ANALYSIS OF A PROBLEM IN REMOTE RADIATION PYROMETRY

by

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ANALYSIS OF A PROBLEM IN REMOTE RADIATION PYROMETRY

INTRODUCTION

Radiation pyrometers have long been used to measure temperatures exceeding 1000 F. Recently, radiation pyrometers have been developed (4, p.23-26) for the range from 100 to 1000 F with target to instrument distances of five feet or less.

The location of high-resistance power transmission line joints presents a unique problem in the field of long-range radiation pyrometry. Measurement of the resistance of a joint necessitates removal of the joint from service. Measurement of the temperature of the joint with the line in service and subsequent calculation of its resistance would reduce service interruptions and inspection costs. The purpose of this paper is to discuss the problems of low-temperature, long-range radiation pyrometry and present the results of some simple experiments in this field.

SCOPE

Radiation pyrometers are of two general types. Total radiation pyrometers are those which measure the overall intensity of radiation from the target at all wave lengths simultaneously. Selective radiation pyrometers are those which measure the intensity of radiation in a narrow wave length interval. Optical pyrometers are of the latter type and depend for measurement upon matching the color or brightness of an incandescent target against the color or brightness of a reference standard. Radiation from sources at temperatures below 1000 F is not visible. The scope of this paper is limited to discussion of total radiation pyrometry and the suggestion of an alternate method for determining the resistance of transmission line joints.

GENERAL CONSIDERATIONS

All bodies emit energy in the form of electromagnetic waves or quanta. Energy emitted in the infrared portion of the spectrum is the result of thermal excitation. The total energy emitted increases with the temperature of the source and can be expressed by the Stefan-Boltzmann law, $W = \sigma A T^4$ for a perfect blackbody (6, p.2-5), where W is the total energy emitted, A is the area from which the radiation occurs, T is the absolute or gas scale temperature, and σ is the Stefan-Boltzmann constant. The numerical value of the constant varies with the units by which W, A, and T are expressed. For W in watts, A in cm^2 and T in degrees Kelvin σ has the value of 5.735×10^{-12} watt per cm^2 deg^4(6, p.5). A blackbody is a perfect radiator which will emit more energy at all wave lengths than any other body at the same temperature, provided that the radiation results from thermal excitation alone. Such a body will absorb all of the radiant energy falling upon it. Perfect blackbodies are approached experimentally but most radiators emit energy at lesser rates dependent on the substance from which they are made.

The ratio of the total energy emitted by a body to the total energy emitted by a blackbody of equal area at the same temperature is termed the emissivity, e, of the body. Similarly, most bodies do not absorb all of the radiation falling upon them. In general, bodies will absorb, reflect, and transmit incident radiation in varying degrees. The sum of the absorbed, reflected, and transmitted energies must equal the total incident energy. For bodies opaque to the incident radiation, reflectivity plus absorptivity must equal unity. It can be shown (6, p.22-23) that the emissivity of a body is equal to its absorptivity for blackbody radiation of the same temperature. Figure 1 indicates the variation of the emissivity of some common materials with temperature and Figure 2 illustrates the effect of surface conditions on the emissivity of copper.

The transmissivity of a body or a material varies with its thickness and the wave length of the incident radiation. Window glass which is transparent to visible radiation is quite opaque to infrared radiation of wave length greater than 2 microns, while other materials

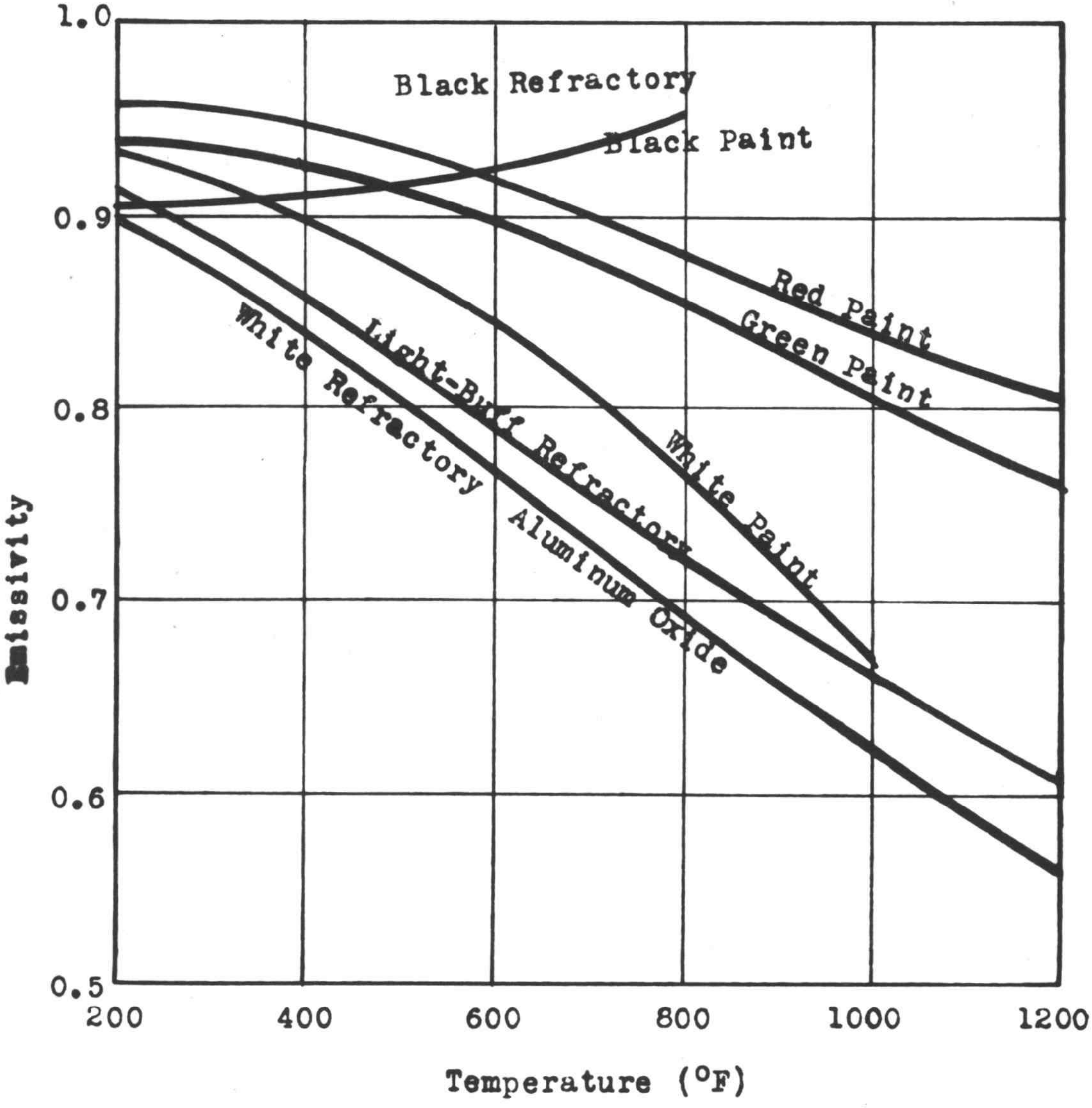


Figure 1 : Emissivities of several paints and refractories versus temperature. (3, p. 26)

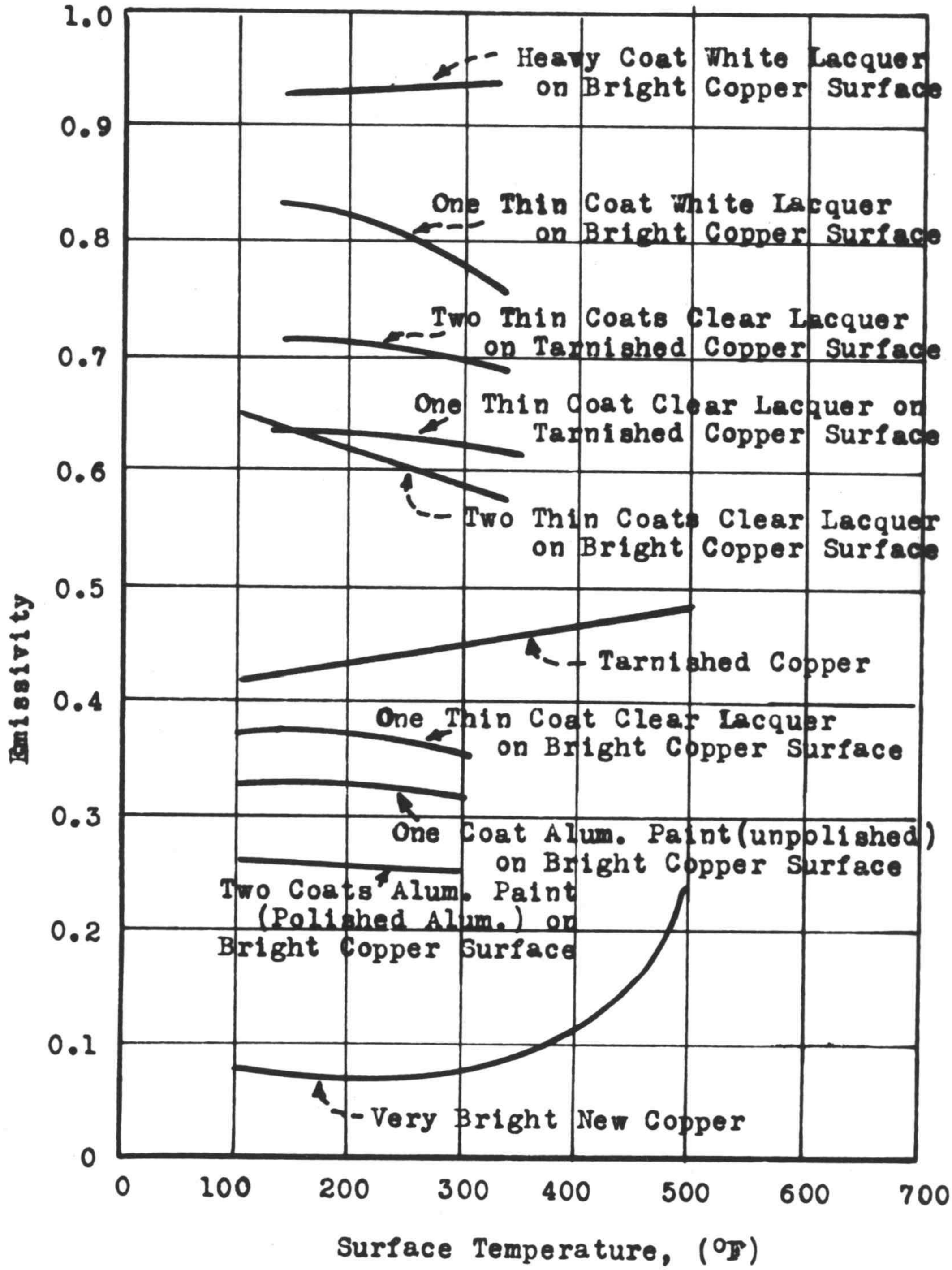


Figure 2: Emissivities of copper uncoated, coated, and tarnished versus temperature (3, p. 26)

opaque to visible radiation are quite transparent to infrared radiation of long wave length.

The design of a radiation pyrometer for a particular application must proceed on the basis of the fundamentals thus far established. To successfully measure the temperature of a power transmission line joint, the pyrometer must:

1. Perform at distances of the order of 100 feet.
2. Distinguish joint radiation from that of the sun, clouds, and sky.
3. Be readily portable.
4. Operate efficiently and reliably.

The total energy emitted by the joint determines the sensitivity required of the pyrometer. For example, let it be desired to measure the temperature of a tarnished copper joint 1.6 inches in diameter and 24 inches in length from a distance of 100 feet. Suppose further that the minimum detectable temperature be 30 C or 303 K.

Total joint area = 1.6 in. x 2.54 cm/in. x π x 24 in. x 2.54 cm/in.

= 778 cm^2.

Energy radiated = $\sigma e A T^4$

5.735 x 10^{-12} watt/cm^2 deg^4 x 778 cm^2 x $(303 K)^4$

= 16.1 watts.

The value of e in the equation is taken from Figure 2. Converted to engineering terms, this power equals a heat rate of 55 Btu/hr.

Since this radiation expands in all directions from the joint, some approximations must be made regarding the end conditions. If the joint were sufficiently long, the energy radiated from the central 24-inch section could be considered as an ever-expanding cylinder just 24 inches in length. In the actual case, however, the joint is only 24 inches in length and the energy radiated expands in the form of a sphere which greatly reduces the concentration in a unit area at a distance from the joint. If the conductor extending from the joint were made of copper or aluminum, it would be reasonable to conclude that the conductor itself would be near joint temperature for some distance on either side of the joint. To approximate the concentration of energy at the location of the pyrometer or receiver, assume that the joint radiation expands in a sphere having a cone removed from each end of a diameter parallel to the joint. Let the apex angle of these cones be 30 degrees. The remaining surface area, S, of a sphere of 100 ft radius then becomes:

$$S = 4\pi r^2 \text{ - the base area of the cones}$$
$$= 4\pi(100 \text{ ft})^2 - 2\,(100 \text{ ft} \sin 15 \text{ deg})^2 \times 2 \times \pi$$
$$= 117{,}500 \text{ sq ft.}$$

This area converted to metric units is equivalent to 108,500,000 cm^2. The energy radiated from the joint is uniformly distributed over this area and results in an energy concentration or flux of 16.1 watt/108,500,000 cm^2 or 1.483×10^{-7} watt/cm^2. Radiation of this feeble intensity will not produce a measurable change in any known material. Recourse must be had to optical means for concentrating the energy from a large area upon a small receiver or detecting element. Presumably, either a lens or a mirror could collect sufficient energy but a lens system would have several disadvantages. Table I indicates the transmission characteristics of various optical materials and their approximate transmission values over their useful range. Figure 3 indicates the spectral energy distribution from a blackbody at various temperatures. Although several of the materials in Table I would satisfy the transmission requirements illustrated by Figure 3, calcium fluoride is best suited due to its insolubility in water and its hardness which would permit cleaning of the lens. Unfortunately, chromatic aberration of such a lens would present a difficult problem due to the large variation of the refractive index with wave length. It is apparent from the foregoing considerations that a mirror for this application must be of the front surface type.

TABLE I. TRANSMISSION RANGES OF VARIOUS OPTICAL MATERIALS (5, p.206)

Optical Material	Useful Wave Length Range, Microns	Approximate Transmission Over Useful Range: %	Approximate Cut-Off Wave Length, Microns	Authority
Calcium fluoride	0.2 - 10	90	12	W. W. Coblentz
Glass (in general)	0.3 - 1	90	1	Corning Glass
Lithium fluoride	0.1 - 5	80	8	Harshaw Laboratories
Potassium bromide	0.2 - 22	90	30	Harshaw Laboratories
Pyrex	0.35 - 2.5	90	2.5	Corning Glass
Quartz	0.2 - 3	90	7	W. W. Coblentz
Rocksalt	0.2 - 12	95	21	W. W. Coblentz
Silver chloride	1 - 20	60 - 80	25	H. C. Kremers
Sylvite	0.3 - 20	80	24	W. W. Coblentz
Thallium bromide-iodide	2 - 30	70	70	O. F. Tuttle and P. H. Egli

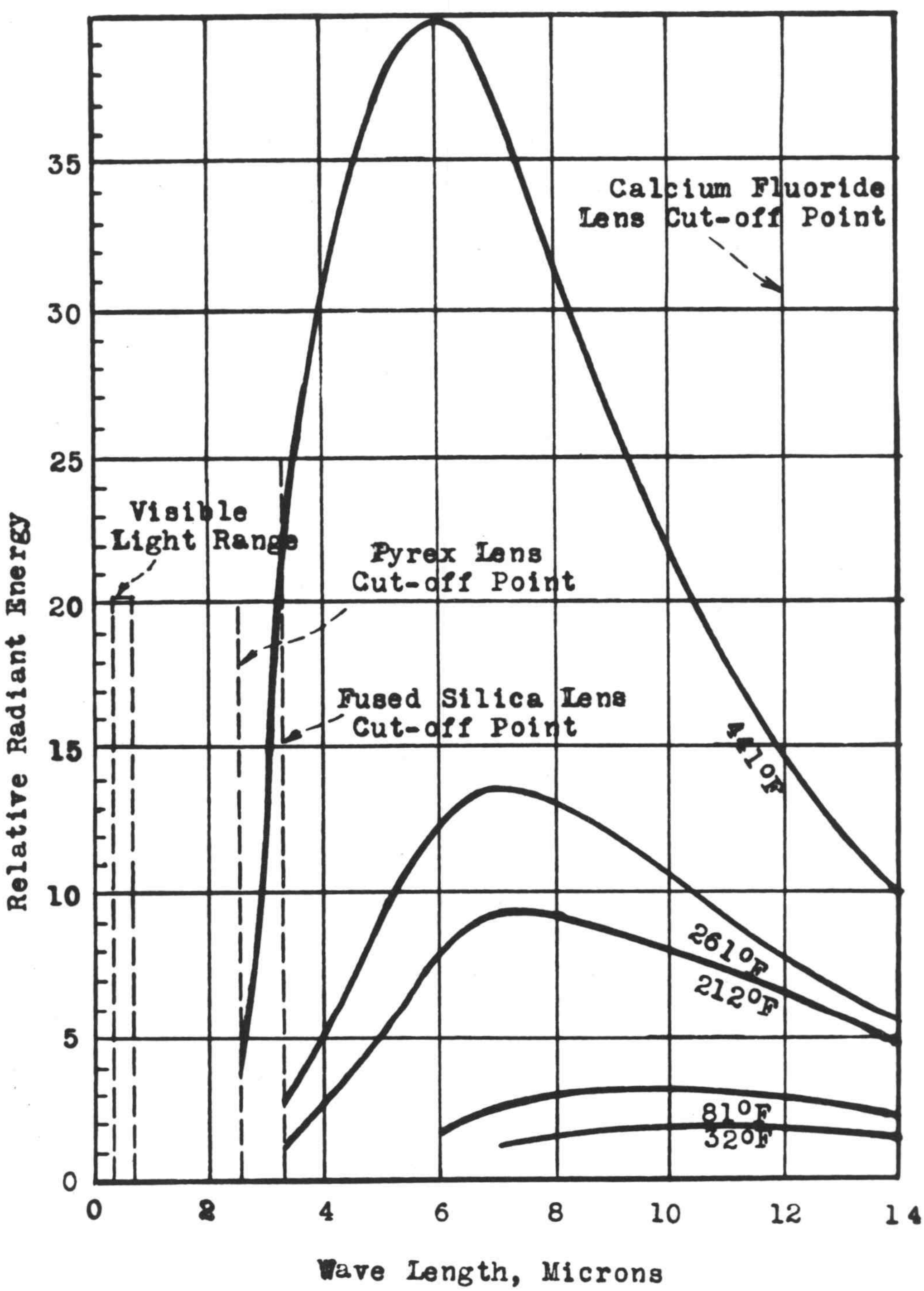


Figure 3: Relative radiant energy versus wave length for a blackbody at relatively low temperatures. (3, p. 25)

RADIATION DETECTORS

A general list of radiation detectors would include: thermocouples, bolometers, pneumatic heat detectors, vane radiometers, phosphors, photographic emulsions, photo-emissive electron tubes, photoconductive cells, photovoltaic cells and lead sulfide cells. Of these, bolometers, thermo-couples, vane radiometers and lead sulfide cells are sensitive in the wave length range from 2 to 15 microns. The lead sulfide cell cuts off at 3 microns unless cooled in liquid hydrogen and a vane radiometer with sufficient sensitivity would be too delicate for portable field use.

The bolometer, invented by Langley in 1881 (7, p.378), consists of a small electrical conductor whose resistance changes with temperature. In operation the conductor is exposed to the radiation being studied and the resultant temperature rise of the conductor alters the current flowing in the measuring circuit. In practice two con-ductors are arranged in the measuring circuit. One of the conductors is exposed to the radiation and one is shielded. The shielded conductor provides compensation permitting the system to be independent of ambient temperature. The most recent and most sensitive detector of this type was developed during World War II by the Bell Telephone Laboratories (1, p.711-725). This detector, known as a thermistor, is a semiconductor composed of sintered powders of nickel, cobalt, and manganese oxides. The thermistor has a high negative temperature coefficient of resistivity (-4% per deg C) and a low heat capacity. The rapid response of this detector permits chopping of the radiation by means of a whirling sector disc to produce an alternating current output which can be readily amplified. Thermistors are currently being manufactued by the Servo Corporation of America, 20-20 Jericho Turnpike, New Hyde Park, New York. The data of Table II were furnished in a letter by Mr. Henry Blackstone, President of the Servo Corporation. Figure 4 illustrates an application of the thermistor to infrared spectrometry.

Thermocouples connected in series to form thermopiles were used nearly a century ago in the measurement of radiant energy (6, p.191). In practice, the hot junctions of all thermocouples in the thermopile are exposed to the radiation and the cold junctions are shielded. Although many metals produce measurable thermal electromotive forces for slight differences of temperature between hot and cold junctions, the minute temperature rise of the hot junctions to be expected in the pyrometer application dictates the use of the most sensitive couple metals available. One of the most sensitive couple combinations is that of bismuth and antimony. Unfortunately, the extreme brittleness of antimony makes the fabrication of a sensitive thermopile from

TABLE II. SERVOTHERM THERMISTOR BOLOMETERS

Servotherm Type	BQ 1	BG 1	BA 1
Western Electric Designation	V-664	V-649	V-652
Receiver Flake	Blackened	Blackened	Blackened
Thermal Sink	Quartz	Glass	Air-Spaced Metal
Flake Size:			
Length	2.5 mm	2.5 mm	2.5 mm
Width	0.2 mm	0.2 mm	0.2 mm
Thickness	0.010 mm	0.010 mm	0.010 mm
Flake Resistance at 25 C approx	3 megohms	3 megohms	3 megohms
Peak applied voltage at 25 C	350 to 400	225 to 250	130 to 180
Sensitivity* volts/incident watt approx	150	200	350
Time Constant, seconds	0.003 to 0.005	0.005 to 0.008	0.020 to 0.040

*For a bias voltage 0.6 peak voltage and interruption of infra-red beam at 15 cps.

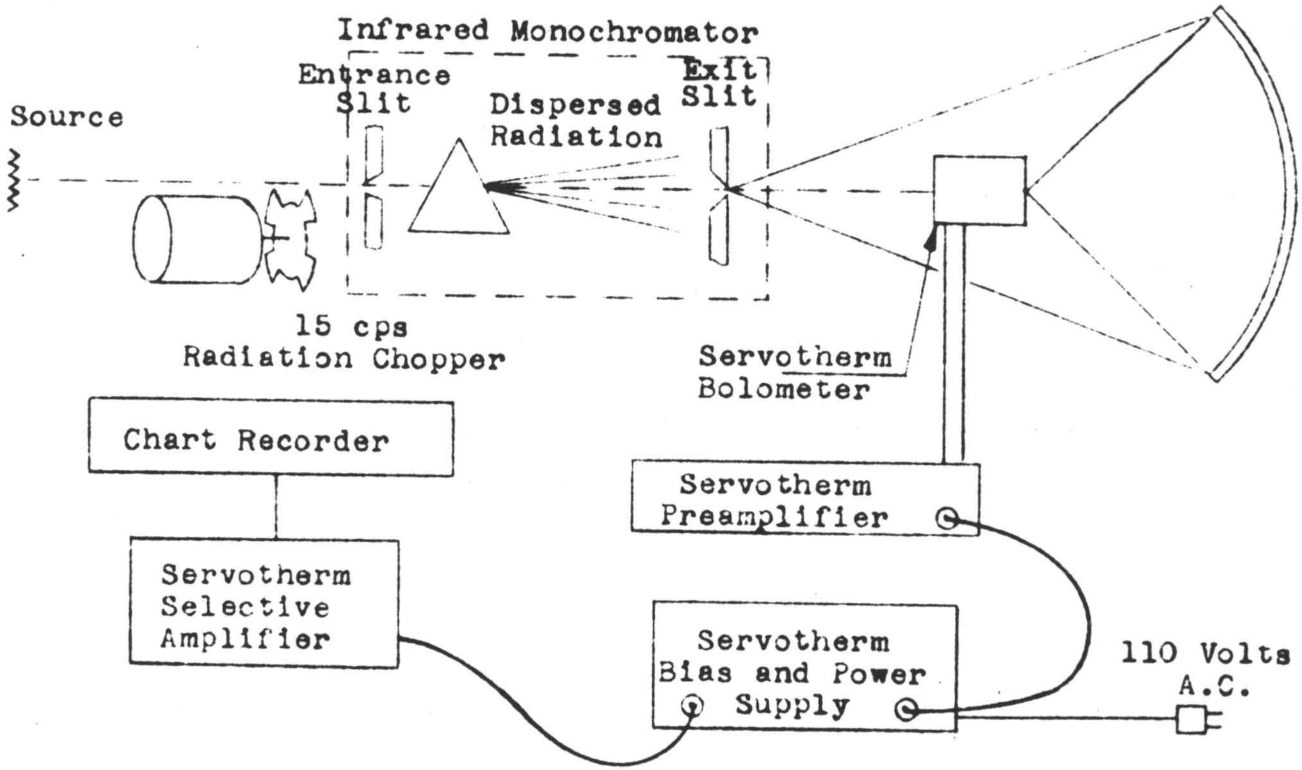


Figure 4

Typical Bolometer Application

this combination a difficult task and the finished thermopile undoubtedly would not be able to withstand the shocks to be expected in a portable field instrument. The combination of silver and bismuth, though less sensitive than the bismuth-antimony combination, has good mechanical properties and low electrical resistance which permits the use of many junctions in the thermopile. Data in the literature concerning the sensitivities of thermopiles are usually expressed in relative values rather than the absolute values of volts per incident watt. M. Rosenfield of the Field Electrical Instrument Company supplied the following data typical of their Type R thermocouple:

Thermocouple	- Field Electrical Instrument Company designation, Type R
Receiving Area	- 4 sq mm
Number of hot junctions	- 1
Resistance, ohms	- 6.44
Sensitivity, microwatts/sq cm per microvolt	- 14.9

The sensitivity of this couple can be compared to that of thermistor Type BA 1 by converting their sensitivities to the same terms. The sensitivity of thermistor Type BA 1 would be the equivalent of 1.75 microwatts per sq cm per microvolt. The signal generated by thermistor Type BA 1 for a radiant energy intensity of one watt per sq cm would be

0.57 volts. The signal generated by the Type R thermocouple for the same radiant energy intensity would be 0.067 volts. A thermopile consisting of ten Type R couples in series would have a sensitivity roughly equal to that of the thermistor.

The design of the pyrometer is directly dependent upon the available instruments for measuring the signal generated by the detecting element. Laboratory galvanometers capable of measuring very minute currents can be readily obtained but such a galvanometer would be much too delicate for use in the field. This difficulty can be overcome by means of an electronic circuit which will amplify the signal from the detecting element to such an extent that it can be measured by a fairly rugged, portable microammeter. After the minimum measurable signal has been established, the mirror dimensions can be readily estimated.

The image of the power line joint formed at the focus of the mirror must be great enough to entirely overlap the receiving area of the detecting element at the greatest joint-to-instrument distance to be encountered if the pyrometer is to function independently of distance. As the target-to-instrument distance increases, the radiation intensity decreases in agreement with the inverse square rule but the image size decreases in the same proportions so that the energy concentration incident upon the detector will remain the same. The size of the image produced by a parabolic mirror is a function of the focal length. For fixed target dimensions and target distance, the image dimensions will increase with increasing focal lengths. To achieve the least serviceable mirror diameter, the sensitive element should be made as small as possible and its shape should be the same as that of the image.

FACTORS AFFECTING PYROMETER CALIBRATION

The chief factors influencing the calibration of such a pyrometer are solar radiation, joint emissivity and humidity. Solar radiation reflected to the pyrometer by clouds or minute particles in the atmosphere would probably be much greater than the joint radiation. Some means must be provided for eliminating the effects of solar radiation lest the pyrometer indicate the apparent temperature of the sky rather than true temperature of the joint. Solar radiation, originating as it does from a source of very high temperature, has a very short wave length compared to the wave length of radiation from a source at temperatures below 500 F.

The effect of short wave length radiation can be eliminated by placing the sensitive element behind a filter opaque to wave lengths shorter than the wave lengths emitted by the line joint. Gold black deposited on a thin film of cellulose nitrate will transmit 90 per cent of all incident radiation in the wave length range from 3 to 15 microns but will have a sharp cut-off at 1 micron (2, p.582). Several filters applicable to a range of sky conditions could be developed and used in much the same fashion as photographic filters.

Joint emissivities, though uncontrollable, could be expected to reach constant values after several years of service. Experimental determination of joint emissivity as a function of length of service could provide a reasonable calibration guide. Collection of soot and foreign material from railroad engines and industrial atmospheres would seriously affect joint emissivities and could thus be the chief source of error in temperature determinations on relatively new joints (4, p.972).

Very few data are available in the literature on quantitative absorption of radiation by water vapor. It is known, however, that radiations of wave lengths greater than 3 microns do not reach the earth's surface due primarily to water vapor absorption. Figure 5 illustrates the effect of humidity upon constant target temperature indications of a low temperature radiation pyrometer designed for small target-to-instrument distances. An absolute humidity of 25 G/M^3 corresponds to 99 per cent relative humidity at 80 F. Cursory inspection of Figure 5 establishes the

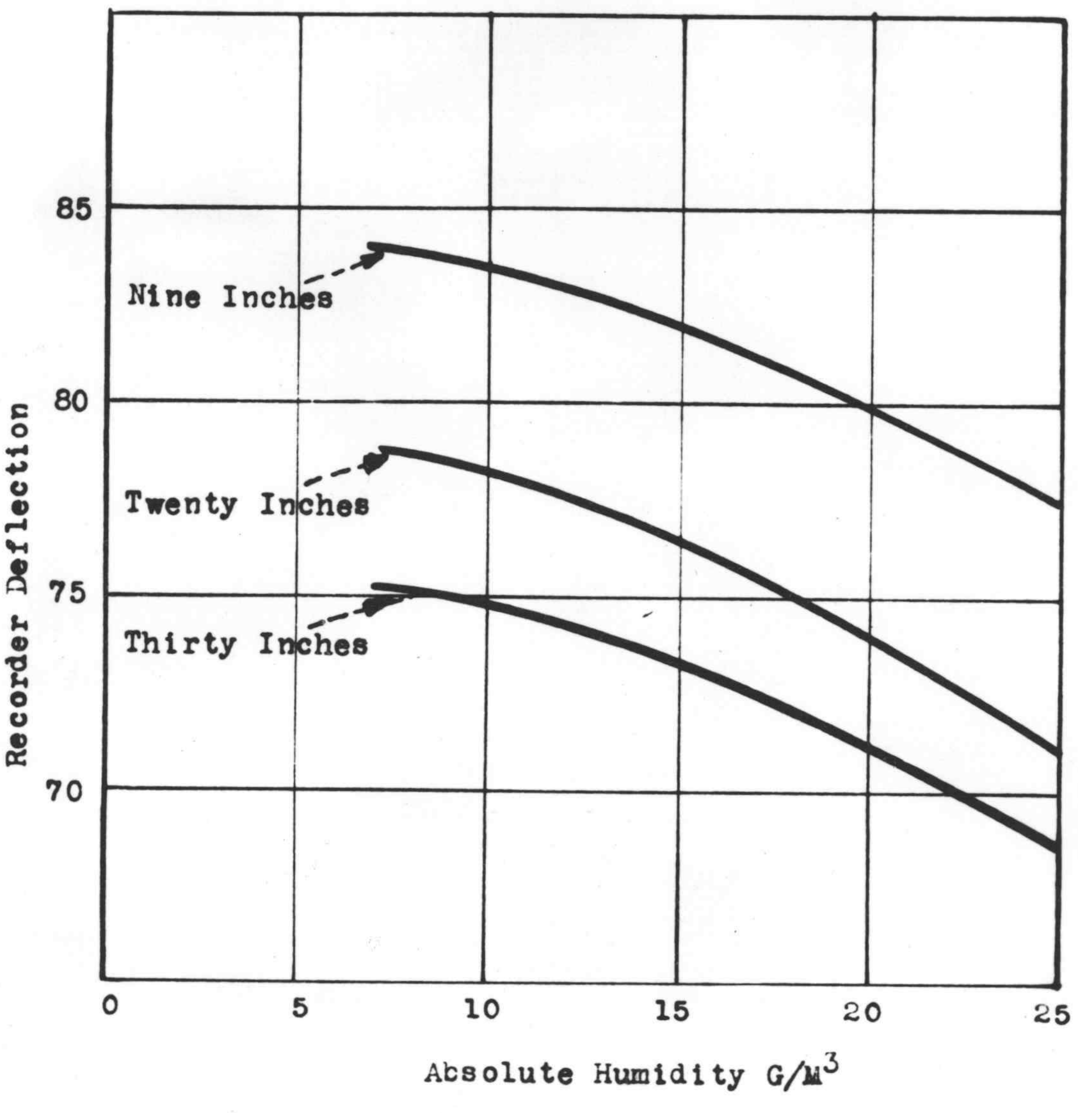


Figure 5: Radiation Pyrometer output as a function of humidity (5, p.208)

conclusion that the change in pyrometer calibration with changes in humidity will be slight due to the usual constancy of humidity in any climatic geographical area. More careful study of Figure 5 produces the alarming conclusion that the pyrometer indications could not be made truly independent of sighting distance. A 50 per cent change in sighting distance would apparently change the instrument indication 5 to 10 per cent as a result of the change in the volume of water vapor through which the radiation must pass.

PYROMETERS NOW IN USE

The Hydro-Electric Power Commission of Ontario developed the first line joint pyrometer during 1947-48 (4, p.969-970). This instrument employed a thermistor element located at the focus of an 8-inch diameter precision polished front surface mirror, and a radiation chopper operating at 15 cps. The radiation chopper consists of a whirling sector disc driven by a constant speed, battery-operated electric motor. With this arrangement, the thermistor element is heated cyclicly and cools by virtue of its small size each time the radiation is interrupted. The output of the thermistor thus becomes a 15 cycle square wave which is easily amplified. The sector disc has a second major purpose. The chopping disc is made of materials opaque to long wave length radiation but transparent to the visible and near infrared waves. The latter are thus not modulated by the disc and produce only a steady d-c heating component which is not amplified by the tuned amplifier. Several discs (glass, mica, quartz) appropriate to various sky conditions enable the instrument to measure joint temperature rather than the apparent sky temperature. This instrument has an impressive service record and accuracies of ± 5 C are claimed. The major source of error in temperature measurement is believed to be the variation of joint emissivities. The Hydro-Electric Power Commission of Ontario has conducted an extensive investigation of joint failures, joint resistances and joint temperatures. In the course of this investigation it was learned that the temperature of a high resistance joint was more dependent on wind velocity than resistance. Loss of heat by convection from the joint considerably exceeds the loss by radiation. Joints dissipating as much as 150 watts were found to be operating near ambient temperature during moderate winds. Figure 6 illustrates the effect of low wind velocities. Although wind velocities do not alter the pyrometer's ability to determine joint temperature, they do defeat the ultimate purpose of temperature measurement, and operation is limited to comparatively calm days.

A pyrometer employing the basic elements of the one

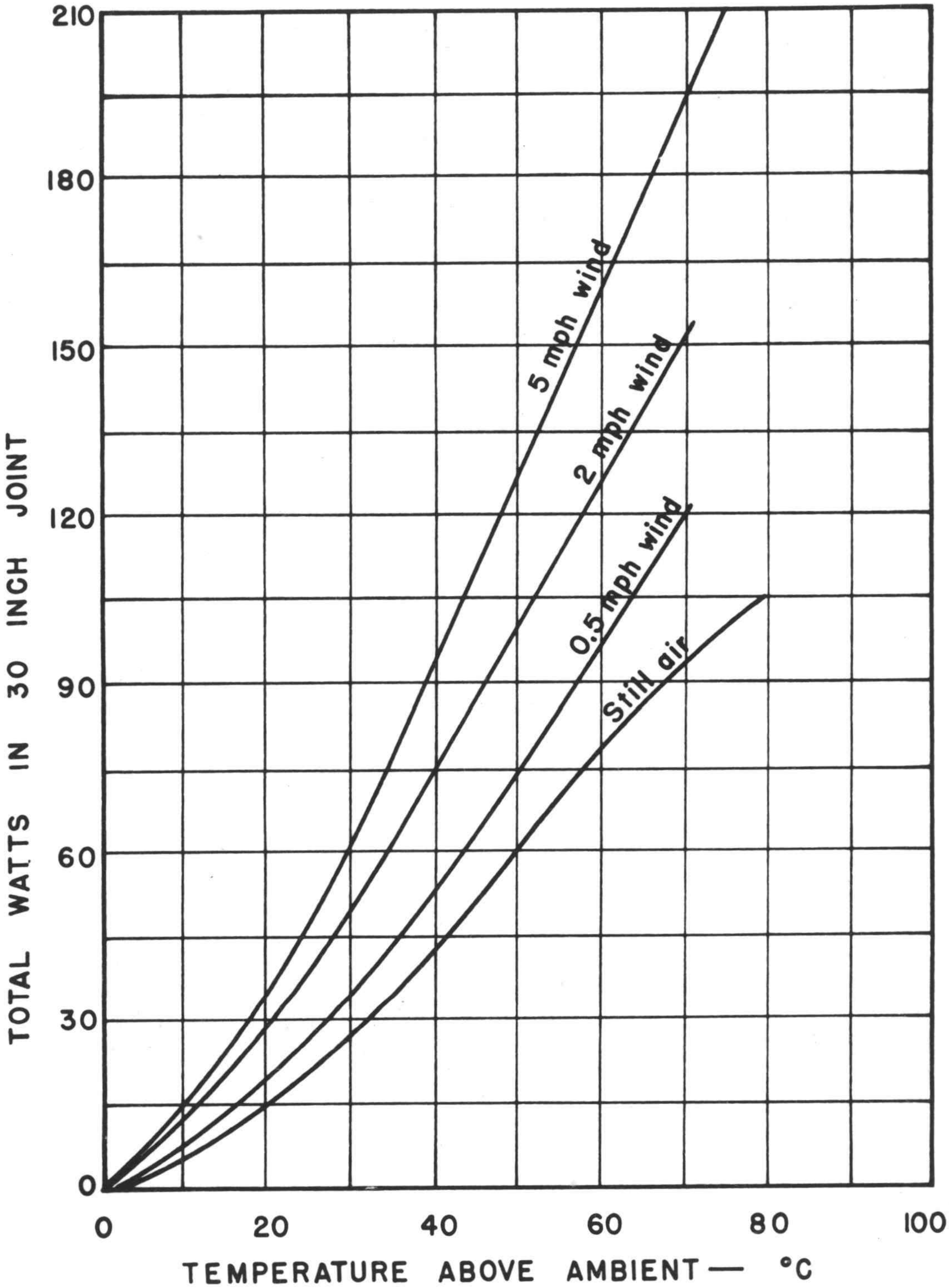


Figure 6. (4, p. 971)

described is now commercially obtainable from the Servo Corporation of America. The author corresponded with Mr. Henry Blackstone, President of the Servo Corporation, requesting price quotations for thermistor bolometers and accessory electrical measuring equipment. Mr. Blackstone's reply, dated May 3, 1950, is quoted here, in part, as follows:

> "In response to your letter of April 25, we are detailing below prices for Thermistor Bolometers and related electronic equipment.

		Price	Delivery Schedule
1.	Bolometers		
	Type BQ-1	$174.00	60 days
	Type BG-1	174.00	60 days
	Type BA-1	198.00	60 days
2.	Servotherm Preamplifier	65.00	60 days
3.	Servotherm Bias and Power Supply	325.00	90 days
4.	Servotherm Selective Amplifier	460.00	90 days

> "The bolometer prices include a silver chloride or fluorothene window. Add $10.00 per unit for rock salt window and $20.00 per unit for potassium bromide or KRS-5 window. All of these prices are quoted on the basis of single units. Lower prices can be quoted on quantity orders."

EXPERIMENTAL PYROMETER

The cost and complexity of the thermistor bolometer and its accessory electrical system led Professor Graf to suggest the use of a thermopile as the detecting element.

The author arranged a simple experiment to establish or exclude the possibility of using a thermopile for this purpose.

APPARATUS

Some preliminary experiments with the mirror from an automobile spot light indicated the need for a mirror of high quality. The author corresponded with several optical firms and received price estimates ranging from $200 to $1800 for a precision ground front surface mirror of eight inch diameter and eight inch focal length. A war-surplus Navy searchlight mirror was accordingly selected. The mirror, a product of Bausch and Lomb, was drop-forged from one-quarter inch steel plate. This mirror, 24 inches in diameter, has a focal length of 9 and 11/16 inches. A very sharp image was produced upon a small, ground glass viewing screen placed at the focus. The mirror, illustrated in Figure 7, was mounted in a plywood frame and attached to a heavy steel foundation plate in such a fashion that it could be rotated through 360 degrees of azimuth and approximately 30 degrees of elevation.

Several unsuccessful attempts were made to construct a bismuth-antimony thermopile and resort was finally made to No. 36 chromel C and copel wires in the belief that measurable results from these wires would indicate the

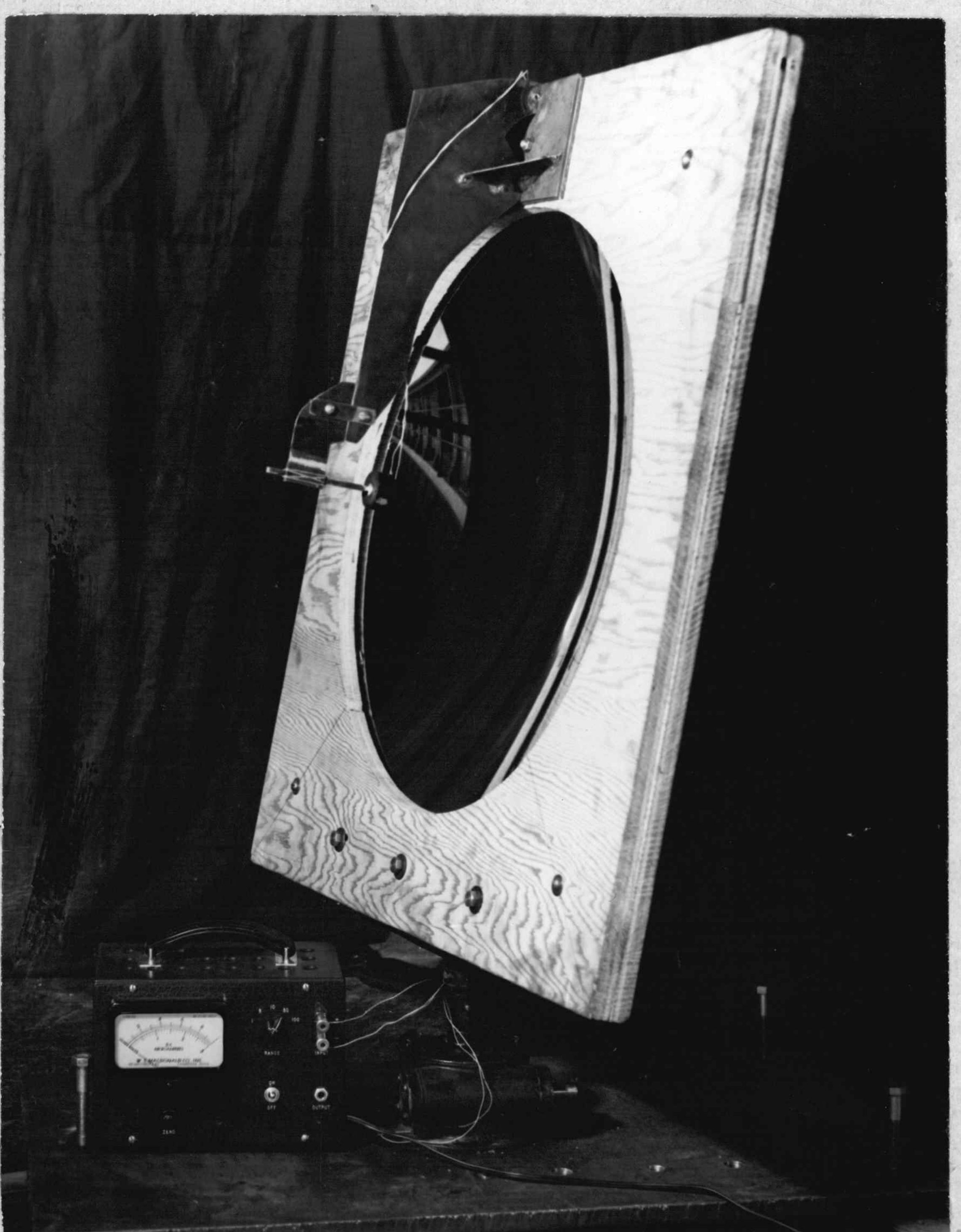


Figure 7. The experimental pyrometer.

possibility of using thermopiles. Several thermopiles constructed by soldering the junctions produced a very small response from a 500 watt lamp at a distance of approximately 75 feet. The thermopile used in the test consisted of three welded hot junctions. The welding was accomplished by carefully soldering the cold junctions to brass screws evenly spaced on a bakelite ring in such a manner that the wires just touched each other at the hot junctions. A very brief application of low voltage a-c to the cold junctions completed the weld. The position of each hot junction was then carefully adjusted by touching the cold junctions with the soldering iron. Additional solder was added to the cold junctions to keep their operating temperature stable and alternate couples were joined by short lengths of copper wire. The completed thermopile, illustrated in Figure 8, had a total resistance of 5.4 ohms. During the test, all three of the hot junctions were located in an area approximately one mm square. The couple on the lower right in Figure 8 was broken by the author in an attempt to straighten one of the wires before making the picture.

The instrument used to measure the output of the thermopile was an electronic microammeter, Type 100, manufactured by the W. S. Macdonald Company of Cambridge, Massachusetts. This instrument provides five full-scale

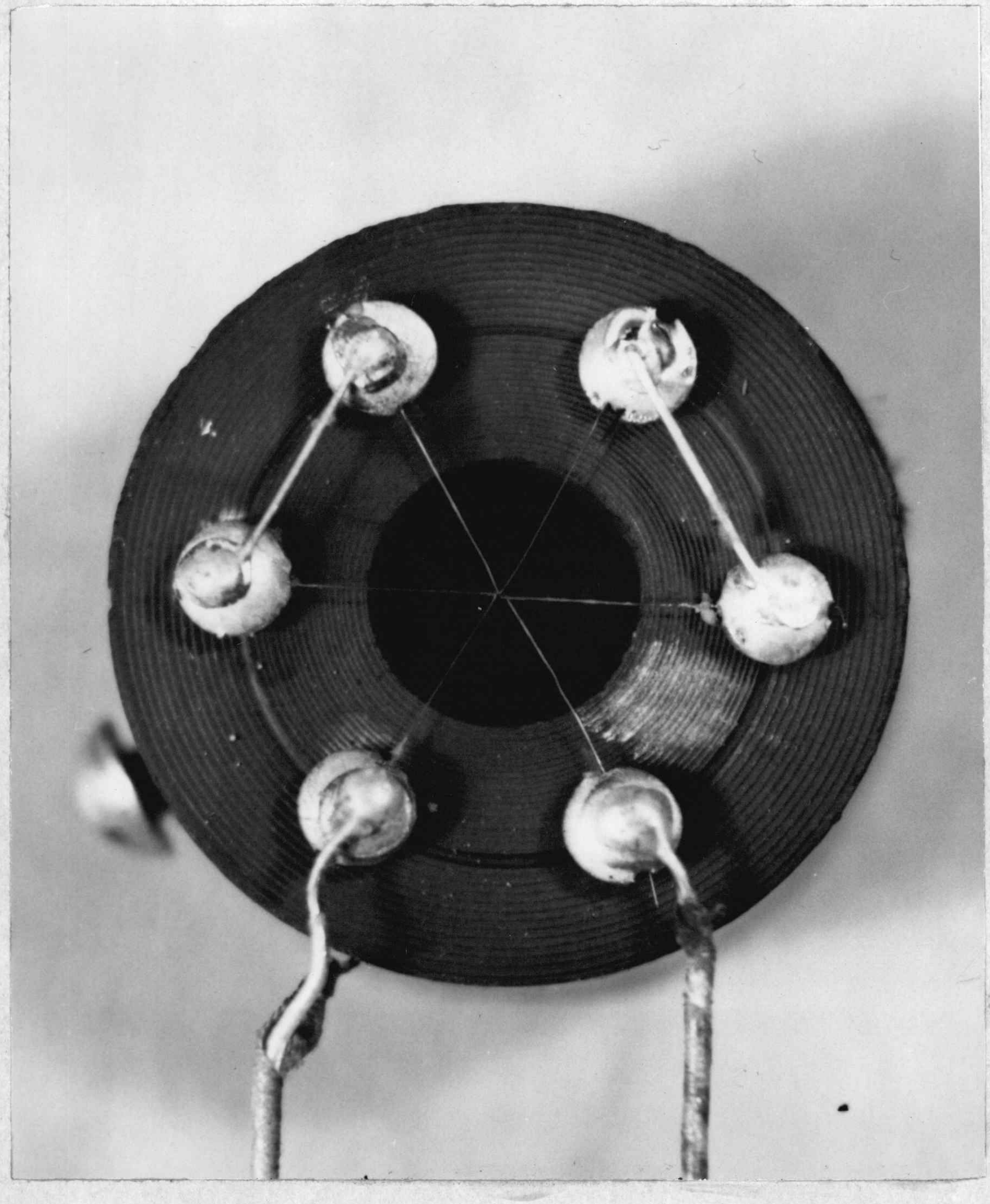


Figure 8. Experimental thermopile.
Magnification 3.

ranges of 1, 3, 10, 30, and 100 microamperes. The accuracy claimed by the maker is ± 3% of full-scale reading. The instrument requires a power supply of 110 volts a-c and the indicating meter has a rugged one-milliampere movement.

An artificial "hot-joint" was constructed by inserting a 1000 watt heating element in the central two-foot section of a four-foot length of copper tube having an outside diameter of 1.6 inches. The joint was mounted in a horizontal attitude at the end of a 12-foot length of iron pipe supported by a three-wheeled cart which carried the apparatus for controlling and recording joint temperature. The joint temperature was controlled by a Variac transformer. The surface temperature of the joint was measured by a thermocouple and automatically recorded by a Brown Electronik potentiometer. Figure 9 is a view of the joint mounted on the cart, and Figure 10 is a close-up of the joint itself.

PROCEDURE

The joint was first located on the roof of Dearborn Hall and the pyrometer located behind an open window on the third floor of the Engineering Laboratory. The sighting distance was approximately 100 feet. Several tests were made and repeated at night. The joint was then stationed at various positions along the balcony of the Engineering Laboratory

Figure 9. Artificial "hot-joint" mounted on the cart which carried the temperature controlling apparatus.

Figure 10. View of the test joint from the side seen by the pyrometer. The temperature measuring thermocouple was located at the bright spot near the center.

with the pyrometer located at the west end of the balcony. A complete test of six runs was made at night. A large, black, cloth backdrop was supported by a crane and maintained at a position 15 feet behind the joint to eliminate reflections from street lighting. The pyrometer viewed the joint in near-total darkness to reduce the effects of extraneous radiations.

RESULTS

Daytime tests with the joint located on the roof of Dearborn Hall produced surprising results. A background of blue sky produced an average thermopile current of 70 microamperes. The passage of a cloud behind the target increased the thermopile current in direct proportion to the apparent density of the cloud. Even the thinnest wisp of cloud behind the target caused an appreciable increase and a very dark cloud would throw the indicator off scale on the 100 microampere range. After several hours of observation, the author could accurately estimate sky conditions from the instrument reading but no effect of change in joint temperature could be noted. The results of the same experiment during a night of cloudy and broken skies yielded an average "clear-sky" current of three microamperes. Although the passage of clouds behind the target did not affect the meter reading at night, no noticeable change in meter reading with changing joint temperatures could be detected.

The results of the indoor test were more gratifying. Figure 11 through Figure 16 indicate the pyrometer response for distances from 9 to 160 feet. The erratic appearance of the curve in Figure 14 resulted from a faulty heater connection. Figure 14 is included here to illustrate rate of response of the pyrometer. The curves of Figure 17 were plotted from data from each of the runs to indicate the effect of distance on pyrometer response. Results from the indoor test indicate that failure to obtain a response from the outdoor test at night could be attributed to improper focusing of the mirror. The pyrometer was focused for this test during the afternoon and may have been disturbed by student traffic prior to the test.

CONCLUSIONS

Further investigation of thermopiles for this purpose would be justified. A carefully designed thermopile of ten to twenty hot junctions could produce a reliable and easily measured signal for joint temperatures exceeding the ambient temperature. Best results could be obtained by housing the thermopile in an evacuated glass bulb provided with a window of calcium fluoride or similar material. The junctions of the thermopile could easily be arranged in

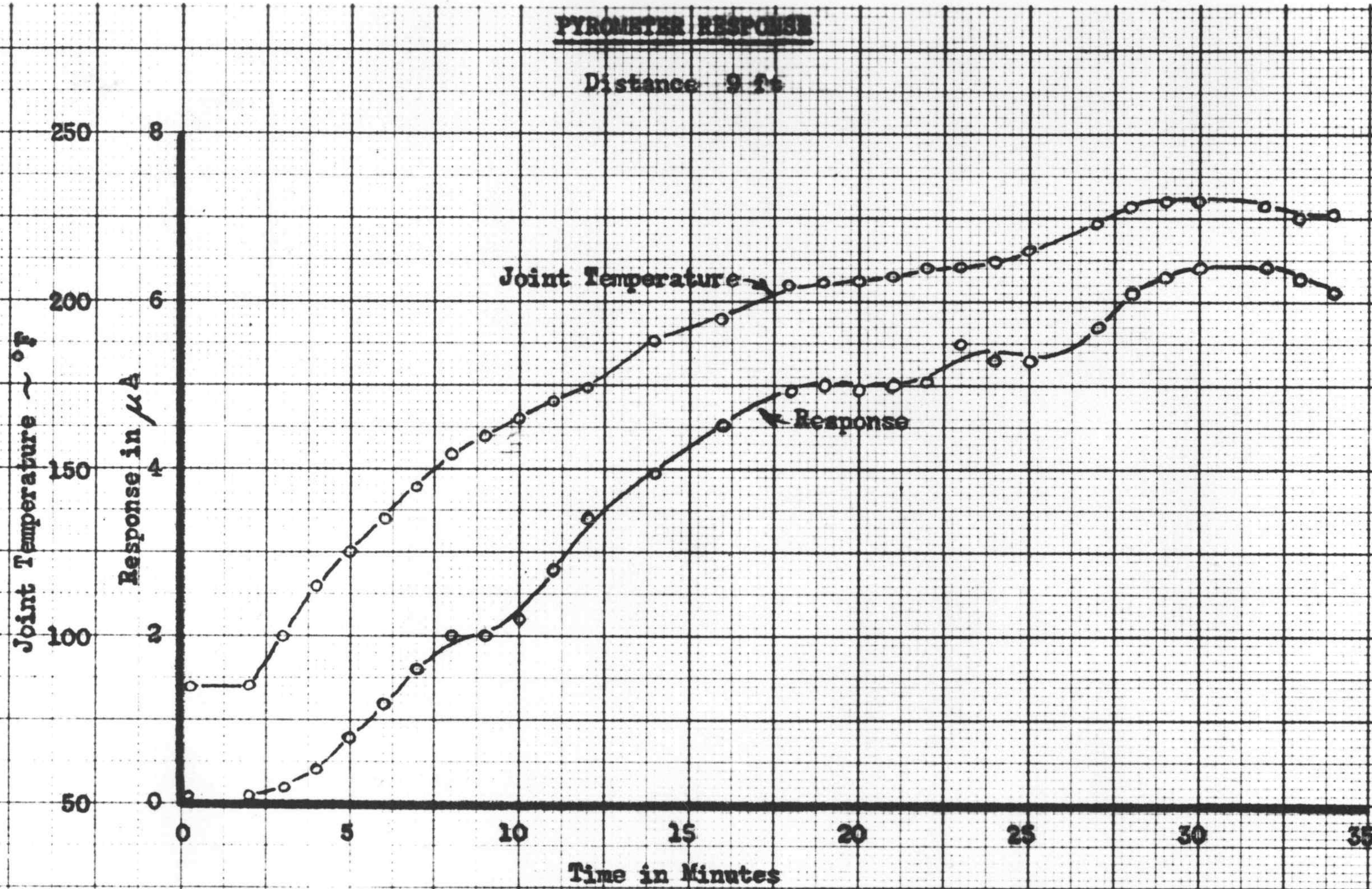

PYROMETER RESPONSE
Distance 9 ft
Joint Temperature ~ °F
Response in μA
Joint Temperature
Response
Time in Minutes
250
200
150
100
50
8
6
4
2
0
0
5
10
15
20
25
30
35

FIGURE 11

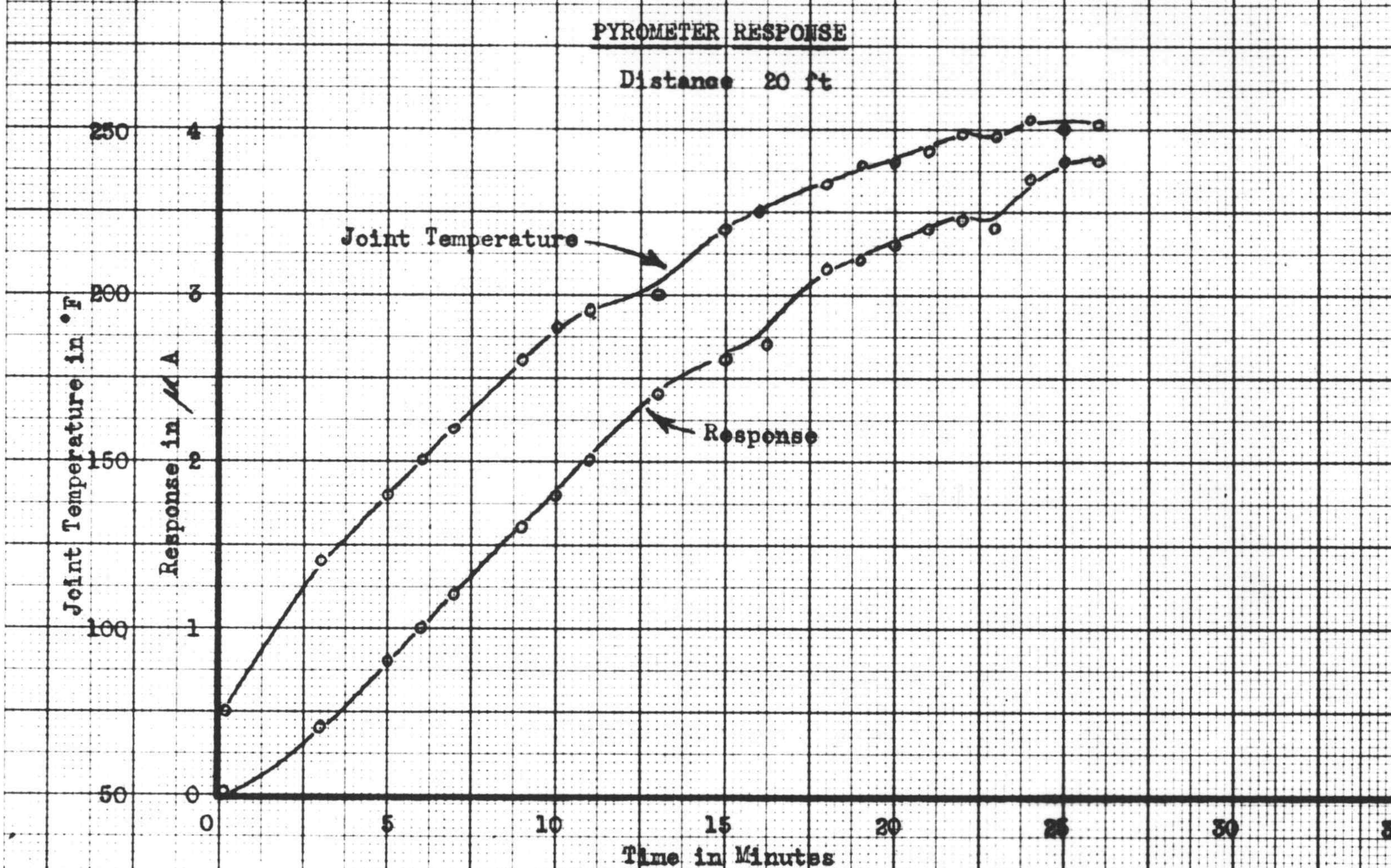
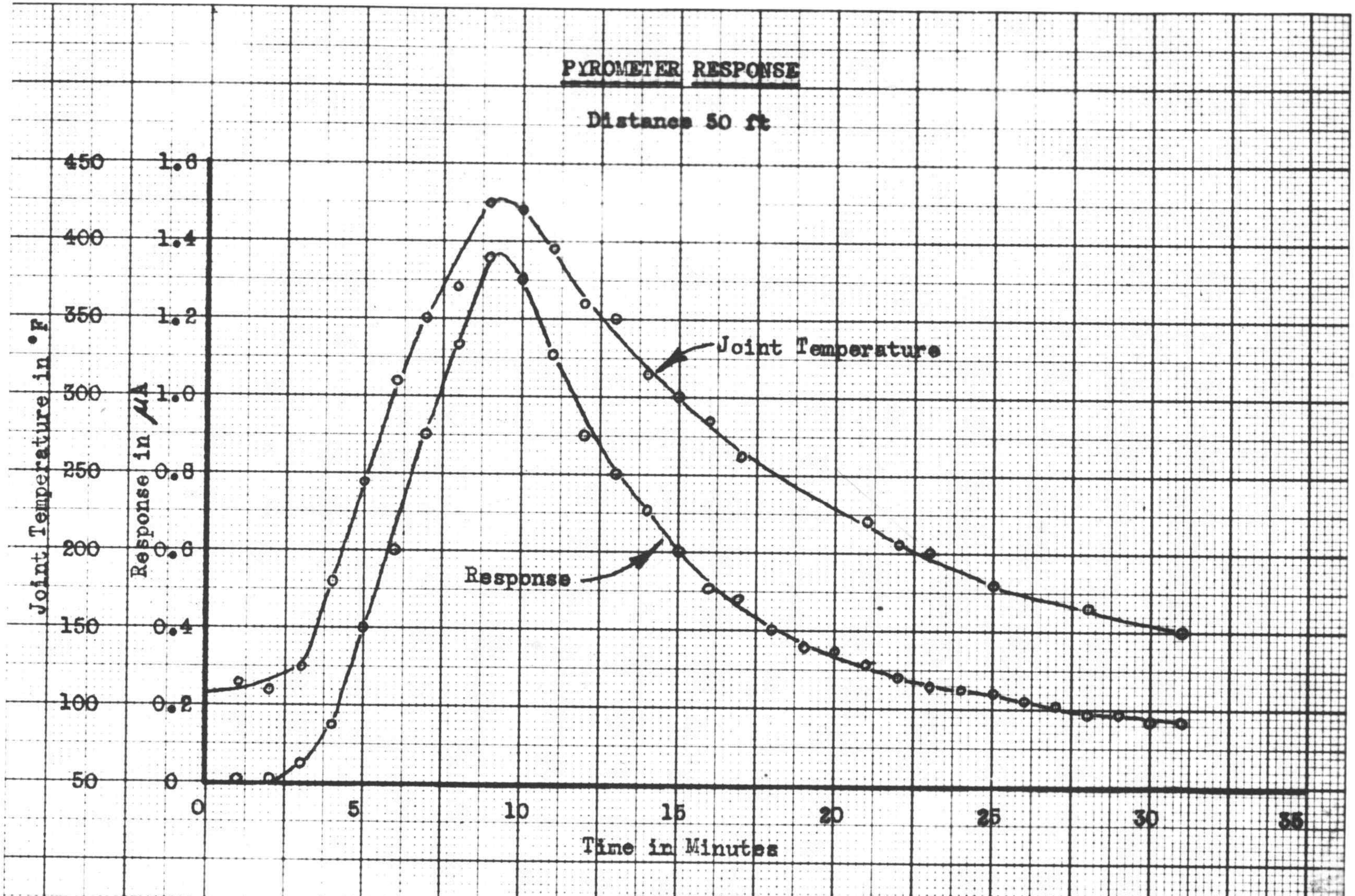

PYROMETER RESPONSE
Distance 20 ft
Joint Temperature
Response
Joint Temperature in °F
Response in μA
250
200
150
100
50
4
3
2
1
0
0
5
10
15
20
25
30
35
Time in Minutes

FIGURE 12



PYROMETER RESPONSE
Distance 50 ft
Joint Temperature in °F
450
400
350
300
250
200
150
100
50
Response in μA
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Joint Temperature
Response
0
5
10
15
20
25
30
35
Time in Minutes

FIGURE 13

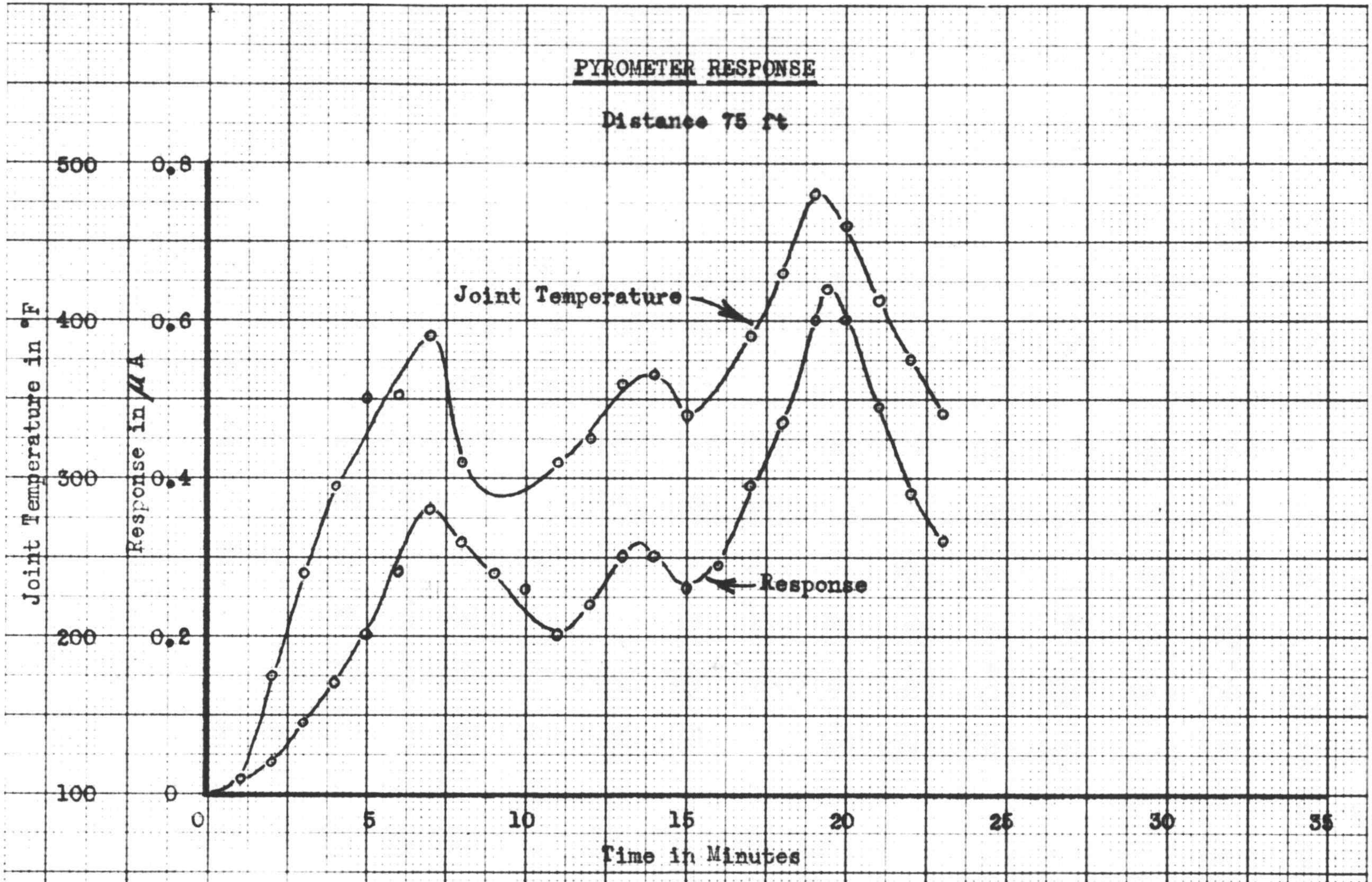

PYROMETER RESPONSE
Distance 75 ft
Joint Temperature in °F
Response in μA
500
400
300
200
100
0.8
0.6
0.4
0.2
0
Joint Temperature
Response
0
5
10
15
20
25
30
35
Time in Minutes

FIGURE 14

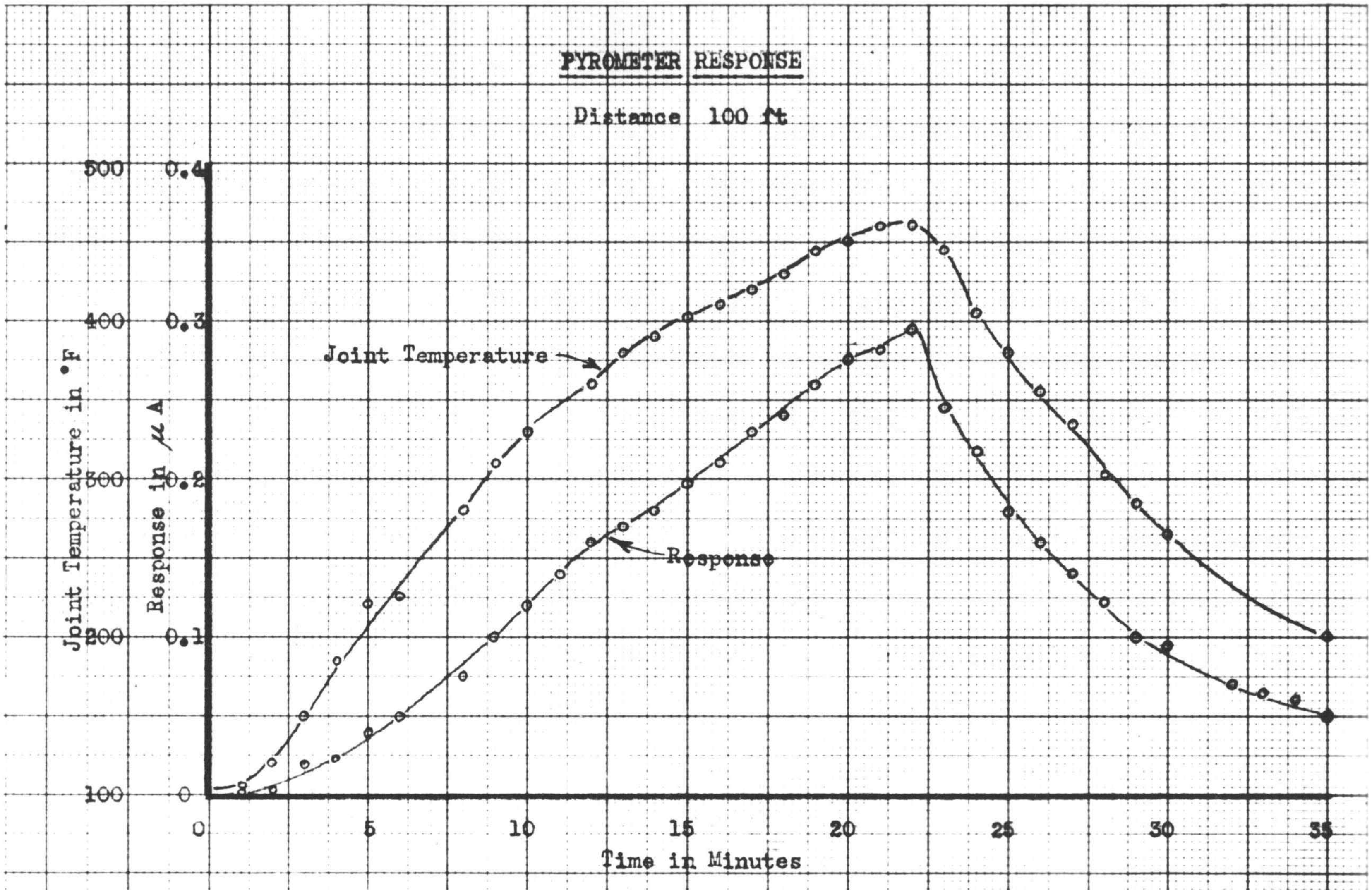

PYROMETER RESPONSE
Distance 100 ft
Joint Temperature
Response
Joint Temperature in °F
Response in μA
500
400
300
200
100
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
Time in Minutes

FIGURE 15

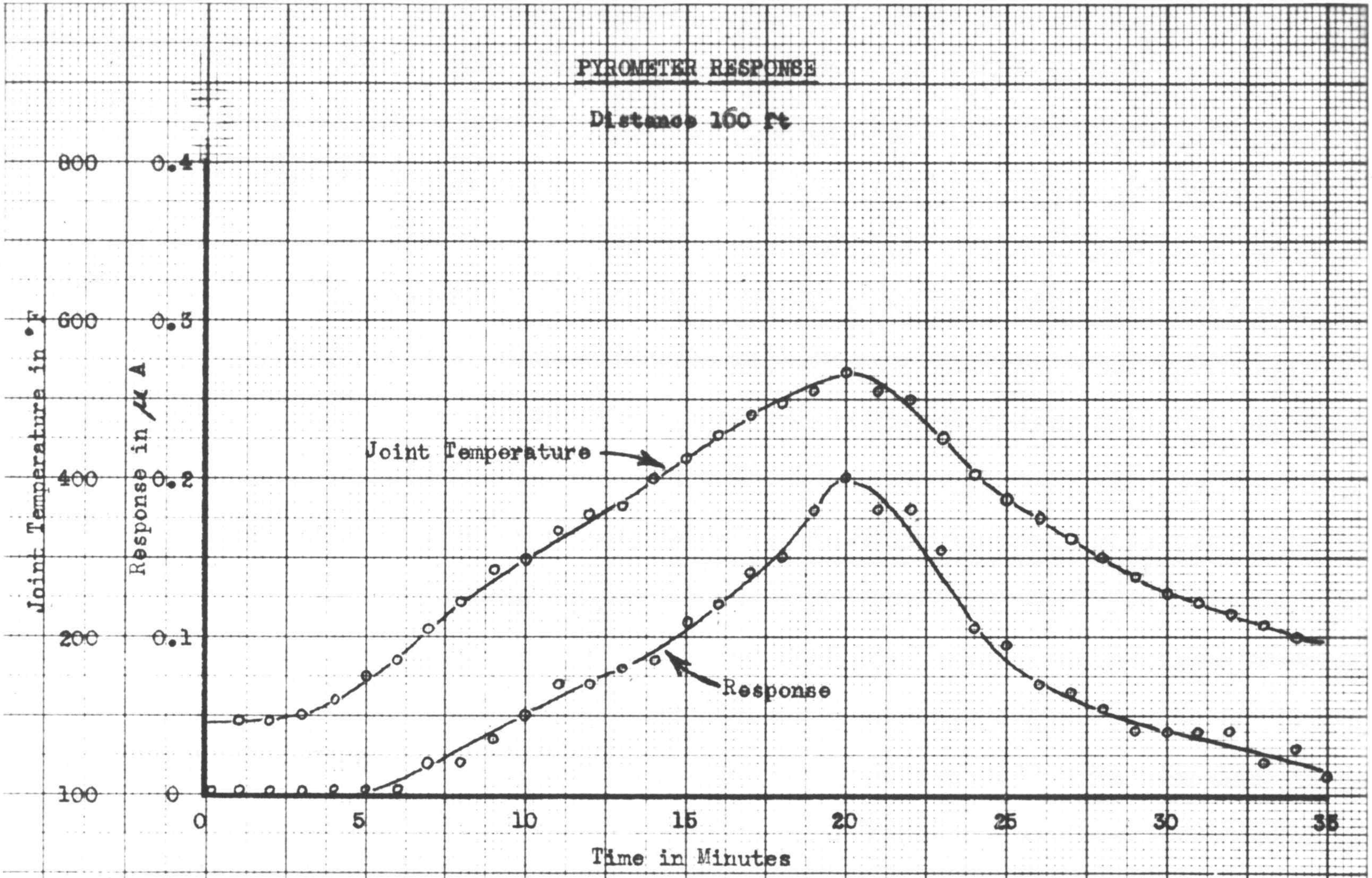

PYROMETER RESPONSE
Distance 160 ft
Joint Temperature in °F
Response in μA
800
600
400
200
100
0.4
0.3
0.2
0.1
0
Joint Temperature
Response
0
5
10
15
20
25
30
35
Time in Minutes

FIGURE 16

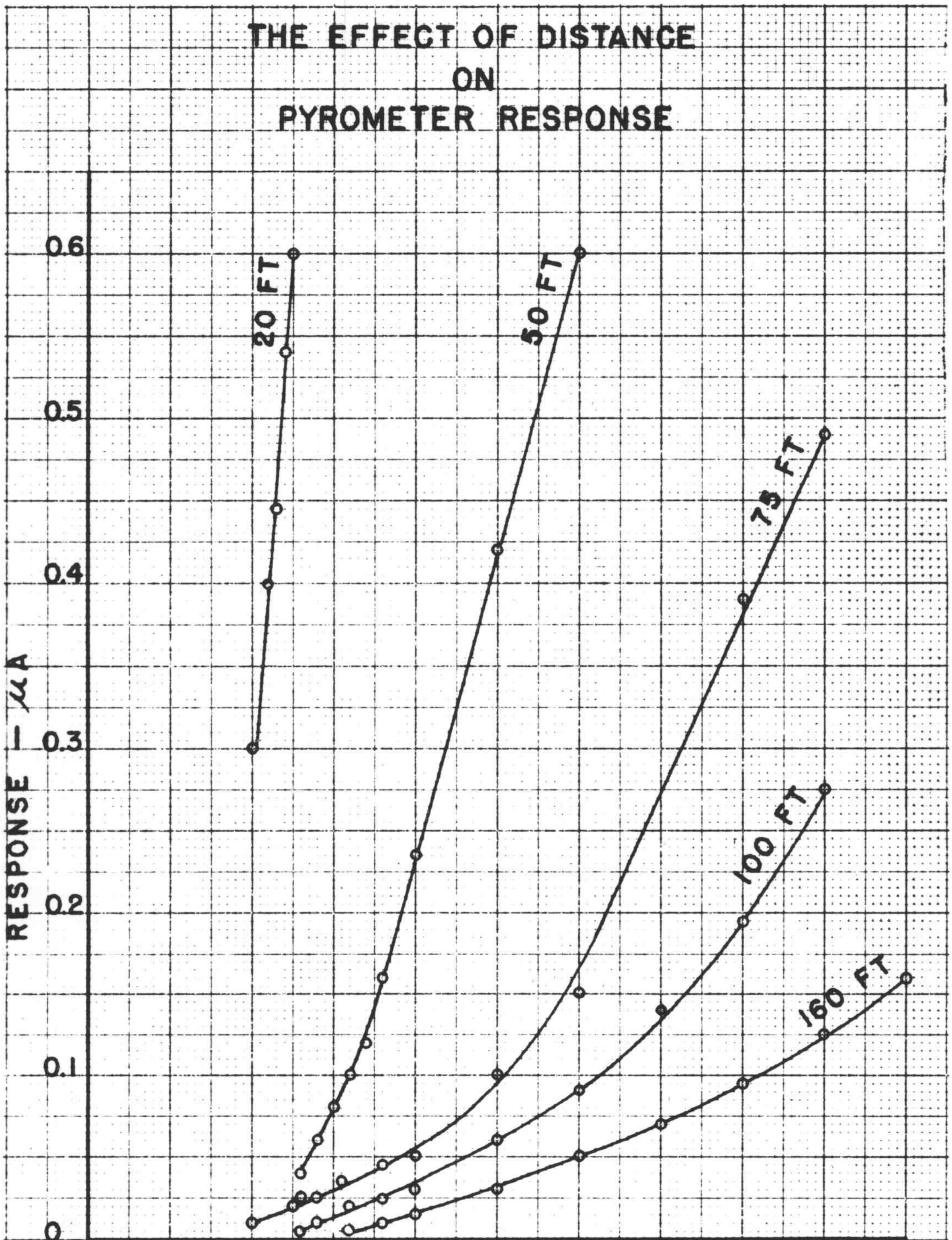

THE EFFECT OF DISTANCE
ON
PYROMETER RESPONSE
RESPONSE — μA
JOINT TEMPERATURE — °F
0
0.1
0.2
0.3
0.4
0.5
0.6
0
100
200
300
400
500
20 FT
50 FT
75 FT
100 FT
160 FT

Figure 17.

a straight line to approximate the shape of the image. This arrangement would necessitate some provision for aligning the thermopile with the image. Such provision could be made in the telescope required for sighting the pyrometer on the joint. Sky radiation could be reduced by filtering all of the radiation reaching the thermopile but the temporature of such filters would tend to rise and radiation from the filters themselves would reduce their effectiveness. This problem might be solved in the design of the thermopile. This solution would require similar characteristics of both hot and cold junctions. The hot junctions would all be grouped together and overlapped by one-half of the image and the cold junctions overlapped by the remainder. The window material above the cold junctions would be opaque to joint radiation and transparent to sky radiation while the window above the hot junctions would be transparent to both. Sky radiation would then heat both hot and cold junctions alike and produce no effect while joint radiation would heat the hot junctions only.

The use of filters for eliminating sky radiation involves observer estimation of sky conditions in selecting the proper filter. Results of the night outdoor test indicate that filters would not be necessary if joint inspections were conducted at night. Night inspection would require the use of a good beam lamp to obtain a sight on the joint but more reliable results could be achieved. The quality of the lamp reflection from the joint might also indicate the condition of the surface of the joint. The surface condition of the joint could then be a measure of joint emissivity.

The imposing list of variables affecting joint resistance determinations from pyrometer readings prompts the author to suggest a simple and perhaps more reliable method. A thin-walled aluminum tube four or five inches in diameter and four feet in length could be split down the center and equipped with a hinge at one side. Each half of the tube could be lined with a pre-shaped insulating material provided with a pocket for a thermometer of the medical or maximum-reading type. The open tube could be hoisted to the joint by meteorological balloons and steered into position by two men controlling two long cords of a non-conducting material. When the tube reached the proper position, a light jerk on a third cord could trip a spring and snap the tube closed around the joint. An additional mechanism would be necessary for releasing the tube from the joint at a signal from the ground. Such a scheme, if workable, would shield the joint from wind and allow it to reach a temperature proportional to its resistance. Sky radiation, joint emissivity, humidity and distance would have no effect on the resistance determination.

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