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NATIONAL BUREAU OF STANDARDS REPORT

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THERMAL CONDUCTIVITY OF A SPECIMEN
OF TYPE 522 ALLOY

by

Henry E. Robinson and Frank J. Powell

Report to the
Champion Spark Plug Company
Toledo 1, Ohio

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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OF TYPE 522 ALLOY

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Heat Transfer Section
Building Technology Division

Report to the
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NBS

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Thermal Conductivity of a Specimen of Type 522 Alloy

by

Henry E. Robinson and Frank J. Powell

1. INTRODUCTION

A specimen of Type 522 Alloy was submitted by the Champion Spark Plug Company, Toledo 1, Ohio, for measurement of its thermal conductivity in the temperature range from room temperature to 1300°F. The sample was shipped by the Champion Spark Plug Company, Toledo 1, Ohio.

2. SAMPLE

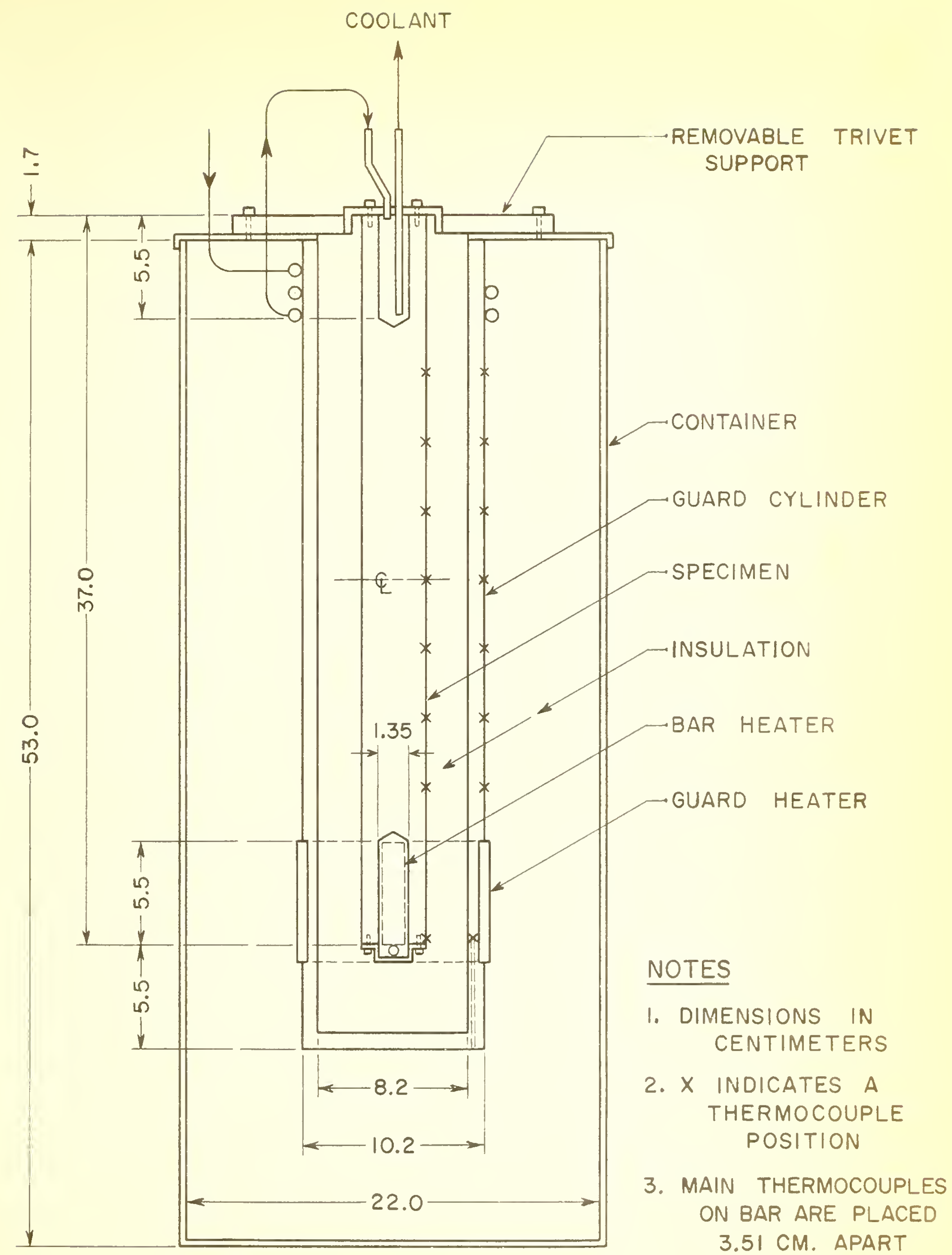
The sample was a bar of metal machined to form a specimen 2.53 cm in diameter and 36.98 cm long. It was stated to be a sample of Type 522 Alloy. No analysis of the metal composition was furnished, or made here.

3. TEST APPARATUS AND METHOD

The thermal conductivity of the sample was determined by means of a steady-state flow of heat longitudinally in a bar specimen, with measurements of the temperatures existing at the ends of six consecutive approximately 3.51 cm spans along the central length of the bar. Each determination required a pair of tests at moderately different temperature conditions, and yielded values of thermal conductivity at six different mean temperatures.

The test apparatus is shown schematically in Figure 1.

The specimen, a bar approximately 37 cm long and of uniform external dimensions, is supported at the top (cool) end concentrically within a stainless steel guard tube of 1-cm wall thickness, which in turn is held concentrically within a cylindrical outer container. The specimen is drilled at each end with a 1.35 cm hole 5.5 cm deep. An electrical heater is inserted and secured in the hole at the bottom (hot) end, and the supporting fixture at the top provides a liquid-tight connection for circulating a coolant through the top drill-hole.



APPARATUS FOR MEASURING THE THERMAL CONDUCTIVITY OF METALS

FIGURE 1.

Temperatures along the specimen were indicated by seven thermocouples located symmetrically about the longitudinal center of the specimen, spaced approximately 3.51 cm apart, with one additional thermocouple near the bottom end of the specimen. Thermocouples were similarly located in almost exactly corresponding longitudinal positions on the guard tube.

The guard tube was equipped near its lower end with an external circumferential electric heater as shown. The guard tube was cooled at the top by means of a copper-tube coil soldered circumferentially at a position corresponding in effect to that of the specimen coolant well. Coolant was pumped through the guard coil and specimen well in series connection, as shown.

The electric heater for the specimen consisted of a porcelain cylinder 1.27 cm in diameter and 5.2 cm long threaded longitudinally with 26-gage nichrome heater wire. Its resistance was approximately 22 ohms. Current was brought to the heater through relatively large heater leads, to which separate potential leads were connected at the point where they entered the porcelain core. The heater was energized by an adjustable constant-voltage d-c source. Heater current and voltage drop measurements were made using standard resistors and the high precision manual potentiometer used for thermocouple observations. The guard was heated with constant voltage a-c power.

The thermocouples were made from calibrated chromel and alumel 26-gage wires, electrically welded to form a spherical junction about 1.0 mm in diameter. Junctions in the specimen were inserted into radially-drilled holes 1.1 mm in diameter and 1.7 mm deep in the side of the bar, and tightly secured by punch-pricking the metal around the hole. The thermocouple wires were individually insulated electrically with fiberglass sleeving, and were wrapped around the bar (one in each direction) and tied at the back to secure them in the transverse plane of the junction. The wires were brought out through the powder insulation near the guard tube. The thermocouples in the guard tube were similarly attached to its exterior surface. The longitudinal positions of the thermocouple junctions were taken as those of the centers of the drilled holes, measured to the nearest 0.01 cm with a laboratory cathetometer.

After installation of the specimen, the space between it and the guard tube was filled with diatomaceous earth powder insulation, which also was used to insulate the space surrounding the guard tube.

In principle, if there were no heat exchange between the specimen and its surroundings, the conductivity could be determined from the measured power input to the specimen and the average temperature gradient for each of the six spans along the specimen, all of uniform known cross-sectional area. In practice, a perfect balance of temperatures between the bar and guard all along their lengths is not possible because of differences in their temperature coefficients of conductivity, and the effect of the outward heat losses of the guard. In addition to heat exchanges between the bar and guard from this cause, a not-insignificant longitudinal flow of heat occurs in the powder insulation surrounding the specimen, and the contribution of the specimen to this heat flow must depend somewhat on the bar-to-guard temperature unbalance.

In order to evaluate the heat flow in the bar at the center points of each of the six spans, a partly empirical procedure was used. Two steady-state test-runs were made with slightly different bar and guard temperatures and power inputs. In the two tests, the heat flow and the observed temperature drop from end to end of a given span differed, as did also the approximate integral with respect to length of the observed temperature differences between bar and guard, summed from the hot end of the bar to the span center point. It is thus possible to write for each span two equations (one for each test-run) of the form:

$$\frac{Ak\Delta t}{\Delta x} + fS = Q$$

where A is the cross-sectional area of the specimen.

k is the specimen conductivity at the mean temperature of the span.

Δt is the temperature drop from end to end of the span.

Δx is the length of the span.

fS represents the total net heat loss from the bar (from the far end at the heater to the span center point) expressed as the product of S, which is an approximation of the integral $\int_0^x (t_{bar} - t_{guard})dx$, and an average heat transfer coefficient f, which lumps the thermal conductance of the path from bar to guard and the contribution of the specimen to the longitudinal heat flow in the insulation up to the span center point.

Q is the measured power input to the specimen heater.

By simultaneous solution of the two equations, the value of k for each span, corresponding to the mean span mean temperature, is obtained. All of the computation of results is effected by use of an IBM-704 digital computer, suitably programmed to compute the value of k for each of the six spans from input data consisting of the average observed temperature values at the several bar and guard positions, and the power input to the bar, for each of the two steady-state test-runs constituting a pair at nearly the same temperatures. Much time is saved by machine computation, and accidental errors in the considerable calculations are avoided.

4. RESULTS

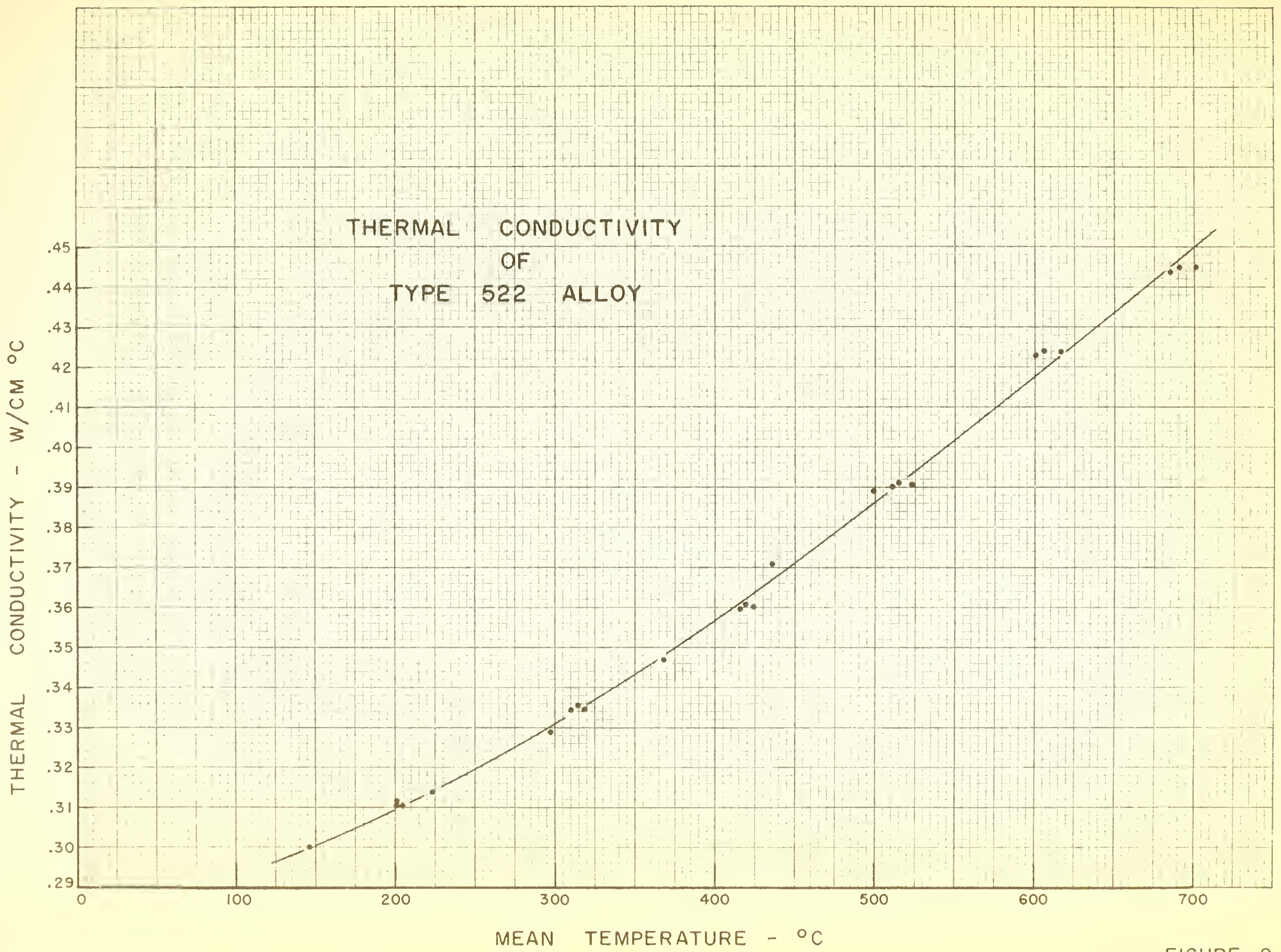
The results of the thermal conductivity measurements are shown in Figure 2. The points plotted on the figure represent the individual values obtained in four runs on the specimen, each run yielding six values. A curve is drawn to represent the trend of the data. Values of conductivity indicated by the curve at particular values of mean temperature are tabulated below

°C	Watt/cm °C	°C	Watt/cm °C
150	0.300	450	0.371
200	.310	500	.386
250	.320	550	.402
300	.331	600	.418
350	.343	650	.434
400	.357	700	.450

5. DISCUSSION OF RESULTS

The individual values of thermal conductivity plotted in Figure 2 show moderate scattering from the smooth curve. The extreme departure (at 600 and 700°C) is about 1.2 percent; most departures are less than 1 percent.

The scattering is believed due chiefly to small inaccuracies in the temperatures at positions on the specimen, as indicated by its thermocouples. Such inaccuracies could arise from departure of a thermocouple from the temperature-emf calibration of the thermocouple wires, or from imprecision in ascertaining the exact longitudinal position of the thermocouple junction, or possibly from heat conduction in the thermocouple wires near the junction. Although the wires encircled the specimen as nearly as possible in the



THERMAL CONDUCTIVITY
OF
TYPE 522 ALLOY
THERMAL CONDUCTIVITY - W/CM °C
.45
.44
.43
42
.41
.40
.39
.38
.37
.36
.35
.34
.33
.32
.31
.30
.29
0
100
200
300
400
500
600
700
MEAN TEMPERATURE - °C

FIGURE 2.

transverse plane of the junction, the temperature gradients in the specimen were from 17.5 to 33.0 deg C/cm, and a slight displacement of the wires from that plane would cause a temperature gradient in them near the junction. However, an error in the indicated temperature at a point intermediate between two spans of the specimen would reduce the observed temperature drop for one span by as much as it would increase that for the other. Thus, the values of thermal conductivity for the two spans would be approximately equally, but oppositely, affected, and the position of a smooth curve drawn amongst a number of such individual points would be affected little.

U. S. DEPARTMENT OF COMMERCE
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THE NATIONAL BUREAU OF STANDARDS

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Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.
Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.
Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment.
Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.
Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.
Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.
Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.
Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.
Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.
Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.
Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.
• Office of Basic Instrumentation. • Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.
Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research.
Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio Meteorology.
Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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