7865

10.00
File

NATIONAL BUREAU OF STANDARDS REPORT

7865

THERMAL CONDUCTIVITY OF TWO FIBERGLASS-REINFORCED
PLASTIC-IMPREGNATED SPECIMEN PANELS

by

Henry E. Robinson and Thomas W. Watson

to the

U.S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and the Central Radio Propagation Laboratory Ionospheric Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 ($1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 ($1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (includes Titles of Papers Published in Outside Journals 1950 to 1959) ($2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | **NBS REPORT**

1006-30-10642 April 24, 1963 7865

THERMAL CONDUCTIVITY OF TWO FIBERGLASS-REINFORCED
PLASTIC-IMPREGNATED SPECIMEN PANELS

by

H. E. Robinson and T. W. Watson
Heat Transfer Section
Building Research Division

to the

U.S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THERMAL CONDUCTIVITY OF TWO FIBERGLASS-REINFORCED PLASTIC-IMPREGNATED SPECIMEN PANELS

by

H. E. Robinson and T. W. Watson

1. INTRODUCTION

A series of comparative tests was initiated by Naval Ordnance Laboratory to investigate the effect of different testing apparatus and procedures on the values of thermal conductivity determined for specimens of plastic-impregnated fiber-glass reinforced panels. The test results reported herein were made on two specimens (DER-332 and E-787) specially prepared by Aerojet General Corporation for testing at Southern Research Institute, National Bureau of Standards, and Aerojet General Corporation, in that order. The measurements at NBS were authorized by NOL Project Order No. P.O. 3-0008 (J/O 958/1819/32050).

2. SPECIMENS

Two different panel materials were submitted for measurement, each in the form of a pair of specimens each approximately 14 by 14 by 0.5 inch in size. At NBS, each specimen was reduced in size to the central 9 by 9 inch square; the principal faces were not worked in any way.

When received, the pairs of specimens were identified by the numbers DER-332-A and DER-332-B, and E-787-A and E-787-B. These numbers were continued on the reduced specimens, and are used for reference in this report.

None of the reduced specimens was flat to 0.002 inch, nor uniform in thickness. Measurements of thickness (recorded to 4 figures) were made on each specimen by micrometer at three locations along each side of the central 7-inch square, and at the center and four corners of the central 4-inch square. These measurements are tabulated in Table 1.

As the tabulation averages show, the average specimen pair thickness over the central 4-inch square was a few mils less than the average pair thickness at the 7-inch-square trace, at room temperature, for both pairs. The average departure of the specimen face contours from two flat planes on both sides indicated by this difference can only be increased by the out-of-flatness, or warp, of the specimens, which may

TABLE 1

SPECIMEN THICKNESS DATA

	DER-332-A		DER-332-B	E-787-A		E-787-B
(Edges)	0.4828 in.		0.4824 in.	0.4592 in.		0.4826 in.
	.4833		.5057	.4638		.4827
	.4982		.5061	.4643		.4827
	.5020		.5073	.4636		.4828
	.5016		.5079	.4696		.4858
	.5072		.5099	.4868		.4927
	.5093		.5103	.4998		.4963
	.4980		.5090	.4970		.4953
	.4922		.5137	.4893		.4956
	.4932		.5155	.4813		.4917
	.4868		.5142	.4621		.4860
	.4833		.5080	.4582		.4834
Avg. 7-in.	(.4948)		(.5075)	(.4746)		(.4881)
Avg. for pair at 7-in.		(.5012)			(.4814)	
(Center)	.4864		.5077	.4684		.4850
	.4934		.5071	.4744		.4902
	.4828		.5090	.4640		.4832
	.4856		.5074	.4626		.4808
	.4896		.5100	.4725		.4853
Avg. over 4-in. sq.	(.4876)		(.5082)	(.4684)		(.4849)
Avg. for pair over 4-in. sq.		(.4979)			(.4767)	
Difference of pair averages		.0033			.0047	

change when a temperature difference exists face-to-face but could not be significantly reduced by the pressure exerted on the faces by the apparatus during tests. At room temperature, the specimens had different apparent amounts of warp:

DER-332-A: slightly out-of-flat, more than thickness difference.

DER-332-B: slightly out-of-flat, more than thickness difference.

E-787-A: saddle-shaped warp, out-of-flat >1/16 in. in two directions.

E-787-B: cylindrical warp, out-of-flat 1/16 in. in one direction.

3. METHOD AND PROCEDURE OF TEST

The thermal conductivity measurements were made in an 8-inch guarded hot plate apparatus (conforming to ASTM C177) having a 4-inch-square central metering section. The tests were conducted in a cabinet in air maintained at within one degree F of the specimen mean temperature; the exposed edges of the specimens were covered by about 1/2 inch of good blanket insulation.

Because of the expected low thermal resistance of the principal specimens, the tests were made using a composite-specimen technique which avoided need for thermocouples applied to the specimen faces. A resilient pad was interposed between each face of the specimen and the adjacent metal hot or cold plate of the apparatus, so that there was on each side of the hot plate a composite specimen consisting of pad, specimen, pad. The total temperature drop through the composite specimen was measured by means of permanent thermocouples installed in grooves in the metal faces of the cold and hot plates, and the test yielded as its result the average thermal resistance of the two composite specimens over the central 4-inch-square area. By subtracting from the average composite resistance the average thermal resistance of the two pads at the same mean temperature and total thickness, as determined in a separate test or tests using the same permanent plate thermocouples, the average net thermal resistance and conductivity of the principal specimens was calculated.

Two different kinds of resilient pad were used. The first was 1/8-inch thick commercial gum rubber (30 to 45 Durometer floating stock, Fed. Spec. MIL R-880A). In the form of an 8 by 8 by 1/8 inch sheet this rubber is practically incompressible under the pressure imposed by the plates of the apparatus (not more than 50 lb/ft^2), but it is resilient enough to conform to slight irregularities of contacting surfaces. However, as mentioned in the Discussion later, the rubber pads were not able to wholly compensate for the variable thickness and warp of the submitted specimens. For this reason, the tests were repeated using pads of an open-cell foam material (similar to Scott Paper Company "Skeletal Structural Industrial Polyurethane Foam") of about 50 pores per lineal inch and 1/4 inch in uncompressed thickness. As used, the 1/2-inch thickness of the foam pads of each composite specimen was compressed to about 0.07 inch. The average combined thickness of the two pads in the 4-inch-square metering area was determined by subtracting from the measured average distance apart of the flat hot and cold plates the average thickness of the principal specimens in the 4-inch-square central area as recorded in Table 1. This procedure compensates for warp of the specimens, and as much as feasible for the variable thickness of the specimens.

The thermal resistance of the foam pads, at various thicknesses and mean temperatures, was determined by a series of tests of the same pads alone, results of which are presented graphically in Figure 1. The resistances corresponding to thicknesses of the pads in the composite tests were obtained from the appropriate curve, with a slight correction for actual pad mean temperature ($dR/dT = -0.0006$ per deg F).

4. RESULTS AND DISCUSSION

The results of the measurements are summarized in Table 2. Because differences are involved, the data are given to four places.

The conductivities obtained for both submitted specimens using the rubber pads are definitely much lower than those obtained using the foam pads. The latter results are considered nearly correct.

Apart from the consideration that the conductivities obtained using rubber pads are of magnitude lower than would be anticipated for materials of this density and composition, there is internal evidence that these results are erroneously low. Table 2 shows that in the test at 66.8°F of the DER-332 specimens there was apparently a total thickness difference of 0.0043 inch not accounted for by the principal specimen and the two rubber pads. It is doubted that resilience of the pads would have accommodated to reduce the total gap to much less than 0.004 inch. An air gap of this thickness has a thermal resistance of 0.004/0.187, or 0.021 deg F per (Btu/hr ft^2). Reducing the net principal specimen resistance given in Table 2 for DER-332 at 66.8°F (0.1728) by 0.021 yields a specimen thermal conductivity of 3.27 Btu/hr ft^2(deg F/in.) which compares with the value 3.23 obtained with foam pads at 67.1°F. The values of conductivity of the submitted specimens deduced from the results of the tests with the rubber pads, by making a correction for the resistance of the putative air gap as above, are indicated in Table 2 by the values in square brackets. The fair agreement of these corrected values with the corresponding values obtained with the foam pads suggests that the foam pads compensated reasonably well for the non-uniform thickness and warp of the specimens, and that the results obtained with the foam pads are approximately correct.

Since the foam material had not been used here before for this purpose, the tests on Pyrex 7740 summarized in Table 2 were made for our own information. The good agreement of the results with the rubber and the foam pads on these flat and smooth Pyrex specimens, which had approximately the same low thermal resistance as the submitted specimens, indicates the acceptability of the foam material for this use, and also the general merit of the composite-specimen technique.

TABLE 2

SUMMARY OF NBS TESTS ON DER-332 AND E-787 (AND PYREX 7740)

With two 1/8-in. Rubber Pads

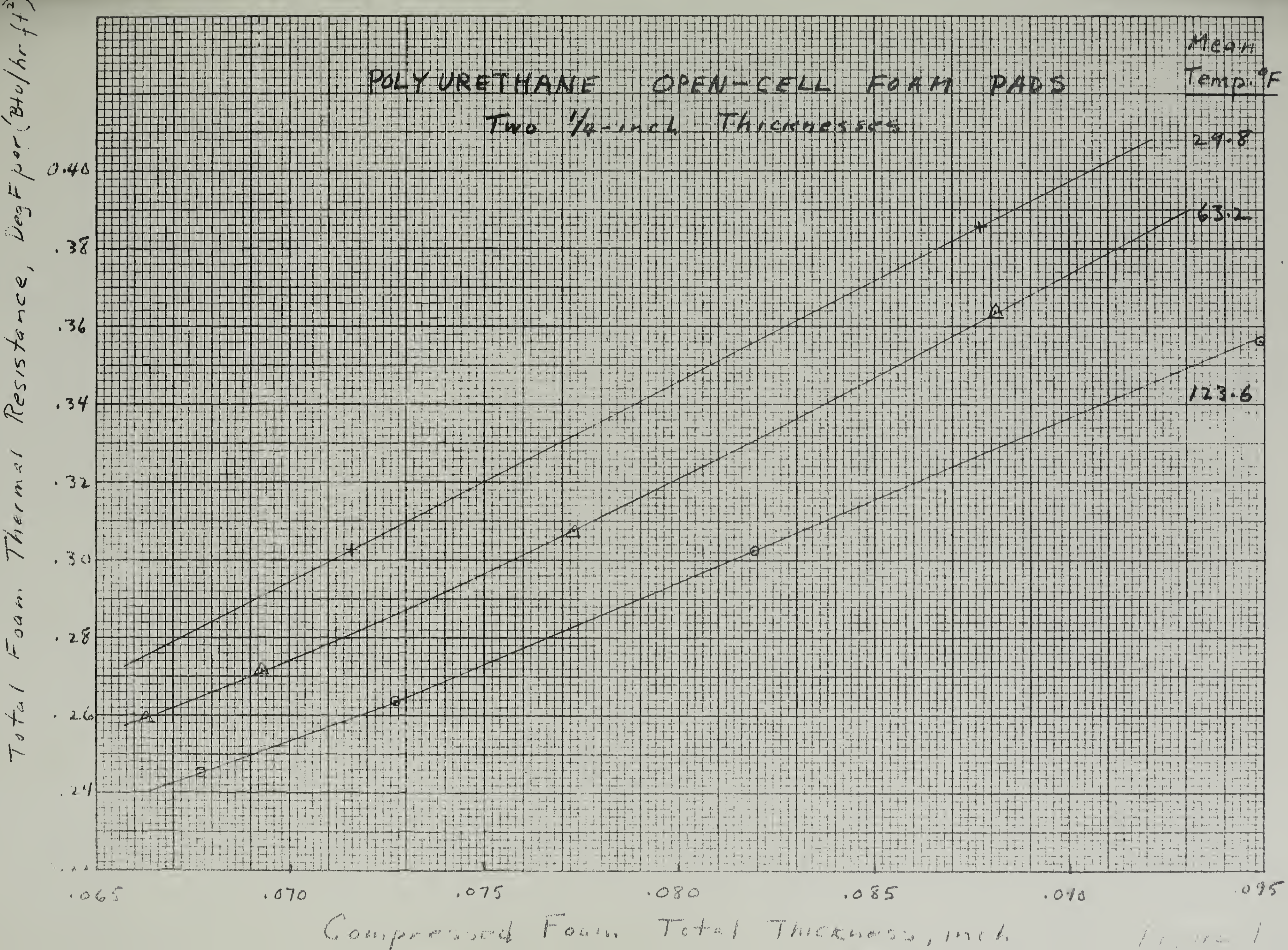
Specimen	DER-332 (128 lb/ft^3)		E-787 (131 lb/ft^3)	Pyrex 7740	
Mean temp., °F	66.8	127.4	68.5	30.4	122.2
Composite specimen R*	0.4198	.4266	.4762	.3665	.3660
Composite spec. thickness, in.	0.7549	.7615	.7506	1.2116	1.2197
Principal spec. thickness, avg., in.	0.4979	.4979	.4767	.9659	.9659
Total pad thickness, by diff., in.	0.2570	.2636	.2739	.2457	.2538
Total pad thickness, meas., in.	0.2527	.2539	.2527	.2465	.2529
Difference of pad thicknesses, in.	0.0043	.0097	.0212	-.0008	.0009
Total pad R*	0.2470	.2496	.2470	.2417	.2481
Net principal spec. R*	0.1728	.1770	.2292	.1248	.1179
Principal spec. thermal conductivity**	2.88	2.81	2.08	7.74	8.19
Temp. gradient in prin. spec., F/in.	22.2	22.8	30.7	8.3	7.8
Th. cond.** after correcting for air gap	[3.27]	[3.91]	[4.10]		

With two 1/4-in. Foam Pads, Compressed

Specimen	DER-332			E-787		Pyrex 7740	
Mean temp., °F	67.1	127.7	128.0	66.7	127.1	32.8	122.6
Composite specimen R*	0.4310	.4135	.4187	.4184	.3916	.4466	.3771
Composite spec. thickness, in.	0.5691	.5742	.5727	.5517	.5530	1.0412	1.0369
Principal spec. thickness, avg., in.	0.4979	.4979	.4979	.4767	.4767	.9659	.9659
Total pad thickness, by diff., in.	0.0712	.0763	.0748	.0750	.0763	.0753	.0710
Total pad R* (from Fig. 1)	0.2769	.2765	.2698	.2945	.2769	.3200	.2580
Net principal spec. R*	0.1541	.1370	.1489	.1239	.1147	.1266	.1191
Principal spec. thermal conductivity**	3.23	3.63	3.34	3.85	4.16	7.63	8.11
Temp. gradient in prin. spec., F/in.	19.7	17.5	19.1	16.6	15.3	8.4	7.9

* R = thermal resistance, deg F per (Btu/hr ft^2)

** Thermal conductivity, Btu/hr ft^2 (deg F/inch)


POLYURETHANE OPEN-CELL FOAM PADS
Two 1/4-inch Thicknesses
Mean Temp. °F
29.8
63.2
123.6
Total Foam Thermal Resistance, Deg F per (Btu/hr ft²)
0.40
.38
.36
.34
.32
.30
.28
.26
.24
.065
.070
.075
.080
.085
.090
.095
Compressed Foam Total Thickness, inch

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

USCOMM-NBS-DC

NBS