NATIONAL BUREAU OF STANDARDS REPORT

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MOTORBOAT FIRE EXTINGUISHER EVALUATION

by

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NBS

U. S. DEPARTMENT OF COMMERCE
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Fire Protection Section
Building Technology Division

for

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

MOTORBOAT FIRE EXTINGUISHER EVALUATION

ABSTRACT

A study has been made of the relative effectiveness of fifteen different small hand-portable fire extinguishers considered suitable for application to flammable liquids. The evaluation was based on the performance of the extinguishers using five different extinguishing agents on ten fires. These fires were selected either because they were standard extinguisher tests or simulation of possible conditions of hazards on small motorboats. Statistical methods have been used for evaluation of the relative merit of the fires for extinguisher testing, the effect of ambient variables on the tests, and the value of the several extinguisher types for use on the fires.

1. INTRODUCTION

The program of tests described in this report was initiated to establish the relative extinguishing efficiency of certain small fire extinguishers, all but one of which are of a size and type allowed by the Coast Guard for use on motorboats, and to determine if the test fires by which these extinguishers are evaluated are adequate and impartially discriminating.

The present motorboat regulations, promulgated in 1941, provide that the smallest allowable extinguishers are to be the 1-qt carbon tetrachloride, 4-lb carbon dioxide and $1\frac{1}{4}$-gal foam sizes. With the development of small dry chemical extinguishers, a 4-lb minimum was established for that type also.

Generally, the Coast Guard's minimum size rule has remained unchallenged except that a manufacturer of carbon dioxide equipment has claimed that the 2-lb (with subsequent manufacturing change, 2½-lb) CO_2 extinguisher was at least the equal of the 1-qt pump gun carbon tetrachloride device (1).* In several tests conducted both by the Coast Guard and the National Bureau of Standards the results were inconclusive, but with some indication that the small CO_2 device was as effective as the minimum carbon tetrachloride pump gun. Further, neither of the extinguishers appeared to be adequate to cope with the problem of fires of a size and configuration possibly occurring on small motorcraft.

In an attempt to better evaluate fire extinguisher effectiveness, the Coast Guard devised and constructed several fire set ups which simulated the geometrical configuration of a small motorboat engine compartment, a bilge space, and a galley stove facility. These models, together with several test fires used by commercial testing agencies and the National Bureau of Standards, were used by the Coast Guard in a preliminary examination of a number of small extinguishers suitable for use on flammable liquids. The results of these tests were inconclusive, but suggested that a more complete investigation of the problem was necessary, and indicated that certain modifications of equipment would be to advantage (2). Since early in 1954, the National Bureau of Standards has continued the investigation of the problem. The proposal for further tests of fifteen extinguishers on ten different fires, made in an NBS preliminary report (3), was agreed to by the Coast Guard. The work on these tests together with results and conclusions, is the subject of this report.

2. DESCRIPTION OF TEST EXTINGUISHERS AND AGENTS

The fifteen extinguishers chosen for the purposes of these tests were all of readily obtainable commercial makes. Each carried the Underwriters' Laboratories B-2 rating.

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* No. in parenthesis refers to reference on page 28.

All were new, or late models in like-new working condition. Including devices using all types of extinguishing agents commonly available, they were chosen to determine the effect on extinguishment of the agent, capacity, discharge rate, duration and range of discharge, and continuous or intermittent discharge patterns.

With three exceptions, two extinguishers of each brand were used in the test program. Used alternately, this served to facilitate charging procedure and tended to reduce wear. However, the extinguishers were examined and the discharge performance noted at the end of the program. In no case was there evidence of wear or damage sufficient to affect the operating efficiency in any way. Table 1 lists the extinguishers used in the tests. The devices are also shown in figure 1.

The extinguishers were charged with standard materials which, where applicable, met the requirements of Federal Specifications. Carbon tetrachloride, Federal Supply Service stock, Specification 0-F380A, was used in both pump gun and stored pressure vaporizing liquid extinguishers. This was the product of three different manufacturers, and was supplied as Type I regular and Type II colored. The single chlorobromomethane extinguisher was charged with material stated to meet the requirements of U. S. Air Force Specification No. 14163. The liquids were procured in small containers so that generally each filling of an extinguisher was from a previously unopened can.

The dry chemical used in three extinguishers was recently received and had the free flowing property characteristic of this material. Although tests have shown that the powders may be used interchangeably, in this program dry chemical manufactured for the particular extinguisher was used in each case.

Carbon dioxide extinguishers were filled from 50-lb commercial cylinders by means of a standard CO_2 liquid type pump. In order to minimize the intake of moisture into the extinguisher, which might adversely affect the charge in dry chemical devices or deteriorate the working parts of vaporizing liquid models, oil-pumped nitrogen was used as the propelling gas in stored pressure extinguishers. To secure correct and consistent pressurization, charging was done with a reducing valve having a calibrated gage, and at an ambient temperature of approximately 70°F. For the one extinguisher depending on a carbon dioxide cartridge as a propelling medium, charges were secured from and refilled by the extinguisher manufacturer.

The $1\frac{1}{4}$-gal foam extinguisher was charged with chemical procured from a manufacturer of foam materials. This charge, tested in extinguishers of several brands, had been found to give consistently good performance which was in full compliance with all applicable requirements. By preparing a charge for a $2\frac{1}{2}$-gal extinguisher and dividing it for the two samples, it was possible to provide uniform, waste-free filling of the devices.

In charging, instructions on the extinguisher label or charge were closely followed. In most cases, charges were established on a weight basis with a tolerance of 0.05 lb. However, in order to provide a space of constant volume for the gas in stored pressure carbon tetrachloride and dry chemical extinguishers, in which the propelling gas and extinguishing charge occupy the same chamber, the charge weight in these devices was regulated to 0.01 lb. Operating pressures were in all cases maintained constant, and at the manufacturers stated value.

The fifteen test extinguishers may be classified into four groups according to the type of agent employed. Of eight extinguishers in the vaporizing liquid group, all but one, a chlorobromomethane model, were charged with carbon tetrachloride. Four hand pump CCl_4 extinguishers were used, two each of 1-qt and $1\frac{1}{2}$-qt capacities, which pairs were further subdivided into liquid-pump and air-pump types. The discharge of the two liquid-pump extinguishers was marked by a slightly intermittent action. The other thirteen extinguishers of the test were characterized by a continuous type discharge, whatever their propelling means. The two liquid-pump carbon tetrachloride were also the only devices in which the discharge rate was entirely under the control of the operator, with average observed rates of 0.055 lb/sec (0.048 min and 0.071 max) for the 1-qt size, and 0.088 lb/sec (0.077 min and 0.101 max) for the $1\frac{1}{2}$-qt. The values shown were obtained as averages over the total discharge time of an extinguisher during the tests. Variations in discharge rates for a single device may be attributed to differences in operator strength and also to time loss occasioned by the operator's maneuvering to adopt the most effective position for the particular fire configuration. Air-pump extinguishers had average discharge rates of 0.056 and 0.047 lb/sec for the 1-and $1\frac{1}{2}$-qt sizes, respectively. The low rate for the larger device was apparently inherent in the design as examination showed there was no clogging of the passages. The remaining three carbon tetrachloride extinguishers, of 1-,$1\frac{1}{2}$- and 2-qt capacities, as well as the 1-qt chlorobromomethane device were of the stored pressure type, which shows consistent discharge rates and characteristics.

The carbon dioxide type extinguishers were of $2\frac{1}{2}$-5- and 10-lb capacities. The gas pressure in a fully charged extinguisher of any size is approximately 850 lb/in^2 at 70° F. From 75 to 80 percent of the discharge is in a form effective for extinguishing fires.

Two of the three extinguishers in the dry chemical group were of the stored pressure type, a 5-lb device operating at 150 lb/in^2 and a 4-lb model at 350 lb/in^2. The gas-cartridge extinguisher, of 4-lb capacity, develops a maximum pressure of approximately 200 lb when operated.

The single extinguisher of the foam type, $1\frac{1}{4}$-gal capacity, is the only device of the fifteen tested that is rated for use on class A fires as well as class B. However, it is not suitable for class C fires, a type for which the other fourteen extinguishers of the program are acceptable. The foam extinguisher is also the only one in which the discharge, once initiated, could not be terminated before total exhaustion.

Discharge rate curves, determined empirically, for extinguishers at approximately 70°F are shown in figure 3. Rates for hand-pump carbon tetrachloride extinguishers are not given, but the overall rate of 1-qt in 50 sec, required in Federal Specification O-F-351, is included. While the observed discharge rates of the hand-pump extinguishers averaged less than that specified, the rate for all but the last 25 percent of the discharge was usually at least as great as that required.

3. DESCRIPTION OF TEST METHODS

As previously stated, the Coast Guard had devised certain test fires in its preliminary examination of the problem of determining the effectiveness of extinguishers for motorboat use. With modifications to improve the consistency of results and eliminate variables where possible, these fires formed the basis for the test program conducted at the National Bureau of Standards.

The fire models comprised three that have been used as standard tests of small extinguishers for flammable liquid fires. These were the 4-ft square spill area, the cotton waste fire, and the nominal 2-ft tub. Four fires were made in a compartment simulating with various degrees and modes of opening the engine space of a small motorcraft. In addition, three fires considered to be types of possible hazard, open bilge, alcohol spill from galley stove, and leak from a damaged container were included in the test.

Changes in engine compartment opening were effected through removal in whole or part of the end plates and top. The design of three of these fire models was such that the fuel consumption rates were maintained approximately the same, about 18 ml/sec. The components of the compartment model are shown in figure 2, with the construction and dimensions of the parts in figures 4 and 5.

Each of the test fires is shown pictorially and in diagram together with all pertinent data on the following ten pages.

As proposed in the NBS Preliminary Report, the tests were conducted with a commercial mixture of heptanes* stated to be available indefinitely. This fuel, having a narrow distillation range at approximately 200°F, while forming a constituent of gasolines, was used in order to create reproducible conditions of fuel consumption throughout the test program as well as to provide fair burning equilibrium throughout the course of a single trial. The properties of gasoline, on the other hand, are known to fluctuate seasonally, and vary with the producer and point of origin. Gasoline also, because of its wide volatile range, exhibits marked differences in characteristics during the burning of a specimen, with rapid consumption of the more volatile portions and ending in progressively slower burning of heavy fractions. Although radiant energy measurements for gasolines (leaded and unleaded) and the heptane mixture were approximately the same, some duplicate tests were made with the two fuel types at intervals throughout the program. In these there were no appreciable differences noted in extinguisher performance that could be attributed to the type of fuel used. The distillation curves for the test fuel and the average of a number of gasolines are shown in figure 6 (4).

Although fuel consumption rates for other fire models were determined from time to time during the program, those for fires VI through X, using the bilge and engine compartment, were established during each series of tests to check the consistency of the test and also to learn what effect, if any, changes in ambient conditions, ranging from calm to moderately high winds and from 32° to 85°F, had on the fuel consumption.

In the final program for extinguisher valuation, a test of each of the fifteen extinguishers on the ten fires, defined as a series, was repeated five times. This was done to provide sufficient data for a significant statistical analysis of the results. The reliability of the interpretation from this number of trials is discussed in a further section of this report.

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*Skellysolve C, Skelly Oil Company, Kansas City, Missouri.

Fire Model I

Type: 4 ft x 4 ft fuel spill

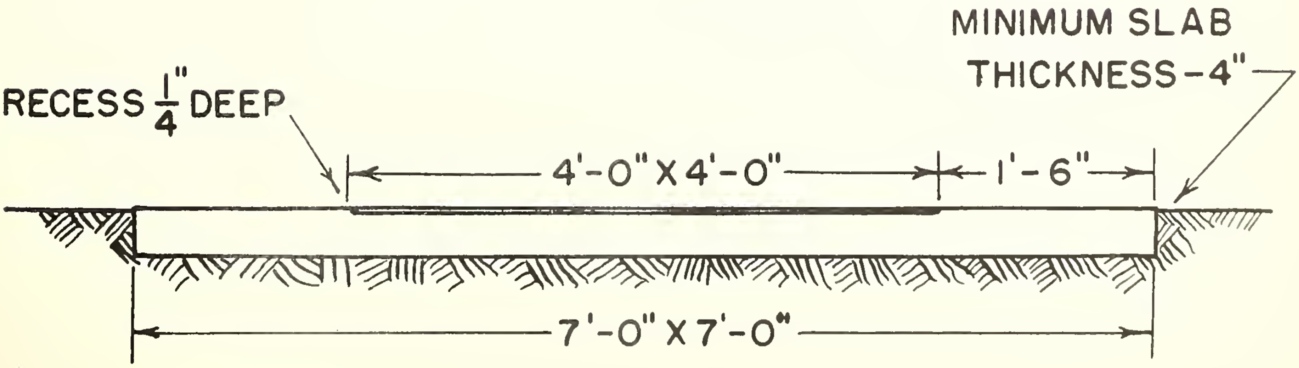
Test Apparatus: Shown in sketch and picture

Fuel: 2½ qt in recessed area

Preburn Time: 5 seconds

Fuel Consumption Rate: About 40 ml/sec (estimated)

Attack: Begin application at windward edge of fire



Fire Model II

Type: Fuel saturated cotton waste - 2 ft x 4 ft area

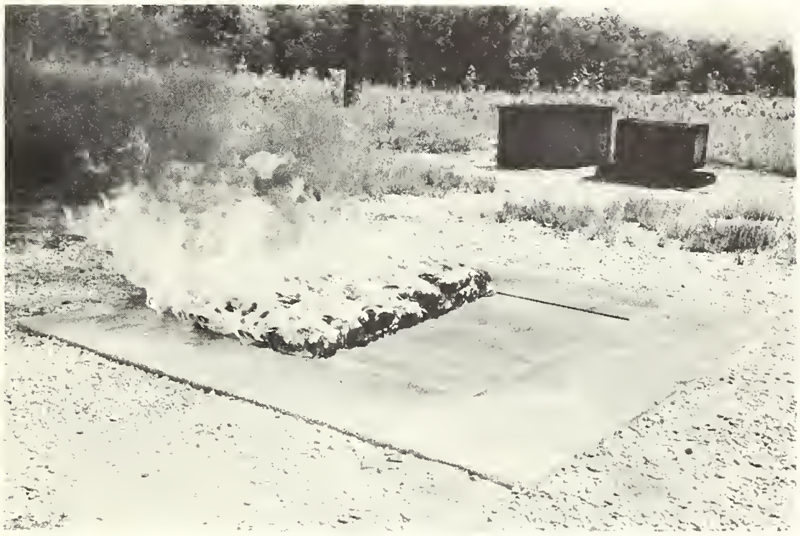
Test Apparatus: 8 lb cotton waste as shown in picture and sketch

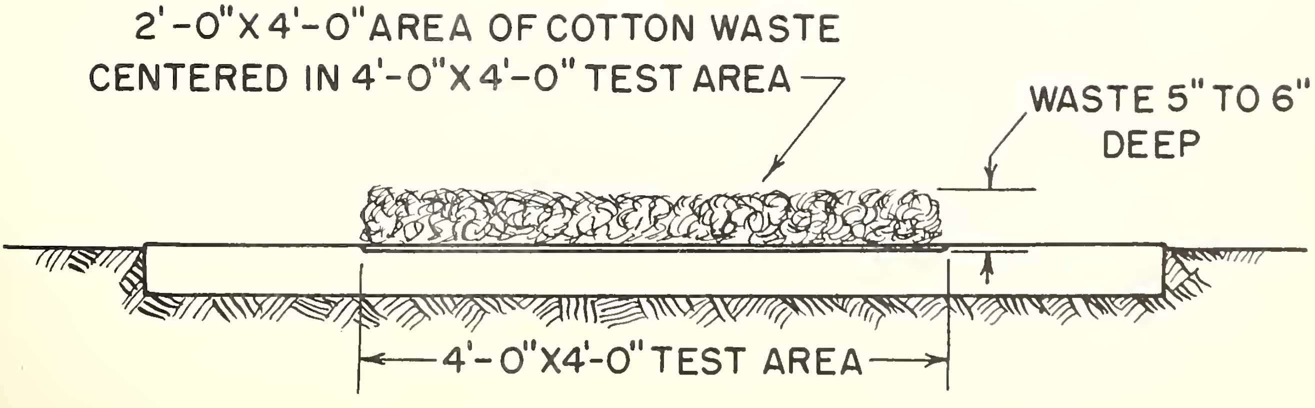
Fuel: 2 qt sprinkled over cotton waste

Preburn Time: 10 seconds

Wind Direction: Toward long edge

Attack: Begin application at center of windward long edge





Fire Model III

Type: Two-foot (nominal) tub

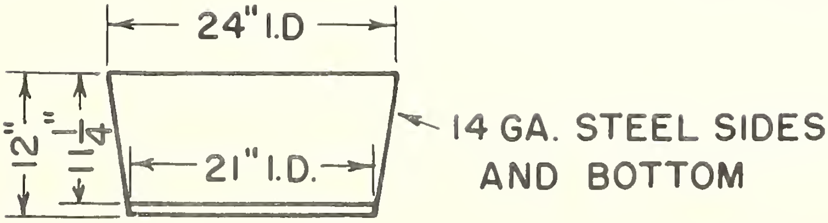
Test Apparatus: Tub as shown. Water to bring level to 10½ in. below top of tub

Fuel: 2 qt poured on top of 1 gal water in tub

Preburn Time: 20 seconds

Fuel Consumption Rate: About 10.5 ml/sec

Attack: Begin application to windward of tub, against opposite side wall.



Fire Model IV

Type: Running, vertical and horizontal

Test Apparatus: 1-gal covered bucket, set on metal stand, bucket flush with sides of stand in downwind corner, hole to direct stream upwind

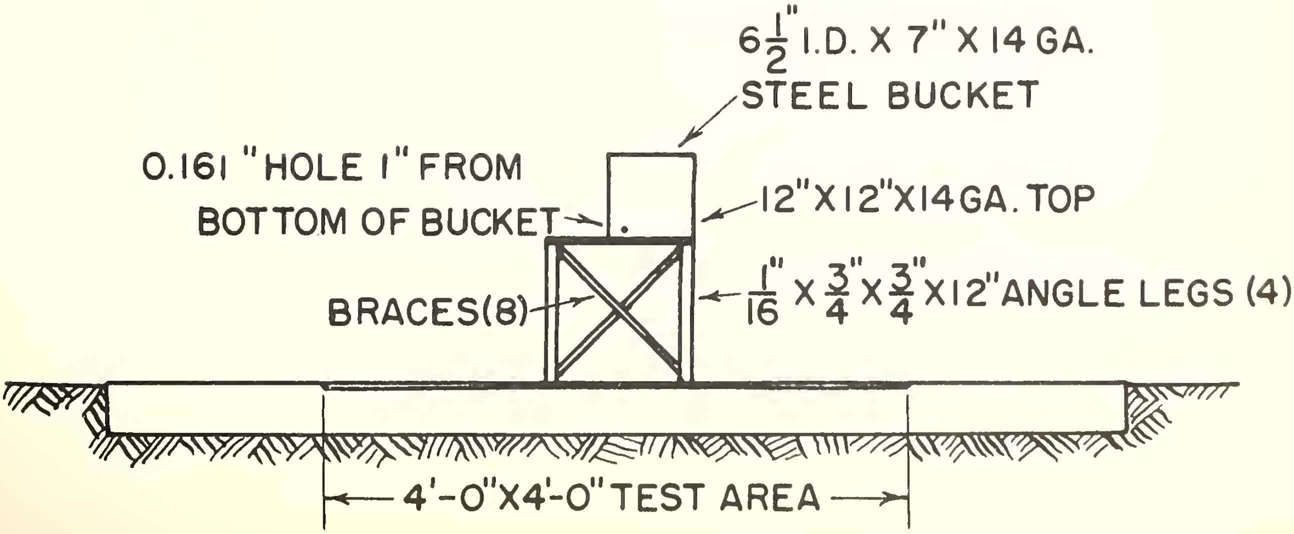
Fuel: 3 qt poured in bucket

Flow Time: 10 seconds

Flow Rate: 14-10 ml/sec (from 0 to 60 sec)

Preburn Time: 20 seconds

Attack: Begin application to windward of spill



Fire Model V

Type: Flowing, vertical surface

Test Apparatus: Shown in sketch and picture

Fuel: 1 gal. 95% ethyl alcohol

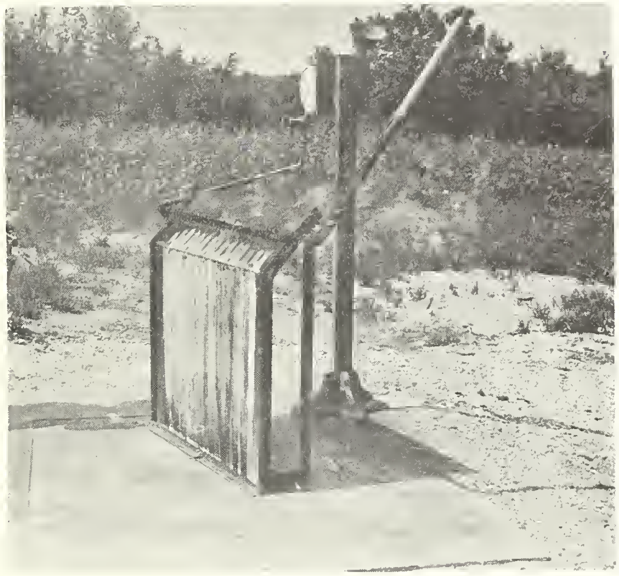
Flow Time: 10 seconds

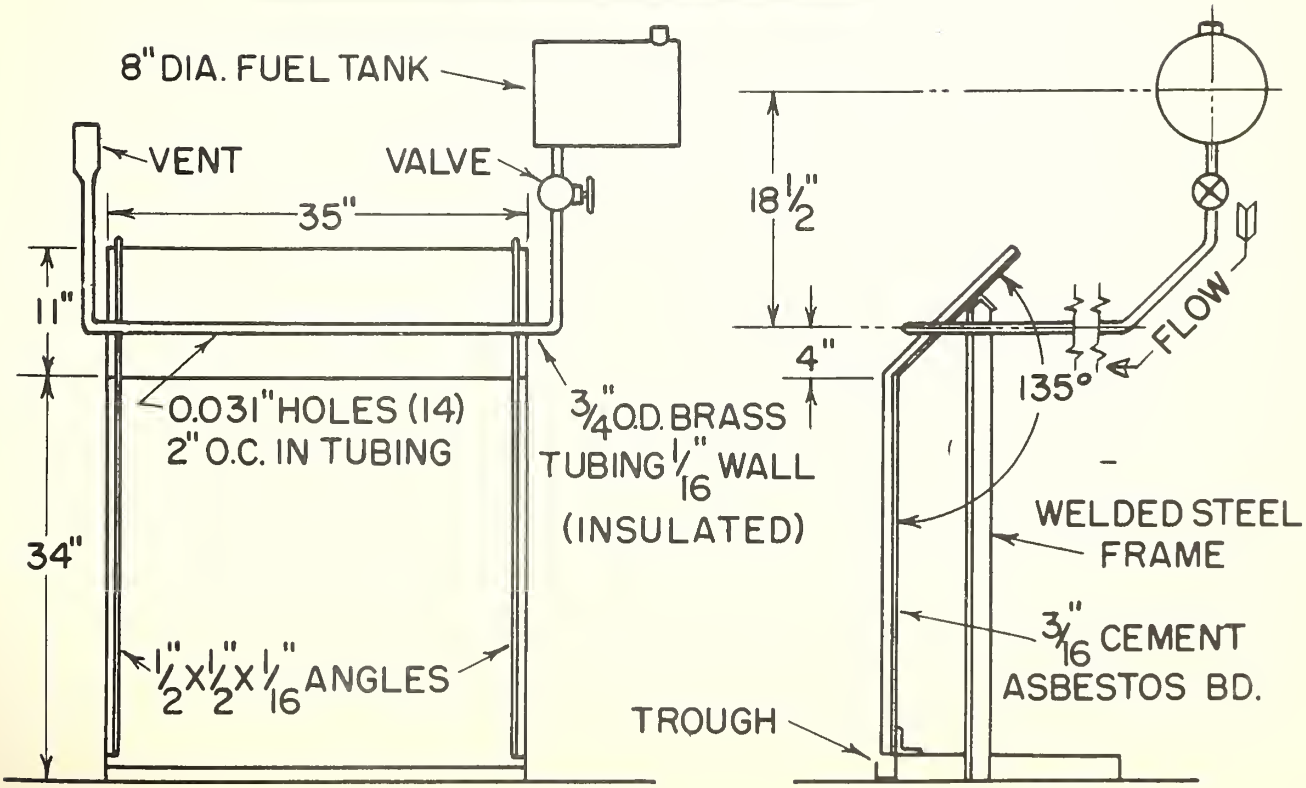
Preburn Time: 30 seconds

Wind Direction: Frontal

Flow Rate: Above 11.5 ml/sec

Attack: Apparatus facing upwind, operator to windward





Fire Model VI

Type: Bilge

Test Apparatus: Shown in picture and sketch. 1-in. water in pan

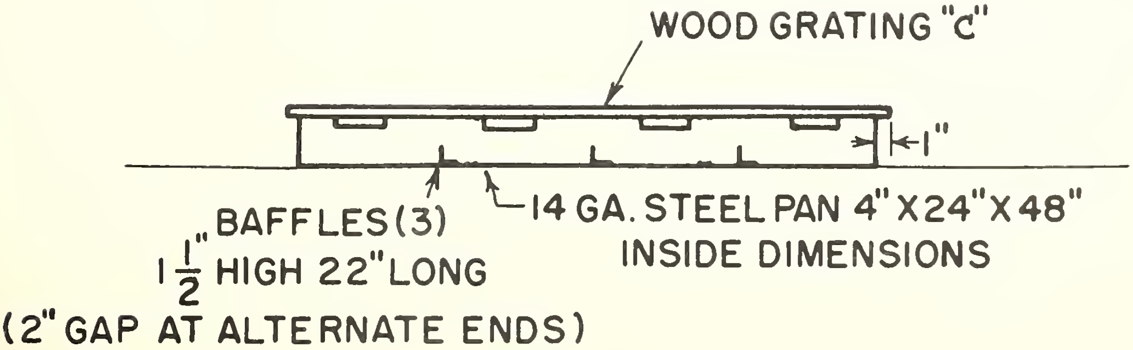
Fuel: 1 gal on water in pan, and wood grating C (3 long 4 short)

Preburn Time: 60 seconds

Wind Direction: Toward long edge

Fuel Consumption Rate: 15.2±1 ml/sec

Attack: Begin application at center of windward long edge.



Fire Model VII

Type of Fire: Compartment (empty)

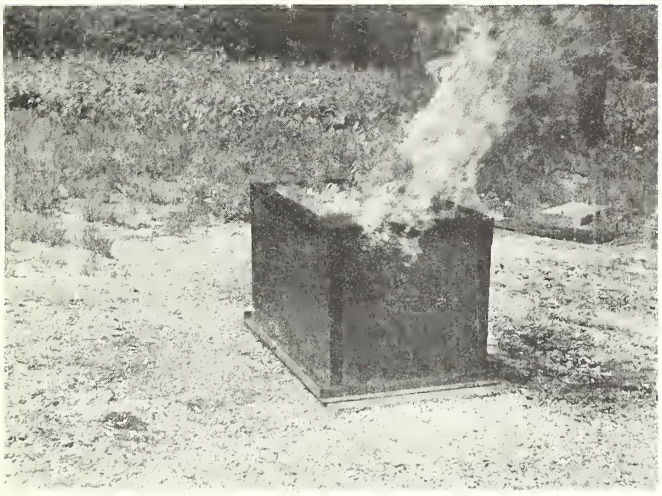
Test Apparatus: As shown in picture & sketch; 1-in. water in pan

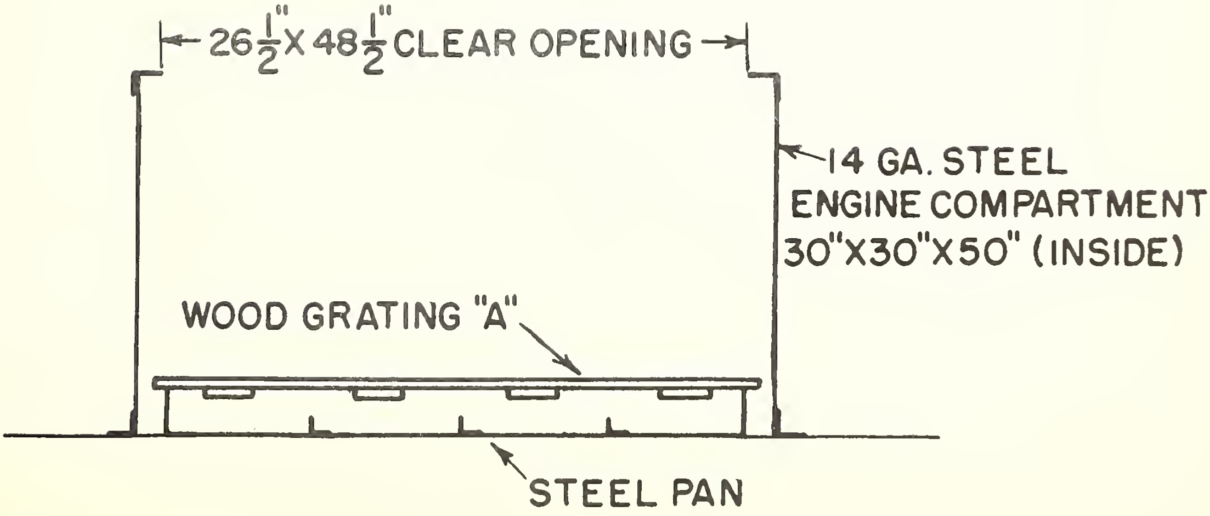
Fuel: 1 gal on water, and wood grating A (4 long and 4 short)

Preburn Time: 60 seconds

Fuel Consumption Rate: 11.8±1 ml/sec

Method of Attack: Through open top, at operator's discretion





Fire Model VIII

Type: Engine Compartment (top and two lower ends opened)

Test Apparatus: Shown in picture and sketch; 1-in. water in pan

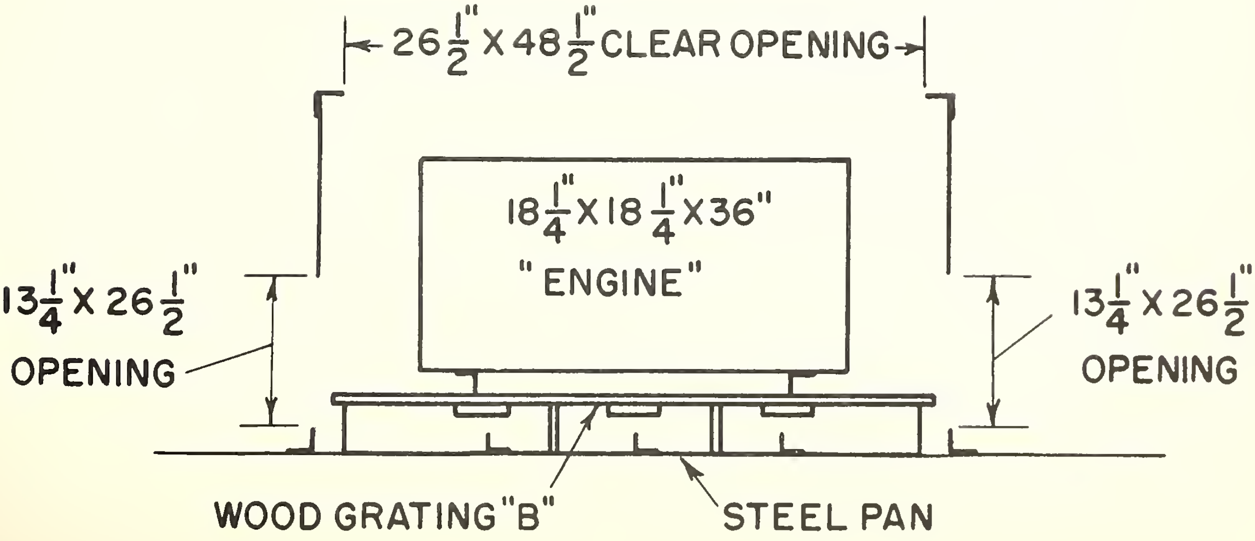
Fuel: 1 gal on water, and wood grating B (3 long 3 short)

Preburn Time: 60 seconds

Wind Direction: Either opened end

Fuel Consumption Rate: 17.8±.7 ml/sec

Attack: Discharge agent into windward lower opened end and then from top of compartment



Fire Model IX

Type: Engine Compartment (top and one end opened)

Test Apparatus: Shown in picture and sketch; 1-in. water in pan

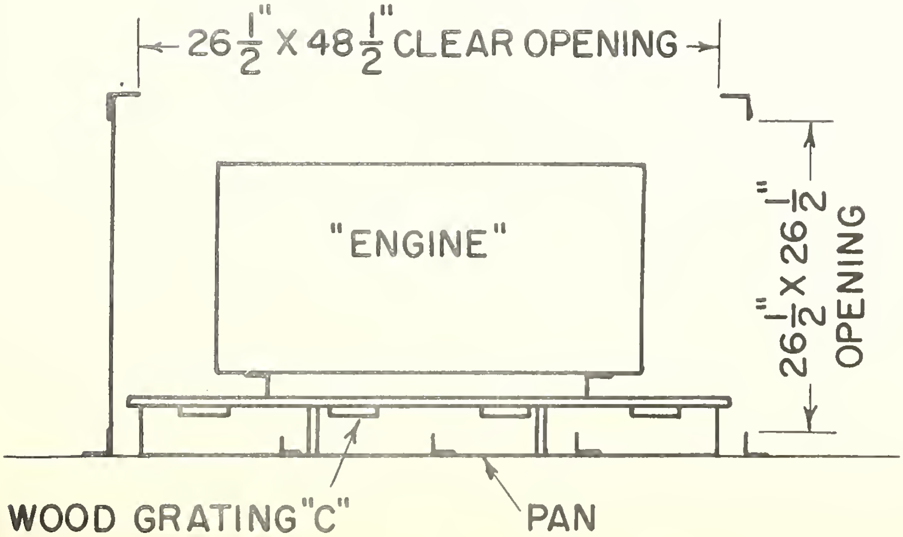
Fuel: 1 gal on water, and wood grating C (3 long 4 short)

Preburn Time: 60 seconds

Wind Direction: Opened end

Fuel Consumption Rate: 19.2±.7 ml/sec

Attack: Discharge agent into opened end, follow through and aim into top of compartment



Fire Model X

Type: Engine Compartment (one end opened)

Test Apparatus: Shown in pictures and sketch; 1-in. water in pan

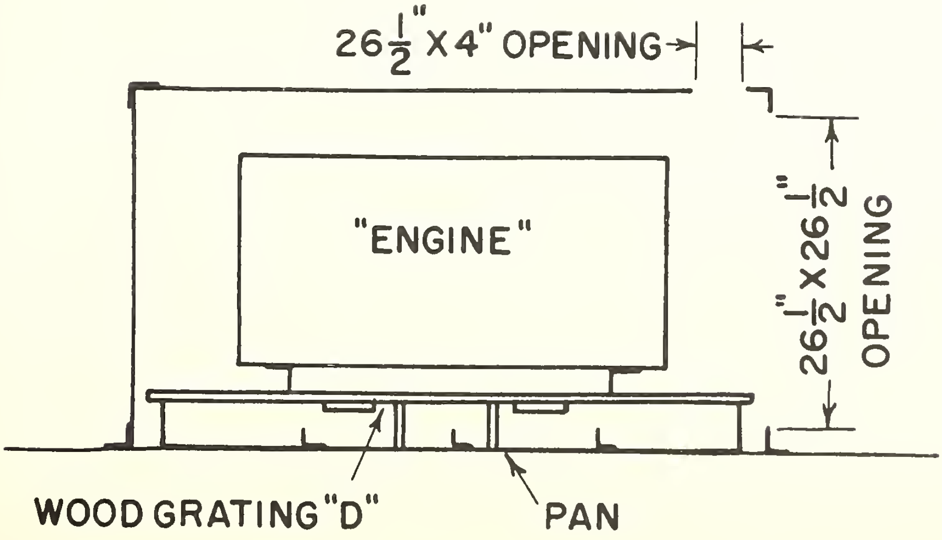
Fuel: 1-gal on water, and wood grating D(2 long and 2 short)

Preburn Time: 60 seconds

Wind Direction: Opened end

Fuel Consumption Rate: 18.0±1.2 ml/sec

Attack: Application through open end



The schedules used for the series are shown below (numbers refer to extinguishers, Table 1). The same schedule was used for all ten fires in a given series.

Schedule for

Series 1			Series 2			Series 3			Series 4			Series 5		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	11	14	3	8	13	2	10	15	1	5	9	6	7	12
5	7	15	9	10	14	3	4	12	2	6	13	1	8	11
6	8	10	1	12	15	5	11	13	3	7	14	2	4	9
9	12	13	2	7	11	1	6	14	4	8	15	3	5	10

It will be noted that any schedule has the property that each day's operation or run is divided into five time periods of three extinguishers each. In the course of the program, all 15 extinguishers were used in each of the time periods.

The experiment was programmed so that the intercomparison between extinguishers would not be affected by differences in weather conditions or other factors changing with time. This was done by arranging the sets of three extinguishers in a balanced way so that an interlocking chain of comparisons could be made among all extinguishers. As a by-product of this experimental arrangement it was possible to determine any variability between the time periods, all five of which were covered in one day's operation by one particular operator.

For the actual experimental work, two operators were employed. The program was arranged so that an operator would handle alternate fire models during a series. Thus by the end of the scheduled tests, each operator would have used a particular extinguisher on a given fire model at least twice. Comparatively experienced operators were used to minimize learning effect on the results. However, as it was impossible to provide operators thoroughly familiar with the specialized test fires used, a small effect of this kind was inevitable. This is seen in an analysis of the results of the first two series of fires. In attacking the fires, the operators approached as closely as possible, using a glove where necessary, or as near as required for the apparent optimum use of the extinguishers. On fire No. 7 the physical limitation of approach may have been a factor in reducing the effectiveness of some extinguishers. In three cases of unmistakable mishap to the operator during the tests, reruns were made immediately.

The extent of the data recorded during a test is shown in a typical sheet, figure 7. Extinguisher temperatures were maintained as nearly as possible at 70°F by conditioning in a special cabinet prior to use. Wind velocities, measured with an anemometer mounted approximately 4 ft above ground level, were the average over the time between ignition of the fuel and final extinguishment or exhaustion of the extinguisher charge. Extinguisher performance was rated on a basis of six

5. DISCUSSION OF RESULTS

In considering the 94 groups of wholly consistent results, either extinguishment or failure in all five trials of a device on a particular fire, it may be assumed that the performance effectiveness of these extinguishers was such that variation in weather conditions and operator skill during any of the five runs was not sufficiently great as to change the outcome. However, the relative success or failure scorings within a group were affected by these variables.

Some extinguishers were almost uniformly successful in fighting fires, while others were equally consistent in noneffectiveness. Also, an extinguisher may be successful against a hazard such as fire model III on every trial, and fail all five times to extinguish fire VIII, a more severe type. The performance of the extinguisher on an intermediate type fire should be neither all success nor all failure. It will be successful under the right combination of environmental conditions and operator technique, and even a minor deviation from these conditions may lead to failure. If against a particular fire an extinguisher may have only 10 percent success, these successes are achieved only under a very restrictive set of conditions. Another extinguisher may achieve 80 percent success, being less sensitive to minor deviations from optimum operating conditions. In these tests, the 5-lb carbon dioxide extinguisher, which had the greatest number of nonuniform group results, appears to be an example of a high sensitivity type device.

The performance of an extinguisher can be described in terms of its percentage success against a given fire. To establish this value to the nearest percent would take an inordinate number of tests. If an additional five tests are made when two or three successes are observed in the initial five trials, the combined results will still only show about equal numbers of successes and failures if the extinguisher has a long run success probability of 50 percent.

These uncertainties point up a difficulty in relying solely on the record of successes or failures. In the first place, there is no weight given to the ease with which the fire is extinguished. And secondly, it ignores completely valuable information that can be gained from the evaluation by an experienced operator. It is quite clear that the inadequacy of a completely ineffective extinguisher on a particular fire can be determined from a single trial. By assigning a score to each trial, an attempt is made to recover some otherwise lost information.

Fire model III was found to be the least difficult of the ten to extinguish, with only some carbon-tetrachloride pump-guns failing (Nos. 1, 2, and 6). For many years this fire was considered a standard test for evaluating small

extinguishers of this type. However, our negative results have been corroborated by other investigators. Coast Guard tests (2) showed only 50 percent success using 1- and 1½-qt devices, with extinguishment in no case occurring in less than 42 sec. Another test with 1-qt pump guns showed complete failure in all of nine trials (5) on the 2-ft tub. The results indicate that to have any effectiveness at all on this fire, carbon tetrachloride extinguishers must have a high rate of discharge.

Where the fuel is fed to the fire through a small opening, as in fire No. 4, extinction can sometimes be accomplished with a carbon tetrachloride extinguisher by directing the stream of vaporizing liquid directly at the source, thus diluting the fuel to a point it no longer sustains combustion.

The comparative results of carbon tetrachloride performance on fire models VI and VII indicate that these extinguishers are sensitive to model configuration, more so for example than are the carbon dioxide extinguishers, as shown in the following table of total scores for five runs.

Extinguisher	CCl_4		CO_2		
Capacity	1½-qt	2-qt	2½-qt	5-lb	10-lb
No.	7	8	9	10	11
Fire Model					
VI	-7	-4	-3	9	14
VII	12	8	-3	4	15

The poorer performance of carbon tetrachloride extinguishers on fire VI than on VII may be attributed to lack of confining surfaces on the bilge fire. Thus there is a reduction in the volume of vapors formed as there are no hot surfaces to cause vaporization, and no means of preventing the quick dissipation of the volatile products. As can be seen from the table, there were no significant differences in the performance of carbon dioxide extinguishers on the two fires. The better confinement offered by model VII was probably offset by the possibility of close approach to fire VI when using carbon dioxide extinguishers.

In fire models VIII, IX and X, where the fuel consumption rates throughout the program were approximately equal (18.5±1.4 ml/sec), confinement was apparently the primary factor affecting extinguisher performance. The following table, giving the total rating for 5 runs of several extinguishers shows there was markedly better performance on those fire models with highly confined configurations, which tended to accumulate the agent to a concentration level necessary for extinguishment.

Extinguisher	CBM	CCl_4		CO_2			Dry Chem.
Capacity	1-qt	$1\frac{1}{2}$-qt	2-qt	$2\frac{1}{2}$-lb	5-lb	10-lb	5-lb
No.	4	7	8	9	10	11	14
Fire Model							
VIII	0	-10	-10	-14	-2	10	0
IX	9	-2	-2	-4	2	11	8
X	14	10	12	5	5	13	14

It is seen from the scores that the vaporizing liquid and some dry chemical types were more sensitive to differences in these fires than were the carbon dioxide extinguishers.

Accumulation of vaporizing agent, however, may not be the only explanation for this apparent correlation between degree of confinement of fire models and effectiveness of extinguishment. Another possible factor may well be the relation of the agent to the flammable limits of the fuel, which for heptane range from 0.8 to 7 percent. Although the fuel consumption rates for the three fires were about equal, the fires were not necessarily burning at the same fuel/oxygen ratio. Thus in some fires, for example No. X, the model configuration is such that air diffusion is restricted, especially as compared with No. VIII, with the apparent result that the fuel mixture was considerably richer than in other fires. On the basis of flammability limit tests, it has been suggested that the volume of vaporizing liquids required for such a fire is much less than that for fires having a lean mixture, to the enhancement of extinguisher efficiency on some enclosed hazards (6).

In conducting the tests, it was found that optimum methods of attack varied with the fire models and particularly with the extinguishers. Generally, carbon tetrachloride was best employed by spraying on a hot surface, preferably metallic for maximum vaporization, and in such manner as to cover the area with the decomposition products. Dry chemical extinguishers appeared most effective when operation was such as to cover the whole flaming area at once. Carbon dioxide types seemed to work best when the agent was discharged near the fuel surface so that the heavy gas apparently displaced the oxygen to a point below the combustible limit. The use of foam, effective only if flowed onto the burning liquid surface, was made difficult by obstructions such as floor boards, engine block or compartment walls. To secure results that would be impartial and unprejudiced, the operators in every case endeavored to use an extinguisher to its maximum effectiveness. That this occurred is borne out by the increase in scores in the second run over those of the first. The learning that occurred initially was applied to the advantage of the extinguishers in all the subsequent trials. Generally, the method of attack was standardized early in the program and thereafter maintained throughout the tests.

6. ANALYSIS OF RESULTS

6.1 Analysis of Data on Scores

Table 2 gives the sums of the scores obtained on each of the five separate trials on the different test fires. The data for each fire were analyzed to determine whether any statistically significant differences were introduced into the results because of the day-to-day variation in the environmental conditions. Fires VI, VII, VIII, and X do show statistically significant variation from day to day. However, for almost all fires there is a marked increase in the scores on the last 4 series when compared to the scores on the first series. The statistically significant day-to-day variation for fires VII, VIII, and X is due almost entirely to the increase in scores from the first to the subsequent series. These fires have a wood grating or other obstruction to limit the operators' access to the fire. The improvement in scores in the later series is undoubtedly due to the improvement in technique evolved by the operators as the tests were repeated.

6.2 Analysis of Data on Number of Successes

Tables 3 and 4 give a tabulation of the number of times each extinguisher succeeded in putting out the ten test fires. The order of listing is roughly that of relative effectiveness of the device but is also determined by extinguisher type. An inspection of the data of Table 3 suggests that Fire II is not representative of the same type of fire as the other 9 fires. It will be noted that Fire VIII has about the same low number of successes but it nevertheless ranks the extinguishers in essentially the same order as the remaining fires. Fire II gives a discordant ranking and for this reason the statistical analysis has been carried out omitting this fire.

This anomalous behavior of Fire II is confirmed by the statistical analysis carried out in transformed units given in Appendix A. With the omission of Fire II, the observed variability of results can be regarded as being in accordance with its theoretical expectation, whereas with the inclusion of Fire II this is not so.

Table 4 shows the data tabulated to display the differences between series. Each entry represents the number of successes of a given extinguisher summed over all fires in a series. A statistically significant effect shown by these data is the fact that series 1 is lower than succeeding series. This is shown in the analysis given in Appendix B.

6.3 Ranking of Test Fires

It was pointed out above that Fire II appears to be a different type of fire than the other 9 and for this reason it has been excluded from the comparison of fires.

The remaining 9 fires rank themselves in order of severity (most difficult to put out has rank 1) as follows:

Fire	Percent of times fire put out in 75 attempts	Rank	Average scores from 75 attempts	Rank
VIII	26.7	1	-1.05	1
IV	37.3	2	-0.53	2
VI	42.7	3	-0.19	4
IX	44.0	4	-0.45	3
VII	57.3	5	0.43	5
V	66.7	6	0.79	7
I	69.3	7	0.68	6
X	70.7	8	0.86	8
III	82.6	9	1.97	9

From an inspection of these values, one is led to suggest that for quick screening of extinguishers, Fire III could be used. An extinguisher that failed to put out Fire III is certainly rather weak in relation to the performance of the extinguishers used in this test. Fire III also requires the least amount of equipment of all the fires. One could then rate the extinguishers that pass the test of Fire III by choosing an intermediate test, such as VII, and a difficult test, such as Fire VIII.

To sharpen the comparison of extinguishers, at least from the point of view of statistical analysis, it would be convenient to have a measure on a continuous scale, such as the area of a given type fire that could be put out. Without this, the alternative is to rate extinguishers on a scale of several test fires in a sequence related to the severity of fires encountered in practice. For this purpose, extinguishment could be defined as the capacity of a device to put out a particular test fire four times in five trials, and further,

to achieve an average score as described in this report of approximately +1 or greater. It is possible that requirements should be set according to the severity of the hazard expected, with consideration given to the establishment of the middle grade of fire severity as that most likely to be encountered. The other two test fires may then be reserved as representative of cases either of very minor hazard or greater conditions of severity. It should be remembered, however, that even fire No. VIII does in no manner encompass the limit of possible hazard on motorcraft, but rather defines the limit of extinguishing capacity of devices of a size considered in this report.

6.4 Ranking of the Extinguishers

The extinguishers have been grouped according to type, and their performance and relative rankings based on several methods of comparison are presented in Table 5. All methods of performance measurement give essentially the same rankings. The standard deviation of 4.7 of individual averages, column C of Table 5, is not considered excessive. To reduce this deviation by 50 percent would require making 15 additional trials of each extinguisher on each fire.

As had been expected, a high rate of discharge in any particular type of extinguisher enhanced the effectiveness of the performance. This is shown in an examination of the results of tests on hand pump and stored pressure type carbon tetrachloride devices and also the 5-lb low pressure dry chemical extinguisher as against the two higher pressure 4-lb models.

Of the 15 extinguishers tested, only 3 were capable of meeting the requirements as herein established for the most severe fire, model No. VIII. These were the 10-lb carbon dioxide, the 4-lb cartridge operated dry chemical and the 4-lb stored pressure dry chemical devices. The 1-qt chlorobromomethane extinguisher narrowly misses the required performance on Fire VIII, but because of high effectiveness on the other fires, stands with the other three extinguishers in a group showing the highest percentage of successes for the whole program. The 5-lb dry chemical, 5-lb carbon dioxide, and 1½- and 2-qt stored pressure carbon tetrachloride extinguishers are suitable for an intermediate fire such as No. VII. Fire No. III could be successfully handled under these standards by the 1¼-gal foam extinguisher, the 2½-lb carbon dioxide, the 1-qt stored pressure carbon tetrachloride and the 1½-qt high-rate pump-gun carbon tetrachloride devices. The two 1-qt and one of the 1½-qt vaporizing liquid pump guns were unsuited for use on even this minimum fire.

In considering ease of operation of the several types and the possibility of their successful use by a novice, it is necessary to remark that the 10-lb carbon dioxide extinguisher, while highly effective, has a charge weight of 2½ times that of other devices in its effectiveness group and a total weight in excess of three times that of the next heaviest. This extinguisher, also, has a relatively short discharge range, forcing a close approach to the fire for effective use. Stored pressure vaporizing liquid extinguishers may be operated at a distance, and this combined with the good performance of chlorobromomethane makes that extinguisher a recommended type. The dry chemical extinguishers are, however, the type most likely to lend themselves to effective use as their moderate-to-good range and high accomplishment for their size are further augmented by the shielding effect which the powder affords against radiant heat.

6.5 Influence of Ambient Conditions on the Results

The fire test program was conducted outdoors between February and June under ambient conditions of the following limits: wind velocity from 1.3 to 17.5 mph, temperature, 32°F to 85°F, relative humidity, 23 to 100 percent, and solar radiant intensity from 0 to 1.4 g cal/cm^2 min. As mentioned earlier, the burning rates of bilge and compartment type fire models tended to increase with increase of wind speed and/or temperature. However, the results based on scoring did not show any apparent influence of any individual measured ambient factor, with the exception of wind speed.

Analysis of the data indicates that wind speed, as a single variable, showed some statistically significant effect on the scores of only a few fire models. The degree of wind sensitivity depends more on fire model than on type of extinguisher. Results of fire Model II, VI and IV were, in the order given, adversely affected by increase in wind speed, whereas Model VII seemed to be favorably influenced by this condition. The rest of the models showed no significant trend.

The following table shows the number of cases in which the wind velocity increased or decreased in successive series with a similar directional change in the scores on Fire Models II, VI, IV and VII.

Fire Model	Wind	Score increased from previous series	Score remained the same	Score decreased from previous series
II	Increased	3	7	10
	Decreased	10	9	1
VI	Increased	8	8	11
	Decreased	7	3	3
IV	Increased	2	11	2
	Decreased	11	10	4
VII	Increased	10	8	4
	Decreased	5	9	4
Total (above)		56	65	39
Total for the program*		119	182	99

*All fires and all extinguishers except the four hand pump CCl_4 and foam extinguishers.

The inequality between the number of cases of increase in score and the number of decreases is a reflection of the increase in proficiency of the operators between the first and second or subsequent series. The great number of cases of scores remaining the same indicates the relative reproducibility of the scoring system used in this program.

7. CONCLUSIONS

The following conclusions seem justified on the basis of the work reported:

1. The tests performed indicate significant differences between the effectiveness of hand pumped carbon tetrachloride and carbon dioxide extinguisher types, the latter being significantly more effective on the basis of equal weight of extinguishing agent.

2. The 1-qt chlorobromomethane, 10-lb carbon dioxide, and two 4-lb dry chemical extinguishers ranked very closely with each other as useful devices for attack on the test fires.

3. The test fires used for the study presented a useful scale for evaluation of extinguisher performance. From these, three fires have been selected to provide a qualitative means for evaluation of performance of other devices intended for use on hydrocarbon type flammable liquid fires.

4. The rather large variations in ambient conditions observed during the tests did not affect extinguisher performance enough to cause statistically significant differences being observed in the results for most fire types used.

ACKNOWLEDGEMENT

The authors wish to acknowledge the valuable help and suggestions given by A. F. Robertson, Chief, Fire Protection Section, and the assistance of J. Loftus in performing the tests.

8. REFERENCES

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4. O. C. Blade, Bureau of Mines, Dept. Interior, National Motor Gasoline Survey of Summer 1954, Report of Investigation 5111, January 1955.

5. T. B. Edwards, Army Fire Extinguishment Research Program for Field Operation, Proceedings Symposium on Fire Extinguishment Research and Engineering, U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California, November, 1954.

6. E. H. Coleman and G. W. Stark, A Comparison of the Extinguishing Efficiency of Bromochloromethane and Carbon Tetrachloride, Chemistry and Industry, p. 563, 1955.

APPENDIX A

In order to perform an analysis of variance on the data on Table 3 of the report, the number of successes must be transformed to units in which the variability is essentially constant. This is accomplished by the arcsin transformation /See "The Use of Transformations" by M. S. Bartlett, *Biometrics*, Vol. 3 (March 1949) pp. 39-52/. The technique of analysis of variance is described in *The Design and Analysis of Industrial Experiments*, edited by D. L. Davies, Oliver and Boyd, London, 1954.

Table A1

Analysis of variance of transformed data (Fire II included).

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square
Extinguishers	14	53,719.16	
Fire	9	20,363.19	
Error	126	30,521.74	242.236
Total	149	104,604.09	

The theoretical value for the mean square for error is 821/n = 821/5 = 164.2. To test whether the observed value can be regarded as conforming to theory, we compute F = 242.236/164.2 = 1.48 and compare this to the tabular value for $F_{126,\infty}$. The value of the F-ratio turns out to be significant at the 1 percent level, indicating the presence of extraneous variation.

Inspection of the data suggests that Fire II, which gives a discordant ranking of the extinguishers relative to the other nine fires, is at fault. The analysis of variance was then computed omitting Fire II.

Table A2

Analysis of variance of transformed data (Fire II omitted)

Source of variation	d.f.	Sum of squares	Mean square
Extinguishers	14	55,695.66	
Fires	8	15,885.26	
Error	112	22,238.21	198.56
Total	134	93,819.13	

The F-ratio for testing the agreement between observation and theory with respect to the error mean square is $F = 198.56/164.2 = 1.21$ which is less than the critical value (5 percent level). Hence, one regards the variance stabilizing transformation as being appropriate.

The standard deviation of the averages for an individual extinguisher turns out to be 4.7 and that of a difference between two extinguishers averages, 6.6.

APPENDIX B

Analysis of data on series and time periods within series.

The arcsin transformation was applied to the percent successes for each extinguisher on 9 fires (omitting II). The analysis given here is described in "Tables of partially balanced designs with two associate classes", R. C. Bose, W. H. Clatworthy, and S. S. Shrikhande, Tech. Bull. No. 107, North Carolina Agriculture Experiment Station, August 1954.

Source of variation	d.f.	Sum of squares	Mean square
Extinguishers (unadjusted)	14	3,445,558.74	
Sets of 3 (adjusted for ext.)	24	175,345.88	7,306.08
series	4	100,675.41	25,168.85*
order	4	12,022.88	3,005.72
residual	16	62,647.59	3,915.47
Error	36	389,419.72	10,817.12[a]
Total	74	4,010,324.35	

*This is statistically significantly larger than error, and series 1 is significantly lower than the other series.

[a] The expected value of the error mean square is 9,122.22. The observed value is in good agreement with its theoretical expectation.

TABLE 1

LIST OF EXTINGUISHERS FOR MOTORBOAT FIRE TESTS

		Type	Range Ft.	Approx. Discharge Duration Sec.	Manufacturer
Vaporizing Liquid:					
1.	1-qt CCl_4	Pump Gun (Liquid)	20	50-60	American-La France
2.	1-qt CCl_4	Pump Gun (Air)	20	50-60	Fyr-Fyter
3.	1-qt CCl_4	Stored Pressure (150 psi)	20-25	22	Stop-Fire
4.	1-qt CBM	Stored Pressure (150 psi)	20-25	22	Stop-Fire
5.	$1\frac{1}{2}$-qt CCl_4	Pump Gun (Liquid)	20	50	General Detroit
6.	$1\frac{1}{2}$-qt CCl_4	Pump Gun (Air)	20	90	Fyr-Fyter
7.	$1\frac{1}{2}$-qt CCl_4	Stored Pressure (150 psi)	20-25	22	Stop-Fire
8.	2-qt CCl_4	Stored Pressure (100 psi)	20-25	36	Phister and Pyrene
Carbon Dioxide:					
9.	$2\frac{1}{2}$-lb	Pistol-grip	4	16	Kidde
10.	5-lb	Squeeze-grip	6	25	Kidde
11.	10-lb	Squeeze-grip	8	43	Fyr-Fyter
Dry Chemical:					
12.	4-lb	Cartridge-type	5-15	11	General Detroit
13.	4-lb	Stored Pressure (350 psi)	5-15	13	Safety-First
14.	5-lb	Stored Pressure (155 psi)	2-10	17	Kidde
Foam:					
15.	$1\frac{1}{4}$-gal	(Durafom Charge)	30-35	40	Badger

TABLE 2

SUM OF SCORES OBTAINED BY THE 15 EXTINGUISHERS ON EACH OF THE 10 FIRE MODELS (SUM OF FIVE RUNS).

	FIRE MODEL NO.									
Ext. No.	I	II	III	IV	V	VI	VII	VIII	IX	X
1	-8	-12	-1	-15	-15	-13	-11	-13	-15	-8
2	-4	-13	-3	-14	-15	-15	-14	-15	-15	-9
3	-10	-10	14	-10	-1	-10	1	-14	-12	-1
4	10	-1	15	12	15	11	14	0	9	14
5	2	-8	7	-10	-10	-10	-7	-13	-11	-4
6	5	-3	-12	-13	-14	-14	-14	-12	-14	-12
7	-1	-6	13	1	9	-7	12	-10	-2	10
8	5	2	14	3	9	-4	8	-10	-2	12
9	-3	-14	13	-12	7	-3	-3	-14	-4	5
10	1	2	14	-9	9	9	4	-2	2	5
11	11	4	15	4	14	14	15	10	11	13
12	13	-8	14	11	14	11	12	10	8	14
13	14	-7	15	11	12	10	11	6	4	8
14	13	-9	15	4	13	7	13	0	8	14
15	3	5	15	-3	12	0	-9	-2	-1	4
TOTALS	51	-78	148	-40	59	-14	32	-79	-34	65

TABLE 3

NUMBER OF SUCCESSES BY EACH EXTINGUISHER IN FIVE TRIALS ON EACH FIRE MODEL

Ext. No.	FIRE MODEL NO.										TOTAL NUMBER IN 50 TRIALS	TOTAL NUMBER IN 45 TRIALS *
	I	II	III	IV	V	VI	VII	VIII	IX	X		
2	2	0	1	0	0	0	0	0	0	1	4	4
1	1	0	2	0	0	0	0	0	0	1	4	4
6	5	2	0	0	0	0	0	0	0	0	7	5
5	4	0	4	0	0	0	1	0	0	1	10	10
3	0	0	5	0	2	0	2	0	0	3	12	12
7	2	1	5	3	5	0	5	0	2	5	28	27
8	5	3	5	3	5	1	4	0	3	4	33	30
15	4	4	5	1	5	2	0	2	2	4	29	25
9	2	0	5	0	4	1	2	0	2	4	20	20
10	2	4	5	0	4	4	4	2	2	5	32	28
11	5	4	5	3	5	5	5	4	5	5	46	42
14	5	0	5	3	5	4	5	2	4	5	38	38
13	5	0	5	5	5	5	5	4	4	5	43	43
12	5	0	5	5	5	5	5	5	4	5	44	44
4	5	2	5	5	5	5	5	2	5	5	44	42
TOTALS	52	20	62	28	50	32	43	21	33	53	394	374

* Omitting Fire No. II

TABLE 4

TOTAL NUMBER OF TIMES EACH EXTINGUISHER SUCCEEDED ON ALL TEN FIRE MODELS IN EACH OF THE FIVE SERIES

Ext. No.	Series 1	Series 2	Series 3	Series 4	Series 5	Total for 5 Series
2	0	1	1	0	2	4
1	0	2	0	2	0	4
6	1	1	1	2	2	7
5	1	2	4	1	2	10
3	2	2	2	3	3	12
7	4	4	7	7	6	28
8	4	7	7	8	7	33
15	3	5	5	7	9	29
9	4	3	5	5	3	20
10	5	7	8	6	6	32
11	9	10	9	9	9	46
14	7	7	8	8	8	38
13	7	9	9	9	9	43
12	9	8	9	9	9	44
4	8	9	9	9	9	44
Totals	64	77	84	85	84	394

TABLE 5

RANKING OF EXTINGUISHERS

Extin-guishers	Ext. No.	A Percent Success	B Percent Success Omitting Fire II	C Trans-formed to Arcsin[a,b]	D Avg. Scores	E Average Scores Omitting Fire II	Ranking By A	B	C	D	E
Hand-Pump CCl_4											
1 qt.	2	8	9	18.6	-2.3	-2.3	1.5	1.5	1.5	1	1
1 qt.	1	8	9	18.6	-2.2	-2.2	1.5	1.5	1.5	2	3
1½ qt.	6	14	11	20.0	-2.1	-2.2	3	3	3	3	2
1½ qt.	5	20	22	26.9	-1.3	-1.2	4	4	4	4	4
Pressur-ized CCl_4											
1 qt.	3	24	27	30.1	-1.1	-1.0	5	5	5	5	5
1½ qt.	7	56	60	51.5	0.4	0.6	7	8	8	7	8
2 qt.	8	66	67	55.4	0.7	0.8	10	10	10	10	10
Foam											
1¼ gal.	15	58	56	48.6	0.5	0.4	8	7	7	8	7
CO_2											
2½ lb.	9	40	44	41.4	-0.6	-0.3	6	6	6	6	6
5 lb.	10	64	62	52.8	0.7	.7	9	9	9	9	9
10 lb.	11	92	93	72.7	2.2	2.5	15	12.5	12	15	15
Dry Chemical											
5 lb.	14	76	84	66.9	1.6	2.0	11	11	11	11	11.5
4 lb.	13	86	96	74.1	1.7	2.0	12	14	14	12	11.5
4 lb.	12	88	98	75.6	2.0	2.4	13.5	15	15	13.5	14
CBM											
1 qt.	4	88	93	72.9	2.0	2.2	13.5	12.5	13	13.5	13

[a] from data of Table 3, Fire II omitted

[b] standard deviation of individual average = 4.7 (see Appendix A)

Figure 1 - Test Extinguishers

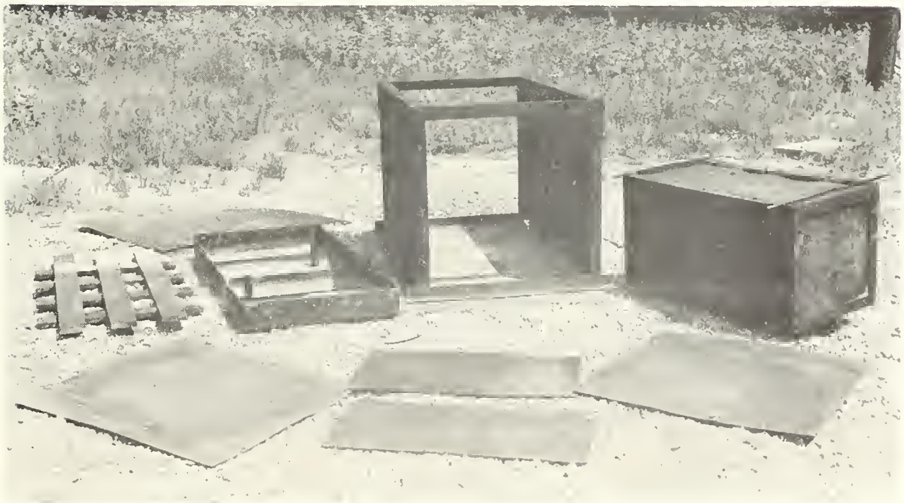


Figure 2 - Motor Compartment Components

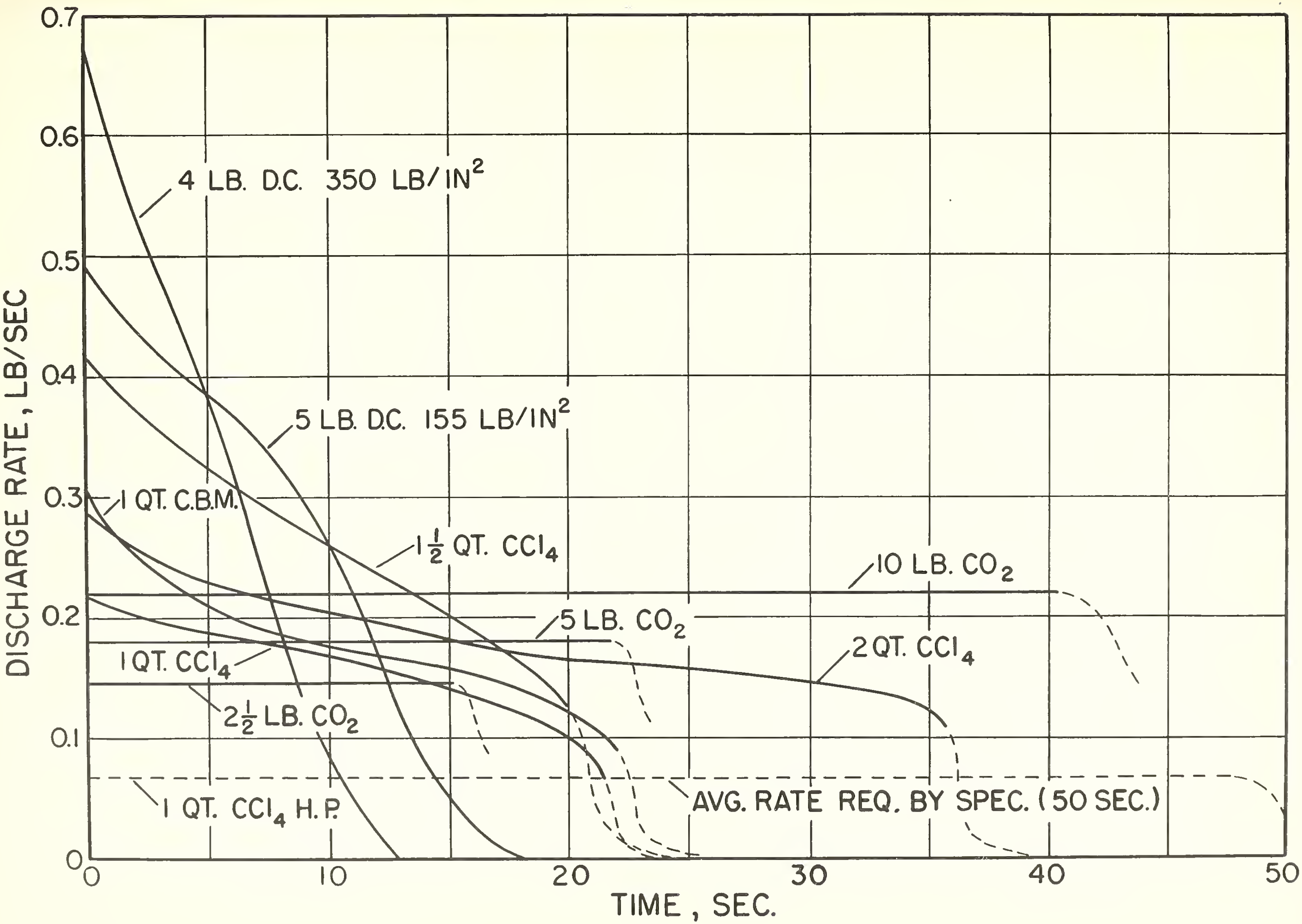


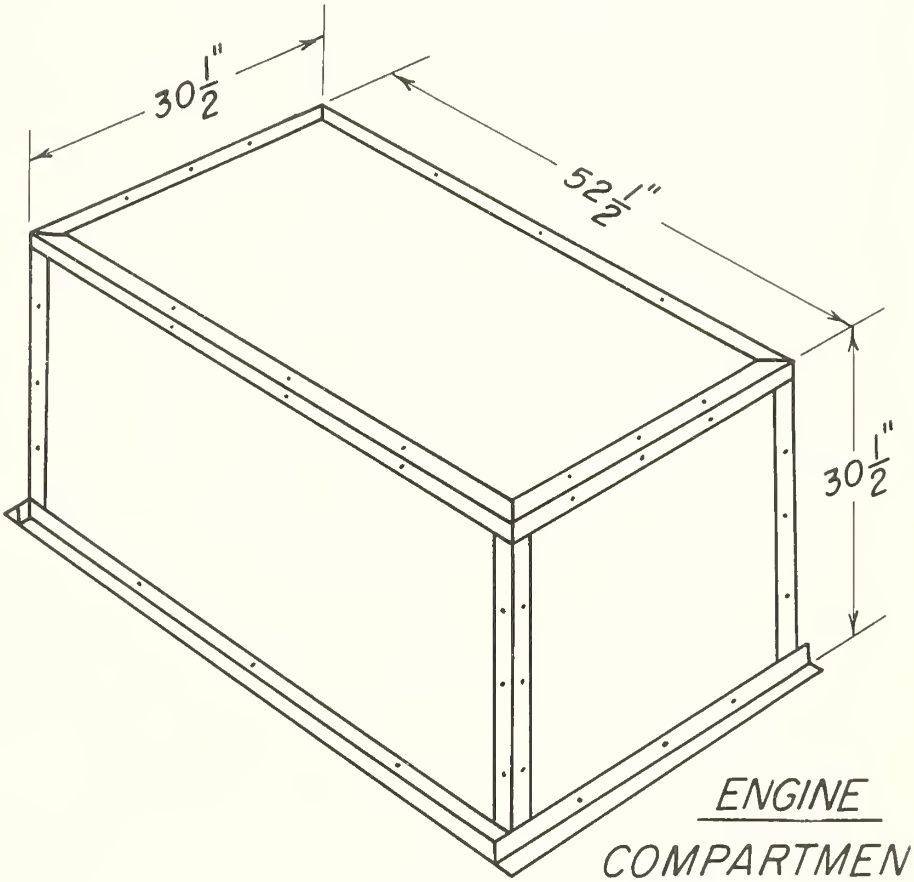
FIG. 3 APPROXIMATE DISCHARGE RATES OF TEST EXTINGUISHERS

Figure 4

Engine Compartment and "Engine"

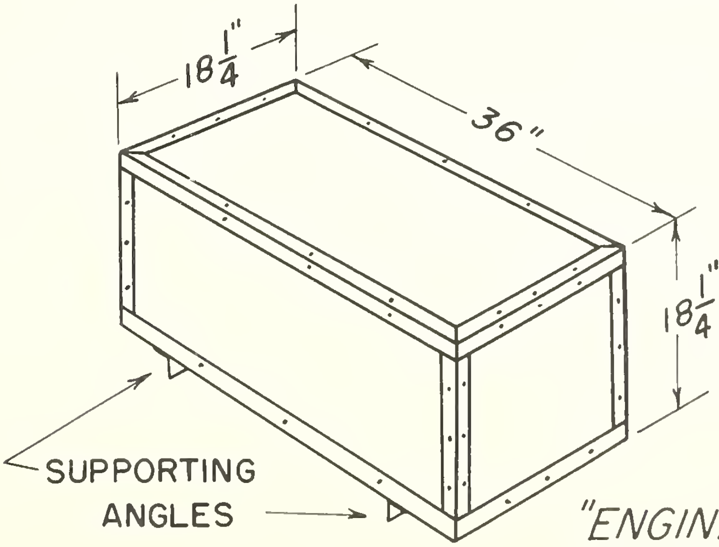
Both units made from 2-in. by 2-in. by 1/8-in. angle and 14 ga steel plate fastened with 1/4-in. bolts

Engine compartment made with bottom open, long sides covered, top and end plates removable.



ENGINE COMPARTMENT

"Engine" covered on all sides.

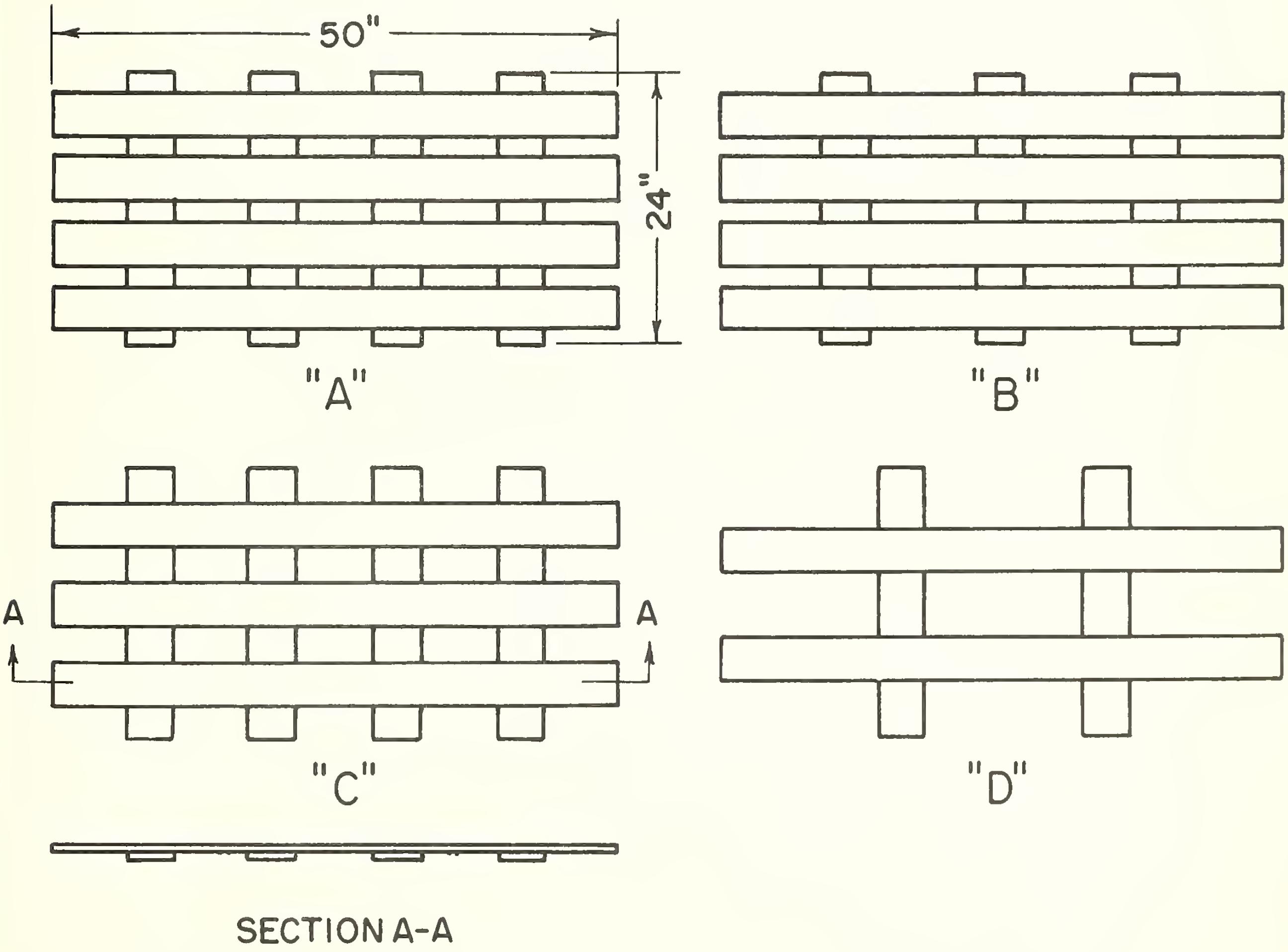


"ENGINE"

Figure 5

Wood Floor Gratings

Gratings are constructed of Ponderosa Pine, No. 2 common, nominal 1-in. by 4-in. mill lumber (dressed dimensions 25/32 in. by 3 5/8 in.).



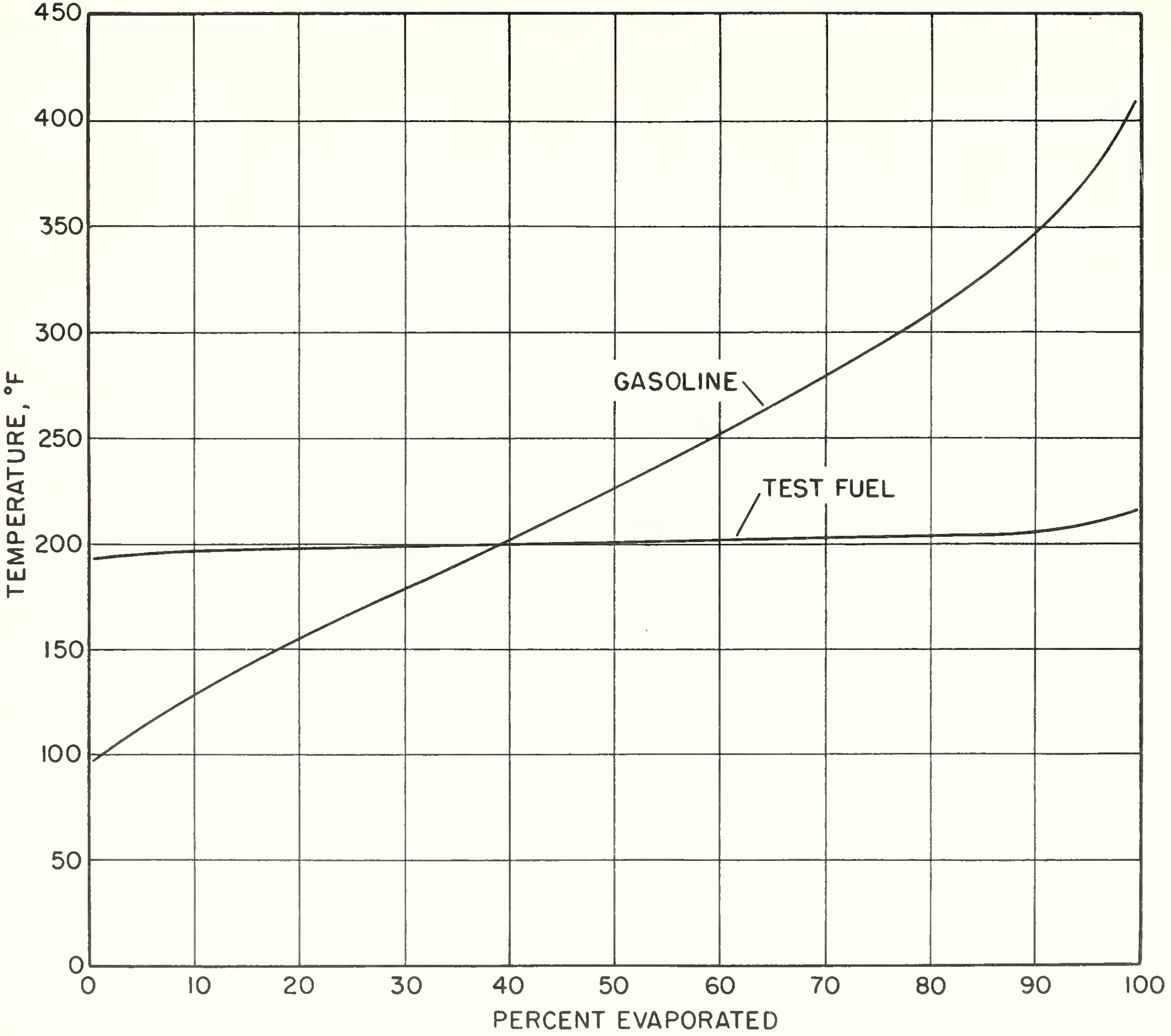


FIG. 6 DISTILLATION CURVES OF GASOLINES AND TEST FUEL
GASOLINE CURVE REPRESENTS AVERAGE OF 350 REGULARS TESTED
MID ATLANTIC STATES, SUMMER, 1954

Figure 7 - Typical Data Sheet

Motorboat Fire Test Data

Fire No. 7 - Series IV

Extinguisher No. 3A

Manufacturer Stop Fire

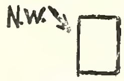
Extg Total wt 6.25

Extg Temp 70

WEATHER:
[✓ sunny] cloudy overcast
rain in/hr

Atm, Temperature 71

Wind Direction (to apparatus)



Humidity 37 %

Fuel 1 gal Heptane

Delay to ignition —

Preburn 60

Time Fire Out 68

Time Extg Used 8

Final Wt 4.76

Final Pressure 60

Agent Expended 1.49

Wood initial wt —

Wood final wt —

Rating: -3,-2,-1;+1,[✓ +2],+3

REMARKS:

Moderately easy

Date 5-6-55 Time 3:00

Extg type size 1-qt.

Type of Charge CCl_4 Gas N_2

Charge wt 3.3

Charge Pressure 150

$\left(\frac{123}{68}\right)$

Test Area Shaded? No

Solar Radiation g cal/cm^{2}min 1.125

Velocity rev/min 109 MPH '0.7

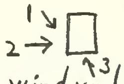
Barometer 29.90

Wet Bulb 56

Temp of Fuel,water 75

Flow Time —

Area of Fire Spread —



Method of Attack Begin to windward

Initial Position 4 ft.

Target sides of compartment

Procedure spray side to side

Final Position 3 ft.

Operator T.L. Recorder HΔ

Units: lb,sec,°F,psi

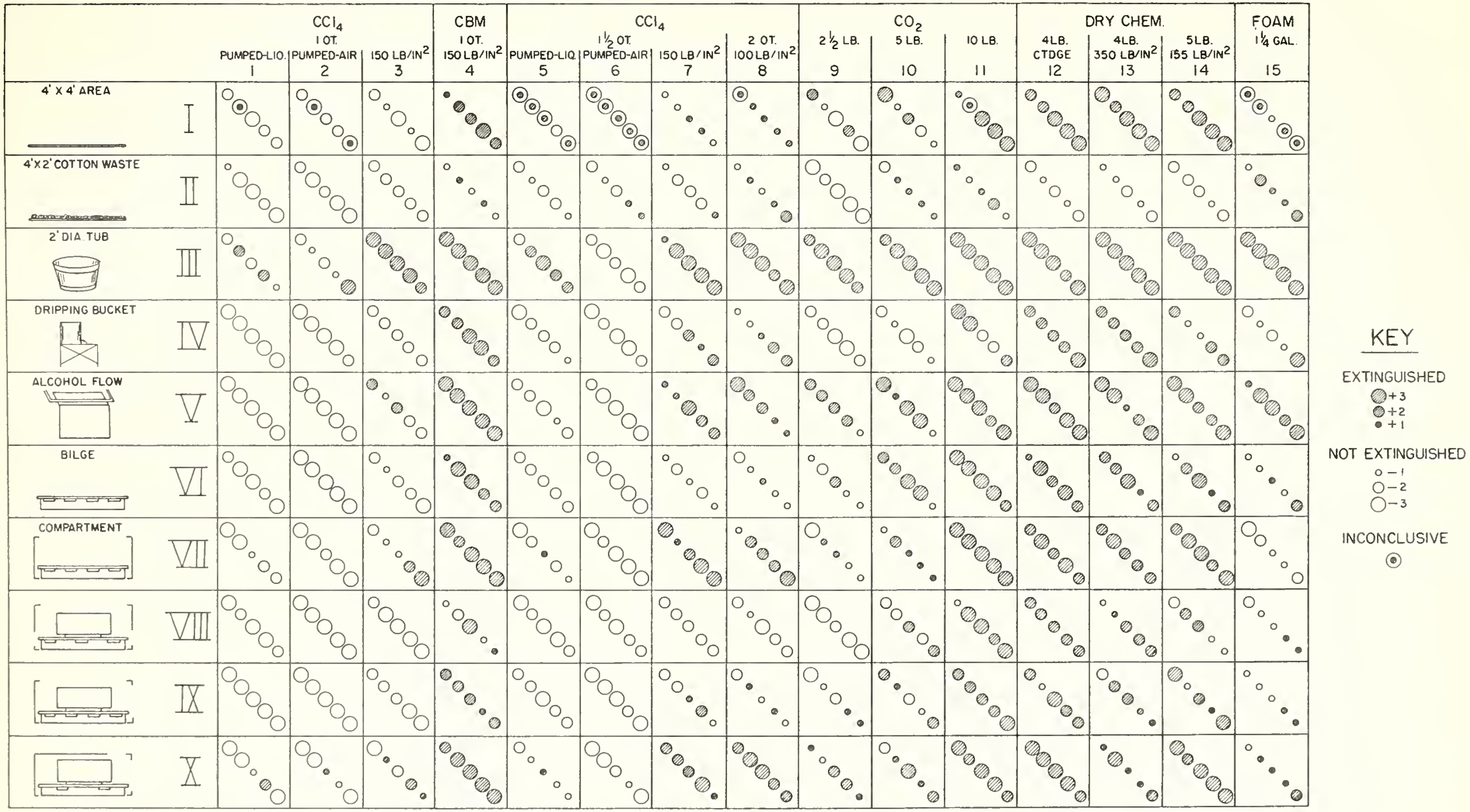


FIG. 8 PERFORMANCE RATINGS OF EXTINGUISHERS ON FIRE MODELS

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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