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ncendiary Particle Capture Device

by

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Naval Weapons Center
CHINA LAKE, CALIFORNIA • JUNE 1972

ABSTRACT

A fluidized bed was produced by means of dry ice blocks under Purple K fire-extinguishing powder for the purpose of capturing burning white phosphorus particles from munition bursts for size distribution studies. This bed chills the burning particles and prevents further oxidation until they are removed. The Purple K powder is easily washed from the captured particles and floated away, because it has been treated to be insoluble and nonwettable.

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FOREWORD

This report describes the development and testing of an apparatus to retrieve falling, burning, white phosphorus fragments from munition bursts for later study. The work was performed by Warren K. Smith during the period 1 December 1971 through 28 April 1972 and is the subject of a patent disclosure to the Navy. Funding was provided by the JTCG Selected Systems Effectiveness Program for Task 4f (MIPR RN 257-72) under the Chairmanship of Morris Johnson, MUCOM ORG, Edgewood Arsenal, Maryland.

This report was reviewed for technical accuracy by Dall G. Brune and Dr. Arthur R. Maddox. It is released at the working level for information only.

Released by
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16 May 1972

Under authority of
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INTRODUCTION

The effectiveness of incendiary weapons depends on the distribution and condition of the hot, burning particles arriving at a target. In some cases, notably white phosphorus, the particles or fragments are mostly in a molten state (or at least very soft) after absorbing heat from surface combustion during their trajectory. Upon impact, the hot particles or droplets spatter into much smaller pieces, which are either lost or completely burned up before recovery. It is then practically impossible to study the size distribution and character of the particles so that this can be related to target damage potential.

Considerable effort has been made in the past to find a suitable medium to capture burning white phosphorus particles from shells and grenades. Various detergent solutions, foams, and soft fibrous beds were tried without success. It is also necessary to quench and prevent further burning immediately upon capture, and this requirement may have prevented successful employment of some of the candidate media. The British were reported to have had success with an indirect method consisting of catching the white phosphorus particles on wet sand. The particles would spatter upon impact, of course, producing star-burst patterns on the wet sand. It was necessary to have a calibration of star-burst size versus known white phosphorus (WP) particle sizes in order to evaluate the star-bursts obtained from the incendiary test. However, no knowledge was gained as to particle shape and condition or what proportion was yet unburned.

In addition to the requirements of softness, practically zero surface tension, ability to cool the incendiary particle rapidly and prevent further oxidation, there is also the necessity for a low-cost and simple system. As many as 24 catching devices may be arrayed around the shell burst point. These must be serviced and the product removed rapidly after each test.

ANALYSIS

The project's sponsor established the general guidelines that particle sizes of 1/8, 1/4, and 1/2 ml by volume were to be expected and that they might have fallen from a maximum height of 100 ft. From this the maximum energy to be absorbed by a capture medium was calculated by the following procedure:

The kinetic energy of the falling WP particle is given by

$$KE = (1/2)\, MV^2 \tag{1}$$

and in turn the velocity, V, at the end of the 100-ft fall is given by

$$V^2 = V_T^2 \left(1 - e^{-\frac{2gS}{V_T^2}}\right) \tag{2}$$

where

V_T = terminal velocity

S = cross-sectional area of the particle

At terminal velocity, weight = drag, hence

$$W = D = (1/2)\, \rho\, V_T^2\, SC_D \tag{3}$$

where

ρ = air density, slug/ft^3

C_D = drag coefficient, 0.47*

---

* *Fluid-Dynamic Drag*, by S. F. Hoerner, 1965, pp. 3-8.

and

$$V_T = \sqrt{\frac{2 \times 0.00203}{0.47 \times 0.000817 \times 0.002378}} = 66.6 \text{ ft/sec}$$

Therefore, from Eq. 2,

$$V^2 = (66.6)^2(1 - e^{-1.445}) = 3400$$

and

$$V = 58.4 \text{ ft}^2\text{/sec}$$

The kinetic energy then is

$$KE = \frac{1}{2} \times \frac{0.00203}{32.2} \times (58.4)^2 = 0.1071 \text{ ft-lb.}$$

This kinetic energy must be absorbed within a reasonable depth of penetration into the capture medium. The next step, therefore, is to measure the energy absorption by penetration. For this purpose the incendiary particles were simulated by arrows in which the tips were styrofoam balls of 1/8, 1/4, or 1/2 ml volume, the shafts were balsa wood, and instead of feathers, paper fins were used at the rear for stability. The shafts and fins were tailored so that the total weight of the arrows divided by the volume of the styrofoam balls gave an apparent density equal to that of solid white phosphorus--namely, about 1.85. A notch was cut at the back of each shaft so that gram weights could be hung by fine threads for the static penetration tests.

The penetration data were obtained by noting the depth of penetration for various loads on the arrow. By measuring the area under the resulting curves of penetration depth versus load and replotting it as energy absorbed versus penetration depth, one can then readily determine penetration depth for any kinetic energy. The use of such an arrow for these tests made it convenient to measure penetration into an opaque medium.

EXPERIMENTS

PRELIMINARY TESTS

Several candidate materials were tried at first. Protein foam, used in firefighting and airport runways, was found not able to support significant weight on an arrow and therefore not capable of absorbing the kinetic energy of the falling WP particles. Ordinary snow was considered, but at the time none was conveniently available, so this was not tried. Carbon dioxide snow also was considered a likely candidate. It was produced by discharging a CO_2 fire extinguisher into a container. However, the CO_2 snow tended to pack, especially after a few minutes, so that it obviously was too firm to stop liquid or semiliquid particles gently.

At this point a member of the Fire Division furnished a bucket of "Purple K" fire-extinguishing powder (potassium bicarbonate treated with silicone) for consideration. This also was packed too heavy and dense, like a bucket full of fine, dry sand. Since one of the original ideas proposed when this project was under negotiation was that of a fluidized bed, it occurred to the writer that here was an opportunity to produce a cold, inert, fluidized bed, using both the dry ice and Purple K powder. Accordingly, a few pounds of dry ice were blown from a fire extinguisher into a bucket, and on top of this about 30 lb of Purple K powder were shoveled slowly. The Purple K increased considerably in bulk volume and appeared to be "boiling." It also provided a soft absorbing medium for a falling particle. To the touch, this fluidized bed felt very cold, but also very soft and without any apparent surface tension. Except for suddenly feeling colder, it was difficult to sense by touch exactly when one's finger penetrated the "boiling" surface.

The production of dry ice by discharging a CO_2 fire extinguisher gives only about 25% efficiency of conversion and, therefore, is not an efficient source for this purpose. Dry ice is furnished to the Chemistry Division in 1-inch-thick slabs twice a week in about 50-lb lots at a cost of approximately $3.75. This was a convenient, low-cost source for these experiments. At first it was believed that granulating the dry ice would give a more rapid boiling action. Three or four pounds of the dry ice slabs were put through a hand grinding mill which produced pea-sized granules. However, the boiling action was so violent that most of the Purple K overflowed the bucket. It was found by trial and error that best results were obtained with blocks of dry ice about 2 x 3 x 1 inches.

An experiment was performed to give some information on the lasting time and the rate of heat transfer to the dry ice by the boiling action. Two blocks of dry ice were cut on a band saw. Each measured 1 1/16 x 2 1/2 x 2 7/8 inches. One was placed in a bucket of Purple K, while the other was placed on a paper towel lying on three layers of corrugated box cardboard. The dry ice in the Purple K was completely vaporized in

2 hours and 25 minutes, while that on the towel and cardboard on the floor lasted 5 hours and 15 minutes. Thus, it is apparent that heat transfer in the fluidized Purple K is a little more than twice what it is in still air.

ARROW PENETRATION TESTS

Purple K fire extinguisher powder consists of potassium bicarbonate ($KHCO_3$), finely ground and treated with a silicone compound to make it insoluble and nonwettable. It is a government-issued stock item supplied by the Chemical Concentrates Corporation, Fort Washington, Pa., to MIL-F-22287A, in 50-lb lots in steel buckets 11 inches in diameter x 15 inches deep, at a cost of about $17.00. This size container appears to be suitable as a convenient collector for the falling white phosphorus particles in the field tests. The area is only slightly less than 1 sq. ft, while the depth is about as much as one would prefer for setting in the ground flush with the surface.

Five pounds of dry ice in blocks averaging about 2 x 3 x 1 inches were placed in the bottom of a Purple K bucket, evenly scattered, and 45 lb of Purple K powder were slowly shoveled on top of the dry ice. The apparent volume increased about 25% due to the boiling or fluidizing action. Gram weights were hung on two arrows, one with a 1/2-ml cube and the other with a 1/2-ml sphere of styrofoam, to obtain load versus penetration curves as shown in Fig. 1. These were replotted as energy absorbed (area under the curves) versus penetration (Fig. 2). As noted earlier, a value of 0.1071 ft-lb or 1,480 g-cm was obtained for a 1/2-ml particle falling 100 ft. This exceeds the range of the curves of Fig. 2, but an extrapolation gives a penetration depth of 34 cm or 13.4 inches, therefore the 15-inch-deep bucket of Purple K would be sufficient.

A drop penetration test was made to check the validity of these calculations. It was difficult to arrange a 100-ft drop test, so the drops were made from a height of 11.2 ft, for which it was calculated the 1/2-ml cube should penetrate 7.5 inches. A total of six drops were made, averaging 7.2 inches penetration, which was considered a reasonably good check.

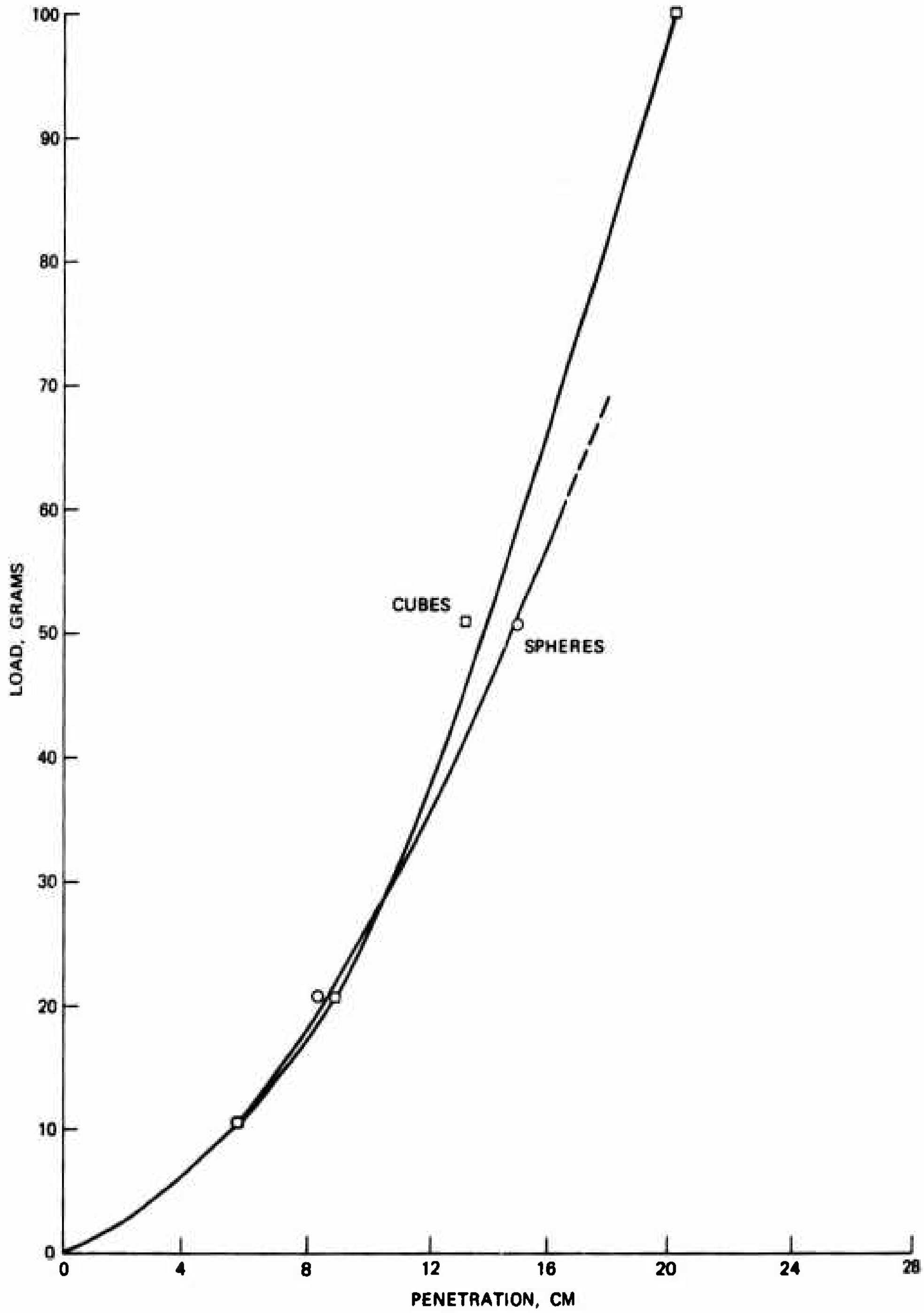

FIG. 1. Penetration of Fluidized Bed by 1/2-ml Arrows.

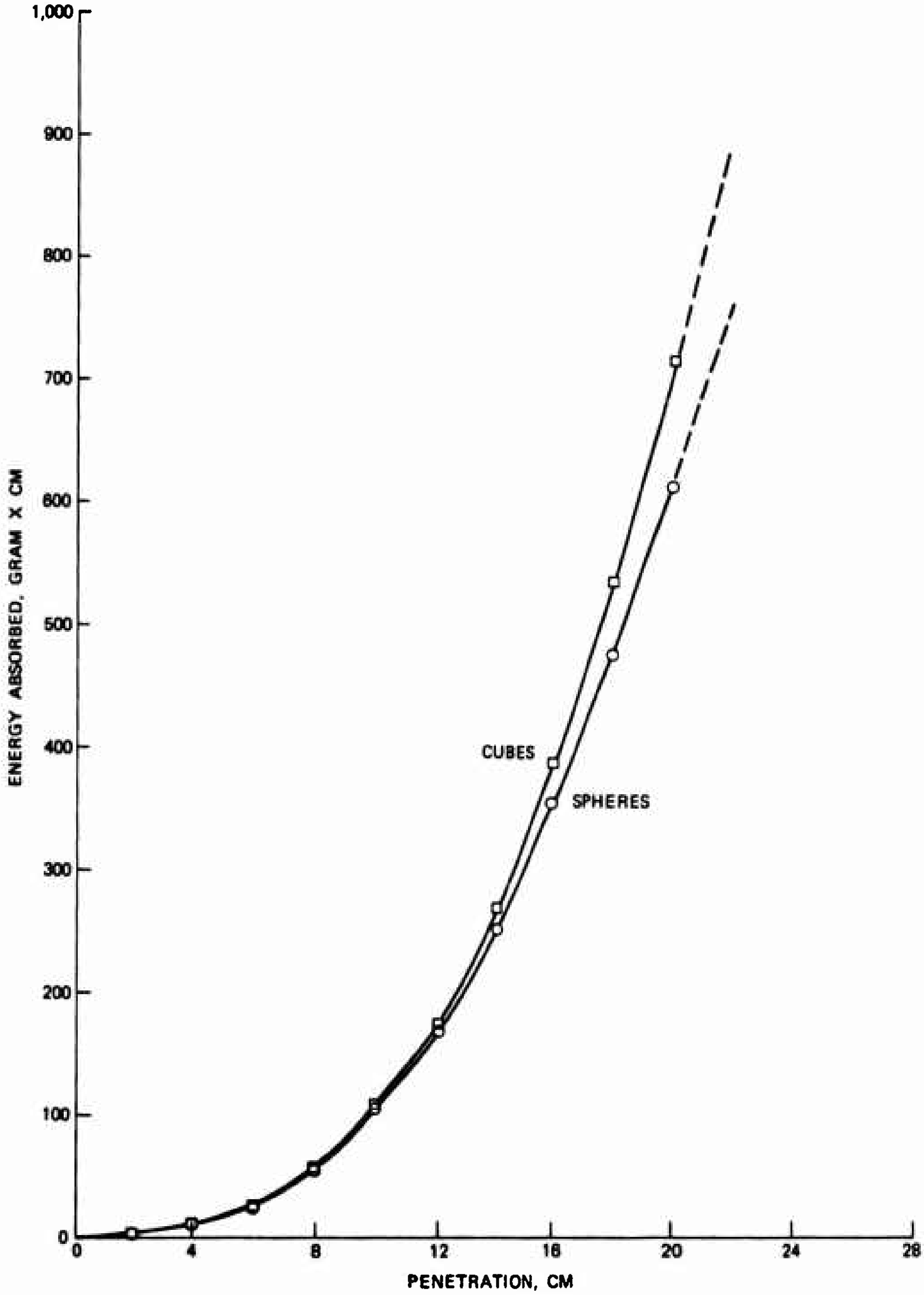

FIG. 2. Energy Absorbed by Penetration by 1/2-ml Arrows.

PHOSPHORUS DROP TESTS

Arrangements were made with the Pyrotechnics Branch (Code 4543) to have 1/8-, 1/4-, and 1/2-ml cubes of white phosphorus cast under hot water into special silicone rubber molds (resembling small ice cube trays). Drop tests were then made from above a 6-ft ladder (about an 8-ft drop) into a bucket of Purple K-dry ice fluidized bed and also into water for comparison. The WP cubes were taken from a pan of water atop the ladder by means of a long metal tweezer, passed through a propane torch flame for good ignition, and allowed to drop.

Figure 3 shows some of the apparatus used in these tests: WP cube trays, blocks of dry ice on the canvas bag, the Purple K in the bucket, and the retrieval screen that is suspended near the bottom of the bucket. Figure 4 shows the purple K "boiling" over the dry ice. Some dust rises from the surface, but note how full the bucket is now compared with when there is no dry ice in it, as in Fig. 3. In Fig. 5 a technician drops phosphorus cubes, after ignition in the torch flame. A burning WP cube is just about to impact into the fluidized bed in Fig. 6. Figure 7 shows the action a fraction of a second after impact. The flame is out; a small dust eruption appears where the burning WP cube entered the surface of the fluidized bed. Two jars of captured burning and falling WP cubes (approximately actual size) are shown in Fig. 8. The large jar contains those captured in the fluidized bed. In this jar are also a few original as-cast cubes which had been dipped in copper sulfate solution and not burned nor dropped; they appear dark. Many of the burned, captured cubes show teardrop shapes and adhering oxides on a corner, indicating the phosphorus had at least partially melted and flowed back by aerodynamic forces during the fall. By contrast, most of the WP cubes in the small jar, which were dropped into water, appear badly shattered and fragmented by impact and steam explosions. This was expected because of the noise at water impact.

FIG. 3. Apparatus Used for Fluidized Bed.

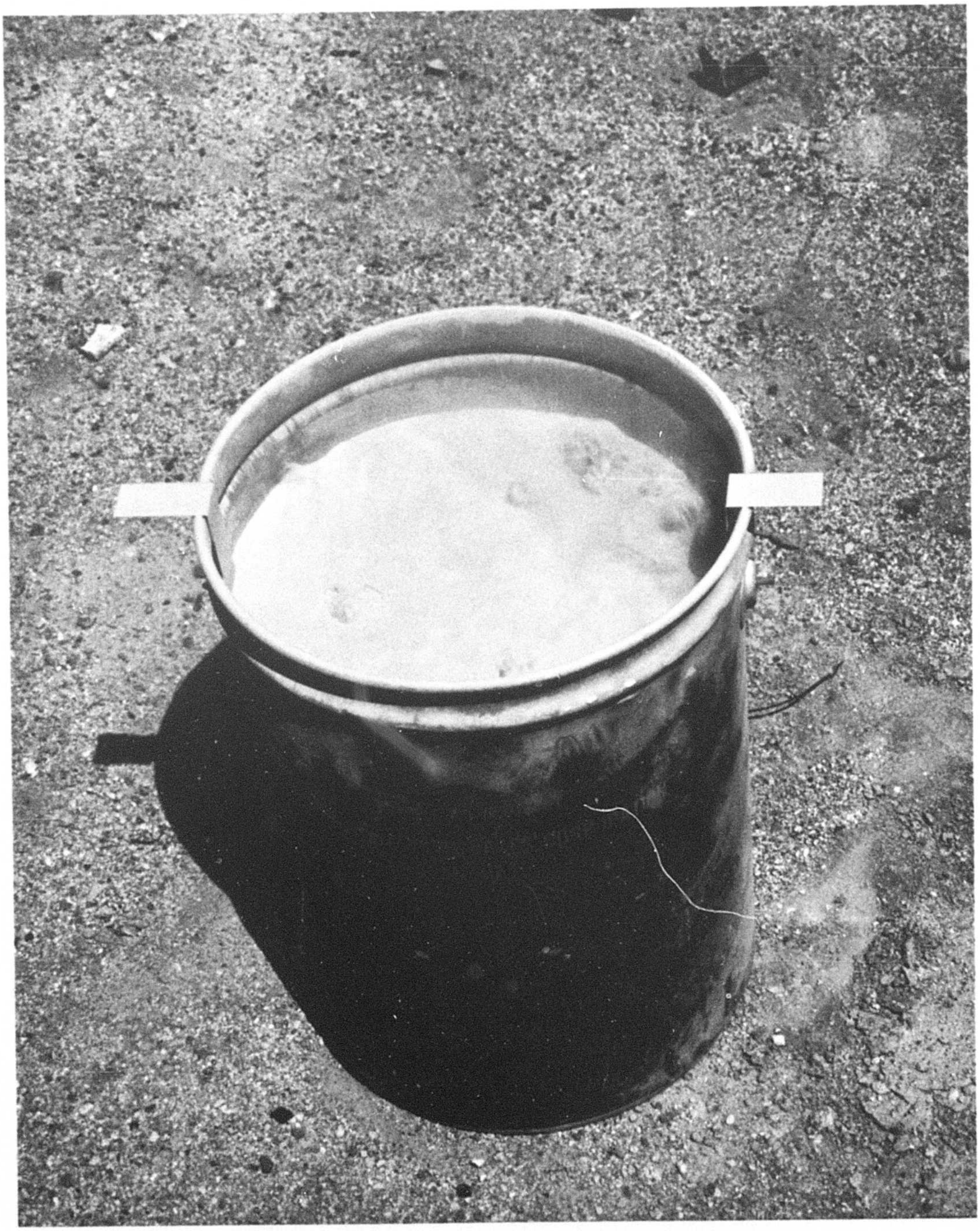

FIG. 4. Dry Ice-Purple K Fluidized Bed.

FIG. 5. Igniting White Phosphorus for Drop Tests.

FIG. 6. White Phosphorus About To Enter Fluidized Bed.

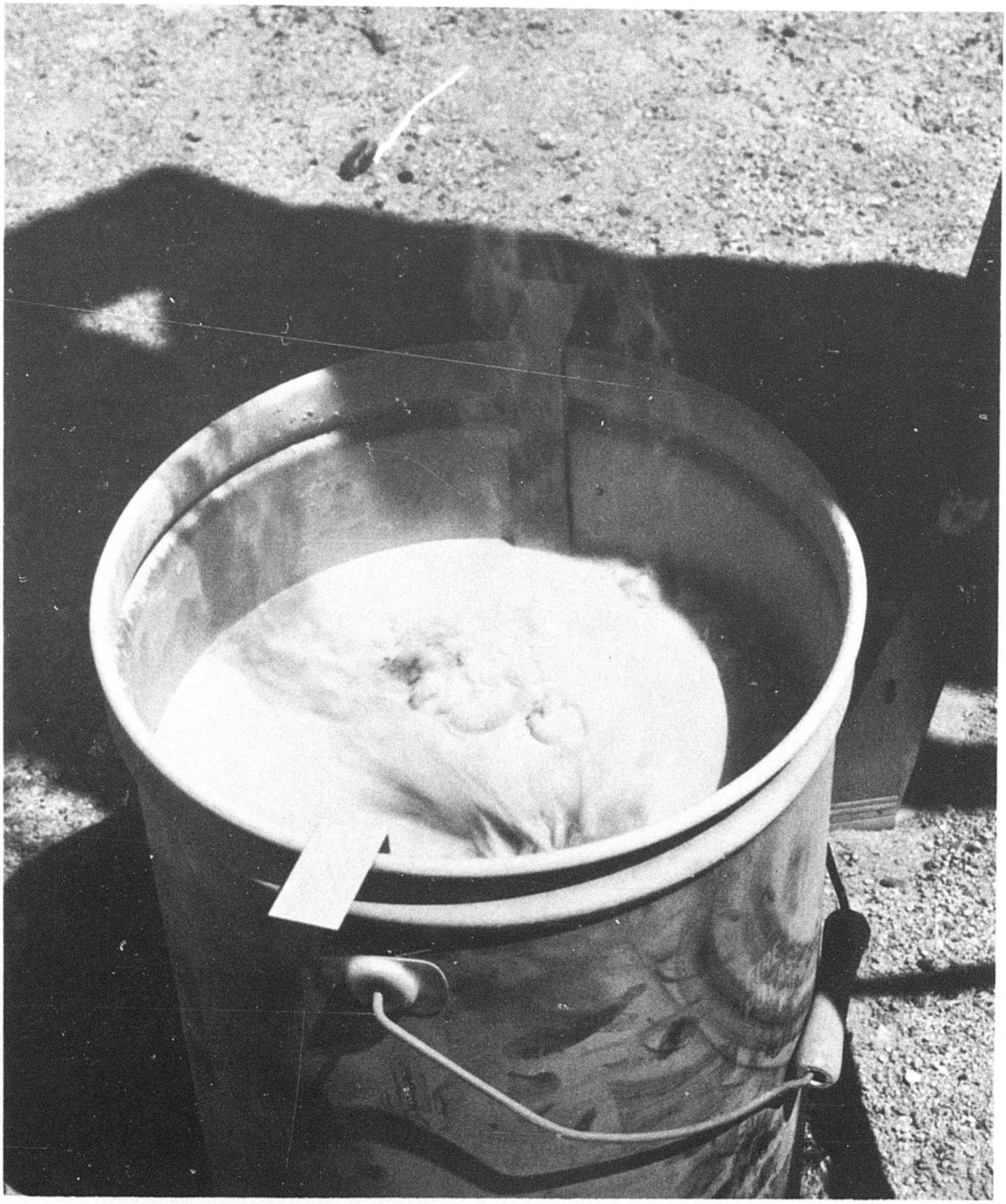

FIG. 7. Entry of White Phosphorus Into Fluidized Bed.

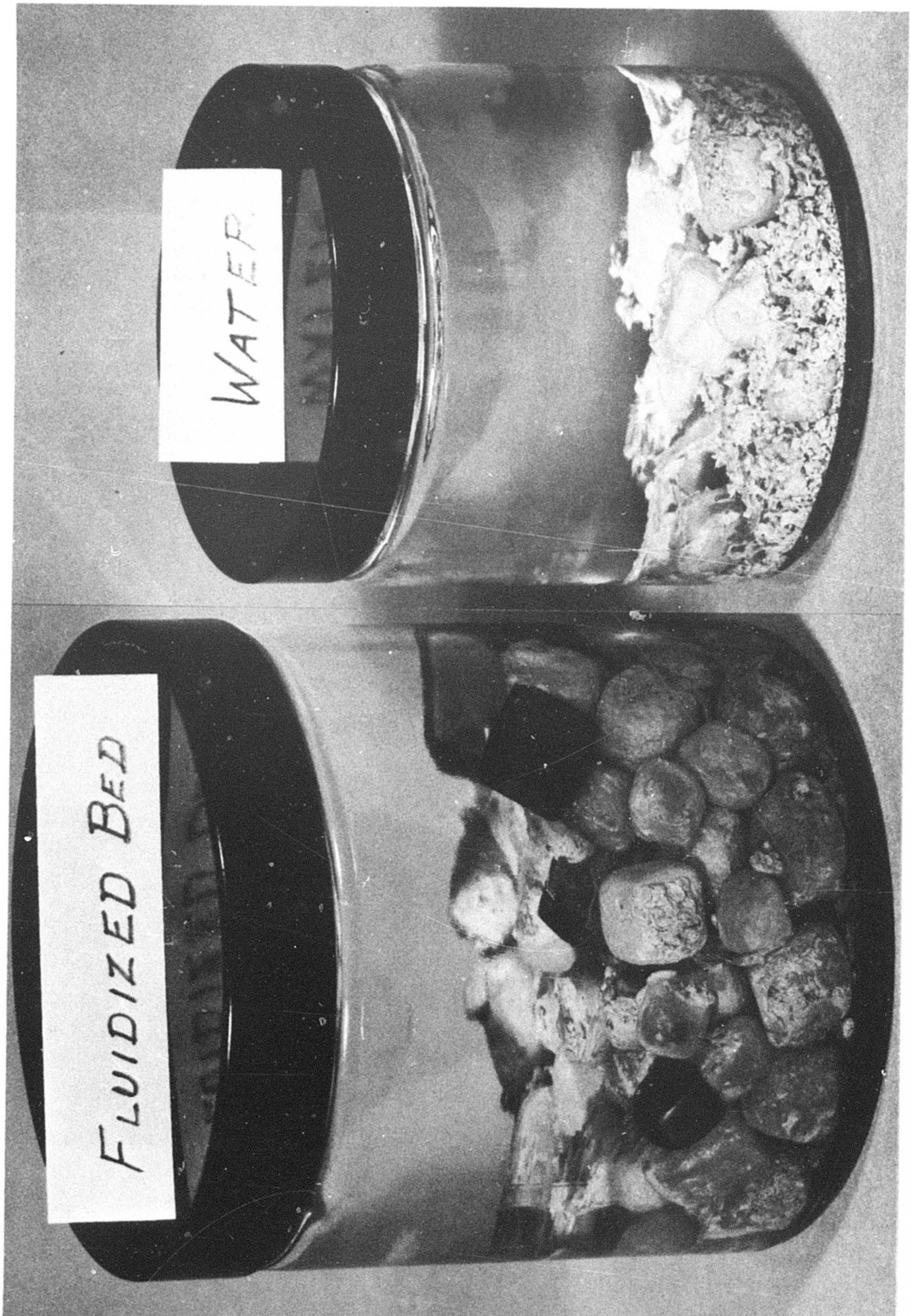

FIG. 8. Captured White Phosphorus Cubes With Some Copper-Plated Original Cubes.

DISCUSSION OF RESULTS

Although drop tests were not made from 100-ft heights, the results indicate that satisfactory recoveries can be expected. It is obvious that 1/2-ml size particles arriving at the bucket after a 100-ft fall would have been much larger at the peak of their trajectory. This would mean a greater rate of fall than calculated in this report, except that the particle was burning violently during the fall and it has been reported that drag coefficients may be increased by a factor of four under such conditions. Because of unknown rates of burning, this effect was neglected. If necessary in practice, some adjustments can be made in bucket depth and dry ice sizes to give a more or less dense fluidized bed. It is also possible to extend the boiling time by simply dropping in more dry ice whenever the action subsides. The new pieces work their way downward in a bed that is still active. In a fully settled bucket of Purple K the pieces must be forced to the bottom with a tool.

Recovery of the captured pieces is accomplished by lifting the screen out of the Purple K. This is made easier if some of the dry ice is placed on the screen instead of all of it being under the screen on the bottom of the bucket; otherwise, the powder may tend to cake and not go through the screen fast enough as it is pulled up.

The nonwetting properties imparted by the silicone coating on the $KHCO_3$ powder are extremely helpful in separating entrained powder from the captured phosphorus. If the screen carrying the phosphorus is set down in a shallow pan of water, a hose can be dipped in the pan and water allowed to run slowly so that it overflows the edge of the pans, carrying away the entrained Purple K.

CONCLUSIONS

1. A simple, inexpensive fluidized bed has been devised, using dry ice and Purple K fire extinguisher powder, for capturing incendiary particles for study.

2. Incendiary particles captured in this fluidized bed are both chilled and prevented from further oxidation until removed.

3. The apparent density of the fluidized bed can be adjusted by regulating the quantity and block size of the dry ice used. Other inert powders should work equally as well.

4. This fluidized bed action lasts more than 2 hours when used in the proportion of 5 lb of dry ice to 45 lb of Purple K. It can be made to last indefinitely if more dry ice is added periodically.

5. The Purple K powder is especially easy to separate from incendiary particles heavier than water because of its nonwetting properties.

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Dry ice						
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