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NATIONAL BUREAU OF STANDARDS REPORT

8013

SUPPLEMENTARY INVESTIGATION OF TEST PROCEDURES FOR HEATING AND AIR CONDITIONING DUCTS

by

Selden D. Cole and Paul R. Achenbach

Report to

Federal Housing Administration
Washington, D.C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NBS REPORT 8013

SUPPLEMENTARY INVESTIGATION OF TEST PROCEDURES FOR HEATING AND AIR CONDITIONING DUCTS

by

Selden D. Cole and Paul R. Achenbach
Mechanical Systems Section
Building Research Division

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1.0 INTRODUCTION

At the request of the Federal Housing Administration task groups appointed by the Building Research Advisory Board of the National Academy of Sciences - National Research Council identified what were considered to be the essential properties of fabricated ducts for residential heating and air-conditioning systems. The reports of these task groups to the Federal Housing Administration were issued as NAS-NRC Publication 651 (1959) entitled "Criteria for Ducts to be Used in Residential Warm Air Heating and Air Conditioning Systems," and NAS-NRC Publication 838 (1961) entitled "Heating and Air Conditioning Ducts Encased In and Under Concrete Slabs-on-Ground," respectively.

Most of the test procedures recommended and described in these reports for evaluating the properties and performance of ducts were new. Subsequently, the National Bureau of Standards, at the request of the Federal Housing Administration, investigated the suitability of ten test procedures described in NAS-NRC Publication 651, applicable to heating and air-conditioning ducts that were not encased in or installed under concrete slabs-on-ground. This investigation covered test procedures for

1. Resistance to Mold Growth
2. Odor Emission
3. Deformation at High Humidity
4. Deterioration at High Humidity and High Temperature
5. Bending Strength and Permanent Deformation after Loading

6. Impact Resistance
7. Erosion
8. Resistance to Rupture Due to Internal Pressure
9. Resistance to Collapse Due to Negative Internal Pressure
10. Airtightness

National Bureau of Standards Report 7362, issued under date of October 31, 1961, contained the results of this investigation and recommended the following revisions of the test procedures described in NAS-NRC Publication 651:

(a) A non-comparative type of odor test with a simplified apparatus
(b) A modified erosion test with both weight and visual evaluation of the eroded material.
(c) A combined deformation and deterioration test with alternating exposure to high humidity and high temperature comprising 7 cycles of 24 hours each. This test would combine Tests 3 and 4 in the originial recommendations.

The proposed test procedure for evaluation of Bending Strength and Resistance to Crushing from Live Construction Loads, identified as Test No. 3 in NAS-NRC Publication 838, covering ducts encased in and under concrete slabs-on-ground was also investigated.

In addition, consideration was given to the logical requirements to be applied to flexible ducts in above-the-floor installations. It was concluded that all of the test procedures recommended for rigid or semi-rigid ducts should be used for flexible ducts except Test 5, Bending Strength and Permanent Deformation after Loading. A modified crushing test is proposed for evaluating the resistance of flexible ducts to excessive change in cross-section area as a result of limited loads that would be imposed by their own weight or by light loads that might be laid on a horizontal run of flexible duct supported under the first floor joists in a basement. In designing this test it was assumed that a horizontal run of flexible duct would be supported at closer intervals than a rigid duct to prevent excessive sagging between supports. In other words, some sagging between supports should be expected when flexible ducts are deliberately chosen to gain the advantage of easier accommodation to change in direction.

This supplementary report describes test results obtained for several duct materials when employing the revised test procedures for rigid and semi-rigid ducts, the proposed bending strength and resistance to crushing test for ducts encased in or under concrete slabs-on-ground and for the proposed test for resistance to crushing for flexible ducts.

2.0 REVISED TEST PROCEDURES FOR RIGID OR SEMI-RIGID DUCTS SUPPORTED UNDER FLOOR JOISTS

2.1 Odor Emission

Purpose

The purpose of this test was to determine whether or not a duct or duct material will emit excessive objectionable or non-objectionable odor during prolonged use.

Test Specimens

A section of duct of each of the following materials was used as a test specimen:

Supplier	Material
Gustin Bacon Mfg. Co.	Semi-rigid glass fiber, plastic covered
International Oil Burner Co.	Laminated paper fiber, foil lined
Flexible Tubing Corp.	Plastic over wire (flexible)
Sonoco Products Co.	Laminated paper fiber, foil lined
Johns-Manville Co.	Cement asbestos
Sonoco Products Co.	Paper fiber impregnated with high-temperature asphalt

Each specimen was a 6-foot length of duct with 4-inch nominal diameter except for the last material listed above. In this case, the specimen consisted of a strip 6 inches wide cut from a 3-foot length of duct with nominal 8-inch diameter.

Other familiar sources of odor were used, as follows: (1) a spoonful of ground coffee in a can, (2) the vapors emitted through the small opening of an ammonia bottle, (3) a cut apple, (4) a dash of ethyl alcohol, (5) a squirt of luminating gas, (6) a stream of fresh air, (7) crushed citrus fruits, and (8) crushed pine needles.

Preconditioning of the Specimens

The duct specimens were preconditioned before test by heating them at 200°F for 8 hours and then alternating the temperature between 70°F and 200°F for two cycles.

Test Apparatus and Procedure

The apparatus used for the odor test consisted of one-half the duct system shown in Figure 1 of NBS Report 7362 which was used for the earlier odor tests. The present system consisted of an 8-inch galvanized duct for holding the specimen connected at one end to a source of outdoor air and at the other end to a chamber or box where odor detection was made. A parallel 8-inch duct containing electric heating elements was connected to the specimen-holder with tees and incorporated a small blower for recirculation of heated air. Dampers permitted circulation of air through the heater duct and the specimen-holder as a closed loop, or the circulation of outdoor air through the specimen-holder to the odor-detection chamber, using two different blowers. The odor-detection chamber consisted of 3-foot cubical box having one-half of the lower side removed, and the vertical side opposite the duct inlet loosely covered with heavy cloth to partly confine the odors and to restrict the entry of ambient air by natural convection.

In conducting the test, the specimen was heated to a temperature of 200°F, as indicated by a thermocouple at a station downstream from the heater and near the end of the specimen. When the specimen had attained the desired temperature, outdoor air at a velocity of 500 fpm, was passed over the specimen and to the odor-detection chamber for individual evaluation by a panel of men and women.

The panel consisted mainly of employees of the National Bureau of Standards. When evaluating the air passing over the heated specimen, each panel member was instructed that a duct specimen was being evaluated for odor. When the panel members' sense of odor detection was being evaluated with well-known products, they were not instructed as to what the odor source would be.

The panel members recorded answers to the following questions on a prepared form:

1. Was an odor observed? Yes or no.
2. Was the odor objectionable? Yes or no.
3. Was the odor weak or strong?
4. Remarks, not required.

Basis of Acceptance

To be acceptable an objectionable odor shall not be recorded by more than 5 of 15 panel members, or a just perceptible (weak), non-objectionable odor by more than 10 of 15 panel members.

Test Results and Discussion

The observations of the odor panel are summarized in Table 1. The total number of observations of each duct specimen exceeded 15 by one or more to eliminate marginal evaluations at exactly 1/3 or 2/3 of the panel. Not all of the specimen ducts were evaluated by each person used on the panel, but each member was exposed to nine determinations including a minimum of five duct specimens.

The data in Table 1 indicates that the panel members were nearly unanimous in detecting that well-known odors were present, but there was substantial disagreement on their strength, and whether or not they were objectionable.

The results of odor detection of the duct materials indicates that none of the ducts would be rejected by the criteria cited above. More than 1/3 of the panel members detected an odor from the Gustin Bacon material, but less than 1/3 of the panel found it objectionable, and less than 2/3 detected any odor. Two members of a panel of 16 detected an odor from cement asbestos duct, indicating that this material could not serve as a reference material for odors. In the previous investigation, described in NBS Report 7362, a higher percentage of the panel members used for that investigation detected an odor from four of the same ducts or the same materials, and the Gustin Bacon duct would have been unacceptable by the same criteria, on the basis of their odor perception.

Table 1

Results of Odor-Detection Tests

Odor Source	Was an Odor Observed		Was it Objectionable		Was the Odor		Number in Panel
Ducts	Yes	No	Yes	No	Weak	Strong	
Gustin Bacon glass fiber	8	11	5	3	5	3	19
International paper, aluminum-lined	4	12	1	3	4	0	16
Connecticut Flexible Tubing	4	12	1	3	3	1	16
Sonoair Paper, aluminum-lined	3	13	1	2	2	1	16
Sonoco paper, enamel 2 sides	1	15	0	1	1	0	16
Johns-Manville Cement asbestos	2	14	2	0	0	2	16
Well-Known Products							
Coffee	14	0	3	11	6	8	14
Ammonia	9	0	7	2	2	7	9
Apple	1	1	0	1	1	0	2
Alcohol	10	0	4	6	5	5	10
Luminating Gas	2	0	2	0	0	2	2
Fresh Air	0	2	0	0	0	0	2
Citrus	13	0	1	12	9	4	13
Pine	1	0	0	1	1	0	1

The results of this supplementary investigation of odor perception together with the previous findings, indicate that judgment will need to be exercised in the use of the criteria for acceptance, especially since each determination of the presence of an odor, its character, and intensity by each panel member represents an exercise of judgment.

2.2 Deformation at High Humidity and High Temperature

Purpose

The purpose of this test was to provide an accelerated means of determining the ability of a duct to maintain its character under exposure to moisture-saturated air and temperature at or above maximum use temperature.

Test Specimen

Sections of duct 6 feet long and 8 inches inside diameter of the following materials were used as test specimens.

Supplier	Material
NBS Sheet Metal Shop	Galvanized sheet metal, 26 gage
Sonoco Products Co.	Laminated paper, foil lined
International Oil Burner Co.	Laminated paper, foil lined
Johns-Manville Co.	Cement asbestos
Gustin Bacon Mfg. Co.	Semi-rigid glass fiber plastic covered
Flexible Tubing Corp.	Plastic over wire, flexible

Test Apparatus and Procedure

The specimens were suspended in a fog room by metal straps about 6 inches from each end for a period of 19 hours. They were then removed and inserted into the supply duct of a unit heater, and air at a velocity of 1000 fpm and a temperature of 250°F was recirculated through the specimen for a period of 4 hours. This alternating cycle of exposure to saturated air and high temperature was repeated each 24 hours for 7 consecutive cycles. About an hour was required for installing the specimen in the fog room and the unit heater system during each cycle.

The air temperature and velocity was measured in the supply duct of the unit heater just ahead of the test specimen.

The distance from the bottom surface of the duct at midpoint between hangers and a reference straight edge drawn between hangers was measured before exposure to conditions in the fog room, and at the conclusion of the seventh cycle. The outside diameter of each duct in a vertical direction was measured at midlength and at each end before the start of the test and at the conclusion, with large outside calipers. These two measurements required replacing of each duct in exactly the same position and orientation for each cycle.

The ducts were examined at the end of the 7 cycles for delamination, cracking, corrosion fractures, and other deterioration.

Basis for Acceptance

The change in vertical diameter, based on measurements before and after exposure to the test conditions described above, shall not exceed 5 percent of the initial vertical dimension at any of the three planes of measurement. The sag at the bottom of the duct midway between hangars shall not increase more than 0.25 inch as a result of this test. There shall be no evidence of delamination, cracks, corrosion, fractures or other deterioration of the duct at the end of the test.

Test Results

The dimensional data on vertical diameter and sag observed for the duct specimens are summarized in Table 2. The change in vertical diameter during the 7 exposure cycles ranged from none for the cement asbestos and flexible duct to a maximum of 2.6 percent of the initial outside diameter for the glass fiber duct. The increase in sag at midlength of the specimens ranged from none for the sheet metal, cement asbestos, and glass fiber ducts to 0.156 inch for the International paper fiber duct. Sag was not evaluated for the flexible duct specimen.

The aluminum foil lining on the inside of the International paper fiber duct showed some small blisters at the conclusion of the fifth cycle, and was separated from the duct over about 2/3 of the inside area after the seventh cycle. No delamination, cracks, corrosion, or fractures were observed for the other specimens at the end of the test.

Discussion

Duct specimens 6 feet long and 8 inches inside diameter appear to be of suitable size for observed dimensional changes resulting from environmental conditions. The combined test for deformation from high humidity and high temperature appears to be satisfactory as an accelerated test. The seven 24-hour cycles of alternate exposure to saturated air and heat appear to be long enough to reveal the effects of absorption of moisture and the drying of the specimen at a temperature which would produce a vapor pressure in the material well above atmospheric pressure, if significant amounts of moisture were present. Rusting of unprotected ferrous metal would also be revealed by this test.

Table 2

Deformation at High Humidity and High Temperature

All Ducts 8 Inches in Diameter and 6 Feet Long

	Galvanized Sheet Metal	Sonoair Paper Fiber	International Paper Fiber	Johns-Manville Cement Asbestos	Gustin Bacon Glass Fiber	Flexible, Plastic Over Wire
			Vertical Outside Diameter, inch			
North End						
Start	8.063	8.375	8.593	8.813	9.750	8.063
Finish*	8.063	8.375	8.437	8.813	9.688	8.063
Middle						
Start	8.063	8.313	8.281	8.813	9.750	8.063
Finish*	8.063	8.406	8.250	8.813	9.500	8.063
South End						
Start	8.063	8.375	8.063	8.813	9.688	8.063
Finish*	8.047	8.375	8.156	8.813	9.656	8.063
			Increase in Sag, inch			
Midlength	0.000	0.063	0.156	0.000	0.000	**
			Maximum Change in Vertical Diameter, %			
	0.2	1.1	1.8	0.0	2.6	0.0

*After seven cycles each of 19 hours in a fog room and heating 3 1/2 hours at 250°F
**Not applicable

2.3 Erosion

Purpose

The purpose of this test is to provide a method for measuring the erosion of a duct under accelerated conditions.

Test Specimens

Each test specimen consisted of two 6-foot lengths of 8-inch duct connected by a galvanized sheet metal elbow. The following materials were tested.

Supplier	Material
Sonoco Products Co.	Laminated paper fiber, foil lined
Gustin Bacon Mfg. Co.	Semi-rigid glass fiber, plastic covered
Johns-Manville Co.	Cement asbestos
International Oil Burner Co.	Paper fiber, foil lined
Flexible Tubing Corp.	Plastic over wire, flexible

Test Apparatus and Procedure

The apparatus used for the erosion test is shown in Figures 1 and 2. The inlet to the blower was enclosed with a plenum chamber measuring 2' x 2' x 2'6". Each of the three vertical sides of the plenum was fitted with a 20" x 20" glass fiber filter, 2 inches thick. The blower had sufficient capacity to provide an average air velocity in an 8-inch duct of 4000 fpm. The collection box at the discharge end of the duct system measured 36 inches in each dimension, and the side opposite the duct opening was covered with a 200-mesh screen. A 2' x 2' metal baffle was centered in the box 6 inches from the duct opening, as indicated diagrammatically in Figure 2.

Prior to the erosion test, air was passed through the system for 10 minutes without the mesh screen in place. The air velocity in the test duct was maintained at 4000 fpm during this purging period as determined by a pitot tube measurement. After purging, the collection box was carefully wiped clean with a damp cloth. One strip of cellophane tape was attached to the baffle opposite the duct opening; and another strip of tape was stretched from top to bottom of the collection box near the screen opening. Both cellophane tapes had the adhesive side facing the air stream. A third strip of tape was fastened over the blower exit upstream of the test duct.

With the tapes and screen in place, air was passed through the test duct at a velocity of 4000 fpm for four hours, after which the screen and tapes were examined for arrested particles and the collection box was brushed out with a soft brush to collect fallen particles.

This procedure was followed with each different duct material.

A Basis for Acceptance

No particles of duct material should be visible to the eye on the screen, and none visible to the eye should be collected by brushing out the collection box. The two tapes removed from the collection box should not show more foreign matter on their adhesive surfaces than the tape removed from the blower outlet position. The three cellophane tapes should be compared under a microscope. This comparison should reveal no deposit on the two tapes taken from the collection box that is attributable to erosion of the duct specimen.

Test Results

No particles were visible on the screen and none were collected by brushing out the inside of the collection box. The three tapes were indistinguishable from each other, and there were no macroscopic particles observable on the tapes. A microscopic examination revealed a widely spaced collection of unidentified air-borne dust of about the same character and density at the inlet and outlet of the test duct.

Discussion

Dust particles or eroded material that could be arrested by a 200-mesh screen would appear as a deposit on floors and furniture in an occupied space, but would be of little significance as an inhalation hazard. However, much smaller particles of eroded material would remain air-borne for longer periods and could be inhaled by the occupants of the building. Thus an identifiable amount of duct erosion products of any size that was collected during a 4-hour test period would be undesirable. A high efficiency panel filter should probably be used at the inlet to the blower instead of the low efficiency filter used in these tests, so any material eroded from the duct during the test period would not be as readily obscured by the background dust concentration in the circulated air.

3.0 TEST PROCEDURES FOR DUCTS ENCASED IN AND UNDER CONCRETE SLABS-ON-GROUND

NAS-NRC Bulletin 838 entitled "Heating and Air-Conditioning Ducts Encased in and under Concrete Slabs-on-Ground" describes test procedures for evaluating ducts with respect to (1) Resistance to mold growth, (2) Odor emission, (3) Bending strength and resistance to crushing from live construction loads, (4) Airtightness, (5) Deterioration at high temperature and high humidity, and (6) Erosion. Since these test procedures, except for the test for bending strength and resistance to crushing from live constructions loads, were essentially the same as for the ducts covered by NAS-NRC Bulletin 651, they were not re-evaluated except for the revisions discussed in Section 2 of this report.

The test procedure for bending strength and resistance to crushing from live construction loads described as Test 3 in NAS-NRC Bulletin 838 was investigated and tried out on five duct materials.

3.1 Bending Strength and Resistance to Crushing From Live Construction Loads

Purpose

To determine the susceptibility of heating or air conditioning ducts to damage before or during installation in concrete slabs.

Test Specimens

Fabricated ducts 6 feet long and 8 inches in diameter, of the following materials, were used for these tests.

Supplier	Material
Johns-Manville Co.	Cement asbestos
Sonoco Products Co.	Laminated paper fiber (foil lined)
International Oil Burner Co.	Laminated paper fiber (foil lined)
Gustin Bacon Mfg. Co.	Semi-rigid glass fiber (plastic covered)
NBS Sheet Metal Shop	Galvanized sheet metal (26 gage)

Test Apparatus and Procedure

An apparatus essentially like that shown in Figure 2, page 33, of NAS-NRC Publication 838 was used for the tests. The increments of load applied to the duct specimens were determined by placing the duct and its supports on the bed of a platform scale having a weighing arm graduated in 1/4-lb. divisions. The load was applied to the top center of the duct by means of a screw jack, placed on top of the loading block, and exerting force downward on the block and upward against a stiff member extending to the ceiling.

A nominal 4" x 4" timber 6-feet long was placed on the scale platform to serve as a continuous support for the duct specimen during the compression test. For the bending tests, supports of 1 1/2-inch pipe 8 inches long were laid crosswise on the 4" x 4" timber and spaced 5 feet apart. These round supports had a tendency to be pressed into the bottom side of the ducts during the bending tests, giving a false indication of the bending deflection at midlength. The pipe supports were replaced with wooden supports 8 inches long and with a cross section of 1 3/4 x 1 5/8 inches with slightly rounded corners at the top. The flat supports eliminated the problem of indentation.

During the bending tests, load was applied in increments of about 5 lb. in the range up to 20 lb. and thereafter in increments of 10 lb. to the final load of 160 lb. The deflection of the bottom of the duct at midlength was determined by measuring the vertical distance between the bottom of the duct and the 4" x 4" timber serving as a bed. The deformation of the top of the duct was determined by measuring the distance from the top of the loading block to a reference point on the stiff member above the screw jack. The load was terminated at 160 lb. or when the deflection of the bottom surface reached 1 inch, which ever occurred first. At the conclusion of the loading period, the load was removed and the top and bottom deformation were measured 5 minutes later.

During the crushing tests, the duct specimen was placed in contact with the 4" x 4" timber for the full length of the specimen. Load was applied in increments of 10 lb. by extending the screw jack, to a final load of 160 lb. or a depression of the upper duct surface of 3 inches, which ever occurred first. The deformation of the upper surface of the duct was determined in the same manner as for the bending test. At the conclusion of the loading period, the load was removed and the residual deformation was measured immediately and again 15 minutes later.

Basis for Acceptance

In the bending test a duct shall be able to withstand a load of 160 lb. without deflecting more than 1 inch at midlength on the bottom or deforming more than 3 inches at the station of load application on the top. Permanent deformation after load removal shall not exceed 2 percent of the original outside diameter of the duct at the bottom or 5 percent at the top.

In the crushing test a duct shall be able to withstand a load of 160 lb. without deforming more than 3 inches at the station of load application on the top. Permanent deformation at the top after load removal shall not exceed 5 percent of the original outside diameter of the duct.

Results and Discussion

The results of the Bending and Crushing tests are given in Table 3 and Table 4, respectively.

Table 3 contains data obtained from four rigid and one semi-rigid type ducts randomly positioned, except for the metal duct which had the seam positioned at the top.

It was found that a round support at the ends of the duct could not be used to indicate bending, as the round supports had a tendency to be pressed into the duct surface with increase in load. This deformation at the supports tended to lower the entire duct and introduced an error in the measurements of bending deflection.

All of the rigid ducts tested supported the full load of 160 lb. with no more than 1/8 (0.125) inch deflection of the bottom surface. The top surface deformation was considerably more than the bottom deflection, but recovery after load removal was almost complete. A semi-rigid glass fiber duct reached a depression of more than 3 inches in the top surface and the full 1 5/8 inch depression permitted by the apparatus on the bottom with a load of 13 lb. The recovery of the fiber glass duct was complete 5 minutes after removal of the load. The top deformation of the 26 gage galvanized duct was 4 to 5 times as great as that for the two paper fiber specimens. The cement asbestos specimen deformed very little for a load of 160 lb.

Table 3

Deformation of Ducts during the Bending Test

Load lb.	Sonoco Paper Fiber Deformation Inch Top	Sonoco Paper Fiber Deformation Inch Bottom	International Paper Fiber Deformation Inch Top	International Paper Fiber Deformation Inch Bottom	Johns-Manville Cement Asbestos Deformation Inch Top	Johns-Manville Cement Asbestos Deformation Inch Bottom	26 Gage Galv. Sheet Steel Deformation Inch Top	26 Gage Galv. Sheet Steel Deformation Inch Bottom	Gustin Bacon Glass Fiber Deformation Inch Top	Gustin Bacon Glass Fiber Deformation Inch Bottom
0	.0	.0	.00	.0	.0	.0	.0	.0	.0	.0
5	.0	.0	.00	.0	--	--	--	--	--	--
10	.0	.0	.00	.0	--	.0	.031	.0	1.00	0.321
13	.0	.0	--	--	--	--	--	--	--	--
20	.025	.0	.025	.0	--	--	.125	.016	3.31	1.625
30	.031	.0	.031	.0	--	.0	.187	--	--	--
40	.032	.0	.032	.0	--	--	.250	.031	--	--
50	.032	.0	.062	.0	.010	.0	.312	.031	--	--
60	.062	.0	.093	.0	--	--	.375	.062	--	--
70	.093	.032	.124	.0	.020	.0	.562	.062	--	--
80	.125	.032	.125	.0	--	--	.750	.062	--	--
90	.125	.032	.126	.0	.025	.0	.812	.187	--	--
100	.125	.032	.156	.062	--	--	.937	.187	--	--
110	.187	.032	.187	.062	.031	.0	1.000	--	--	--
120	.188	.062	.218	.062	--	--	1.062	--	--	--
130	.188	.062	.218	.062	.031	.0	1.125	.125	--	--
140	.218	.062	.125	.093	--	--	1.218	.125	--	--
150	.250	.109	.125	.093	.031	--	1.250	.125	--	--
160	.250	.125	.312	.125	.06	.0	1.312	.125	--	--
Deformation Immediately after Load Removal										
0	--	--	--	--	--	--	--	--	.125	.00
Deformation 5 minutes after Load Removal										
0	.023	0	.031	0	0	0	.031	.0	--	--

In Table 4 the deformation is reported for two different orientations of the Sonoco paper fiber duct 90 degrees apart and for three different positions of the crimped seam of the 26-gage galvanized sheet steel duct. The data show that the deformation was essentially the same for the two positions of the fiber duct. However, the deformation of the galvanized sheet steel duct was consistently somewhat greater with the seam on top than for the other two positions. The deformation of the sheet metal duct was several times as large as for either of the two paper fiber ducts at the final loading of 160 lb. The glass fiber duct deformed 3 inches with a 40 lb. load, but returned to its original condition when the load was removed. A small increase in load completely flattened the glass fiber duct, but it suffered no permanent deformation on removal of the load. The permanent deformation of the galvanized sheet steel duct ranged from 0.062 to 0.093 inch for the different positions of the seam.

The results shown in Tables 3 and 4 for the glass fiber duct indicate that it would not be suitable for encasement in or under a concrete slab-on-ground.

4.0 CRUSHING TEST FOR FLEXIBLE DUCTS

Purpose

The purpose of this test was to evaluate the crushing resistance of flexible ducts as a basis for recommending criteria for this characteristic of this type of duct.

Test Specimens

Sections of duct 8 inches in diameter and 6 feet in length of the following materials were used as test specimens.

Table 4

Deformation of Ducts during Crushing (Compression) Test

	26 Gage Galv. Sheet Steel			Sonoco Paper Fiber		International Paper Fiber	Johns-Manville Cement Asbestos	Gustin Bacon Glass Fiber
Load lb.	Seam Up Deformation Inch	Seam 90° Deformation Inch	Seam Down Deformation Inch	Position 1 Deformation Inch	Position 2 Deformation Inch	Deformation Inch	Deformation Inch	Deformation Inch
0	.0	.0	.0	.0	.0	--	.0	0.0
10	--	--	.062	--	--	--	--	0.250
20	.093	.093	.125	--	--	.031	.0	0.562
30	--	.156	--	.031	.031	--	--	1.500
40	.250	.218	.187	--	--	.031	.0	3.000
50	--	--	--	.031	.031	--	--	--
60	.375	.343	.375	.062	--	.093	.0	--
70	.593	.437	.437	.062	.062	--	--	--
80	.718	.500	.500	.093	--	.125	.0	--
90	.812	.593	.593	.093	.093	--	--	--
100	.875	.687	.687	.093	--	.187	.0	--
110	.937	.781	.718	.125	.125	--	--	--
120	1.000	.875	.875	.125	.125	.187	.0	--
130	1.093	.937	.937	.125	.156	--	--	--
140	1.187	1.000	1.031	.156	.187	.250	.0	--
150	1.250	1.093	1.093	.156	.187	--	--	--
160	1.312	1.187	1.187	.187	.187	.250	.023	--
Deformation Immediately after Load Removal								
0	.062	.093	.093	.031	--	.000	.000	0.125
Deformation 15 Minutes after Load Removal								
0	.062	.093	.093	--	--	--	--	0.00

Supplier	Material
Wiremold Co.	Spiral metal and plastic type laminate
Flexible Tubing Co.	Plastic over plastic coated spiral of wire
Gustin Bacon Mfg. Co.	Semi-rigid glass fiber, plastic covered.

Test Apparatus and Procedure

The apparatus used for this test was the same as that described in Section 3 for the crushing and bending tests of rigid ducts.

The duct supplied by the Flexible Tubing Co. was tested with the material allowed to assume its natural degree of elongation and a second time with the duct compressed longitudinally as much as possible when placing it on the bed of the apparatus, and then allowed to expand naturally. These two methods of placing the specimen on the bed allowed a different number of wires to be under the loading block.

The flexible duct supplied by the Wiremold Co. was tested only in an extended condition. The semi-rigid glass fiber duct was included because it appeared to have limited flexibility.

The specimens were placed in contact with the 4" x 4" timber as a bed, for the full length of the test specimens. Load was applied in 5 lb. increments by means of the screw jack, until a 3-inch deformation occurred, or until the duct collapsed.

Basis of Acceptance

Flexible duct shall be able to withstand a crushing load of 40 lb., using the test procedure described, without deforming more than 3 inches or fracturing any of the component materials of the duct. Permanent deformation at the top after load removal shall not exceed 5 percent of the original outside diameter of the duct.

Table 5

Deformation of Flexible Ducts during Crushing Test

Load lb.	Flexible Tubing Co. Duct, Extended Inch	Flexible Tubing Co. Duct, Compressed Inch	Wiremold Co. Duct, Extended Inch	Gustin Bacon Fiber Glass Duct Inch
0	0.000	0.000	0.000	0.000
5	.156	.031	.187	--
10	.250	.187	.312	.250
15	.437	.250	.468	--
20	.562	--	.625	.562
25	.718	.531	.813	--
30	.875	--	1.062	1.500
35	1.062	.812	1.312	2.125
40	1.250	--	1.75	3.000
42.5	--	--	2.312	--
45	1.500	1.250	2.562*	--
50	1.687	1.468	--	--
55	1.875	1.937*	--	--
60	2.062*	--	--	--
	Deformation Immediately after Load Removal			
0	0.218	--	1.187	0.125
	Deformation 15 Minutes after Load Removal			
0	0.156	0.843	1.125	0.000

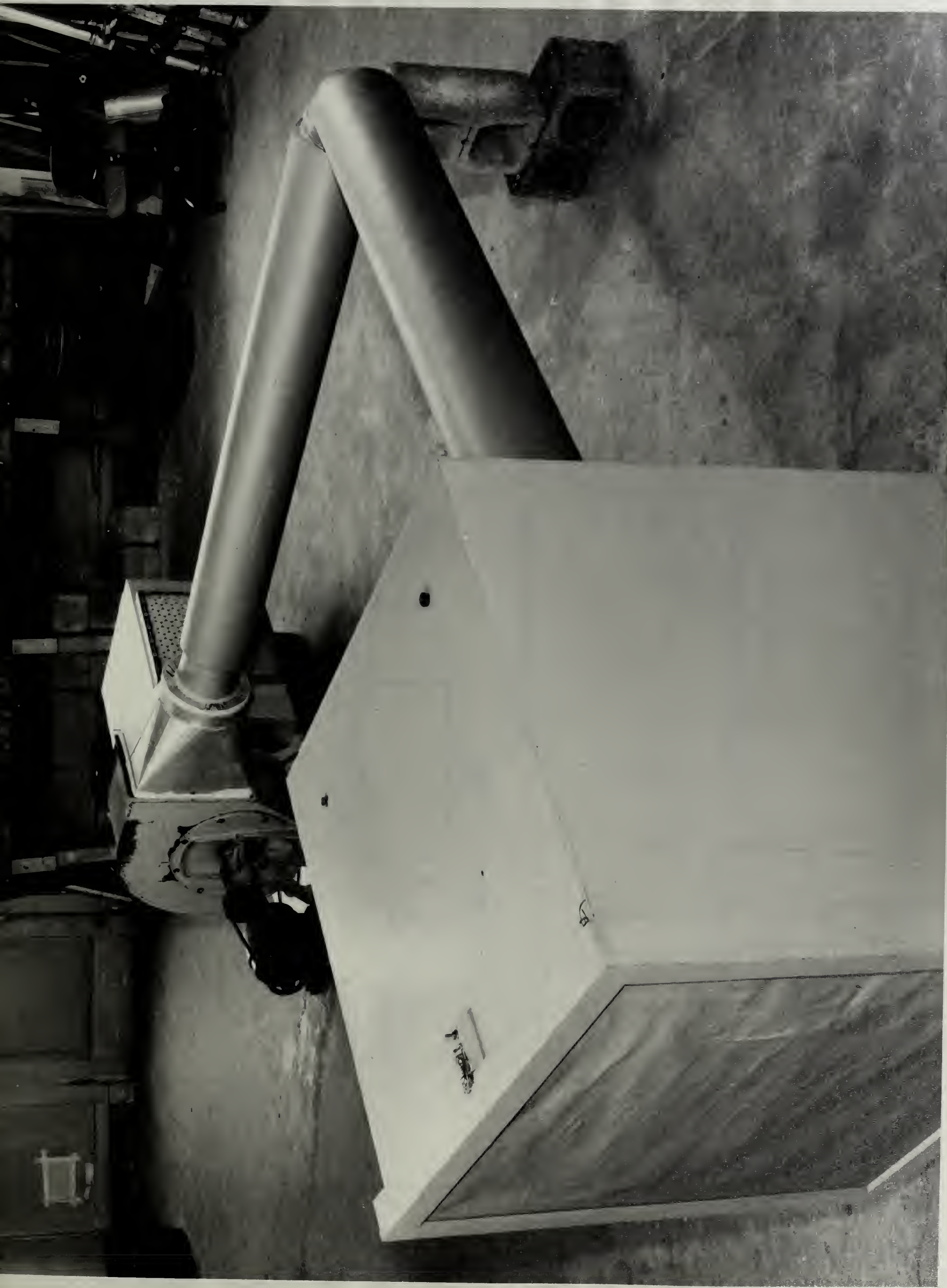
*Additional load destroyed elasticity of metal ribbing and resulted in no recovery.

Test Results

Table 5 summarizes the deformation of the test specimens during the crushing tests. The maximum loads reported in the table for the two flexible ducts produced the maximum deformation that could be tolerated without elastic failure of the metal ribbing. Greater loads produced serious bending of the metal ribbing from which no recovery occurred after removal of the load. On the other hand, the fiber glass duct exhibited complete recovery after a deformation of 3 inches.

Discussion

Neither flexible duct or glass fiber duct will support much of a load without excessive permanent deformation or collapse. For this reason these types would probably not be suited for encasement in or under concrete slabs-on-grade. Flexible ducts could probably be used in horizontal runs under first floor joists in a basement, provided they could be supported at close intervals and provided a little sagging between supports could be tolerated. The principal application for flexible ducts appears to be for making offsets or unusual turns in a duct system in locations where adequate support can be provided.



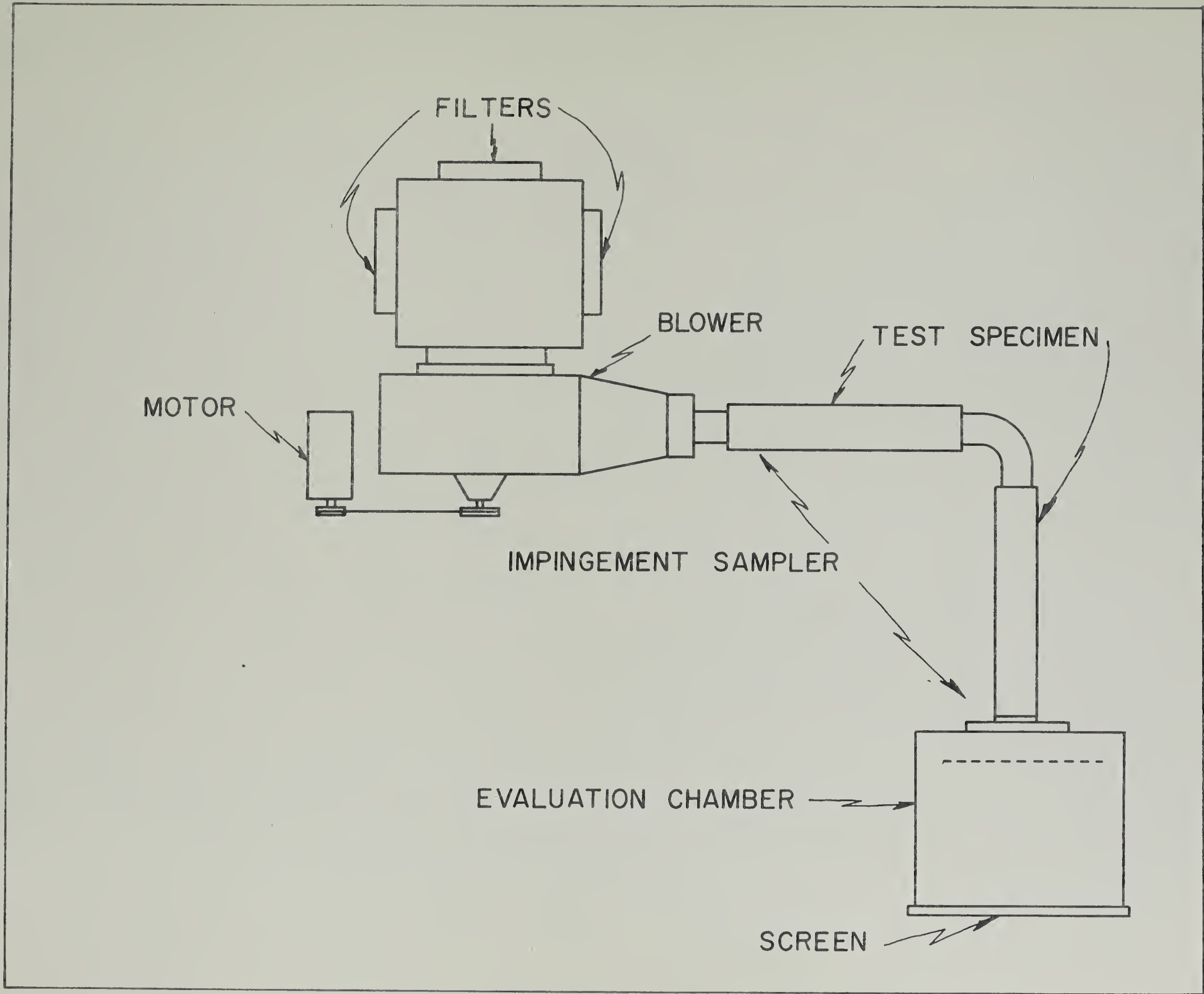

FILTERS
BLOWER
TEST SPECIMEN
MOTOR
IMPINGEMENT SAMPLER
EVALUATION CHAMBER
SCREEN

Fig. 2

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

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

THE NATIONAL BUREAU OF STANDARDS

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

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

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. 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.

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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.

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Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

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Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. 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 Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

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

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