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THE USE OF GROUND COVER MATERIALS TO SUPPRESS FUEL SPILL FIRES

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16. Abstract

Small-scale experiments were conducted to determine the effectiveness of crushed and graded stone aggregate in preventing or retarding the rate of flame propagation from a fixed-ignition source when it was employed as a simulated ground cover material under controlled experimental conditions, for each of three aviation fuels. Tests included the use of loosely packed aggregate and no-fines concrete made with the same material. No significant difference in the rate of flame spread was noted between the loosely packed aggregate and no-fines concrete under equivalent test conditions. The experiments showed that the effectiveness of an aggregate in retarding flame propagation was a function of its size and the flash point of the hydrocarbon fuel and of its depth below the surface of the simulated ground cover. The fire suppression and/or containment effectiveness of the ground cover materials increased as the size of the aggregate decreased and the flash point of the fuel increased and as the depth of the fuel below the surface of the stone increased.

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INTRODUCTION

PURPOSE.

The objective of this effort was to determine the effectiveness of crushed and graded stone aggregate in preventing or retarding the rate of flame propagation from a fixed-ignition source, when it was employed as a simulated ground cover material under controlled experimental conditions for each of three aviation fuels.

BACKGROUND.

During the course of previous project work it was observed that inorganic ground cover materials, such as crushed and graded traprock, demonstrated significant fire suppression and containment characteristics toward the spread of simulated JP-4 fuel spill fires when it was present in sufficient depth above the fuel surface. Additional observations of the phenomenon and several exploratory experiments indicated that the size of the stone aggregate and the depth of fuel below its surface were the major contributing factors in establishing the rate of flame spread for a particular aircraft fuel. From these considerations it was apparent that the use of such inorganic ground cover materials in areas exposed to the hazards associated with a large fuel spill could contribute materially toward reducing the devastating effects of a major fuel fire.

DISCUSSION

DESCRIPTION OF THE FIRE TEST BED.

The test bed comprised a circular pan 6 feet in diameter (28 square feet), and 5 inches in depth, fabricated from 0.25-inch thick steel. In the center of this pan was a vertical cylinder 5 inches long and 6 inches in diameter, fabricated of 0.375-inch hardware cloth (wire mesh). As an aid in estimating the area of flame spread over the ground cover material during five 2-minute consecutive time intervals, the surface of the pan was sectioned into areas of 0.5 foot-square by means of a grid (concrete reinforcement wire), fabricated of 0.125-inch diameter steel rods.

The test bed configuration is shown schematically in Figure 1, and pictorially in Figure 2.

GROUND COVER MATERIALS.

LOOSELY PACKED TRAPROCK. The first experimental ground cover material tested was crushed and graded traprock (Reference 1). This aggregate is a dense crystalline rock, irregular (angular) in form, and available commercially in several different standard sizes. The commercially available sizes of traprock evaluated in this effort were 3/8, 1/2 and 3/4 inch. Traprock

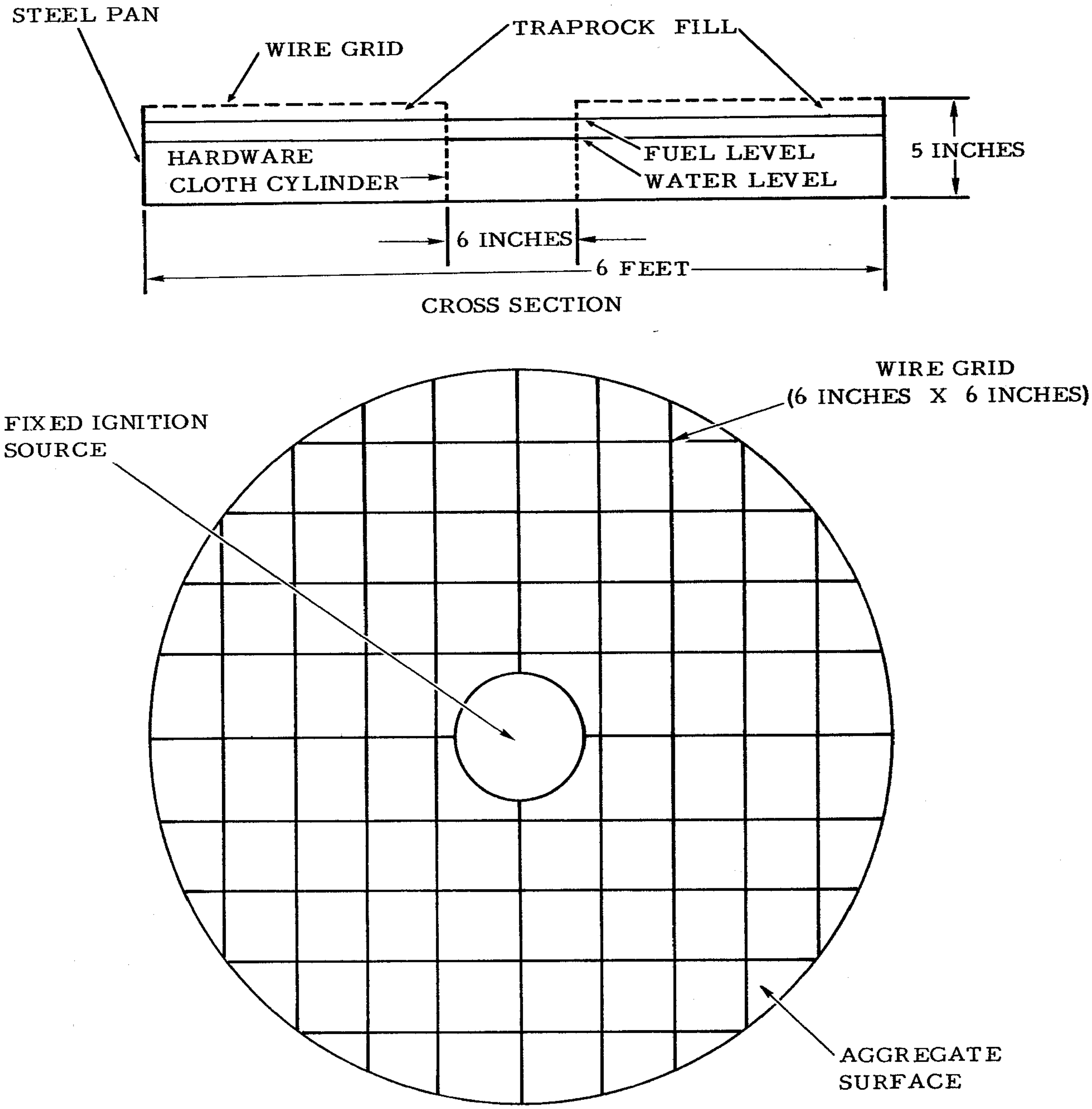


FIGURE 1. FIRE TEST BED CONFIGURATION (NOT TO SCALE)

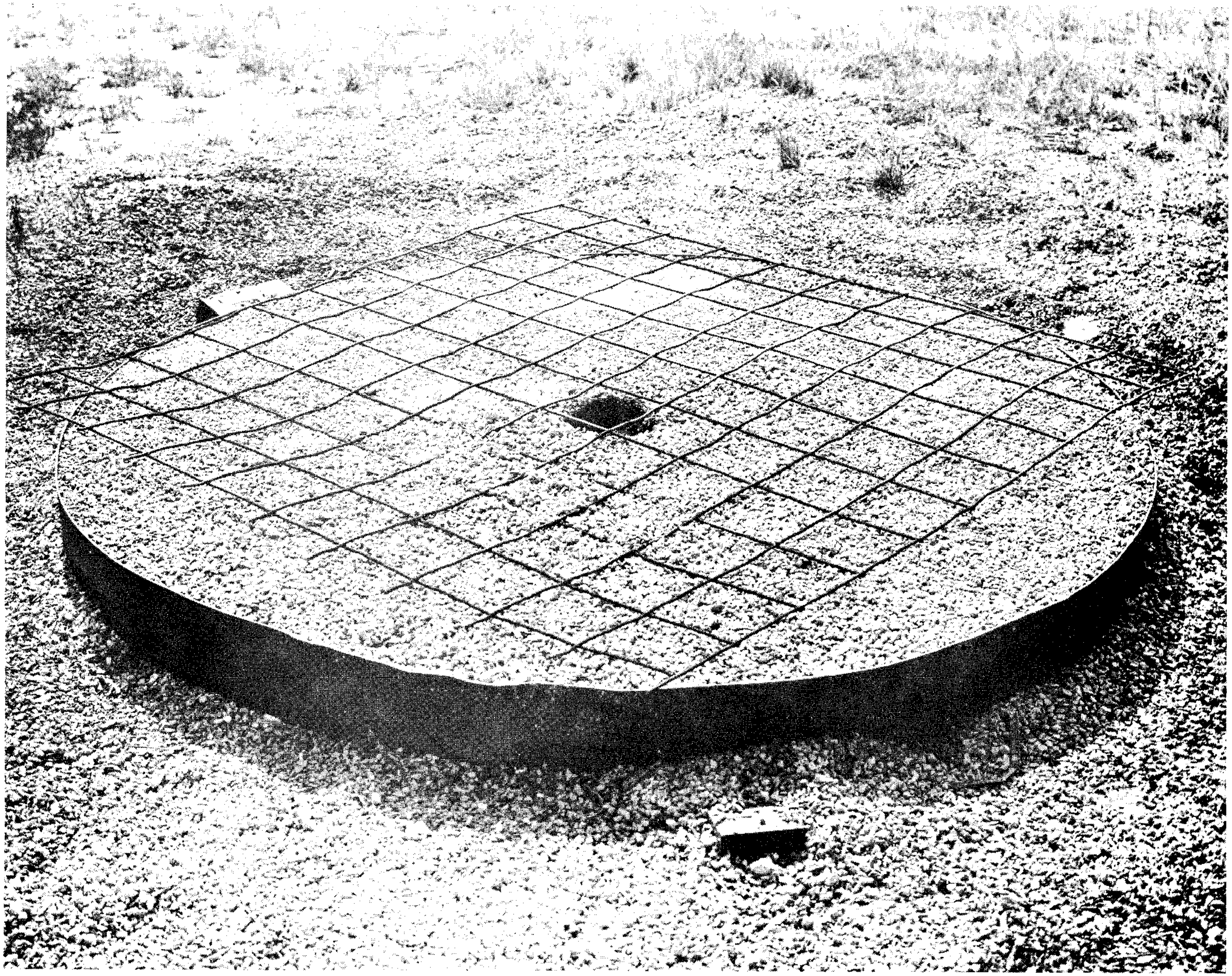


FIGURE 2. FIRE TEST BED SHOWING THE LOCATION OF THE FIXED IGNITION SOURCE AND WIRE GRID

is used as a road ballast and in the manufacture of bituminous macadam-base highway materials. Several important packing characteristics of the aggregate are presented in Table 1.

LOOSELY PACKED GRAVEL. A second potential ground cover material employed in this series of experiments was 3/8-inch siliceous gravel. This aggregate is a dense crystalline material roughly spheroidal (rounded edges) in form and used extensively in the manufacture of concrete. The packing characteristics of the gravel used in these experiments are indicated in Table 1.

TABLE 1. PACKING CHARACTERISTICS OF TRAPROCK AND GRAVEL

Aggregate	Nominal Aggregate Size (in)	Approximate Weight (lb/ft^3)	Approximate Free Volume (pct)
Traprock	3/8	104	44.4
	1/2	107	45.3
	3/4	110	45.8
Gravel	3/8	101	36.7

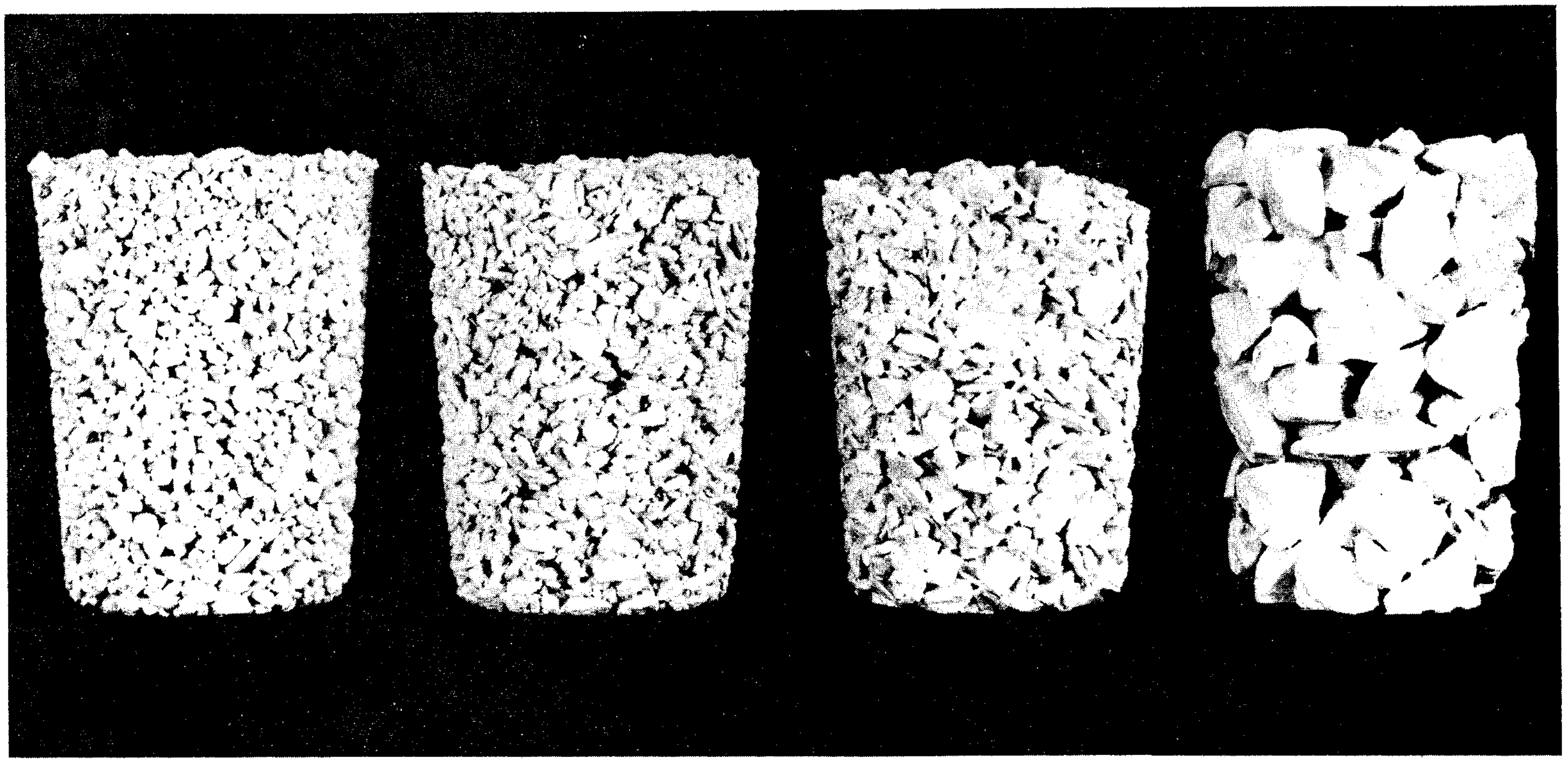
The physical characteristics of the bed of crushed stones were determined, since it was evident from exploratory experiments conducted with traprock of different sizes that the bulk density and free volume or void were significant factors in establishing the effectiveness of the aggregates in preventing or limiting the area of flame propagation over the traprock surface.

NO-FINES CONCRETE MADE WITH CRUSHED STONE AGGREGATE.

To minimize the potential hazard associated with the possible erratic dispersal of loose stone aggregate from protected locations where it is employed as a ground cover within the area of aircraft operations or ground vehicle movement at airports, a no-fines concrete was prepared and tested for fire containment by mixing graded stone with a neat cement-water slurry in sufficient quantity to just coat each aggregate particle without any significant run-off. The prepared concrete mix was then poured in place and allowed to set.

The open structure of no-fines concrete made with 3/8-, 1/2-, and 3/4-inch traprock and 3/8-inch gravel is apparent in Figure 3. A more detailed view of the physical structure of no-fines concrete made with 3/4-inch traprock showing the cement binder at the aggregate points of contact is presented in Figure 4.

A small-scale test bed was constructed to evaluate the flame-containing characteristics of 3/8-inch no-fines concrete by pouring it over a 7-square foot circular area 5-inches deep in the center of the 28-square foot steel pan and by surrounding it with loosely packed 3/8-inch traprock. This configuration was capable of providing comparative data concerning the rate of flame propagation across the surface of both the no-fines concrete and the



3/8 INCH GRAVEL | 3/8 INCH TRAPROCK | 1/2 INCH TRAPROCK | 3/4 INCH TRAPROCK

FIGURE 3. PHYSICAL STRUCTURE OF 3/8, 1/2, AND 3/4-INCH NO-FINES CONCRETE SHOWING THE OPEN STRUCTURE

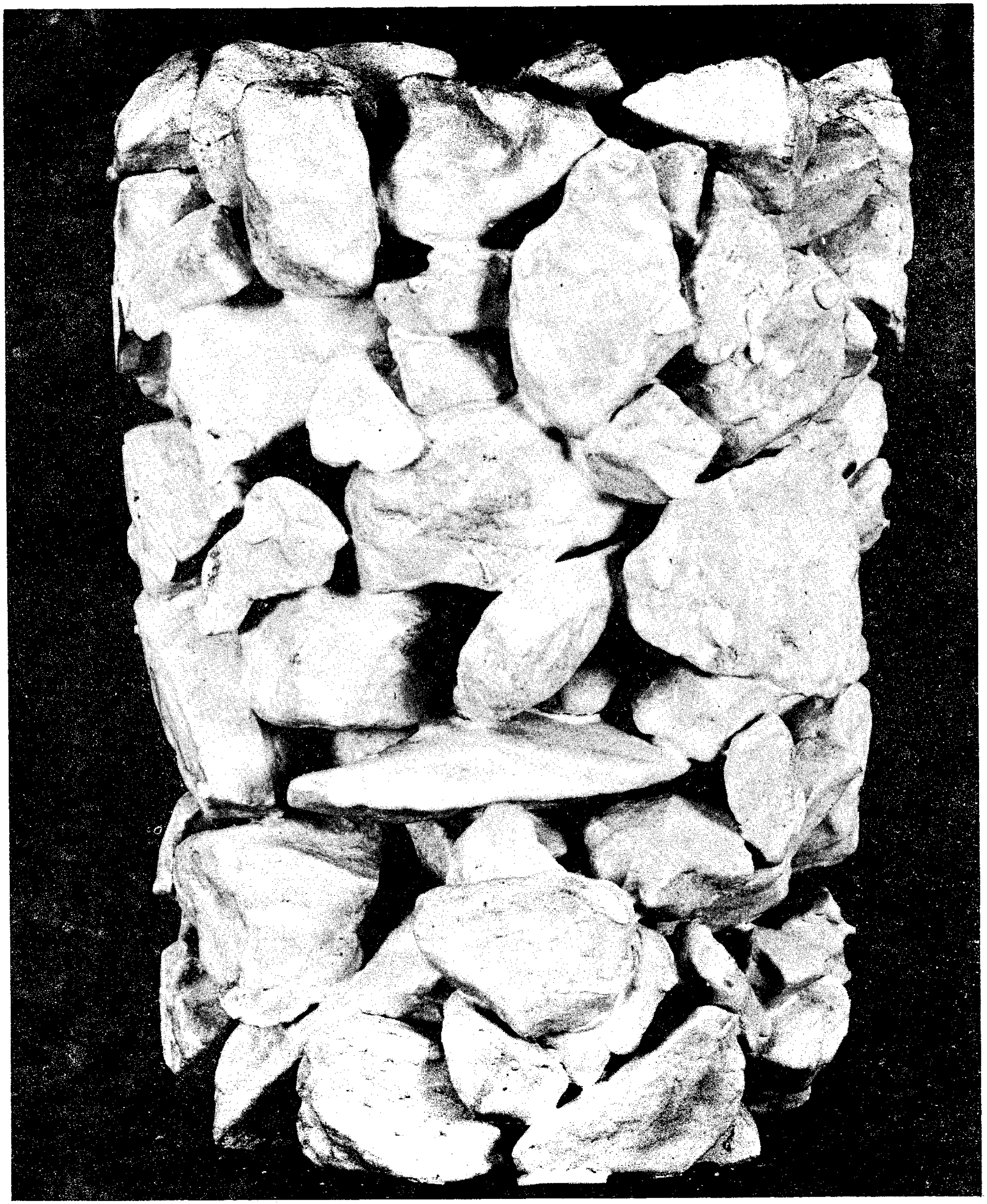


FIGURE 4. PHYSICAL STRUCTURE OF 3/4-INCH NO-FINES CONCRETE SHOWING THE CEMENT BINDER AT AGGREGATE POINTS OF CONTACT

loose traprock under the same environmental conditions. Experiments were conducted with JP-5, JP-4 and aviation gasoline (avgas) fuels using the test bed configuration shown in Figure 5.

The proportions of aggregate, cement and water used to prepare no-fines concrete with 3/8-, 1/2-, and 3/4-inch stone aggregate are indicated in Table 2 together with the approximate free-volumes and the compressive strength associated with each mix. The purpose in preparing specimens of no-fines concrete from these aggregates was to determine the potential load-bearing property of each concrete.

TABLE 2. NO-FINES CONCRETE (WATER, CEMENT, AGGREGATE RATIOS)

Aggregate Size (Inch)	Water (Milliliter)	Cement (Grams)	Aggregate (Grams)	Free Volume (Percent)	Average Strength (lbf/in^2)	
Traprock					7 Days	28 Days
3/8	60	99	1205	38.8	424	460
1/2	60	99	1205	42.5	389	470
3/4	20	33	908	43.8	258	393
Gravel						
3/8	60	99	1318	35.6	442	570

FIRE TEST PROCEDURE.

The ground cover materials to be evaluated for fire suppression and containment were placed in the test bed within the void between the outside of the hardware cloth cylinder and the inside of the steel pan and leveled even with the rim as shown in Figures 1 and 2. The test fuel was placed in the steel pan to a depth of 1 inch, and the difference between the fuel level and the surface of the traprock was regulated by adding the proper amount of water beneath the fuel.

Experiments were conducted in which the level of fuel was 1/2, 1, 2 and 3 inches below the surface of the traprock. The test was performed by igniting the fuel inside the hardware cloth cylinder and observing the rate of flame propagation across the surface of the traprock at 2-minute intervals for a period of 10 minutes. Three different sizes of traprock and one size of

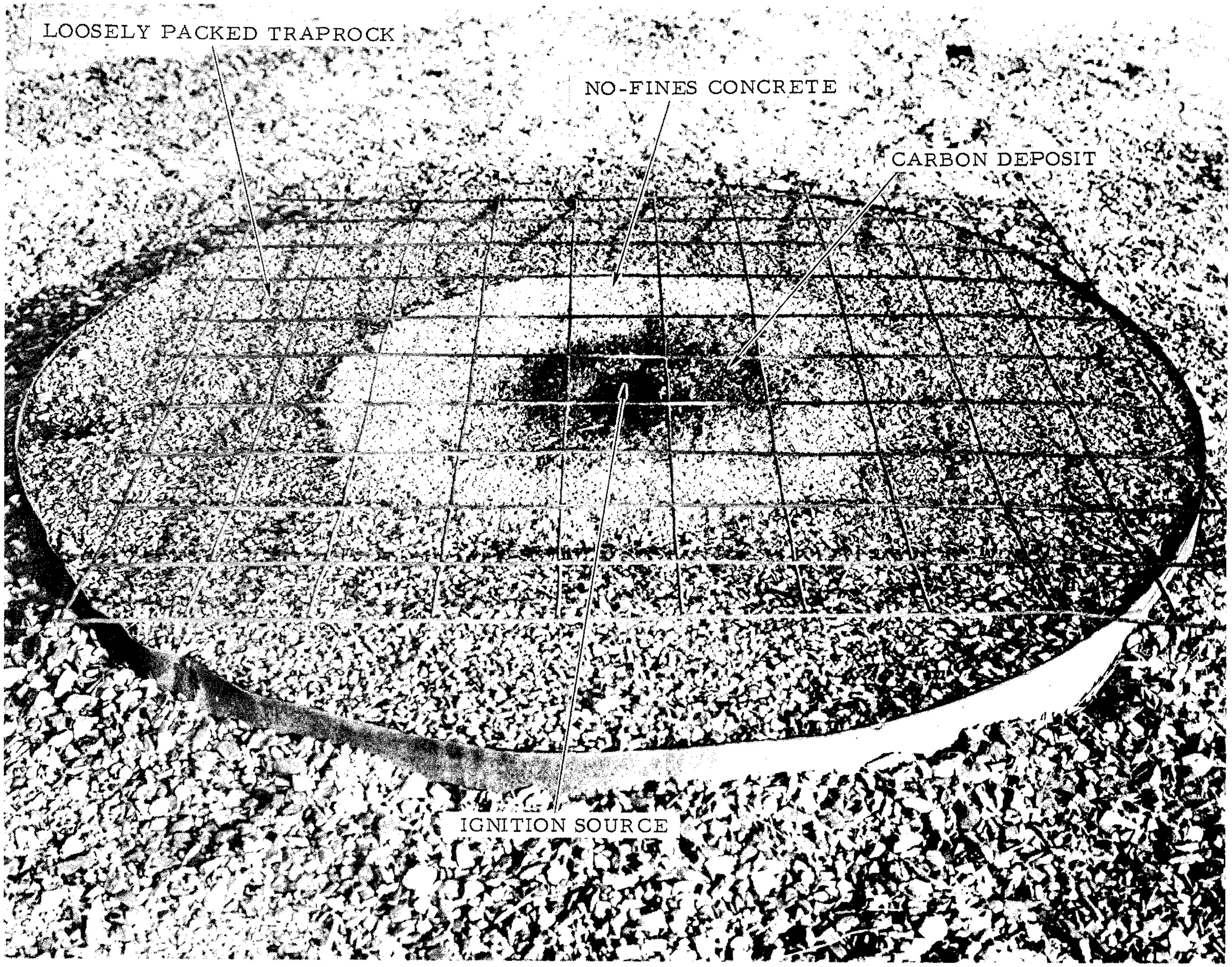


FIGURE 5. TEST BED SHOWING THE POSITION OF THE NO-FINES CONCRETE WITHIN THE STEEL PAN

gravel were evaluated for their fire suppression and containment effects against the flame spread of Jet A, JP-4 and avgas (115/145 octane) fuel fires. Some pertinent physical properties of the aviation fuels are shown in Table 3.

TABLE 3. SOME PHYSICAL PROPERTIES OF AVIATION FUELS

Fuel	Specific Gravity (@70°F)	Kinematic Viscosity (@70°F) (Centistokes)	Absolute Vapor Pressure @100°F PSIA (Reid)*	Flash Point* (°F)	Approximate Rate of Flame Travel Over Fuel Surface (Ft/Sec)**
Avgas	0.680	0.65	5.5 to 7.0	-50	7.3
JP-4	0.775	1.10	2.0 to 3.0	-10 to 30	1.7
Jet A	0.825	2.09	0.1	95 to 145	0.2 to 0.4

*Reference 2
**Reference 3

EFFECTIVENESS OF INORGANIC GROUND COVER MATERIALS FOR CONTROLLING FUEL SPILL FIRES.

The flame suppression and containment of three aircraft fuels (Jet A, JP-4 and avgas) by three different sizes of traprock (3/8, 1/2, and 3/4 inch) are shown in Figures 6, 7 and 8. The effectiveness of each different size of traprock using a particular aircraft fuel is shown as a function of the area of flame spread and the depth of the fuel below the surface of the traprock.

The profiles presented in Figure 6 show the increase in the fire burning area beyond the fixed-ignition source as a function of the depth of Jet A fuel below the surface of the three different sizes of traprock. The curves indicate that the fire containment effectiveness increases as the size of the aggregate decreases from 3/4 to 1/2 and 3/8 inch, and as the depth of the fuel below the traprock surface increases. No experiments were conducted with Jet A fuel at a depth of 3 inches since there was no increase in the fire area beyond the fixed-ignition source when the fuel level was 2 inches below the traprock surface. The profiles show an average flame spread over the 3/8- and 1/2-inch traprock of 1.0 square foot when the fuel is 1/2 inch below the surface, while that for the 3/4-inch aggregate was 8.0 square feet. Therefore, these data tend to indicate that the actual critical aggregate size is approximately 1/2 inch using Jet A fuel and that there is little or no advantage to be gained by using aggregate below the 3/8-inch size.

Figure 7 show the profiles obtained when JP-4 fuel was substituted for Jet A under the same test conditions as in the previous experiments. The profiles indicate that the 3/8-inch size traprock was moderately effective in that it limited the flame spread to 2 square feet beyond the fixed-fire area over a 10-minute burn period when the fuel level was 1/2 inch below the

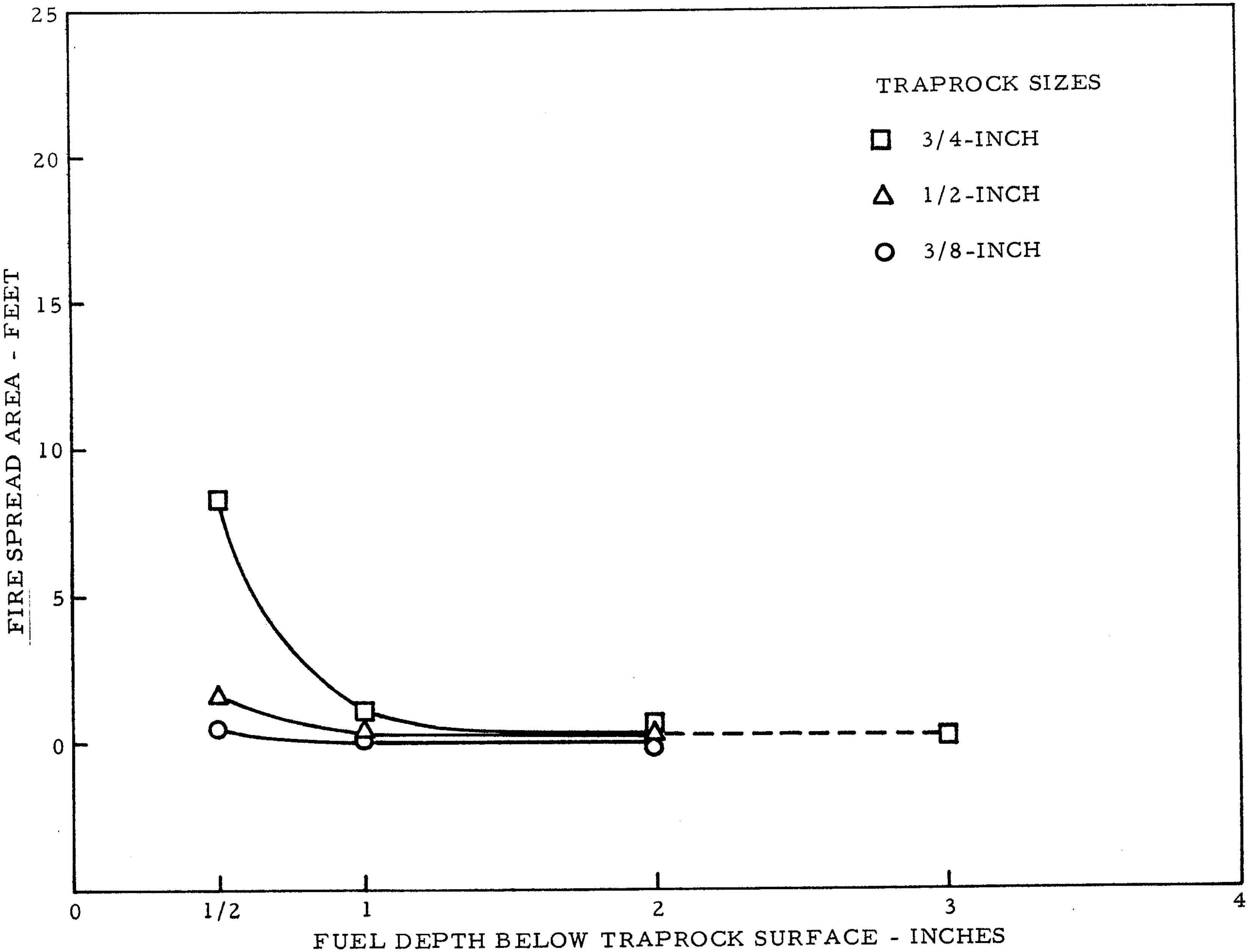


FIGURE 6. FIRE AREA AFTER A 10-MINUTE BURNING TIME USING JET A FUEL AND 3 DIFFERENT SIZES OF TRAPROCK

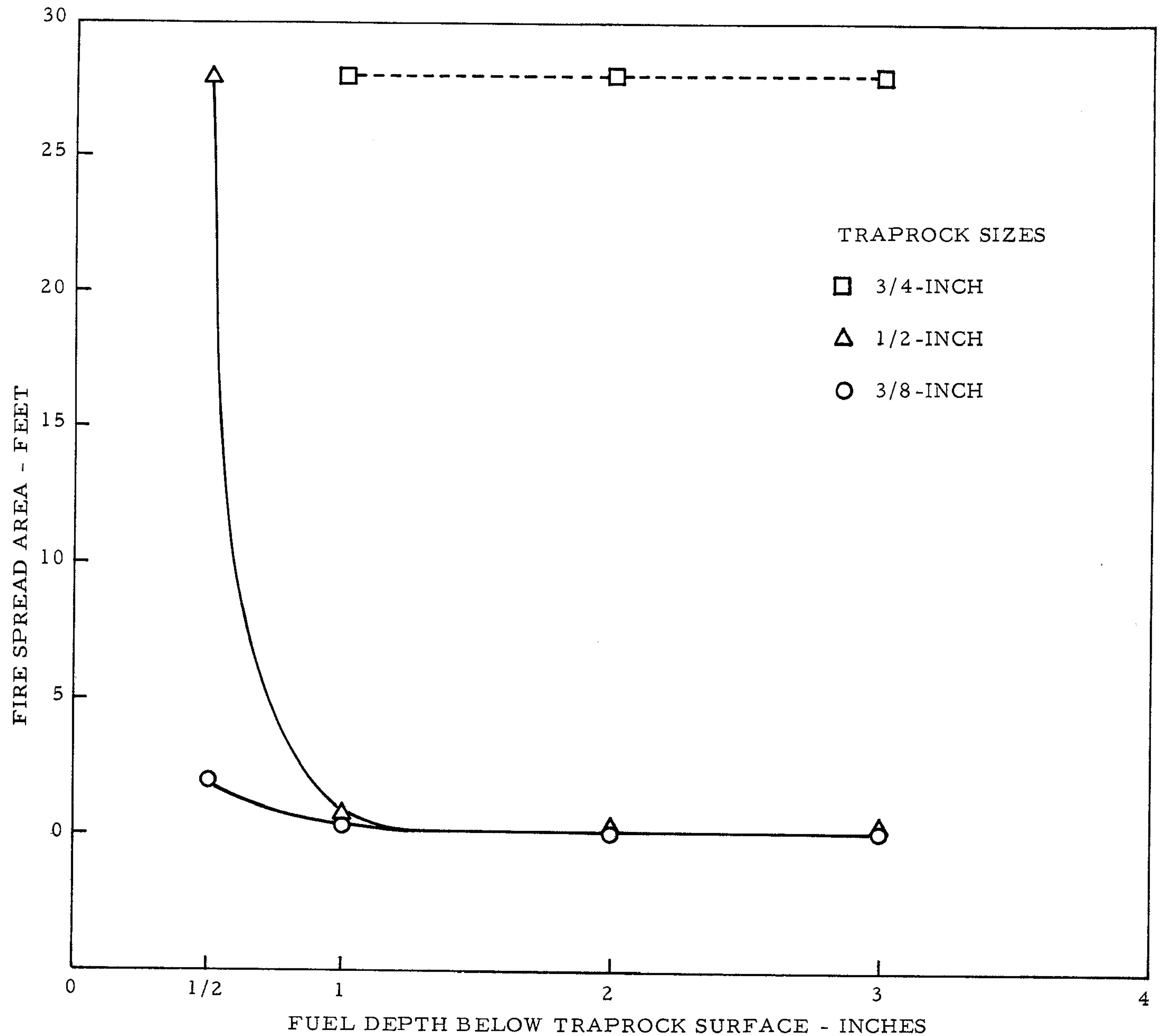


FIGURE 7. FIRE AREA AFTER A 10-MINUTE BURNING TIME USING JP-4 FUEL AND 3 DIFFERENT SIZES OF TRAPROCK

traprock surface. When the fuel depth was lowered to 1 inch below the aggregate surface, the area of flame spread was reduced to approximately 0.30 square foot. No increase in the fire area beyond the fixed-ignition source was observed when the fuel surface was 2 and 3 inches below the traprock surface. The data profile for the 1/2-inch size aggregate indicates that when the fuel was 1/2 inch below the traprock surface, the flame propagated across the entire traprock surface as soon as the fixed-ignition source was ignited. However, when the fuel was lowered to 1 inch below the traprock surface, the fire area increased to only 0.40 square foot beyond the fixed-ignition source. As the fuel surface was further lowered to 2 and 3 inches below the traprock surface, no increase in the fire area was observed beyond the fixed-ignition source. The 3/4-inch size traprock showed no fire suppression or containment characteristics when the level of the JP-4 fuel was 1/2 or 1 inch below the traprock surface and, in fact, the flames flashed across the surface of the pan as soon as the torch was applied to the fuel. However, a phenomenon did occur when the fuel level was lowered to 2 and 3 inches below the aggregate surface, which was observed to be a characteristic of the more volatile aviation fuels such as JP-4 and avgas (Table 3). The phenomenon was manifest by an audible combustion process which developed and maintained itself within the interstices provided between the surface of the traprock and the fuel. In these experiments the 3/4-inch size traprock was considered to be ineffective as a ground cover material, even though there was no visible flame activity above the surface of the traprock. This fact is shown by the dashed line in Figure 7, indicating that some form of combustion phenomena maintained when 3/4-inch aggregate was used as cover material with JP-4 fuel.

It is speculated that the reason this combustion phenomenon maintains with the 3/4 inch, but not the 1/2- or 3/8-inch traprock, is because the 3/4-inch aggregate provides a larger and perhaps critical free volume that allows for the rapid diffusion of air for the formation of a combustible oxygen fuel mixture and the subsequent rapid expulsion of the products of combustion within the time-cycle requirements to produce a self-propagating combustion wave throughout the aggregate bed.

The profiles presented in Figure 8 show the increase in the fire burning area beyond the fixed-ignition source after 10 minutes for three sizes of traprock with avgas fuel. These data indicate that no fire suppression or containment was obtained when avgas fuel was 1/2 inch below the aggregate surface for any size of traprock tested. When the fuel surface was lowered 1 inch below the aggregate surface, the 1/2- and 3/8-inch traprock showed an increase of approximately 1.5 square feet beyond the fixed-ignition source, which decreased to zero when the depth was increased to 2 and 3 inches. However, the same combustion phenomenon associated with the 3/4-inch traprock and JP-4 fuel was observed to maintain with avgas fuel, but the rate of flame propagation and combustion within the interstices of the traprock appeared to increase in magnitude although no flames were visible above the traprock surface. The presence of the combustion flame within the interstices of the traprock was verified by removing approximately 1 square foot of traprock surface near the rim of the pan to expose the fuel surface beneath, which was promptly ignited as the combustion wave passed over the unprotected fuel.

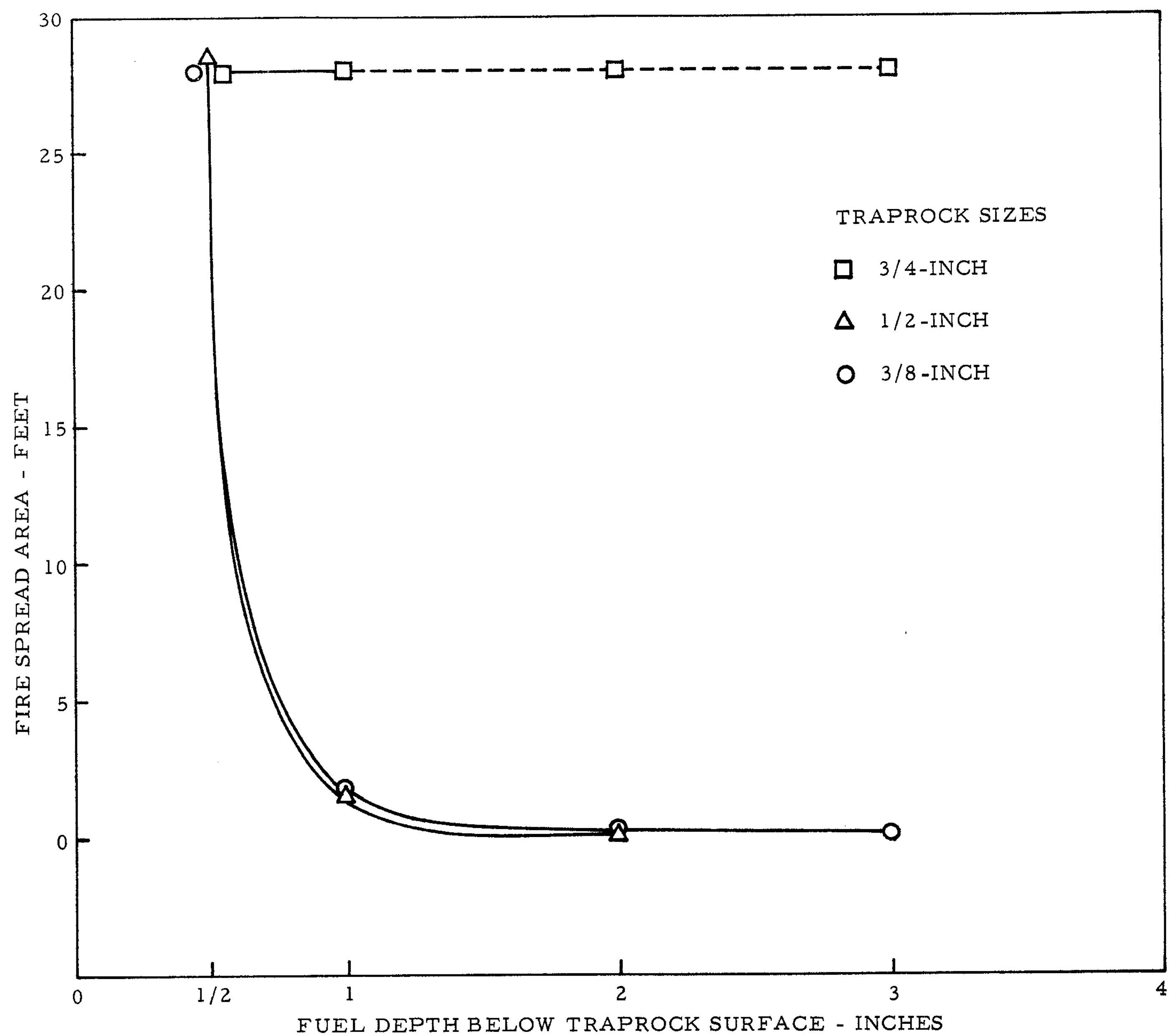


FIGURE 8. FIRE AREA AFTER A 10-MINUTE BURNING TIME USING AVGAS FUEL AND 3 DIFFERENT SIZES OF TRAPROCK

The fire suppression and containment experiments performed in this effort are considered related in theory to the phenomenon observed and reported in Reference 4 and 5, in which the "horizontal flame spread rate" was controlled by immobilizing an exposed surface of JP-5R fuel. In Reference 4, surface immobilization was accomplished by blanketing the fuel surface with floating thin-walled epoxy resin spheres which acted as a barrier against the heat transfer mechanism from flame to fuel and the distribution of this heat within the fuel in front of the flame by eddy currents. The epoxy spheres provided an in-depth floating-fuel cover similar in effect to that provided by lowering the surface of the fuel below the level of the ground cover materials in the current experiments.

An estimate of the relative merits of safety for JP-5R fuel, both neat and in the gelled state, and of a surface immobilized by epoxy spheres in terms of the horizontal flame spread rate (Reference 4) indicates that the rate for gelled JP-5R was lower by a factor of approximately 10 than that for liquid fuel, but fuel immobilized by epoxy spheres was less than it was in the gelled state by a factor of 500. Therefore, it is apparent that the most effective means for inhibiting the horizontal flame spread rate for aircraft fuels is by providing a cover over its surface by either floating objects or by lowering its surface below a fixed level of dense cover material.

SUMMARY OF RESULTS

The results obtained from small-scale fire control and containment experiments using three different sizes of stone aggregate and three aviation fuels under controlled conditions are:

1. The fire suppression and/or containment effectiveness of stone ground cover materials was determined to be a function of the stone size, the flash point of the hydrocarbon fuel, and of the depth of the fuel below the surface of the aggregate.

2. The fire suppression and/or containment effectiveness of the ground cover material increased as the size of the aggregate decreased from 3/4, 1/2, to 3/8 inch and as the distance between the fuel level and the surface of the stone increased for any given fuel.

3. No-fines concrete, prepared with 3/8-, 1/2-, and 3/4-inch traprock, provided a load-bearing surface of 460, 470 and 393 pound-force per square inch, respectively, for compressive test cylinders aged for 28 days.

4. No-fines concrete, prepared with 3/8-inch gravel (rounded silicious stone), provided a load-bearing surface of 570 pound-force per square inch for compressive test cylinders aged for 28 days.

5. No significant difference was found in the fire suppression and containment of loosely packed stone and no-fines concrete prepared from the same size and kind of aggregate when it was present in equal depth over a fuel surface.

CONCLUSIONS

Based upon the fire control and containment experiments conducted with three sizes of crushed and graded aggregate and three different aviation fuels under controlled fire conditions, it is concluded that:

1. Crushed and graded stone aggregate in either the loosely packed condition or as no-fines concrete can provide an effective ground cover material in and around areas subject to fuel spill fire conditions.

2. No-fines concrete can provide a material to minimize the hazards associated with the dispersal of loose stone, as well as providing a load-bearing surface in areas where it is employed as a ground cover material for the suppression of potential fuel spill fires.

3. The most effective fire suppressing ground cover material in terms of size was the 3/8-inch aggregate. Its effectiveness increased as the flash point of the fuel decreased for any given fuel depth below the surface.

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