# NATIONAL BUREAU OF STANDARDS REPORT

5123

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 and L. E. Mong
and R. A. Clevenger



NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

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

# THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

**Electricity and Electronics.** Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Process Technology. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

**Optics and Metrology.** Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

**Heat and Power.** Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels.

**Atomic and Radiation Physics.** Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

**Chemistry.** Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. 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. Organic Plastics. Dental Research.

**Metallurgy.** Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

**Mineral Products.** Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

**Building Technology.** Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

**Applied Mathematics.** Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

**Data Processing Systems.** Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems.

**Cryogenic Engineering.** Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

**Radio Propagation Physics.** Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services.

**Radio Propagation Engineering.** Frequency Utilization Research. Tropospheric Propagation Research.

**Radio Standards.** High Frequency Standards. Microwave Standards.

- Office of Basic Instrumentation
- Office of Weights and Measures

# NATIONAL BUREAU OF STANDARDS REPORT

**NBS PROJECT** | **NBS REPORT**

0903-20-4428 | January 22, 1957 | 5123

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, L. E. Mong
and R. A. Clevenger

Refractories Section
Mineral Products Division

Sponsored by
Department of the Navy
Bureau of Yards and Docks

Reference: NT4-59/NY 420 008-1
NBS File No. 9.3/1134-C

Approved:
Dr. Samuel Zerfoss
Chief, Refractories Section



NBS

**U. S. DEPARTMENT OF COMMERCE**

**NATIONAL BUREAU OF STANDARDS**

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

## 1. INTRODUCTION

This phase of the project includes the determination of the cause or causes of failure that occur in concrete aprons and runways exposed to jet exhaust gases. A combustion chamber that delivers hot gases at velocities and temperatures approximating those of field conditions is being used. The approach includes instrumentation of the concrete test panels to determine the heat gradients and stresses set up during flame impingement at several locations on the test area and at varying depths below the surface.

## 2. ACTIVITIES

### 2.1 Concrete with Diabase Aggregate

As previously reported[1/] a concrete was designed with diabase aggregate. A batch was mixed, specimens were fabricated.

Results of preliminary tests on the diabase aggregate, the design of the concrete mix using the aggregate, and the properties of the fresh concrete follow:

| | Coarse[2/] | Fine[2/] |
|---|---|---|
| Absorption | 0.6 | 1.54 |
| Bulk Specific Gravity (SS Dry) | 2.96 | 2.87 |

Percent loss in Los Angeles
Abrasion Test - - - - - - - - 25.9

Ratio of coarse-to-fine
aggregate - - - - - - - - - - 65 to 35

---

1/ NBS Report 4869, October 5, 1956.

2/ The properties of the aggregate were determine on the same sizings as used in concrete.

## Gradation

| Coarse U. S. Standard Sieve | Percent | Fine U. S. Standard Sieve | Percent |
|---|---|---|---|
| on 1 | 22 | No. 8 | 16 |
| 3/4 | 30 | 16 | 20 |
| 1/2 | 18 | 30 | 29 |
| 3/8 | 15 | 50 | 25 |
| No. 4 | 15 | 100 | 9 |
| | | Thru 100 | 1 |

## Properties of Fresh Concrete

| | |
|---|---|
| Proportions, by weight: Cement ) to coarse and to fine aggregate ) | 1 : 3.18 : 1.71 |
| Cement content[3/] | 7.31 sacks/yd$^3$ of concrete |
| Vinsol resin | 0.01% by weight of cement |
| Water content | 32.7 ~~37.7~~ gals/yd$^3$ of concrete |
| Air content | 2.2% gravimetric method |
| Slump | 2.25 inches |
| Weight of fresh concrete | 161.44 lbs/ft$^3$ |
| Water cement ratio | 0.40 |
| Remarks | Easily placed but harsh |

The flexural strength of the concrete after curing for 28 days in fog-room was 845 psi. Heating to 500°C for five hours (complete immersion) reduced the strength to 305 psi. Heating to 750°C resulted in a further loss of strength to 100 psi. The cured specimens failed by aggregate fracture and the heated specimens by bond failure. Two test panels fabricated from this concrete were subjected to the jet blast. Both had been cured for 28 days in the fog-room, one had

---

3/ Designed as a seven-sack mix, calculated to 7.3.

been stored at 73°F and 50 percent relative humidity for 28 days; the second had been stored for 49 days at the same temperature and humidity. This concrete appears to have the best resistance to the jet blast of any thus far tested.

### 2.2 Absorption and Evaporation of Water During Curing and Drying of Concrete

The drying of tile shape specimens, three by three inches, having different thicknesses, and fabricated with concrete designed with different aggregates has been continued. These specimens were vapor proofed on all but one three by three inch face. The results appear in Table 1.

The results indicate that the dimension of the specimen is a factor in:

1) The amount of water absorbed during fog-room curing;
2) The amount of water evaporated during storing;
3) The amount of non-evaporable water in concrete after storage and drying.

The concrete designed with crushed brick aggregate while containing less cement than that designed with crushed olivine aggregate had more combined water after curing and drying. R. C. Valore found in his work on Cellular Concretes[4] that brick dust acts as a pozzolan cement.

The concrete tile fabricated with the crushed building brick aggregate and those fabricated with the White Marsh aggregate were stored for nine months after curing. The one-half inch tiles were the only ones that reached water

[4] Cellular Concretes by R. C. Valore, Journal of American Concrete Institute, May and June 1954.

Table 1. Effect of Curing and Drying of Concrete

| Identification a/ | Mixing Water b/ | Cement Content c/ | Thickness of Tile d/ | Change in Water Content During e/ | | | Non-Evaporable Water i/ |
|---|---|---|---|---|---|---|---|
| | | | | Curing f/ | Storing g/ | Drying at 110°C to Constant Weight h/ | |
| | % | sacks/yd3 of concrete | inches | % | % | % | % |
| P-O | 6.5 | 7.7 | 6 | +0.83 | -0.45 | -4.04 | 2.46 |
| | | | 4 | +0.86 | -0.52 | -4.18 | 2.32 |
| | | | 2 | +1.05 | -0.83 | -3.89 | 2.61 |
| | | | 1 1/2 | +1.01 | -0.94 | -3.81 | 2.69 |
| | | | 1 | +1.40 | -0.88 | -3.58 | 2.92 |
| | | | 1/2 | +1.36 | -1.44 | -3.58 | 2.93 |
| P-B | 8.5 | 6.5 | 2 | +0.80 | -1.90 | -5.13 | 3.37 |
| | | | 1 1/2 | +0.97 | -2.09 | -5.37 | 3.13 |
| | | | 1 | +1.08 | -2.17 | -5.19 | 3.30 |
| | | | 1/2 | +1.76 | -2.02 | -4.22 | 4.28 |
| P-WM | 6.3 | 5.3 | 2 | +1.08 | -1.18 | -3.99 | 2.31 |
| | | | 1 1/2 | +1.06 | -1.02 | -3.49 | 2.81 |
| | | | 1 | +1.41 | -1.09 | -3.35 | 2.95 |
| | | | 1/2 | +2.70 j/ | +0.59 j/ | -0.93 j/ | 5.37 j/ |

a/ The first letter, P = portland cement; the second letter or letters, O = olivine, B = building brick, WM = White Marsh sand and gravel.

b/ Based on weight of wet mix.

c/ As calculated.

d/ All tile were three inches square.

e/ Cumulative change in water content as determined by change in weight from time specimens were removed from mold (20 hours).

f/ Fog-room curing, 73°F and 100 percent relative humidity.

g/ Stored at 73°F and 50 percent relative humidity, vapor proofed on all but one three-inch face.

h/ Vapor proofing removed before drying.

i/ Percent water retained after drying to contant weight at 110°C; this value does not take into consideration any carbon dioxide acquired during curing, storing or drying, but affords a comparative estimate of the amount of chemically combined water in the specimen.

j/ Anomalous results probably due to high cement content of the one-half inch tile.

equilibrium under the conditions of storage i.e. stored at 73°F, 50 percent relative humidity, and vapor proofed on all but one three-inch face. The one-half inch tile fabricated with concrete designed using White Marsh aggregate reached constant weight at seven months storage, the one-half inch tile fabricated with concrete designed using crushed building brick reached constant weight at eight months storage. Those made with concrete using olivine aggregate have not as yet reached constant weights.

## 2.3 Humidity in Concrete Specimens

A two-month delay in shipment of the miniature hygrometers, that are to be used in correlating humidity, at increasing depths, from the exposed surface, with water loss has deferred this work.[5] January 24, is the date now scheduled for delivery.

## 2.4 High-Alumina Hydraulic Cement

During the period covered by this report a concrete was designed with crushed building brick and a high-alumina hydraulic cement (AlCOA - XCA-25), low in impurities. Specimens fabricated from a trial batch of this concrete developed their maximum strength more rapidly than those fabricated with concrete designed with portland cement. Specimens (16 x 4 x 3 inches) fabricated from this concrete developed a flexural strength of 720 psi during 14 days in the fog-room.

---

[5] The method was described in detail in NBS Report 4869, October 5, 1956.

Additional specimens after the same curing period were heated at 500 and 750°C for 5 hours and tested. The flexural strength of those heated at 500°C was 645 psi and those heated at 750°C was 585 psi. Concretes designed with portland, portland pozzolan, or Lumnite cement, and tested after such heat treatments show a loss in flexural strength of from 50 to 60 percent. X-ray diffraction patterns were made on samples of this concrete, after curing, 500°C heat, and 750°C heat. Careful inspection failed to identify any cement component or a shift in the patterns due to heating. A study of the effect of heating on neat high-alumina cements is included in a current project at this Bureau. The data when available will be included in a future report.

### 2.5 Pressure Developed in Concrete During Rapid Rate of Heating

In the study of the pressure developed in concrete, as the temperature is raised at a rapid rate, a bomb was constructed. This bomb was equipped with thermocouples located in different positions in the concrete charge and a pressure gauge to measure the vapor pressure surrounding the concrete specimen. The bomb was first checked for performance using water only and the data from the steam tables was reproduced. The bomb was then charged with a concrete mix and cured in the fog-room, and the only water in the system was that contained in the concrete. During heating at 200°C per hour the pressures and temperatures in the concrete

charge were recorded. However, the total amount of water present in the system was so small that the volume of the colder connecting tubes served as a condenser for the water vapor driven from the concrete and only small net pressures were observed. These net pressures did not develop till the temperature of the concrete was above 230°C.

Since the pressure gauge must operate at room temperature it will be necessary to fill the voids of the system with a liquid having a very low vapor pressure for the temperature of the test. Samples of such liquids have been obtained including Dow Corning silicone fluid 550, and Esstic Oil 42.

It is noteworthy that only about 23 percent of the water, originally present, was lost from the concrete in the heat treatment which included heating to 310°C and cooling to room temperature in the closed system. Concretes heated in air to such temperatures loose nearly all of their water.

### 2.6 Mineralogic Examination of Aggregates

A mineralogic examination was made on aggregates submitted by NAVCERELAB. Six aggregates were examined before and after four heat shock treatments (1250, 1500, 1800, and 2000°F). Five samples representing the predominating material occurring in San Gabriel gravel and nine samples not marked for an identification were also examined. The results of the examination occur in Tables 2, 3, and 4.

TABLE 2. EFFECTS OF THERMAL SHOCK TREATMENT

| Aggregate NBS No. | Field Condition Before Exposure to Thermal Shock[1] | Thermal Shock<br>1250°F<br>3-min.<br>667-668 | 1500°F<br>3-min.<br>726-727 | 1800°F<br>3-min.<br>740-741 | 2000°F<br>3-min.<br>779-780 |
|---|---|---|---|---|---|
| 1 | Milky quartz, fairly well rounded, trace of muscovite mica and biotite highly fractured structure, dense. | Not altered much, will hand fracture, will fracture more readily on outside portion.[2] | Open fractures, fractured readily throughout.[2] | More open fracture[2] | Same as 1800°F[2] |
| 2 | Schistose, considerable amount of micaceous material, high percentage of quartz. Mica, feldspar, decomposed biotite. Medium dense, fairly friable, badly weathered.[1] | 661-662<br>Very little change in structure. | 722-723<br>Micaceous material shows expansion cracking in weathered specimen, especially, large specimen fractured in various directions along fresh surface. | 752-753<br>Mica not as fresh appearing as in lower fired specimens, medium fracture throughout. | 781-782<br>Badly fractured, quite friable, alteration of micas. |
| 3 | One specimen was a two-feldspar biotite granite, quite fresh. One specimen contained mostly quartz with some feldspar and amphibole, garnet also present, rock is compact and quite fresh.[1] | 673-674<br>Alteration of micas and friability depends on the extent of weathering that the specimen underwent. The more the weathering the more destructive the thermal exposure. | 720-721<br>Micaceous material altered, expanding especially on surface, fractured throughout. | 744-745<br>Quite friable; fractured throughout, alteration of micas. | 787-788<br>Less micaceous material than occurred in field specimens, quite friable, failure throughout. |
| 4 | Pegmatite sample shows much variation piece to piece. Principal impurity limonite, iron stains penetrating the cracks, recemented quartz grains, occasional manganese stains, leached structure, dense.[1] | 665-666<br>Fresh fracture on surface, finger breaks readily. Where iron oxide is isolated iron turning brownish in color losing its $H_2O$, highly fractured, new fractures. | No sample | 750-751<br>Same as 1250°F sample except iron more altered and more highly fractured. | 663-664<br>Thoroughly fractured |
| 5 | Igneous rock, fresh not badly altered, amphibole gneiss, shows altering to chlorite, more feldspar than quartz, altered biotite, epidote.[1] | 669-670<br>Quite friable, not badly cracked, some minerals show alteration on surface, different samples show different degrees of friability. | 724-725<br>Highly fractured, more friable, alteration of minerals increasing. | 754-755<br>Increasing in friability and alteration of minerals. | 783-784<br>No strength |
| 6 | Very dense schist, containing mica, feldspar porphyroblaste, some pebbles are coated with calcium carbonate.[1] | 675-676<br>Schist structure very noticeable, not much alteration of minerals. | 730-731<br>Micaceous materials altering, still only slight fracture. | 742-743<br>Slight fracture, still micas oxidizing. | 777-778<br>Highly fractured across feldspar grain, ground mass and feldspar showing alteration. |

1/ The numbers of the photographs of shock-treated specimens of this aggregate all appeared on this sample.

2/ Inversion temperature cracks.

TABLE 3

Five samples of the predominating materials that occur in San Gabriel gravel.

Sample No. 1

Rock, in form of rounded pebbles, containing quartz, feldspar, biotite, materials quite fresh.

Sample No. 2

Contains a two-feldspar biotite granite and a gneissoid granite with altered biotite.

Sample No. 3

A two-feldspar red granite (biotite), fairly fresh. A gray granite (biotite) weathered. A gray granite badly weathered. A two-feldspar granite (biotite) badly weathered. Sample highly variable piece by piece.

Sample No. 4

A schistose metamorphic rock, varying considerable in composition, many of the particles coated with calcium carbonate.

Sample No. 5

A schistose metamorphic rock, more uniform than sample No. 4, and finer grained with darker minerals. Considerable biotite mica present which has been altered to chlorite in some specimens.

TABLE 4

The following samples were not marked for our identification. They were, however, examined and may be identified by the number of the photographs.

Picture No. 716-717

Temperature 1500°F/3 min.

A sandstone, high in iron oxide, firm in body, some fractures.

Picture No. 748-749

Temperature 1800°F/3 min.

Hornblende schist, some fractures recemented with epidote, new fractures, little alteration of minerals, considerable feldspar, secondary mineral epidote, different samples vary in composition. Smaller samples show greater weathering and as a result are more friable.

Picture No. 663-664

Temperature 1250°F/3 min.

Feldspar and quartz, not appreciably effected by heat shock.

Picture No. 671-672

Temperature 1250°F/3 min.

Quite similar to materials shown in picture 748-749 but effected less by lower heat shock.

TABLE 4 (continued)

Picture No. 728-729

Temperature 1500°F/3 min.

A mixture of gneiss and schist, fine of grain, few fractures, fairly firm.

Picture No. 718-719

Temperature 1500°F/3 min.

Gneiss, thoroughly altered and disintegrated.

Picture No. 746-747

Temperature 1800°F/3 min.

This sample appeared to be similar to sample No. 4 of the San Gabriel gravel. Minerals altered, especially the micas, badly weakened.

Picture No. 785-786

Temperature 2000°F/3 min.

Appeared to be similar to sample No. 4 San Gabriel gravel, badly fractured, separated on bedding.

Picture No. 789-790

Temperature 2000°F/3 min.

Schist structure highly fractured, alterations of micaceous minerals pronounced resembles sample No. 5 of San Gabriel gravel.

No attempt was made to make a detailed petrographic examination of the materials since it was evident that there was a wide degree of variability item to item in each sample. Only the gross effects relating the failure to structure, mineralogy, and temperature were tabulated. It was noted that the major failures occurred above 1250°F. The three main types of failure were: (1) through quartz inversion, especially when the quartz grains were large; (2) failure through mica exfoliation, especially pronounced where the mica was in the advanced weathered condition, and (3) failure through exfoliation of Shistose structure (through expansion and breakdown of mica, chlorite, quartz, etc). Though preliminary, one may point to these three items as quite important to any aggregate specification for use above 1500°F.

## 3. PLANS FOR NEXT QUARTER

Due to the behavior in our tests of the concrete (Section 2.1) designed with diabase aggregate and its frequency of occurrence additional tests are planned on concretes using this aggregate. It is suggested that it be included with other aggregates now being studied at NACERELAB.

It has been found[6] that carbonization occurs during curing treatment resulting in a greater weight increase for the smaller specimen. (In proportion to weight-area ratio.) To determine the extent of this weight increase due to carbonization (Section 2.2) it is planned to analyze a series of the concrete specimens for carbon dioxide.

---

[6] E. T. Carlson and C. M. Hunt, N.B.S. Project 0906-11-0923, Chemical Properties of Cementing Materials.

Further work is planned on the design, fabrication, and testing of concretes containing AlCOA - XCA-25 cement (Section 2.4) since this cement is unusual in the concretes made with it had an exceptionally small percent reduction in strength resulting in heat treatments. This type of cement is now marketed by several manufacturers.

Additional data will be taken to determine the pressures developed in concrete during heating (Section 2.5).

## 4. LITERATURE

A review of the following articles was made during the month:

1. La capillarité des bêtons manufacturér par L. Marill Revue des Materiaux de Construction et de Travaux Public Edition C, Feburary 1956, No. 485.

### Summary

The proper $\frac{W}{C}$ ratio is the primary condition necessary to obtain a low absorption concrete. When the water does not completely fill the normal voids between the grains of cement the voids persist after hydration and create a path for water penetration and at best forming a less dense concrete.

The fineness modulus of the aggregate should be the one that would develop a compact concrete.

In a very porous concrete the water penetrates thru the large pores for a distance of several centimeters but can travel thru large thicknesses by following the small cracks to the interior of the large pores.

A concrete can carry an excess of material that is similar in fineness to the cement. However, if a small portion of this material is of the size of 5 microns, clay or other materials smaller than 1 micron should not be used. The addition of clay was not included in this work since its inclusion is generally known to be harmful.

The cement content is not the predominating factor. Concretes may be designed that will develop capillaries when the cement content is as low as 160 $Kg/m^3$, nevertheless, a low porosity was obtained by going below the 10 percent cement content using the Joisel method of concrete design.

The method of curing has a marked influence on the water penetration of concrete. The curing in water has a favorable action in reducing the area of the capillary network.

The use of an additive to a concrete that already has good density reduces its porosity.

The use of wax, rubber etc and the techniques of impregnation is another method of obtaining impermeable concrete.

In addition to the interest of building construction where water tight walls are desirous, the study of the porosity of concrete can furnish indications as to the speed of drying or wetting and consequently the effect on expansion and contraction observed in construction.

2. Concrete Pavements on the German Autobahnen, F. H. Jackson and Harold Allen, Journal of the American Concrete Institute, Vol. 19, No. 10, June 1948.

This publication is merely an Engineers' report on the durability of concrete pavements where particular care was taken in placing and curing concrete. No data is given on design or mix except accuracy in grading aggregate. Since this publication is readily available a more detailed summary is not considered necessary.

## 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. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

### Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Inquiries regarding the Bureau's reports should be addressed to the Office of Technical Information, National Bureau of Standards, Washington 25, D. C.

NBS