Small Signal Full Power Response Slew Rate Inverting Unity Gain Overload Recovery Inverting Unity Gain	350kHz 5kHz min (16kHz) 0.3V/ μs min 100V/ μs max	*	*
INPUT OFFSET VOLTAGE vs. Temperature, $T_A = \text{min to max}$ vs. Supply, $T_A = \text{min to max}$	3.0mV max 50 $\mu\text{V}/^\circ\text{C}$ max 400 $\mu\text{V}/\text{V}$ max	1.0mV max 15 $\mu\text{V}/^\circ\text{C}$ max 100 $\mu\text{V}/\text{V}$ max	1.0mV max 25 $\mu\text{V}/^\circ\text{C}$ max 200 $\mu\text{V}/\text{V}$ max
INPUT BIAS CURRENT Either Input	300fA max	150fA max	75fA max
INPUT IMPEDANCE Differential Common Mode	1.6pF 10 ¹³ Ω 0.8pF 10 ¹⁵ Ω	*	*
INPUT NOISE Voltage, 0.1 Hz to 10 Hz f = 10 Hz f = 100 Hz f = 1 kHz Current, 0.1 to 10 Hz 10 Hz to 10 kHz	4.0 μV (p-p) 75nV/ $\sqrt{\text{Hz}}$ 55nV/ $\sqrt{\text{Hz}}$ 50nV/ $\sqrt{\text{Hz}}$ 0.003pA (p-p) 0.01pA rms	*	*
INPUT VOLTAGE RANGE Differential Common Mode, $T_A = \text{min to max}$ Common Mode Rejection, $V_{IN} = \pm 10\text{V}$ Maximum Safe Input Voltage	$\pm 20\text{V}$ min $\pm 10\text{V}$ min 66 dB min $\pm V_s$	*	*
POWER SUPPLY Rated Performance Operating Quiescent Current	$\pm 15\text{V}$ typ $\pm 5\text{V}$ min 1.5mA max	*	*
TEMPERATURE Operating, Rated Performance Storage	0 to +70 $^\circ\text{C}$ -65 $^\circ\text{C}$ to +150 $^\circ\text{C}$	*	*

*Specifications same as AD515J.



Data Library

Power controllers

A range of trigger modules for use in general purpose thyristor drive application.

SKPC 200-240 Phase angle trigger module 658-148

A phase angle trigger module to provide the control signals for an ac load, half controlled B2HZ or a half controlled B2HK single phase bridge eg. SKCH 28/08 262-999.

Features

- Separate 240V ac 10% control supply allowing the load circuit to run on a lower supply voltage
- Output gate drive is short circuit protected
- Will operate on both 50 and 60 Hz supplies
- Built in uncommitted op-amp for closed loop control use if required
- Improved control characteristics
- Low voltage and high voltage terminals with mechanical separation
- Screw terminals for ease of connection

Electrical characteristics Unless otherwise stated : V=240V, 50 Hz T_{AMI} = +20 °C

	Parameter	Condition	Symbol	Limits		Units
				Min.	Typ. Max.	
Reference	Reference output	Terminal 4 to 6	V _{ref}	-4.5	-5.5 +5.25	V
	Current source ability	Terminal 4 to 6	I _{ref}	20		mA
	Short circuit current	Terminal 4 to 6, V _{ref} =0		40		mA
	Load regulation	I _{ref} =0 to 20mA		ΔV _{ref} /ΔI _{ref}		%
	Temperature stability	Terminal 4 to 6		ΔV _{ref} /ΔT		mV/°C
Uncommitted Op Amp	Input voltage range	Terminal 1 or 2	V _{AI}	-10.5	-10.5	V
	Common mode range	Terminal 1 and 2	V _{ACM}	±10		V
	Common mode rejection ratio		CMRR	65	70	dB
	Input offset voltage	Between terminal 1 and 2		±2	±7	mV
	Large signal voltage gain	R _L ≥ 2K between 3 and 6	A _v	25	100	V/mV
	Short circuit current	R _L = 0 between 3 and 6		12		mA
	Output swing	Terminal 3 R _L = 10K		±10		V
Phase Angle Range	Control range maximum	Terminal 5 to 6	V _{IMAX}	+4.5	+5 +5.25	V
	Input threshold	Terminal 5 to 6	V _{ITH}	0.1	0.3 0.6	V
	Input impedance	Terminal 5 to 6	R _I	100K	110K	Ω
	Input filter time constant	Terminal 5 to 6	TC _I	0.5		ms
	Controllable retard angle	V _{IN} = V _{ITH} fop = 45-65 Hz	<F _{MAX}	180		Degrees
	Controllable advance angle	V _{IN} = V _{IMX} fop = 45-65 Hz	<F _{MIN}	0	10	Degrees
Gate Driver	Peak gate circuit	V _S = Max., <F = 90°C	I _{ODRM}	1.9		A
	Short circuit protection time	V _{AF} = V _S , <F = 90°C	T _{0S/C}	250	500	ms
	Rep. Forward voltage withstand	Between 7 and 9	V _{ODRM}	600		V
	Breakover voltage	Between 7 and 9	V _{OBO}	480		V _{rms}
	Rise time (10% to 90%)	V _S = Max., 0 = 90°C	t _{OR}	10		μs
	Offstate leakage current	V _S = Max., V _{IN} = 0 V	I _{OL}	1		A
	Critical rate of rise of off-state voltage	V _{ODRM} = 1/2 Rated	(dv/dt) CR	500		V/μs
	Isolation resistance input to output circuitry	Dc = 500V RH = 40-60%		5x10 ¹⁰	10	Ω
	Typical gate current	<F ₀ = 0	I _o	10 ⁻²		A _{rms+}
	Mismatch of 1/2 cycles firing			0	1 2	degree

APPENDIX C

Table C-1 The data of plateau test of sample TK-L.

Temperature (°C)	N			Mean
	1	2	3	
250	0.00	0.00	0.00	0.00
260	0.06	0.07	0.06	0.06
270	0.15	0.20	0.26	0.20
280	0.40	0.36	0.48	0.41
290	0.70	0.64	0.76	0.70
300	1.15	1.00	1.20	1.12
310	1.60	1.44	1.62	1.55
320	2.08	1.82	1.96	1.95
330	2.21	2.15	2.17	2.18
340	2.32	2.31	2.22	2.28
350	2.14	2.22	2.06	2.14
360	1.90	1.97	1.86	1.91
370	1.55	1.69	1.61	1.62
380	1.43	1.50	1.36	1.43
390	1.25	1.25	1.23	1.24
400	1.35	1.30	1.04	1.23

Temperature (°C)	N+5021 Gy			Mean
	1	2	3	
250	0.50	0.68	0.93	0.70
260	0.52	0.69	0.94	0.72
270	0.72	0.81	1.13	0.89
280	1.38	1.12	1.47	1.32
290	2.05	1.60	1.97	1.87
300	2.78	2.13	2.55	2.49
310	3.48	2.80	3.25	3.18
320	4.02	3.48	3.98	3.83
330	4.37	3.97	4.35	4.23
340	4.50	4.37	4.67	4.51
350	4.34	4.33	4.55	4.41
360	3.87	3.98	4.11	3.99
370	3.27	3.57	3.65	3.50
380	2.93	3.03	3.13	3.03
390	2.71	2.70	2.70	2.70
400	2.80	2.35	2.35	2.50

Temperature (°C)	N+10245 Gy			Mean
	1	2	3	
250	0.40	0.40	0.50	0.43
260	0.65	0.65	0.68	0.66
270	0.95	1.10	0.94	1.00
280	1.40	1.72	1.13	1.42
290	2.11	2.52	1.42	2.02
300	2.90	3.27	1.92	2.70
310	4.08	4.08	2.55	3.57
320	4.74	4.74	4.00	4.49
330	5.20	5.30	4.18	4.89
340	5.30	5.40	4.85	5.18
350	4.81	5.00	5.25	5.02
360	4.73	4.73	5.52	4.99
370	4.30	4.30	5.28	4.63
380	2.80	2.82	5.10	3.57
390	2.52	2.50	4.03	3.02
400	2.30	2.30	3.40	2.67

Temperature (°C)	N+15458 Gy			Mean
	1	2	3	
250	1.80	1.60	1.45	1.62
260	1.75	1.55	1.60	1.63
270	1.92	1.83	1.92	1.89
280	2.35	2.35	2.35	2.35
290	3.05	3.30	3.05	3.13
300	4.10	4.27	4.10	4.16
310	5.10	5.48	5.40	5.33
320	5.95	6.42	5.95	6.11
330	6.68	6.58	6.39	6.55
340	6.83	6.65	6.56	6.68
350	6.53	6.20	6.31	6.35
360	5.64	5.50	5.24	5.46
370	4.75	4.62	4.35	4.57
380	3.75	3.98	3.50	3.74
390	3.13	3.57	2.91	3.20
400	2.90	3.40	2.50	2.93

Temperature (°C)	N+21125 Gy			Mean
	1	2	3	
250	1.60	3.55	1.42	2.19
260	1.69	3.10	1.50	2.10
270	2.09	3.09	1.85	2.34
280	2.75	3.6	2.45	2.93
290	3.57	4.45	3.50	3.84
300	4.80	5.42	4.70	4.97
310	6.25	6.48	6.21	6.31
320	7.11	7.57	7.49	7.39
330	8.07	8.50	8.40	8.32
340	8.40	8.77	8.63	8.60
350	7.87	8.60	8.21	8.23
360	7.03	8.00	7.54	7.52
370	6.00	7.00	6.54	6.51
380	5.13	6.03	5.39	5.52
390	4.16	5.00	4.55	4.57
400	3.60	4.30	3.44	3.78

Table C-2. The results of the ratio of the height peak natural to irradiated samples of the sample TK-L.

Temperature (°C)	Mean values					TL ratio (N/N+γ)			
	N	N+5021 Gy	N+10245 Gy	N+15458 Gy	N+21125 Gy	1	2	3	4
250	0.00	0.70	0.43	1.62	2.19	0.00	0.00	0.00	0.00
260	0.06	0.72	0.66	1.63	2.10	0.09	0.09	0.04	0.03
270	0.20	0.89	1.00	1.89	2.34	0.23	0.20	0.11	0.09
280	0.41	1.32	1.42	2.35	2.93	0.31	0.29	0.18	0.14
290	0.70	1.87	2.02	3.13	3.84	0.37	0.35	0.22	0.18
300	1.12	2.49	2.70	4.16	4.97	0.45	0.41	0.27	0.22
310	1.55	3.18	3.57	5.33	6.31	0.49	0.43	0.29	0.25
320	1.95	3.83	4.49	6.11	7.39	0.51	0.43	0.32	0.26
330	2.18	4.23	4.89	6.55	8.32	0.51	0.45	0.33	0.27
340	2.28	4.51	5.18	6.68	8.60	0.51	0.44	0.34	0.27
350	2.14	4.41	5.02	6.35	8.23	0.49	0.43	0.34	0.26
360	1.91	3.99	4.99	5.46	7.52	0.48	0.38	0.35	0.25
370	1.62	3.50	4.63	4.57	6.51	0.46	0.35	0.35	0.25
380	1.43	3.03	3.57	3.74	5.52	0.47	0.40	0.38	0.26
390	1.24	2.70	3.02	3.20	4.57	0.46	0.41	0.36	0.27
400	1.23	2.50	2.67	2.93	3.78	0.49	0.46	0.38	0.33

Table C-3. The data of plateau test of sample TK-S.

Temperature (°C)	N			Mean
	1	2	3	
250	0.00	0.00	0.05	0.02
260	0.00	0.00	0.05	0.02
270	0.00	0.00	0.10	0.03
280	0.00	0.00	0.10	0.03
290	0.06	0.06	0.16	0.09
300	0.14	0.14	0.20	0.16
310	0.20	0.20	0.27	0.22
320	0.29	0.29	0.32	0.30
330	0.40	0.42	0.44	0.42
340	0.42	0.40	0.45	0.42
350	0.46	0.46	0.44	0.45
360	0.44	0.44	0.46	0.45
370	0.45	0.50	0.41	0.45
380	0.52	0.53	0.43	0.49
390	0.58	0.68	0.45	0.57
400	0.55	0.75	0.30	0.53

Temperature (°C)	N+5021 Gy			Mean
	1	2	3	
250	0.54	0.90	0.76	0.73
260	0.55	0.90	0.78	0.74
270	0.61	0.80	0.78	0.73
280	0.68	0.78	0.85	0.77
290	0.76	0.77	0.93	0.82
300	0.90	0.82	0.94	0.89
310	0.95	0.87	0.97	0.93
320	0.90	0.94	0.98	0.94
330	1.00	0.95	0.98	0.98
340	1.04	0.98	0.95	0.99
350	1.02	0.95	1.06	1.01
360	1.00	0.91	0.96	0.96
370	1.00	0.87	0.95	0.94
380	0.91	0.82	0.95	0.89
390	0.90	0.80	0.94	0.88
400	1.00	0.60	1.00	0.87

Temperature (°C)	N+10245 Gy			Mean
	1	2	3	
250	1.10	1.05	1.10	1.08
260	1.20	1.16	0.97	1.11
270	1.25	1.20	1.02	1.16
280	1.27	1.23	1.06	1.19
290	1.35	1.36	1.18	1.30
300	1.38	1.45	1.25	1.36
310	1.55	1.50	1.34	1.46
320	1.45	1.59	1.43	1.49
330	1.57	1.58	1.50	1.55
340	1.54	1.49	1.45	1.49
350	1.55	1.56	1.48	1.53
360	1.32	1.57	1.45	1.45
370	1.25	1.53	1.65	1.48
380	1.20	1.92	1.51	1.54
390	1.10	1.45	1.34	1.30
400	1.00	1.55	1.25	1.27

Temperature (°C)	N+15458 Gy			Mean
	1	2	3	
250	2.70	1.30	1.10	1.70
260	2.49	1.37	1.20	1.69
270	2.40	1.54	1.40	1.78
280	2.41	1.75	1.55	1.90
290	2.26	1.96	1.72	1.98
300	2.30	2.17	2.04	2.17
310	2.30	2.27	2.25	2.27
320	2.21	2.35	2.50	2.35
330	2.20	2.40	2.61	2.40
340	2.08	2.48	2.60	2.39
350	2.15	2.47	2.60	2.41
360	2.12	2.38	2.34	2.28
370	2.00	2.37	2.20	2.19
380	2.45	2.40	2.88	2.58
390	1.95	2.38	1.84	2.06
400	1.80	2.65	2.15	2.20

Temperature (°C)	N+21125 Gy		Mean
	1	2	
250	1.86	2.28	2.07
260	1.84	2.24	2.04
270	2.05	2.38	2.22
280	2.21	2.69	2.45
290	2.40	2.96	2.68
300	2.70	3.15	2.93
310	2.84	3.26	3.05
320	3.03	3.35	3.19
330	3.17	3.42	3.30
340	3.26	3.35	3.31
350	3.30	3.30	3.30
360	3.13	3.05	3.09
370	2.89	2.88	2.89
380	2.58	2.75	2.67
390	2.45	2.75	2.60
400	2.10	2.25	2.18

Table C-4. The results of the ratio of the height peak natural to irradiated samples of the sample TK-S.

Temperature (°C)	Mean values					TL ratio (N/N+γ)			
	N	N+5021 Gy	N+10245 Gy	N+15458 Gy	N+21125 Gy	1	2	3	4
250	0.02	0.73	1.08	1.70	2.07	0.02	0.02	0.01	0.01
260	0.02	0.74	1.11	1.69	2.04	0.02	0.02	0.01	0.01
270	0.03	0.73	1.16	1.78	2.22	0.05	0.03	0.02	0.02
280	0.03	0.77	1.19	1.90	2.45	0.04	0.03	0.02	0.01
290	0.09	0.82	1.30	1.98	2.68	0.11	0.07	0.05	0.03
300	0.16	0.89	1.36	2.17	2.93	0.18	0.12	0.07	0.05
310	0.22	0.93	1.46	2.27	3.05	0.24	0.15	0.10	0.07
320	0.30	0.94	1.49	2.35	3.19	0.32	0.20	0.13	0.09
330	0.42	0.98	1.55	2.40	3.30	0.43	0.27	0.17	0.13
340	0.42	0.99	1.49	2.39	3.31	0.43	0.28	0.18	0.13
350	0.45	1.01	1.53	2.41	3.30	0.45	0.30	0.19	0.14
360	0.45	0.96	1.45	2.28	3.09	0.47	0.31	0.20	0.14
370	0.45	0.94	1.48	2.19	2.89	0.48	0.31	0.21	0.16
380	0.49	0.89	1.54	2.58	2.67	0.55	0.32	0.19	0.19
390	0.57	0.88	1.30	2.06	2.60	0.65	0.44	0.28	0.22
400	0.53	0.87	1.27	2.20	2.18	0.62	0.42	0.24	0.25

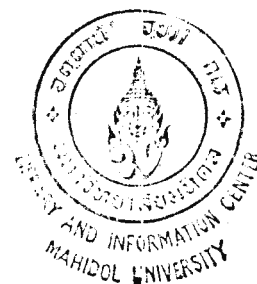
Table C-5. Paleodose of the sample TK-L was measured the glow area between 340-350°C.

N+ γ (Gy)	TL signal (Arbitrary Units)			Mean	TL ratio		
	1	2	3				
0	158	160	161	160	0.99	1.00	1.00
5021	368	392	354		2.30	2.45	2.21
10245	513	515	518		3.21	3.22	3.24
15458	568	596	578		3.55	3.73	3.61
21125	681	694	-		4.26	4.34	-

Table C-6. Paleodose of the sample TK-S was measured the glow area between 330-340°C.

N+ γ (Gy)	TL signal (Arbitrary Units)			Mean	TL ratio		
	1	2	3				
0	25	29	32	29	0.86	1.00	1.10
5021	80	69	51		2.76	2.38	1.76
10245	105	121	120		3.62	4.17	4.14
15458	169	190	204		5.83	6.55	7.03
21125	247	268	-		8.52	9.24	-

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