4740

NATIONAL BUREAU OF STANDARDS REPORT

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Progress Report

Heat Absorbing Capacity of an Underground Reservoir used as a Heat Sink

by

B. A. Peavy
R. S. Dill

Report to
Office of the Chief of Engineers
Department of the Army

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in 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 reports and publications, appears on the inside back cover of this report.

WASHINGTON, D. C.

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.

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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. Ceramic Engineering. 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. Applications Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

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

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

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

Radio Standards. High Frequency Standards Branch: High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Microwave Standards Branch: Extreme High Frequency and Noise. Microwave Frequency and Spectroscopy. Microwave Circuit Standards.

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Heating and Air Conditioning Section
Building Technology Division

to

Protective Structures Section
Protective Construction Branch
Office of the Chief of Engineers
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NATIONAL BUREAU OF STANDARDS

HEAT ABSORPTION CAPACITY OF A 1.5 MILLION GALLON UNDERGROUND RESERVOIR USED AS A HEAT SINK

by

B. A. Peavy and R. S. Dill

I. INTRODUCTION

As far back as 1952, there were serious discussions of the vulnerability of the outside cooling water service of underground installations. The Bureau of Standards, by request of the Office of Chief of Engineers, initiated a study of the use of underground reservoirs for the absorption of heat dissipated by engines, compressors, etc. This study involved both a theoretical and experimental approach to the subject. The experiments were made with a relatively small existing underground reservoir containing about 13,000 gallons and heat was added to the water at a constant rate during two periods each of about 30 days duration. Results of these tests show that a considerable portion of the heat added to the water is stored in the surrounding rock. These tests involved lower heat input rates than were anticipated for larger reservoirs.

As suggested by staff members of the National Bureau of Standards, the reservoir in a large installation was considered for absorption of heat from the Diesel engines and refrigeration condensers. From computations made by both the architect engineer and the NBS staff members, it was determined by analytical approach that the installation could by self-sustaining for a period of seven days or more with a heat input rate to the water of 6 million Btu per hour. This estimate was made on the assumption that the initial water temperature would be 52°F and that water would be discharged from the Diesel engines to the sewer after it attained a temperature of 95°F at the outlet from the reservoir. A resume of the findings is given under Discussion in this report.

2. PROCEDURE

A test was conducted under a simulated emergency condition, to determine the time at which a 1.5 million gallon reservoir becomes too hot to be suitable for absorbing heat from the refrigeration condenser and Diesel engines. This time was defined arbitrarily as the instant at which the temperature of the water leaving the reservoir attained a temperature of 95°F. The object of this test was to determine the feasibility of using the reservoir as a heat absorber during the emergency condition when outside water would not be available for cooling purposes, to corroborate the design computation and also to show the potentialities of storing heat in the surrounding rock mass.

3. INSTRUMENTATION

A water meter was installed in the water line from the reservoir. Thermocouples were installed in the pipes to measure temperatures of water flowing from the reservoir and water returning to the reservoir. Thermocouples were also located in the reservoir, at the water surface and at depths of 6, 10, 15, and 21 feet. The temperatures were recorded on a strip chart by a potentiometer recorder. Heat input rates to the reservoir were computed from water flow rates and the differences in temperature between water entering and leaving the reservoir.

4. RESULTS

Observed conditions during the test were as follows:

1. Initial reservoir water temperature, deg F	50

2.	Duration of test, hours	117
3.	Average heat input rate to water, Btu/hr	6.13×10^6
4.	Temperature history-see accompanying graphs, Figures 1 and 2	
5.	Average reservoir water temperature at 117 hours, deg F	101
6.	Heat added to water, total, Btu	717×10^6
7.	Heat absorbed by water, Btu	638×10^6
8.	Heat absorbed by surrounding rock, Btu	79×10^6
9.	Additional time allowed by storage of heat in the surrounding rock, hours	13

An analytical study of the heat absorption of the rock surrounding the large reservoir is given in NBS Progress Report No. 2942, submitted to the Office of the Chief of Engineers, November 27, 1953. The results of the computations from the above report are shown below in Figure 3 for a heat input rate of 6.13×10^6 Btu per hour to the reservoir. The resulting curve closely follows the observed temperatures which are also plotted on Figure 3. The observed temperatures were obtained by averaging the water temperatures measured at the various depths. The temperatures obtained analytically and given in Report 2942 were adjusted for the actual heat input rate of 6.13×10^6 Btu per hour by means of the formula:

$$T = (T' - 50)\frac{6.13 \times 10^6}{6 \times 10^6} + 50$$

where T' is an analytically-determined temperature taken from Report 2942.

During the tests, the water returned to the reservoir through spray nozzles and bathed the rock above the water in the reservoir and then drained into the reservoir by gravity. In the reservoir, the warmer water, due to its lower density, tended to stay on top and decended to lower levels as colder water was taken from the bottom. Figure 1 illustrates this point. The outgoing water temperature is seen to remain at approximately 50°F for the first 52 hours. Some mixing of the water may be noticed during the period from 40 to 52 hours by a slight increase above 50°F. Beyond 53 hours a sharp temperature increase of the water from 51 to 70°F in 16 hours occurred after which the increase was at a slower rate. This temperature increase at the bottom follows the initial temperature increase of the surface at a slower rate and with a time lag of 52 hours.

If there were perfect mixing of water in the reservoir, the leaving water temperature would closely follow the average water temperatures of Figure 3 and 95°F outgoing temperature would have been reached at 101 hours. The effects of stratification increased the length of this test by approximately 16 hours. This appears to be considerable savings in time, but it must be realized that after 117 hours, the water in the reservoir which is to be dumped to the sewer after being used for cooling the refrigeration condenser and Diesel engines was above 95°F or an average of 101°F..

If the installation must be self-sustaining for a period of one week (168 hours), 168-117=51 hours are left in which to drain the reservoir at a water flow rate from the reservoir of 490 gpm. At the average heat input rate of 6.13×10^6 Btu per hour the temperature rise of the water through the refrigeration condenser and Diesel engine would be 25°F, which indicates that temperatures as high as 130°F leaving the Diesels might occur.

During the 117 hour period, 717×10^6 Btu were added to the water of which 638×10^6 Btu were in the reservoir water and 79×10^6 Btu were dissipated

by conduction of heat into the surrounding rock and, to a minor extent, overflow from the reservoir due to expansion of the water. Although the heat thus accounted for comprises only 11 percent of the total heat added to the water, it served to lengthen the reservoir life by about 13 hours.

To perform by use of the present reservoir, one or both of the following functions: (1) extend the length of the emergency period beyond one week, and/or (2) exceed the heat input rate of 6×10^6 Btu per hour, strong consideration should be given to maintaining the reservoir at some temperature below 50°F. For the sake of example, one degree F temperature rise in 1.5 million gallons accounts for 12.5×10^6 Btu per hour or approximately 2 hours of running time at a heat input rate of 6.13×10^6 Btu per hour. The present test was probably run at the optimum time of the year when the well water temperature was near its minimum. Late summer well water temperatures are probably higher. Maintaining the reservoir at 40°F would have increased the reservoir life by 20 hours if the only consideration were the heat in the water. It is also feasible to maintain an ice to water balance in the reservoir whereby the latent heat of fusion (114 Btu/lb) will add a heat sink. An example of this, assume that one-fourth of the water is ice at 32°F. Then the increase in reservoir life would be 110 hours, which does not include the additional heat capacity of the surrounding rock due to its lower temperature.

Proportionately, the benefits possible from utilizing the heat storage capacity of rock surrounding a reservoir is greater at lower heat input rates since lower input rates permit a longer time interval for the rock to absorb heat in any given temperature increment.

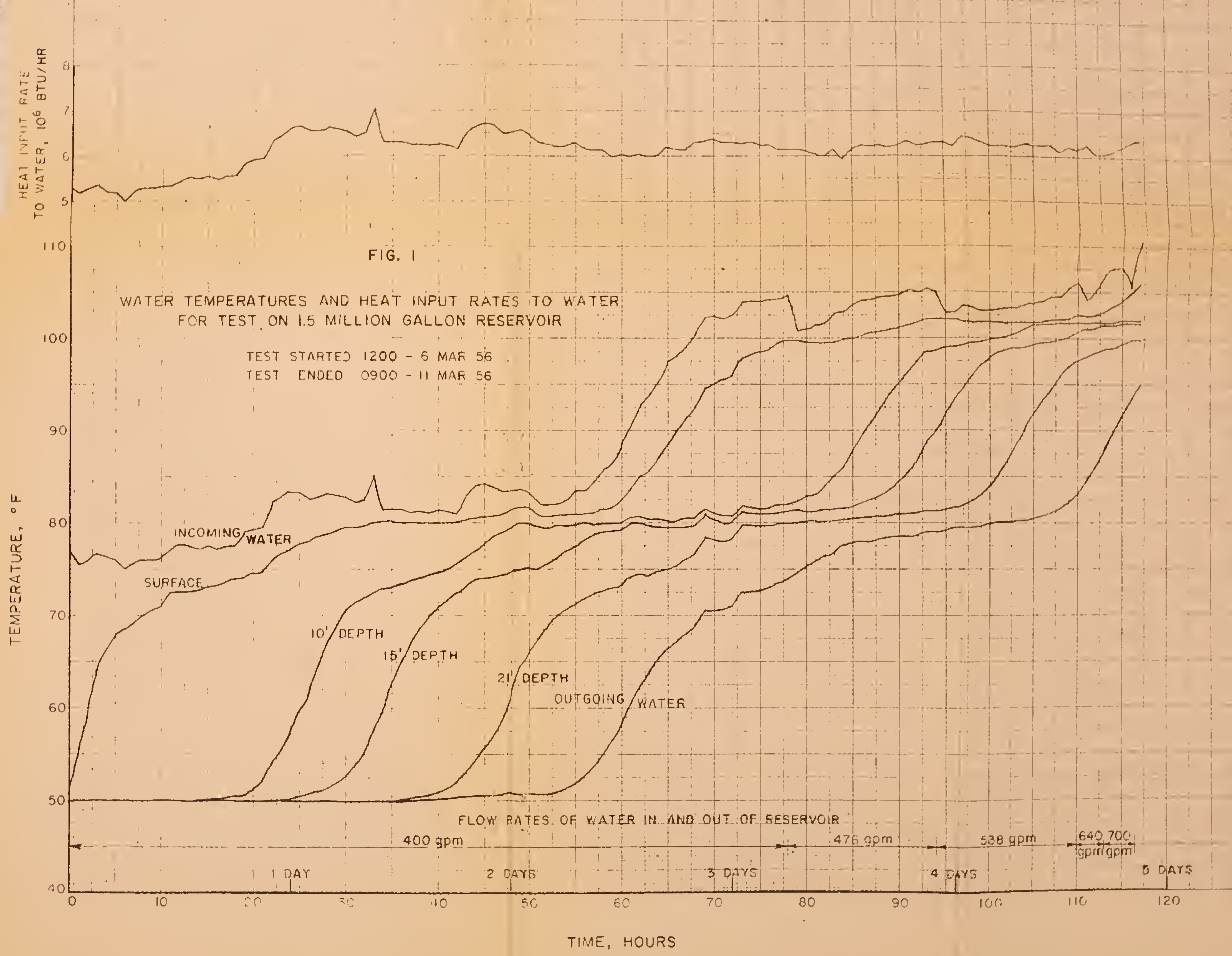


FIG. 1

WATER TEMPERATURES AND HEAT INPUT RATES TO WATER FOR TEST ON 1.5 MILLION GALLON RESERVOIR

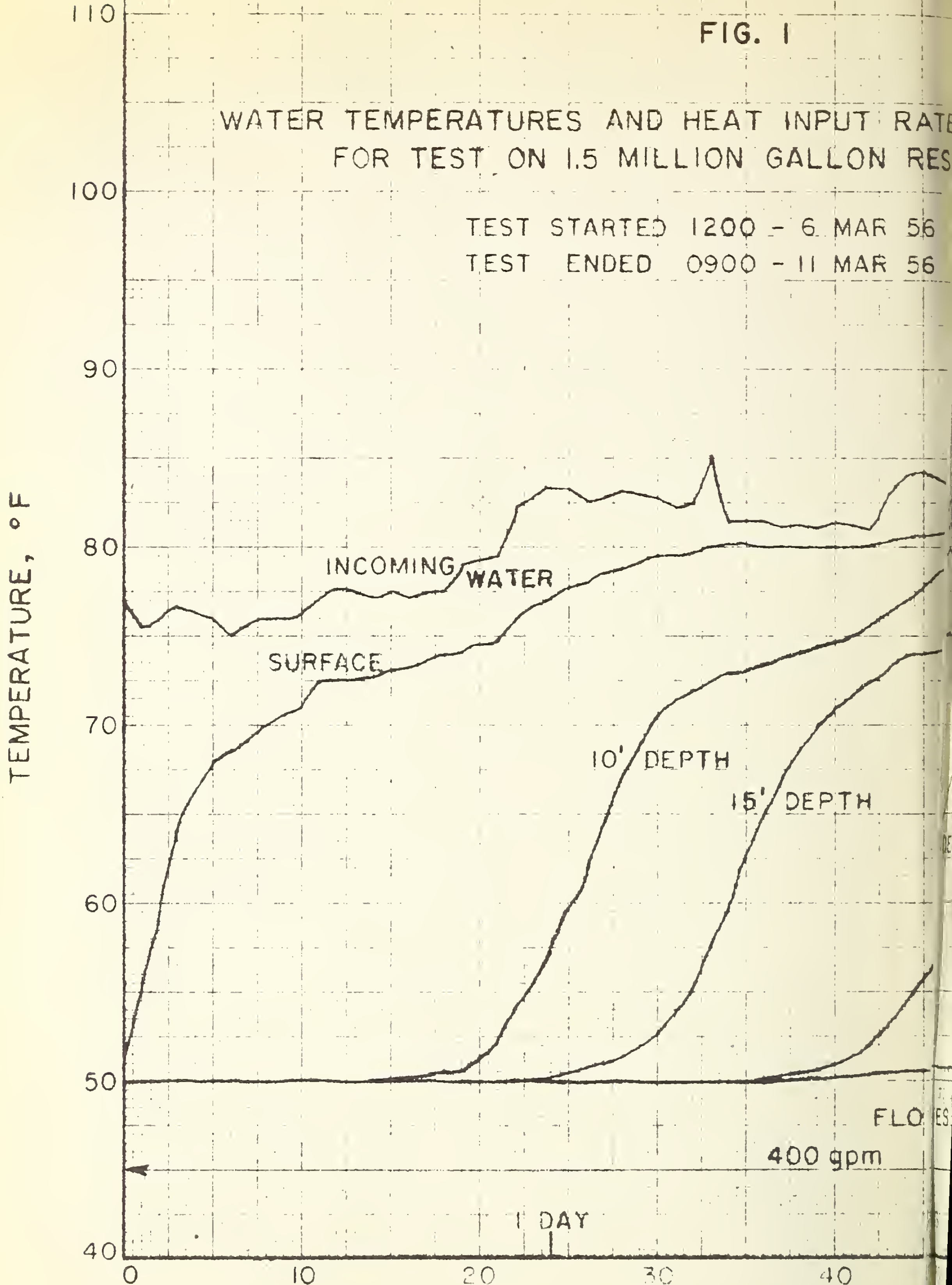


FIG. 1
WATER TEMPERATURES AND HEAT INPUT RAT
FOR TEST ON 1.5 MILLION GALLON RES
TEST STARTED 1200 - 6 MAR 56
TEST ENDED 0900 - 11 MAR 56
TEMPERATURE, °F
110
100
90
80
70
60
50
40
INCOMING WATER
SURFACE
10' DEPTH
15' DEPTH
FLO
400 gpm
1 DAY
0
10
20
30
40

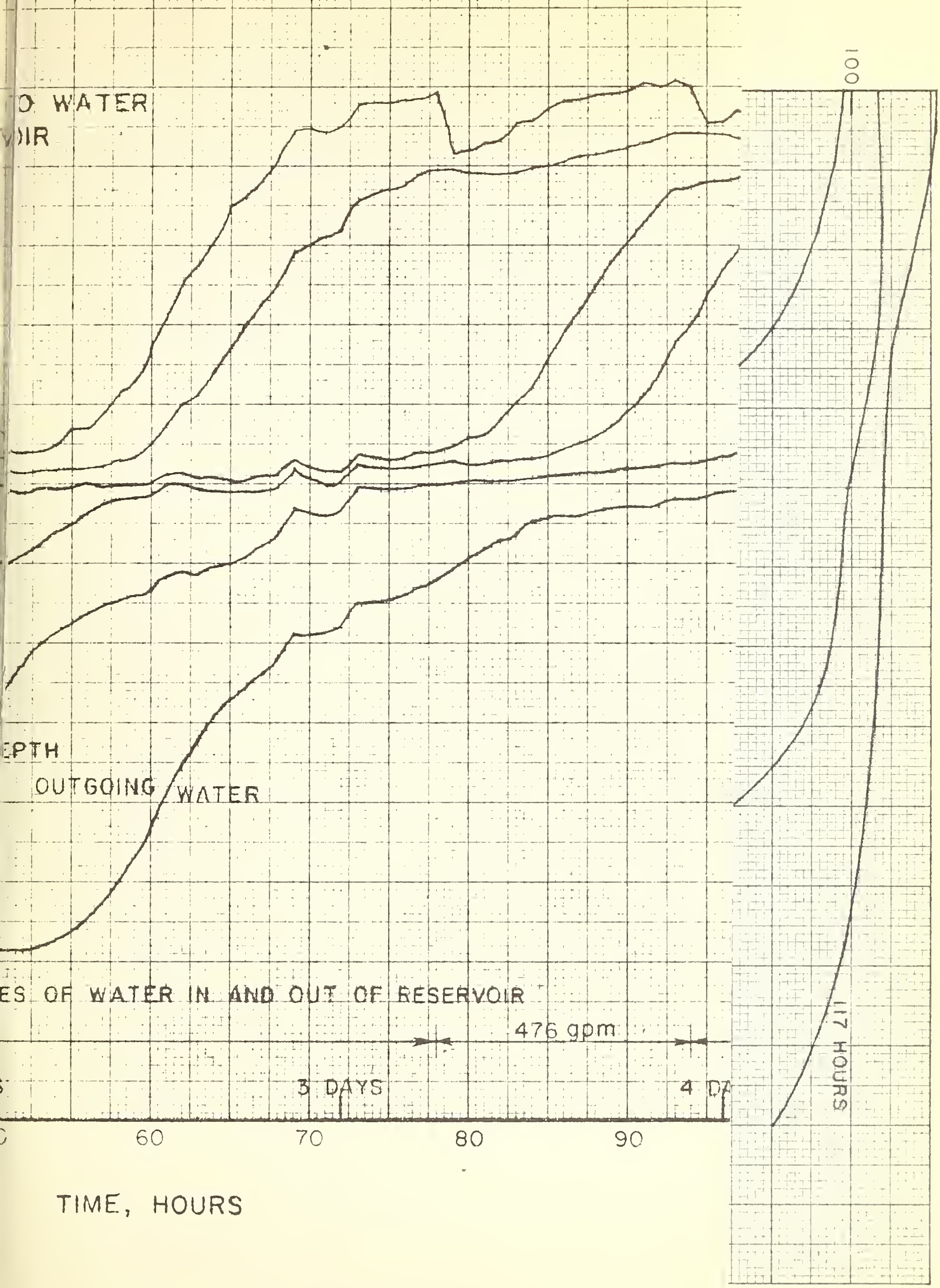


FIG. 2 WATER TEMPERATURE AT DEPTH IN RESERVOIR

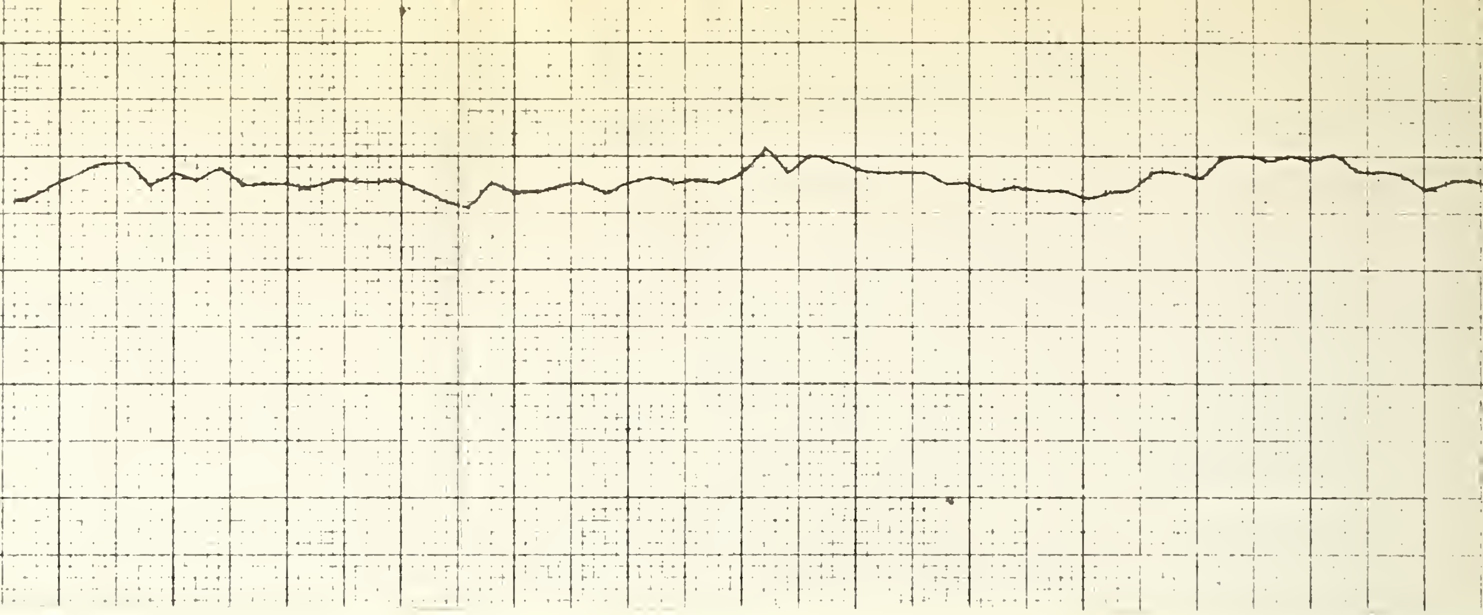
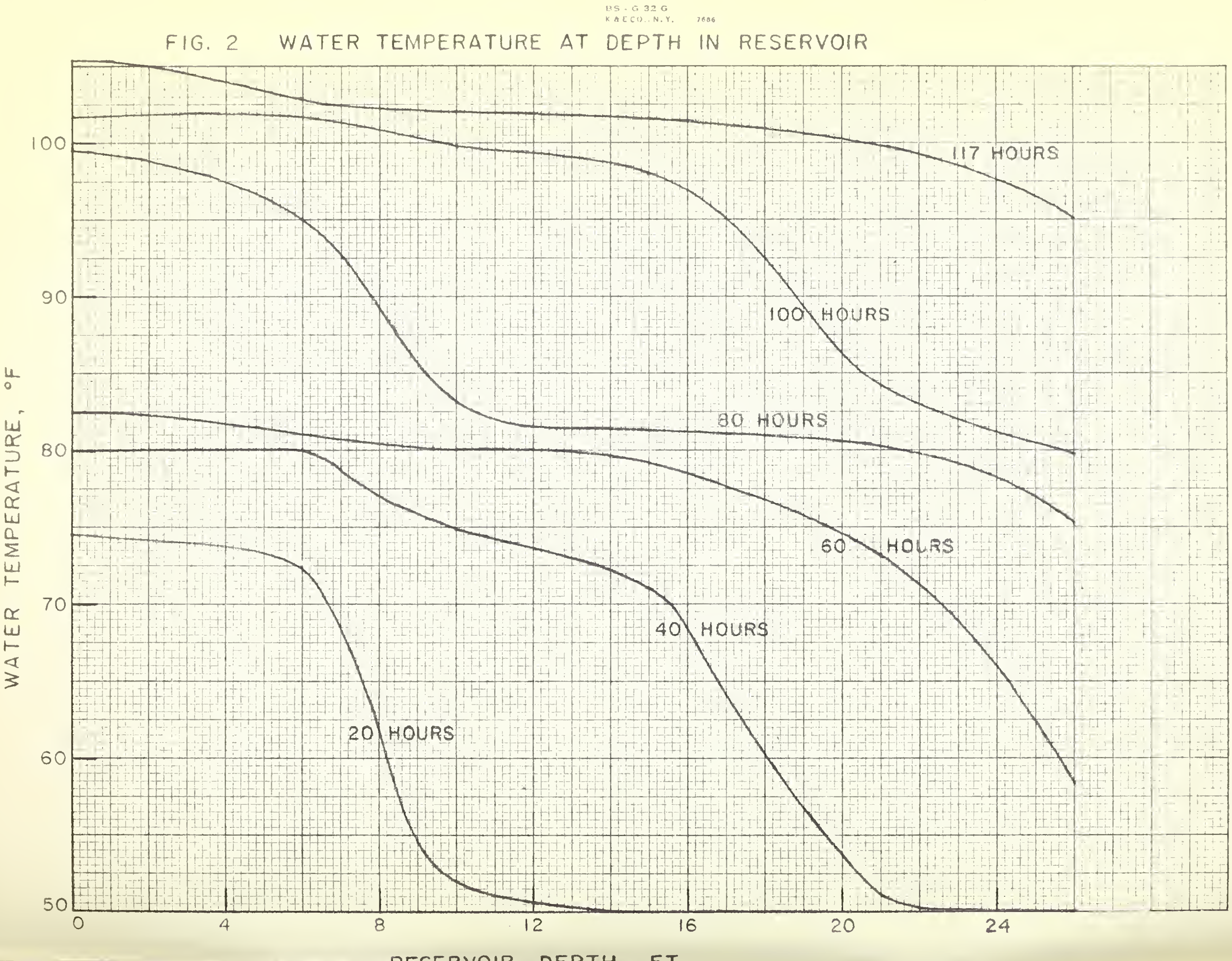


FIG. 2 WATER TEMPERATURE AT DEPTH IN RESERVOIR



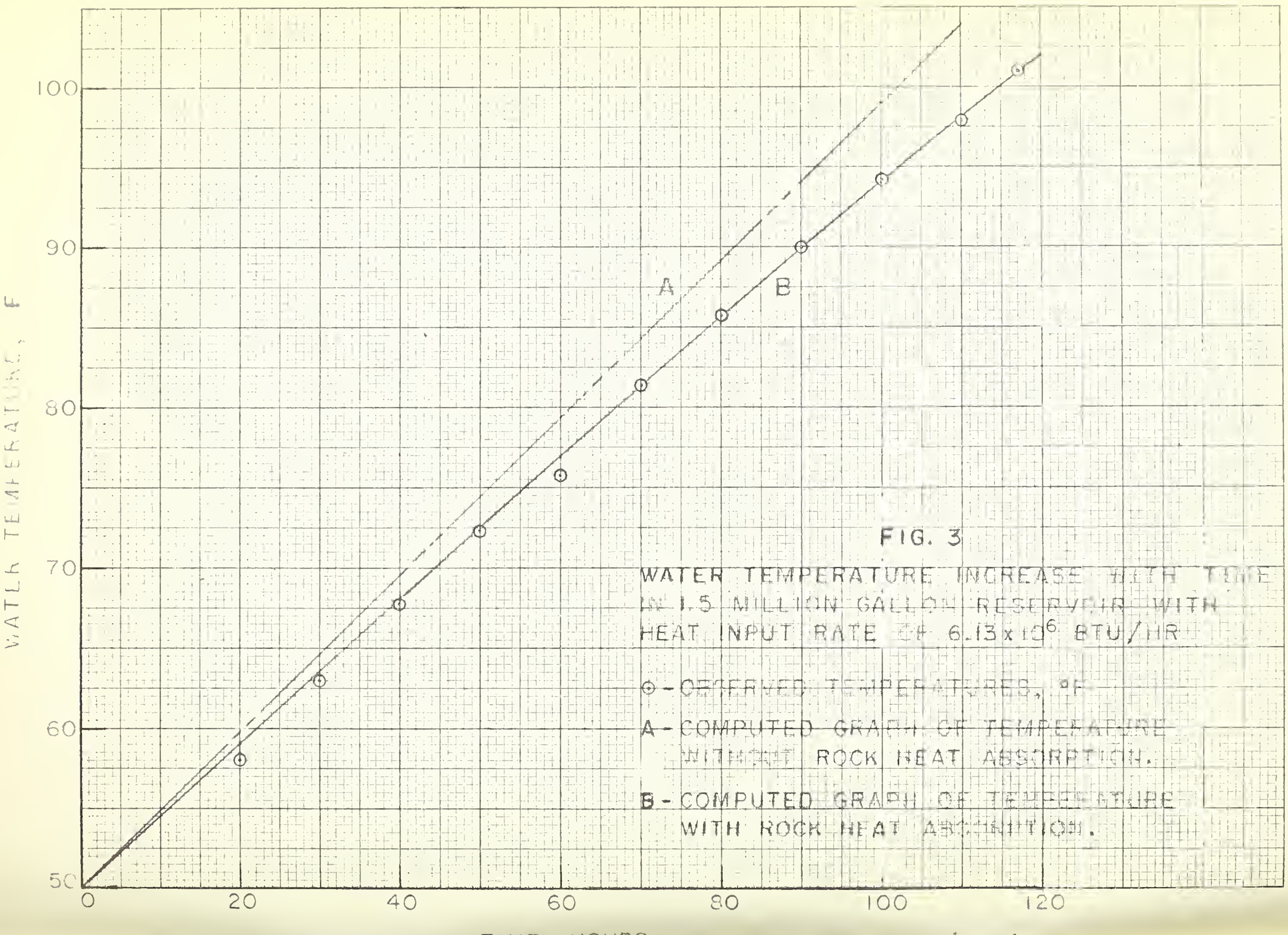


FIG. 3

WATER TEMPERATURE INCREASE WITH TIME IN 1.5 MILLION GALLON RESERVOIR WITH HEAT INPUT RATE OF 6.13×10^6 BTU/HR

⊙ - OBSERVED TEMPERATURES, °F

A - COMPUTED GRAPH OF TEMPERATURE WITHOUT ROCK HEAT ABSORPTION.

B - COMPUTED GRAPH OF TEMPERATURE WITH ROCK HEAT ABSORPTION.

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. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

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