THERMOGRAPHY AS APPLIED TO MEDICINE

INVESTIGATIONS INTO THE TEMPERATURE ABNORMALITIES ASSOCIATED WITH HUMAN BREAST CANCER, AND METHODS OF DETECTION.

by

Ray N. Lawson, B.A., M.D., F.R.C.S.(C), F.A.C.S.

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Department of Experimental Surgery,
McGill University,
Montreal, Canada.

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PREFACE

This manuscript is the product of a continuing series of investigations chiefly conducted in the surgical laboratories of the Royal Victoria Hospital, Montreal It is conceivable that the physical sign of increased local temperature in breast cancer first pointed out by the author could be an important addition to our diagnostic armamentarium if certain criteria could be met. Its significance must be elucidated, adequate measuring instruments must be engineered, and finally suitable reliability criteria must be well established. Part of this investigative work has been published in a series of articles in the Journal of the Canadian Medical Association, the Journal of the New York Academy of Sciences, the Canadian Services Medical Journal, and the Journal of the Motion Picture and Television Engineers Society.

I wish to express my gratitude to members of the instrument section, particularly Bert Hassall, to the various members of the photographic section , the carpenters, electricians, building personnel, who have constantly co-operated with the challenge of a never ending series of problems. My thanks are also due to Dr. Donald Webster and Dr. J. Gilbert Turner for their constant encouragement in these efforts, which in the early phases did not really appear to justify any interest or support. I am extremely indebted to Dr. Erik Pedersen for his competent constructive help and criticism in the approach to many physical facets of this project.

INTRODUCTION

Cancer is almost as old and pervasively present as life itself. Its toll has mounted relentlessly through recorded history, and its claim of human life to-day is second only to circulatory diseases. The word cancer is Latin for 'crab'. The inference is from the crab-like roots observed by the G eeks, in breast cancer. It is, however, better to regard it as a large group of diseases having the common property of being composed basically of savage cells[1] which somehow evade the laws of the body. The biggest contemporary barrier to recognizing the idiosyncracies of the cancer cell is in the prevailing ignorance of the nature of a normal cell. Until the fundamental aspects of normal cell life are understood, one can only speculate on what makes the cancer cell different. The cancer cell adopts the primitive code of early life forms and reproduces rapidly at the expense of the host. In the course of the disease, growth is not necessarily steady and relentless. Temporary remissions are common, but spontaneous cures are extremely rare. Certainly some cures are effected by surgery, but surgery will not be the ultimate treatment. For instance, there is no evidence in the case of breast cancer that radical surgery results in a better survival rate than simple exterpative procedures. The term 'cure' is inappropriate since the vast majority of patients eventually succumb to the disease regardless of treatment. To improve the survival rate better methods of treatment resulting from more basic knowledge of the disease is necessary. This obviously requires the application of new ideas and technologies.

Mammary carcinoma is the commonest tumour in women. The attack rate of breast tumours varies significantly in various parts of the world. In North America no convincing evidence exists to accept the thesis that over the past 20 or 30 years any significant progress has been made in efforts to prolong the life of breast cancer patients[2].

The disease is unpredictible. At present medical armamentarium lacks sophisticated instrumentation capable of measuring the effectiveness of a variety of therapeutic attacks.

At the time of this writing, the author has made 36 trips into the Canadian Arctic since 1944 for various purposes. These include employment by the Department of Northern Affairs on Eskimo health surveys; in his capacity as physician to the Hudson's Bay Company; with exploration parties sponsored by commercial mining companies; for the Audubon Society; the Canadian Industrial Preparedness Association; and for purely vacational purposes (Fig. 1 and 2). By 1948 it had become apparent that malignant disease [illegible] in the Canadian Eskimo population of approximately 12,000, was extremely rare. The first pathologically authenticated malignancy was described in 1949[3]. This situation in no sense infers that malignant disease did not previously afflict Eskimos, but it was so striking that in 1953 the author reviewed the available medical records. Six cases of breast cancer had been reported. These were checked and in each instance the final pathological diagnosis was tuberculoma. The first pathologically proven patient with breast cancer occurred in Nain, Labrador, in 1956. This woman was operated on at the Grenfell Mission by Dr. G. Thomas of St. Anthony, Newfoundland. She is alive and well to-day. The second instance occurred in a forty year old woman in Cape Dorset, Baffin Island, in 1959 (Fig.3). This patient had ten children and had nursed them all. She died in the Mountain View Sanitorium, Hamilton, in 1960 from the disease[4]. Up to the present time no other breast cancer patients have been reported.

In the interval between 1945 and 1960 it was estimated by statistical comparison with age attack rates of the average Canadian population, that sixty-two cases of breast cancer should have occurred in the Eskimo population. Hence it seemed worth while to

PELLEY BAY, N.W.T. MARCH 1958.

Lawson and wandering group of Eskimos. They have no contact with outer world - no boats ever come - they eat only what they can fish or hunt.

ESKIMO MEDICAL SURVEY, BACK'S RIVER, N.W.T. MARCH 1958. TEMPERATURE: -45° F.

Here a group of 62 of Canada's most primitive, but healthiest, Eskimos were living in 12 igloos.

These snow houses were completely concealed below the surface by drifting hard packed snow.

Author is seen with portable generator connected to x-ray apparatus in one of the burrows.

At the time of visit these Eskimos had survived for 6 months solely on raw fish.

Two years later 23 of the group died from starvation.

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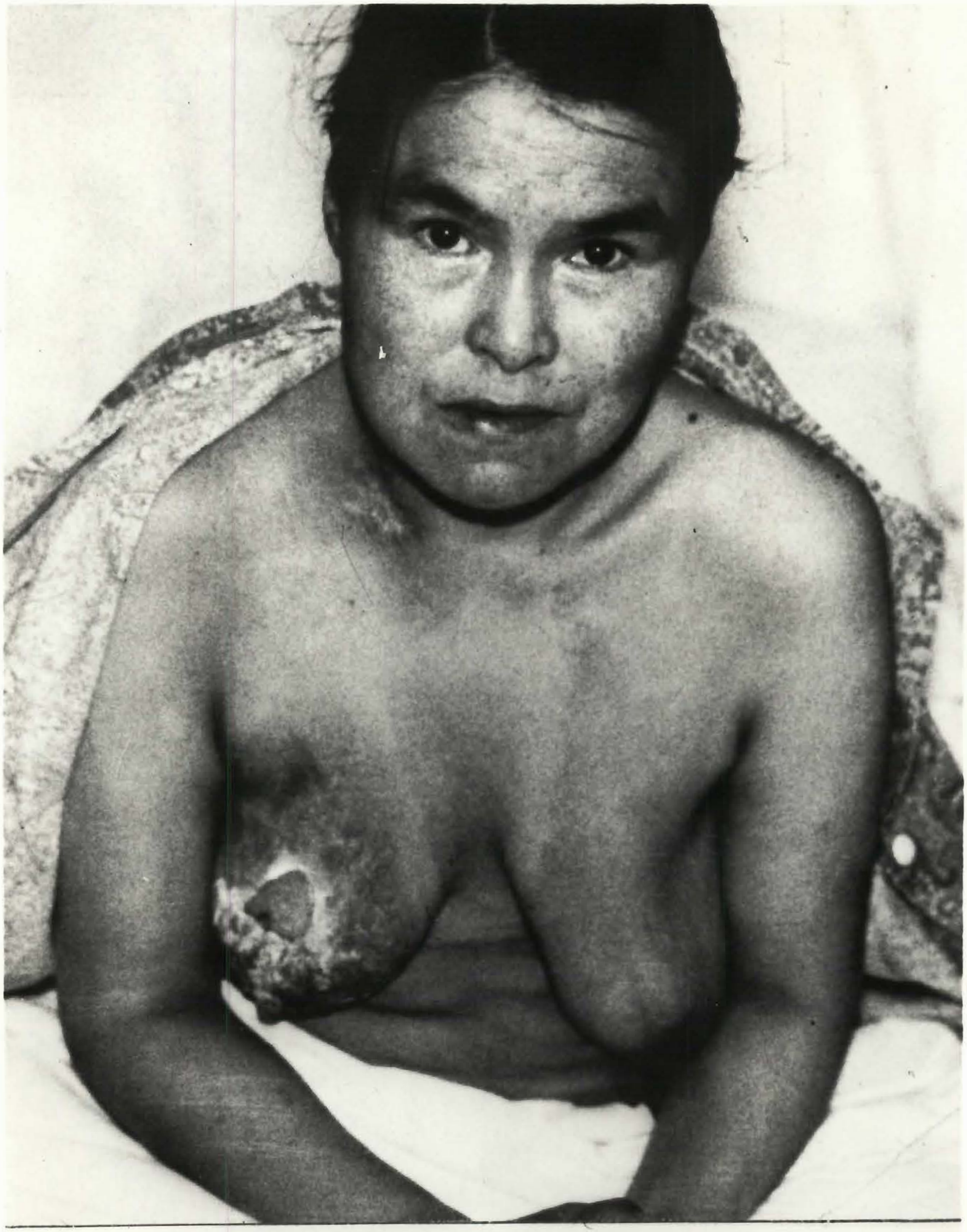

FIRST CANADIAN ESKIMO WOMAN KNOWN TO HAVE SUCCUMBED FROM BREAST CANCER. MAY 1960 HAMILTON MOUNTAIN SANATARIUM.
EETOOKSHAJK E7-998 CAPE DORSET, BAFFIN ISLAND. AGE 40 YEARS.
LUMP RIGHT BREAST 5 YEARS. HAD NINE CHILDREN AND NURSED THEM ALL.
FATHER'S MOTHER WAS HALF WHITE.

examine any possible cultural differences that might lead to clues in the etiology of breast cancer. At this juncture, discussions and visits with the Eskimo expert V. Stefansson of Dartmouth College, were arranged, and the noted anthropologist was persuaded to gather together the reported data on Eskimo malignant disease. Most of the documents that might be of possible value were contained in anthropology libraries, not in medical archives. Stefansson culled through this data and published it in book form[5]. Personal observations were repeatedly made on the primitive Eskimo diets. The outstanding feature from the point of view of the "civilized" white man was their old custom of eating odoriferous rancid fats from caribou, fish and seals. The existing work on the effect of oxidized fats in experimental cancer was reviewed[6], with particular attention to the aldehydes. Incidentally a perusal of the published literature on the relationship of dietary saturated fat to atherosclerosis elicited many conflicts with the observed facts. For instance, Eskimo groups with a high intake of saturated fat did not appear to have the problem of atherosclerosis to the same degree as white races. This situation was documented[7]. Interesting laboratory data on heptaldehyde, a component in rancid fat, was noted. It was reported to cause liquefaction of week old embryos in mice and rats, and also had some anti-tumour effects[8]. This substance was obtained and administered to a series of fifty-six late stage cases of human breast cancer. In most instances, after one cc intramuscular injection, subjective pain in the tumour nodules was complained of within ten to twelve minutes. The phenomenon did not take place in benign breast disease[9]. The subjective pain was somewhat similar to that seen in about thirty percent of cases of Hodgkins disease after the consumption of alcohol. The idea occurred to the writer of making skin temperature measurements over the tumour sites before, during, and after this pain. A striking finding was that in about ninety percent of cases, areas of temperature elevation could be detected with a skin temperature probe: and following the intramuscular injection of one cc of the aldehyde, temperature decreases were observed. It was immediately apparent that the significance of this new sign should be explored. Temperature recording could possibly be extremely important in many aspects of experimental and clinical cancer work. The extreme complexities and unforseen difficulties in the application of "state of the art" thermal physics to medicine were unanticipated. Preliminary investigations disclosed the fact that military needs rated a much higher priority than those of medical research. This situation still exists, and implies that knowledge of certain new advances in thermal physics is unavailable to medical research. Nevertheless it is obvious that the life sciences will ultimately benefit from the many new developments derived as the result of war needs. Engineering research in thermal physics is particularly costly because it requires expensive measuring tools for the production of worth while data. For this reason it has taken about ten years to accumulate enough information to justify support for medical engineering in this work. Research grant applications are now being accepted to enable the explorations that were suggested and applied for by this writer in 1956. For instance, starting November 1965 the American Cancer Society is sponsoring a $200,000. program designed to evaluate thermography in the diagnosis of breast disease.[11] This student's observations over the past decade have recently been confirmed and extended at numerous medical research centers. These reports will be duly catalogued during the course of this thesis. (Fig. 4.)

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From:

Cade C.M. Thermal Patterns
Science Journal, Vol. 2. No. 2
Feb. 1966.

THERMAL PICTURES OF THE BODY were first used as a medical tool by a Canadian breast surgeon, Ray Lawson, in 1957. Working at the Royal Victoria Hospital, Montreal, Lawson demonstrated by conventional methods that certain cancers of the breast show a rise in the overlying skin temperature. He reasoned that, if the thorax could be scanned thermally, one might be able to detect these cancers at an early stage when treatment would be most effective. Using successively the Baird Atomic Evaporograph, the Barnes Engineering Thermoscan and a scanner specially made by Radiation Electronics, Lawson produced heat pictures which clearly portrayed the temperature variations he had previously noted with thermocouples. His work has now been amply confirmed in both Britain and the United States.

Fig. 4.

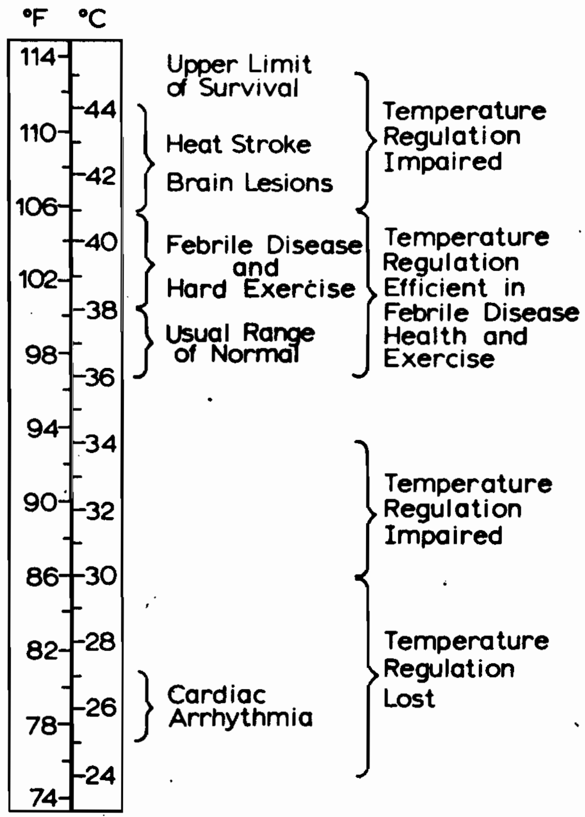
ELEMENTARY THERMAL PHYSICS

The Distinction between the Terms "Temperature" and "Heat"

Since this research is concerned with the problem of temperature measurement, it is appropriate to orient the reader by starting with an outline of the specialized branches of thermo-physics which are used. The concepts of temperature and heat appear, for some reason, to be extremely difficult for many students to grasp. Therefore the area will now be discussed in some preliminary detail. An "up-to-date" acceptance of the term "heat" is as follows: Heat is the name for energy as it is transferred from one region to another by the thermal processes of conduction, convection, and radiation. It is .quantitative. By analogy we can regard heat flow as equivalent to an electric current, whereas, on the same basis, temperature is a measure of the availability or level of internal energy: as voltage is a level of electrical energy. The term "temperature" is chiefly used to denote the relative ability of a body to transfer heat to its surroundings. Stated in another manner one can say that there is a temperature difference between two bodies if, when they are placed in thermal contact with each other, the temperature of one body increases and that of the other decreases. Temperature is an indication of the thermal energy level of a body. Thermal energy will flow from a warm object to a cooler one. Thus temperature is a property which determines the rate and direction of this heat flow. Temperature, however, is not a complete measure of the total amount of energy in the form of heat which a body possesses. The temperature change produced by a change in the total amount of heat in a body depends on the mass of the body and its composition. Thus two objects at the same temperature may differ greatly in heat content. Practically all properties of matter such as size, colour, electrical and magnetic properties and physical state (i.e. whether it is in the form of a gas, liquid or solid) can be changed by changing the temperature. According to Bridgman[(10)] "it appears that the temperature concept is not a clear cut thing which can be made to apply to all experience, but that it is more or less arbitrary, involving the scale of our measuring instruments". On the other hand Worthing[(11)] writes "At present we know of no purely mechanical quantity - that is, one expressible in terms of mass, length and time only - which can be used, however inconveniently, in place of temperature. We are inclined to conclude that temperature probably is itself a basic concept". In summary one might say that temperature is that property of a system which determines whether the system is in thermal equilibrium with other systems. Heat is the total energy contained in molecular motion in a given quantity of matter, whereas temperature represents the average speed of molecular motion in that matter. Heat can be detected only by a thermal exchange. Thus measurements designed to estimate this type of energy tend to destroy the actual values we seek. Nevertheless temperature is probably the most widely (and crudely) measured of all biological variables. It is still, however, even in modern physics, inadequately understood, as will be pointed out in the next few pages. The rates of most chemical reactions increase with increasing temperature. In the body chemical changes may increase by a factor of two for every 2 or 3 degrees centigrade rise in temperature. Since life processes are so largely a result of many interdependent organic chemical reactions it is not surprising that life as we know it, is possible only within relatively narrow temperature ranges. (Fig.5)

History of Thermometry

The idea that heat is a form of mechanical energy on a microscopic scale is a relatively new one, and as previously pointed out, it is now generally agreed that temperature may be considered a basic concept as are mass, length, and time. No thermal measurements were possible and therefore the science of thermal physics could not develop, until after the invention of the thermometer near the beginning of the 17th Century. Galileo is commonly credited with its invention in 1593, but Drebbel of Holland made one independently at about the



Extremes of body temperature. (After DuBois, *Fever and the regulation of body temperature,* Springfield, Ill., Charles C Thomas, 1948.)

Fig. 5.

same time[12]. These instruments were not thermometers as we know them to-day but rather thermobaroscopes; they were open to the atmosphere and therefore responded to changes in atmospheric pressure as well as to changes in temperature. It should be pointed out, however, that at this time the pressure of the atmosphere had yet to be discovered. In 1641 the Grand Duke of Tuscany sealed his alcohol-in-glass thermoscopes in order to prevent evaporation of the alcohol, and he attached to them scales having arbitrary graduations. These devices were the prototypes of modern thermometers.

Hooke and his contemporaries had observed that the level of the liquid in a thermometer always came to the same position whenever the thermometer was immersed in a mixture of ice and water. It was reasonable to assume that there existed a characteristic temperature for the freezing of water. In 1664 Hooke utilized the freezing point of water for standardizing thermometers, and thirty years later Renaldi adopted both the freezing and boiling points of water for this purpose.

A few years later, Roemer (1702)[13] and Fahrenheit (1717) proposed the temperature scales which in modified form serve to this day. Meanwhile Elvins (1710), and seemingly Linnaeus independently (1740), suggested the centigrade or centismal scale. However, by the vagaries of historical accident the latter scale became associated with the name of Anders Celsius. (Note *).

(Note *). In 1954 the Tenth International Conference on Weights and Measures formally adopted the name CELSIUS for the old centigrade scale. The symbol °C then is read "degree Celsius".

The Energy Concept of Heat *

In 1620 Sir Francis Bacon said "heat itself, its essence and quality, is motion and nothing else". The English physicist Robert Boyle expressed the same view and his co-worker Robert Hooke had described heat as being "nothing else but a very brisk and vehement agitation of the parts of the body". In the 18th Century John Locke agreed with this idea, and fifty years later the American, Benjamin Thomson (Count Rumford) further agreed. At this time the prevailing idea was that heat was generally considered to be a substance; it was termed "caloric", an elastic fluid that flowed into or out of substances depending on whether or not they were heated or cooled. While supervising the bore of brass cannon for the Bavarian army, Rumford's attention was arrested by the very large amounts of heat produced during the boring. He was aware that the calorists attributed such heat to the squeezing out of caloric from any substances, in this case from the brass and the drill. Rumford asserted that if this theory were correct there should be less caloric in the shavings than in the same weight of solid brass, because a great deal of heat had been evolved in the conversion. Rumford found that no such change took place. There was no reduction of heat in the chips in this mechanical process. He pointed out that "the portion of water into which hot chips were put was not, to all appearances, heated either less or more than the other portion in which the slips of equally hot solid metal were put". Motion, Rumford concluded, was the source of the heat. Rumford's cannon boring observations were confirmed by Davy. Sir Humphrey Davy, by subjecting ice to friction in a va vacuum, finally refuted that heat was a substance. He showed that ice could be melted by friction, without the possibility of

* Apologies to some reviewers may be in order for this preliminary, brief, repetitious and oversimplified digest of thermal physics. However much of the subject matter is outside the scope of orthodox medical experience and hence requires an easy introduction.

heat flowing in from anywhere. It occurred to Mayer of Heilbronn, and to Joule of Manchester, that the heat thus generated might exactly account for the apparently lost work energy. In other words, that heat itself was a sort of energy and if all the heat developed by a machine were collected, it would exactly account for the energy apparently lost. Joule supported this contention with numerous experiments. For instance he found that apart from evaporation and other cooling disturbances, the water at the bottom of a fall 770 feet high should be 1F° warmer than the water at the top. This represents the heat equivalent of gravitational energy, or what he called "the mechanical equivalent of heat". About this time it became realized that energy could not be gained or increased in amount and it was now shown that it could not be lost or diminished, that it merely changed its form, but continued constant in quantity. Thus gradually the law of the conservation of energy was established. Soon energy was perceived to be something which could take many forms, but could never be altered in amount. There is no waste in the physical universe, but only transformation. By no mechanism whatsoever can energy be either increased ot diminished in quantity.

It is still easy for us in modern times to appreciate the difficulty these pioneer physicists felt in comprehending the true nature of heat, that it was not a substance but a form of energy, a mode of motion as Tyndall called it. In fact Joule's remarkable early papers on the subject were not accepted by the Royal Society. For instance, Sir William Thomson found it difficult to realize that in a steam-engine the heat not only "fell down" in temperature from boiler to condenser, like water flowing over a water wheel from high to low level and thereby doing work, but that, unlike water heat was actually consumed in the process, so that less heat was given to the condenser than was taken from the boiler. That is not so for the volume flow in a hydraulic engine, nor in an electric motor: just as much electrical current flows away from a motor as flows into it. The work is done at the expense of the drop in voltage. But heat engines, according to Joule, were exceptional. Heat not only fell in temperature but was actually consumed and turned into other forms of energy. This is equivalent to the First Law of Thermodynamics, which is a definite assertion that heat is energy. The Second Law has to do with the availability of heat energy, the efficiency of a perfect engine, and the advantages which a body at high temperature possesses as an available source of energy, provided some other body reasonably near it is cold. The availability of heat energy depends on the possible drop of temperature: in that respect it is like hydraulic or electric power, which depends on the drop of level or of voltage. If all bodies were at the same temperature, heat would be useless, though if they were all very hot that would possess and retain plenty of unavailable energy - unavailable because they have nothing to pass it on to. Work can only be done by passing or transferring energy from something at high level or potential or temperature to something else at lower level or potential or temperature. As a crude analogy; to a hydraulic engineer, in a certain sense all the water in the sea is useless, for it is all at the same level. The fact that water tends to run downhill and reach the sea is an example of the dissipation of available energy. It may do work on the journey, but the ultimate result is stagnation. The fact that bodies which are warmer than their surroundings automatically cool, or in other words that heat tends to flow down from high temperature to low, is another example. Reservoirs of power may leak, but they never automatically fill themselves, except by some expenditure of energy in actual or virtual pumping; nor does inequality of temperature arise without some cause.

Availability of Heat Energy

The conditions under which heat energy is available are specified by the second law of thermodynamics, which involves the terms "temperature" and "entropy". These are statistical expressions, suited to deal with a vast number of units which cannot be dealt with individually. Temperature represents the average energy of molecules, and is meaningless when applied to a single particle, but since humans happen to have temperature sense organs located in the skin, we have grown accustomed to it and think it a fairly simple idea. Temperature determines the transfer of heat energy and as transfer is necessary to activity, so a difference of temperature is necessary as well. In that way temperature in thermodynamics is analogous to level in hydraulics, to pressure in pneumatics, and to voltage in electrical engineering. However, there is no negative temperature. Temperature is heat potential, but there is an absolute zero of temperature below which it is impossible to cool anything because at that temperature a body possesses no heat to be removed.

If we could deal with individual molecules the terms "heat" and "temperature" would lose their meaning. One should not then have to depend on automatic transference between a vigorous and a placid group of molecules; we could extract the energy from a molecule by harnessing it, as we harness a flywheel or a piston rod. Maxwell pointed out that a control over the motions of individual molecules was imaginable, and that thus the law of dissipation of energy was not a fundamental law of nature like conservation. The accurate mathematical specification - the second law of thermodynamics - is statistical too. Statistical and probability treatments, though still much in favour at present, are after all confessions of comparative failure and may be regarded as a temporary expedient to tide over the periods of uncertainty and comparative ignorance about essential and intimate and unobservable details. Nevertheless such ideas are useful and perhaps unavoidable at present, but outside the scope of this essay. "Entropy" the measure of that part of the heat or energy of a system which is not available to perform work, is a much more difficult concept than temperature. It will not be discussed as it does not apply directly to this work.

Description of Instruments Employed in Temperature Measurement

A variety of thermal electric thermometers were investigated and tested for suitability in thermal recording. These will be briefly described.

The Thermocouple.

This instrument dates to the discovery by Seebeck[13a] in 1882, that in an electric circuit having two different materials as wires, when the two junctions were at different temperatures a potential would exist at the terminals in an open circuit; and if the circuit were closed a current would flow (Fig 4,7). The magnitude of the potential depends on the materials used and the temperature difference between hot (or measuring) junction, and the cold (or reference) junction. Thermal electromotive force values are small, of the order of 40 microvolts per Centigrade degree of temperature difference between hot and cold junction. Frequently several thermocouples are connected in series, and are then called thermipiles. Pairs of metals which may be employed are iron and constantan, copper and constantan, and chromel and alumel. Constantan is an alloy mainly of nickel and copper. Chromel is an alloy of nickel and chromium. Alumel is an alloy of nickel, aluminium, manganese, and silicon. Thermocouples are designated by type letters which are standard symbols established by the Instrument Society of America. For example, type 'T' is copper-constantan in which the copper is positive and the constantan negative. Thermocouples yield less precise temperature measurements than resistance thermometers. They change somewhat with age and require constant recalibration. For good precision, expensive potentiometers are necessary to measure the small electrical potentials, and an experienced technician is required.

Fig. 6.

Assorted thermocouples with sensitive galvanometer.

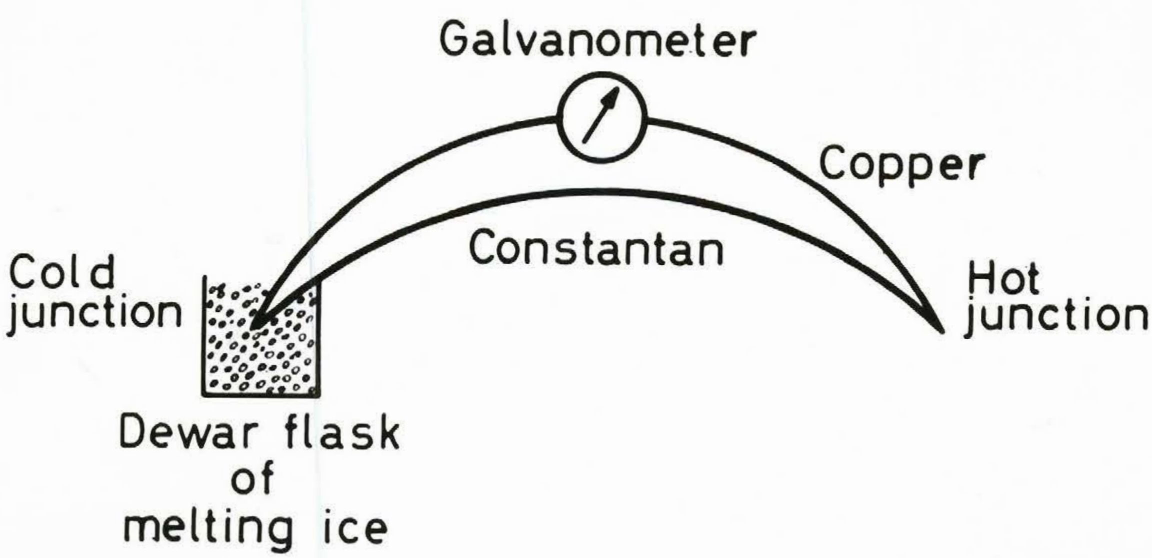
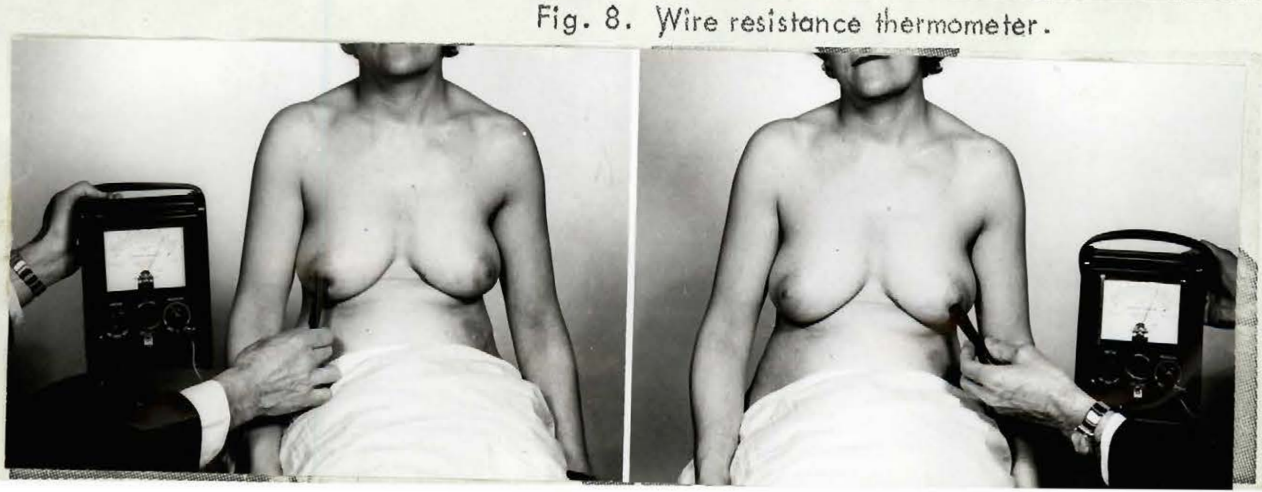


Fig. 7.

Resistance Thermometers

A. Metal wire resistance thermometers. Pure platinum wire, nickel iron, or nickel are used as temperature sensors. This type of resistor is usually supported in a framework for protection from strain and trauma. A resistor of this character requires about two meters of wire which is wound into a coil around a frame enabling it to expand or contract on heating with a minimum of mechanical stress and time lag. A precision Wheatstone bridge with a high sensitivity amplifier null detector is used to determine the resistance of the sensor, and hence its temperature. The temperature coefficient of resistance is about 0.3% change in resistance per centigrade degree change in temperature. Disadvantages are: the comparison resistors in the Wheatstone bridge circuit which is usually used also may have a comparable temperature coefficient unless made of a low coefficient alloy such as manganin or constantan; the problem of getting a few feet of very fine wire (0.001 or 0.002 inches in diameter) wound into a small space to make a small probe; the thermal mass and accompanying lag time due to the large mass of wire, and the low resistance of the resulting probe requiring an expensive galvonometer. Its principal advantage is that the temperature coefficient of resistance of platimum is well known and the probes, once calibrated, need checking only rarely. Considerable use of this type of thermometer was made in the early part of this work. In fact the only available electrical thermometer was a McKesson Dermalor, manufactured by McKesson Industries, Toledo, Ohio. While it was characterized by a relatively fast response, the sensor was extremely gragile, and covered a surface area of 1 cm^2. This was too large an area (Fig.8).

Fig. 8. Wire resistance thermometer.



Semi conducting Metal Oxide Resistance Thermometers (Thermistors).

Thermistors (Fig. 9) are "thermal resistors" or resistors with a high negative temperature coefficient of resistance. As the temperature increases, the resistance goes down. This is just opposite to the effect of temperature changes on the resistance of metals. Thermistors are semiconductors of ceramic material made by sintering (transforming by heating without melting) mixtures of metallic oxides such as manganese, nickel, cobalt, copper, iron, and uranium. It is only in the past twenty years that adequate techniques of producing thermistors have been developed which permit production of reproducible and stable probes. Their electrical characteristics may be controlled by varying the type of oxides used, and also adjusting the physical size and configuration of the unit. They are sold commercially in forms such as rods, discs and beads, and are incorporated into a variety of sealers. Thermistors have many advantages over thermocouples and resistance thermometers. The temperature coefficient of resistance of these solid state, semiconducting metal oxides, is around 5% per centigrade degree. This is about fifteen times that of metallic resistance thermometers. However, at the time of writing, further technical advances are required to engineer adequately a small probe with an adequately fast response time. This work is in progress and there are indications that our requirements will be reasonably approximated in the near future. Currently time delay(14) and undue leakage of heat energy into the body of the probe(15, 16) from the source being measured, are the main obstacles to an acceptable thermistor thermometer.

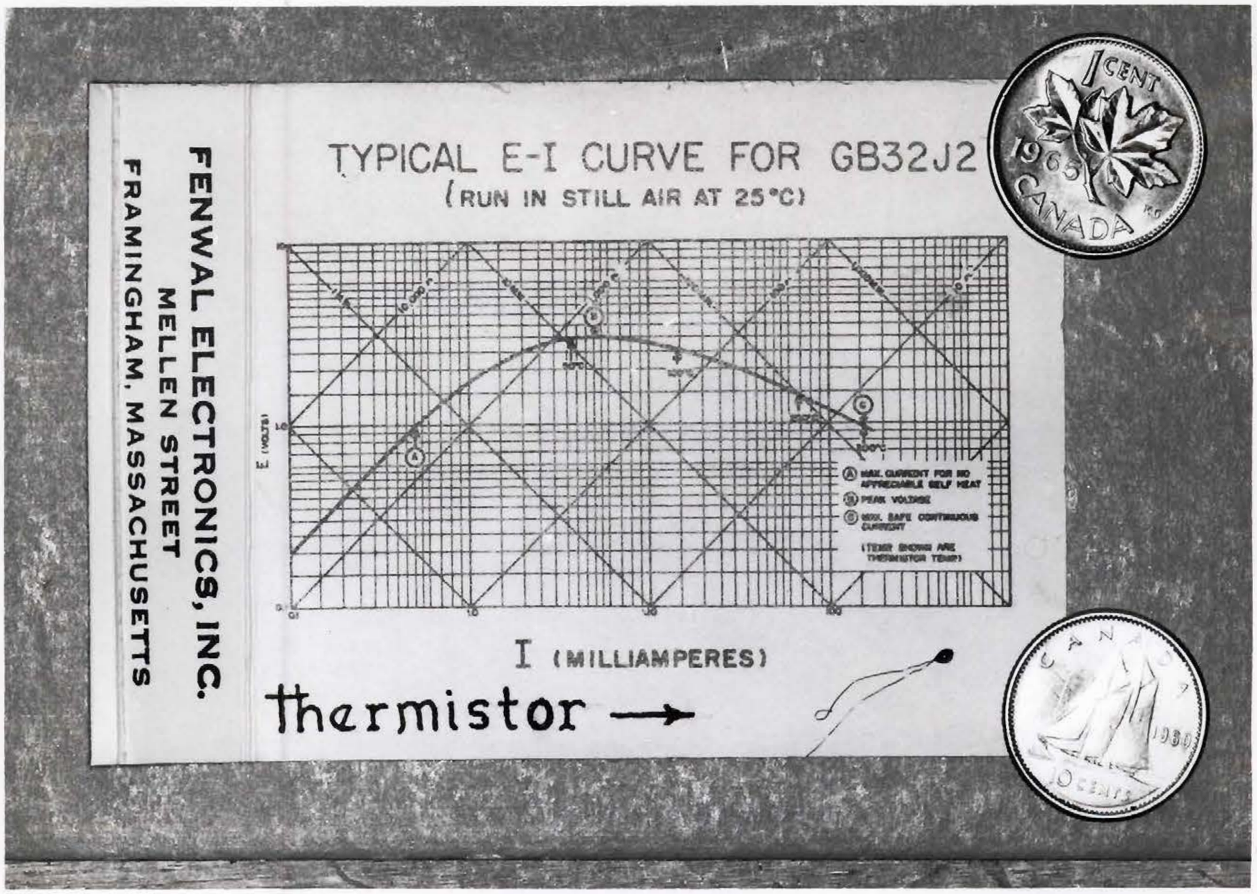


Fig. 9. Thermistor

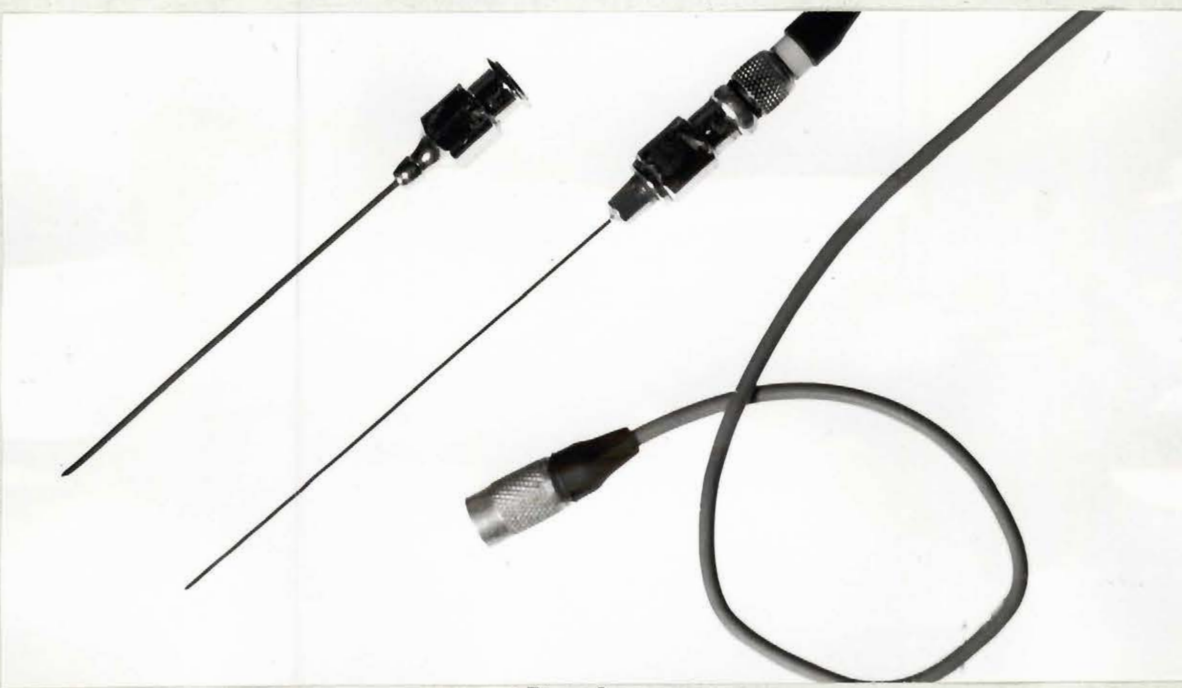


Fig. 9a.
Thermistor embedded in needle tip, in the form of trocar designed for taking temperatures of breast cysts prior to aspiration.

When thermistors were first made there was a problem of ageing, and the resistance at a given temperature depended not only on the temperature but on the thermistor's thermal history. Recent thermistors are subject to this non-reproducibility only if they are cycled through temperature considerably outside the physiological range. They are stabilized even further by enclosing in a thin glass envelope to prevent moisture from effecting the metallic oxide from which they are made.

RADIATION THERMOMETRY

Infrared Radiation

Historical

In 1800 Sir William Herschel, British Astronomer Royal, made experiments to determine the distribution of heating power among the rainbow colours produced by passing sunlight through a prism. His apparatus was so arranged that the spectral colours were projected upon a table and, by means of a mercury thermometer, he explored every part of the visible spectrum by measuring the temperature produced. He found that the heating power increased as the thermometer was moved from the visible to the red end of the spectrum, and to his surprise, that the maximum was not reached until the thermometer had been moved beyond the end of the red[17]. In this way Sir William proved the existence of an invisible infrared radiation, less refrangible than red light, and of a marked heating power. He followed up this discovery by demonstrating that this radiation was refracted and reflected in accordance with the known laws of optice. His son, Sir John Herschel, continued the research and rendered the infrared spectrum visible[18]. He covered strips of paper with lamp black and then soaked them in alcohol. When infrared radiation was focussed on these strips the alcohol evaporated more rapidly from the parts which received the stronger radiation, and thus appeared lighter in colour. Sir John termed these crude pictures "thermographs". In 1840 the 'younger' Herschel discovered that the solar spectrum showed at least three separate infrared bands; today these wavelengths are known to correspond to "windows" where the earth's atmosphere is relatively transparent to radiation. (Fig10).

Just before this, in 1833, L. Ritchie experimentally established the validity of the fundamental laws of thermal radiation, namely that a material which is a good emitter of infrared radiation is an equally good absorber. A more cogent statement of this law was given by G. Kirchhoff in 1859 (and independently by B. Steward); as a result, this law bears Kirchhoff's name.

For thirty years following the pioneering experiments of the elder Herschel, progress in the study of infrared was rather slow because of, among other reasons, the lack of sensitive and accurate detectors. But by the 1880's detectors were made available that depended on some of the numerous physical characteristics of matter which are functions of temperature, particularly the thermoelectric effect and electrical resistivity.

(18) Herschel, J.F.W. Philosophical Trans Roy Soc London, 131: 1-60, 1840.

Note: These references to appropriate original contributions in this branch of physics were obtained from (a) Niels Bohr Library, American Institute of Physics, 335 East 45th Street, New York., and (b) Engineering Societies Library, 345 East 47th Street, New York.

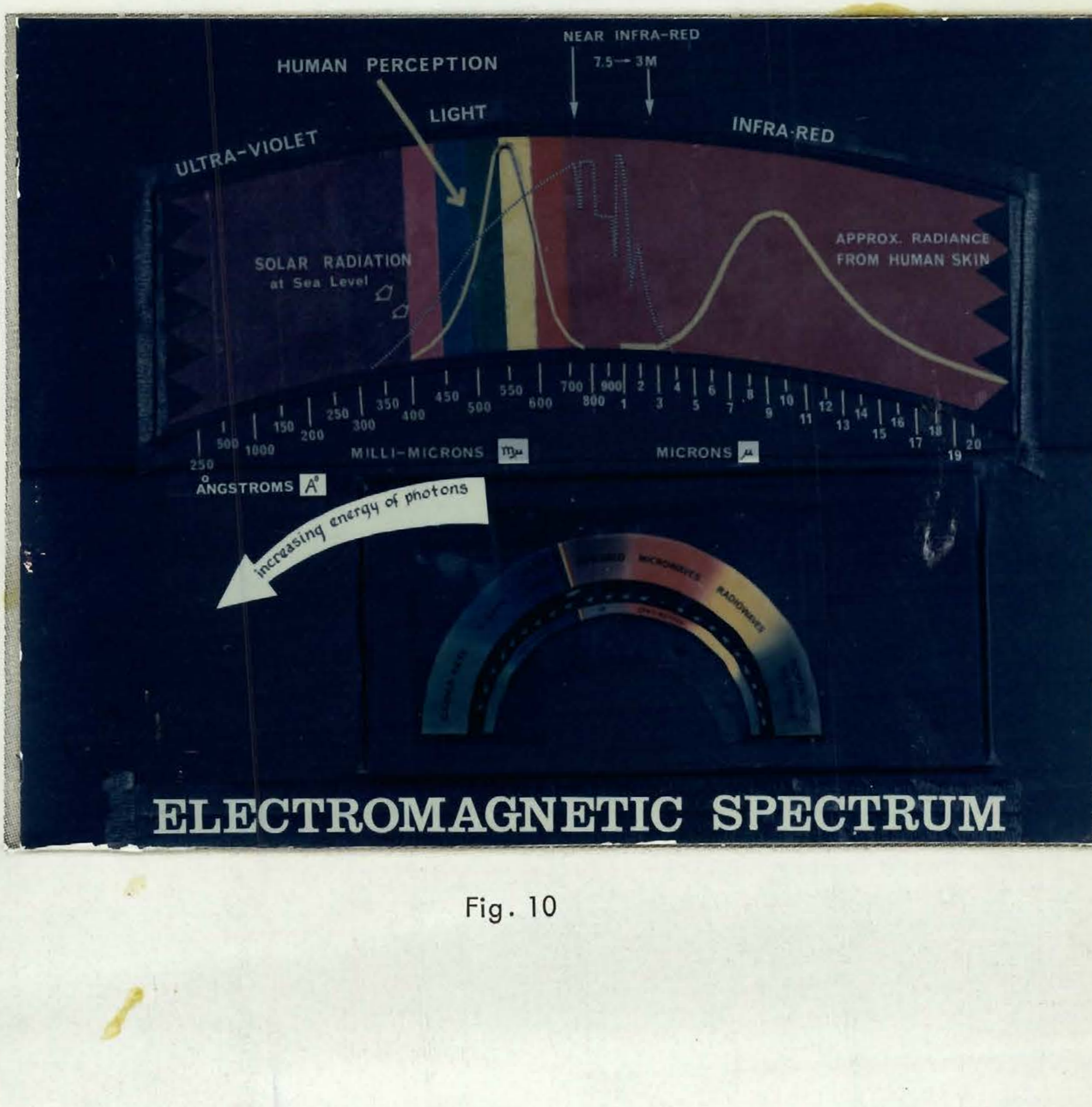

NEAR INFRA-RED
7.5 → 3M
HUMAN PERCEPTION
LIGHT
ULTRA-VIOLET
INFRA-RED
SOLAR RADIATION
at Sea Level
APPROX. RADIANCE
FROM HUMAN SKIN
MILLI-MICRONS mμ
MICRONS μ
ANGSTROMS Å
increasing energy of photons
ELECTROMAGNETIC SPECTRUM

Fig. 10

In addition, at that time instrumentation and techniques for measuring electrical quantities had been developed to such a degree that they could be used in conjunction with these effects to make possible the accurate detection of infrared radiation.

The first step in this direction was the invention of the radiation thermocouple by L. Nobili. The logical extension of this idea to a number of thermocouples in series, that is, a thermopile, was accomplished by M. Melloni three years later. He was to use this device to extend his experimentation further into the infrared region. That approximately 1 μ radiation produced phosphorescent and photographic effects was shown by E.Becquerel in 1843. Although physical effects such as heating were involved in most of the advances in infrared detection, W. Abney in 1880 was able to produce photographic plates which were sensitive to 2 μ. Beginning in 1881, S. Langley was able to make bolometers that were more sensitive than the thermocouples available at that time.

By utilizing these detectors when they became available, the science of infrared moved steadily ahead and the idea that infrared radiation was quite similar to light was beginning to be accepted.

Starting in 1814, J. Fraunhofer contributed greatly to spectroscopy and was responsible for the application of the diffraction grating to spectroscopic studies. Despite the fact that most of his work was done in the visible portion of the spectrum, the techniques and instrumentation he developed also implemented the study of infrared. The development of the first practical spectroscope by G. Kirchhoff and R. Bunsen in 1859 was a major step forward.

Wavelengths up to 1.5 μ were measured by A. Fizeau and J. Foucault in 1847. Subsequent investigators extended measurements of the infrared range to even longer wavelengths:

J. Muller to 1.9 μ in 1859; M. Moulton to 2.14 μ in 1879; Curie and Desains to 7 μ in 1880. Following his invention of the bolometer, Langley extended measurements of the solar spectrum to 18 μ. In the last decade of the nineteenth century Paschen, Rubens, and co-workers, active in many phases of infrared, were able to extend the range to 20 μ by utilizing techniques which depend on the ability of some materials to selectively reflect radiation. Other groups, primarily in Germany, were able to make measurements to 300 μ.

All this experimental activity in the field of infrared had far-reaching theoretical consequences. For example, on the basis of measurements made by J. Tyndall of the power transferred by radiation from one heated body to another, Stefan in 1879 concluded that the rate at which heat was transferred from one body to another was proportional to the difference of the fourth power of their absolute temperatures. This strictly experimental result was then derived theoretically by Boltzmann in 1884 from thermodynamic considerations. This law is now called the Stefan-Boltzmann law. (Fig 12).

Probably the outstanding experimental achievement relative to the study of thermal radiation was the verification of Maxwell's classical electromagnetic theory of radiation (1862). Because longer wavelengths are involved, substantiation of Maxwell's theory is more readily evident from experiments involving infrared rather than ultraviolet or visible radiation. In the course of just such experiments concerned with the examination of the electromagnetic theory, H. Hertz, in 1887, was able to produce by electrical means very long wavelength infrared radiation. It became increasingly apparent that there was no essential difference between thermally and electrically produced electromagnetic waves.

Some Useful Radiation Formuli

1. Temperature Conversion Formuli

a. °F = 9/5 °C + 32

b. °C = 5/9 (°F − 32)

c. °K = °C + 273.1

2. Black Body Radiation Processes

a. Stefan-Boltzmann Law

$$H = \sigma T^4$$

b. Planck's Radiation Law

$$H(\lambda, T) = \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1}$$

c. Wein's Radiation Law

$$H(\lambda, T) = \frac{c_1}{\lambda^5} e^{-c_2/\lambda T}$$

d. $\lambda_{max} T$ = Constant

3. Radiation Constants

c_1 = 3.7413 x 10^{-12} watt cm^2

c_2 = 1.4388 cm degree K

σ = 5.669 x 10^{-12} watts/cm^2 degree K^4

$\lambda_{max} T$ = 0.2898 cm degree K

4. Wavelength Conversions

1 cm = 10^4 micron = 10^8 Angstrom units

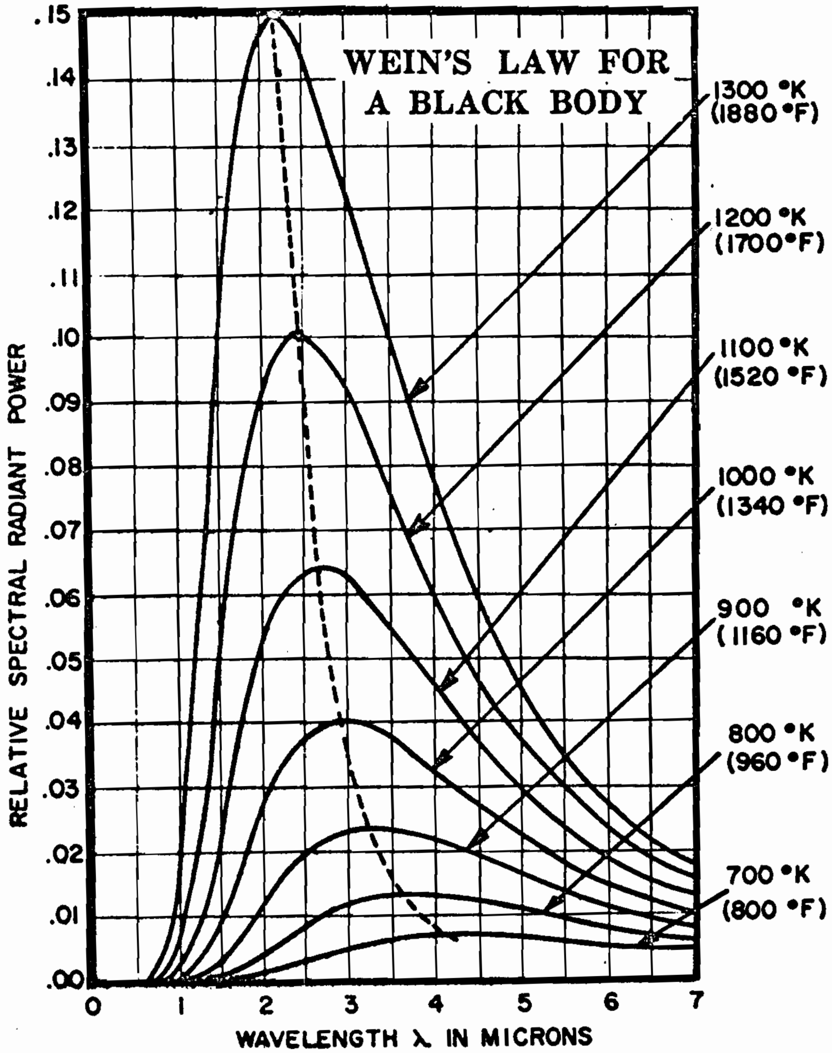
1 millimicron = 10^{-3} microns
= 10 Angstrom units

Fig. 12.

Strangely enough, these same experiments of Hertz, which did so much to establish the existence of electromagnetic waves, were also instrumental in the demise of the concept that the wave picture is the only manner by which radiation may be described, and led to the reassertion of the particle or photon theory of radiation. Hertz noted during his work that when radiation fell on an air gap, the gap could conduct electricity more easily. This observation initiated an extended investigation of the photoelectric effect by which radiation of sufficiently short wavelength is able to ionize atoms.

One of the outstanding problems facing scientists of the last decades of the nineteenth century was that of explaining the wavelength distribution of thermal radiation emitted from a small hole in the side of a heated enclosure. Attempts to describe the observed wavelength distribution of this thermal radiation in terms of the classical concepts of the electro magnetic and kinetic theories were fruitless, although Wien had been able to discover the form of the functional relationship. In addition, he was able to relate the temperature of the enclosure to the wavelength interval at which the maximum power was emitted (Wien's displacement law) (Fig. 13). In analyzing this phenomenon, Planck in 1900 was led to the concept of energy quantization, asserting that the emission of radiation took place not continuously but in discrete steps. Einstein's successful explanation of the photoelectric effect, based on Planck's hypothesis, also contributed to the establishment of the validity of the quantum theory.

Thus we have two different theories, the corpuscular and the wave theory, each of which describes some, but not all, of the observed facts. It is disturbing to have two different concepts of radiation; either light is a shower of particles or it is a wave, but we are tempted to say it cannot be both.



WEIN'S LAW FOR A BLACK BODY
1300 °K (1880 °F)
1200 °K (1700 °F)
1100 °K (1520 °F)
1000 °K (1340 °F)
900 °K (1160 °F)
800 °K (960 °F)
700 °K (800 °F)
RELATIVE SPECTRAL RADIANT POWER
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.00
0
1
2
3
4
5
6
7
WAVELENGTH λ IN MICRONS

FIGURE 13

It must be realized that this apparent dichotomy concerning the nature of light arises because of the limitations in our own means of perception. The following may illustrate this point. Consider a man who on alternate days is either deaf or blind but never both at the same time. He goes to see plays and on the days he can see but not hear, these plays are pantomimes; and on the days he can hear but not see, the plays are similar to a radio presentation. By two completely different mechanisms he can consistently explain this world of sense impressions. In time he may be able to combine these separate impressions into one coherent experience; so it may be with the scientist who attempts to reconcile conflicting theories.

We have seen how the study of thermal radiation played an extremely important role in the establishment of the dual nature of light and of the quantum theory in the early part of the twentieth century. By this time the experimental aspects of infrared had moved ahead. Bolometers, thermopiles, and associated electrical apparatus combined with interferometric and wavelength measuring techniques permitted a vigorous approach to infrared experiments. W. Coblentz, by obtaining infrared absorption, emission, and reflection spectra of a large number of organic and inorganic materials, provided evidence of the analytical value of infrared. Intensive interest in the study of molecular quantum mechanics was stimulated by the observation in 1913 of rotational spectra and the concept of molecular vibrational modes of motion. The use of infrared absorption spectra remains a powerful tool in fundamental studies of chemical bonding and molecular structure.

This renewed interest in infrared, coupled with its obvious military applications, was responsible for subsequent development of more sensitive and rapid detectors. Although the detection capabilities of bolometers and thermopiles had been increased tremendously, these devices remained rather slow. More rapid and sensitive detection mechanisms were to be found in sensors which depended on the photon or particle characteristics of thermal radiation. Photon detectors do not rely on the heating effect of infrared; therefore they do not depend on the thermal diffusivity of the detector material and as a result are much faster.

Photon effects, such as the photoemissive, photoconductive, and photovoltaic effects, had been observed with visible and ultraviolet radiation in the nineteenth century; but infrared detection mechanisms utilizing the photon characteristics of thermal radiation were not exploited until much later.

One of the earliest sensitive photon detectors utilizing the photoemissive effect in which photons, striking a cathode made of certain materials, eject electrons which are collected by an anode. Unfortunately, although much work has been done, it has not been possible to extend the useful range of this effect very far into the infrared beyond about 1.3 μ. This was the photoeffect employed in the sniperscope and snooperscope used in World War II.

The phenomenon by which absorbed infrared radiation lowers the electrical resistance of certain materials without a change in temperature is known as the photoconductive effect. It was first observed by W. Smith in 1873, who noted that the resistance of selenium decreased when exposed to light. In 1917, Case in the United States was able to produce thallous sulfide photoconductive detectors which were sensitive to 1.2 μ. However, the mechanisms responsible for the operation of these cells were not understood until the work of Gudden and Pohl. These scientists began their work in Germany in the early 1920's. Fournier of France, Todesco of Italy, Sewig of Germany, and Asao of Japan also conducted research on thallous sulfide photoconductive detectors. Lead sulfide cells were developed and studied intensively by the Germans beginning before World War 2. They were able to extend the PbS sensitive range to approximately 4 μ. The Germans also carried on extensive infrared system developments; the most notable of these was the Kiel IV, an infrared airborne system with outstanding range capability. This equipment was developed at the Carl Zeiss works in Jena under the direction of Werner K. Weihe. In 1941, Cashman at Northwestern University conducted research efforts which were successful in solving the problems in fabricating stable thallous sulfide cells. Since that period, much time, effort, and money have been expended to study the photoconductive effect. Among other prominent materials investigated have been lead telluride, lead selenide, silicon, tellurium, indium antimonide, indium arsenide, and doped germanium.

Infrared photovoltaic detectors which yield a voltage when irradiated have also been of great interest. With the advent of the junction transistor, the technology associated with the fabrication and study of p-n junctions has been employed to develop and refine detectors utilizing this effect. In addition to these three photoeffects, the photoelectromagnetic (PEM) effect holds much promise of yielding a very useful type of detector.

It must not be inferred from the preceeding outline, that work on thermal detectors has not also been actively pursued. Indeed, some extremely interesting and important developments have taken place along these lines.

In 1947, for example, Golay constructed an improved pneumatic infrared detector in which the radiation heats a small amount of occluded gas, causing a flexible mirror which forms part of the gas chamber to be distended. This movement is detected by the change in intensity of light reflected from the mirror to a photocell. Another thermal detector has been developed which utilizes the temperature shift of the absorption edge in certain materials to modulate radiation passing through that material. The thermistor bolometer (temperature sensitive resistor) has found widespread use in detecting radiation from low temperature sources. The superconducting effect has been used to make extremely sensitive bolometers.

Another important area of infrared technology pertains to the development of radiation sources. The nature of emission from thermal sources is such that they have two serious deficiencies; they cannot be modulated at the frequencies at which fast detectors operate, and they are not coherent. Progress in this area has been slow, although developments in laser techniques show promise of overcoming these deficiencies.

Investigations of materials useful as windows, lenses, and prisms in the infrared were probably begun by M. Melloni who discovered that sodium chloride was transparent to a large part of the infrared spectrum. Later P. Desains found that calcium fluoride (fluorite) was also a good infrared optical material with the added advantage that it was not deliquescent. Following the experiments of Desains, other investigators reported still more useful transmissive materials. Among these silver chloride and silver bromide were found to be good windows at long wavelengths.

During World War 2 the Germans introduced two types of mixed crystals, KRS-5 and KRS-6, which could be grown from the molten state. Recently, semiconductor materials such as germanium and silicon have been adopted for use as lenses and windows. The last decade has seen the development of a wide variety of infrared transmitting glasses.

Optical filters are another class of components which has recently occupied the attention of workers in the field of infrared technology. The art of making multilayer interference filters has progressed to such a point that these items are now readily available. Semiconducting materials have also been used for infrared filtering.

In addition to this work, much has been done to develop means of detecting entire infrared images. These efforts have been along two lines. The first technique utilizes a single element or a multielement detector. Either the detector or the associated optics may be moved to scan the infrared scene. Electronic scanning of an extended-area detector upon which the entire scene is imaged is the second and more sophisticated manner by which an entire infrared picture can be obtained. Each of these methods can be used with both thermal and photon detectors, although because of its faster response the latter type is preferred.

The commercial uses of infrared are expanding rapidly. The utility of infrared as a tool for the identification of molecules and functional groups was realized by chemists in the late 1920's. Today this nondestructive means of material identification is used by industrial, medical, and other research scientists. Infrared is also being used to measure temperature whenever it is not practical or convenient to touch the heated object with a sensor.

Among the many possible examples of this are the monitoring of metal rolling or extruding processes, railroad hotbox detection, and temperature determination within an explosion chamber.

The military uses of infrared are legion. There are several reasons for this. First, most targets of military interest, vehicles, troops, airfields, factories, and the like differ from the general terrain either in temperature or emissivity or both. They therefore have different radiating characteristics which are difficult to camouflage and which can readily be seen by infrared equipment. Second, infrared systems can perform many tasks passively, that is, by utilizing the radiation which is emitted by the targets they seek. This has the advantage that the detection system does not disclose its presence in the way that a radar system does. Third, infrared, when compared to radio or radar, is capable of revealing considerably greater detail because of the shorter wavelengths being used.

Some of these advantages of infrared are utilized in each of the following types of equipment. Very compact and lightweight infrared equipments have been developed to guide missiles. Infrared can be used to acquire, track, and direct fire toward enemy targets. This field of technology makes it possible also to keep enemy movements under surveillance even in complete darkness. Infrared equipment can be used by the military to form a thermal image of terrain disclosing such things as streets, runways, buildings, and missile launching sites. Although active infrared systems forego one of the previously mentioned advantages, this type of system has been effectively used, for example, in the sniperscope, snooperscope, and communications devices.

MODERN THERMAL PHYSICS

Review of the 'State of the Art' as it applies to Medicine.

It can be shown that every object in nature emits radiant energy as a function of its absolute temperature while simultaneously absorbing some of the energy emitted in its direction by other objects in direct line of sight. Therefore, every object continuously absorbs and emits radiant energy. Objects which absorb more energy than they emit become warmer, and vice versa. It is the self-emitted radiant energy within the infrared region that is used in thermography.

The basic relationship derived by Max Planck in 1901 shows that the energy radiated by a perfect emitter, called a black body, at a particular temperature has an energy distribution which varies with wavelength. Planck's equation expresses this distribution curve thus:

$$W_\lambda = C_1 \lambda^{-5} (e^{C_2/\lambda T} - 1)^{-1}$$

W_λ is the spectral radiant emittance (emitted power per unit wavelength), C_1 and C_2 are constants, and T is absolute temperature (degrees Kelvin). It can be seen that radiation in a narrow wavelength band W_λ varies with wavelength and with temperature.

By setting the derivitive of the above form of Planck's equation to zero and solving it, we can determine the wavelength at which the radiation peak occurs. The result is Wien's displacement law, expressed as :

$$\lambda_{max.} = \frac{2897}{T}$$

Wien's law enables us to calculate the wavelength at which peak energy emission from human skin occurs. For skin surface temperature of 25 to 37 degrees C. (298 to 310 degrees Kelvin), this wavelength is about 10 microns. This is shown graphically for a black body in Figure .

If Planck's equation is integrated over all wavelengths, we can determine the total power radiated over all wavelengths by a black body at a given temperature (T). This is the Stefan-Boltzmann law, $W = \sigma T^4$, where σ is the Stefan-Boltzmann constant. Naturally occurring radiators such as human skin are not perfect and their degree of perfection is stated as a radiation efficiency factor called emissivity (ϵ). For practical applications, therefore, the Stefan-Boltzmann equation must be rewritten as $W = \epsilon \sigma T^4$.

From this equation we can see that if the radiated power (W) can be measured, we can determine temperature (T), provided the emissivity (ϵ) is known. Hardy[20] has shown that human skin is a nearly perfect absorber and emitter of infrared energy (ϵ = 0.989 0.01) in the infrared wavelength region beyond several microns. Figure taken from one of Hardy's papers[21] shows that for all practical purposes the human skin emits in a manner as if it were a black body over the region of 3 to 15 microns.

Fortunately, normal human skin has an emittance so nearly perfect that it cannot be made to appear hotter (greater than normal emittance) by application of foreign substances to its surface. Attempts to make it "blacker" have failed. Skin pigments which produce great differences in its appearance in visible light play no role in the long wavelength region where the skin is a nearly perfect emitter and absorber. This fact is clearly demonstrated in a striking series of photographs and thermograms of four individuals of different races in a recent report by Barnes.[22]

It therefore follows that if the skin is an almost perfect black body, its temperature can be determined by measuring the infrared energy it emits over a suitable wavelength region. The numerous factors which can affect the temperature of the skin have been discussed in an excellent paper by Barnes[23].

Several detectors are available for measuring infrared radiation, of which the flake thermistor, the thermopile and the indium antimonide semiconductor are presently the most widely used. The advantages of devices which are infrared-sensitive at a distance over those which actually contact the skin are (1) more rapid response, (2) area averaging, (3) lack of thermal loading, (4) greater accuracy. In addition, scanning or imaging devices can be constructed which rapidly produce a two-dimensional "heat-picture" or thermogram.

The input of an infrared detector is radiant energy from the human skin. The output is an electrical signal or a visible picture. Infrared-sensitive elements accomplish this detection of incident radiation by virtue of several fundamental properties, namely photo-conduction, the quenching of temperature sensitive phosphors, and the measurement of several thermal effects. The basic infrared detectors now in use are indium antimonide (photoconductive effect), thermistors (thermal effect) thermally-sensitive phosphors (phosphor effect), differential evaporation (evaporograph), and cholesterol crystals (liquid crystal detector).

One of the most commonly used photoelectric effects utilized in infrared detection is the photoconductive effect. This phenomenon occurs in a group of materials that absorb photon energy from infrared radiation to produce a change in resistance or conduction independent of any heating effects. The list of infrared-sensitive photoconductive materials developed by researchers in solid state physics is most impressive; however, indium antimonide is today the leading material for medical applications. This material has the disadvantage of being sensitive to only about 5.5 microns, and therefore only a small amount of the energy emitted by a given area of the human body is available for measurement. It has the advantage of having an extremely fast response time.

For infrared detection beyond 5 microns thermal elements are often used. The principle of these detectors is based upon the absorption of infrared radiation, which causes heating (unlike photoconductive devices, which are sensitive to photon energy). Heat causes secondary phenomena in the detector material, such as a change in resistance (bolometers), the generation of an electromotive force (thermocouples or thermopiles), or differential evaporation (evaporograph).

Bolometers are heat-sensitive devices which depend for their sensitivity on a change in the resistance of a material with temperature. Most of these devices can detect nearly all of the infrared energy emitted by a given area of the body. The metal -strip bolometer is a sensitive device containing thin strips of metal which undergo a change of resistance of about 0.3 to 0.4 per cent per Centigrade degree. The superconducting bolometer is a novel device which utilizes columbium nitrate immersed in liquid hydrogen. Although this apparatus has a fast response time and is sensitive beyond 20 microns, it is impractical for medical purposes.

Perhaps the most widely used device for medical, industrial and military applications is the thermistor bolometer. The thermistor contains a semiconductor substance with a large negative temperature coefficient. The thermistor itself is composed of a thin flake of nickel, cobalt and magnesium oxide mounted on a sapphire backing. The thermistor undergoes a change in resistance of about 4.0 per cent for each Centigrade degree. Its response time is not as rapid as that of photoconductive devices. It is the detector used in the Barnes Medical Thermograph, which is undergoing current evaluation by the American Cancer Society.

Thermocouples are thermoelectric detectors whose operation is based on the Seebeck effect; i.e., a voltage is generated across a junction of dissimilar metals. (Fig. 14) When the junction is blackened and placed so that infrared radiation can impinge upon it, the device functions as an infrared detector. A thermopile is merely a series of thermocouples suitably connected so as to provide a greater output voltage or current. These devices have a relatively poor response time.

The Golay pneumatic cell is another type of thermal detector which is about the only practical infrared detector for producing a useful output signal by mechanical effects. In its simplest form it consists of a small gas-filled chamber with an infrared transmitting window and a blackened receiver of very thin foil. When infrared energy falls upon the receiver, the temperature of the gas increases, causing the foil membrane to distend a small flexible mirror. The extent of distortion is measured by an optical system within the instrument.

Evaporography (Fig 14) is a means of measuring the thermal effect of infrared energy on a thin film of oil in an evacuated chamber. This detector will later be discussed at greater length.

42.

SCIENCE

Heat-Sensitive Eva

Electronic devices for seeing in very dim light have become commonplace, but all of them are blind in total darkness. Last week Baird Associates, Inc. of Cambridge, Mass. showed a recently declassified "camera" that needs no light at all, only infra-red (heat) radiation from faintly warm objects.

Baird's Evaporograph (Eva for short) is based on a prewar German idea which until recently was not followed up diligently. It has a concave mirror which concentrates heat rays as the mirror of an astronomical telescope concentrates light. Just before they come to a focus, the rays enter a vacuum chamber through a sheet of salt (transparent to infra-red) and form their image on the blackened surface of a thin sheet of plastic. The other side of the plastic is covered with a film of silicone oil.

When the heat-ray image forms on the plastic, the "bright" parts of it are warmer than the dim parts. Their heat passes through the plastic and evaporates part of the oil film, making it locally thinner. When light is turned on the oil film, it glows in the bright "interference" colors of an oil slick floating on water. The colors have nothing to do with the real colors in visible light of the object that Eva is viewing. They show thin or thick parts of the oil film—and therefore outline the object by its temperature. Hot parts show in one color, cool parts in another. Eva can distinguish 1° differences in temperature.

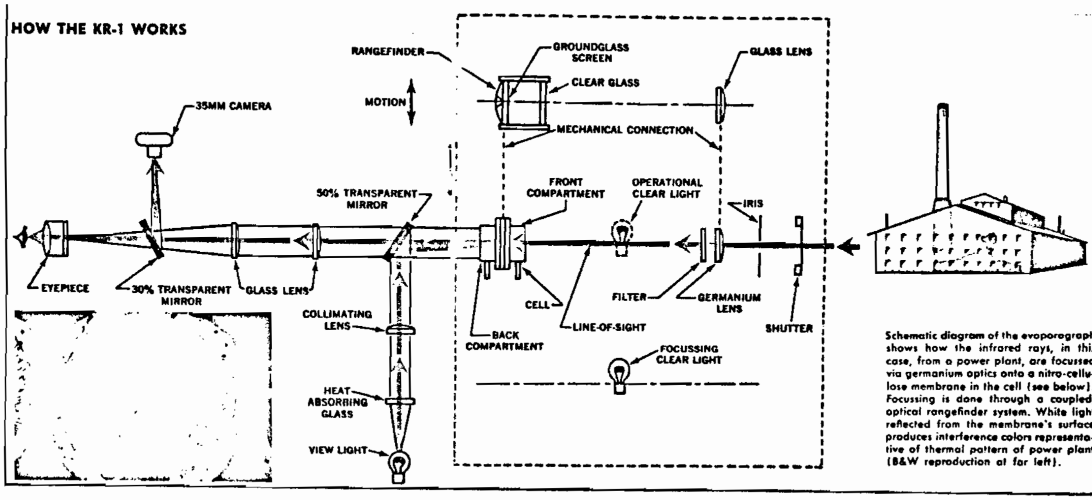
When Eva looks at an airplane in total darkness, the hot engine parts may show up yellow while the cold wings look blue. A heated house is visible against its cooler background, and factory chimneys stand out conspicuously with trails of hot gas. The heat-pictures on the film are bright enough to be photographed in black and white or color with an ordinary camera. A picture can be erased by heating the film momentarily and evaporating all the oil. In about two seconds the oil film forms again, ready for another picture.

Baird Associates workers had lots of fun looking at distant islands in Boston harbor on pitch-black nights and taking darkroom pictures of the office staff. One of the girls, photographed by the heat-rays flowing out of her skin, proved to have a cold nose.

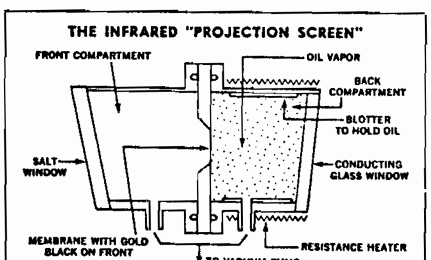
But Eva (cost: $9,500) was not built for such frivolity. The military uses are obvious. Blacked-out cities, whose warmth cannot be eliminated, will stand out conspicuously on Eva's screen. An underground factory will be betrayed by heat rising from it.

Many nonmilitary uses are also showing up. Since Eva was declassified, Baird Associates has been getting inquiries from industries that want to chart hot spots in electronic apparatus, find flaws in hot metal parts. Another obvious use is to check the insulation of a building by taking a snapshot of the heat escaping through its walls.

OIL-FILM PICTURES (AUTO, AIRPLANE, WARM GIRL WITH COLD GLASSES)
Hearts are yellow: noses are blue.



Schematic diagram of the evaporograph shows how the infrared rays, in this case, from a power plant, are focussed via germanium optics onto a nitro-cellulose membrane in the cell (see below). Focussing is done through a coupled, optical rangefinder system. White light reflected from the membrane's surface produces interference colors representative of thermal pattern of power plant (B&W reproduction at far left).



Heart of evaporograph is a sealed cell holding a nitro-cellulose membrane and heaters producing film of oil. Thermal image, entering from left, heats the membrane from point to point depending on intensity. Image thus produced causes oil vapor, condensed on membrane's reverse, to evaporate at different rates. This reflects as variegared colors in white light.

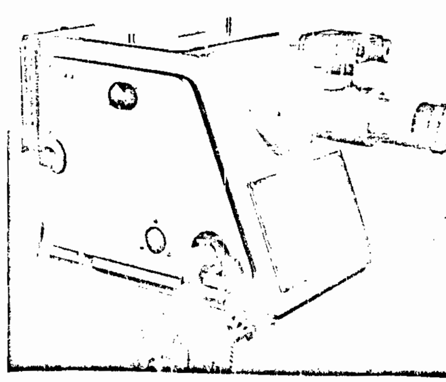


Fig 14.

Maser and laser concepts have also been applied to infrared detection. Devices which can operate within the wavelength region required by medical thermography are still in the research stages of development.

In 1949, Urbach, Nail and Perlman[24] described methods of making infrared thermograms using the fluorescence which occurs when certain materials have been excited by ultraviolet light. One approach requires that a phosphor material be applied directly to the surface of the skin. The skin temperature pattern is demonstrated by increased quenching of fluorescence as the temperature of the phosphor is increased. This technique has a temperature discrimination of about 0.1 centigrade degree. Warmer areas appear darker (more quenched), while cooler areas are lighter. It is currently being improved by the writer.

Yet another method currently in vogue for the display of surface temperatures on the body has been introduced by Dr. Fergason[25] of the Westinghouse Research Laboratories, Pittsburgh. It employs the so-called 'liquid crystals' of cholesterol derivatives. The cholesterol method depends upon the ability of liquid crystals substances, which share some of the properties of both liquids and crystals, to register minute fluctuations in temperature, mechanical stress, electromagnetic radiation or chemical environment, by changing their colour. In general, the substance is smeared on to the patient's previously blackened skin (an aqueous suspension of colloidal graphite is suitable) and illuminated with white light at an angle of about 45°. The type of crystals employed by Fergason reflect a colour spectrum of red - yellow - green - blue over designated temperature ranges of 2, 3, and 4°C respectively. Thermocouple measurements over different areas of the same colour showed the following maximal differences for liquid crystals with designated colour ranges of 4°C: Yellow .1°, red .6°, green 1.0°, blue 1.0°, dismissing arbitrarily designated areas of orange, light green and bluegreen. There are obvious objections to coating the skin with chemicals, especially where there burns and open wounds. Moreover the procedure is far from easy, and further difficulties lie in the preparation of permanent clinical records with an accuracy of calibration which will allow the patient's thermal condition to be compared over a period of weeks or months. Nevertheless, this method offers 'instant seeing' beyond the capability of any infrared scanner presently available.

Another thermographic device is the Westinghouse Thermoscope. It uses a cholesterol liquid crystal detector. This remarkable instrument uses the principle of instantaneous imaging (without scanning). Changes in temperature are manifested as changes in the light-reflecting properties of the liquid crystal detector. With a suitable light source it produces thermographic images in colour, or, with mercury light, in black and green. A unique feature of this device is that a simple switching procedure makes it possible to view the patient on the cathode-ray monitor scope directly in visible light, thus simplifying the anatomic location of the thermographic pattern. The detection time for this instrument is about five seconds.

The Barnes Medical Thermograph uses a thermistor detector and has a scanning time of about three minutes -- longer than that of all other instruments available (Fig. 15). The writer has used this instrument in thermographic research. It is claimed to have a temperature sensitivity of less than 0.1 degree C. and an optical resolution of one angular mil (one milliradian). The writer's images have not been satisfactory, and the cost of operation is too high because of the Polaroid film consumption. The main objections to the Barnes technique, (which will now be discussed) are: long-scan time, lack of resolution of images, and failure to obtain identical readouts on subsequent examinations. This latter drawback is no doubt due to the long scan time coupled with changing physiological states of the skin. It will later be pointed out that instantaneous imaging is both desirable and necessary for ideal infrared scanning.

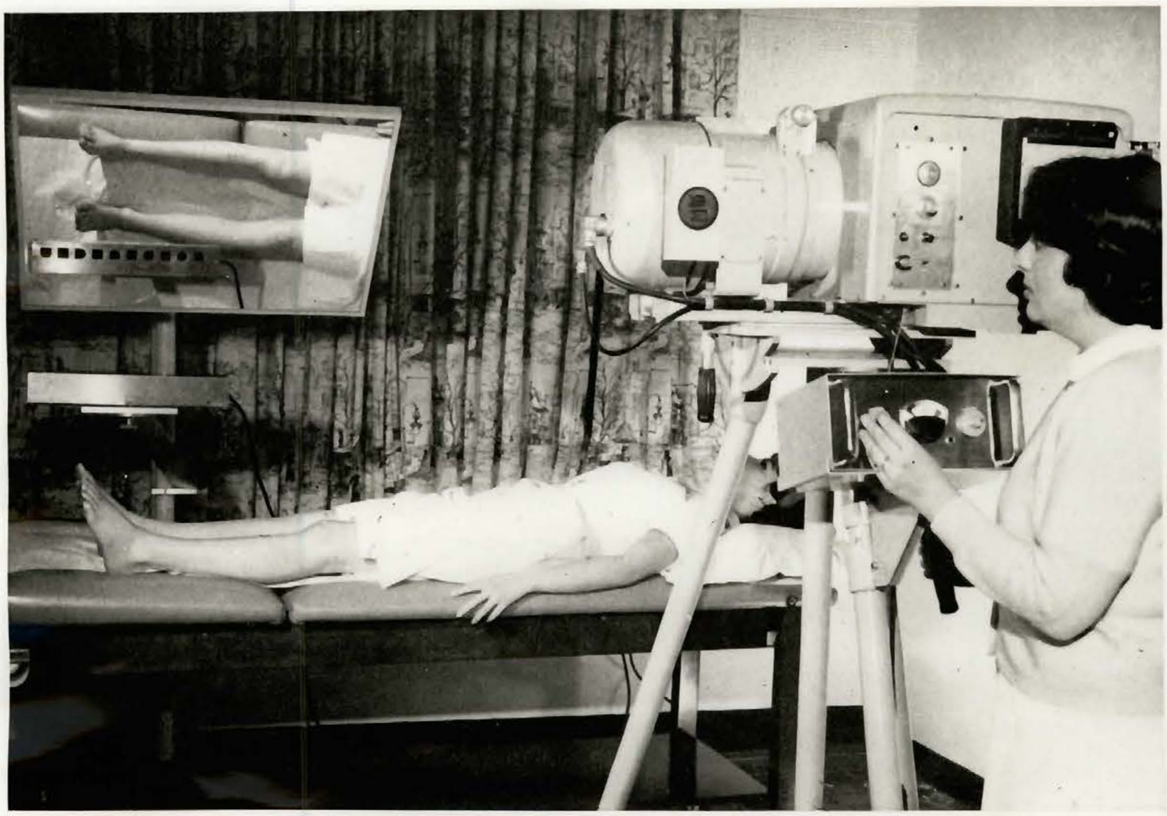


Figure 45 The Barnes Thermograph. Infrared radiation from lower extremities is reflected into the camera by the overhanging mirror, in which may be seen the thermal gray scale.

Description and Rationale of Thermographic Techniques Employed with Barnes I.R. Scanner

The average internal temperature of the human body remains essentially unchanged because the metabolic rate is regulated (37 degrees C., 98.6 degrees F., or 310 degrees K., measured orally), even though it be exposed for brief periods to extremes of weather, excessive exercise or overindulgence in food. The temperature of the skin, on the other hand, fluctuates widely, depending on many factors: structural abnormalities of vessels, abnormalities of vascular control, local effects on vessels from systemic reactions, changes in thermal conductivity in the tissues, and increased heat production in the tissues. There is also a constant exchange of infrared energy between the skin and its environment.

If, for example, the palms of the hands are held upward and apart and their temperature is taken, it would be found to be considerably less than "body" temperature - perhaps 29.4 to 32.2 degrees C. (85 to 90 degrees F.) - for the palms are losing heat to the ceiling in the exchange of energy. If they are turned toward one another and slowly approximated, one can begin at once to feel them heat up as they exchange radiation. When approximation is almost complete, both palms will have a temperature of about 37 degrees C. (98.6 degrees F.) in conformity with the body's internal temperature.

Because of this factor and the false positive influences of such things as clothing (which retains heat about the body), and convection by air currents, etc., the part to be thermographed is exposed, nude, for 10 to 15 minutes in a controlled ambient temperature of 21.1 to 22.2 degrees C. (70 to 72 degrees F.). Temperatures below 21.1 degrees C. (70 degrees F.) are uncomfortable for the patient. This period of exposure permits the skin temperature to come into equilibrium with the environment and tends to maximize the display of temperature differences. The patient may recline while the scanning is done, since the radiation emitted by his body can be reflected into the camera by a front-silvered mirror angled above him.

The infrared radiation is focused upon a sensitive thermistor and, by means of a rotating chopper, is compared 200 times per second with the energy being emitted by an ambient controlled temperature reference. After the radiation has been converted to an electrical signal by the thermistor and processed, the proportional output is used to control the intensity of a glow-modulator tube which emits visible light. This light is reflected from a mirror attached to the back of the scanning mirror and is made to fall upon Polaroid film in the camera. After each horizontal scan, a blanking circuit cuts off the glow-modulator tube during the period of rapid return, while simultaneously the scanning mirror is tipped upward by one line-width. The process is repeated until a vertical height of 10 degrees and a horizontal width of 20 degrees have been scanned. The optical system has an instantaneous field of view which is equivalent to 1/8 inch at a range of 10 feet.

Scanning of large body surfaces takes approximately 3 minutes. Small areas that do not require the vertical height of the film can be scanned in less time. With suitable electronic circuits, the sensitivity of the apparatus can be varied over wide values, so that the full capabilities of the film can be used effectively to cover the range of temperatures that exist over the surface of the part examined. The film of the scanned subject (thermogram) is available for study 10 seconds after the scan is completed, if Polaroid 47 film is used.

The final result is a quantitative two-dimensional thermal map of the patient's surface temperatures. Some 60,000 variations are depicted in a chiaroscuro of grays, the hot areas being portrayed in light shades, the cool areas in the darker tones. To facilitate calibration, 10 blocks with a series of known temperatures are included in the field of view of each thermogram, forming a "thermal gray scale" for comparison .

Current Medical Assessments of the Value of Infrared Imaging.

Discussion

This section is a summary of the current status of medical thermography. The technique is in its infancy yet it can pinpoint areas of undue physiologic and metabolic activity. It promises to be of considerable aid in the diagnosis, prognosis, and treatment of disease. To be diagnostically reliable, thermograms must naturally represent faithfully the actual temperature changes occurring within the body. Certain qualifying factors should therefore be kept in mind. Fat, a poor thermal conductor and a good insulator compared to skin, will show up as "cold" on thermograms, as one would expect. So will the skin over bony prominences, such as knuckles and knees, where the vascular supply is less abundant. Where cross-radiation occurs because of skin infolding, such as the region of the gluteal folds, the umbilicus, the canthi, and the areas between fingers held close together, the regions will of course appear "hot". Thermography must not be confused with infrared photography, which requires that the subject first be illuminated with an external source. Infrared photographs can be taken with any ordinary camera equipped with film sensitive to rays at the red end of the spectrum and a filter to eliminate visible light.

Thermograms, on the other hand, can be taken in total darkness and the subject needs no illumination. Although the technique of thermography is now in its infancy - about where radiology stood at the turn of the century - its horizons are too broad to define. Engineering compromises that exist in present equipment will undoubtedly be subject to improvement with time. The investigation of the infrared portion of the electromagnetic spectrum occurring as a corollary of the missile and space programs cannot help eventuating in more precise and sophisticated devices. It can be said that thermograms may be likened to fingerprints. It has definitely been shown that when repeat satisfactory thermograms are done on the same person, duplicate thermal patterns are obtained unless some significant physiological change has occurred in the subject. Thermography may be used to supplement other diagnostic systems. However, this new technique is capable of giving information of a highly desirable nature which has heretofore been unobtainable by any other means. It should be of special value to roentgenologists, who already are accustomed to analyzing various shades of gray in roentgenograms.

At a conference held in New York City, (sponsored by the New York Academy of Sciences) in December 1963[26], the potentials of thermal scanning in medical diagnosis were appraised. The technique was felt to have value in many fields and conditions, among them obstetrics, gynecology, orthopedics, oncology, rheumatology, dermatology, peripheral vascular disturbances and infections. Some of the more important observations disclosed then and others more recently made will be discussed.

(26) Monograph of The New York Academy of Sciences on "Thermography and Its Clinical Applications", Vol. 121, Art.1. Oct. 9, 1964 (303 pp).

Breast Diseases.

The technique of thermography was first applied to patients with breast cancer by the writer in 1956[27]. The Baird Evaperograph was used for this on the Company's premises, 33 University Road, Cambridge, Massachusetts. The subjects used for this initial testing were one patient from the outdoor clinic at the Royal Victoria Hospital, Montreal, and two patients from the New England Deaconess Hospital, Boston. All these patients had obvious clinical cancer. The thermograms in each showed increased temperature over the tumour site. As a result of these tests it was concluded that the Evaperograph technique, while interesting, was too crude to add anything to clinical diagnosis. Further studies were made by the writer on the Barnes optical scanner the following year, immediately it was militarily declassified[28]. The shortcomings in the Barnes scanner appropos medical applications, were pointed out to design engineers at the time. The following year a much faster optical scanner was obtained and tested[29]. Significant improvement in the images was obtained but this scanner had an unstable indium antimonide detector cell. The problem was to stabilize the intrinsic temperature of the cell. Work was commenced on this problem. This involved essentially the employment of controlled nitrogen evaporation.

(27) Lawson, R.N., Can. Med. Ass. J., 75: 309 (1956), "Implications of Surface Temperatures in the Diagnosis of Breast Cancer".

(28) Lawson, R.N., Can.Servvices Med.J., 13: 517-524 (1957). "Thermography - A New Tool in the Investigation of Breast Lesions".

(29) Lawson, R.N., Can. Med. Ass. J., 79: 402-403 (1958), "A New Infrared Imaging Device".

Mr. Lloyd Williams, surgeon at the Middlesex Hospital, London, England, reported an infrared survey of two hundred cases of breast cancer[30] in 1960. One hundred and eighty of these patients showed a 1 C degree. rise in the skin temperature over the breast when carcinoma existed. His series was extended in 1961[31]. R.S. Handley, following the suggestion of the writer, published an essay implying that the absolute temperatures could be used as a guide to prognosis[32]. Further studies by the author were published in 1963[33]. In this work it was shown that the abnormal increases in temperature associated with breast cancer were the result of the local matabolic disturbances rather than increase in circulation about the tumour. At this point J. Gershon-Cohen, Radiologist in Chief of the Albert Einstein Medical Center, Philadelphia became interested in this technique, and published his results of breast surveys in conjunction with R. Bowling Barnes, President of the Barnes Engineering Company, manufacturers of the scanner. Dr. Gershon-Cohen was so impressed with the potential scope of thermography in clinical medicine that he acquired the necessary funds and created a diagnostic section in his hospital, completely devoted to thermography as a distinct specialty. He has published a great number of papers describing his results.[34 to 46]

It is a rather curious fact that all the published papers concerning thermography in the detection of breast cancer that have so far come to this writer's attention, are extremely optimistic about the potential of the technique. For instance J.F. Connell, Jr., et al [47] summarized their review of more than three hundred patients with symptomatic breast lesions as follows - "Thermographic Techniques of recording the emission of infrared heat from the human breast is based on the principle of Lawson et al., who indicated that the infrared heat from a carcinomatous mass is a result of both local increased cellular metabolism and vascularity. This study was controlled either by biopsy or excision of the lesion. The results indicate that infrared thermography is an extremely useful aid in cancer detection, evaluation of benign conditions in the human breast and as a follow-up procedure in determining the efficacy of tumour therapy.". At the time of this writing, the First International Congress on Thermography is being held at the University of Strasbourg under the chairmanship of Professor Ch. Gros,(March 26, 1966). This student declined an invitation in order to write this thesis, and also for reasons to be mentioned in the next few pages.

In addition to the diagnosis of breast disease thermography is currently being assessed in many other medical situations.

Placental Localization. Numerous claims have been made that it is possible to locate the placenta thermographically, with complete maternal and fetal safety, avoiding the hazards of radiation from roentgenography and the use of radioactive isotopes for placental localization.

The placenta, a site of dynamic biologic activity, is warmer than surrounding tissues and liberates heat which is conducted to the surface of the abdomen. This temperature rise is portrayed on the thermogram as a well defined area and indicates the placental site with significant accuracy[48, 49]. Cohen et al.[50], have had occasion to check the placental location at term in 54 cases, and in 48 of these the thermographic indication was correct. Eleven patients had roentgen placentography and of these, 4 subsequently underwent caesarean section. In 6, the placental site was confirmed by visualization at cesarean section. Two of the 6 patients delivered by section had complete placenta previa, and were demonstrated thermographically. The remaining 37 placental sites were determined by manual intrauterine exploration before placental separation had occurred.

Pregnancy. During the first trimester of pregnancy the heat patterns of the breasts are similar to those seen in women taking contraceptive drugs. Pregnancy can be detected as early as two weeks after conception provided a pre-conception thermogram is available for comparison. In a non pregnant woman the breasts are uniformly cool. Those of a gravid woman are warmer. Beginning with the second trimester, the skin temperature increases more markedly, and by the third trimester the intensity of the skin temperature elevation is unmistakable. The administration of oral contraceptives produces the appearance of a pseudopregnancy state and, thermographically, the breasts reveal temperature patterns very similar to those seen in pregnancy. The breasts of some non-pregnant patients respond less markedly to the effect of anovulatory drugs, and the patterns of increased temperature are less pronounced and less uniform. Such circumstances may make the interpretation of breast disease from the thermographic picture more difficult.

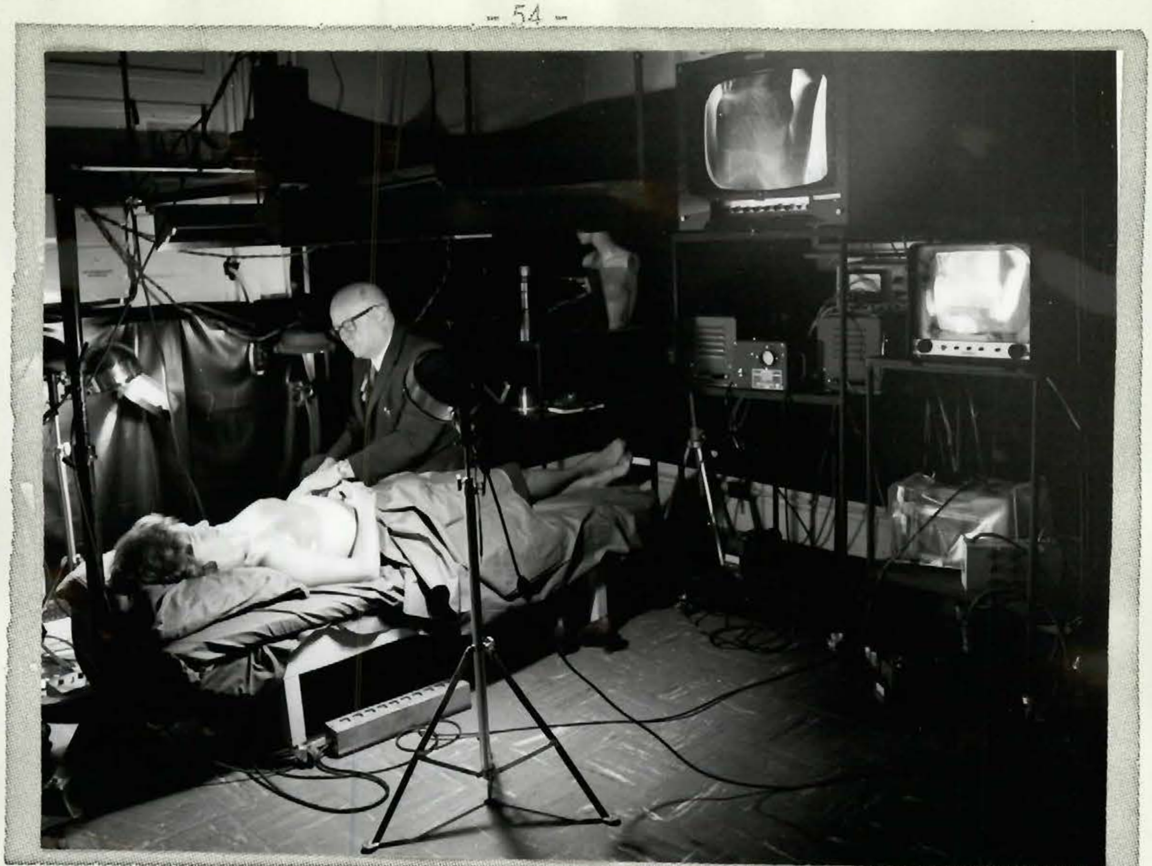


Fig. 11

Phosphor thermography. In the early stages of this work phosphor was applied in spray form to the breast. The area was then exposed to longwave ultraviolet radiation and the temperature patterns observed on the monitor. Temperature anomalies were checked with a thermistor probe. Areas of increased temperature were found to correlate precisely with areas of decreased fluorescence.

CONCLUSIONS FROM REVIEW OF THE LITERATURE

From the foregoing summary of the literature it is apparent that thermography, while relatively untested, is a new medical tool of great potential value. The practical applications of a good thermographic technique, moreover, are extremely varied. Because of both the novelty of this new approach and, in the writer's opinion, the inadequacy of the instruments currently being applied to medical problems, it is clear that developmental engineering efforts directed to instrument improvement are urgently required, and should take priority over clinical work. A sufficient amount of data now exists to justify appropriate financial support for both applied and basic thermal research in medicine. Available evidence supports the contention that in at least ninety percent of patients with breast carcinoma, abnormal temperature elevations of 1 centigrade degree or more appear in the breast skin somewhere over the lesion. In addition there are intimations that the degree of clinical malignancy bears some direct relationship to the degree of temperature increase. Therefore it is a fair assumption that the presence of factors that exert an inhibitary effect on tumour growth may be revealed by a nulling effect on this abnormal temperature rise. The development of measuring equipment that would efficiently reveal changing temperatures on the surface of the body would be most desirable. Such a tool should be of great value particularly in cancer research.

PRESENT STUDY, GENERAL DESIGN, OBJECTIVES, COMPONENTS, PROCEDURES.

Broad Objectives

This study was carried out to determine whether or not new thermal information could be acquired as the result of application of heat quenched phosphors to the surface of the body. The scope of the work will include the testing and development of appropriate techniques and instrumentation to provide optimum thermal imaging. It is desired to compare and evaluate heat patterns derived from phosphor fluorescence and those obtained from optical infrared scanners.

PHOTOMETRIC UNITS AND DEFINITIONS

The study of fluorescence intensity requires application of photometric science. Photometry (60 - 66) deals with the measurement of visible light, and the flow of light from a source to a receiver. Photometry is based on the concept of a mythical 'standard candle', which is a source having an intensity, or illuminating power, of one 'candle' now called the candela, and defined as one sixtieth of the intensity of a blackbody of one square centimeter in area at the temperature of melting platinum (2,046°K). However, the working standards are a number of carefully calibrated tungsten-filament lamps kept at various national standards laboratories.

The illumination produced by a source of 1 candle intensity at a distance of 1 foot is called a foot-candle. Illumination exists in space whether there is anything to be illuminated or not. We cannot see light itself; we see only the object that is illuminated, or an object that is self-luminous (Fig. 16). If the receiver is inclined at an angle to the direction of the light, the illumination is reduced by a factor of cos. θ (where theta is the angle between the direction of the incident radiation and the perpendicular to the plane of the receiver), and if the receiver is

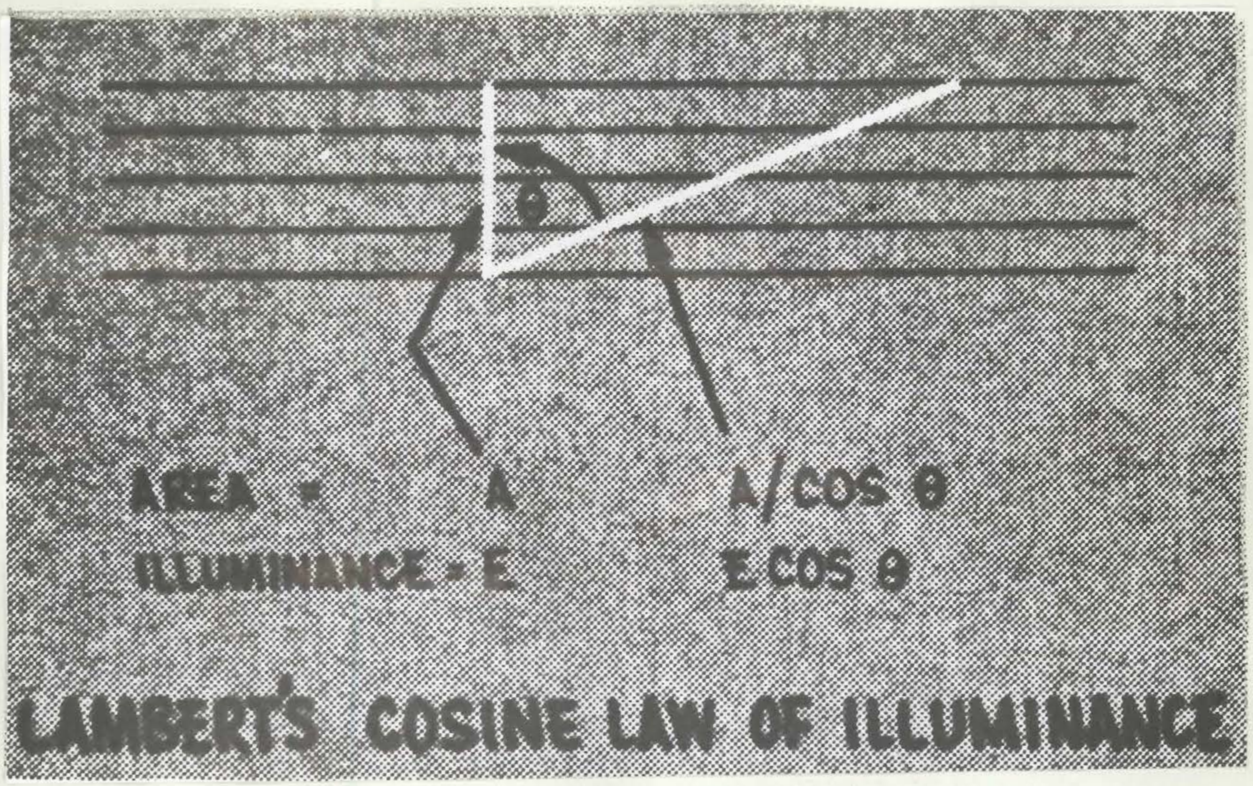


Fig 16

edge-on, it is not illuminated at all even though there is considerable illumination streaming past it. The illuminance produced by a given small source falls off as the square of the distance from the source (the inverse square law) (Fig. 17.). Hence the illumination at a distance of 1 meter from a source having an intensity of 1 candle is 1 meter-candle, which is much smaller than a foot-candle (i.e., 10.7 meter-candles equal 1 foot-candle). There is a recent trend to use the foot candle as a unit of illuminance, leaving the word "illumination" to refer to a process rather than to some measurable quantity.

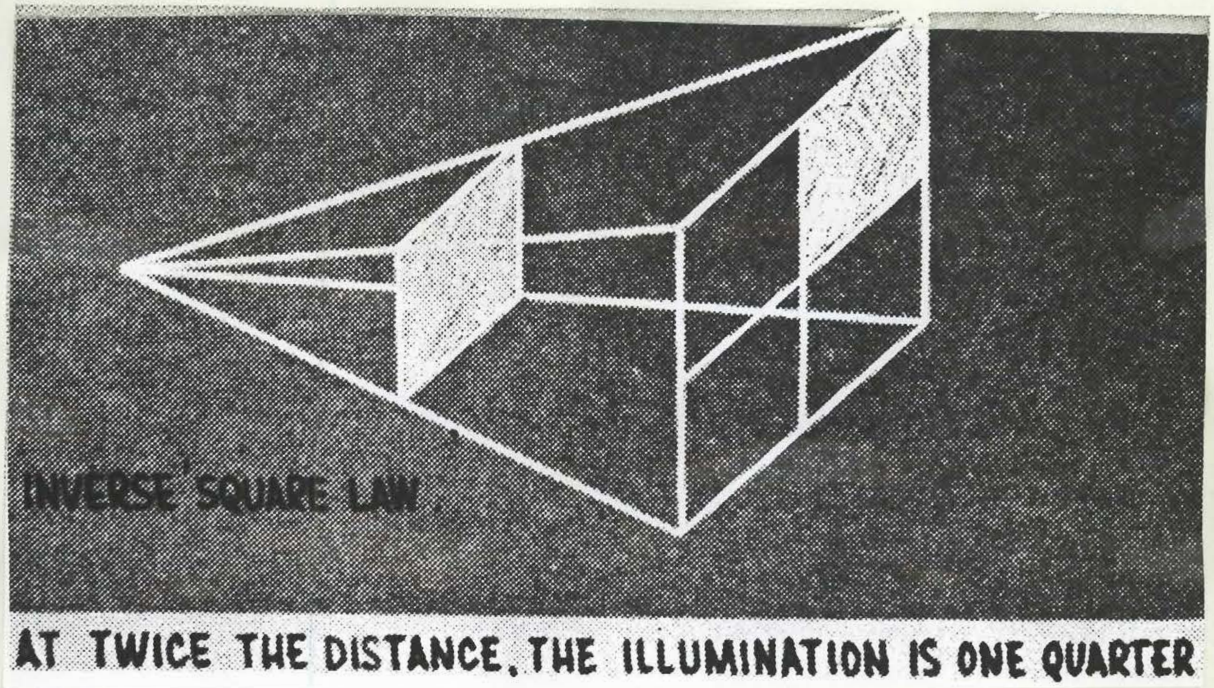


Fig. 17

The inverse square law.

The term 'lumen' is used to express the amount of light flux proceeding from a source to a receiver. Thus, the lumen is defined as the amount of flux flowing from a point source of 1 candle intensity into a cone having a solid angle of 1 steradian. In Figure 18 we see a point source of I candles sending light to a small screen of area "A Sq. Ft" at a distance of L feet from the source. The solid angle of the cone is A/L^2 steradians, and the flux in this cone is therefore IA/L^2 lumens. By the inverse square law, the illuminance on the screen is I/L^2 foot-candles; the flux density of the light falling on the screen is $(IA/L^2)/A = I/L^2$ lumens per square foot. Thus, we can establish the complete

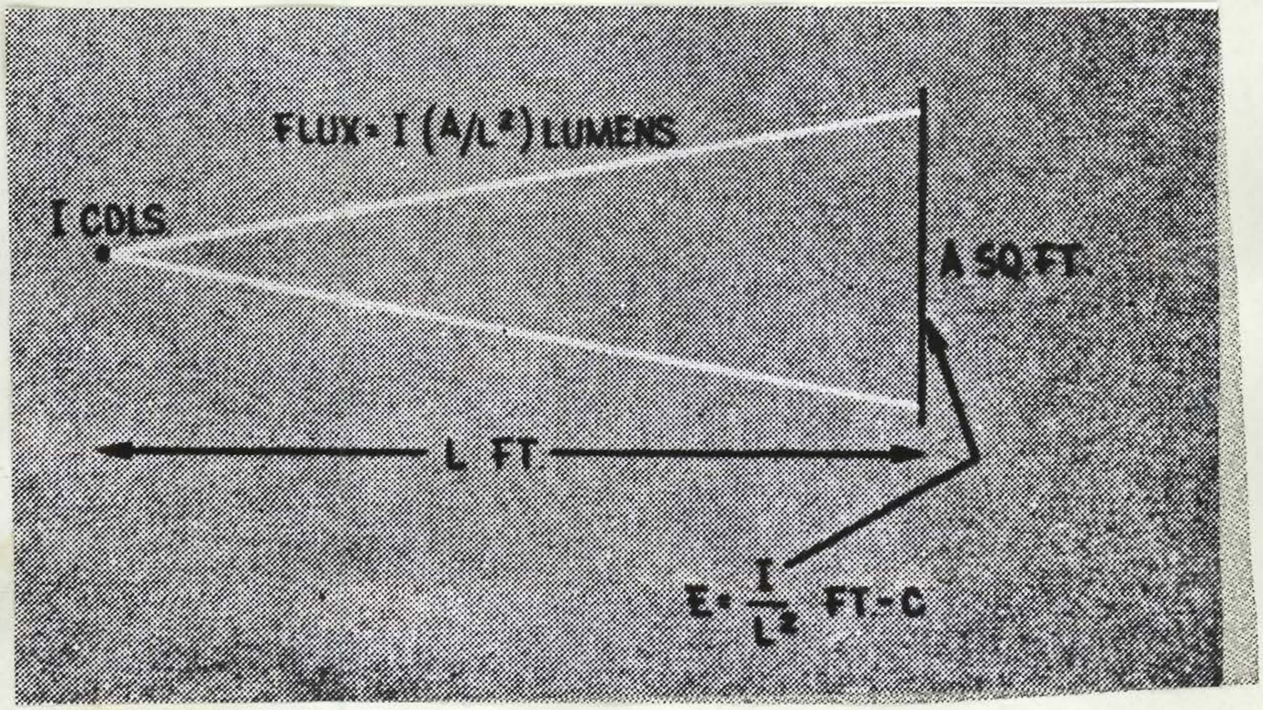


Fig. 18

Lumens per square foot .

identity of lumens per square foot and foot-candles.

The luminance of a source is defined as its candle power per unit area. For lamps and other bright sources this is commonly expressed in terms of candles per sq.mm; for low-brightness objects, the luminance is better expressed in candles per sq.foot or candles per sq. cm. The normal intensity of a flat source of area A and luminance B is $I = AB$ candles (see figure 18). However, if the source is perfectly diffusing, its luminance will be the same no matter from what direction it is viewed. Its intensity in an oblique direction

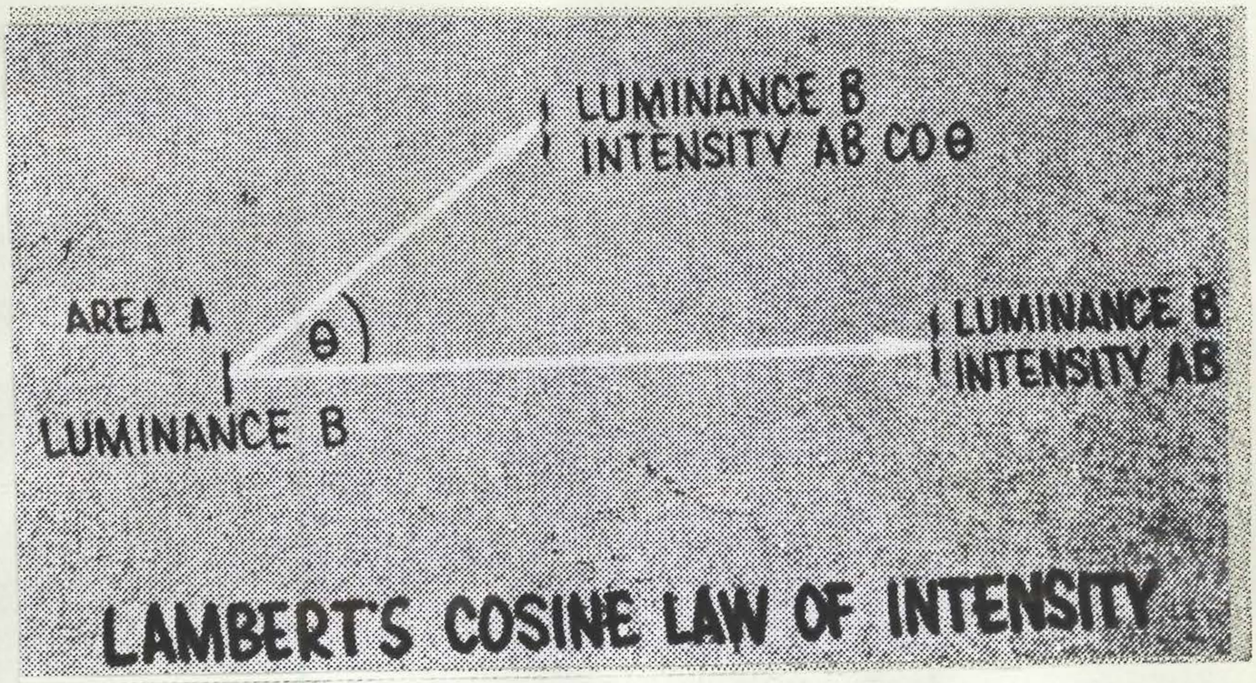
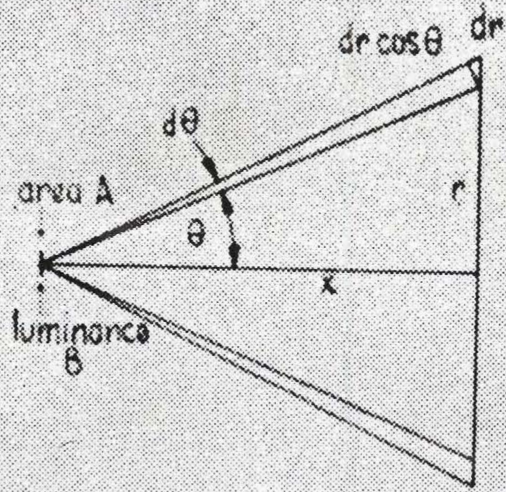


Fig. 19.

will be only AB cos. θ , its edge-on intensity when $\theta = 90^\circ$ being zero.

We now come to the problem of calculating the flux radiated by a plane source into a cone of half-angle θ . This will be much less than if the source were a point because the source will appear fore-shortened at the outer border of the cone. An integration must be performed, using the steps shown in Figure 19.. The flux in the conical shell bounded by angles θ and $(\theta + d\theta)$ is given by AB cos. θ multiplied by the solid angle of the shell, namely,

$$\left(\frac{2\pi r\, dr \cos\theta}{x^2 \sec^2\theta} \right)$$



$$\text{Solid angle of shell} = \frac{2\pi r\,dr\cos\theta}{(x\sec\theta)^2}$$

$$\text{Intensity in direction of shell} = AB\cos\theta$$

$$\text{flux in shell} = \text{Intensity} \times \text{solid angle}$$

$$\therefore dF = \frac{2\pi AB\,r\,dr\cos^2\theta}{x^2\sec^2\theta}$$

$$\text{But } r = x\tan\theta \quad \text{and} \quad dr = x\sec^2\theta\,d\theta$$

$$\therefore dF = 2\pi AB\sin\theta\cos\theta\,d\theta$$

$$F = \pi AB\int 2\sin\theta\cos\theta\,d\theta$$

$$\therefore F = \pi AB\sin^2\theta$$

Fig. 20

Calculating the flux radiated by a plane source into a hemisphere.

Writing everything in terms of θ, we integrate the expression and find the total flux to be $F = \pi AB\sin^2\theta$, the flux emitted by this source into a complete hemisphere, for which $\theta = 90^\circ$ is πAB. For a point source having the same intensity I = AB candles, the flux sent into a hemisphere would be $2\pi I$, or exactly twice as much as for the plane source.

This leads to the concept of the lambert unit of luminance, as applied to a diffusing source. The lambert is defined as such a luminance that 1 square centimeter of it will radiate 1 lumen into a hemisphere. If the surface luminance is B candles per square centimeter, or B_L lamberts, then the flux radiated into a hemisphere by 1 square centimeter of the surface will be $B_L = \pi B$. The lambert is about one-third as great a luminance as the candle per square centimeter, but it represents a very high level of brightness, comparable to the brightness of white paper in sunlight. The millilambert is a much more commonly used unit.

If the English units are preferred, the term foot-lambert is such a luminance that 1 square foot radiates 1 lumen into a hemisphere. Since there are 930 square centimeters in a square foot, there are 930 foot-lamberts in a lambert; the foot-lambert is a little larger than the millilambert.

There are several photometric terms found in European technical journals: The 'Phot', or centimeter-candle is 10,000 times as large as the 'lux', or meter-candle. The 'stilb', or candle per square centimeter, is 10,000 times as bright as the nit, or candle per square meter. The 'apostlib' is a ten-thousandth part of a lambert, or a tenth of a millilambert.

The last problem will be to determine the luminance of a diffusing surface when it is seen under a given illuminance. Suppose the illuminance is E and the receiver is A; the flux falling on it is AE lumens. A fraction k of this flux will be scattered into a hemisphere; if the luminance is B candles per square unit, we have the equation:

Flux radiated = k times flux received

therefore $\pi AB = kAE$

or $$B = \frac{kE}{\pi}$$

Or expressing the luminance in lambert units, $B_L = kE$

The value of k is always less than one. For white paper it is about .93; for a dark table top it may be only 0.1 or less. It may be called the reflectivity of the surface upon which the illumination falls. From this we see that a diffusing surface under an illumination of 1 foot-candle has a luminance of approximately 1 foot-lambert.

PHOSPHORS

A phosphor is any substance which exhibits luminescence. Phosphorescence is defined as luminescence delayed by more than 10^{-8} seconds after excitation. Fluorescence is the process of immediate emission of electromagnetic radiation as a consequence of absorption of energy from an exciting source, such as x-rays, ultraviolet, visual, infrared radiation, or election beams. Fluorescence is a luminescence that ceases within 10^{-8} seconds after excitation stops. At the present time a multitude of organic and inorganic phosphors are used in fluorescent lighting, television, radar, paints, inks, and a variety of radiation detecting instruments. The current exploitation of phosphor properties is such that the total annual world production is estimated to be more than one million pounds in spite of the fact that most applications require extremely small amounts of the material, less than 1 gram in many devices.

The word phosphor comes from a Greek word meaning "light carrier" (phos: light; phorein: to carry). From the same Greek is derived the name of the element phosphorus which, upon exposure to natural weathering, emits light. This has been shown to be due to the chemical release of energy by oxidation of the element. Photoluminescent phosphors are substances which absorb electromagnetic energy, usually ultraviolet 'light', C4.

Fig. 21

An assortment of phosphors. These were examined for thermographic potentialities.

and then re-emit this energy in the form of visible light. The absorption of energy by the phosphor is called "excitation" of the phosphor, and the release of the energy is called "fluorescence". The differences in wavelength of the absorbed and emitted light is an important property of the phosphor because the material as a consequence does not reabsorb much of the light it emits. There are many natural phosphors, such as the minerals Willimite (zinc orthosilicate); Wurtzite (zinc sulphide); Fluorite (calcium fluoride). The preparation of good photoluminescent phosphors evolves quite sophisticated chemical processes, and the composition must be rigidly controlled. The property of fluorescence is known to be due to the presence of small amounts of impurities in the compound, called "activators". There is a great deal of secrecy in the industry about technical production details and some companies absolutely refuse to reveal the chemical formulas of their phosphors. (Fig. 21)

There is much interest in the electronic industry today in the application of thermographic phosphors, particularly in reliability testing of miniature circuitry. In operating electronic devices there is a theory that "the hotter the operating temperature of a unit the shorter the life". To the extent that this theory has validity, a means of quickly, repeatedly, and positively determining which units and which parts of the units were at a higher temperature would be a valuable tool in reliability studies. When units fail under load, even on short time periods, there must be a locus for the initiation of the failure. This locus must exist some finite time before, and at a lower load than the final failure point. This locus will be at a higher temperature than other areas. The same means of examining temperature distribution again would be a valuable tool. If one can observe the temperature distribution accurately, one could use such observations to improve heat sink paths, determine safe power dissipation ratings both for types of devices and also for individual units in a production line so as to reduce the probability of escape of manufacturing faults. A good deal of work has been done on determining junction temperature. Such a means of observing, directly, junction temperature distribution would be a valuable tool. The phenomenon known by the term "second breakdown" in transistors seems to be related to either a localized or general heating of certain parts of a semiconductor crystal.

Although the temperature sensitivity of inorganic phosphors has been known for many years, it was not until 1949 that Franz Urbach, of the Eastman Kodak Company, Rochester, N.Y. commenced formal study of the actual temperature distributions (Fig.22). He was prompted to methodically investigate the heat quenched effects because of troubles he encountered in developing a built-in automatic exposure meter for Eastman cameras. At this time the heat quenching properties of some of his phosphors were a most undesirable attribute. The Eastman Kodak Company were not interested in commercially exploiting Urbach's work and his patents were assigned to the New Jersey Zinc Company. This firm was sold in 1956 to the U.S. Radium Corporation, and in the past few years this company has undertaken further developmental efforts to determine optimum phosphor characteristics for a variety of applications. A sample of a thermographic phosphor was submitted to the writer in 1957 by Mr. Henry Lott, phosphor specialist, employed by Canadian Westinghouse Company, Hamilton, Ontario. At the time, the inconvenience of applying it in powder form seemed too great for practical application, and in addition the lack of equipment for proper calibration discouraged a formal investigation. Following a medical seminar on Surface Temperature Measurements delivered by the writer to the engineers of the

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Fig. 22.

Left - Dr. Franz Urbach, Eastman Kodak Co. Rochester, N.Y., with writer, September 1965.

General Electric Company, Schnectady, in July 1963, the problem was again discussed. An aerosol spray preparation was made available. Feasibility studies of this technique were completed and reported[67].

Zinc cadmium sulfide phosphors are extremely insoluble, and their preparation in aerosol spray form involves certain problems. The proprietary vehicle utilized by the General Electric Company was analyzed and found to consist of 5% of a mixture of 70% polyvinylpyrrolidone - 30% vinyl acetate. This combination is in a 50% solution in anhydrous ethanol. The other ingredient is 15% isopropyl alcohol. This suspending formula is commonly used as a commercial hair spray. In addition to this vehicle, a ball bearing about 1 cm in diameter is placed in the spray can, and the chemical agent is propelled by freon gas. In order to obtain an even spray the mixture must be vigorously shaken before applying.

A good thermographic phosphor was obtained from Derby Luminescents Ltd. England. The formula of this material (phosphor grade 114E) has a similar formulae to the Radelin material - 42.5% CdS, 57.5% ZnS, less than 0.004% Ag, less than 0.003% Ni, and a trace of halide from the flux salts.

The phosphor employed for the greater part of this study was obtained from Dr. Robert Byler, The United States Radium Corporation, Morristown, New Jersey. It is designated Radelin 1807. The chemical nature of this phosphor is: 59% cadmium sulfide, 41% zinc sulfide, less than 0.05% silver, less than 0.005% nickel, and a trace of halide from flux salts. Another thermographic phosphor obtained during the past two weeks, designated as Radelin 1962 which shows more complete quenching characteristics than Radelin 1807, contains 53% CdS and 47% ZnS.

Thermographic phosphor applied in spray form has the disadvantages of difficulty in applying a uniform coating to the skin, and of drying, wrinkling and cracking of the applied coating after about eight minutes.

The question of cadmium toxicity brought this project to a temporary halt, and during the time the potential health hazards were being evaluated, the idea occurred to this student of incorporating the material in a plastic adhesive type film which could be conveniently applied to and removed from the skin. Such a vehicle would reduce any chemical hazard and also expedite the clinical technique. Cooperation with the Minnesota Mining and Manufacturing Company of St. Paul, Minnesota, was sought and obtained. Mr. Robert L. Goodlad of their Medical Products Laboratory undertook the project of developing an optimum tape vehicle and the ascertainment of the most suitable phosphor thickness for human application. This work is still in progress, and involves many interesting problems. At the present time Mr. Goodlad's phosphorized tape is being tested by over fifty medical investigators. One of the advantages of the tape is that it can be sterilized in a gas autoclave. The writer is receiving many requests each week for details of the tape application to thermography.

TOXICITY

Cadmium toxicity hazards were discussed following a paper delivered by the writer to the annual meeting of the Society of Photographic Scientists and Engineers, Washington, D.C., October 1964. Dr. Herman Erikson, Polaroid Corporation, 730 Main Street, Cambridge, Mass., offered support for this project but withdrew it because of the hazards, in his opinion, from cadmium poisoning. Therefore it was mandatory to fully evaluate this situation before continuing any work involving humans. Standard text books[68,69,70] on Industrial Hygiene and Toxicology were of little assistance, and a search of the literature on cadmium was made. Authorities such as Herbert E. Stokinger, Chief Toxicology Section, Division of Occupational Health, United States Public Health Service, Cincinnati; Dr. Willard Johnson, Pure Food and Drug Division, Department of National Health and Public Welfare, Tunney's Pasture, Ottawa, were consulted. In addition chemists at the firm of National Semiconductors Limited, 2150 Ward Street, St.Laurent, Quebec, who had been working in a cadmium sulfide environment for many years were interviewed. Experts of the Mine Safety Appliances Company, Montreal and Pittsburgh, were also consulted about cadmium hazards.

Cadmium is known to be a dangerous metal. Dermititis from cadmium plating is a common ailment. The soluble salts are all extremely toxic to humans. However, it was impossible to obtain any data incriminating cadmium sulfide as a cause of human or animal poisoning. The inference is that this insoluble salt behaves much in the same way as barium and its components. Dr. J.D. McColl of Frank W. Horner Limited, Montreal, attempted to determine the acute toxic dose of our thermographic phosphor in rats. He was unable to find an LD_{50}. Doses up to 6.4 Grams/kg (in carboxymethylcellulose) were administered orally to a total of 35 Sprague-Dawley rats. No signs of toxicity were observed up to 24 hours. The animals were then killed for gross and histological examination. No significant pathology was seen as a result of this phosphor feeding experiment.

Chemists associated with Dr. Willard Johnson's group in the Government Toxicology Laboratories, Ottawa, undertook chronic toxicity studies in 1965 on rabbits, rats, mice, and hampsters, utilizing their new facility for testing aerosol sprays. At the end of three months they were unable to detect any evidence of poisoning.

The group representing the General Electric Company, X-Ray Division, Milwaukee, conducted formal toxicity tests at the Wisconsin Alumnae Research Foundation Laboratories, Madison. They were unable to elicit any evidence of toxic changes, and are now applying for the necessary clearances and authorizations for clinical application. Their studies have followed the regulations laid down for appraisal of the Safety of Chemicals in Foods, Drugs, and Cosmetics, The Association of Food and Drug Officials of the U.S., 1959, Division of Pharmacology, Food and Drug Administration, Washington, D.C.

It is interesting to note that Pitman-Moore, Division of Dow Chemical Company, Indianapolis, have marketed a shampoo product called "Capsebon" for many years. This contains 1% cadmium sulfide[71, 72], and has been approved by the Food and Drug Administration of the United States.

It is concluded from the above data and source material, that no practical health hazards exist with the application of these thermographic phosphors to the human body.

FLUORESCENCE CHARACTERISTICS OF THE PHOSPHOR (Radelin 1807)

This type of phosphor has a non linear relation between the intensity of excitation of near ultraviolet light and the intensity of the resulting fluorescence at a given temperature (Fig.24) . The temperature range at which the sensitivity to temperature is at a maximum may be controlled by the concentration of trace elements incorporated in its activities and also by details in the furnacing during the manufacturing process. The fluorescence spectrum (Fig.23) has its peak in the yellow, providing a good match to the spectral response of the eye. The temperature sensitivity is also a function of the near ultraviolet illumination intensity and resulting fluorescence intensity of the phosphor, as may be seen in the characteristic curve. It is seen that an illumination intensity of ultraviolet radiation which gives a phosphor brightness of 0.001 Foot-Lamberts, the brightness change is about 30%per centigrade degree, while at 1 Foot-Lambert (about the brightness of a television picture tube) the sensitivity is down to 15% per centigrade degree. One may make an estimate of the smallest difference detectable by the unaided eye by using the commonly accepted value of 2% for the minimum difference in brightness detectible by the dark adapted eye viewing a uniformly bright extended target surrounded by a background of slightly different brightness with a sharp boundary between the two areas (Fig. 24. work of Konig and Brodhun). Using this figure of 2% minimum perceptible brightness differnce yields a minimum perceptible difference in temperature of about 0.1 centigrade degree for the dark adapted eye. In the practical use of the phosphor technique, however, the observer would generally not have time for the eye to become dark adapted, and furthermore one would prefer to have a temperature difference of 0.1 centigrade degree easily visible, rather than just barely perceptible. Also the boundaries between areas of different brightness seen

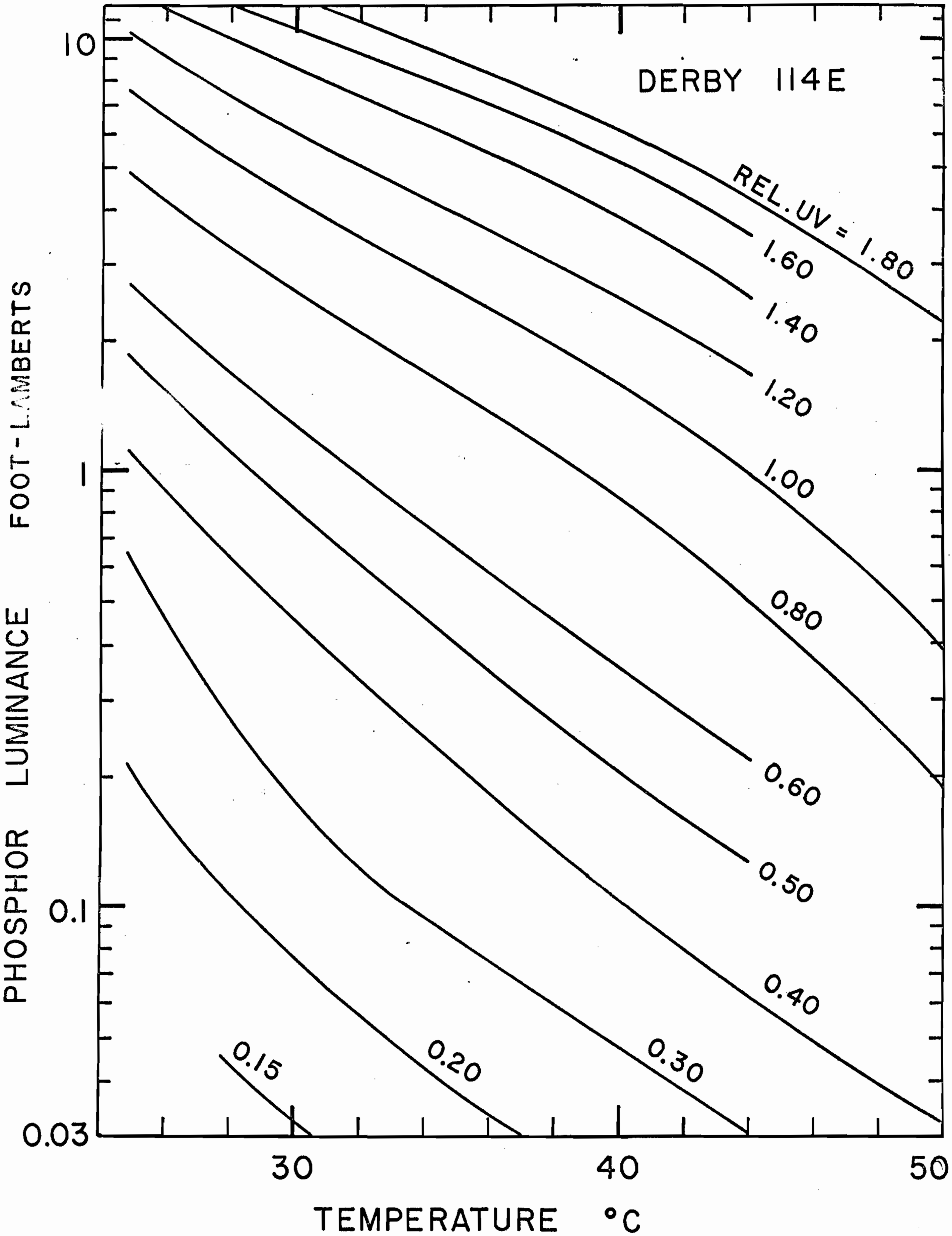

DERBY 114E
REL. UV = 1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.50
0.40
0.30
0.20
0.15
10
1
0.1
0.03
PHOSPHOR LUMINANCE FOOT-LAMBERTS
30
40
50
TEMPERATURE °C

Table 6.

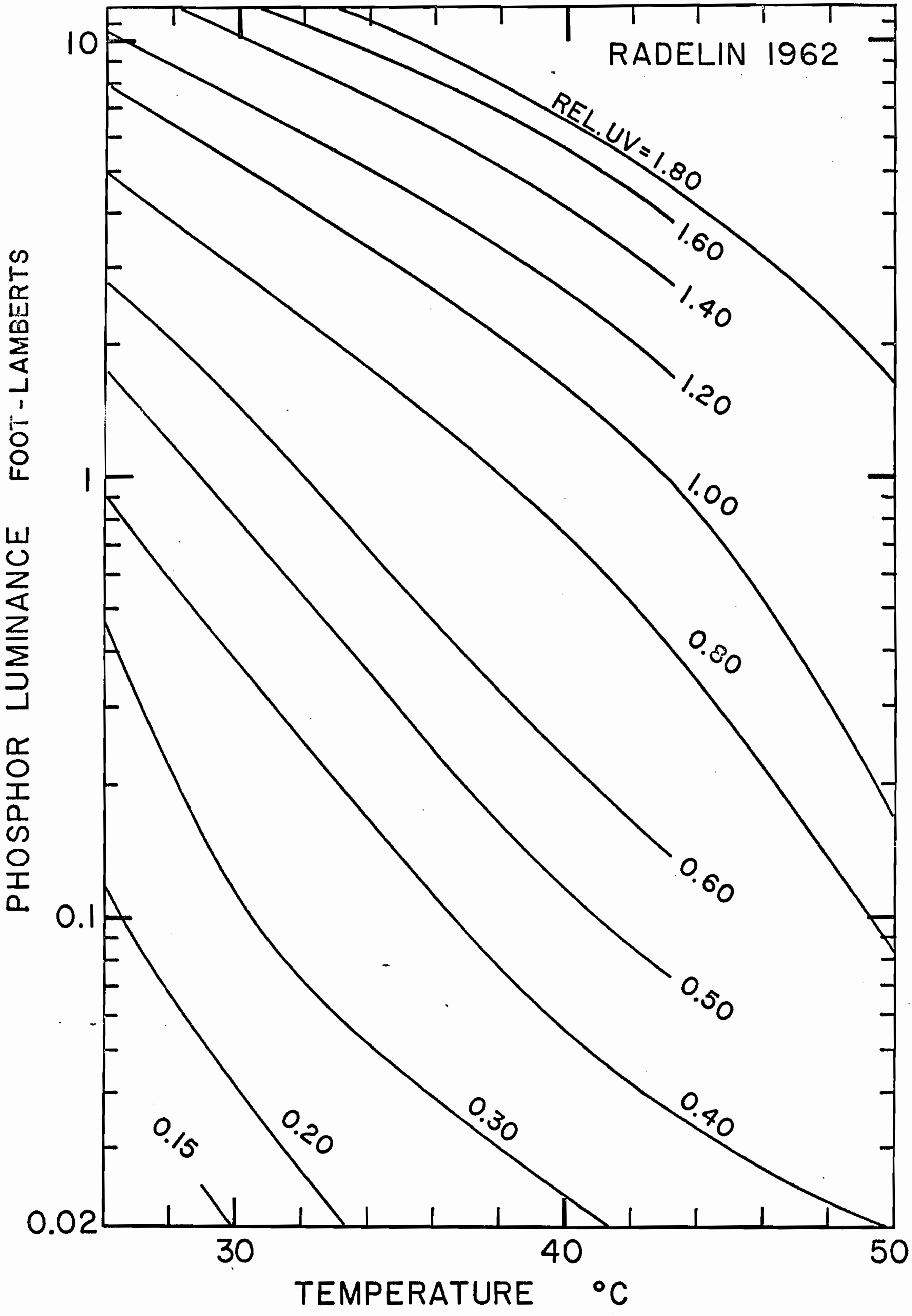

RADELIN 1962
REL. UV = 1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.50
0.40
0.30
0.20
0.15
PHOSPHOR LUMINANCE FOOT - LAMBERTS
10
1
0.1
0.02
30
40
50
TEMPERATURE °C

Table 7.

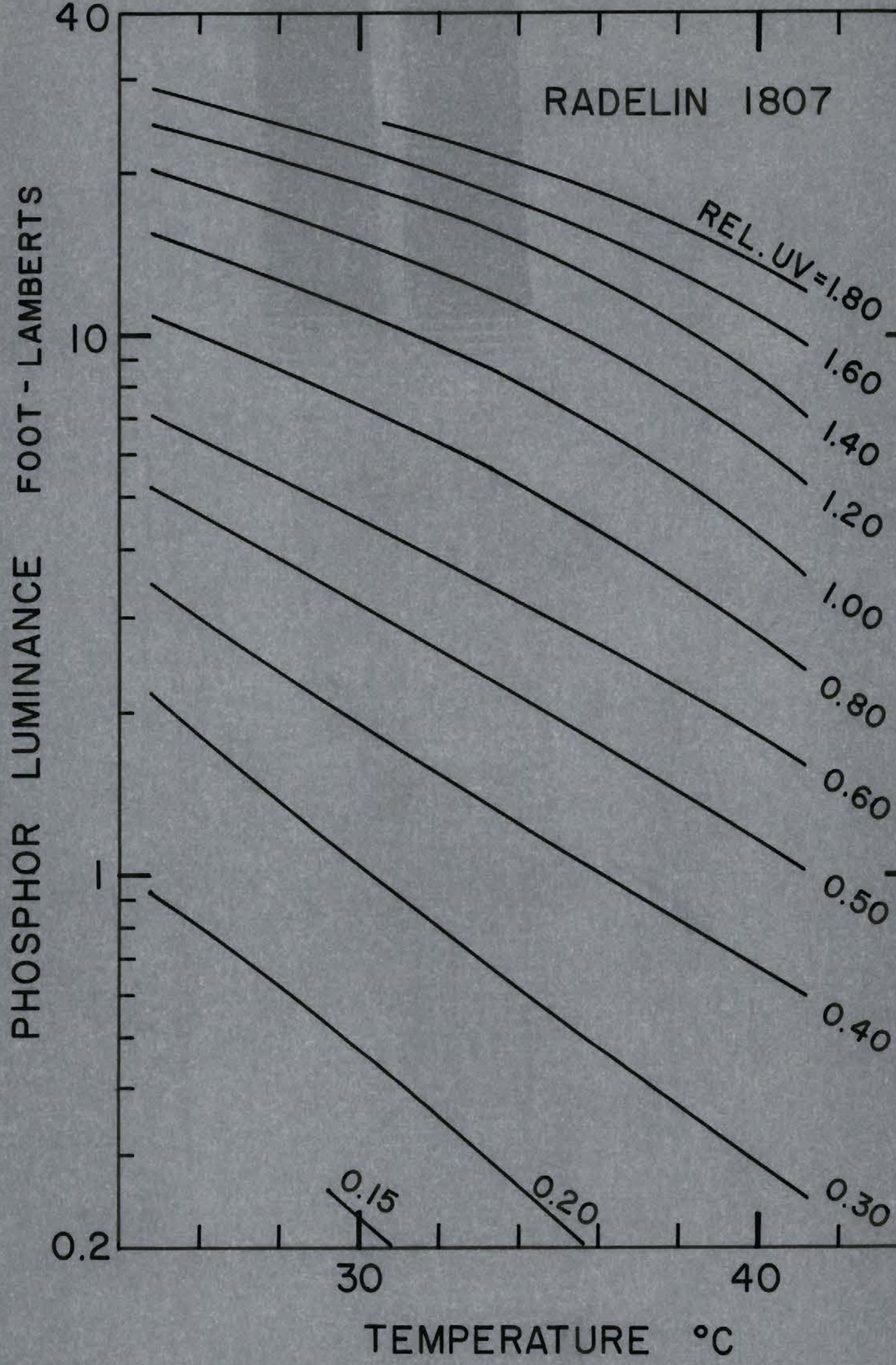

RADELIN 1807
PHOSPHOR LUMINANCE FOOT - LAMBERTS
TEMPERATURE °C
REL. UV=1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.50
0.40
0.30
0.20
0.15
40
10
1
0.2
30
40

Table 8

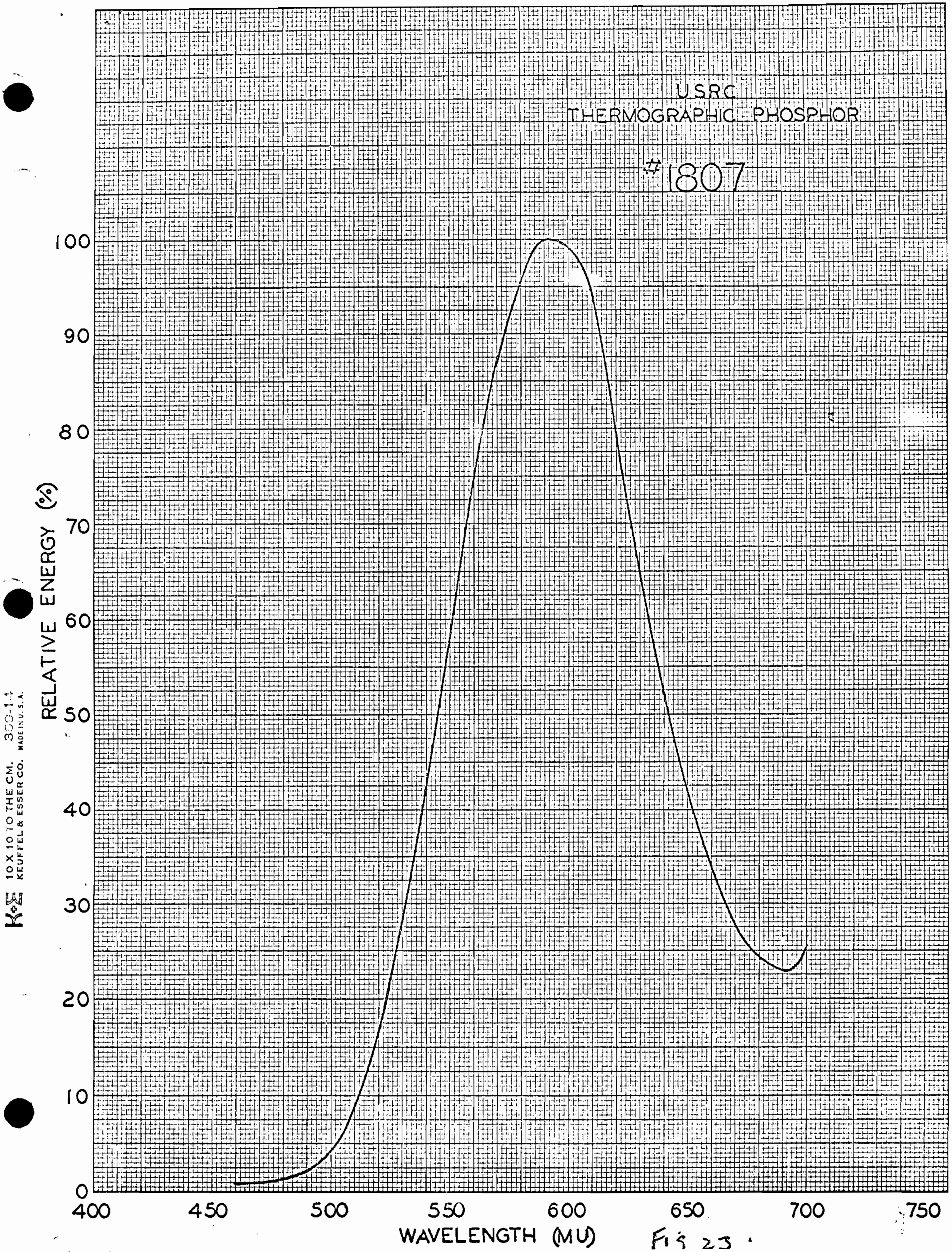
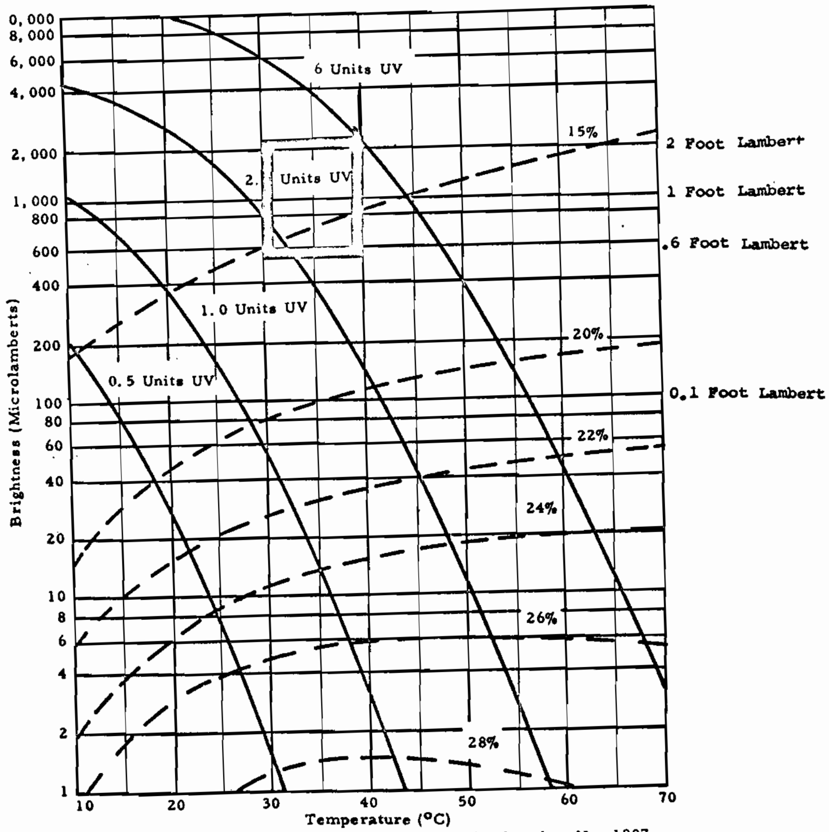

USRC
THERMOGRAPHIC PHOSPHOR
#1807
RELATIVE ENERGY (%)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
750
WAVELENGTH (MU)
K&E 10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.

Fig 23.



Performance of Radelin thermographic phosphor No. 1807. Solid curves show brightness against temperature at four levels of ultraviolet excitation. Dashed curves show sensitivity (percent brightness change per degree Centigrade change of temperature) against brightness and temperature.

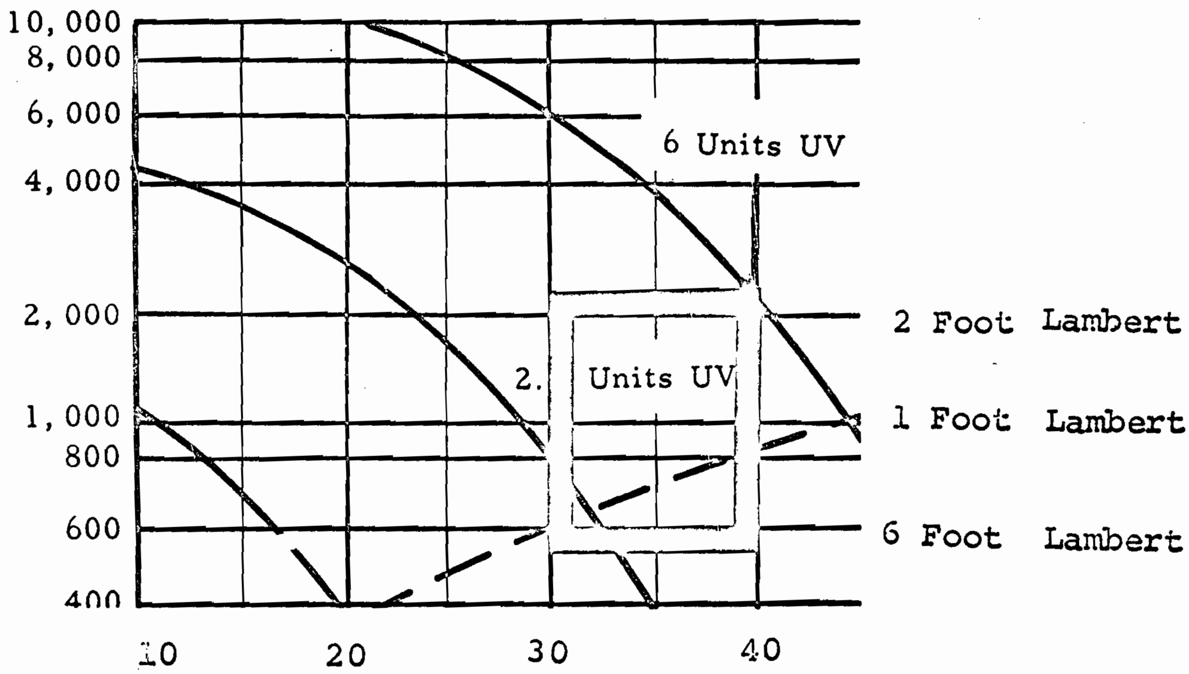


Fig. 24.

when the phosphor is applied to the skin would not be as sharp as under the conditions from which the figure for the minimum perceptible brightness difference of 2% was derived, because there is some lateral diffusion of heat in the skin and in the overlying phosphor, preventing large differences in temperature between adjacent areas from occurring. This effect would make an area differing in temperature at its center from the surrounding area more difficult to see if the temperature differnce is small, compared to a test situation in which the boundary is sharp. Furthermore, the minimum perceptible brightness difference also increases as the size of the test area decreases. Thus the estimate of 0.1 centigrade degree as the minimum perceptible brightness difference using this phosphor is optimistic.

TELEVISION TECHNIQUES

TELEVISION CONTRAST ENHANCEMENT

Because a phosphor having a temperature sensitivity greater than that of Radelin 1807 is not yet available, the use of a contrast enhancement scheme was explored, to enable small differences in brightness of the phosphor to be more easily seen. Various contrast enhancement schemes have been applied in the past to radiological film reading[73,76,77]. Some of these schemes are: the use of high contrast photographic media; the use of multiple negatives in photographic printing; and the use of the "out-of-focus" positive transparency in association with a sharp negative for making a positive print which then shows edge enhancement. Various electronic techniques have been used, such as flying spot scanners for x-ray film with electronic processing of the video signal to expand a narrow range of the gray scale in the original film up to the full range between black and white on the resultant photographic print or display tube.

QUANTUM LIMITED NOISE IN THE PHOSPHOR TECHNIQUE.

A consideration in the use of a contrast enhancement technique is the minimum perceptible brightness difference due to the quantum limited noise in the phosphor being used. This is due to the particle like nature of the emitted light. These considerations are valid for phosphor viewed by the naked eye or by a non integrating scheme for contrast enhancement (as opposed to an averaging system such as a photographic time exposure). Assume that the surface brightness of the phosphor is 1 Foot-Lambert. This is a brightness at which the temperature sensitivity is about 15% per centigrade degree. At higher values of surface brightness the temperature sensitivity of the phosphor drops off severely (Fig. 24). Assume that the scene area being viewed by a television camera is 12" x 15" focussed onto a 0.6" x 0.8" area on the camera tube by an F.1 lens. For a 500 line resolution television system this gives a picture element 0.0036 cms^2 at the scene. If one calculates the number of photons reaching the camera tube in 1/30th of a second (frame time for television), from this element using the laws of photometry, one gets $n = 3.3 \times 10^5$ photons. The statistical fluctuation in this number will be approximately the square root of n. This gives a signal to noise ratio of approximately 1 in 600 corresponding to a temperature difference of 0.01 centigrade degree. If one were to have a phosphor brightness of 0.001 Foot-Lambert the signal to noise ratio would be down to 20 : 1. But at this brightness the phosphor sensitivity would be up to 30% per centigrade degree. Combining these figures yields a temperature difference of 0.15 centigrade degree which is about the temperature difference that can be seen by the naked eye at 1 Foot-Lambert with this phosphor. These calculations explain why it is essential to have a television system with a good signal to noise ratio for looking at a brightness of 1 Foot-Lambert.

A system designed for simply looking at brightness of 0.001 Foot-Lambert will be quantum limited to a sensitivity of 0.15 centigrade degree. By increasing the phosphor brightness by a factor of a thousand, the gain in signal to noise ratio of a factor of thirty is achieved at the expense of a loss of only a factor of two in thermal sensitivity of this phosphor, yielding a net gain in signal-to-noise ratio of 15.

The above remarks consider only the quantum noise from the phosphor and do not conclude any noise contributions from the camera tube or electronic circuitry. Furthermore, each picture element is considered as separate. One would expect to be able to just barely detect a real temperature difference over one picture element corresponding to a brightness change of this element approximately equal to the quantum noise. If the area of the temperature anomaly is larger than one element in width the noise with respect to this area is then apparently reduced by a factor of approximately the square root of the number of picture elements in the area. If larger integration times are used, for example by the employment of a persistent phosphor on the monitor tube such as one with a decay time of 1 to 2 seconds, improvement in visual signal to noise ratio of a factor of about six can be expected.

For viewing the phosphor and obtaining simultaneous display of a contrast enhanced image, a conventional closed circuit television system, which had been modified, was used. The modification consisted in adding a severely non-linear stage before the last video output stage in the television monitor. This stage passes no video signal until a selectable voltage level is reached, and gives an additional gain of about 10 for video signals above that level. In this way the picture on the monitor represents only a narrow range of the gray scale in the original scene, and this narrow range is expanded up to the full range between black and white on the monitor picture tube. The present system uses a Philips Plumbicon camera originally designed for viewing x-ray image intensifier tubes. The Plumbicon has a better signal to noise ratio than any vidicon or image orthicon system which the author has tried, and at the light levels available from the phosphor, permits a temperature difference of 1 centigrade degree in the phosphor to cause the display on the monitor to go from full black to full white, with a tolerable amount of visual noise on the display. The level of phosphor brightness which is displayed is controlled by the level of ultraviolet illumination, the video gain on the camera and by the bias level on the contrast enhancement circuit, and the degree of contrast enhancement is controlled by the video gain and by the contrast adjustment on the monitor. The system has the advantage of immediate display, actual imaging of temperature distribution, and ease of photographic recording. Adjustments on the system may be made while simultaneously watching the results on the monitor, so that the optimum conditions for observing temperature anomalies may be reached quickly. At present the main problems with the phosphor-contrast-enhancement technique are: the difficulty in getting a uniform illumination intensity over the whole area to be viewed, independent of curvature of the skin surface; the difficulty of uniformly applying a tape to a curved skin surface without introducing wrinkles, and the effect of a non-uniform skin reflectance on the amount of light reflected back through the tape from the skin surface. The contrast enhanced display, when viewing a non-uniformly illuminated surface, shows a pattern which is almost a contour plot of surface brightness, and the operator must vary the displayed brightness level to move this contour across the region where it is desired to explore for temperature anomalies.

An anomaly then shows up on the display monitor as a non uniform motion of the contour line as the contour line is moved across the area of interest. This problem is made more severe by the non-linear response of the phosphor brightness with ultraviolet illumination, With a more nearly linear phosphor, or with a phosphor having greater temperature sensitivity, this problem would be less severe.

The present limitation on the sensitivity of the system appears to be in the phosphor; in particular there is some non-uniformity in the phosphor tape, contributing a steady "spatial noise" component to the display which is larger than the visual noise which is contributed by the camera system. The phosphor tape which was used was not manufactured with any special attempts at achieving uniformity, but now that this appears to be a limitation, a more uniform phosphor tape is anticipated. A further difficulty with the present system is time variation of the intensity of ultraviolet sources. The ultraviolet illumination is provided by four Sylvania Black Light Fluorescent lamps of 40 watts each, located in pairs about 2 - 3 feet from the patient. (Fig 25.) The average level of illumination is controlled by a silicon-controlled rectifier which varies the average current through the lamps. The lamps appear to be unstable at some levels of average current, switching from one mode of electrical discharge in the lamp to another mode with resultant changes in brightness of the lamps. Selection of lamps has not eliminated this difficulty entirely. There is also sensitivity of the lamp brightness to the severe line voltage fluctuations which occur in the hospital., in spite of a 3 kilowatt constant setting transformer in the laboratory.

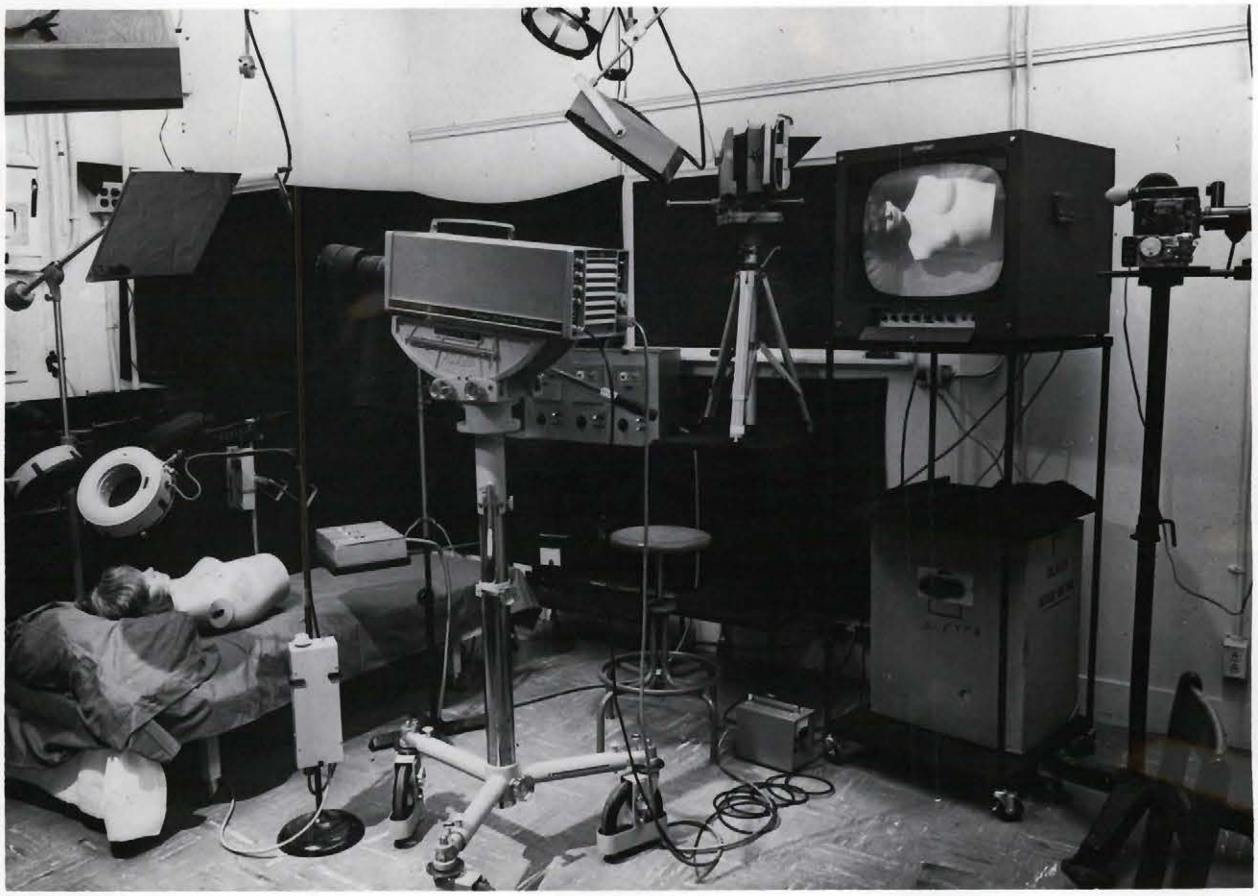


Fig. 25

A television system capable of expanding both the sensitivity and the human perception range in the electromagnetic spectrum is illustrated. Engineering problems can be studied with the use of mannequins in which equivalent temperature patterns are installed.

SUMMARY AND CONCLUSIONS ON THE TELEVISION SYSTEM.

The contrast sensitivity of the eye can be enhanced by a factor of ten in this television system. It is therefore worth while. It is much simpler making photographs from a television monitor than directly from the subject. The system is useful for finding areas of temperature anomalies, these can subsequently be measured directly by a temperature probe. At the present time direct temperature measurements cannot be obtained from the monitor. This is because there are too many variables involved in image presentation such as the ultraviolet light levels, shadows, and contour irregularities of the subject.

ANCILLARY MEASURING EQUIPMENT

For measuring the fluorescence efficiency of thermographic phosphors a photo-electric brightness spot meter was used (Fig.27). This photometer has a full scale sensitivity of 0.003 Foot-Lamberts on its most sensitive setting.

A reference thermal gray scale (Fig.28) was employed for testing the temperature sensitivity of the phosphor and the closed circuit television systems. This gray scale has ten copper blocks each separately heated with power transistors. The temperatures are controlled by thermistors through feedback amplifiers. The blocks were set by the manufacturer in 1 centigrade degree steps from 29 to 38 degrees Centigrade. The copper blocks were covered with the same phosphor tape employed on the subjects being observed. This item is a standard commercial product and functions satisfactorily, as far as can be ascertained.

Fig. 27

Sensitive photoelectric spot meter used for calculating fluorescence of phosphors.

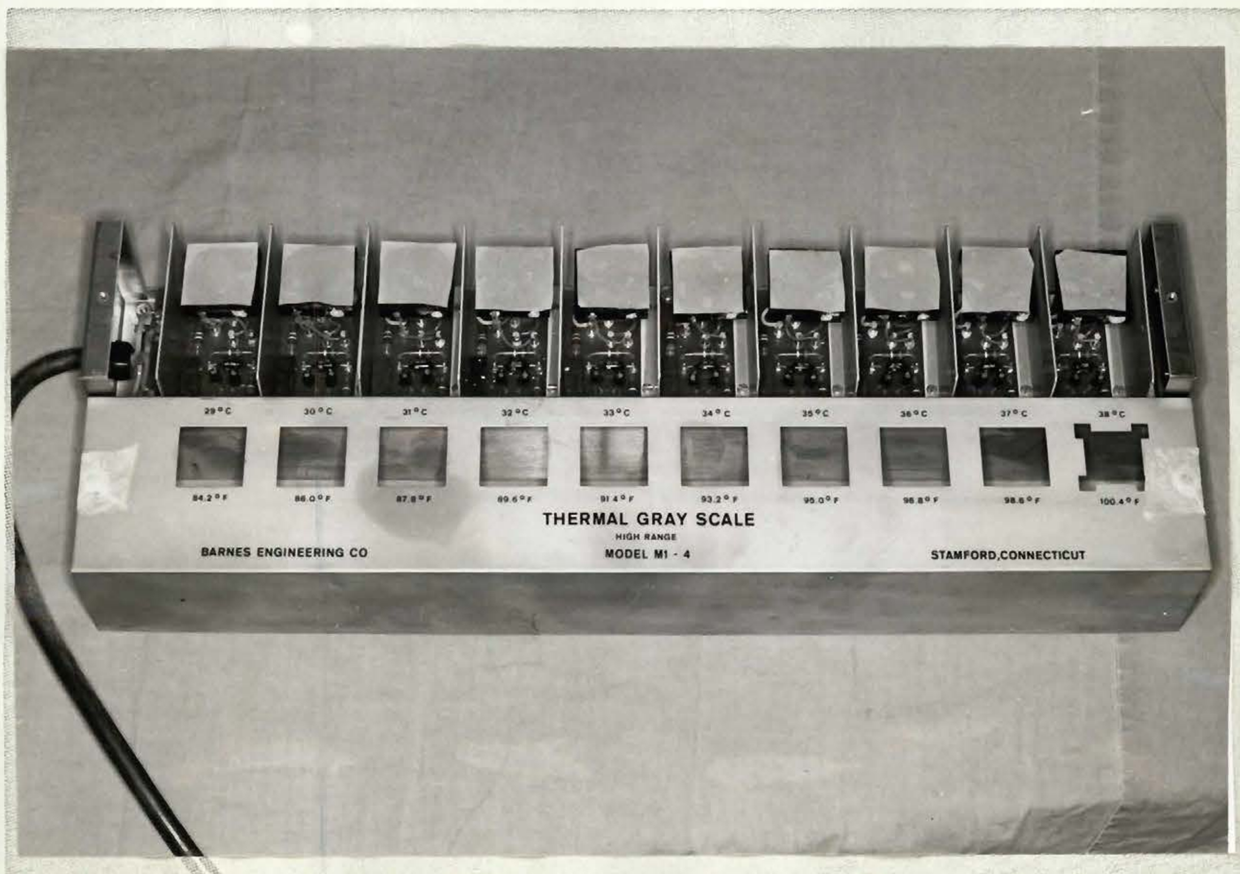


Fig. 28 Thermal gray scale.

COMPARISON OF THE IMAGES OBTAINED FROM INFRARED OPTICAL SCANNERS AND THOSE OBTAINED FROM THERMOGRAPHIC PHOSPHOR

The temperature patterns obtained from thermographic phosphor assumed a completely different configuration from those derived from all ten types of infrared scanners used in the past in the course of this work. These phosphor thermogram differences were so marked, that at first they were difficult to accept or explain. The temperature patterns at certain ambient settings of the instrument had a striking similarity to the surface veins depicted by conventional infrared photographs. At the commencement of this phosphor thermographic investigation, an optical scanner was not available with which to make immediate comparisons. Some members of the thermal engineering group at the National Research Council , Ottawa, were consulted, and an assortment of heat measuring equipment was temporarily procured. An optical infrared scanner designed and built by this group was employed but the resolution and sensitivity of the temperature images obtained from it were of extremely poor quality. However tests with their focusing bolometers and thermister probes indicated that the temperature patterns revealed by the phosphor were in fact correct. To prove the reliability of the phosphor thermography patterns, three volunteer patients cooperated by having grid lines painted on their breasts (Fig.34). Lines were made 1 cm apart and temperature readings by thermister probe made at all intersections. Phosphor was applied and excited by long wave ultraviolet radiation (peaking at 3600 A). These multiple spot temperature checks showed that the thermographic patterns derived from the quenching of phosphor fluorescence accurately represented a highly resolved temperature map of the skin.

Further experiments with a television camera fitted with a vidicon tube that was sensitive out to 1 μ and fitted with an F O.95 lens and an infrared filter to block out visible light, revealed that in the normal breast the skin temperature patterns coincided with the subcutaneous veins when the ambient temperature was 24 C (75 F). With this television modification, which was developed as part of the project, it is possible to obtain images of the human body in the near infrared region, that are almost identical to those obtained by standard infrared photography. This particular television technique is simpler and more efficient than emulsion photography because of the ease of adjusting the equipment for the optimum image. Standard Polaroid photographs are easily taken from the monitor for permanent records. (Fig) It is of interest to know that venous blood absorbs almost all the infrared radiation at 0.8μ, and also the human skin is somewhat transparent at this wave length. Arterial blood does not absorb this wave length to nearly the same degree. It reflects radiation of this wave length and hence vessels containing arterial blood are never depicted by infrared photographs. The relationship of this type of near infrared imaging to temperature patterns is purely coincidental. To obtain near infrared images by photography or by television, it is necessary to radiate the subject with a source of near infrared energy. Thus the images obtained with either technique merely represent reflected near infrared radiation. The images result from the difference between infrared absorption and infrared reflection. In contradistinction to phosphor thermography, such images are not in any way directly related to surface temperatures. On the other hand, by using the phosphor technique or far infrared scanners, it has become clear that the surface temperature patterns are specific for each individual, and it is quite logical to anticipate that these techniques will, in the future, be used for identification purposes. These observations also suggest that at normal ambient temperatures the skin receives the major part of its heat energy from deeper structures through the processes of conduction from subcutaneous veins.

Comparisons between infrared scanning methods and those obtained by thermographic phosphors can best be appreciated by referring to Figures .

TABLE 1.

BIOLOGICAL DATA

"SPOT" TEMPERATURES ASSOCIATED WITH BREAST CANCER AT OPERATION

(All readings derived with single thermistor probe (Waters), therefore sources of technical error common to all values).

Case No.	Lateral Thoracic Artery	Tumour Temperature	Lateral Thoracic Vein	Difference in Centigrade
1. 302261	32.0	37.2	34.0	2.0
2. 301211	34.3	36.2	35.0	1.7
3. 318268	35.4	35.7	35.4	0.0
4. 214807	34.0	36.6	34.5	0.5
5. 219954	35.0	37.0	35.0	0.0
6. 301789	34.8	36.7	35.2	0.4
7. 215866	34.4	36.0	35.0	0.6
8. 213364	34.2	36.8	36.0	1.8
9. 207075	34.0	36.6	35.0	1.0
10. 217301	33.5	36.0	36.5	3.0
11. 502864	34.6	36.7	35.5	0.9
12. 211237	34.4	36.5	35.0	.6

This data suggests that the metabolic processes of breast carcinomata tend to cause local elevation in the temperatures of the draining veins.

TABLE 2.

BIOLOGICAL DATA

"SPOT" TEMPERATURES ASSOCIATED WITH BREAST CANCER AT OPERATION

(Venous blood leaving a tumour is hotter than the arterial blood entering).

Patient	Tumour Temperature	Lateral Thoracic Artery	Lateral Thoracic Vein	Temperature Difference
1. Br.	36.5	34.4	35.0	0.6
2. Ho.	36.7	34.6	35.5	0.9
3. Ke.	36.0	33.5	36.5	3.0
4. Pe.	36.6	34.0	35.0	2.0
5. Au.	36.8	34.2	36.0	1.8
6. Pa.	36.6	34.4	35.0	0.6
7. Fo.	36.7	34.8	35.2	0.4

TABLE 3

BIOLOGICAL DATA

"SPOT" TEMPERATURES ASSOCIATED WITH BREAST CANCER AT OPERATION

Patient	Tumour Temperature	Internal Mammary Artery	Internal Mammary Vein	Temperature Difference
1. Fo.	36.7	32.2	32.8	0.6
2. Au.	36.8	32.0	33.0	1.0
3. Pa.	36.6	32.0	33.0	1.0
4. Pe.	36.6	31.0	32.0	1.0
5. Ho.	36.7	34.1	34.7	0.6
6. Br.	36.5	32.0	33.0	1.0

TABLE 4

BIOLOGICAL DATA

RELATIONSHIP OF INCREASE IN TUMOUR TEMPERATURE TO PREDOMINATING PATHOLOGICAL TYPE.

"Spot" thermistor thermometer readings taken in the substance of the tumour at operation.

Scirrhous	Simplex	Intraductal, and Intraductal cancer with local invasion
2.5	2.1	0.8
2.1	1.2	0.7
1.3	1.1	0.7
1.2	0.9	0.7
0.9	0.9	0.6
0.8	0.9	0.4
0.6	0.8	0.3
0.6	0.8	0.2
0.5	0.7	0.0
0.3	0.7	0.0
0.3	0.4	
	0.3	Fibrosarcoma
	0.3	1.7
	0.0	

It is not presumed that this data has statistical significance, but it does suggest that the more actively growing tumours tend to have higher temperatures.

TABLE 5

BIOLOGICAL DATA

Fourteen months follow-up of thirty-six consecutive cases of breast cancer, correlated with increased temperatures, - spot checks at operation.

Temperature increase		Case Number	
1.	2.5	221190	Dead 6 months
2.	2.1	229325	
3.	2.1	302880	Dead 2 months
4.	1.7	216994	Dead 13 months
5.	1.3	216803	Dead 8 months
6.	1.2	217653	
7.	1.2	302261	
8.	1.1	217301	
9.	0.9	215856	
10.	0.9	307154	
11.	0.9	219954	
12.	0.9	202586	Dead 12 months
13.	0.8	214566	
14.	0.8	211237	
15.	0.8	302264	
16.	0.8	300107	
17.	0.7	212363	
18.	0.7	306117	
19.	0.7	304669	
20.	0.7	302015	
21.	0.7	301211	
22.	0.6	218179	
23.	0.6	213369	
24.	0.6	305515	
25.	0.5	218368	
26.	0.4	303129	
27.	0.4	308088	
28.	0.3	318344	
29.	0.3	218716	
30.	0.3	219007	
31.	0.3	305879	
32.	0.3	305305	Dead 7 months
33.	0.2	305255	
34.	0.0	306094	
35.	0.0	219646	
36.	0.0	308644	

A tendancy is seen for the more biologically malignant tumours to have greater temperature elevations. However, for these spot temperature readings to have significance, a correlation with long-term continuous temperature graphs (circadian rhythm studies) is mandatory.

DISCUSSION

The principle aim of this investigation originally was to try to devise a temperature imaging system that would have the capability of both displaying high resolution temperature patterns with a sensitivity of at least 0.1 centigrade degrees, and at the same time clearly and instantaneously depict, in a dynamic fashion, changing temperatures of this order. While this latter parameter has not yet been realized, there are reasons to justify continued efforts. A simple technique for time-lapse photography from the monitor has been employed. It also appears that there will eventually be a place for video tape recording of the temperature changes at such time when it is possible to eliminate some of the uncontrollable variables which are essential ingredients in the present imaging system.

Relatively little applied research has taken place so far in developing the most suitable thermographic phosphors. For instance, the physical attributes of the rare earth chelates still remain to be explored in connection with fluorescence quenching by heat. The suitability of a large group of liquid cholesterol crystals are currently being examined for their thermographic potentials. It might be worth while to attempt incorporation of some of these crystals in microspheres layered on an opaque tape backing. There is much well supported basic research work currently in progress directed to improvement of performance of low light level television systems.

The potential possibilities of temperature measurement of this nature have important biological implications. For instance it is a rather disturbing idea to physiologists that any tissue can be much more than 1 centigrade degree warmer than the blood entering it (unless it is in contact with an extraneous source of heat). The type of work described in this thesis draws attention to the fact that the body temperature represents the summation of many local independent chemical reactions of metabolism. It should be appreciated that there can never be a situation of precise thermal uniformity from one organ to another because of the differences in rates of metabolism and heat production in the various tissue types. Even in one organ thermal uniformity does not exist over any appreciate volume, because from some parts of the organ, the heat produced locally is carried away with a different efficiency than from other parts. The concept that some tissues may at times have a "negative" metabolism owing to a preponderance of endothermic anabolic processes may, in future, be held less reprehensible than at present. It is obvious that detailed observations of the temperature distribution in an organism would be a fundamental and desirable biological measurement for the study of growth and metabolism. This can only be pursued when adequate measuring instruments become available. Temperature measuring equipment that will permit such observations must be able to pictorially display whole areas. Single temperature measurements lose significance because of the lack of the controls which in a thermogram are supplied by the surrounding areas of the point being examined. It is believed by the writer that this work is playing a part in the engineering and design of thermographic instruments suitable for medical application. (See Fig. 41).

SUMMARY AND CONCLUSIONS

The events leading up to the initial observation of the temperature anomalies associated with breast cancers contributed by the writer, and now verified by many collaborators, have been sketched.

The basic concepts of heat as a form of energy have been outlined together with the history of important events in the evolution of temperature measuring technology. An evaluation of currently applied instrumentation is presented.

A review of the literature of the new science of medical thermography has been made.

In this thesis the significance of elevated skin temperatures overlying breast cancers has been defined by the demonstration that the hotter areas found on the skin are due to heat transfer by conduction from specific subcutaneous veins. Veins with increased temperatures acquire their heat energy from the tumours themselves. The metabolic mechanisms resulting in increased production of heat energy by breast carcinomata remain to be investigated.

The photographic images accumulated during the course of this work clearly illustrate that the thermal patterns of the normal skin assume an individual specific configuration. Skin temperature measurements as frequently made by clinicians are not only futile, but may often be misleading. Guides are needed to indicate specific and meaningful areas on which to place a thermistor probe.

The newer temperature techniques as outlined in this thesis are capable of supplying important biological information which is otherwise unavailable.

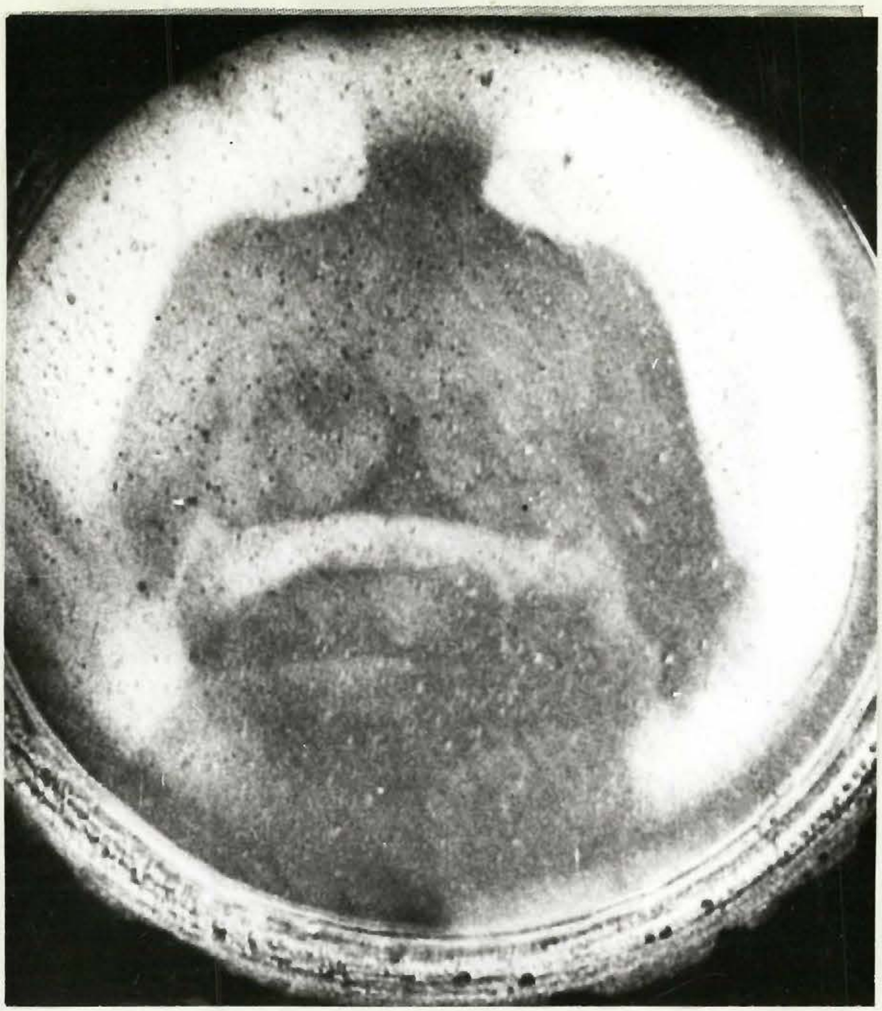


Fig. 29
Infrared image of female with cancer of the right breast obtained with the Baird Evaporograph. This was made in Boston in 1956 by the writer. The darker area in the upper part of the right breast represents increased heat. This is believed to be the first infrared image of a human breast cancer.

Fig. 30
Phosphor thermogram carcinoma left breast, 1966. The increased temperature resolution depicted by the darker areas overlying the veins, will be readily appreciated.

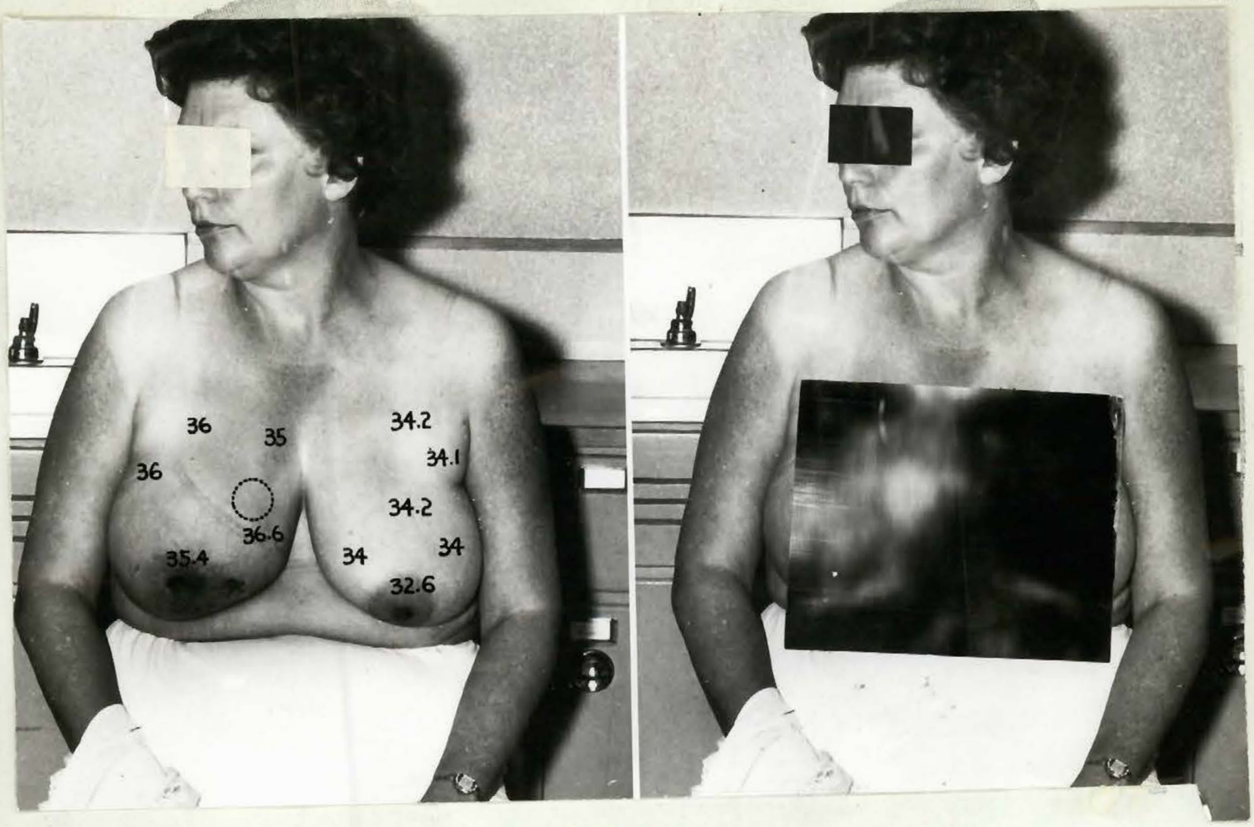


Fig. 33

Patient with cancer right breast. On the left random skin temperature measurements were made. These are now known to be meaningless. On the right an infrared scan is superimposed. The lack of resolution resulting in a smearing effect of the area of increased temperature is quite obvious. The subject matter of this thesis illustrates the point that if a phosphor thermogram had been made of this subject, the temperature pattern would have resolved into the surface vein configuration as in Fig. page 96.

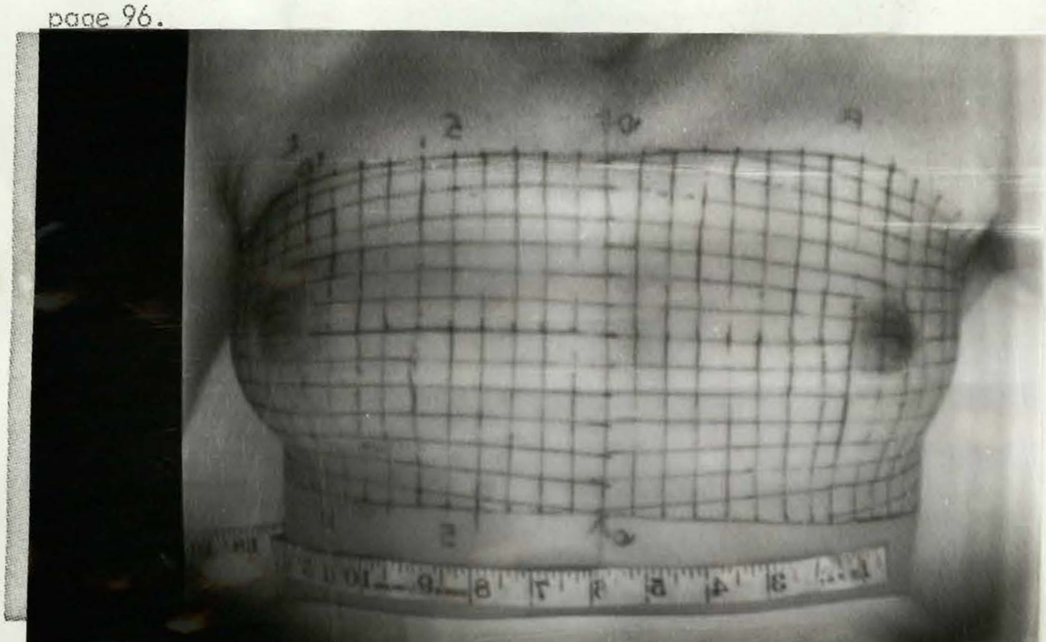
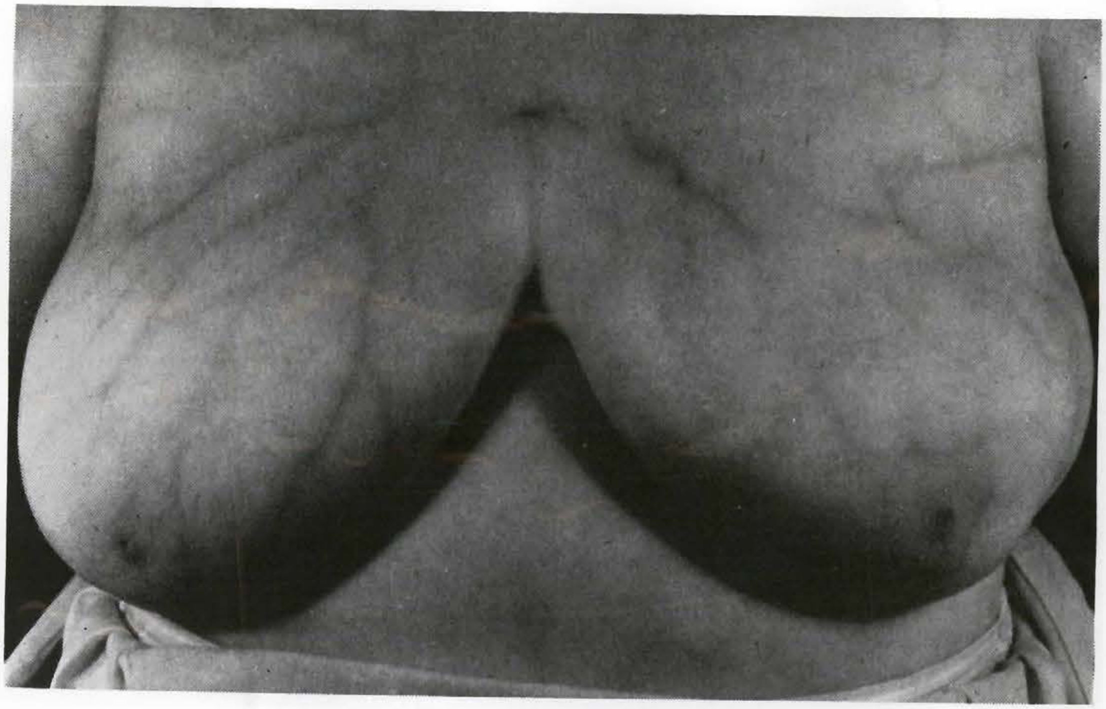


Fig. 34

Patient with grid lines drawn on the breasts for plotting skin temperatures with thermistor probe. The accuracy of phosphor thermographic patterns was first established by coordinating them with multiple spot temperature values.



Carcinoma of the left breast. The superficial veins in the right breast are regularly distributed and are uniform in density. The venous pattern in the left breast is disturbed and there is a serpentine engorged vein in the upper inner quadrant.

Fig. 31

Infrared photograph of breast containing a cancer. Note the dilated vein in the upper part of the left breast. This picture does not portray surface heat. It depicts the absorption of infrared radiation at .8μ. It clearly illustrates the fact that veins leaving breast cancers tend to dilate and lose their normal muscle tonus. The differences in vein diameter, and also temperature, are more apparent after exposure to lower ambient temperatures such as 60F (15.5C). The presence of dilated veins has recently become a cardinal sign in the interpretation of mammograms. The role of increased temperatures as opposed to anatomical interference with vasomotor nerves by the tumour in the etiology of vein dilatation has not yet been determined. Veins that have come to the surface after leaving a breast cancer do not constrict to the same degree as other veins on exposure to cold.

Fig. 32

Phosphor thermogram cancer left breast. In contradistinction to the picture at the top, [illegible]

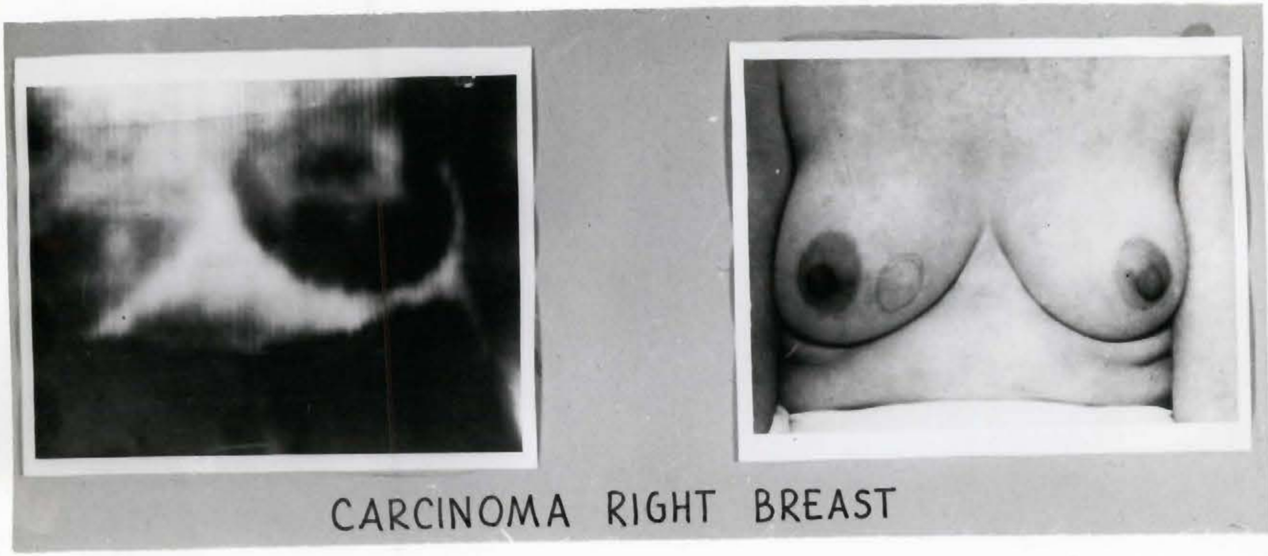


Fig. 35

Thermogram made from patient with cancer of the right breast in 1960. This image shows poor resolution. The warmer area (lighter) in the right breast has a completely different presentation to the temperature patterns obtained by phosphor thermography.

On the next page Fig. the image from an improved infrared optical scanner is displayed.

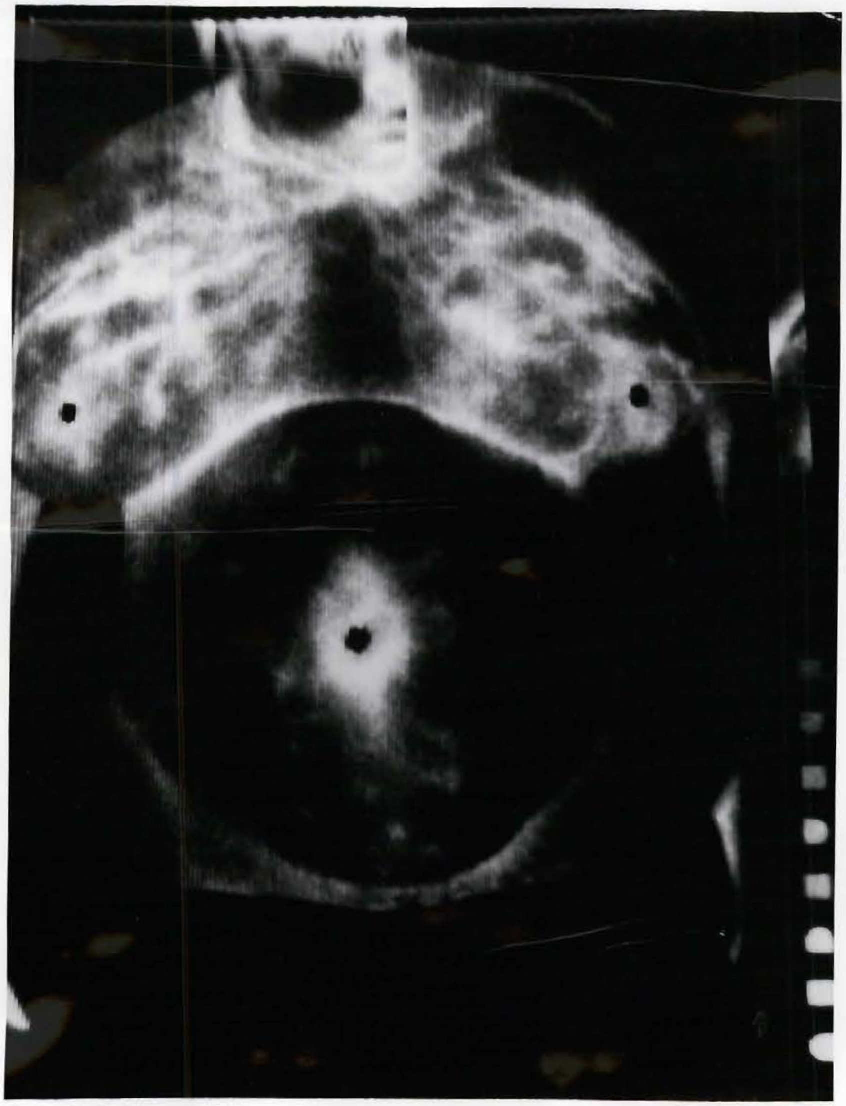


Fig. 3C

Thermogram obtained by optical infrared scanner 1966. This image shows vastly improved resolution. It also clearly depicts the fact that the surface temperatures follow the pattern of the subcutaneous veins. This is a relatively good thermogram but yet does not have the degree of temperature resolution obtained by phosphor thermography. On the other hand the advantage of this type of image is that it allows for more accurate quantitation of the radiated heat energy than phosphor thermography, at the present time.

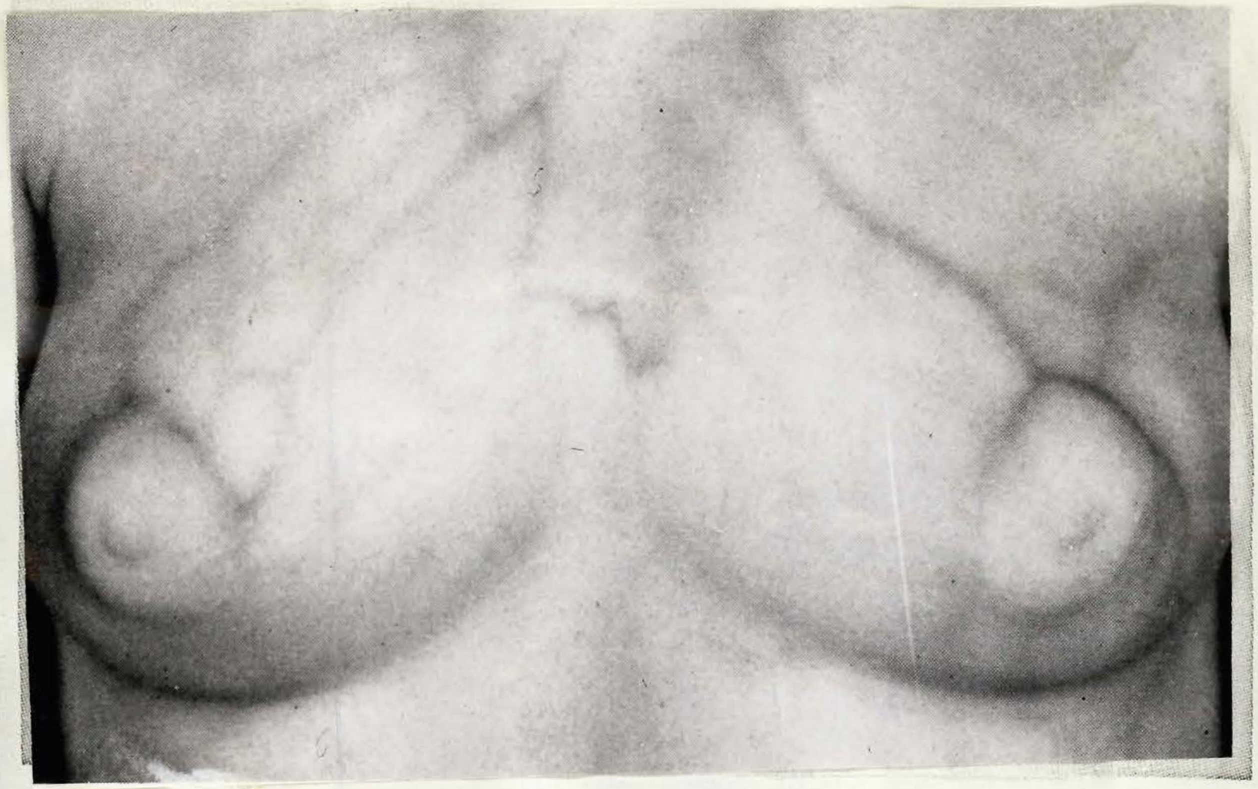


Fig. 37

Near infrared image of female breasts obtained by the television technique described on pages 82, 83. Optical information displayed on the television monitor comes mainly from wave lengths at .8u.

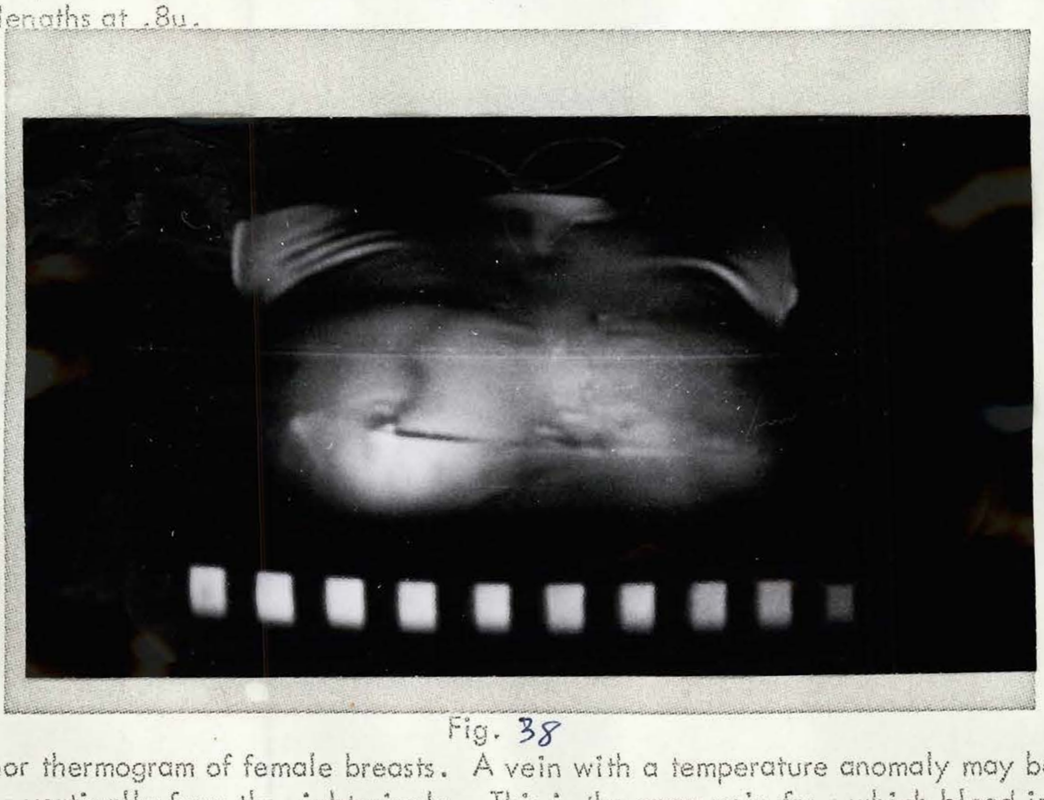


Fig. 38

Phosphor thermogram of female breasts. A vein with a temperature anomaly may be seen running vertically from the right nipple. This is the same vein from which blood is being withdrawn, Fig. page 99, and also the same vein which was injected with a dye as portrayed in Fig. on page 99.

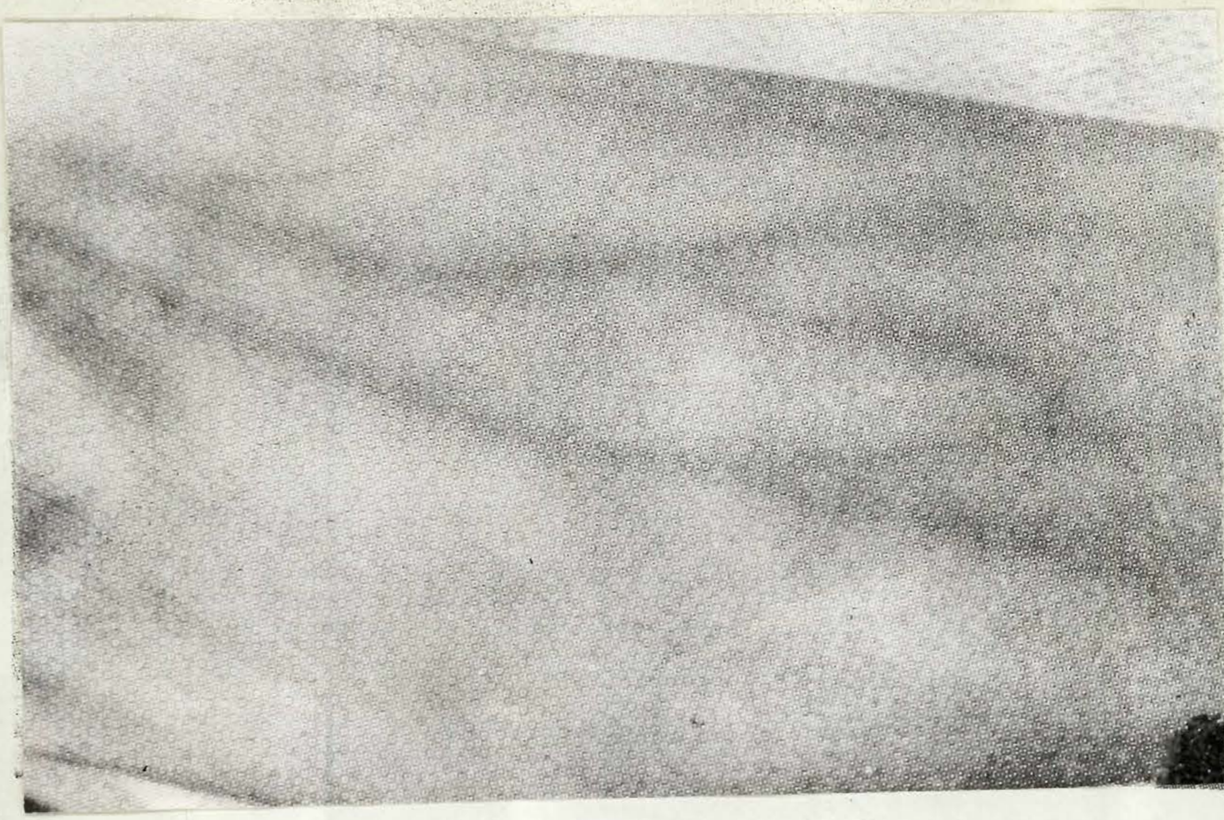


Fig. 39
Phosphor thermogram of forearm veins.

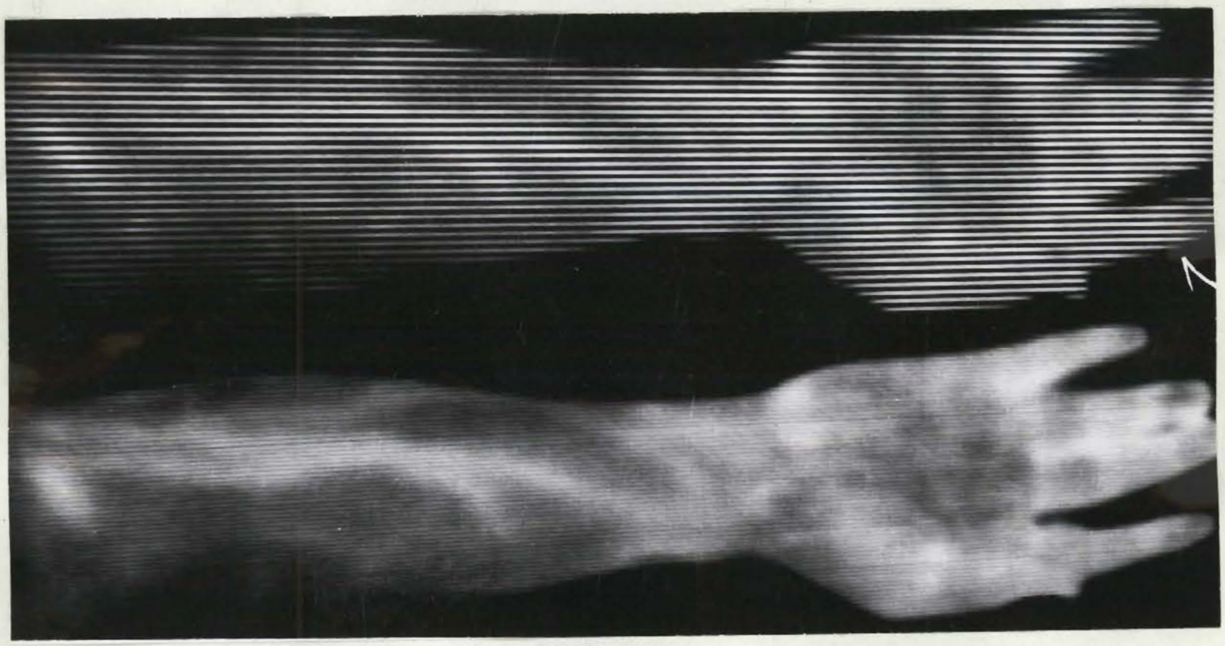


Fig. 40
Infrared radiation thermogram of forearm veins. This is unusually good resolution for an optical infrared scanner but emphasises that the temperature patterns on the skin are chiefly due to veins. This image also substantiates the higher resolution of phosphor thermography.

FROM;

Bernard, B.
"The Promise of Infrared"
Electronic Engineer's Design.
Vol. 10: 15, p.150, Dec. 1965.

The term "thermography" is used to describe the technique involving infrared scanning cameras. It was coined by Ray N. Lawson, M.D., of Montreal, Canada. The word "thermograph" generally is used to describe the final picture.

It has been found that identical symmetrical areas of the body surface are almost always within 1°C unless there is a derangement of the vascular supply of some pathological process to explain it.[2]

Applying IR

Development of the infrared scanner was influenced by the work of Dr. Lawson. He recognized the fact that breast cancer provokes varying degrees of local inflammatory reactions associated with an increased blood and lymphatic supply. Subsequent tests showed that the average temperature rise in either the area of the tumor or ipsilanteral aerola is 2.27F.[3] No temperature rise has been associated with cysts or fibroadenomata.

Hundreds of cancer patients at the Royal Victoria Hospital in Montreal have had an infrared scanner used on them by Dr. Lawson. He feels his results, although not official, are quite significant in warranting further experimentation. Dr. Lawson has been carrying on an extensive research program in all phases of medical applications at this hospital and at McGill University in Montreal.[4]

One hundred patients, each having a lump in one breast, were investigated at the Middlesex Hospital in London, England.[2] All cases showing a rise of more than 1°C over the contralateral normal area were designated as "hot" while the others were "cold."

The "hot" group consisted of abscesses and cancers, while the "cold" group contained degenerative lesions, such as cysts and duct stasis. There were only four exceptions to this: three cases of carcinoma failed to show a rise in temperature and one cyst did show a temperature increase.

The value of infrared diagnosis lies in its early detection of symptoms. In a speech to the General Electric Co. in 1963, Dr. Lawson stated, "I am firmly convinced that many thousands of breast-cancer victims could be saved as a result of earlier operations made possible by earlier infrared diagnosis."

More recently[6] Dr. Lawson has been experimenting with a new type of thermal imaging process that uses a zinc-cadmium-sulfide phosphor. This temperature-indicating phosphor, packaged in an aerosol can for easy application, glows orange when excited by ultraviolet radiation. The phosphor responds instantly to changes in skin temperature. A temperature change of 1°C can result in a decrease of brightness by 25 percent.

According to Lawson, temperature variation of ..1°C may be observed with the phosphors. Phosphor thermography offers many advantages over the previously described, more conventional scanning approach. Some advantages are:

1. Dependable data can be obtained by relatively untrained operators.
2. The thermal image can be directly observed.
3. The thermal image can be photographed or transmitted by TV cameras, providing extremely high optical resolution.
4. There is essentially no time delay in observing the thermal image.

References

1. Bernard, B.; *"10 Most Asked Questions on Infrared"; Instruments and Control Systems; May 1961.*
2. Williams, K. L., Cade, C. M., and Goodwin, D. W.; *"The Electronic Heat Camera in Medical Research"; J. Brit. I.R.E., Vol. 25, No. 3; March 1963.*
3. Brown, W. C.; *"An Infrared Scanning Camera and Its Uses in Cancer Research"; Bulletin of the Radio and Electrical Engineering Div., National Research Council of Canada, Vol. 9, No. 2; April, June 1959; p. 1.*
4. Lawson, R. N.; *"A New Infrared Imaging Device"; Canadian Medical Assoc. Journal 79; September 1958; p. 402.*
5. Lawson, R. N., Woldak, G. D., and Webster, D. R.; *"Thermographic Assessments of Burns and Frostbite"; Canadian Medical Assoc. Journal 84; May 1961; p. 1129.*
6. Lawson, R. N., and Alt, L. L.; *"Skin Temperature Recording with Phosphors"; Canadian Medical Assoc. Journal 92; February 6, 1965; pp. 255-260.*

Fig. 41

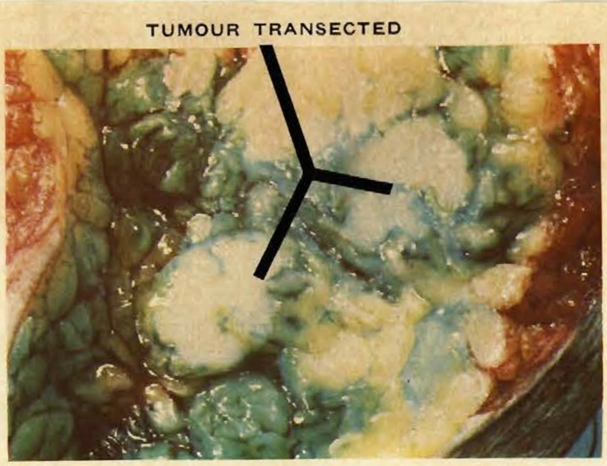


Fig. 6.—The "hot" vein illustrated in Fig. 1 was cannulated and a 1% aqueous solution of lissamine green dye injected. The intact breast was then transected through the tumour. In spite of some smearing of the dye, the avascularity of the cancer and the hypervascularity at its edges are clearly demonstrated. This technique further illustrates that the venous blood in this particular subcutaneous vesse is coming from the neoplastic process.

Fig. 42

Dye injection of dilated subcutaneous vein in the vicinity of a breast cancer. This vein was identified by phosphor thermography. It showed 1 degree centigrade increase over the adjacent skin. (See Ref. 78.)

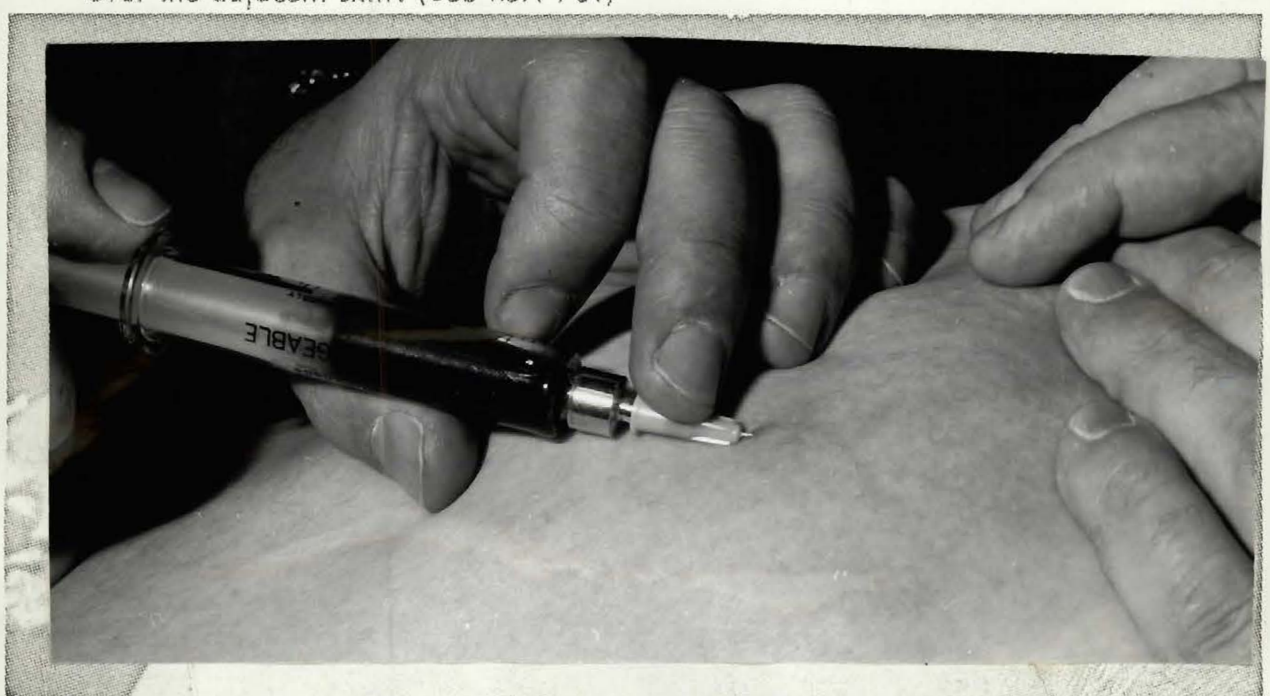


Fig. 43

Blood sample being drawn from the hot vein depicted Fig. 38 page 96.
Since this blood is coming directly from the cancer, its constituent may be subjected to various types of analyses to determine the presence of unusual components. Thus it is seen that a new approach in cancer research has become available.

BIBLIOGRAPHY

1. McGrady, P.
The Savage Cell, 1964
(Basic Books Inc., New York).

2. Berlin, N.I. et al.
Breast Cancer.
Ann. Intern. Med., 63: No.2, 321, 1965.

3. Brown, G.M. et al.
The Occurance of Cancer in an Eskimo.
Cancer, Vol. V, 1, 142, 1952

4. Urban, J.A.
Current Trends in Breast Cancer Treatment.
New York State Journal of Medicine, Vol.61: No. 18, 3120-3132; No.19, 3469-3477; No.20, 3286-3301, 1961.

5. Stefansson, V.
Cancer: Disease of Civilization?
Hill and Wang, New York, 1960.

6. Karaman, G.
An Index of Tumour Chemotherapy.
National Service Center, Bethesda, Md..May 1956.

7. Lawson, R.
"Fat in the Diet".
Agriculture Institute Review, 13: No.3, 18, June 1958

8. Strong, L.C., and Whitney, L.F.
The Treatment of Spontaneous Tumours in Dogs by the Injection of Heptyl Aldehyde.
Science, 88: III, 1938.

9. Shungo, O.
"Study on Chemotherapy for Human Carcinoma with Citronellal and Citral and Histological Findings in the Healing Process of Carcinoma".
Tohoku J. exp. Med., 86: 102-147, 1965.

10. Lawson, R., et al.
Implications of Surface Temperature in the Diagnosis of Breast Cancer.
Canad. Med. Assoc. J. 75: 309, 1956

11. Lilienthal, A.
Thermography Cooperative Study, Nov. 5, 1965
Department of Chronic Diseases,
The Johns Hopkins School of Hygiene,
614 North Wolfe Street,
Baltimore, Maryland. 21205.

12. Bridgman, P.W.
Logic of Modern Physics,
(Macmillan, New York, 1927), p.121

13. Worthing, A.G.
"The Temperature Concept"
Am. J. Phys. 8: 28, 1940

14. Bolton, H.C.
Evolution of the Thermometer 1592-1743.
(Chemical Publishing Co. Easton, Pa. 1900).

15. Roller, D.
Case 3, The Early Development of the Concepts of Temperature and Heat.
(Harvard University Press, Cambridge, 1950).

16. King, A.L.
Thermophysics.
(Freeman, San Fransisco, 1962).

17. Hilsdon, R.M.
Applied Thermodynamics.
(Pergamon, London, 1965).

18. Landsbeng, P.T.
Thermodynamics.
(Interscience, New York, 1961).

19. Zemansky, M.W.
Heat and Thermodynamics.
(McGraw-Hill, Toronto, 1957).

20. Eisberg, R.M.
Fundamentals of Modern Physics.
(Wiley, New York, 1964).

21. Halliday, and Resnick.
Physics for Students of Science & Engineering,
(Wiley, New York, 1964).

22. Vanderslice, J.T.
Thermodynamics.
(Prentice Hall, New York, 1966).

23. Uber, F.M.
Biophysical Research Methods. p.141.
Interscience, New York, 1950.

24. Schiff, R.I.
Yellow Springs Instrument Co.
Personal c-mmunication, March 8, 1966.

25. Alfonso, S., and Herrick, J.
The Physiologist. p.63, 1960

26. Miller, J.H. Handbook of Applied Instrumentation.
(McGraw-Hill, Toronto, 1964).

27. Herschel, W.
Philosophical Trans Roy Soc. London, 90: 255-283, 1800.
(Reprinted in full, in Phil. Mag. 8, 9 (1800).

28. Herschel, J.F.W.
Philosophical Trans Roy Soc. London, 131: 1-60, 1840.

29. Hardy, J.D.
The radiating power of human skin in the infrared.
Amer. J. Physiol. 127: 454-462, 1939.

30. Hardy, J.D.
Summary review of the influence of thermal radiation on human skin.
U.S. Naval Air Station Development Center Report NADC-MA-5414,
Johnsville, Pennsylvania, 1954.

31. Barnes, R.B.
Thermography of the human body.
Science, 140: 870-878, 1963.

32. Barnes, R.B.
Thermography.
Ann. N.Y. Acad. Sci. 121: 34-48, 1964

33. Urbach, F., Nail, N.R., and Perlman, D.
The observations of temperature distribution and of thermal radiations by means of nonlinear phosphors.
J. Opt. Soc. Amer. 59: 1011, 1949.

34. Fergason, J.L.
Liquid crystals.
Sci. Amer. 211: 77-85, 1964.

35. Monograph of The New York Academy of Sciences
"Thermography and Its Clinical Applications", Vol. 121: Art. 1.
Oct. 9, 1964. 303 pp.

36. Lawson, R.N.
Implications of Surface Temperature in the Diagnosis of Breast Cancer.
Can. Med. Ass. J. 75: 309, 1956.

37. Lawson, R.N.
Thermography - a New Tool in the Investigation of Breast Lesions.
Can. Services Med. J. 13: 517-524, 1957.

38. Lawson, R.N.
A New Infrared Imaging Device.
Can. Med. Ass. J. 79: 402-403, 1958.

39. Lloyd Williams, K., F. Lloyd Williams (wife), and Handley, R.S.
Infrared Radiation Thermometry in Clinical Practice.
The Lancet, 958-959, 1960.

40. Lloyd Williams, K., F. Lloyd Williams, and Handley, R.S.
Infrared Thermometry in the Diagnosis of Breast Disease.
The Lancet, 2: 1378-1381, 1961.

41. Handley, R.S.,
The Temperature of Breast Tumours as a Possible Guide to Prognosis.
Acta Union Inter. Contre le Cancer, 18: 822, 1962.

42. Lawson, R.N., and Chugtai, M.S.
Breast Cancer and Body Temperature.
Can. Med. Ass. J. 88: 68-70, 1963

43. Gershon-Cohen, J., and Haberman, J.D.
Thermography.
Radiology, 82: No. 2, 280-285, 1964.

44. Gershon-Cohen, J., Berger, Simon M., JoAnn D. Haberman, and Barnes, R.Bowling.
Thermography of the Breast.
Amer. Journal of Roentgenology, 91: No. 4, 919-926, 1964.

45. Barnes, R. Bowling, Gershon-Cohen, J., Brueschke, E.E., and J.D. Haberman. Applications of Thermography to Clinical Medicine. Medical & Biological Illustration, 14: No. 3, 175-183 1964.

46. Haberman-Brueschke, J.D., and Gershon-Cohen, J. Thermographic Localization of the Placental Site. Journal of the Albert Einstein Medical Center, 12: No. 4, 248-254, 1964.

47. Haberman, J.D., Gershon-Cohen, J., and Erich Brueschke. Background Enhancement Techniques for Thermograms. Proceedings of the 17th Annual Conference on Engineering in Medicine and Biology, 6: 1964.

48. Gershon-Cohen, J., and Barnes, R.Bowling. Thermography. Gevaert X-Ray Bulletin, No. 1, 12-16, 1965.

49. Brueschke, E., J.D. Haberman-Brueschke, and Gershon-Cohen, J. Infrared Thermoprofile Analysis in Clinical Medicine. The American Journal of Medical Electronics, 4: 65-69, 1965.

50. Haberman-Brueschke, JoAnn D., Brueschke, Erich E., Isard, Harold J., and Gershon-Cohen, Jacob. Effect of Smoking on Skin Temperature as Demonstrated by the Thermograph. Journal of the Albert Einstein Medical Center, 13: No. 3, 205-210, 1965.

51. Gershon-Cohen, J., and J.D. Haberman. Medical Thermography. Amer. Journal of Roentgenology, 94: No. 3, 735-740, 1965.

52. Gershon-Cohen, J., JoAnn D. Haberman-Brueschke, and Brueschke, Erich E. Medical Thermography: A Summary of Current Status. The Radiologic Clinics of North America, 3:, No. 3, 403-431, 1965.

53. Gershon-Cohen, J., J.D. Haberman-Brueschke, and Brueschke, Erich E. Obstetric and Gynecologic Thermography. Obstetrics and Gynecology, 26: No. 6, 842-847, 1965.

54. Gershon-Cohen, J., J.D. Haberman, Berger, S.M., and Barnes, R.B. Newer Techniques in the Detection and the Diagnosis of Breast Cancer, Mammography and Thermography. Proceedings 5th National Cancer Conference, 165-173, 1965

55. Gershon-Cohen, J., J.D. Haberman-Brueschke, and Brueschke, E.E.
Current Advances in Diagnosis of Breast Cancer: Mammography and Thermography.
Academy of Medicine of New Jersey Bulletin, 11: No. 3, 188-193, 1965.

56. Connell, J.F. Jr., Ruzicka, Francis F., Grosst, Carlo E., Osborne, Alan W., and Conte, Alexander J.
Thermography in the Detection of Breast Cancer.
"Cancer", Journal of the Amer. Cancer Soc. Vol. 19: No. 1, 1966.

57. Birnbaum, S.J., and Kliot, D.
Thermography - Obststrical Applications.
Ann. N.Y. Acad. Sci. 121: 209-222, 1964.

58. Haberman-Brueschke, J.D., and Gershon-Cohen, J.
Thermographic Localization of the Placental Site.
J. Albert Einstein Med. Ctr. 12: 248-254, 1964.

59. Gershon-Cohen, J., et al.
Medical Thermography.
Rad. Clin. North America, Vol. 3. No. 3, December 1965.

60. Walsh, J.W.T.
Photometry, 3rd Edition.
(Dover Publications, New York,) 1965.

61. Stenstrom, S.
Optics and the Eye.
(Butterworth's, Toronto.) 1964.

62. Ditchburn, R.W.
Light, Vol. 1 and 2.
(Blackie & Son, Glasgow.) 1963.

63. Cotton, H.
Principles of Illumination.
(John Wiley & Son, New York,) 1960.

64. Bauer, G.
Measurement of Optical Radiations.
(Focal Press, London,) 1962

65. Larach, S.
Photoelectronic Materials and Devices.
(Van Nostrand, Toronto), 1965.

66. Born, M., and Wolfe, E.
Principles of Optics.
(MacMillan Company, 2nd Edition, New York, 1962.

67. Lawson, R., and Alt, L.L.
Skin Temperature Recording with Phosphors.
Canad.Med.Ass. J. 92: 255-260, 1965.

68. Sax, N.R.
Dangerous Properties of Industrial Materials, 2nd Edition. p.559.
(Reinhold Publishing Corp., New York,) 1960.

69. Monier-Williams, G.W.
Trace Elements in Food. p. 428-437.
(Chapman Hall Limited, London), 1949.

70. Patty, F.A.
Industrial Hygiene and Toxicology, Vol. 2: p.1011-1016
(John Wylie & Sons, New York), 1962

71. Gabby, J.L.
Toxicity of Cadmium Sulfide and Cadmium Sulfoselenide Pigments.
(Arch.Indust. Hyg.) 1: 677, 1950.

72. Potts, A.M. et al.
Distribution and Fate of Cadmium in the Animal Body.
(Arch. Indust. Hyg) 2: 175, 1950.

73. Jacobson, B., and Mackay, R.S.
Radiological Contrast Enhancing Methods,
Advances in Biological and Medical Physics, Vol. V1: 201-261
(Academic Press Inc. New York,) 1958.

74. Amos, S.W., and Birkinshaw, D.C.
Noise in Video Frequency Amplifiers, p. 256
Television Engineering,
(Philosophical Library, New York,) 1956.

75. McGee, J.D., and Wilcock, W.L.
Signal to Noise Ratio in Imaging Devices.
Photo-Electronic Image Devices,
Advances in Electronics and Electron Physics, Vol. X11: 291-306
(Academic Press, New York,) 1960.

76. McGee, J.D., Wilcock, W.L., and Mandel, L.
Photo-Electronic Image Devises - many papers.
Advances in Electronic and Electron Physics, Vol. X1V:
(Academic Press, New York,) 1962.

77. Zworykin, V.K., and Ramberg, E.G.
Photo-Electricity, p.250
(John Wylie & Sons Inc. New York,) 1956.

78: Lawson, R.N.
A Technique for Identifying Suitable Veins for Blood Sampling in Breast Cancer.
Canad. Med. Assoc. J. 94: 451-453, 1966.

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April 5, 1966

Mr. E. G. Greene, Advertising Manager
United States Radium Corp.,
P. O. Box 246
Morristown, New Jersey 07960

Re: 50 copies of 2 papers

Dear Mr. Greene:

In response to your letter of March 28, we advise as follows:

1. "Kolb, F. J., Jr., and Urbach, F., "Temperature Sensitive Phosphors for the Evaluation of Air Jets Designed to Cool Motion Picture Film," Vol. 62, No. 5, May 1954, pp. 364-376.

The May 1954 issue of the Journal is out of stock. It is possible that you can obtain reprints from Dr. Kolb whose address is Eastman Kodak Co., Kodak Park Works, Bldg. 35, Rochester 4, New York.

Or it is possible that you could obtain photostats from the Engineering Societies Library, 345 E. 47th St., New York, N.Y. We enclose a copy of this letter which you may forward to the Engineering Societies Library if you seek copies from them and thus they will have the authorization for making them for you.

2. Lawson, Dr. Ray M., and Pedersen, E., "Television Imaging of Human Surface Temperature," November 1, 1965.

N.B. * This paper is planned for publication in the June issue of the Society's Journal. Dr. Lawson has supplied us with a final and a very good version of the manuscript; however, use of it is not authorized before it appears in the Journal. Then, reprints can be made only in the usual way and in form in which it appears in the Journal, unless rearrangement and possibly such copy as "Distributed by United States Radium Corp., etc.," is suggested and approved after our review.

If you believe we can help further, please do not hesitate to write us.

*Dr. Lawson - Please excuse this offhand type of corresponding to advise you.

Sincerely yours,

Victor H Allen

Victor H. Allen
Editor

VHA:SS
cc: Dr. F. J. Kolb, Jr.
Dr. Ray M. Lawson ✓

JEFFERSON MEDICAL COLLEGE HOSPITAL

DEPARTMENT OF RADIOLOGY

11TH AND WALNUT STREETS
PHILADELPHIA, PA., 19107

PHILIP J. HODES, M.D.
CHAIRMAN

11 April 1966

Dr. R.N. Lawson
Dept. of Surgery
Royal Victoria Hospital
Montreal, P.Q.
Canada

Dear Ray:

We are progressing well on the paper - we plan to submit it to Journal of Investigative Radiology so I suppose you will see it officially also.

The last few weeks have been busy. Dr. Grossman, the Chief at the Lovelace Clinic in New Mexico was in to be taught thermographic reading techniques- they are getting a Pyroscan in the next few weeks. Dr. S. Wallace who is going to M.D. Anderson in Houston has also been learing. Last week I spent a day with Eric Samuel, the Chief of Diagnostic Radiology at the Royal Infirmary in Edinburgh. They have purchased a Sweedish thermograph and finally I'm expecting Curtis Artz the South Carolina Medical Center Surgery Chief to train him. Maybe your technique is finally being taken up as it should.

Personal communication from J. Wallace, Professor of Biophysics, Jefferson Medical School.

(This is offered in evidence of increasing interest in medical applications of thermography.)