NATIONAL BUREAU OF STANDARDS REPORT

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QUARTERLY REPORT

ON

EVALUATION OF REFRACTORY QUALITIES OF CONCRETES FOR JET AIRCRAFT WARM-UP, POWER CHECK, MAINTENANCE APRONS, AND RUNWAYS

by

W. L. Pendergast, E. C. Tuma, D. K. Ward

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Sponsored by

Department of the Navy
Bureau of Yards and Docks

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Bruce E. Foster, Assistant Chief
Inorganic Building Materials Section

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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1. INTRODUCTION

The purpose of this project is the development of criteria for the fabrication of jet exhaust resistant concretes. Concretes under development are evaluated by exposure to hot gases from a combustion chamber. The combustion chamber delivers these gases at velocities and temperatures approaching field conditions.

2. ACTIVITIES

A Study of Concreting Materials and Concretes for Naval Facilities

Two sets of concrete test specimens were received during the period covered by this report. One set of specimens was fabricated from the mix used in placing power check facilities at the Naval Air Station, Meridian, Mississippi, South East Naval District. Concrete containing blast-furnace slag as the aggregate from Alabama and type I portland cement was used at this installation. The second set of specimens was fabricated from the mix used at China Lake, Naval Ordnance Test Station, Southwest Division, using expanded shale as the aggregate and a calcium aluminate, Fondu, cement. The design and properties of the fresh concretes together with the 28-day flexural strength of these concretes appear in Table I. With the exception of the ratio of coarse to fine aggregate of the expanded shale, coated, ("Rocklite") that was used in power check facilities at China Lake, California, both met the requirements of NAVDOCKS Specification S-P16 Aircraft Power Check Facility.

Eleven jet impingement tests were completed on panels previously submitted from the following power check facilities.

> One panel, from the 12th Naval District, Naval Air Station at Lemoore, California was tested after 42 days drying at 50% relative humidity and 73°F. The spalling loss during the test was slight.
>
> Three panels, from the 6th Naval District, Jacksonville, Florida were tested after 42, 56, and 70 days drying respectively. The panel tested after 42 days drying showed a slight loss during the jet impingement test. Those tested, after 56 or 70 days drying, evidenced no loss.
>
> Three panels, from the 5th Naval District, Marine Corps Air Station at Cherry Point, North Carolina were tested after 42, 56, and 70 days drying. The three panels spalled considerably during jet impingement.

Table I. Properties of Fresh Concrete [1]

Identification	Type of Aggregate	Type of Cement [2]	Admixture A. E. A.	Ratio of Coarse to Fine Aggregate	Cement Content	Ratio w/c	Slump	Air Content	Flexural Strength 28 days
			oz/sack of ct.		sack/yd^3		inches	%	psi
5th Naval Dist. N. A. S. Norfolk, Va.	Trap Rock	I	Darex 1.0	66:34	7	.435	1 to 2	6.2	750
8th Naval Dist. N.A.A.S. Kingsville Texas	Basalt Variety	I	Darex 1.0	63:37	5.5	.58	2	5.0	650
8th Naval Dist. N.A.A.S. Chasefield Beeville, Texas	Basalt Variety	I	None	63:37	5.5	.61	1.5	2.0	655
11th Naval Dist. M.C.A.S. El Toro California	Expanded Shale	High [3] Alumina Hydraulic	None	67:33	6.5	.75	3.25	[4]	600
13th Naval Dist. N.A.S. Whidbey Is. Oak Harbor, Wash.	Quarry or Trap Rock	II	Darex [5] 0.75	63:28	6.5	.42	2.0	5.2	450
6th Naval Dist. N.A.S. Sanford Florida	Blast-Furnace Slag	I	Darex 1.0	58:42	7.5	.39	2.0	[4]	755
11th Naval Dist. U.S.M.C.A.A.S. Yuma, Arizona	Blast-Furnace Slag	II	Pozzolith 8AA 4.0	62:38	8.0	.43	3.0	7.7	704
6th Naval Dist. U.S.M.C.A.A.S. Beaufort, S. C.	Trap Rock	I	Aermix 1.75	57:43	7.0	.43	3.25	5.5	720
6th Naval Dist. N.A.S. Glynco, Georgia	Trap Rock	I	Darex 1.3	66:34	7.5	.40	[4]	[4]	[4]
5th Naval Dist. M.C.A.S. Cherry Point, N. C.	Trap Rock	I	Darex 1.53	68:32	6.5	.46	2.5	6.4	650
6th Naval Dist. N.A.S. Jacksonville, Fla.	Basalt Variety	I	Darex 1.4	53:47	7.0	.43	1.25	5.8	610 [6]
11th Naval Dist. N.A.S. Miramar, California	Expanded Shale	High [7] Alumina Hydraulic	Air-in 0.5	56:44	6.75	.60	2.0	5.0-8.0	660
12th Naval Dist. N.A.S. Lemoore, California	Expanded Shale	II	Liquid Plastair 2.75 Fl. oz.	47:53	7.5	.33	[8] 1--1.25 2--1.25 3--1.75 4--1.00 5--1.25	4.1 3.2 3.2 4.1 3.2	685 [4] 695 625 635
Southeast Division N.A.S. Meridian, Miss.	Blast-Furnace Slag	I	Air-in 1.50	59:41	7.0	.53	2.0-3.0	5.0-8.0	765
Southwest Division N.O. Test Station China Lake, Calif.	Expanded Shale	High [3] Alumina Hydraulic	Durair 1.25	66:34	6.75	.475	3.0	6.3	[9]

[1] Data furnished by testing laboratories.
[2] Portland unless otherwise specified.
[3] Imported; Fondu
[4] Data not received even after repeated inquiries.
[5] 0.25 oz. of Pozzolith per sack, also.
[6] Average of nine beams sawed from the panels submitted; as requested by Mr. P. P. Brown, Bureau of Yards and Docks, Washington 25, D. C.
[7] Domestic; Lumnite.
[8] Power Check Station number.
[9] Data not received.

Three panels from the 11th Naval District, Naval Air Station, Miramar, California were tested after but 6, 13, and 20 days drying. These panels showed no spalling loss during the test.

One panel from the Southeastern Division, Naval Air Station at Meridian, Mississippi, was tested, after 14 days drying, and showed appreciable loss during the jet impingement test.

More complete data for the jet impingement tests are given in Table II.

The flexural strength of beams, approximately 18 x 6 x 6 inches cut from each panel after completion of the jet impingement test was determined. The results of tests made on these beams cut from the edge of the test area are given in Table II.

Previous reports have given data, on 18 x 6 x 6 inch beams cut from the 18 x 18 x 6 inch test panels, that indicated the loss in flexural strength could be attributed to heat treatment during the jet-blast test. The effect of drying the specimen was not taken into consideration. Further study of the data on this subject has led to the conclusion that the drying shrinkage may be a greater factor affecting flexural strength than the damage from the jet-blast. A comparison of flexural strengths determined on specimens cut from within the central test area with those cut from the edge of the test area, and with those cut from panels similarly dried, but not subjected to the jet-blast, confirm these views. It appears, therefore, that our data on the change in flexural strength should be associated with loss in moisture due to drying. Table II shows that the sensitivity of flexural strength to changes in moisture differs widely for concretes containing different types of aggregate and different types of cements. It is greater in concretes made with either lightweight or blast-furnace slag aggregate and portland cement than when dense aggregates are used. The use of high alumina cements with either lightweight or blast-furnace slag accentuates this sensitivity. Table III shows the flexural strength of these beams and beams soaked in water for 48 hours before testing.

TABLE III. EFFECT OF JET IMPINGEMENT ON THE FLEXURAL STRENGTH OF CONCRETE BEAMS

			Specimens Cut From		
Power Check Facility	Aggregate	Cement	Outside Test Area		Within Test Area
Beeville	Diabase	Portland I	459		494
Oak Harbor	"	Portland II	400		336
"	"	"	414		400
Sanford	Blast-furnace slag	Portland I	384		394
Cherry Point	Diabase	Portland I	490	460 1/	460
Miramar	Expanded shale	High Alumina Hydraulic	170	190 1/	150
"	"	"	245	275 1/	245
Meridian	Blast-furnace slag	Portland I	310	295 1/	280

1/ Beams cut from outside test area and water soaked for 48 hours before testing.

Table II. Data on Panels During Moist Curing, Drying, and Results of Jet Impingement Tests

Identification	Panel Number	Days in Sawdust	Water[1/] Content of Sawdust	Weight Change[2/] of Panel During Sawdust Storage	Storage in Fog-room	Weight Change[2/] of Panel During Fog-room Curing	Drying Period	Loss in Drying	Spalling Loss by Wt.	Spalling Loss by Sand Volume	Flexural[3/] Strength
			%	%	days	%	days	%	c.c.	c.c.	psi
5th Naval Dist.	1	15	38	-0.13	13	0.00	36	0.40	43.6	15.4	480
N.A.S.Norfolk,	2	15	do	-0.26	13	0.00	50	0.67	45.3	None	465
Virginia	3	14	do	-0.13	13	+0.14	68	0.82	90.6	1.20	455
	4	14	do	-0.13	13	+0.14	84	0.89	225.3	119.3[4/]	395
8th Naval Dist.	A	15	60.5	-0.14	13	+0.06	42	0.63	149.5	70.2[4/]	370
N.A.A.S.Kingsville,	B	15	60.5	-0.58	13	+0.16	58	0.87	43.9	24.6	430
Texas	C	15	60.5	-0.58	13	+0.16	Note[5/]	----	-----	-----	---
	D	17	52.0	-0.43	10	0.00	87	0.86	87.2	22.6	415
8th Naval Dist.	A	17	52.0	+0.57	10	0.00	42	0.57	303.0	226.0[4/]	370
N.A.A.S. Beeville,	B	17	do	+0.14	10	+0.14	59	0.83	43.6	26.2	495
Texas	C	17	do	+0.69	10	0.00	70	0.79	34.5	None	460
11th Naval Dist.	1	28	54.0	+2.26	6/	6/	42	8.20	68.0	None	135
U.S.M.C.A.S.	2	28	39.0	+3.02	"	"	56	8.22	206.5	"	130
El Toro, California	3	28	38.0	+1.86	"	"	71	5.49	96.3	Slight	205
13th Naval Dist. [7/]	1	32	61.0	+0.23	6/	6/	43	1.70	49.9	None	485
N.A.S. Whidbey Is.	2	32	62.0	+0.34	"	"	56	2.00	50.7	"	400
Oak Harbor, Washington	3	32	57.0	+0.21	"	"	71	2.45	None	"	415
6th Naval Dist.	1	28	53.0	+0.76	6/	6/	42	0.79	50.7	9.0	385
N.A.S. Sanford,	2	28	53.0	+0.57	"	"	56	1.11	51.5	Slight	275
Florida	3	28	53.0	+0.57	"	"	71	0.94	514.6	331.0[4/]	390
11th Naval Dist.	1	37	60.0	-0.32	6/	6/	42	0.96	51.8	None	325
U.S.M.C.A.A.S.	2	37	60.0	-0.48	"	"	56	1.43	31.1	do	300
Yuma, Arizona	3	37	60.0	-0.16	"	"	70	1.13	93.0	do	300
6th Naval Dist.	2	120	47.5	+0.77	6/	6/	56	0.46	10.5	None	475
U.S.M.C.A.A.S.	4	"	"	+1.15	"	"	42	0.23	55.0	16.9	505
Beaufort, S.C.	5	"	9/	None	"	"	70	0.44	45.0	16.0	415
6th Naval Dist.	1	50	49.0	+2.31	6/	6/	42	0.45	38.0	None	365
N.A.S.Glynco	2	43	49.0	+0.71	"	"	56	0.31	68.0	Slight	465
Georgia	3	42	49.0	+2.62	"	"	70	0.71	237.0	181.0[4/]	490
5th Naval Dist.	1	20	43	+0.29	8	+0.06	42	0.40	98.0	59.0	445
M.C.A.S.	2	20	50	+0.29	8	None	56	0.43	48.0	38.0	570
Cherry Point, N.C.	3	20	52	+0.16	8	+0.06	70	0.47	93.0	76.0	490
6th Naval Dist.	1	47	18	-0.42	6/	6/	42	0.54	54.0	29.0	390
N.A.S.	2	"	27	None			56	0.42	82.0	None	515
Jacksonville, Fla.	3	"	65	None			70	0.72	28.0	None	565
11th Naval District	1	38	40	+0.77	6/	6/	6	0.68	161	None	170
N.A.S.	2	38	40	0.00			13	0.21	116	None	280
Miramar, California	3	38	40	-0.85			20	0.17	116.5	None	245

Table II - Continued.

Identification		Panel Number	Days in Sawdust	Water 1/ Content of Sawdust %	Weight Change 2/ of Panel During Sawdust Storage %	Storage in Fog-room days	Weight Change 2/ of Panel During Fog-room Curing %	Drying Period days	Loss in Drying %	Spalling Loss by Wt. c.c.	Spalling Loss by Sand Volume c.c.	Flexural 3/ Strength psi
12th Naval District 10/												
N.A.S.	1	1	28	37	+0.97	6/	6/	17	0.48	170.0	None	365
Lemoore, California		2	do	do	+0.54			8	None	60.0	do	370
		3	do	do	+0.41			22	0.81	57.0	do	375
	2	1	28	38	+0.42	6/	6/	29	0.83	68.0	None	315
		2	do	do	+0.37			36	1.00	125.0	34	335
		3	do	do	+0.42			42	1.04	68.0	Slight	335
	3	1	28	53	+0.79	6/	6/	9	0.59	651.0	500.0 4/	395
		2	do	do	+0.79			20	None	565.0	None	380
		3	do	do	+1.09			23	0.86	26.0	None	405
	4	1	28	37	None	6/	6/	30	1.00	79.0	None	300
		2	do	do	+0.05			37	0.85	65.0	None	370
		3	do	do	+1.00			43	0.98	Not Tested	Not Tested	Not Tested
	5	1	28	69	+0.32	6/	6/	29	0.92	65.0	None	320
		2	do	do	+1.03			35	1.00	57.0	None	290
		3	do	do	+0.48			Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Southeast Division		1	21	41	-0.32	7	+0.16	14	0.19	105.0	8/	310
N.A.S.		2	do	41	-0.10	7	+0.03	28	8/	8/	8/	8/
Meridian, Mississippi		3	do	41	-0.13	7	+0.03	8/	8/	8/	8/	8/
Southwest Division		1	11/									
N.O. Test Station		2										
China Lake, Calif.		3										

1/ $\frac{\text{wet weight-dry weight}}{\text{wet weight}} \times 100$

2/ Based on one day weight

3/ Determined on beams cut from panels after jet impingement tests.

4/ Results of this magnitude indicate complete destruction of test surface.

5/ Flexural strength determined on 3 beams cut from panel at request of Budocks.

6/ Considered as moist cured during transit, 28 or more days

7/ The water in the sawdust was frozen through to the panels on receipt.
Since the concrete from which these panels were fabricated was rejected, as failing to meet flexural strength requirements; additional panels will be shipped fabricated from concrete used in new installation.

8/ Data not complete.

9/ Not packed in sawdust.

10/ Power Check Station number.

11/ Shipment not received; 14 days past due.

Pressure Developed Within Concrete During Rapid Heating

Since we have been unable to detect pressure within concrete during a jet impingement test of sufficient magnitude to account for spalling, we have been approaching it in another manner. During many jet-blast tests, free moisture is forced out through the back of a six inch thickness of concrete. An apparatus to determine the minimum steam pressure necessary to account for this phenomenon has been assembled and was mentioned in N.B.S. Report 7197.

Photographs of this apparatus are shown in Figures 1 and 2. A line drawing of the apparatus appeared in N.B.S. Report 7197 but further instrumentation warrants including photographs in this report.

Cylinders, 6 x 6 inches, were fabricated using blast-furnace slag aggregate or diabase aggregate with portland cement. The mixes used in casting these cylinders were given in N.B.S. Report 6398 and N.B.S. Report 6909 as P-BF-3 and P-Di-PH respectively. Two of the cylinders fabricated with blast-furnace slag were subjected to steam pressure after having been moist cured for 28 days and dried for 20 or 21 days.

In the first test the base of the cylinder was exposed to 300 psi pressure for five and one-half hours. No noticeable amount of water appeared on the top face exposed to ambient temperature and pressure.

The second cylinder was exposed to similar conditions except that heat was applied at the base of the cylinder mold (see Figure 1(6)) for the purpose of keeping the water in a gaseous state. This resulted in a rise in temperature of the base of the mold to 170°C during one and one-half hours. The applied pressure during this part of the test averaged 200 psi. Condensed steam was noticed covering an area of the open surface of approximately one square inch. Water continued to emerge from the top of the cylinder for an additional three hours, during which time the pressure was kept constant at 285 psi, depositing sulphur and other materials on the surface. This cylinder, after removal from the mold, was broken. There was considerably more water apparent near the top surface than near the bottom.

A third cylinder fabricated with the same concrete mix, blast-furnace slag aggregate and portland cement, but containing thermocouples and pressure probe tubes (see Figure 1 (10) and (9) respectively) positioned within the specimen, along the center axis and at one and one-half inch spacings was tested.

Numbers indicate parts of apparatus shown in Figures 1 and 2

(1) Top enclosure for specimen; cold rolled steel; 1 1/2" plate machined and recessed to fit cylindrical mold containing specimen.

(2) Specimen mold; 6" high duty steel pipe with top and bottom ends machined to a plane surface; inside diameter trued to remove zinc coating.

(3) Bottom enclosure recessed the same as (1) and an additional recess to act as steam chamber.

(4) Release valve, for condensed steam.
(5) Steam inlet
(6) Bunsen burner used to heat bottom of specimen holder.

(7) Pressure control

(8) Pressure gauge on steam generator

(9) Pressure probe tubes

(10) Thermocouple leads

(11) Steam generator

(12) Thermometer well

(13) Safety Valve; blow off at 300 psi

(14) Pressure transducer

(15) Transducer balancing unit and power supply

(16) Rubber gaskets

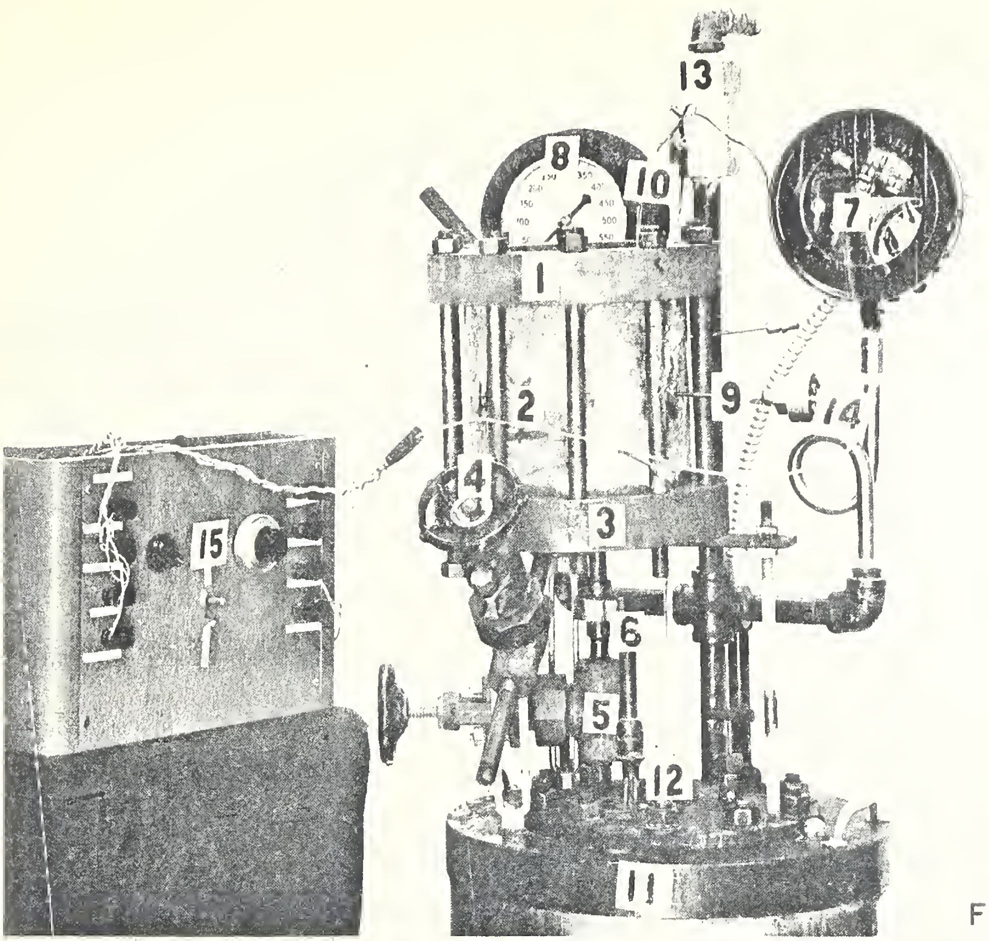


FIG. 1

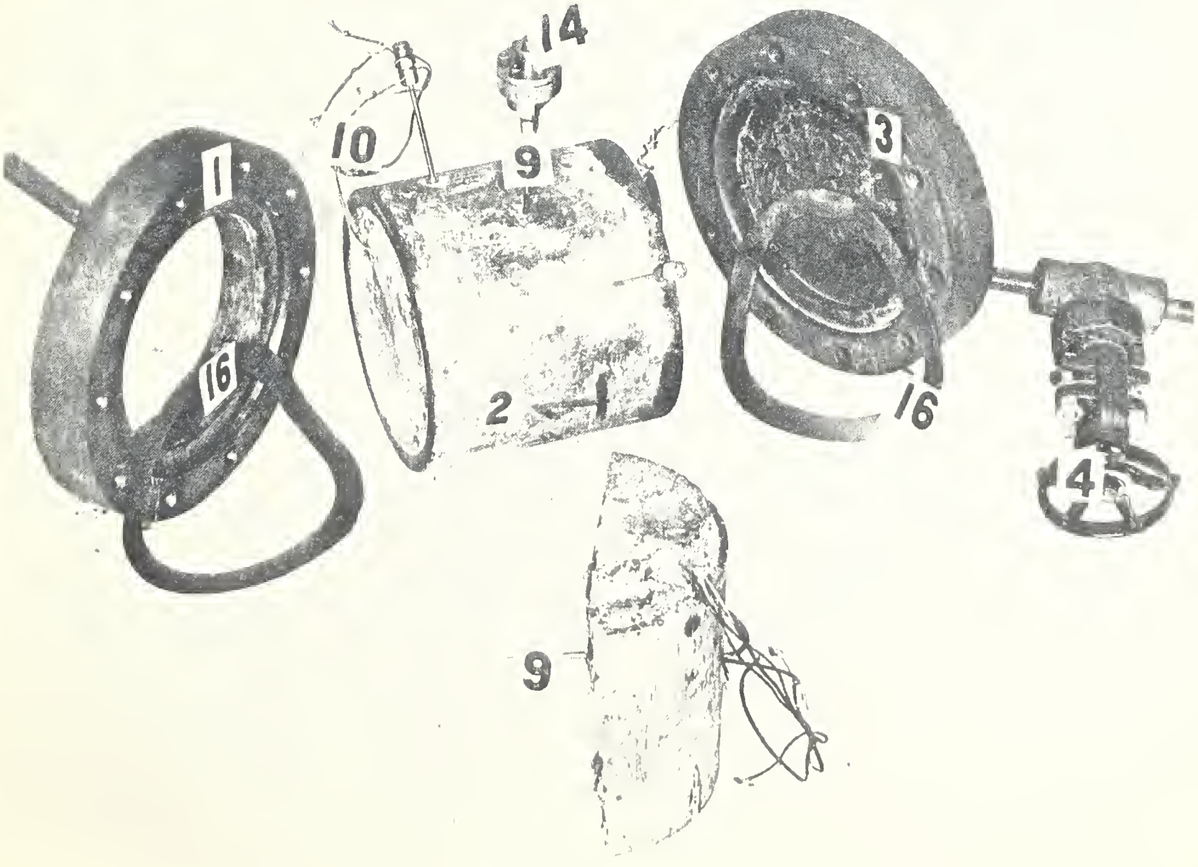


FIG. 2

During this test, as in the two previous tests here reported, one face of the cylinder was open to the atmosphere while steam pressure was applied to the other. The pressure applied at the start of the test was 100 psi and increased to 300 psi over a period of 30 minutes. The first temperature increase noted was 49°C at 12 minutes, on the thermocouple (Figure 3) one and one-half inches from the face exposed to steam. The other two thermocouples at distances of three and four and one-half inches from the exposed face indicated no increase in temperature for 30 minutes. After one hour thermocouples 1, 2, and 3 at one and one-half inches, three inches, and four and one-half inches from the bottom face, indicated temperatures of 99, 65, and 53°C respectively. Throughout the entire test, pressure measurements in the specimen were taken only at probe tube #2 at the middle of the specimen. Tube #1, one and one-half inches from the steam face, was mechanically defective, causing a leakage at the place where the tube entered the steel mold, and tube #3, four and one-half inches from the steam face, showed no indication of pressure. After two hours the pressure at the center of the specimen, as indicated by probe tube #2, increased rapidly to approximately 50 psi and then gradually to 100 psi during the next three and one-half hours, at which time the test was discontinued. No moisture had appeared on the face of the specimen.

The following day the test was repeated on the same specimen with somewhat different results (see Figure 4). Pressure of 100 psi was applied to the bottom face of the cylinder immediately and increased to 300 psi in 35 minutes as it was in the first test. After one hour the pressure in the test cylinder was less than ten psi. The pressure increase to 165 psi in approximately two hours, at which time the power to the autoclave was cut off inadvertently. After a total of three and one-half hours from the start of the test, the applied pressure had dropped to 165 psi before the power was turned back on and heat applied at the base of the mold. The pressure then increased to 320 psi in one-half hour and was adjusted at 300 psi throughout the remainder of the test. Near the end of the test, the pressure at the center of the specimen, probe #2, reached 240 psi.

Figure 4 shows the applied (generated) pressure and the resultant pressure within the concrete at increasing periods of time. Temperatures at the 3 inch level within the concrete are also shown. Data collected during this second test, may not be truly indicative of concrete since the first test may have effected the concrete or the mechanism controlling the passage of water.

Effect of Drying on the Temperature Gradients, Measured in Concrete at Increasing Depths From the Test Surface, During Jet Impingement Tests.

The following work was done to study the effect that the length of the drying period, at 50% relative humidity and 73°F, had on the temperature gradients.

RELATIONSHIP OF APPLIED STEAM PRESSURE TO RESULTANT PRESSURE AND TEMPERATURES WITHIN A CONCRETE CYLINDER.

FIG. 3

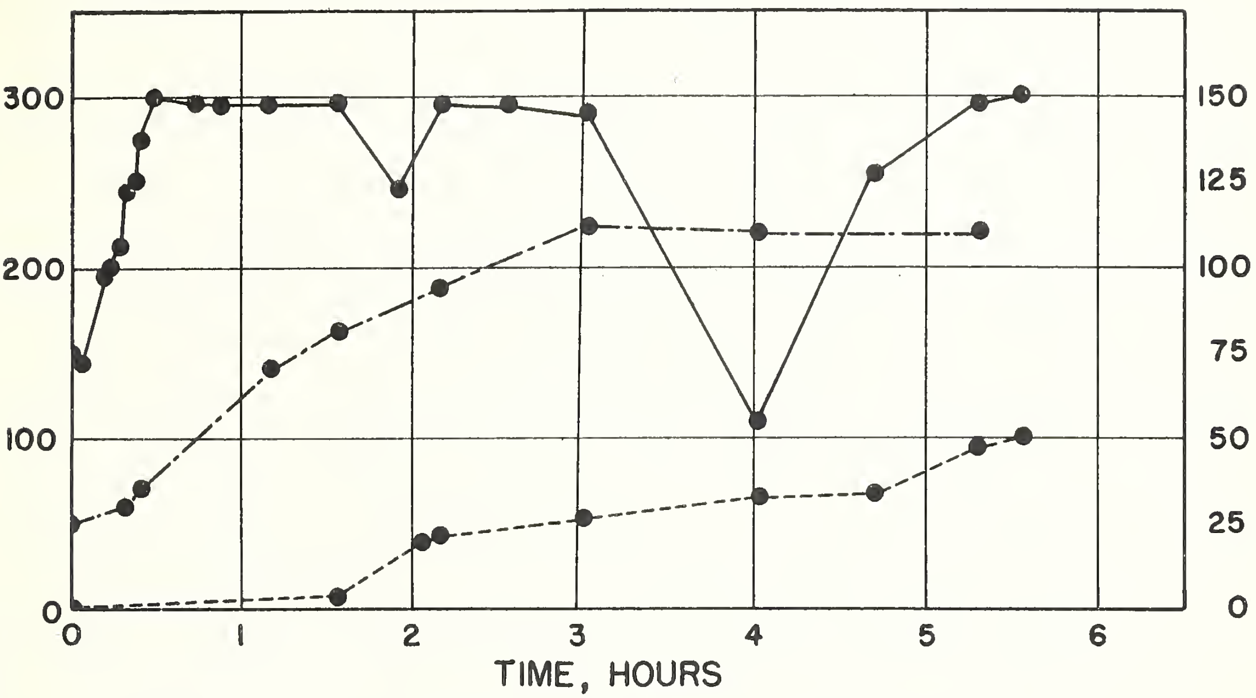
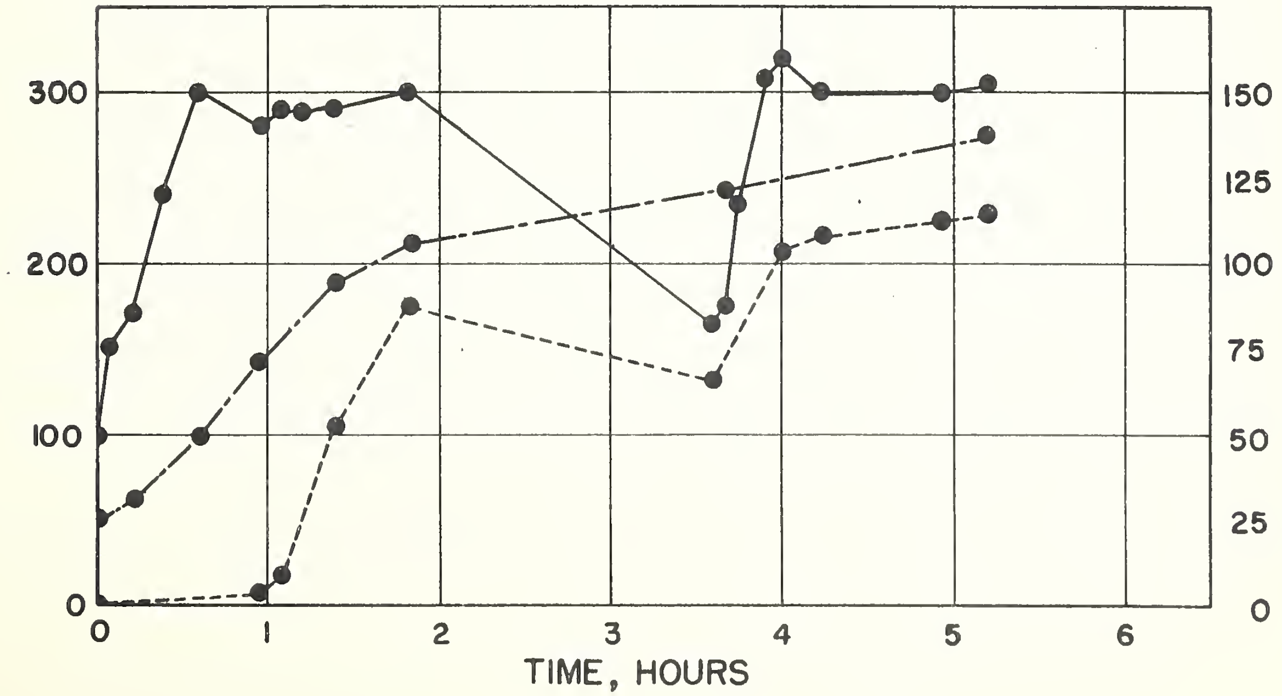


FIG. 4



Six concrete panels, 18 x 18 x 6 inches, were fabricated, three using the concrete containing blast-furnace slag aggregate and portland cement referred to before in this report and N.B.S. Report 6398. Three were fabricated using diabase aggregate and portland cement referred to before in N.B.S. Report 6909. These panels were instrumented with three multiple thermocouples at various locations in the concrete. Three of the thermocouples were positioned at the surface of the panel, one at the center of the test area, one three inches to the right of the center and one three inches to the left. The remaining thermocouples were positioned at various depths directly below the surface. This arrangement made possible the determination of temperatures at depths of one-quarter, one-half, and 3/4 inches below the test surface. An additional thermocouple was placed at the one inch depth below the center of the test area. Data previously obtained at one-quarter and one-half inch depths below the test surface was insufficient for our purpose.

Two of the blast-furnace slag-portland-cement panels were subjected to the jet impingement test after 21 days moist curing, seven and 21 days drying. The data collected on the panel dried for seven days appears in Figure 5 and Table IV. Similar data for the panel dried for 21 days appears in Figure 6 and Table V.

In comparing the data collected during the test of the first panel with that of the second panel, the effect of placing the thermocouples at the surface of the test panel is evident. The results of these tests and the examination of the panels after test indicate that in the first panel the surface thermocouples were slightly below the surface and in the second panel the center surface thermocouple was slightly exposed.

When the multiple thermocouples are placed in the panel mold, before casting, the three common leads are in tension. A misplacement of the surface junction results in setting up errors of depth of the same magnitude for other junctions of the same multiple thermocouple.

The quarter inch spacings between junctions of the chromel and alumel wires were made with the use of a template or jig.

Due to an unavoidable error in the positioning of the surface thermocouples, data from tests of panels #1 and #2 are not wholly comparable. However, the data shows that at increasing periods of time, up to 20 minutes, at depths up to one inch, the temperature gradients decrease in magnitude and approach constancy.

A cooling curve is included in Figure 6 for specimen 2 after 20 minute exposure to jet impingement. This data has not yet been evaluated. It may, however, be used to advantage in the study of heat transfer during cooling.

Table IV Temperatures, During Jet Impingement, of a Concrete Test Panel at Three Positions on the Surface Area and at Increasing Depths of One-quarter Inch Directly Below These Positions at One Minute Intervals.

Location of Thermocouple	Degrees, F																
	1 min.	2 min.	3 min.	4 min.	5 min.		1 min.	3 min.	5 min.		1 min.	3 min.	5 min.	10 min.	15 min.	20 min.
Center of Test Surface	860	995	1065	1095	1110	24 hour lapse between tests	980	1105	1155	24 hour lapse between tests	1000	1120	1155	1210	1210	1205
1/4" below "	290	400	520	605	670		370	665	770		375	685	795	905	955	985
1/2" " "	155	280	340	350	375		160	360	470		160	380	510	655	730	775
3/4" " "	100	145	205	245	290		100	225	295		100	225	300	445	525	580
1" " "	85	100	135	165	200		90	145	220		85	140	215	315	370	420
3" Right of Center of Test Area	570	610	645	650	655		670	725	755		700	755	770	805	805	805
1/4" below "	220	290	335	370	395		350	410	475		260	435	505	575	615	635
1/2" " "	130	195	240	270	295		135	260	315		135	260	335	425	480	515
3/4" " "	95	125	160	190	220		95	175	235		95	170	230	310	360	395
3" Left of Center of Test Area	630	710	750	765	780		610	670	645		620	670	695	730	730	725
1/4" below "	265	340	380	425	460		250	410	465		260	420	405	555	590	610
1/2" " "	145	235	300	350	370		140	265	315		140	270	335	430	480	510
3/4" " "	95	140	190	230	270		100	185	260		95	180	255	320	365	400

Table V Temperatures, During Jet Impingement, of a Concrete Test Panel at Three Positions on the Surface Area and at Increasing Depths of One-quarter Inch Directly Below These Positions at One Minute Intervals. Normal Cooling for Five Minutes After Completion of Test.

Location of Thermocouple	Heating								Cooling (Normal)					
	Degrees, F													
	1 min.	2 min.	3 min.	4 min.	5 min.	10 min.	15 min.	20 min.	1	2	3	4	5	6 1/2
Center of Test Surface	1355	1335	1340	1395	1380	1360	1340	1390	735	645	590	540	500	450
1/4" below "	650	780	860	935	970	1050	1095	1140	880	775	700	640	595	525
1/2" " "	225	315	380	450	515	700	800	860	830	765	710	660	615	550
3/4" " "	120	190	250	300	340	460	580	655	670	655	630	600	570	520
1" " "	90	120	160	200	235	345	400	480	505	510	510	500	485	465
3" Right of Center of Test Area	----	----	----	----	----	----	Malfunction of Thermocouple							
1/4" below "	415	510	555	595	620	665	690	720					405	
1/2" " "	190	270	315	350	385	485	540	575					405	
3/4" " "	115	175	220	250	280	355	415	455					385	
3" Left of Center of Test Area	980	985	1005	1045	1030	1015	1000	1040					440	
1/4" below "	455	585	645	700	735	805	835	870					465	
1/2" " "	190	285	330	365	405	550	615	655					465	
3/4" " "	105	160	210	250	285	370	425	480					420	

FIG. 5 TEMPERATURE OF CONCRETE AS A FUNCTION OF DISTANCE FROM EXPOSED SURFACE DURING JET IMPINGEMENT TEST, AT ONE MINUTES INTERVALS

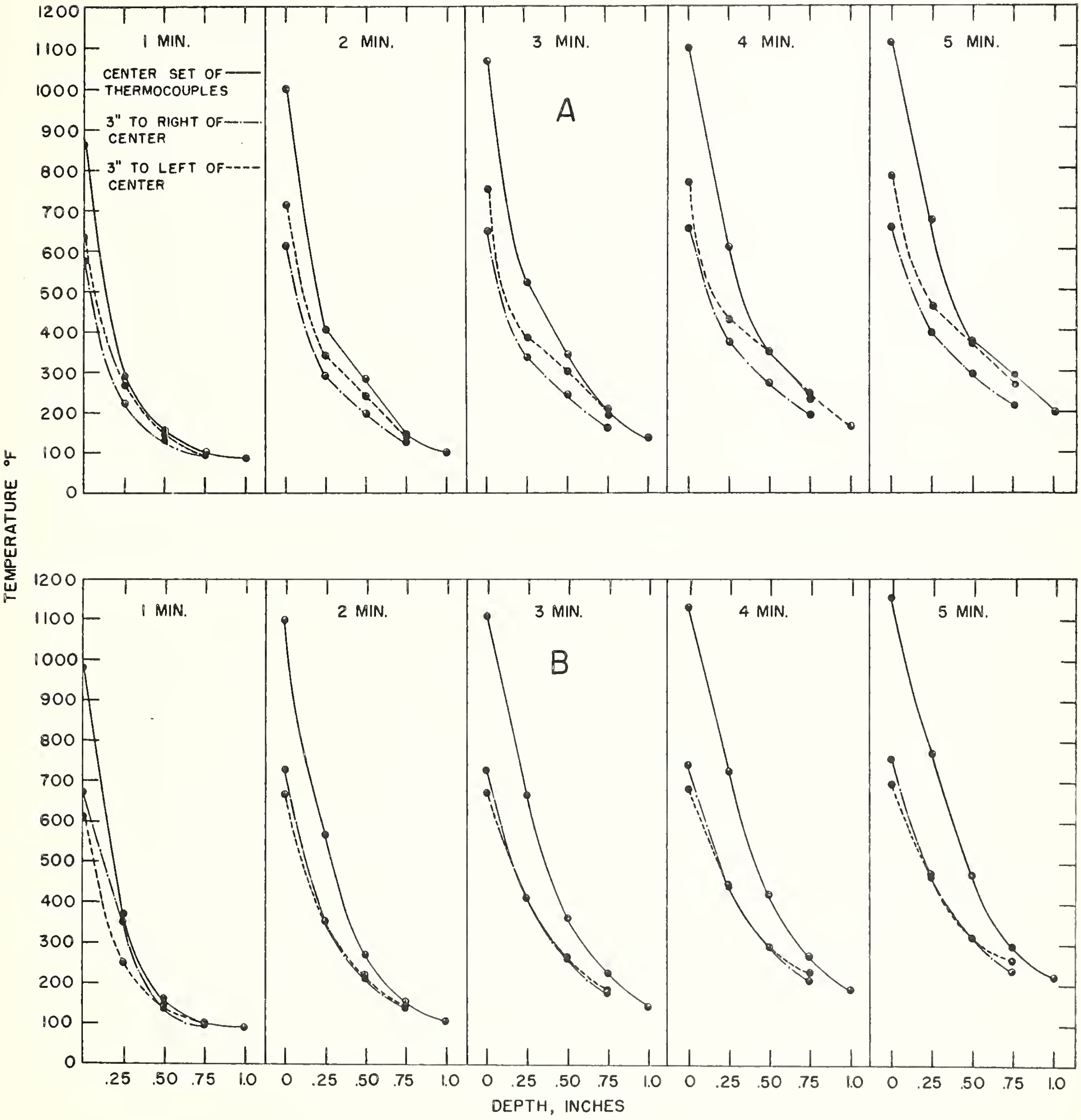


FIG. 5 TEMPERATURE OF CONCRETE AS A FUNCTION OF DISTANCE FROM EXPOSED SURFACE DURING JET IMPINGEMENT TEST, AT ONE MINUTES INTERVALS.

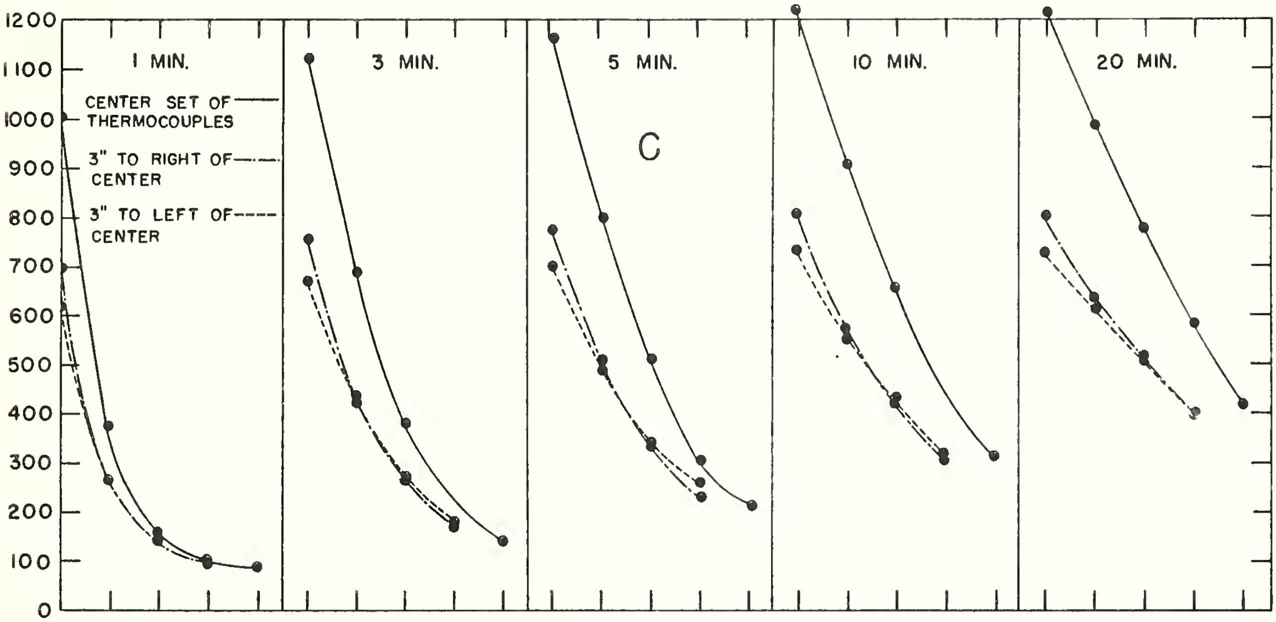
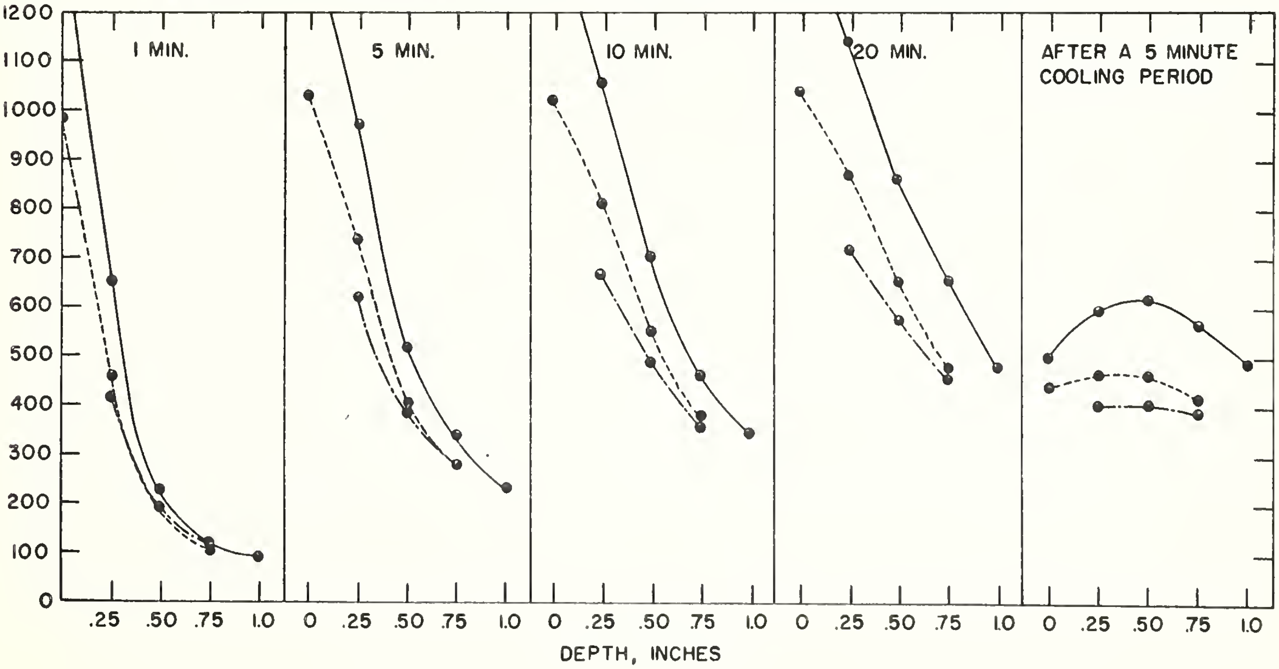


FIG. 6 TEMPERATURE OF CONCRETE AS A FUNCTION OF DISTANCE FROM EXPOSED SURFACE DURING JET IMPINGEMENT TEST, AT ONE MINUTES INTERVALS WITH COOLING CURVE ADDED.



U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS
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Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

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