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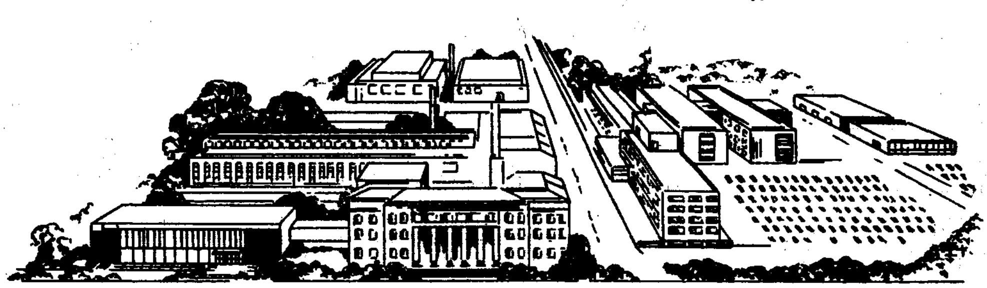

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ELEVENTH QUARTERLY REPORT
(Covering the Period: April 1 through June 30, 1963)

on

ENGINEERING PROPERTIES OF POTASSIUM

to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

by

Alexis W. Lemmon, Jr.

July 30, 1963

Contract NAS 5-584

Technical Management
NASA-Lewis Research Center
Space Electric Power Office

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Columbus 1, Ohio

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ELEVENTH QUARTERLY REPORT

on

ENGINEERING PROPERTIES OF POTASSIUM

by

Alexis W. Lemmon, Jr.

INTRODUCTION

The objective of this program for the National Aeronautics and Space Administration (NASA) is to investigate the engineering properties of potassium. It is being performed at Battelle under Contract NAS 5-584. This Eleventh Quarterly Report on this program covers work conducted from April 1 through June 30, 1963.

The thermodynamic and transport properties of potassium, both liquid and vapor, are of interest in the temperature range from 900 to 2100 F. Experimental values for vapor pressure, specific heat of liquid, thermal conductivity of liquid, viscosity of liquid, and P-V-T characteristics have been obtained. Currently the experimental program for measuring the thermal conductivity of potassium vapor is in progress. Experimental techniques for the direct measurement of the specific heat of potassium and for the measurement of the viscosity of the vapor have also been of interest. From some of the data obtained, the latent heat of vaporization, enthalpy, entropy, and specific heat of the vapor have been computed. It is anticipated that the information derived will be useful in the design, testing, and operation of nuclear electric-power generating systems, for use in space, for which potassium is the working fluid.

SUMMARY

Measurements of the viscosity, vapor pressure, thermal conductivity, and heat content of liquid potassium have been concluded. In addition, vapor compressibility has been measured in the P-V-T apparatus. Also concluded has been the design study of equipment for the direct determination of the specific heat of potassium vapor. The vapor pressure and compressibility data were used to derive a virial equation of state which, in turn, was used for the computation of enthalpy, entropy, and the specific heat of the vapor; the specific heat values of the vapor are currently reported. Experimental effort is currently limited to the final assembly of the apparatus for measuring the thermal conductivity of potassium vapor and its subsequent operation.

The thermal conductivity and electrical resistivity of liquid potassium have been measured to about 1150 C and the experimental results are reported. The data are considered to be reliable to about 800 C, and from 87 to 781 C they can be expressed by

$$k = 0.543 - 0.333 \times 10^{-3}t,$$

where k is the thermal conductivity in watts cm^{-2} cm C^{-1} and t is temperature in degrees C. Above 800 C, extrapolation by means of the average Wiedemann-Franz-Lorenz constant of 2.14×10^{-8} watt-ohm C^{-1} and the observed electrical resistivity values is recommended. Leakage of potassium within the apparatus probably explains the anomalous behavior of the thermal conductivity data between 800 and 1150 C.

Activity on the experimental program directed at the measurement of the viscosity of potassium vapor has been indefinitely suspended.

Values for the specific heat of potassium vapor have been computed from known thermodynamic relations and the virial equation of state previously derived in this program from experimental data obtained. A graphical representation is presented.

Effort has continued on the design and construction of the dynamic, bare-wire probe apparatus for the measurement of the thermal conductivity of potassium vapor. In addition, estimates of convection effects have shown them to be negligible for short times but radiation effects have been estimated to be extremely significant. Radiation will represent about 75 per cent of the heat transferred from a bare-wire probe 0.001 inch in diameter at 1200 C. Proper and essentially continuous calibration will be necessary to subtract the radiation mode in the measurements. Assembly of the apparatus followed by the experimental measurements is planned.

EXPERIMENTAL MATERIALS

No additional special development work has been performed recently on materials for construction or on the purification of potassium. Procedures described in earlier quarterly reports are being followed for the Nb-1Zr alloy and the purification of potassium; these have been found suitable.

DETAILS OF INDIVIDUAL PROGRAMS

At the current time most experimental and analytical activities on this program have been brought to a conclusion with the preparation of topical reports describing the work performed. Also, previous quarterly reports contain most of the pertinent information regarding the work already completed. For a number of items in this program, therefore, no new information is available, and these items are omitted in this report. To assist those who desire more information, the final section of this report lists reports distributed previously and those in preparation.

Phase I - Item 3. Measurement of Thermal Conductivity of Liquid

(Joseph Matolich, Jr., and Herbert W. Deem)

The thermal conductivity of liquid potassium has been measured from 100 to 1150 C (212 to 2100 F). A longitudinal, steady-state, comparative method was used.

Because ideal measuring conditions could not be met at top temperatures, only data to 800 C are considered to be reliable. Experimental work has been concluded and a topical report describing these results has been prepared.

Two separate runs were made to measure the thermal conductivity of liquid potassium. Figure 1 shows all the experimental points obtained in making these runs. In addition, Table 1 gives tentative interpolated values of thermal conductivity and electrical resistivity of potassium at selected temperatures. The electrical resistivity was measured concurrently with the thermal conductivity.

TABLE 1. INTERPOLATED THERMAL CONDUCTIVITY AND ELECTRICAL RESISTIVITY VALUES OF LIQUID POTASSIUM

Temperature, C	Thermal Conductivity, watt cm^{-2} cm C^{-1}	Electrical Resistivity, microhm-cm
100	0.51_0	$15._4$
200	0.47_7	$21._5$
300	0.44_4	$28._4$
400	0.41_0	$35._8$
500	0.37_7	$44._4$
600	0.34_4	$54._7$
700	0.31_0	$66._4$
800	0.27_7	$79._5$
900	--	$93._8$
1000	--	11_0
1100	--	13_1
1150	--	14_5
1175	--	15_3

Failure of thermocouples at the highest apparatus temperatures, probably caused by a small potassium leak, terminated the measurements before satisfactory measuring conditions could be obtained for the values above about 800 C. The data above 800 C are considered to be low because of the thermal transients existing. Unfortunately, the data are not such that a correction can be applied.

The data covering the temperature range from 87 to 781 C are expressed by the equation

$$k = 0.543 - 0.333 \times 10^{-3}t,$$

where

k = thermal conductivity, watts cm^{-2} cm C^{-1}

t = temperature, C

The standard deviation of the 50 points used for the least squares treatment is 0.014 watt cm^{-2} cm C^{-1} or 3.6 per cent at 0.4 watt cm^{-2} cm C^{-1}.

The Wiedemann-Franz-Lorenz constants calculated from the data below 800 C average 2.14×10^{-8} watt-ohm C^{-1}. Use of this value with the high temperature

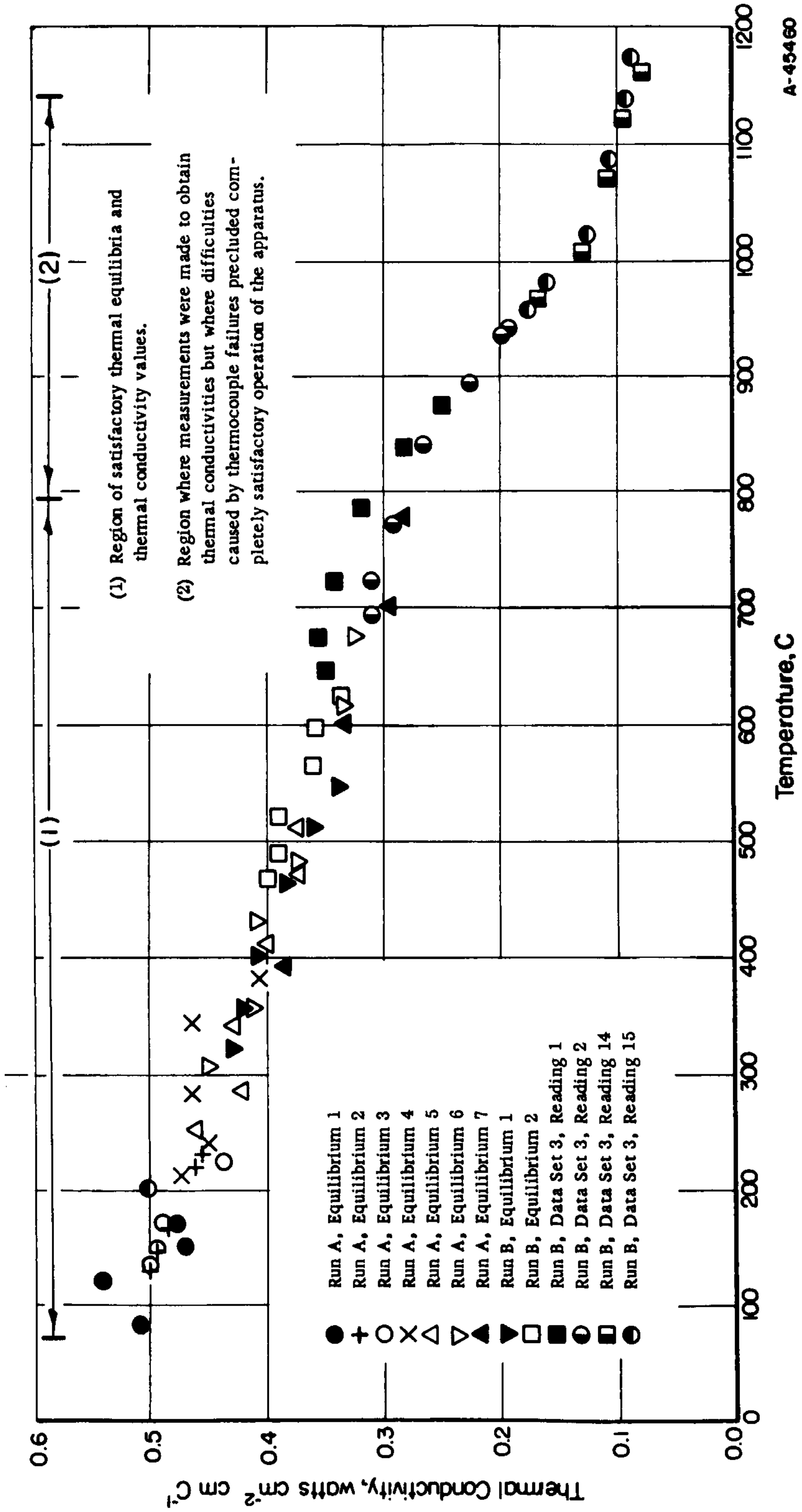

FIGURE 1. OBSERVED THERMAL CONDUCTIVITY OF LIQUID POTASSIUM

electrical resistivity values, which are considered reliable, probably provides the best means for extrapolating thermal conductivities to the higher temperatures.

Thermal conductivity values for the Nb-1Zr container material were given in the Tenth Quarterly Report.[1]

Phase I - Item 4. Measurement of Viscosity of Vapor

(E. H. Hall and J. M. Blocher, Jr.)

Activity on this item has been indefinitely suspended.

Phase II - Item 1. Pressure-Volume-Temperature Measurements

(Joseph F. Walling)

Battelle's digital computer has been programmed to calculate the heat capacity of gaseous potassium at any arbitrary pressure by use of the relation:

$$C_p = C_p^\circ - 0.0242179 \left[T \frac{d^2B}{dT^2} p + T \frac{d^2C}{dT^2} \frac{p^2}{2} \right] .$$

C_p°, the heat capacity of the ideal monomer, was taken from previous computations.[2] Virial coefficients B and C' have been estimated from the experimental portions of the program as discussed previously.[1] Note that $C'RT = C$.

Calculated values at selected pressures are shown in Figure 2. Calculations will be discussed in more detail in a forthcoming topical report.

Phase III - Measurement of Thermal Conductivity of Vapor

(Joseph Matolich, Jr., and Herbert W. Deem)

The thermal conductivity of potassium vapor is to be measured over a temperature range from 900 to 2100 F. A dynamic method using a bare-wire probe will be used to make the thermal conductivity measurements.

During this report period, estimates have been made of expected convection and radiation effects when making thermal conductivity measurements with the bare-wire probe. Estimated values were used for potassium vapor thermal conductivity, viscosity, and thermal diffusivity, as well as wire diameters and temperature gradients from wire to wall.

The calculations show that convection heat transfer can be neglected for times up to about 7 seconds at 2200 F, 12 seconds at 1475 F, and 40 seconds at 750 F. As

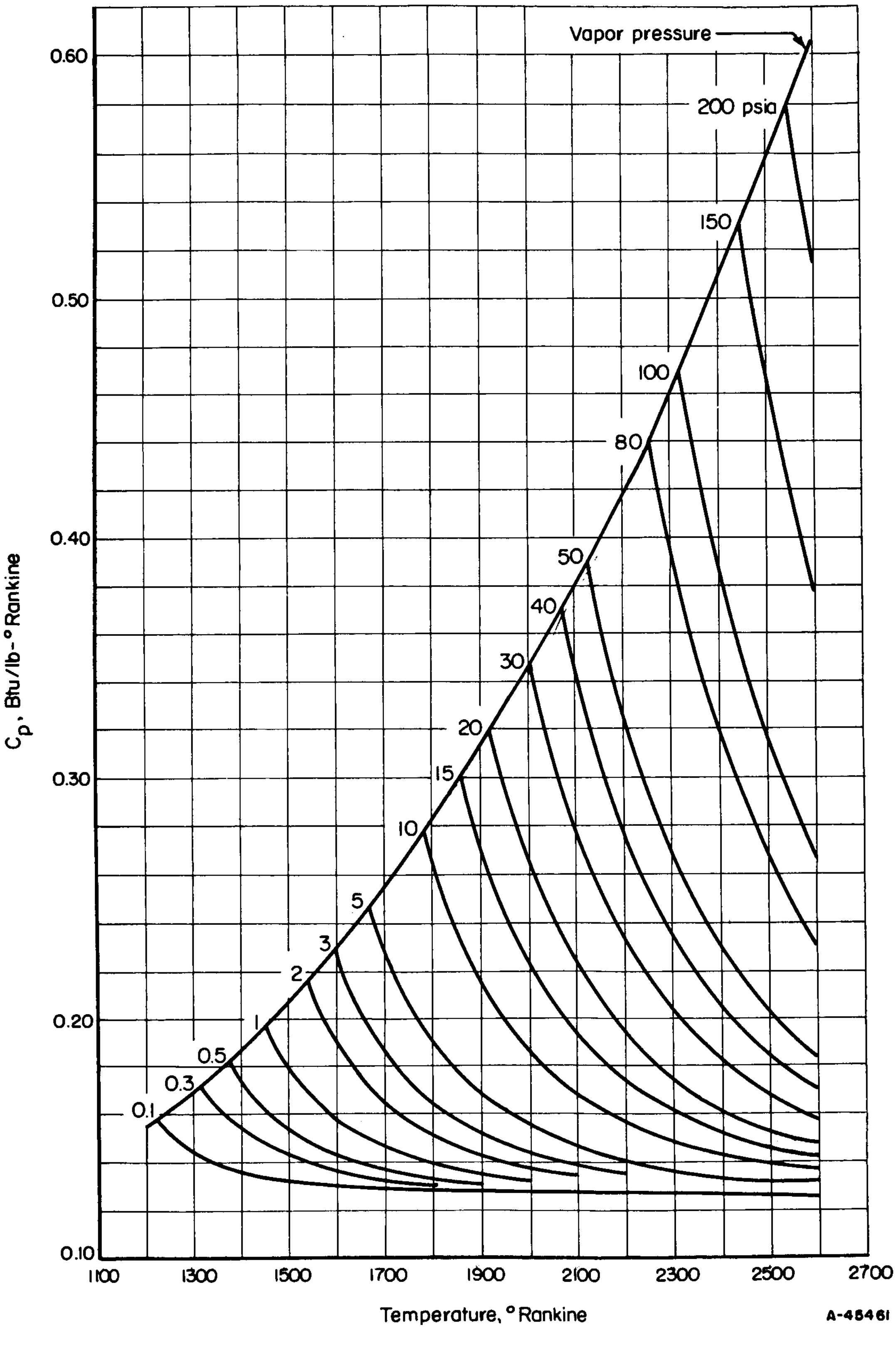

FIGURE 2. HEAT CAPACITY OF POTASSIUM VAPOR

measuring times are expected to be shorter than these, measured values should be unaffected by convection.

However, radiation heat transfer is much larger than convection transfer and can be very large compared to conduction transfer. Calculations indicate that the ratio of conduction transfer to radiation transfer is about 3.0 at 400 C, about 0.7 at 800 C, and about 0.3 at 1200 C for a bare-wire probe about 0.001 inch in diameter. It is believed that the radiation heat transfer can be accurately and frequently measured by pumping out the potassium vapor from the chamber while at temperature, using the wire probe as a resistance thermometer (checked by a thermocouple in the chamber wall), and measuring the power dissipated per unit area of the wire at a known temperature greater than that of the chamber wall. A regulated power source will be used to power the probe.

It is estimated that the error of the measured thermal conductivity of potassium vapor will be about 10 per cent at the top measuring temperature, with smaller errors at lower temperatures.

Work has continued on the purchase of materials and supplies, specifying auxiliary apparatus, and on the details of design.

Figure 3 is a block diagram of the thermal conductivity apparatus circuit for potassium vapor. The x-y recorder (1) will plot a curve similar to the general response curve given in Figure 1, page 10 of the Ninth Quarterly Report[3]. The time generator (2) and logarithmic amplifier (3) will give logarithm time response over about 3-1/2 decades on the x-axis of the recorder (1). The temperature rise of the probe wire will be recorded on the y-axis as a change in resistance of the probe. A timer (4) on the y-scale will be used to establish the correct time, and so it will not be necessary to calibrate the generator and amplifier system.

The power output of the probe wire will be determined by monitoring the current through the probe wire by use of the current measuring recorder (5) and from knowing the resistance of the wire.

Figure 4 is a schematic drawing of the probe apparatus. The measuring probe chamber (1) is within the work chamber (2). Although the measurements are to be made with a vacuum in the work chamber, the work chamber is designed to operate at 200 psi. The probe chamber (1) and its heater (3) are in the top section of the apparatus. The bottom section contains the potassium boiler (4), the temperature of which will determine the vapor pressure within the probe chamber (1). It is planned to use boron nitride as the gasket material for the lead-in seals (5). Measurements will be made at pressures slightly below the saturation values. This will insure that there will be no condensation of potassium within the probe chamber.

During the next report period it is planned to assemble the apparatus as component parts are completed or received, and to measure the thermal conductivity of potassium vapor.

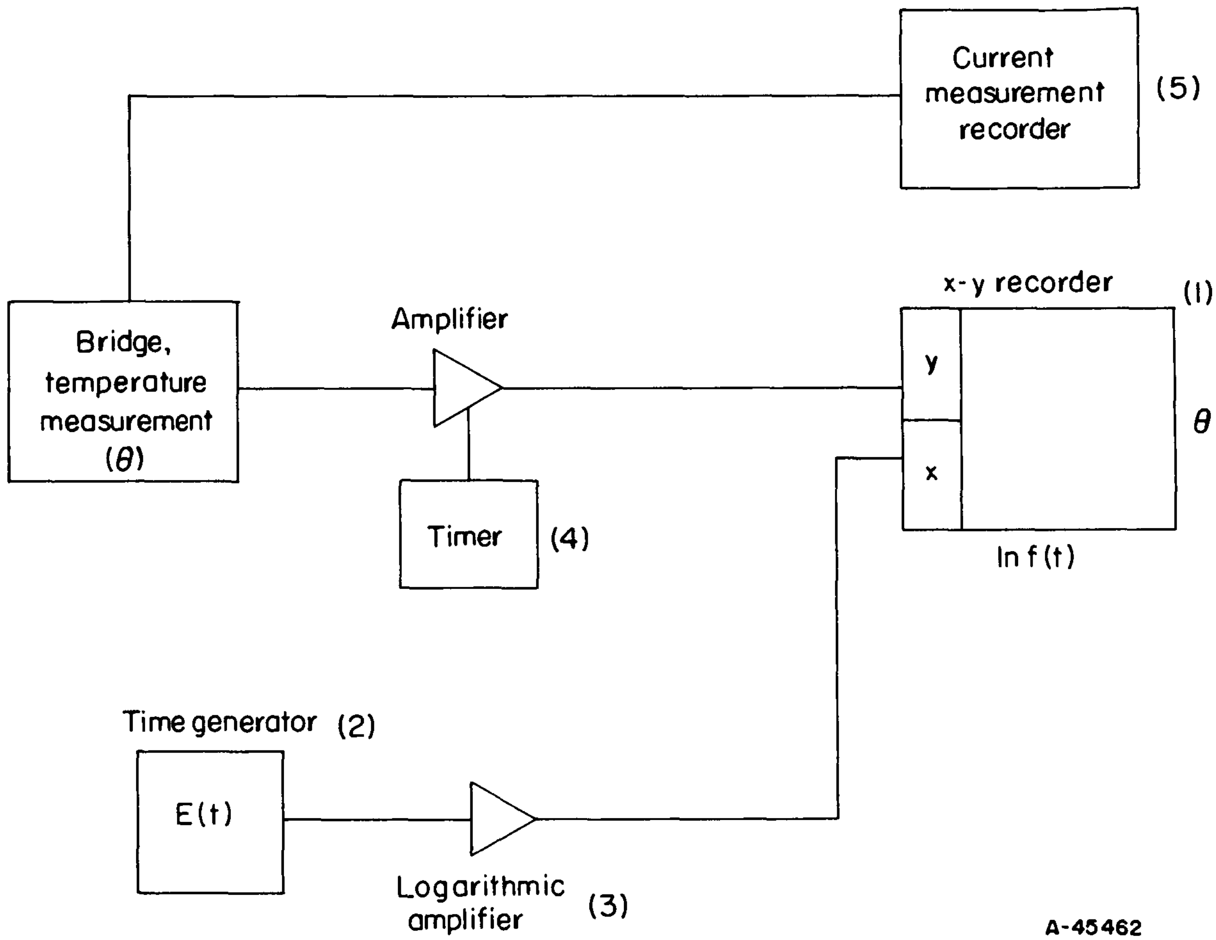

FIGURE 3. BLOCK DIAGRAM OF CIRCUIT USED IN MEASURING THERMAL CONDUCTIVITY BY BARE-WIRE PROBE

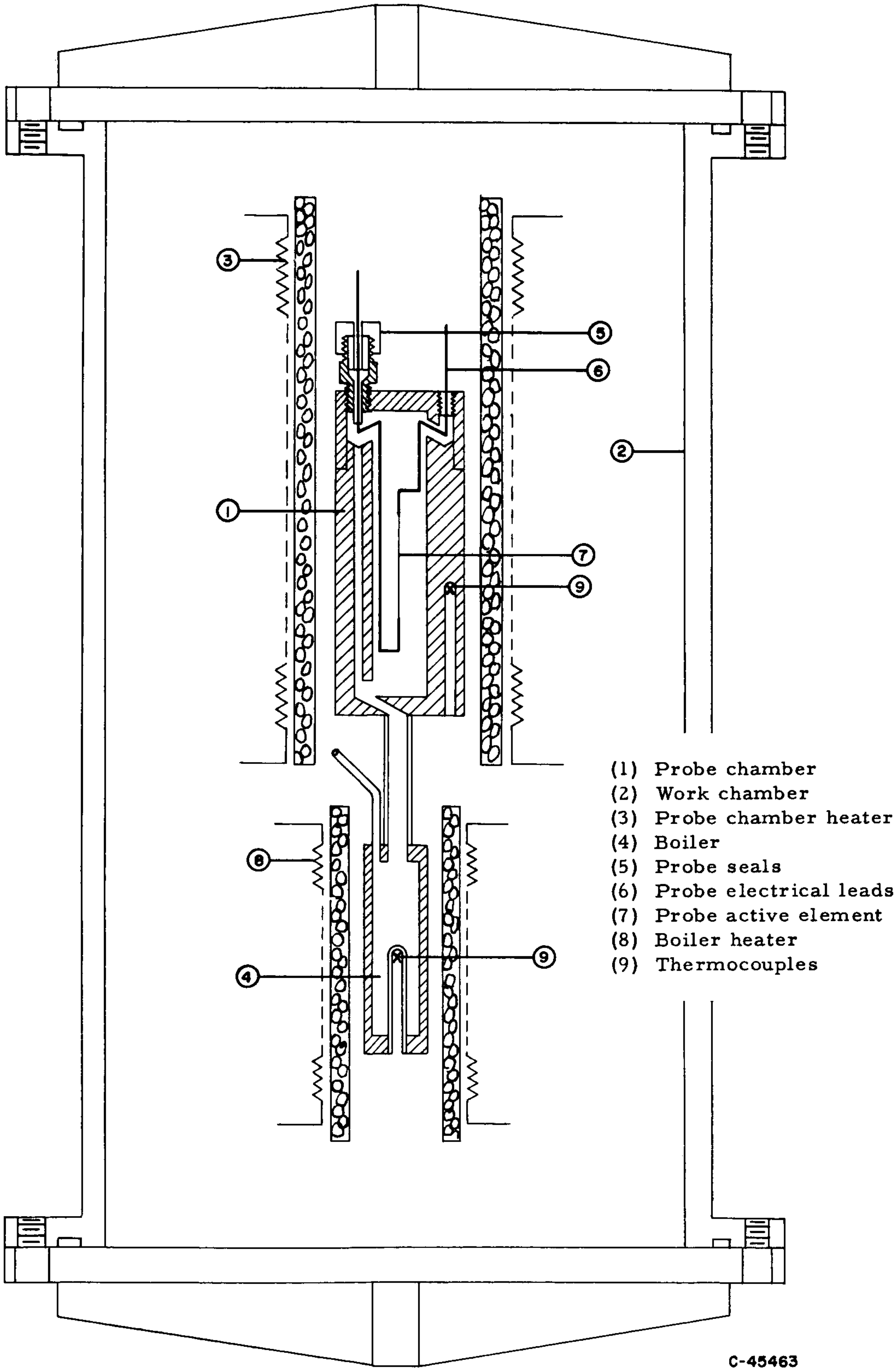

FIGURE 4. SKETCH OF THE APPARATUS FOR MEASURING THE THERMAL CONDUCTIVITY OF POTASSIUM VAPOR

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(2) Evans, W. H., Jacobson, R., Munson, T. R., and Wagman, D. D., "Thermodynamic Properties of the Alkali Metals", J. Res. N.B.S., 55, 83 (1955).

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LIST OF REPORTS COVERING CONTRACT NAS 5-584 ENGINEERING PROPERTIES OF POTASSIUM

(July 30, 1963)

"Engineering Properties of Potassium" by Alexis W. Lemmon, Jr., Battelle Memorial Institute.

(a) First Quarterly Report (Covering the Period: October 1 through December 31, 1960), January 30, 1961.

(b) Second Quarterly Report (Covering the Period: January 1 through March 31, 1961), April 30, 1961.

(c) Third Quarterly Report (Covering the Period: April 1 through June 30, 1961), August 3, 1961.

(d) Fourth Quarterly Report (Covering the Period: July 1 through September 30, 1961), October 30, 1961.

(e) Fifth Quarterly Report (Covering the Period: October 1 through December 31, 1961), January 30, 1962.

(f) Sixth Quarterly Report (Covering the Period: January 1 through March 31, 1962), April 30, 1962.

(g) Seventh Quarterly Report (Covering the Period: April 1 through June 30, 1962), July 30, 1962.

(h) Eighth Quarterly Report (Covering the Period: July 1 through September 30, 1962), October 30, 1962.

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