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EVALUATION OF THE SAFETY OF ONE-HOUR CHEMICAL SELF RESCUERS

By

R.W. Watson, W.J. Doyak, and A.L. Furno
Pittsburgh Research Center

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PITTSBURGH RESEARCH CENTER
COCHRANS MILL ROAD
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PITTSBURGH, PENNSYLVANIA 15236

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We are enclosing two copies of the report on the "Evaluation of the Safety c One-Hour Chemical Self Rescuers". A copy of the memorandum to the Chief, Office of Public Information, approving Open File Placement is attached. Tl Open File Report number is OFR 123-80.

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INTRODUCTION

In January 1980, the Bureau of Mines initiated an experimental program to examine the fire and explosion hazards of one-hour self-contained self rescuers (SSRs). This action was prompted by a growing concern on the part of government and industrial safety officials over the potential hazards of these devices when deployed on a large scale in underground coal mines. Prior evaluation of the safety of these devices had been at best sporadic and usually limited to experimental models. The recent availability of preproduction models of a 1-hour SSR fabricated by the Mine Safety Appliance Company* and a production model manufactured by Dragerwerk Ag Lubeck of the Federal Republic of Germany allowed for a more comprehensive and meaningful evaluation of their safety in underground coal mines. This report summarizes the results of a 5-month study of the potential hazards of these two items.

During the course of the work, periodic progress reports were presented to officials of the Mine Safety and Health Administration and various mining organizations including the American Mining Congress, Bituminous Coal Operators of America, National Independent Coal Operators Association, and the United Mine Workers of America. The free exchange of ideas that occurred during these meetings had a significant impact on the direction of this study and a serious attempt was made to address all of the issues that were raised at these meetings. The authors are extremely grateful to the individuals that participated in defining the specific problems that could arise as a result of deploying the self-contained self rescuers in an underground coal mine environment.

ACKNOWLEDGMENTS

The work presented in this report represents the efforts of a large number of individuals, most of whom made contributions outside their normal pursuits. Without their efforts this work could not have been accomplished.

We gratefully acknowledge the members of the Pittsburgh Research Center who participated in the many experiments reported here and in report preparation.

In addition, the authors are extremely grateful for the suggestions and constructive criticism provided by the representatives of the American Mining Congress, Bituminous Coal Operators of America, the Mine Safety and Health Administration, the National Independent Coal Operators Association, United Mine Workers of America and various mining companies who attended the briefings held during the course of the experimental work. Particular mention should be made of the generous efforts of Mr. Jim Gerod of the United States Steel Corporation and Mr. Ralph Hatch of Conoco Inc., in providing samples of the western coals used in some of the experiments. We would also like to thank Dr. Frank Smith of Mine Safety Appliance Company for providing the raw KO_2 used in many of the experiments.

* Reference to specific products does not imply endorsement by the Bureau of Mines.

PRELIMINARY CONSIDERATIONS

The MSA and Drager Self Rescuers

The self rescuers used in this study were the Drager Oxy-SRR 60B and the MSA One-Hour SSR units. The Drager SSR is manufactured by the Dragerwerk AG Lubeck, FRG. The MSA unit is manufactured by the Mine Safety Appliance Company, Pittsburgh, Pennsylvania, U.S.A. Both SSRs are designed primarily to provide oxygen for a minimum period of 60 minutes for emergency escape. In both units the oxygen required for breathing is generated by the reaction of potassium superoxide (KO_2) with the moisture from the breath of the wearer; carbon dioxide is removed by combining with potassium hydroxide formed in the KO_2-water reaction. Both units are closed-cycle requiring no access to the outside atmosphere. Two-minute oxygen candles are included as an integral part of each unit to provide oxygen during the time required for activation of the KO_2. The candle in the Drager SSR is functioned by a lanyard which breaks a water capsule which in turn activates the candle. The candle in the MSA unit also functions when a lanyard is pulled but in this case a percussion-cap combined with an ignitor mix is used to activate the candle. Photographs of the two SSRs are shown in figure 1. The Drager SSR is contained in a rugged plastic case which is 30.2 cm (11.8 in) high and has an oval cross section of 22.0 cm x 13.6 cm (8.7 x 5.3 in) and a wall thickness of 0.40 cm (0.16 in). The KO_2 is contained in an inner stainless steel canister having a height of 21.9 cm (8-5/8 in) (including the boot covering the top of the oxygen candle) and a maximum cross section of 17.8 x 8.9 cm (7 x 3-1/2 in). At the time of writing the Drager unit had passed all of the required life support performance tests and had been approved by both MSHA and NIOSH. The MSA unit used in this study was a preproduction prototype model which had also been approved. The KO_2 canister (figure 1) is 24.8 cm (9-3/4 in) high and has a rectangular cross section of 15.2 x 7 cm (6 x 2-3/4 in); it is also of stainless steel. The canister is contained in a rugged stainless steel case having overall dimensions of 26 x 19 x 7.6 cm (10-1/4 x 7-1/2 x 3 in) and a wall thickness of 0.09 cm (0.035 in). As indicated in figure 1(c) the stainless steel case is protected by a thin wall (.025 cm) plastic outer cover. This outer cover has been eliminated in the final production version of the MSA unit which has now received MSHA and NIOSH approval.

The Drager and MSA units have a total weight of 3.8 kg (8.36 lbs) and 3.97 kg (8.75 lbs) respectively; each unit contains approximately 1.0 kg (2.2 lbs) of KO_2. The KO_2 in the Drager unit was in the form of compressed pellets having a diameter of 0.9 cm (0.35 in) and a maximum thickness of 0.5 cm (0.2 in) and weighing approximately 0.253 gm (3.9 grains). The KO_2 in the MSA unit was of the form of irregular lumps having a maximum width of approximately 1.0 cm (3/8 in); average lump weight was estimated to be 0.239 gm (3.7 grains). Photographs of the lump and pelletized KO_2 are shown in figure 2 along with photographs of lump and pulverized coal used in some of the tests to be described.

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* Convention used here designates heat liberation (ΔH) as a positive quantity; ΔH is specified as Kcal per mole of KO_2.

Properties of KO_2

On an industrial scale, potassium superoxide (KO_2) is produced by the oxidation of dispersed liquid potassium in oxygen enriched air. It is a yellow solid having a specific gravity of 2.14 and a melting point of 380°C (1). On the addition of heat it can decompose to form potassium peroxide according to the reaction:

$$2KO_2 \rightarrow K_2O_2 + O_2 \ (\Delta H = -8 \text{ kcal/mole}) \tag{1}$$

or to form potassium oxide (K_2O) by the reaction:

$$2KO_2 \rightarrow K_2O + 1.5O_2 \ (\Delta H = -23.8 \text{ kcal/mole}). \tag{2}$$

This latter reaction does not occur until the KO_2 is heated to above 425°C (2). Thus by itself KO_2 is a fairly stable chemical substance. However, it reacts readily with water or water vapor to form oxygen according to the reactions:

$$2KO_2 + H_2O(\ell) \rightarrow 2KOH(s) + 1.5O_2 \ (\Delta H = +0.63 \text{ kcal/mole}) \tag{3a}$$

or

$$2KO_2 + H_2O(g) \rightarrow 2KOH(s) + 1.5O_2 \ (\Delta H = +5.9 \text{ kcal/mole}) \tag{3b}$$

If excess water is present reaction (3a) can be considerably more exothermic due to the heat of solution of KOH (3) as follows:

$$2KO_2 + H_2O(\ell) \rightarrow 2KOH(aq) + 1.5O_2 \ (\Delta H = +13.2 \text{ kcal/mole}) \tag{3c}$$

The KO_2-water reaction combined with the reaction of carbon dioxide (CO_2) with KOH,

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O(g) \ (\Delta H = +17.1 \text{ kcal/mole}) \tag{4}$$

makes KO_2 uniquely suitable for use in closed-cycle breathing equipment where both the generation of oxygen and the elimination of carbon dioxide are essential.

Other important reactions of KO_2 are the reaction with carbon,

$$4KO_2 + 3C \rightarrow 2K_2CO_3 + CO_2 \quad (\Delta H = +93.5 \text{ kcal/mole}) \tag{5}$$

or with coal in roughly stoichimetric proportions,

$$\begin{gathered} 88\%\ KO_2 + 12\%\ \text{coal} \rightarrow \\ 0.519\ K_2CO_3 + 0.202\ KHCO_3 + 0.159\ CO_2 + 0.103\ C \\ (\Delta H = +86.0 \text{ kcal/mole}) \end{gathered} \tag{6}$$

or with fuel oil or hydraulic fluid

$$91\%\ KO_2 + 9\%\ \text{oil} \rightarrow$$

$$0.616\ K_2CO_3 + 0.848\ KOH + 0.665\ H_2O + 0.020\ C$$

$$(\Delta H = +86\ \text{kcal/mole}) \qquad (7)$$

The foregoing chemical equations enable us to draw certain conclusions regarding the potential hazards of KO_2 but they are inadequate for a complete description of these hazards. For example, equations (1) and (2) show that KO_2 alone does not pose much of a hazard since relatively high temperatures are required to chemically decompose the substance and further, the decomposition reactions are endothermic (do not release energy); thus KO_2 does not possess any inherent explosive properties. Equations (3) through (7) indicate that KO_2 can react with water, moist CO_2 or combustible materials to produce considerable heat. However, they give no information regarding the ease of initiation or rates of temperature rise associated with the various reactions. As a consequence, a number of small-scale laboratory experiments were conducted to further quantify the nature of these reactions. The experiments included burning rate studies of various KO_2-combustible mixtures, studies to determine the temperature rise associated with KO_2-water and KO_2-CO_2 reactions and tests to determine the impact and friction sensitivity of varous KO_2-combustible mixtures.

Burning Rates of KO_2-Combustible Mixtures

While KO_2 is a well known oxidizer, little quantitative information could be found regarding its "strength", i.e. how readily it gives up oxygen. Some years ago, the Bureau of Mines developed a burning rate test (4) for the purpose of ranking oxidizers according to this ability. In this test, burning rates of oxidizer-fuel mixtures are measured using the apparatus depicted in figure 3. It consists of a rectangular rack that is mounted horizontally and equipped with a 60-mesh steel screen to support the sample. The sample bed is separated from the side rack mounts to insure unrestricted burning along the sides of the sample. To form a sample bed, the oxidizer-fuel mixture is placed on the rack between two spacer bars which fix the bed size and are removed before ignition. The sample is ignited with a propane torch and the burning rate is determined by measuring the burning time between two fuse-wire stations with an electric timer. In the standard test, the oxidizer is mixed with select-grade oak sawdust; the sample size is ordinarily 17.8 cm (7 in) long by 5.08 cm (2 in) wide by 2.54 cm (1 in) high. Results of the application of this test to various KO_2-combustible mixtures are presented in table 1 along with results obtained with several other oxidizers. It will be noted that the burning rate of the KO_2-sawdust mixture was considerably in excess of that observed with other more common oxidizers indicating that KO_2 is indeed a very "powerful" oxidizing material.

It was also of interest to determine the burning rate of coarse KO_2-coal mixtures. For this purpose lump KO_2 was mixed with three different crushed bituminous coals (0.64 to 1.0 cm lumps) and tested in a larger bed chosen to give a more accurate burning rate measurement. The coals were dried at 70°C for 24 hours prior to testing. The results of these tests are also presented in table 1. The highest burning rate was observed with the Pittsburgh Seam coal which was somewhat lower than that observed with the pulverized KO_2-sawdust mixtures. As will be discussed later, the Emery and Somerset coals were judged to be somewhat more reactive than the Pittsburgh Seam coal on the basis of some small-scale self-heating tests. This higher reactivity was not reflected in the burning rate shown in table 1.

One other series of tests was performed with coarse KO_2-coal mixtures. This series was designed to determine the effect of moisture on the burning rate. For this purpose coarse KO_2 was added to the three crushed coals which were wetted with 5% water before mixing. The mixtures were immediately ignited to minimize decomposition resulting from the KO_2-water reaction. The burning rates observed in these tests are shown in parentheses after the corresponding values for the dry mixes. As can be seen the addition of small amounts of water very significantly reduces the KO_2-coal burning rates.

Reaction of KO_2 With Water and Carbon Dioxide

The reaction of KO_2 with water is an important one in assessing the potential hazards of KO_2 since it produces significant quantities of heat. The reaction of KO_2 with moist CO_2 is interesting for the same reason. (KO_2 will not react with dry CO_2 and therefore, it is really the KO_2-water-KOH-CO_2 reaction we are concerned with.) In principal, the temperature rise associated with these reactions [equations (3a, b, and c) and (4)] can be calculated given the details of the reacting system, i.e. the amounts of KO_2, water, and CO_2 involved, the container material and mass, specific heat and thermal conductivity of all the materials, and appropriate thermochemical properties. In practice it is necessary to make measurements of the temperature rise associated with these reactions to check the theoretical calculations. This was done for KO_2 activated by water and moist CO_2 using the experimental arrangement shown in figure 4.

The apparatus consisted of a 4-liter dewar flask insulated with a layer of asbestos. The flask was equipped with a coiled metal feed tube for injecting either water or moist CO_2 into a bed of KO_2 placed in the bottom of the flask. In some tests the KO_2 was covered with a layer of crushed Pittsburgh Seam coal (-1/4 mesh) to insulate the KO_2 layer and also to determine if ignition of the coal could be brought about by the heat generated by the KO_2 reaction. Temperatures were determined with thermocouples placed in the KO_2 and at two positions in the overlying coal bed, 2.54 cm (1.0 in) and 10.16 cm (4.0 in) above the KO_2-coal interface.

The first test using this arrangement involved 1000 gm of KO_2 covered with 2500 grams of crushed coal. The KO_2 was reacted with 715 cc of water slowly added until no further increase in temperature could be detected at the thermocouple stations. The results given in table 2 show that the KO_2 reached a maximum temperature of 150°C, 140 minutes after the start of water injection. The temperature of the coal at this time was 150°C at the station 2.54 cm (1.0 in) above the KO_2-coal interface and 68°C at the upper station. These were the maximum coal temperatures recorded. Assuming an average coal temperature of 75°C and no external heat losses, simple thermodynamic calculations yield an energy release of approximately 10 kcal/mole of KO_2 for the KO_2-water reaction. This is somewhat less than the value of 13.2 kcal/mole quoted in reference (3) for this reaction. However, the agreement is reasonable con-

TABLE 1. - Burning rates of various oxidizer-fuel mixtures

Mixture	Bed Size (cm)	Burning Rate (cm/sec)
50% Pulverized KO_2 50% Sawdust	17.8 x 5.08 x 7.54	25
50% Sodium Peroxide 50% Sawdust	"	6.35 1/
50% Ammonium Perchlorate 50% Sawdust	"	1.52 1/
50% Lump KO_2 50% Pgh. Seam Coal	"	16.1 (.31) 2/
50% Lump KO_2 50% Emery Coal	"	5.9 (.39)
50% Lump KO_2 50% Somerset Coal	61 x 5.08 x 2.54	9.7 (.35)

1/Taken from reference (4).
2/Results in parentheses obtained with coal wetted with 5% water.

sidering that the value of 13.2 kcal/mole corresponds to infinite dilution of the KOH formed in the KO_2-water reaction; experimental conditions here allow only partial dilution of the KOH with reduced heat of solution. In this experiment no thermal reaction of the coal was observed.

In the second experiment, 1000 grams of KO_2 covered with 2500 grams of crushed coal was reacted with water and water-saturated air containing 5% CO_2. To start the experiment 130 cc of water were added to the KO_2 which raised the KO_2 to a maximum temperature of 124°C in 30 minutes. At this time the moist air-CO_2 mixture was injected into the KO_2 bed at a rate of 0.05 ℓ/min. The thermal records show no detectable increase in temperature associated with the addition of small quantities of moist air-CO_2. Subsequent injections of water for a total of 455 cc including the initial 130 cc raised the temperature of the KO_2 to a maximum of 150°C after 320 minutes. The coal reached a maximum temperature of 126°C at the 2.54 cm (1.0 in) station and 52°C at the 10.16 cm (4.0 in) station at approximately the same time. These temperatures are somewhat lower than those observed in the first experiment possibly due to a cooling effect produced by the flowing air-CO_2 mixture. Again as in the case of the first experiment, no thermal reaction of the coal was induced by the heat generated during the KO_2 reaction. The results of this test are also presented in table 2.

In a third experiment 1000 grams of KO_2 was reacted with water saturated air and 5% CO_2 to determine the temperature rise associated with this reaction alone. The results, also presented in table 2, show that the KO_2 temperature rose to 24°C after 20 minutes at a flow rate of 1.0 liter/min. Increasing the flow rate to 3.0 liters/min resulted in a temperature of 126°C after 200 minutes and a further increase in the flow rate to 4 liters/min resulted in a temperature of 273°C. Thus the temperatures attainable through this reaction are significantly higher than those observed for the KO_2-water reaction which is reasonable considering the relative energetics of the two reactions given by the equations (3) and (4).

Sensitivity of KO_2-Fuel Mixtures to Impact and Friction

The fact that KO_2-fuel mixtures are highly flammable has already been demonstrated by the burning-rate tests described earlier. In these tests the KO_2-fuel mixtures were easily ignited with a hot flame. In analyzing the potential hazards of KO_2, it is of interest to know something about the impact and friction sensitivity of such mixtures. For this reason, various KO_2-fuel mixtures were evaluated using two sensitivity tests commonly used at the Bureau for determining the sensitivity of coarse physical mixtures. These are the 85 kg drop weight impact test and the so called sliding rod friction test.

In the drop weight test, an 8.0 gram sample of test material is distributed in a uniform layer over a 10 cm (4.0 in.) diameter circular steel anvil. The sample is then struck by an 85 kg steel drop weight released from various heights to determine a go/no go condition.

Results of drop weight tests for KO_2 alone and KO_2 mixed with Pittsburgh Seam coal, hydraulic oil, and No. 2 diesel fuel oil are presented in table 3. It will be noted that there was no reaction with KO_2 alone at the maximum drop height of 2.4 m (8.0 ft). This result, of course, is in keeping with the ther-

TABLE 2. - Reaction of KO_2 with water and CO_2

Mixture	Time (Min)	Total H_2O (cc)	Moist Air + CO_2 (ℓ/Min)	Maximum Temperatures (°C)		
				KO_2	Coal (2.54 cm)	Coal (10.16 cm)
1000g KO_2 + 2500g coal	140	715	0	152	150	68
1000g KO_2 + 2500g coal	320	455	0.05	150	126	52
1000g KO_2	20	0	1.0	24	---	--
	200	0	3.0	126	---	--
	400	0	4.0	273	---	--

TABLE 3. - Results of 85 kg drop weight tests

Test Material	Results	Material Response
Lump KO_2	No go at 2.4 m	Material crushed, no reaction
50% Lump KO_2 50% Pulverized Coal	No go at 0.3 m	Material crushed, no reaction
	Go at 0.6 m	Loud noise, material consumed
91% Lump KO_2 9% Hydraulic Oil	No go at 0.45 m	Material crushed, no reaction
	Go at 0.61 m	Loud noise, material consumed
91% Lump KO_2 9% No. 2 Diesel Fuel	No go at 0.45 m	Material crushed, no reaction
	Go at 0.6 m	Loud noise, material consumed
5010 Smokeless Powder	No go at 0.3 m	Material crushed, no reaction
	Go at 0.6 m	Loud noise, material consumed

mochemical nature of KO_2 discussed earlier. However, all of the KO_2-fuel mixtures could be initiated at drop heights as low as 0.6 m (2.0 ft) indicating a high degree of sensitivity to mechanical stimuli. The observed reactions were explosive in the sense that they produced loud reports. As shown in table 3, similar results were obtained with a military grade smokeless powder. It should be mentioned that there was no evidence of spontaneous heating when the KO_2-fuel oil and KO_2-hydraulic oil mixtures were prepared. This was also true of KO_2-gasoline mixtures.

The sliding rod friction test used at Bruceton consists of a 5.08 cm (2.0 in) diameter, smooth steel anvil located at the bottom of an inclined aluminum trough having a maximum usable vertical height of 140 cm (55 in). A 5.0 kg (10 lb) cylindrical impact tool having a length of 29.8 cm (11.75 in) and a diameter of 5.08 cm (2.0 in) and a hemispherical nose is slid down the inclined trough to impact the test sample placed on the steel anvil at the point of impact. The results are expressed in terms of the vertical release height required to induce reaction; the interval used is 13 cm (5 in) with 25.4 cm (10 in) being the lowest height available.

Results of sliding rod friction tests are presented in table 4 for lump KO_2 and lump KO_2 mixed with three different fuels. As in the case of the drop weight tests, no reactions were observed with plain KO_2 at the highest stimulus level available (140 cm); however, the KO_2-fuel mixtures all reacted at or near the lowest level of 26 cm. Again, the reactions were explosive in nature in the sense that they were accompanied by both flame and noise.

It was also of interest to determine the potential effect of moisture on the sensitivity of KO_2-coal mixtures. An attempt to do this was made with the sliding rod friction test since it was possible with this test arrangement to minimize the time of exposure of KO_2 to moist coal thus reducing the decomposition of KO_2 in the presence of moisture. For this purpose, four batches of coal dust were prepared having 0, 5, 10, and 20% added moisture. Layers 0.034 cm (1/16 in) thick were then spread over the anvil and a single lump of dry KO_2 was placed on the coal dust layer at the point of impact. The sliding rod was then immediately released from a preset height of 25.4 cm (10 in). The sults of these tests shown in table 4 indicate a significant desensitizing effect due to the presence of moisture in excess of 5%.

EVALUATION OF THE SAFETY OF KO_2 SELF RESCUERS

Before discussing the actual tests with the SSRs, it is desirable to outline the reasoning behind the various experiments. From preliminary considerations, we have seen that KO_2 can generate considerable heat when reacted with water or moist CO_2. We have also seen that the KO_2-combustible mixtures are readily ignited by flame, impact, or friction. These characteristics along with the configuration of the self rescuers and the usage environment serve to broadly define the hazards of the self rescuers. All questions of the form "what if this happens" or "what if that happens" can be generalized as follows:

In a mine environment,

(1) What hazards do the self rescuers pose if they remain essentially intact?

TABLE 4. - Results of sliding rod friction tests

Test Material	Test Results
Lump KO_2	0/5 goes at 140 cm
Lump KO_2 Pulverized Pgh. Coal	5/5 goes at 25.4 cm
Lump KO_2 Hydraulic Oil	0/5 goes at 25.4 cm 5/5 goes at 38.1 cm
Lump KO_2 No. 2 Diesel Fuel	5/5 goes at 25.4 cm
Lump KO_2 Coal Dust	5/5 goes at 25.4 cm
Lump KO_2 Coal Dust + 5% Moisture	5/5 goes at 25.4 cm
Lump KO_2 Coal Dust + 10% Moisture	1/5 goes at 25.4 cm
Lump KO_2 Coal Dust + 20% Moisture	1/5 goes at 25.4 cm

(2) What mechanical abuse can the self rescuers sustain without releasing KO_2?

(3) What are the consequences of the release of KO_2?

The experiments to be discussed were designed to answer these three basic questions.

In answer to question (1), experiments were designed to determine the potential hazards of essentially intact self rescuers. These included tests to determine the potential ignition hazards of self rescuers exposed to water and rifle fire as well as tests to determine the behavior of self rescuers exposed to external fire.

In answer to question (2), a number of mechanical integrity tests were performed including 1000 pound drop tests, runover tests with various mine vehicles, and tests with a feeder breaker.

In answer to question (3), situations where mechanical failure of the units with attendant release of KO_2 could occur were examined in some detail with emphasis on events that might happen in a mine environment.

The results of these series of experiments will be discussed in the following sections of the report.

Water Stimulation of KO_2 Self Rescuers

It is easy to envision a self rescuer being accidently buried in a coal pile through the action of a roof-fall or similar incident. The question arises as to whether the self rescuer, either damaged or undamaged, poses a short term ignition hazard or a longer term spontaneous combustion hazard. In view of the thermal stability of KO_2 and in the absence of flame or mechanical disturbances, this could only come about if the KO_2 in the self rescuer was exposed to some external stimulus such as water, moist air, or moist air containing appreciable CO_2. The CO_2 reaction has the potential for generating the highest temperatures but requires unrealistically high flow rates (~N ℓ/min) to generate these temperatures. This flow rate would require the complete purging of the free space in the self rescuer every 15 seconds which is impossible to visualize in any real-life situation involving natural convective flow impinging on a slightly damaged unit. Therefore, invasion by water is the only practicable way of significantly elevating the temperature of a buried self rescuer. We have seen that temperatures of the order of 150°C are available through the interaction of KO_2 and water. This is near the ignition temperature of some coals which is as low as 160°C for layered bituminous coal dust (5). However, due to the presence of free oxygen resulting from the KO_2-H_2O reaction, it is impossible to predict, apriori, whether a water activated KO_2 canister could ignite coal. This is due to the fact that oxygen could depress the ignition point of coal as it is known to do for other substances. For example, it is reported that the minimum ignition temperature of cotton sheeting in air, 465°C, is lowered to 360°C in pure oxygen (6). Unfortunately similar data are not available for coal. For this reason, a series of experiments were conducted to determine if, in fact, the ignition of coal could be brought about by the water activation of a KO_2 self rescuer.

The experimental arrangement illustrated in figure 5 was used for this purpose. It consisted of a 61 cm (24 in) diameter by 61 cm (24 in) high, steel drum filled with crushed coal. A KO_2 canister from a self rescuer fitted with a water feed pipe was completely buried in coal in a vertical position with the bottom of the unit roughly 7.6 cm (3 in) above the bottom of the drum. The canister was equipped with internal and external thermocouples to monitor the temperature of the KO_2 and the temperature of the metal case. Thermocouples were also used to monitor the temperature of the oxygen escaping from the unit and the temperature of the coal at three different points. The positioning of the thermocouples is shown in figure 5 and a photograph of an MSA unit with a copper flow tube attached is shown in figure 6a. In order to simulate worst conditions the external covers of the self rescuer, were removed for these trials in order to promote maximum heat transfer to the coal. A photograph showing a unit buried in the coal filled drum is shown in figure 6b.

Thermocouple records from a trial with a MSA unit buried in dry Pittsburgh Seam coal crushed to a nominal size of 1.0 to 0 cm (3/8 to 0 in), are shown in figure 7. For purposes of clarity, only those records corresponding to the maximum observed temperatures of the KO_2, case, oxygen and coal are reproduced here. At the beginning of the experiment (t = 0 min), 250 cc of water were injected into the canister. This is about twice the amount of water required to completely reduce 1000 grams of KO_2 to KOH and O_2 (127 grams of H_2O). As can be seen from the records, the KO_2 reached a maximum temperature of 129°C (thermocouple #2) in about 9 minutes after the addition of the water. The maximum case temperature was observed to be 78°C (thermocouple #7) and this occurred 17 minutes after the addition of the water. The oxygen temperature at one of the outlets (thermocouple #6) rose to a maximum of 94°C in 21 minutes. The coal temperature reached 37°C (thermocouple #0) approximately 71 minutes after the addition of water. After this trial was started, an additional 250 cc of water was added at t=75 minutes. The effect of this second addition of water can be seen as inflections in the temperature time curves of figure 7; it did not increase the KO_2, case or oxygen temperatures beyond the maximum value recorded for the initial injection of 250 cc. However, the coal temperature did gradually increase to a maximum of 40°C.

In this experiment which is summarized in table 5, there was no indication of any exothermal reaction in the coal induced by the heat associated with the water activation of the KO_2 canisters. This is not surprising since the maximum temperature observed in the coal was only 40°C which is far below the ignition temperature of Pittsburgh seam coal which is about 170°C for dust layers (5).

A similar trial was conducted using a Drager canister in this same test arrangement. The plastic exterior case of the unit was removed to improve heat transfer. As in the case of the MSA trial, 250 cc of water were injected into the unit at the start of the experiment. After 30 minutes another 150 cc of water were injected and another 50 cc were added 30 minutes after this. The maximum temperatures observed in this test along with their time of occurrence are also presented in table 5. It will be noted that the maximum observed temperatures for the KO_2 and case were roughly the same as those observed in the trial with the MSA unit. However, the oxygen efflux temperature for the Drager unit was significantly lower than that observed for the

Table 5. - Water activation of KO_2 canisters in coalbeds

Canister	Coalbed	Maximum temperature (time) °C (min)			
		KO_2	Case	O_2	Coal
MSA	Crushed Pittsburgh Seam	129(9)	78(17)	94(21)	40(120)
Note: 250 cc H_2O added at t=0 and at t=75 min.					
Drager	Crushed Pittsburgh Seam	107(34)	76(34)	59(30)	38(30.5)
Note: 250 cc H_2O added at t=0; additional 150 cc added at t=30 min and at t=60 min.					
MSA	Crushed Pittsburgh Seam wetted with hydraulic fluid	128(9)	106(2)	103(11)	87(2)
Note: 250 cc H_2O added at t=0; and at t=75 min.					

MSA unit, 59°C compared to 94°C. The maximum observed coal temperature was somewhat lower in the Drager test. Again the maximum coal temperature was far below that required for the ignition of Pittsburgh seam coal and there was no evidence of coal reaction.

A third test was conducted with the experimental arrangement of figure 5 in order to determine if coal soaked with hydraulic fluid might be more prone to ignition by heat generated by a buried self rescuer. This was suggested as a realistic mine scenario. For this purpose, a test was conducted with an MSA unit buried in Pittsburgh Seam coal (3/8 x 0 in) which was liberally wetted with a mineral base hydraulic oil. The oil used was Texaco Rando Oil 68 which is reported to have an autoignition temperature of 365°C and a flash point of 218°C. The results of this test are also presented in table 5. The observed temperature for the KO_2 was essentially the same as that observed in the first trial with an MSA unit. Case and oxygen temperatures were somewhat higher but the maximum coal temperature of 87°C was significantly higher than the 40°C value observed in the first test. This was attributed to better heat transfer to the coal thermocouple due to the presence of the hydraulic oil since no evidence of coal combustion could be found after careful examination of the area in and around the thermocouple. The three trials with water activated canisters offer evidence that there is little likelihood that a buried canister could ignite coal either with or without hydraulic oil. However, they were limited to a single variety of coal and, in addition, they did not yield any information on the effect of free oxygen or the presence of hydraulic oil on accelerating (or retarding) the ignition of coal. For these reasons, two other types of coal were obtained and a number of additional experiments were conducted to further explore these points.

Ignition Tests With Different Coals

Through the generous efforts of Mr. Jim Gerod of the U.S. Steel Corporation and Mr. Ralph Hatch of Conoco, Inc., coal samples from the Somerset Mine in Somerset, Colorado, and the Emery Mine in Emery, Utah, were made available for test purposes. Both were bituminous coals with a history of spontaneous heating. Proximate and ultimate analyses of the two coals are presented in table 6 along with data from Pittsburgh Seam (Bruceton) coal. Estimates of the ignition temperatures of these three coals were obtained using a modification of ASTM D-2155 apparatus. With this test arrangement, 50 gram samples of pulverized coal contained in a 500 cc vessel are uniformly heated to a constant temperature in the presence of air. The temperature is raised until self heating of the coal is observed. Results of trials with Pittsburgh, Somerset, and Emery coals are presented in table 7.

With Pittsburgh Seam coal pulverized to 100 - 200 mesh some self heating was observed when the coal was uniformly heated to 140°C. However, the coal did not ignite. The finely pulverized (100 - 200 mesh) Emery and Somerset coals exhibited some self heating with initial temperatures as low as 110°C. When heated to 120°C both samples exhibited appreciable self heating and eventually ignited. With coarse samples (1 to 0 cm) some self heating was observed at temperatures as low as 150°C but no ignitions were observed even with samples heated to 200°C. The tests indicate that the two Western coals have about the same reactivity and are significantly more reactive than the Pittsburgh seam coal.

TABLE 6. - Analyses of "as received" coals

Proximate Analysis	Pittsburgh Coal	Emery Coal	Somerset Coal
Moisture	1.5	2.9	3.2
Volatile Matter	38.9	40.0	37.5
Fixed Carbon	55.8	47.3	47.0
Ash	3.8	9.8	12.3
Ultimate Analysis			
Hydrogen	5.6	5.2	5.2
Carbon	79.7	71.5	70.0
Nitrogen	1.8	1.1	1.2
Sulfur	1.2	0.7	0.6
Oxygen	7.9	11.8	10.6
Ash	3.8	9.8	12.3
Heating Value (Btu/lb)	14,500	12,551	12,421

Table 7. - Results of small scale self-heating tests with three different coals

Coal Type	Coal Size	Initial Temperature °C	Final Temperature °C
Pittsburgh Seam	100 - 200 mesh	140	295
	1 cm x 0	160	195
		200	250
Emery	100 - 200 mesh	110	135
		120	>500
	1 cm x 0	150	160
		200	238
Somerset	100 - 200 mesh	110	130
		120	>500
	1 cm x 0	150	160
		200	270

Tests With a "Thermal Simulator"

In order to obtain more information for assessing the potential ignition hazards of buried canisters, additional ignition experiments were conducted using a "thermal simulator". The purpose of the simulator was to more or less duplicate the geometry and oxygen-flow characteristics of a KO_2 canister but allow for more control over the quantity of oxygen and thermal energy available for coal ignition. If these quantities turned out to be much greater than those available from a water stimulated KO_2 self rescuer, then it could be concluded with certainty that the self rescuers posed no ignition hazard in this particular failure mode. A sketch of the simulator experiment is shown in figure 8.

In essence, the simulator consisted of a 17.8 x 12.7 x 7.6 cm (7 in x 5 in x 3 in) box constructed of 0.1 cm (0.040 in) aluminum sheet metal. The exterior of the box was wrapped with No. 22 nichrome heater wire which was connected to a variable power supply to control the temperature. A length of 0.63 cm (1/4 in) I.D. aluminum tubing entered the top of the box, encircled the interior, and exited at two points along one side of the box. The aluminum tubing in the interior of the box was also wrapped with No. 22 nichrome heater wire supplied with independent power. The purpose of the aluminum tubing was to provide a source of heated oxygen to simulate the action of the KO_2 canisters. The temperature of the simulator case could be controlled over the temperature range from ambient to 200°C; oxygen outlet temperatures were variable over the same range.

Initial tests were conducted using the simulator to explore the ignition of crushed Pittsburgh, Somerset and Emery coal at approximately 150°C. The ex perimental arrangement used for this purpose (figure 8) was basically the same as was used in the water stimulation trials with KO_2 (figure 5) except that the thermal simulator replaced the self rescuer as a source of heat and oxygen.

Records from a trial with dry crushed Pittsburgh coal 1 to 0 cm (3/8 to 0 in) are shown in figure 9. During this experiment, the heating elements on the case and O_2 feed tube were adjusted to maintain an exterior case temperature and oxygen efflux temperature of approximately 150°C. Oxygen flow rate was adjusted to 12.6 ℓ/min which was initial flow rate of oxygen from a 1-hour self rescuer simulated with 250 cc of water as observed in independent experiments.

As the thermal records show, the external case and oxygen efflux temperatures were stabilized at approximately 150°C about 2 hours after start-up. During the first 7 hours of run, the coal in the vicinity of the #5 thermocouple (See figure 8) heated from ambient temperature to about 134°C. The coal reached the same temperature as the simulator in about 9 hours and at the end of 9-1/2 hours the coal temperature exceeded that of the simulation by some 30°C (189°C vs 159°C) indicating that ignition of the coal had taken place. At the end of 10 hours the coal temperature at the #5 station was observed to be 512°C compared with 614°C recorded for the exterior of the simulator indicating that the coal near the surface of the simulator was somewhat hotter than the coal at station #5. This is to be expected since the coal at the surface of the simulator was exposed to higher temperatures for longer periods of time.

Results from trials with dry crushed Emery and Somerset coals conducted under the same experimental conditions are shown in figure 10 and figure 11, respectively. It will be noted that in both cases the coal ignited in about 6-1/2 hours compared to 9-1/2 hours for the Pittsburgh coal indicating greater reactivity for the two western coals. This was also observed in the small scale ignition tests discussed earlier. It should also be noted that the Emery coal gave evidence of some self heating as early as 2-1/2 hours into the run since the observed coal temperatures were slightly higher than the case or oxygen outlet temperatures from this time until the coal ignited.

Another run with Emery coal was conducted with the simulator case and oxygen outlet temperature adjusted to 100°C. The thermocouple records from this run are shown in figure 12. Since there was no evidence of self heating of the coal, the experiment was terminated at the end of 32 hours.

In figure 13 coal temperature profile from the 100°C simulator run is compared to the temperature profiles obtained in the trials with the MSA and Drager units heated by water stimulation. It is obvious from the results shown here that the one-hour self rescuers heated by water stimulation are not capable of delivering enough thermal energy to ignite any of the coals examined here. Since the coals were dried and crushed to enhance their ignitibility and in the case of the two western coals were among the most reactive bituminous coals mined underground, it can be concluded that the 1-hour KO_2 self rescuers do not pose any immediate ignition problems when accidently buried in a coal pile and exposed to the elements.

As was pointed out earlier, the experiments with water activated KO_2 canisters buried in coal beds did not provide any information on the possible effect of oxygen or the presence of hydraulic fluid in accelerating (or retardding) the ignition of coal. To clarify these two points, additional runs with the thermal simulator were made to compare the ignition of coal with and without added oxygen and with and without hydraulic fluid. Records from these trials are presented in figure 14 and figure 15.

Figure 14 compares the coal temperature profile (Pittsburgh coal) observed in a 150°C simulator run with oxygen to the profile observed in a similar run where air was pumped through the simulator at the same flow rate as the oxygen. As can be seen, the air flow experiment did not result in an ignition even after 22 hours whereas the oxygen run resulted in ignition indicating that the presence of oxygen produces a significant acceleration of the coal reaction. This of course is not surprising and was really the basis for the design of the thermal simulator. However, it is gratifying to see confirmation of at least the magnitude of this effect.

Figure 15 compares thermal records from simulator runs using dry, crushed Pittsburgh coal and the same coal wetted with 5% by weight hydraulic fluid. The records indicate a significant retardation of coal reaction due to the presence of hydraulic oil. This is associated with the fact that the hydraulic fluid has a significantly higher ignition temperature than coal (365°C versus 150°C) and serves to shield the coal, especially the fines, from the source of oxygen required for combustion.

Ignition Tests With Oxygen Candles

Since the oxygen candles used in the two self rescuers have the potential for generating higher local temperatures than those possible through water activation of the KO_2 canisters, it is conceivable that they could serve as an ignition source if activated in an accident involving burial of the self rescuers in a coal bed. For this reason, two additional trials were conducted with MSA and Drager oxygen candles activated and burned in dry, crushed (1 to 0 cm) Emery coal. As indicated in figure 16, the candles were equipped with thermocouples to monitor the temperature of the candle body and oxygen outlet. Thermocouples were also embedded in the coal approximately 2.54 cm (1-inch) from the "oxygen end" of the candles to monitor coal temperatures.

Results of the two tests are shown in figure 17. The maximum temperatures of the candles were observed to be 210°C for the Drager unit (near the firing mechanism) and 150° C for the MSA unit (candle body); however, the maximum coal temperatures did not exceed 40°C. Since the exposed candles represented "a worst case situation" insofar as energy transfer to the coal was concerned, it was concluded that there was no ignition hazard associated with the activation of the oxygen candles during the accidental burial of a KO_2 self rescuer.

Spontaneous Combustion Hazard

Having seen that the KO_2 self rescuers do not pose any immediate ignition hazard when accidently buried, either through water activation of the KO_2 or initiation of the oxygen candles, a question concerning longer term effects, specifically whether the units pose any spontaneous combustion problems, needs to be answered. By immediate ignition we mean coal ignition associated with the principal thermal flux from the activated canister or candle as opposed to spontaneous combustion involving only thermal activation of the coal by this energy flux with the principal energy being released by the activated coal over much longer periods of time. It is conceivable that experiments could be designed and conducted to determine the effect of small thermal fluctuations on the course of events occuring during the spontaneous heating of coal but certainly not in the time frame of this particular work. Therefore, we must dispose of the question on the basis of simple intuitive arguments alone. Kuchta (7) has shown that the minimum volume (critical mass) of bituminous coal that can ignite through spontaneous heating is of the order of one cubic meter, say 1 ton to be on the conservative side. Heat loss from the surface of a volume of coal smaller than this would be so great that any spontaneous heating of the coal, if activated, would be quenched. For larger volumes of coal, heat generated by the reacting coal can exceed surface heat loss resulting in an accelerating reaction and eventual ignition of the coal. This can happen if the entire volume of coal is brought to some minimum critical temperature for self heating to occur. It can also happen if some smaller volume of this same critical mass is brought to a temperature in excess of the critical temperature for self heating. With some coals, notably the lignites and some low grade subbituminous coals, this critical temperature is near ambient temperature and the coal will self ignite when exposed to air providing that the mass of coal is greater than the critical mass for that particular coal. Kuchta et al (8) report a minimum self heating temperature of 60°C for bituminous coals. This number is conservatively low since it was determined under adiabatic conditions with moist air and with dry, finely pulverized samples prone to self heat. For example, in the simulator tests we saw that dry pulverized Emery coal did not self heat after long exposure to 100°C temperatures even in the presence of oxygen. The point we would like to make is that to be effective in igniting coal, a heat source must be capable of heating some small volume of coal to the ignition point (>150°C) or at least elevating the temperature of a critical mass of coal to the minimum temperature for self heating to occur. We have shown experimentally that this first alternative (immediate ignition) is not possible with a water activated KO_2 canister or a candle ignition. We have also seen that the maximum energy available from a KO_2-water reaction (Eq. 3c) is 13.2 kcal/mole or 185 kcal for 1000 gm of KO_2. This amount of thermal energy if uniformly distributed over a ton of coal would lead to a temperature rise of approximately 0.7°C. The additional thermal energy associated with the burning of an oxygen candle would raise this to perhaps 1°C which is far too low to induce self heating in any bituminous coal. We therefore conclude that in addition to not posing any immediate ignition hazard, an activated KO_2 canister (with or without candle ignition) does not pose a spontaneous combustion hazard.

Bonfire Tests

It is reported that the burning of oxygen self rescuers (for purposes of destruction) is "characterized by calm flame; first-with black smoke, then-with blue white one; the burning lasts 30-40 min" (9). The same reference recommends that the number of units to be burned at one time not exceed 500, and that reasonable safeguards be taken during the burning operation. On the basis of this information, it would appear that exposure of oxygen self rescuers to fire does not present any formidable problems. However, in order to gain some first hand experience on the behavior of KO_2 self rescuers when exposed to fire, a number of them were burned in a bonfire; fire exposure tests were also made with raw KO_2.

Results of a bonfire test with an MSA self rescuer are shown in the pictoral sequence of figure 18 selected from 35 mm photographs of the event. The figure shows in numerical order: (a) the unit suspended by an iron wire over a pile of wood primed with a gelled JP-4 aviation fuel; (b) the action of a small quantity of black powder used to ignite the fire; (c) the charring of the exterior plastic cover of the unit; (d) mild burning of the unit; (e) some flaring at the top of the unit associated with the oxygen released by the decomposing KO_2; (f) some more intense flaring and a "hot-spot" in the upper left hand corner of the unit; (g) formation of a dense white smoke cloud when the iron support wire sagged, disturbing the canister; (h) the remnants of the canister in the fire; (i) a close-up of a hole burned through the bottom of the unit. The duration of the burn was approximately 24 minutes. The intense flaring accompanied by the generation of the heavy cloud of white smoke shown in figure 18(g) persisted for about 30 seconds. The only other unusual event noticed during this trial was a "popping" sound heard approximately 7 minutes after the fire was started. This was probably associated with the thermal activation of the ignitor used to start the oxygen candle.

Results from a similar trial with a Drager unit are presented in figure 19. This burn lasted approximately 24 minutes and was rather uneventful except for a fairly intense flaring and the generation of some white smoke approximately 23 minutes after the fire was started. This time corresponds roughly with the time photograph 19(g) was taken but happened so abruptly that it was not recorded on film.

In one of the mechanical strength tests to be discussed in the next section of the report, a Drager self rescuer was slightly damaged while being run over with a crawler mounted front-end loader. This resulted in two circular tears in the KO_2 canister caused by exposed bolt-heads in the crawler track. A small amount of crushed KO_2 was apparent at the edge of one of the tears and it was decided to burn this canister to see if the exposed KO_2 would intensify the fire.

The results of this trial are presented in figure 20. Unlike the two previous tests, which involved wood fires, this test was conducted using a small coal fire. The two damaged portions of the canister can be seen in 20(a). This burn lasted approximately 7 minutes and resulted in the generation of more white smoke than was observed in the trials with the complete units burned in a wood fire. The white smoke started about 4 minutes into the burn and lasted for about 2 minutes. Otherwise the burn was uneventful.

In order to obtain a better idea of the source of white smoke observed in these trials, several additional burns were made by drawing paper bags filled with lump KO_2 into a small coal fire. The results of one such trial involving 500 grams of KO_2 are presented in figure 21. This burn lasted only 30 seconds but in this time there was considerable white smoke generated (scenes e through h). Equation 6 suggests that the interaction of KO_2 in a coal fire would essentially produce either potassium carbonate, K_2CO_3, or potassium bicarbonate, $KHCO_3$, as a particulate byproduct. In order to check the composition of the white smoke, a number of grab samples were obtained from KO_2-coal fires for chemical analysis. X-ray diffraction analysis of the residues showed the presence of K_2CO_3 and $2K_2CO_3 \cdot 3H_2O$ (the hydrated carbonate) and a little soot. There were no other compounds ($KHCO_3$, KO_2, K_2O_2, etc) detected in the residues. Potassium carbonate (K_2CO_3) is caustic and therefore toxic and exposure to the white smoke clouds generated by the burning should be avoided if possible. This also applies to the smoke generated during the burning of the exterior plastic cases of the self rescuers which consist of polypropylene for the Drager unit and ABS for the MSA unit. Like most plastics these materials also produce toxic combustion products. However, none of the combustion products, including potassium carbonate, which would be formed in fires fought with common dry powder extinguishers, are unique. Thus, there appear to be no unusual hazards associated with the exposure of the 1-hour self rescuers to fire.

Bullet Impact Trials

To supplement some earlier work in 15 minute KO_2 self rescuers involving bullet impact (10), a number of tests were performed to evaluate the effect of rifle fire on the 1-hour self rescuers. For this purpose both the MSA and Drager units were impacted with steel jacketed bullets (Military 30 caliber M2 ball) fired from a 30-06 rifle at a distance of approximately 20 yards. The muzzle velocity for this ammunition is reported to be 2970 ft/sec.

Figure 22(a) shows the entrance hole resulting from a test firing with a 1-hr MSA self rescuer; the bullet entered up and to the left of the aiming point marked with an X. Figure 22(b) shows the exit damage in the outer plastic case of the unit. There was some charring of the plastic around the exit hole. Figure 22(c) shows the entrance hole in the felt pad on the face of the KO_2 canister exposed by removing the outer plastic and stainless steel covers of the unit while figure 22(d) shows the exit hole in the canister. There was no evidence of combustion during this trial other than the slight charring of the outer plastic case near the exit perforation.

Results from a similar test with a Drager unit are shown in figure 23. The entrance hole shown in 23(a) was above and to the right of the aming point. Figure 23(b) shows the exit damage produced by the bullet. There was considerable charring of the plastic case and flame and smoke issuing from the back of the unit were observed during the trial. The entrance hole in the canister is shown in 23(c) and the exit hole is shown in 23(d). The reason for the combustion reaction observed here is probably associated with the expulsion of some fine KO_2 from the exit hole in the canister which promotes the ignition of the plastic case material heated by the passage of the bullet.

Bullet impact tests were also made on the oxygen candles contained in the MSA and Drager units. The two candles were more or less destroyed in the impact trials but there was no evidence of any combustion reaction generated by the impacts.

MECHANICAL INTEGRITY OF 1-HOUR SELF RESCUERS

We have addressed the problems associated with essentially intact self rescuers exposed to a variety of external stimuli and have shown that if the units remain intact (i.e. no massive release of KO_2), they do not pose any serious ignition problems. If the self rescuers were to remain intact on exposure to even the most severe abuse that could reasonably be expected to occur underground then the safety problems connected with the self rescuer would be minimal. In an effort to determine what level of abuse the self rescuers could sustain without releasing KO_2, a number of experiments designed to simulate "worst mining conditions" were conducted with the 1-hr MSA and Drager units. These included 1000-pound drop weight tests to simulate a roof fall, runover tests with heavy equipment, and tests where the units were loaded through a feeder breaker. The results of the drop weight and runover tests will be discussed in this section of the report. Due to its length, the discussion of the feeder breaker tests is presented in a separate section of the report which follows.

Drop Weight Tests

One of the obvious ways a self rescuer could suffer mechanical damage leading to the escape of KO_2 is through a roof fall. For this reason a number of drop weight tests were conducted with a 1000 lb weight to simulate a roof fall. All drops were made from a height of 6.0 ft which is close to the maximum entry height for underground bituminous coal mines. The 1000 lb weight consisted of a 2 ft cube of reinforced concrete that had been previously used in canopy strength tests. In terms of mass loading per unit area this is a good simulation of a major roof fall.

Tests were conducted with MSA and Drager self rescuers placed on an asphalt roadway with the self rescuers lying flat, as shown in figure 24(a), or on end as shown in 24(c) and (d) or on small coal beds 24(b). Tests were also run with damaged MSA and Drager KO_2 canisters recovered from the initial drop tests.

The results of the drop weight tests are summarized in table 8. Figure 25 illustrates the damage sustained by the units; figure 25(a) through (g) corresponds to tests 1 through 7 respectively.

There was only one instance of candle ignition; this occurred in test 1 with the Drager unit. Otherwise the units withstood the 1000 lb impact trials in a rather remarkable fashion with no release of KO_2. An interesting feature of test No. 6 was the fact that the Drager KO_2 canister retained its integrity even though it was compressed to about half its original height.

Runover Tests

Aside from roof falls, another source of abuse possibly leading to the mechanical failure of a self rescuer is runover by a heavy mining vehicle. In order to determine the degree of damage associated with this form of abuse, a number of self rescuers were run over with a 24,000 lb crawler mounted high lift, a 20,000 lb rubber tired front-end loader and a 96,000 lb continuous mining machine. Tests with the high lift and the front-end loader were made on an asphalt roadway. The trials conducted with the mining machine took place on a simulated mine floor composed of crushed slate and coal.

Selected views of the tests are shown in figures 26 and 27. Test results are summarized in table 9 in terms of the qualitative damage sustained by the units; photographs of each of the units shown in figure 28 give a somewhat better idea of the damage resulting from vehicles runover. Photographs 28 (a) through (i) correspond to Tests 1 through 9 respectively.

In all of these trials there was only one instance where the KO_2 canister was ruptured. This occurred in Test No. 3 with the bare KO_2 canister from the Drager unit used in Test No. 1. While it is not obvious from the photograph 28 (c), two exposed bolt heads on the crawler of the high lift left deep impressions in the KO_2 canister and one actually punctured the case exposing the KO_2 along a thin cresent-shaped tear. However, no significant quantities of KO_2 were released. It will be recalled that this canister was used in one of the bonfire tests described earlier. As in the case of the drop weight tests, the runover tests indicate that the self rescuers are extremely rugged units and can withstand considerable abuse including runover by a continuous mining machine without releasing KO_2 into the environment.

FEEDER-BREAKER TESTS

Another source of mechanical abuse having the potential to destroy the mechanical integrity of self rescuers is a feeder-breaker. It is alleged that any item small enough to be loaded through a breaker _is_ loaded through, ultimately reappearing somewhere downstream, usually on a sorting table. It is reported that the filter self rescuers currently worn by miners have gone this route. We must accept the possibility of the same thing happening to a 1-hour

TABLE 8. - Results of 1000 lb. drop weight tests

Test	Unit	Configuration	Result
1	Drager	Flat on coal bed	Plastic case shattered; O_2 candle ignited; no release of KO_2
2	MSA	Flat on coal bed	Unit flattened; no release of KO_2
3	Drager Canister (from Test 1)	Flat on roadway	Unit flattened; no release of KO_2
4	MSA Canister (from Test 2)	Flat on roadway	Unit flattened; no release of KO_2
5	Drager	Upright on roadway	Plastic case shattered; canister distorted; no release of KO_2
6	Drager	Upright (inverted) on roadway	Plastic case shattered; canister compressed; no release of KO_2
7	MSA	Upright on roadway	Unit badly distorted; no release of KO_2

TABLE 9. - Results of runover tests

Test	Unit	Vehicle/Roadway	Results
1	Drager	High-lift/Asphalt	Plastic case cracked; KO_2 cani[illegible] intact; No release of KO_2
2	MSA	High-lift/Asphalt	Unit deformed; KO_2 canister in [illegible] No release of KO_2
3	Drager (from Test 1)	High-lift/Asphalt	Canister punctured by bolt hea[illegible]; No significant release of KO_2
4	MSA (from Test 1)	High-lift/Asphalt	Further deformation; KO_2 canister intact; No release of KO_2
5	MSA (from Test 4)	High-lift/Asphalt	Further deformation of caniste[illegible]; KO_2 canister intact;
6	Drager	Front-end Loader/ Asphalt	Very light damage to plastic case KO_2 canister intact; No release of KO_2
7	MSA	Front-end Loader/ Asphalt	Very little damage; KO_2 canist[illegible] intact; No release of KO_2
8	Drager	Mining Machine/ simulated mine floor	Severe deformation of case and canister; KO_2 canister intact; No release of KO_2
9	MSA	Mining machine simulated mine floor	Severe deformation of outer ca[illegible]es and canister; KO_2 canister int[illegible]t No release of KO_2

self rescuer. Therefore, a feeder-breaker was obtained in order to explore the problems that might arise as a result of such an event. The feeder-breaker was a Long-Airdox, Rosco 1; an overall view of the unit is shown in figure 29 (a).

A closer view of the rotary pick breaker unit is shown in 29 (b). Note the heavy crossbar to the immediate left of the rotary picks. In the tests to be described, impacts on this bar by self rescuers impaled on the picks were chiefly responsible for destruction of the units.

Initial Tests

Initial experiments with the feeder-breaker were unsuccessful in the sense that the self rescuers slipped by the picks when fed into the unit, suffering little or no damage. This happened several times with both MSA and Drager units when they were just randomly placed in the coal filled hopper, even with a minimum setting for the clearance between the bottom of the pick arc and the conveyor bed which was about 6.4 cm (2-1/2-inches). In all probability this would be the normal course of events for a self rescuer accidently loaded through a feeder-breaker. However, in order to simulate worst conditions, a method was devised to increase the chances of a unit being impaled as it passed the rotating pick head.

Through trial and error it was found that a self rescuer had a good chance of being impaled if it rode on coal piled high at the restricted entrance to the rotating pick assembly. Once impaled, the subsequent rotation of the self rescuer together with repeated impacts on the crossbar were enough to open the units on occasion. A self rescuer wedged in coal piled high in the throat of the breaker is shown in figure 29 (c).

Using this approach, a number of 1-hour self rescuers were fed through the breaker loaded with dry run-of-mine Pittsburgh seam coal in order to obtain some idea of the consequences. Essentially three types of behavior were observed: (1) the units would feed through with little or no damage; (2) the units would suffer considerable damage and at times release some KO_2 without an attendant fire; (3) the units would be torn open releasing significant quantities of KO_2 resulting in a fire. These three types of behavior are illustrated in figures 30, 31 and 32 for cases 1, 2, and 3, respectively. Since the "action" shown in these three figures typify all of the tests conducted with the feeder-breaker they will be discussed in some detail.

Figure 30 shows: (a) an MSA unit positioned ahead of the breaker assembly in a manner aimed at maximizing the chances of the unit becoming impaled on a pick; (b) the start-up of the feeder-breaker; (c) the unit riding forward toward the breaker assembly; (d) and (e) the unit passing by the breaker; (f) and (g) the unit loading out of the feeder-breaker; (h) and (i) the subsequent damage to the unit which was minimal.

Figure 31 depicts: (a) a Drager unit riding toward the breaker assembly; (b) the impaled unit striking the crossbar; (C) the plastic case being stripped from the KO_2 canister by repeated impacts on the crossbar; (d) and (e) further destruction of the unit; (f) and (g) the KO_2 canister and pieces of the plastic case being fed out of the feeder-breaker; (h) and (i) damage suffered by the KO_2 canister. Note the exposed KO_2 in 31 (h). An examination of a video tape made of this test showed that the self rescuer struck the crossbar five or six times before the unit was released and fed out of the breaker. The number of such impacts was used to characterize the severity of the feeder-breaker tests.

The scenes in figure 32 illustrate: (a) a Drager unit positioned behind the breaker assembly prior to machine start-up; (b) the unit riding into the breaker; (c) the impaled unit releasing a cloud of KO_2 after striking the crossbar several times; (d) the ignition of a KO_2 combustible mix; (e) the burning unit being fed out of the breaker; (f) the burning unit tumbling down the coal pile; (g) burning unit issuing a white cloud of smoke; (h) late stages of burning; (i) remnants of the KO_2 canister.

The photographs of this test (or any of the feeder-breaker test for that matter) did not provide any insight into the exact mode of initiation of the observed fire. However, in view of the impact and friction sensitivity of KO_2-combustible mixes, it is easy to imagine the ignition of a KO_2-coal mixture taking place as a result of the rather harsh treatment inflicted on the self rescuers. Recalling the rifle bullet impact trials with the Drager unit it is also possible that the ignitions might involve the interaction of KO_2 with combustible case materials. In any case it was demonstrated that ignitions can take place when the self rescuers are loaded through a feeder-breaker.

From the photographs of figure 32, it would appear that the heavy plastic case of the Drager unit was the chief combustible involved in the fire. This can be seen by examining views (f) through (i) which show the consumption of a major portion of the plastic case as well as the most pronounced flame. Other feeder-breaker tests also indicated that the combustible material used in the construction of the self rescuers played a major role in determining the intensity of the fire resulting from an ignition in the feeder-breaker. For example in an early test with an MSA unit, the KO_2 canister was essentially stripped of all combustible accessories (outer plastic case, rubber breathing tubes and seals, composition hinges, etc.) and the resulting fire was very much subdued compared with fire observed with the Drager unit shown in figure 32. This is illustrated in the photographic sequence of figure 33. In another test with an MSA unit shown in figure 34, a composition hinge was the chief source of flame after the unit was fed out of the breaker.

The results of seven exploratory trials with the feeder-breaker are summarized in table 10. These include two early tests (1 and 2) made during the process of learning how to impale the units and five additional tests (3 through 7) with the throat of the breaker piled high with coal in order to promote maximum damage to the units. The "No. of Impacts" refer to the number of times the unit was observed to strike the crossbar while impaled on the rotating pick assembly. Three out of these five tests resulted in fires; photographs of the fires have already been presented in figures 32, 33, and 34, which correspond to tests 3, 5 and 6 respectively. The fire with the Drager unit in Test No. 3 was the most pronounced, attributable in part to the complete combustion of the plastic case. It should be noted that in no case

Table 10. - Results of initial feeder-breaker runs

Test	Unit	Coal Type	No. of Impacts	Fire	Remarks
1	MSA	Dry Pittsburgh Seam	0	No	Unit slipped by
2	Drager	Dry Pittsburgh Seam	0	No	Unit slipped by
3	Drager (From Test No. 2)	Dry Pittsburgh Seam	4-5	Yes	Plastic case contributed to fire (see fig. 32)
4	MSA	Dry Pittsburgh Seam	0	No	Minimal damage (see fig. 30)
5	MSA (from test no. 4)	Dry Pittsburgh Seam	7-8	Yes	Minimal fire (see fig. 33)
6	MSA (from test no. 1)	Dry Pittsburgh Seam	5	Yes	Case combustibles contributed to fire (see fig. 34)
7	Drager	Dry Pittsburgh Seam	5-6	No	Unit completely destroyed (see fig. 31)

was there an appreciable amount of coal ignited by the burning canisters. The fires were purposely allowed to burn themselves out. In an accident situation the fires if detected early could be easily extinguished, preferably with water or rock dust.

Tests With Stripped Units

In preceeding section, two mechanisms were suggested as the source of ignitions observed when the self rescuers were fed through the feeder-breaker. One involved the friction or impact ignition of a KO_2-coal mixture while the other involved the ignition of combustible case materials in the presence of KO_2. In an effort to gain additional insight regarding the influence of case material on ignition frequency, a number of additional trials were conducted with 1-hour self rescuers stripped of all combustible materials, i.e. with the metal KO_2 canisters alone. Except for one case, Drager units were used because of an abundant supply of the Drager self rescuers. As in the case of the tests with full units, the stripped units were carefully positioned in coal piled high in the throat of the breaker in order to maximize damage. The results of seven trials with stripped units are presented in table 11. The stripped MSA and Drager units prior to testing are shown in figure 35 (a) and (b) while the damage sustained by the canister is illustrated in the remaining views. Photographs (c) through (i) correspond to tests 8 through 14 respectively.

While the canisters, in general, were seriously damaged, there was only one ignition observed in this series of tests; this is illustrated in figure 36. The subsequent fire was relatively minor and had extinguished itself before the canister was completely out of the feeder-breaker. The brevity of this fire adds support to the contention that the combustible materials used in the construction of the self rescuers contribute to the intensity of the fires observed in the feeder-breaker tests.

It is obvious that the frequency of ignitions is significantly reduced by removing the combustible accessories from the self rescuers. This follows from the fact that ignitions were observed in three out of five tests with the complete units (prepositioned for maximum damage) while only one ignition in seven tests was observed with the stripped units. It is tempting to conclude that the second proposed ignition mechanism, i.e. the interaction between KO_2 and case combustibles, is the principal cause of ignition. However, this is not necessarily true due to the fact that the impact damage sustained by the full units seemed to be much more severe than that inflicted on the stripped units. In particular, several of the tests with full units resulted in the generation of a cloud of pulverized KO_2 prior to ignition. With the possible exception of Test No. 14 where an ignition occurred, this was not observed in any of the feeder-breaker runs with stripped units. Since an ignition was obtained with a stripped unit one can only conclude that both ignition mechanisms are operable.

Effect of Water Sprays

In the feeder-breaker tests described so far the runs were made with dry coal in an effort to duplicate the worst conditions that could exist in a mine operation.

TABLE 11. - Results of feeder-breaker tests with self rescuers stripped of combustibles

Test	Unit	Coal Type	No. of Impacts	Fire	Remarks
8	Stripped Drager	Dry Pittsburgh Seam	1	No	Canister Punctured; KO_2 Exposed
9	Stripped MSA	Dry Pittsburgh Seam	1	No	Canister Ruptured; KO_2 Exposed
10	Stipped Drager	Dry Pittsburgh Seam	0	No	Canister Punctured; KO_2 Exposed
11	Stripped Drager	Dry Pittsburgh Seam	10	No	Canister Punctured; KO_2 Exposed
12	Stripped Drager	Dry Pittsburgh Seam	0	No	Canister Punctured; No KO_2 Exposed
13	Stripped Drager	Dry Pittsburgh Seam	1	No	Canister Punctured; KO_2 Exposed
14	Stripped Drager	Dry Pittsburgh Seam	11	Yes	Canister Punctured; KO_2 Exposed

However, in practice many (most?) feeder-breakers are equipped with water sprays to reduce the formation and dispersion of respirable dust. We have seen that the presence of water has a strong influence on moderating the reaction of KO_2-coal mixtures. This was evidenced in both the sliding rod friction tests and burning rate tests with KO_2 and moist coal. In order to determine the effectiveness of water sprays in reducing the tendency for ignitions to occur when self rescuers were fed through a feeder-breaker, several tests were conducted with the Long-Airdox unit equipped with a simple spray system. The system, shown in operation in figure 37, consisted of four spray nozzles (Spraying Systems Type BD3) fed by 1.0 inch water line operating at 40 psi; the water flow rate was 2.5 gallons/min which is typical for this application. The sprays were mounted directly over the rotary breaker assembly.

The results of three runs with Drager units are summarized in table 12. As will be noted, the units were punctured and KO_2 was released in all three trials. In fact, Test No. 17 set a record for the number of cross bar impacts sustained by a self rescuer in the feeder-breaker. Photographs of this test shown in figure 38 give some idea of the violence of the encounter. A careful examination of view (F) shows some KO_2 pellets being ejected from the unit. In all, no ignitions occurred with the wetted coal although the damage sustained by the units in these trials was judged to be at least as severe as that observed in trials with dry coal where ignitions occurred. It was therefore concluded that the use of water sprays would drastically reduce the probability of ignition or serve to eliminate ignitions altogether. It probably would make little difference whether the coal was wetted before or during passage through the breaker.

Feeder-Breaker Tests With Emery and Somerset Coals

Since the laboratory thermal tests showed the Emery and Somerset Coals to be somewhat more reactive than the Pittsburgh seam coal, it was of interest to determine the possible effect of coal type on the behavior of self rescuers in the feeder-breaker. Therefore a number of trials were conducted with Drager units fed through the feeder-breaker loaded with either Emery or Somerset run-of-mine coal. The experiments were run with dry coal without water sprays on the feeder-breaker. The two coals from the western mines were somewhat finer than the Pittsburgh coal used in the feeder-breaker trials and the coal from the Emery mine was significantly dustier than either the Pittsburgh or the Somerset coal.

Results of several runs with each of the two western coals are summarized in table 13. Only one fire (Test No. 22) was ignited and this occurred in a run with Emery coal using a self rescuer that was damaged in a previous run (Test No. 18). Scenes from a photographic study of this event are presented in figure 39. The dust produced in runs with the Emery coal is shown in 39(a); ignition occurs in (b) in the presence of a coal dust cloud around the breaker assembly. The compact white cloud in (c) is probably potassium carbonate, a combustion product, rather than pulverized KO_2. The remaining views show that the fire quickly subsides and is essentially out by the time the KO_2 canister, stripped of its outer plastic case, is fed out of the feeder-breaker.

TABLE 12. - Summary of results with feeder-breaker equipped with water sprays

Test	Unit	Coal Type	No. of Impacts	Fire	Remarks
15	Drager	Wet Pittsburgh Seam	4	No	Canister punctured; considerable KO_2 released
16	Drager	Wet Pittsburgh Seam	9	No	Canister punctured; considerable KO_2 released
17	Drager	Wet Pittsburgh Seam	14	No	Canister punctured; considerable KO_2 released

TABLE 13. - Summary of feeder-breaker tests with Emery and Somerset coal

Test	Unit	Coal Type	No. of Impacts	Fire	Remarks
18	Drager	Dry Emery	8	No	Canister punctured; KO_2 exposed
19	Drager	Dry Emery	1	No	No damage to unit
20	Drager (from Test 19)	Dry Emery	3	No	Canister punctured; KO_2 exposed
21	Drager	Dry Emery	5	No	Canister punctured; KO_2 released
22	Drager (from Test 18)	Dry Emery	10	Yes	Test run with damaged unit; minimal fire
23	Drager	Dry Somerset	11	No	No significant damage to unit
24	Drager	Dry Somerset	3	No	Canister punctured; KO_2 released
25	Drager	Dry Somerset	3	No	Case fractured; canister intact

Tests with Somerset coal were even less dramatic in the sense that it was found to be extremely difficult to inflict enough physical damage on the self rescuers to produce the conditions prerequisite for a fire i.e. significant release of KO_2 at the breaker assembly. After a number of unsuccessful attempts to induce a fire it became obvious from observations of the manner in which the units were interacting with the breaker that an ignition would be extremely difficult to produce with the relatively fine Somerset coal and the experiments were discontinued. The damage sustained by the self rescuers used in this series of tests is illustrated in figure 40; photographs (a) through (f) correspond to tests 18, 20, 21, 22, 24, and 25 respectively.

The three coals used in the feeder-breaker tests (Pittsburgh, Emery, and Somerset) approximate the extremes in reactivity to be found in bituminous coals mined underground. It was therefore concluded that the qualitative nature of the ignitions and subsequent fires resulting from self rescuers being fed through a feeder-breaker was not significantly affected by the type of coal being processed.

MISCELLANEOUS TESTS

At the completion of the physical testing of the 1-hour self rescuers, several questions concerning the potential hazards of these units remained unanswered. For example, it will be recalled that KO_2 was not released even when the units were run over with a 96,000 lb mining machine. However great the odds against a self rescuer being torn open under such circumstances, such an event could occur in principle. Exposed KO_2 could then be subjected to the impact-frictional action of the moving vehicle. It was therefore of some interest to expose raw KO_2 to such action and several crude experiments were conducted along these lines.

An additional question was raised concerning the effect air flow over a burning KO_2 canister ignited in a feeder-breaker and fed onto a beltway. It was suggested that the high velocity airflow over the burning canister resulting from the combined effects of the natural ventilation and the belt movement might intensify the fire. Several tests were also conducted in an attempt to answer this question.

A third and more serious concern was over the possibility of a feeder-breaker induced canister fire igniting the coal dust cloud around the breaker assembly in the presence of small percentages of methane resulting from the breaking of fresh coal. In order to address this concern, data were gathered on the ignitability of coal dust in the presence of methane and estimates were made of the amount of coal dust that could be generated in operations involving a feeder-breaker.

A final question concerned the possibility of the oxygen candles contained in the self rescuers igniting methane or coal dust in the process of being activated or while decomposing to produce oxygen. Older work on the incendivity of oxygen candles was reviewed and found deficient because of differences in the firing mechanisms and candle geometry. For this reason additional tests were made in the explosion gallery at the Electrical Testing Laboratory of Mine Safety and Health Administration (MSHA).

The results of the experiments and deliberations made in an attempt to answer the first three questions are presented in this section of the report. The early work on the incendivity of oxygen candles and the more recent experiments conducted by MSHA are included in Appendices 1, 2, and 3 of this report.

Runover Tests With Raw KO_2

As was discussed earlier none of the runover tests with the self rescuers resulted in the release of KO_2. While these experiments did provide valuable information on the resistance of the units to mechanical abuse, they left unanswered questions concerning the consequences of the release of KO_2 in such an event. Since it is conceivable that a KO_2 canister could be torn open during runover by a heavy vehicle, a few crude experiments were conducted to determine if ignitions could easily occur as a result of the frictional-grinding action associated with the passage of a crawler mounted vehicle over KO_2-coal mixtures.

In the first test dry Emery coal was liberally salted with lump KO_2 and run over with the 24,000 lb front end loader used in earlier tests. Scenes from photographs of this event are presented in figure 41(a), (b) and (c). No reaction of the KO_2-coal mix ture was observed in repeated trials. The second test involved running over a quantity (500 gm) of lump KO_2 piled onto a wet slurry of crushed Pittsburgh coal and water. The KO_2 was dumped onto this slurry immediately before the passage of the vehicle in order to minimize the reaction of KO_2 with water. Photographs (d), (e), and (f) of figure 41 illustrate the progress of this run. View (d) shows the 500 grams of KO_2 in a plastic bag before it was dumped into the slurry. As shown in view (f) the only reaction observed was the KO_2 reacting with the moisture in the slurry. The results of these tests together with the demonstrated ability of the self rescuers to sustain considerable mechanical abuse without releasing KO_2 indicates that the encounter between a self rescuer and a piece of mobile mining equipment does not represent a hazard worth pondering.

Simulated Conveyor Belt Fires

The feeder-breaker tests described in the preceeding section of this report were designed to answer questions relating to the frequency of ignitions occuring when a self rescuer is fed through the breaker and the magnitude of the subsequent fire when ignitions did occur. The self rescuers were purposely positioned to assure maximum inter action with the breaker assembly; in addition, dry coal was used to promote ignition. Thus the observed ignition frequency was probably much higher than would be experienced in a real mine operation, assuming that a self rescuer would occasionally pass through a breaker. In this sense the tests represented worst case conditions. However, in a real mine operation it is possible for a burning canister to be loaded onto a belt conveyor. This aspect of the interaction of a self rescuer with a feeder-breaker assembly was not simulated in the tests performed. In particular, the burning units would be exposed to a relatively high, directed air flow comprised of the ventilation flow (~0.5 m/sec or 100 ft/min) superimposed on the air movement associated with the motion of the belt (~3.0 m/sec or 600 ft/min) resulting in a total air flow of about 3.5 m/sec (700 ft/min) over the unit. It was suggested that such air movement would enhance the fire resulting from an ignited unit being fed onto a beltway. Since there was no practical experience to draw from and since in mine experiments were out of the question, a small belt conveyor was obtained and an attempt was made to determine the effect of air flow over a KO_2-coal fire ignited on the conveyor.

The belt conveyor was 6.4 m (21-ft) long and 0.6 m (2-ft) wide and utilized a belt 0.5 m (20-in) wide and 0.85 cm (1/3-in) thick. The conveyor was loaded with run-of-mine Pittsburgh, Emery or Somerset coal and KO_2-coal fires were ignited at one end of the belt and exposed to either natural air movement or air forced over the fire at 3.5 m/sec (700 ft/min) by a 38 cm (15-in) electric fan. Comparisons were made of the fire size and duration with and without forced ventilation. The fires involved 200 gm of lump KO_2 mixed with coal fines and ignited with an electric match. Results of six tests are summarized in table 14 for the three coals with and without forced ventilation. Visual observations of the fires did not show any marked differences due either to variations in coal type or in ventilation; flame duration was observed to vary from 20 to 35 seconds, with no obvious dependence on these two variables. It was concluded that high velocity air flow over a burning self rescuer would not significantly alter the initial stages of a fire resulting from a self rescuer being ignited in a feeder-breaker and fed onto a beltway. This is reasonable since the KO_2 provides more than enough oxygen to support the local combustion process. If the fire were to spread to much larger volumes of coal possibly resulting in a fuel-rich combustion mode then the air flow could have a significantly effect on the course of the fire. A photographic sequence of Test No. 29 which involves Emery coal with forced ventilation is shown in figure 42. The total duration of the fire from the ignition of the event to the last visible flame was 31 seconds.

Coal Dust Ignition Studies

The ignitions and subsequent fires observed in the feeder-breaker tests would appear to be the most serious safety hazard associated with the KO_2 self rescuers. Fortunately, the fires were relatively minor and in practice could be easily controlled if detected at an early stage. However, in a gas or dust filled environment the ignition of the self rescuers also poses an explosion hazard. It goes without saying that the observed fires would be sufficient to ignite a gas-air or coal dust air mixture providing that the mixtures were within the flammable limits i.e., between 5 and 15% methane for methane-air mixtures and above 50 mg/liter for coal dust-air mixtures. Of course, such mixtures could be ignited by other sources and consequently vigorous control over methane and dust levels is mandated by law. Coal dust-methane-air mixtures pose a similar hazard. In particular, a question was raised concerning the hazard associated with the coal dust generated in a feeder-breaker in the presence of small percentages of methane resulting from the handling of fresh cut coal. It was suggested that methane levels of the order of 1 to 2% might be present under such circumstances. Mixtures of two percent methane in air alone cannot be ignited but mixtures of 2% methane and coal dust can be ignited depending on the coal dust concentration. Nagy (11) reports that the coal dust concentration required to produce a flammable mixture with 2% methane/air is 40 mg/liter for Pittsburgh coal. Unfortunately, a fairly intensive search of available data on airborne dust in and around coal mining operations failed to produce any specific information concerning dust generation in a feeder-breaker. For this reason a few in mine measurements were made in order to estimate the dust concentration around a feeder-breaker

TABLE 14. - Results of simulated conveyor belt fires

Test No.	Coal Type	Ventilation	Flame Duration (sec)
26	Pittsburgh	Natural	30
27	Pittsburgh	700 fps	20
28	Emery	Natural	25
29	Emery	700 fps	31
30	Somerset	Natural	35
31	Somerset	700 fps	30

during the passage of coal. In addition, explosibility tests were run with Pittsburgh, Emery and Somerset coal dust in methane air mixtures in order to extend the observations of Nagy to cover a wider variety of coals.

For the latter purpose, the modified Hartmann apparatus of Hertzberg, et al (12) was used to determine the lean limits of pulverized Emery, Somerset, and Pittsburgh coals. Results of measurements in air and in methane-air mixtures are presented in table 15 and figure 43. Data from Pittsburgh coal indicate a linear relationship between methane concentration and coal dust concentration at the lean limit for coal dust-methane-air mixtures. The lean limit dust concentration in 2.4% methane-air was about one-half of that for coal dust in air alone. The lean limits for all three coals were not significantly different either in air or in methane-air mixtures, although the lean limit for Emery coal dust appears to be slightly lower than those for the other two coals. This may be attributed to the higher volatile content of the Emery coal.

The linear relationship shown in figure 43 is in qualitative agreement with Nagy's observations (11) but it is important to note that the coal dust concentrations at the lean limit reported here are roughly twice those reported by Nagy. This discrepancy is due primarily to differences in the way in which the coal dust is predispersed and ignited in the two measuring devices. A detailed explanation of these differences is given in Reference (12).

In order to obtain information on the amounts of airborne dust generated in underground feeder-breaker operations, a few dust measurements were recently made at two local bituminous coal mines. The first mine visited was the Gateway Mine of the Jones and Laughlin Steel Corporation. This mine uses both Long-Airdox Roscoe 2 and Stamler DF143 feeder-breakers in their operations. Three Anderson cascade impactors were used to sample the airborne dust generated by one of the Long-Airdox units; measurements were made only while coal was being passed through the unit which was operated without water sprays. Two sampling points were located adjacent to the breaker assembly and one was located two feet downstream of the breaker. Visual observations indicated that maximum airborne dust concentrations would be recorded at these positions. The results of measurements extending over a two day period with coal that was judged to be relatively dry are summarized in table 16. The observed values ranged from 0.025 to 0.041 mg/liter (25 to 41 mg/m^3) and did not significantly differ from day to day.

The second mine visited was the Renton Mine of the Consolidation Coal Company. This mine uses one Owens 300 and four Stamler DF143 breakers in its operations. Airborne dust generated by one of the Stamler units was sampled with an Anderson cascade impactor with the inlet located approximately 6-inches above the breaker drum. As in the case of the Gateway mine, the breaker was operated without water sprays and measurements were made only while coal was being passed through the unit. The coal was judged to be fairly dry but seemed damper than the coal at Gateway. Results of measurements at the Renton Mine are also presented in table 16. The value of 0.038 mg/liter is in good agreement with the results from the Gateway mine.

TABLE 15. - Lean limit coal dust concentrations for three coal types

Coal Type	Volatiles (Percent)	Ash (Percent)	Lean Limits, mg/ℓ			
			Air	1% Methane	2.4% Methane	5% Methane
Pittsburgh (-200 mesh)	35	9	130	110	65	0
Emery (-200 mesh)	40	9.8	110-115	-	55-60	-
Somerset (-200 mesh)	37.5	12.3	135	-	65	-

TABLE 16. - Airborne dust measurements from feeder breaker operations

Mine	Sampler Location	Total Dust milligrams/liter
Gateway (June 16)	Right Side	0.041
	Left Side	--
	Downstream	0.025
Gateway (June 18)	Right Side	0.038
	Left Side	0.027
	Downstream	0.031
Renton (June 24)	Top Center	0.038

The results presented here are to the best of our knowledge the first dust measurements reported for underground feeder-breaker operations. Therefore it is difficult to say whether they are typical of such operations. In fact, somewhat higher values have been reported for similar operations in coal preparation plants. For example, maximum dust concentrations of 0.130 mg/liter (130 mg/m^3) have been reported for breakers and values as high as 0.647 mg/liter (647 mg/m^3) have been recorded for crushing operations in surface preparation plants (13). However, there is no evidence that the dust concentrations around such operations is anywhere near the level required to form a combustible mixture in the presence of 2% methane which is 40 mg/liter according to the conservative estimates of Nagy or 80 mg/liter according to the recent results obtained in the large scale Hartmann apparatus (see fig. 43). Thus we conclude that the dust generated in a feeder-breaker operation does not pose an ignition hazard in itself or increase the hazard posed by the presence of small percentages of methane. Larger percentages of methane, i.e. within the flammable limits of 5 to 15% could of course be ignited by a burning self rescuer or any other source of flame for that matter.

Ignition Tests With Oxygen Candles

The oxygen candles in both the Drager and MSA 1-hour self rescuers have been demonstrated to generate relatively high temperatures when ignited. The temperatures (~200°C) are inadequate for the ignition of methane but could possibly ignite coal dust under the right circumstances, for example in layers. In addition, both candles are equipped with pyrophoric ignitors which could also pose an ignition hazard. In order to determine the hazards associated with the oxygen candles and ignitors, a series of ignition tests were conducted in the explosion gallery at MSHA's Electrical Testing Laboratory. Complete test results for Drager and MSA units are presented in Appendicies 1 and 2 respectively. It will be noted that no ignitions in 7.0 or 8.6 percent methane air mixtures were obtained when the Drager candles were fired either with or without coal dust placed on the candle bodies. Similar results were obtained with the MSA units except that it was found that the firing mechanism (ignitor) is a potential explosion hazard if loosely attached to the body of the candle or completely detached. This is a quality control problem that is addressed in the approval schedule for these devices.

Results from earlier work performed at the Bureau on a candle assembly designed for use in a prototype 10 minute oxygen self rescuer are presented in Appendix 3. The firing mechanism used with this candle did not pose much of an ignition problem even in oxygen enriched natural gas atmospheres but hot slag from a burning candle was observed to ignite 8% natural gas air mixtures. Since the oxygen candles in both the MSA and Drager units under consideration are completely enclosed in a gas-tight system and have been proven in the recent MSHA tests to pose no ignition hazard, this result is of no particular significance here. However, results of these early tests have been requested from time to time and are presented for completeness.

SUMMARY AND CONCLUSIONS

From preliminary considerations we have seen that potassium superoxide (KO_2) is a relatively stable chemical compound having no inherent explosive properties. However, it forms highly flammable mixtures with combustible materials commonly found in coal mines. These mixtures are readily ignited by flame, friction or impact resulting in short-lived fires when unconfined. As with many oxidizers, mixtures of KO_2 and solid or liquid fuels are potentially explosive under the proper conditions of confinement. It was shown that the presence of water (or moisture) tends to reduce both the mechanical sensitivity of KO_2-fuel mixtures and the subsequent burning rates of such mixtures once ignited. It was also found that KO_2 does not spontaneously react with diesel fuel, mineral based hydraulic fluid or gasoline at normal temperatures.

The nature of KO_2 is such that appreciable heat is evolved in reactions with water and moist carbon dioxide. However, experimental evidence was presented to show that the 1-hour self rescuers do not pose an immediate ignition or spontaneous combustion hazard if accidently buried in a coal pile and exposed to the elements. This was demonstrated to be generally true for coals of varying reactivity and coal soaked with hydraulic oil. In addition, rifle-fire and bonfire tests with complete units failed to show any unusual hazards associated with the self rescuers.

The results of rigorous mechanical abuse tests showed that the 1-hour self rescuers are surprisingly rugged and would probably survive massive roof falls and runover by mobile mining equipment without releasing significant quantities of KO_2. Experiments involving the runover of raw KO_2-coal mixtures showed that the consequences of the release of KO_2 under such circumstances, although highly improbable, would be negligible.

The coal mining environment being what it is, a realistic way was found to damage 1-hour self rescuers to the extent required for the release of significant quantities of KO_2. This involved the passage of the units through a feeder-breaker. Under certain conditions, with the feeder-breaker fully loaded with coal, it was found possible to impale a unit on a rotating pick. Subsequent impacts on nearby mechanical components of the breaker lead to the destruction of the unit with release of KO_2. On occasion the violence of this action lead to the frictional or impact ignition of fires near the rotating breaker assembly. These fires were ordinarily short-lived and were essentially self extinguished by the time the units were fed out of the feeder-breaker. Fires of longer duration and intensity also occurred and were found to be primarily associated with the burning of combustible materials used in the construction of the self rescuers. To appreciate the magnitude of the initial fires started in this manner it is instructive to note that the KO_2 contained in an individual self rescuer (~1000g or 2 lbs) is only capable of supplying oxygen for the complete combustion of 125 gm (4.4 oz) of coal which corresponds to a 4.5 cm (1-3/4-inch) lump of coal.

The frequency and severity of ignitions was found to be independent of coal type. More importantly, ignitions were not observed with coal wetted by machine mounted water sprays. Since water was found to reduce the mechanical sensitivity of KO_2-coal mixtures this would also apply to wet coal being processed in a feeder-breaker without spray. Some of the consequences of the fires induced by the passage of a self rescuer through a feeder-breaker are not difficult to imagine. If they occurred in the presence of a flammable methane-air or methane-coal dust-air mixture, it can be assumed that the mixture would be ignited. However, a survey of feeder-breaker operations in local underground coal mines together with other data indicated that the dust generated in such operations is far below the level required to produce a flammable mixture in air alone or in the presence of small quantities (2%) of methane.

As mentioned earlier the fires observed in the feeder-breaker runs were short-lived and involved relatively small quantities of material. If detected early they could easily be controlled by the application of water or rock-dust However, it is possible for a burning canister to be fed onto a moving beltway unnoticed. Some simple experiments indicated that the early stages of such fires would not be significantly altered due to the air flow over the burning unit associated with belt motion. This is reasonable since the KO_2 supplies its own oxygen to support local combustion. The fire although localized could travel a considerable distance before it extinguished itself or came to rest. Stationary elements of the mine would not be exposed to sufficient energy flux for ignition to occur while the unit was in motion. If the unit was still burning when it came to rest it could serve as an ignition source for combustible material in the vicinity. In this respect the burning unit is no better or worse than the other ignition sources found in mines.

At this point, it may be of some value to compare the hazards posed by the introduction of 1-hour self rescuers for general use in mines with existing hazards of a similar nature. Our intention is not to minimize the hazards of self rescuers but to put them in a perspective for weighing their safety advantages and disadvantages. In order to make such a comparison we need an estimate of the frequency of ignitions (and fires) that might occur as a result of the general use of 1-hour self rescuers. We will assume, if the rescuers are carried by miners, that a misplaced unit would find its way into a feeder-breaker once a month. This seems reasonable since an incident rate higher than this would alert mine officials that something was amiss and corrective action would be taken to reduce the frequency. On the basis of our experience with a feeder-breaker, we estimate that the chances of a unit being significantly damaged (impaled and obattered) while passing through a breaker are 1 in 10. In our experiments the observed frequency was much higher than this (about 5 in 10) but the tests were especially staged to produce a high frequency for this event. We will also place the frequency of ignitions, given significant damage, as 1 in 10. The observed ignition frequency with full units in dry coal was considerably higher, 4 in 12, but under actual mining conditions the coal would probably be wetted before entering the breaker or the breaker would be equipped with water sprays. This would drastically reduce the ignition frequency and for this reason we feel that the 1 in 10 figure is entirely reasonable. Thus the compound probability for the occurrence of a fire resulting from general deployment of the 1-hour self rescuers is one fire every 100 months (1/month x 1/10 x 1/10), or 1 fire in roughly 8 years. In this time we would have had 129 fires (from all other sources) based on fire statistics for 1970-1977 (14). The same eight year period would have produced at least 500 frictional ignitions of methane at the face (15). (Recent trends indicate that this number is more like 800 than 500). In any case, if our simple statistics are anywhere near correct and the only number in doubt is the number of units being accidently fed through a feeder-breaker on a monthly basis...the introduction of the self rescuers for general usage in underground coal mines would have an insignificant impact on the frequency of ignitions and fires already occurring even if the miners wore the units. The choice of alternative methods of deployment would reduce this impact to negligible proportions.

RECOMMENDATIONS

The following recommendations, based on this study, should be considered for inclusion in the general guidelines being developed for 1-hour chemical self rescuers.

1. The deployment plan for 1-hour chemical self rescuers should take cognizance of the potential safety hazards of these devices.

2. The deployment plan should assure rigid accountability of each SSR as it enters or leaves the mine.

3. Miner training on the care and use of SSRs should emphasize the need to avoid situations that could lead to physical abuse of the units.

4. Miners should be instructed to anticipate fires if SSRs are damaged to the extent that they release KO_2.

5. SSRs damages to the extent that they expose raw KO_2 should immediately be doused with water.

6. Fires involving SSRs may be fought with water or copious quantities of rock dust.

7. Care should be taken to assure that the interior components of SSRs are not contaminated with liquid or solid combustibles.

8. To avoid contamination, self-contained self rescuers should not be stored with flammable liquids.

9. Damaged or depleted units should be immediately removed from the mine.

10. Damaged or depleted units should be disposed of according to the recommendations of the manufacturer.

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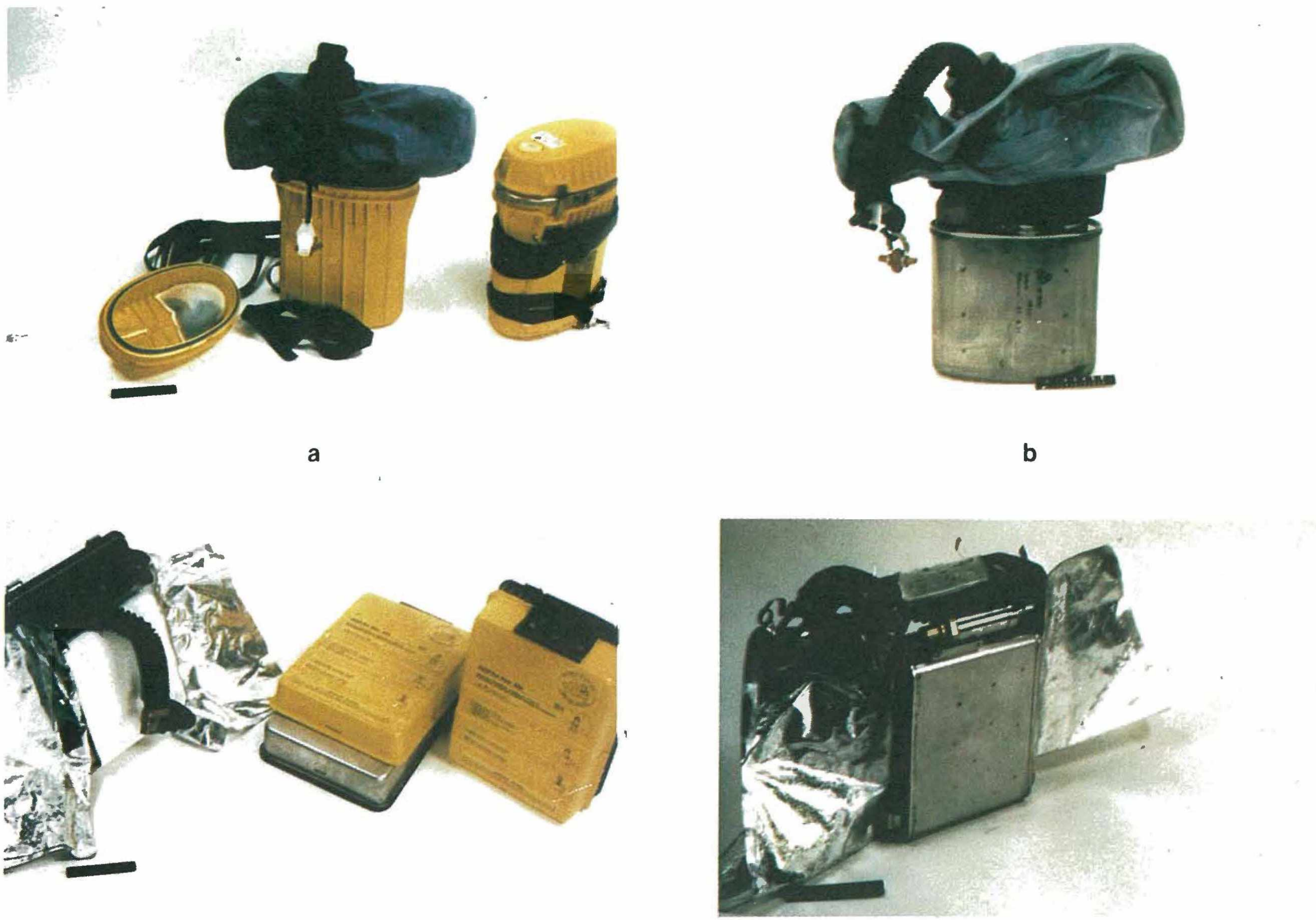
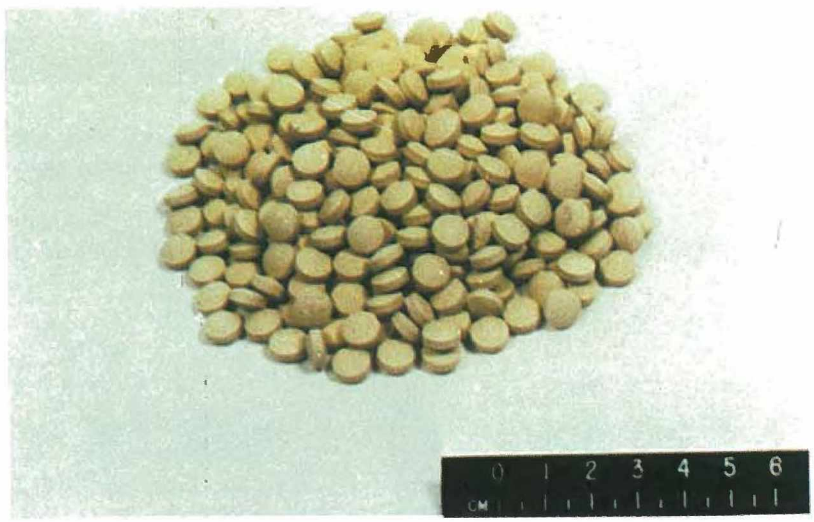


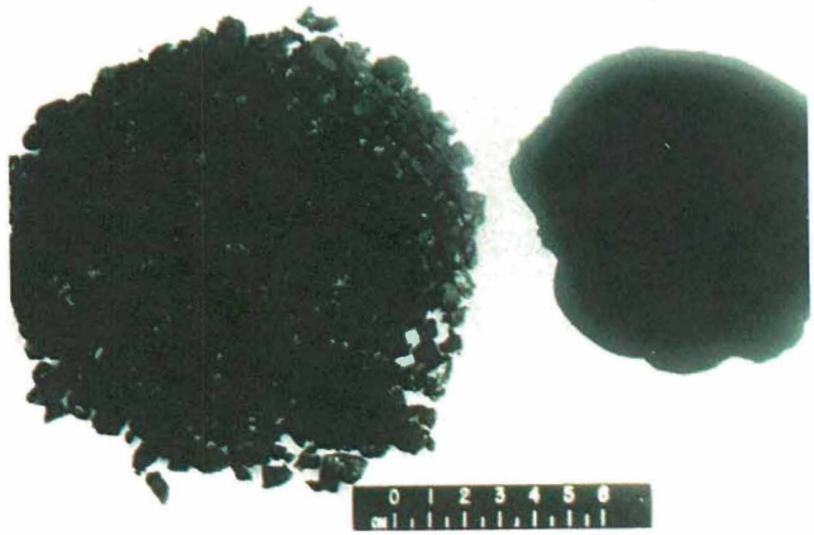
a b c d

FIGURE 1. - Photographs of Drager (a, b) and MSA (c, d) self-contained self rescuers.

a



b



c

FIGURE 2. - a. Lump and pulverized KO_2.
b. Pelletized KO_2.
c. Lump and pulverized coal.

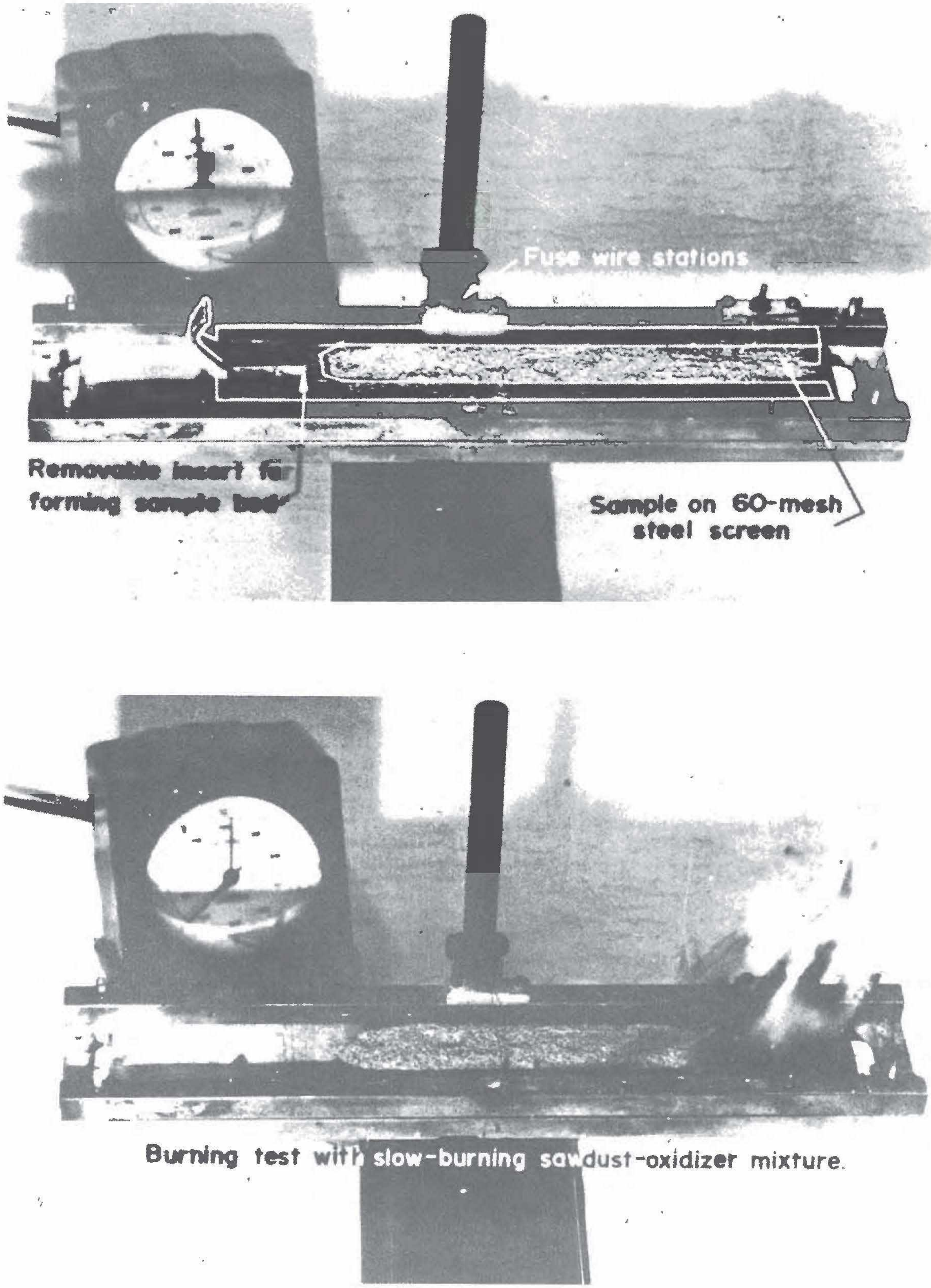


FIGURE 3. - Burning rate apparatus.

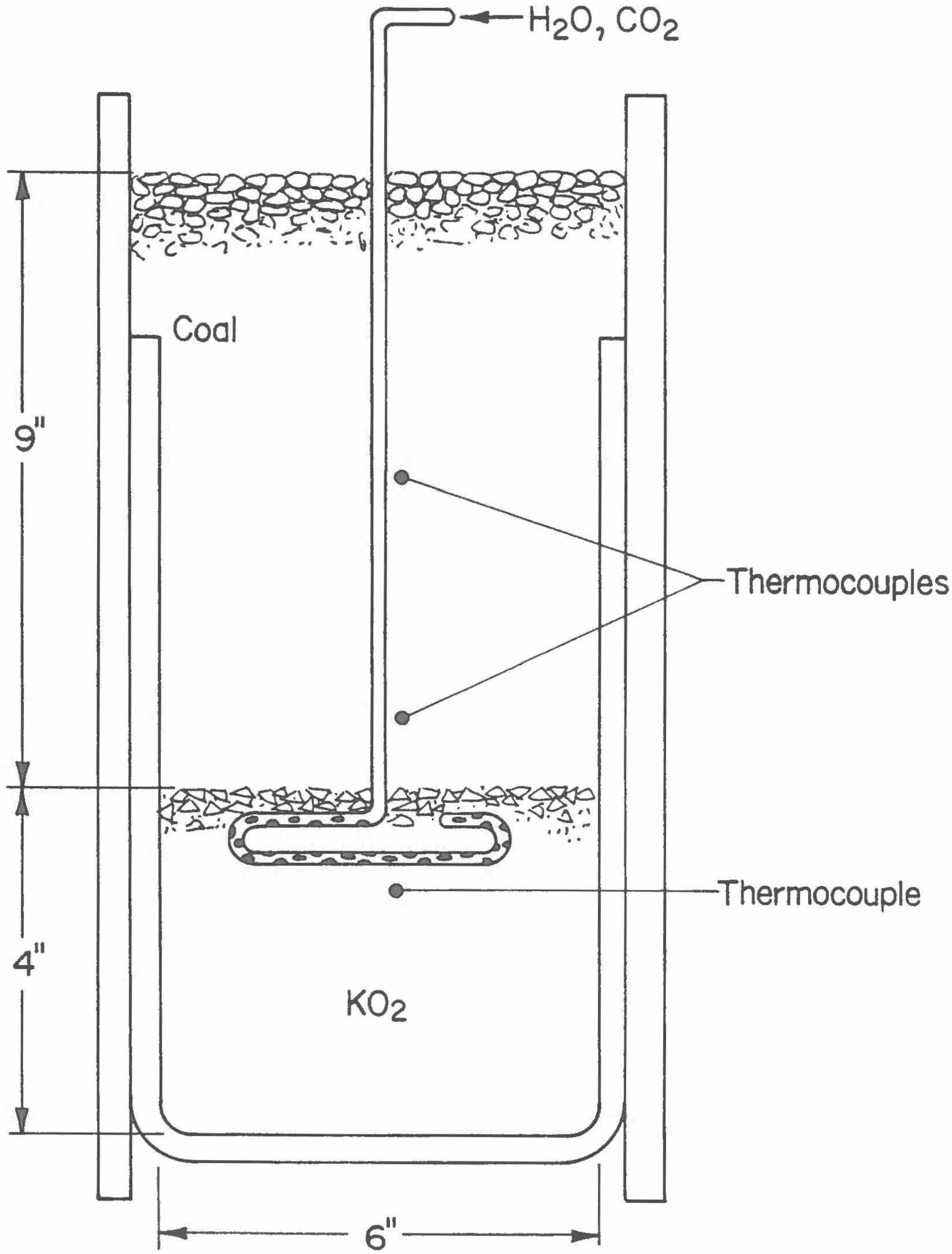


FIGURE 4. - Arrangement used to study reactions of KO_2 with water and moist carbon dioxide.

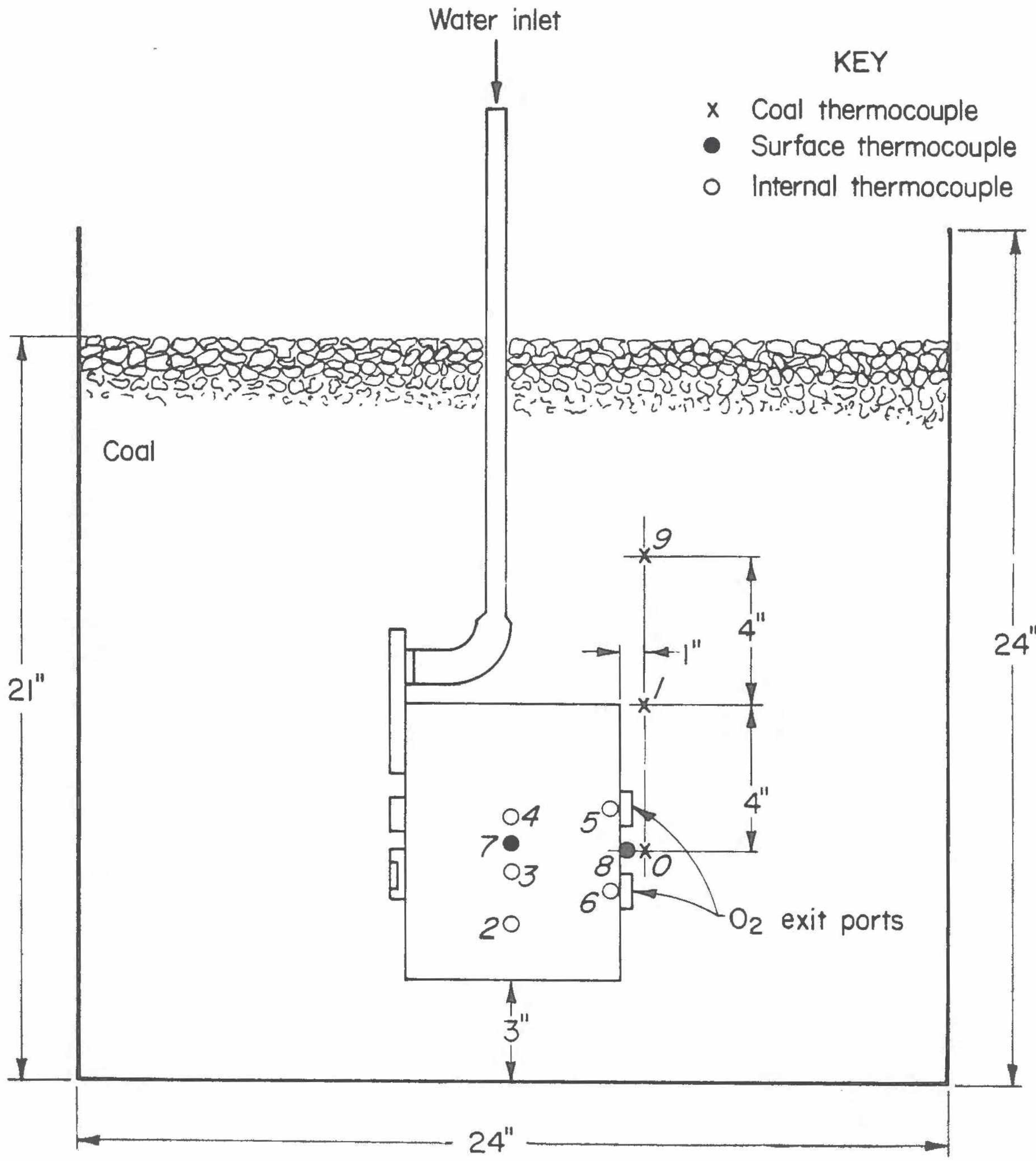
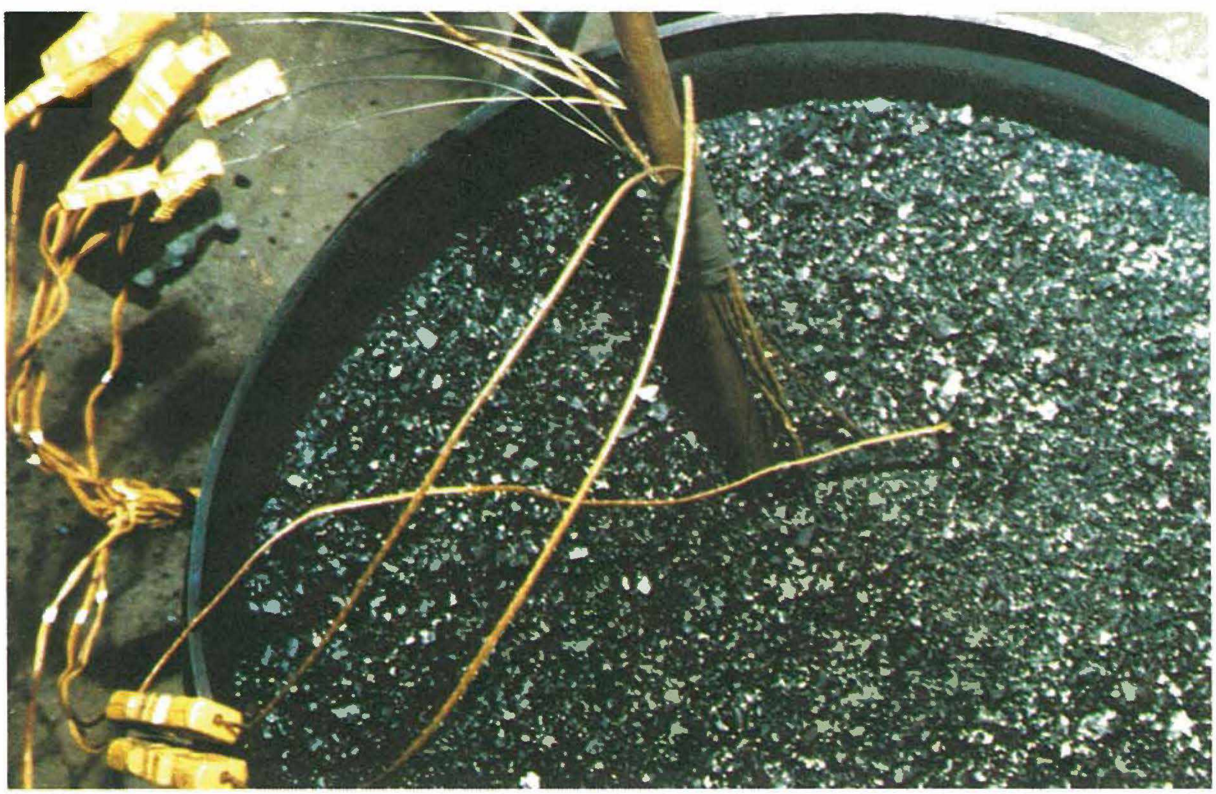


FIGURE 5. - Experimental arrangement used to study ignition hazards of water activated self rescuers.

a



b

FIGURE 6. - a. Photographs of a MSA self rescuer equipped with a water feed pipe.
b. Unit buried in bed of crushed coal

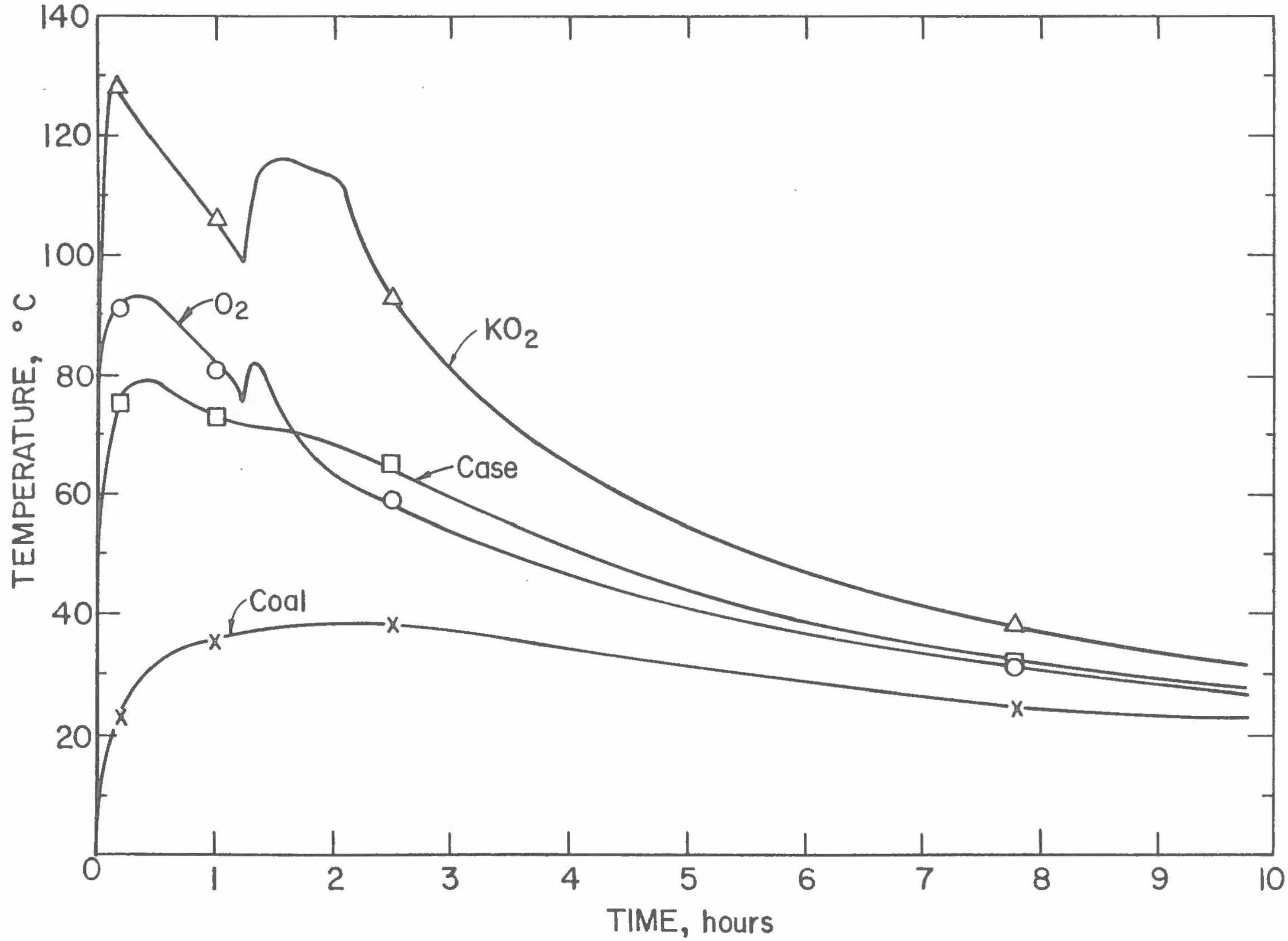


FIGURE 7. - Thermal records from test with water activated KO_2 canister buried in coal.

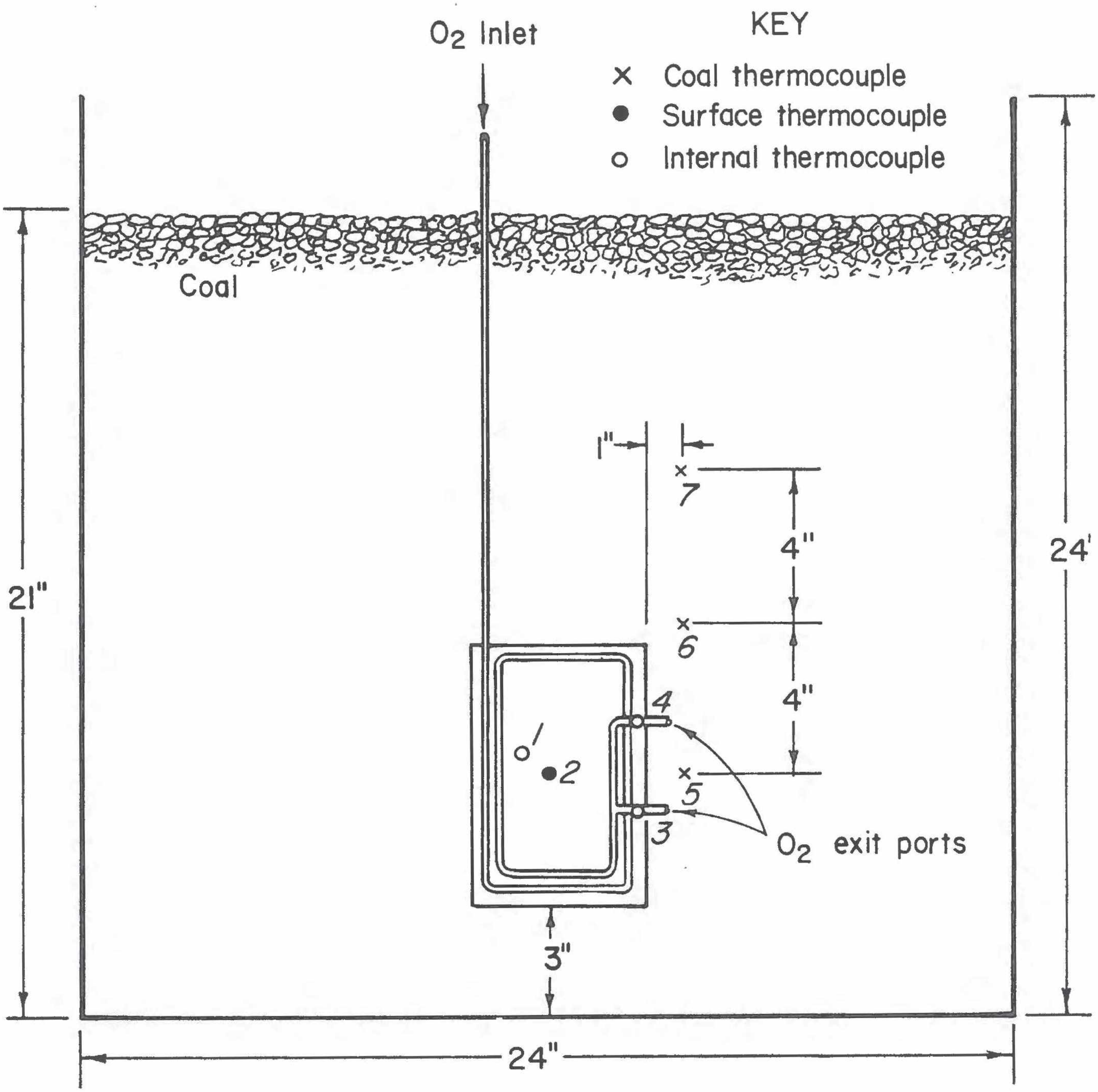


FIGURE 8. - Arrangement used in coal ignition studies with a "thermal simulator".

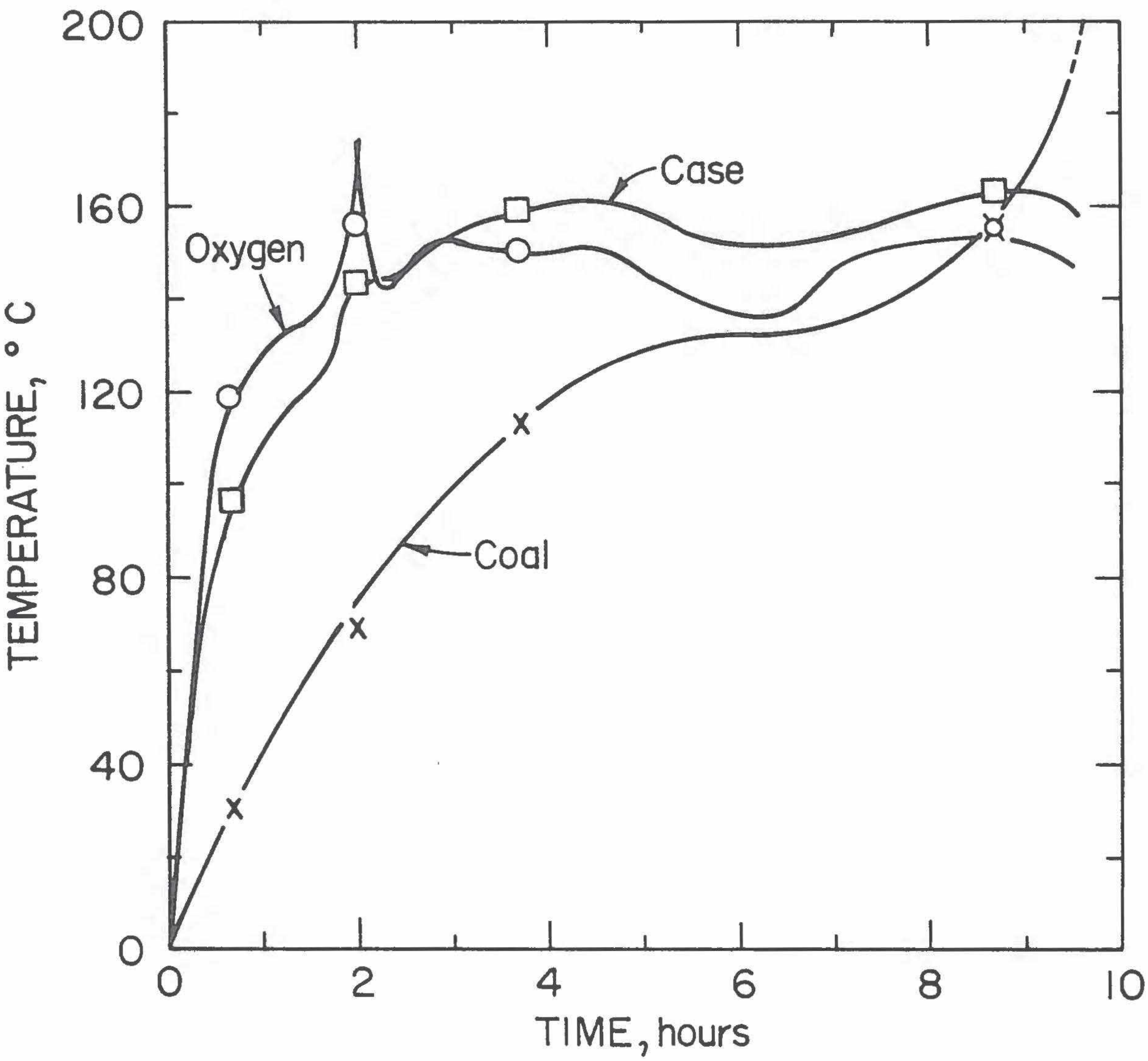


FIGURE 9. - Thermal records from a 150°C simulator run in crushed Pittsburgh coal.

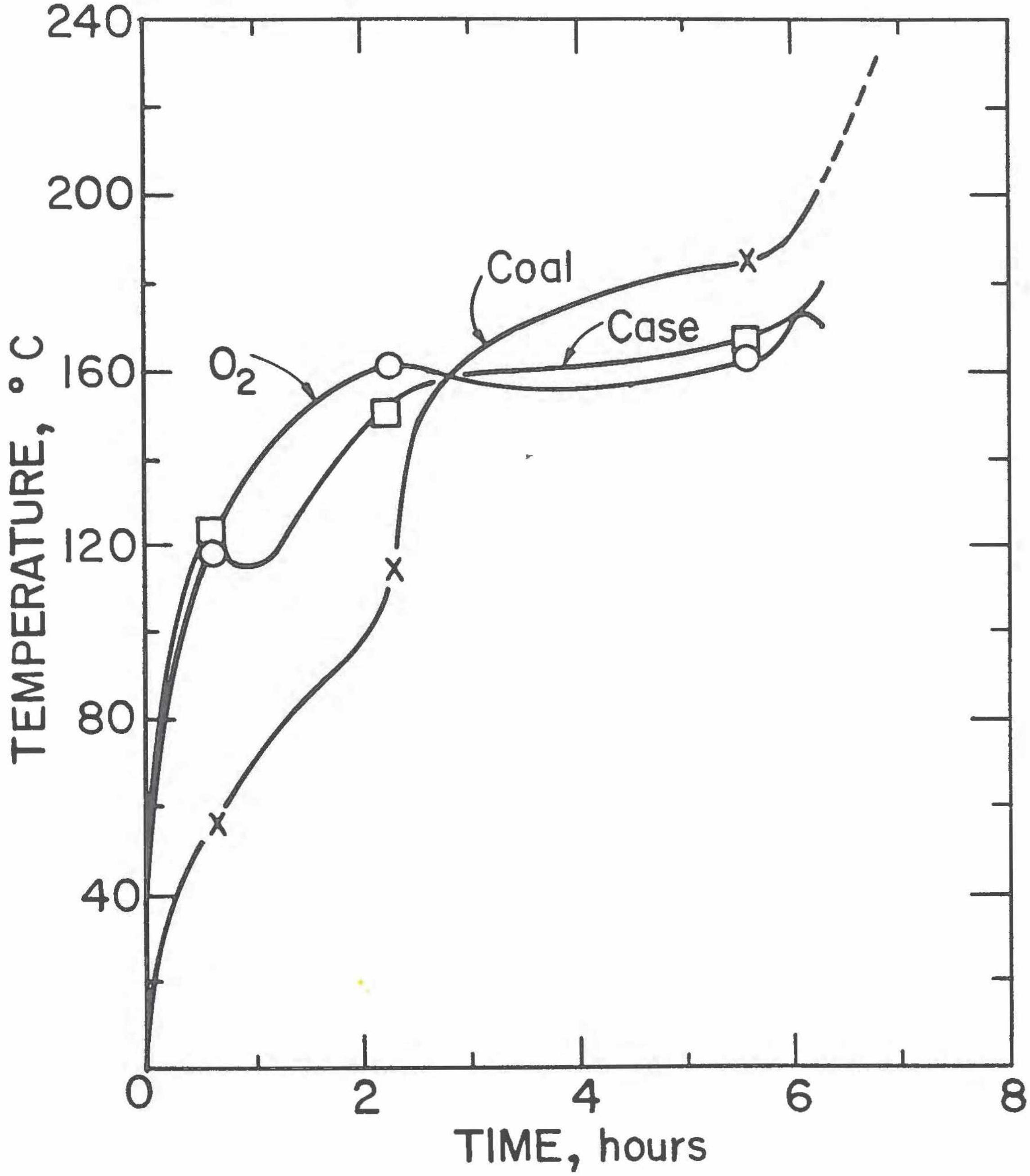


FIGURE 10. - Thermal records from a 150°C simulator run in crushed Emery coal.

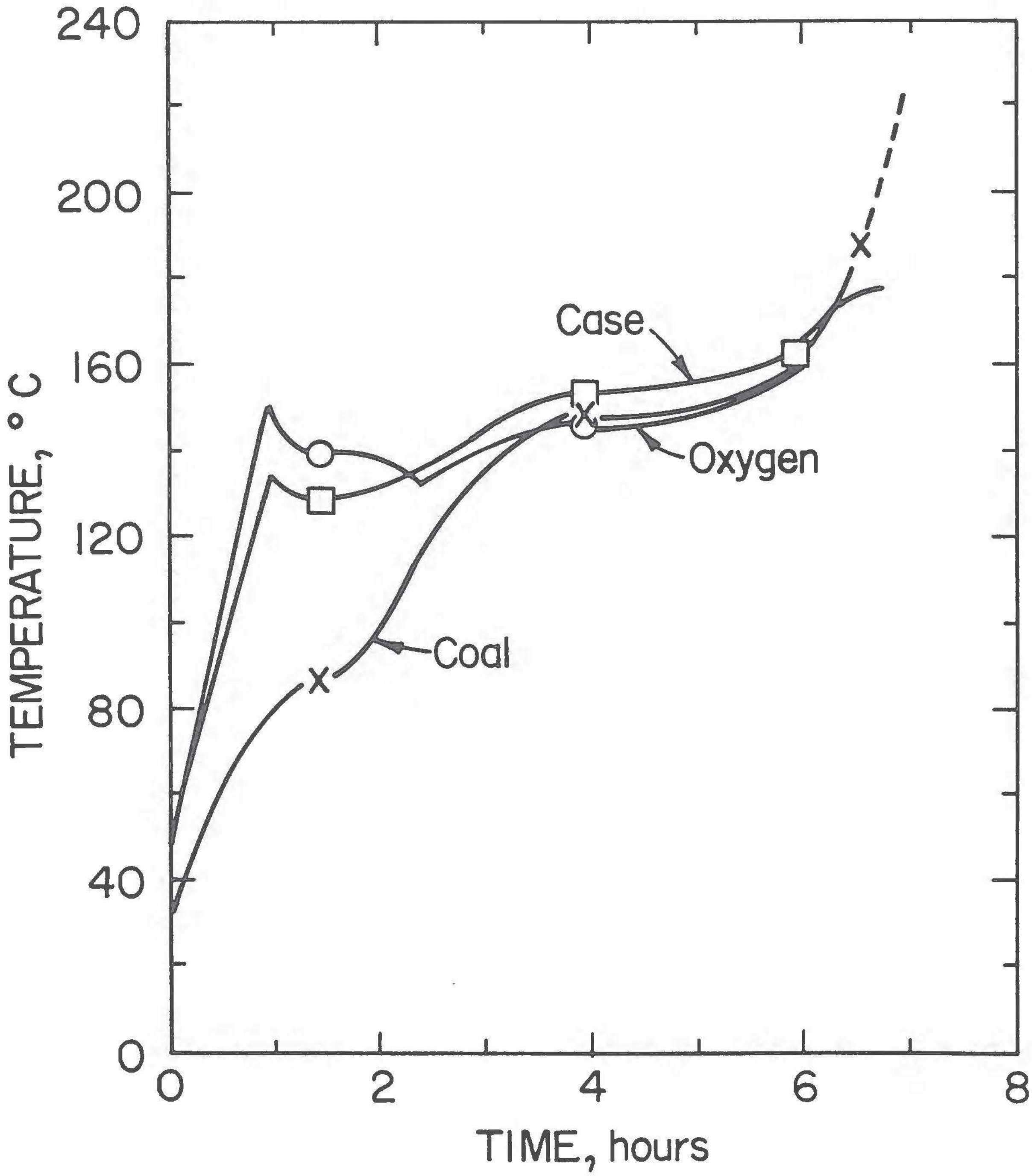


FIGURE 11. - Thermal records from a 150°C simulator run in crushed Somerset coal.

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 4

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas tight weld. The test was conducted in 8.6 percent methane in air mixture with no coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple-270 degrees.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	32.0	270	262.4
15	136	285	259.2
30	193	300	255.6
45	221	315	252.2
60	249	330	248.8
75	265	345	245.1
90	272.6	360	242.2
105	277.6	375	238.8
120	280.2	390	235.4
135	281.6	405	232.2
150	281.6	420	229.2
165	280.6	435	226.2
180	279.2	450	223.6
195	277	465	220.2
210	274	480	217.2
225	272	495	214.2
240	269	510	211.2
255	265.8	525	208
		540	205.4

Time (Sec)	Temperature (° C)
555	202
570	199

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 3

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas tight weld. The test was conducted in 8.6 percent methane in air mixture with no coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple-180 degrees.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	31.6	270	260.6
15	136	285	257.6
30	193	300	254.4
45	220	315	251.4
60	239	330	248
75	251	345	244.6
90	259.8	360	241.8
105	265.8	375	238.6
120	270.2	390	235
135	272.8	405	232
150	273.4	420	229
165	274	435	226
180	273.4	450	222
195	272.2	465	219.9
210	270.4	480	216.8
225	268.4	495	214
240	266	510	211
255	263.4	525	208.2
		540	205

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 2

Comments: This test was conducted with the starter sealed to the <u>empty</u> canister. The seal appeared to be a gas tight weld. The test was conducted in 7.0 percent methane in air mixture with <u>no</u> coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple- 90 degrees.

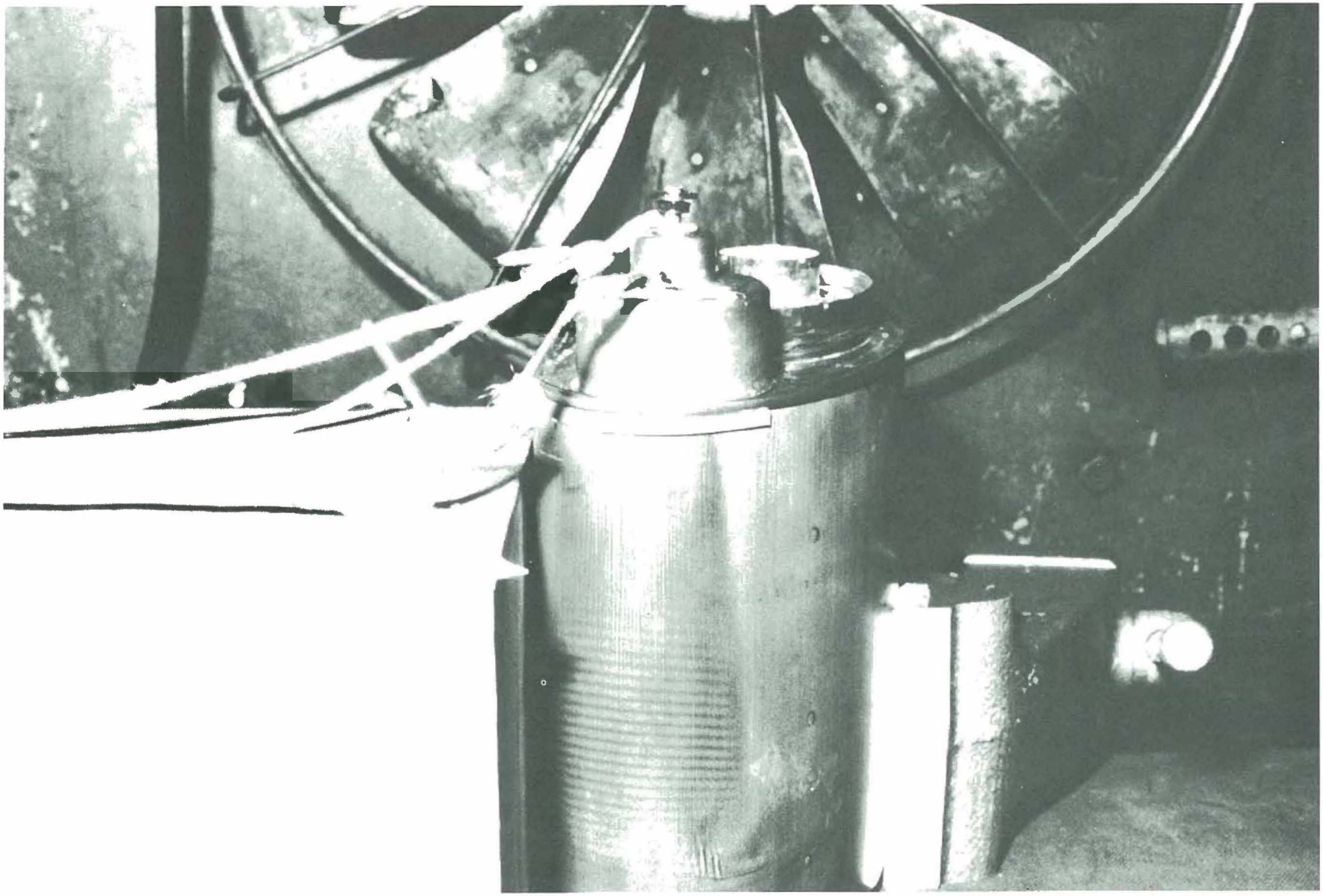
Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	32.2	270	245.8
15	83.0	285	242.2
30	147	300	239.4
45	184	315	236.4
60	214.8	330	232.6
75	241.4	345	229.6
90	251.6	360	226.6
105	255.6	375	223.4
120	258.8	390	220.4
135	260.6	405	217.6
150	261.2	420	214.6
165	260.8	435	211.6
180	260	450	208.6
195	258.4	465	206
210	256.4	480	203
225	254.2	495	200.3
240	251.6	510	197
255	248.8	525	192
		540	189
		555	186

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 1

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas-tight weld. The test was conducted in 7.0 percent methane in air mixture with no coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple-0 degrees.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	31.6	270	146.0
15	110	285	100.0
30	185	300	79.2
45	217	315	
60	240	330	Thermocouple detached from the canister in the gallery. That is the reason for the rapid decline of the temperature. Experiment was completed without temperature data.
75	257.6	345	
90	267.8	360	
105	274.2	375	
120	279.2	390	
135	279.6	405	
150	279.8	420	
165	279.8	435	
180	278.6	450	
195	277.2	465	
210	273.2	480	
225	270.8	495	
240	266.6	510	
255	208.0	525	
		540	



PHOTOGRAPH 5. **Test set-up without coal dust**

Special Investigation: Dragerwerk Breathing Apparatus

Date: 3/7/80 Test Sheet No.: 6

Comments: This test was conducted with a complete canister assembly. The starter assembly was sealed to the canister. The canister was filled with potassium dioxide (KO_2). Seven percent methane in air mixture was supplied to the gallery; no coal dust and the temperature measurement was made at 270 degrees as shown in figure numbers 1 and 2, pages 4 and 5.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	26.2	270	229
15	85.2	285	226
30	149	300	223
45	207	315	220
60	232	330	217
75	244	345	213
90	248	360	211
105	250	375	208
120	250	390	205
135	250	405	202
150	249	420	200
165	248	435	197
180	246	450	
195	243	465	
210	240	480	
225	238	495	
240	235	510	
255	232	525	
		540	

2

Time (Sec)	Temperature (^{o} C)
255	207
270	203
285	200
300	197

Special Investigation: Dragerwerk Breathing Apparatus

Date: 3/7/80 Test Sheet No.: 5

Comments: This test was conducted with a complete canister assembly. The starter assembly was sealed to the canister. The canister was filled with potassium dioxide (KO_2). Seven percent methane in air mixture was supplied to the gallery; no coal dust and the temperature measurement was made at 270 degrees as shown in figure numbers 1 and 2, pages 4 and 5.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	26.2	270	277
15	126	285	273
30	202	300	269
45	244	315	265
60	270	330	261
75	287	345	257
90	297	360	252
105	303	375	249
120	305	390	245
135	305	405	241
150	304	420	238
165	302	435	234
180	300	450	231
195	297	465	227
210	293	480	224
225	289	495	220
240	286	510	217
255	282	525	213
		540	210

Special Investigation: Dragerwerk Breathing Apparatus

Date: 3/7/80 Test Sheet No.: 4

Comments: This test was conducted with a complete canister assembly. The starter assembly was sealed to the canister. The canister was filled with potassium dioxide (KO_2). Seven percent methane in air mixture was supplied to the gallery; no coal dust and the temperature measurement was made at 180 degrees as shown in figure numbers 1 and 2, pages 4 and 5.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.4	270	254
15	105	285	251
30	179	300	248
45	218	315	244
60	240	330	241
75	258	345	237
90	268	360	234
105	273	375	230
120	275	390	227
135	276	405	223
150	275	420	220
165	274	435	217
180	272	450	214
195	270	465	211
210	267	480	208
225	264	495	205
240	261	510	202
255	258	525	199
		540	

2

Time (Sec)	Temperature (^{o} C)
555	204
570	201
585	198
600	195
615	192
630	189

Special Investigation: Dragerwerk Breathing Apparatus

Date: 3/7/80 Test Sheet No.: 3

Comments: This test was conducted with a complete canister assembly. The starter assembly was sealed to the canister. The canister was filled with potassium dioxide (KO_2). Eight and six-tenths percent methane in air mixture was supplied to the gallery; no coal dust and the temperature measurement was made at 90 degrees as shown in figure numbers 1 and 2, pages 4 and 5.

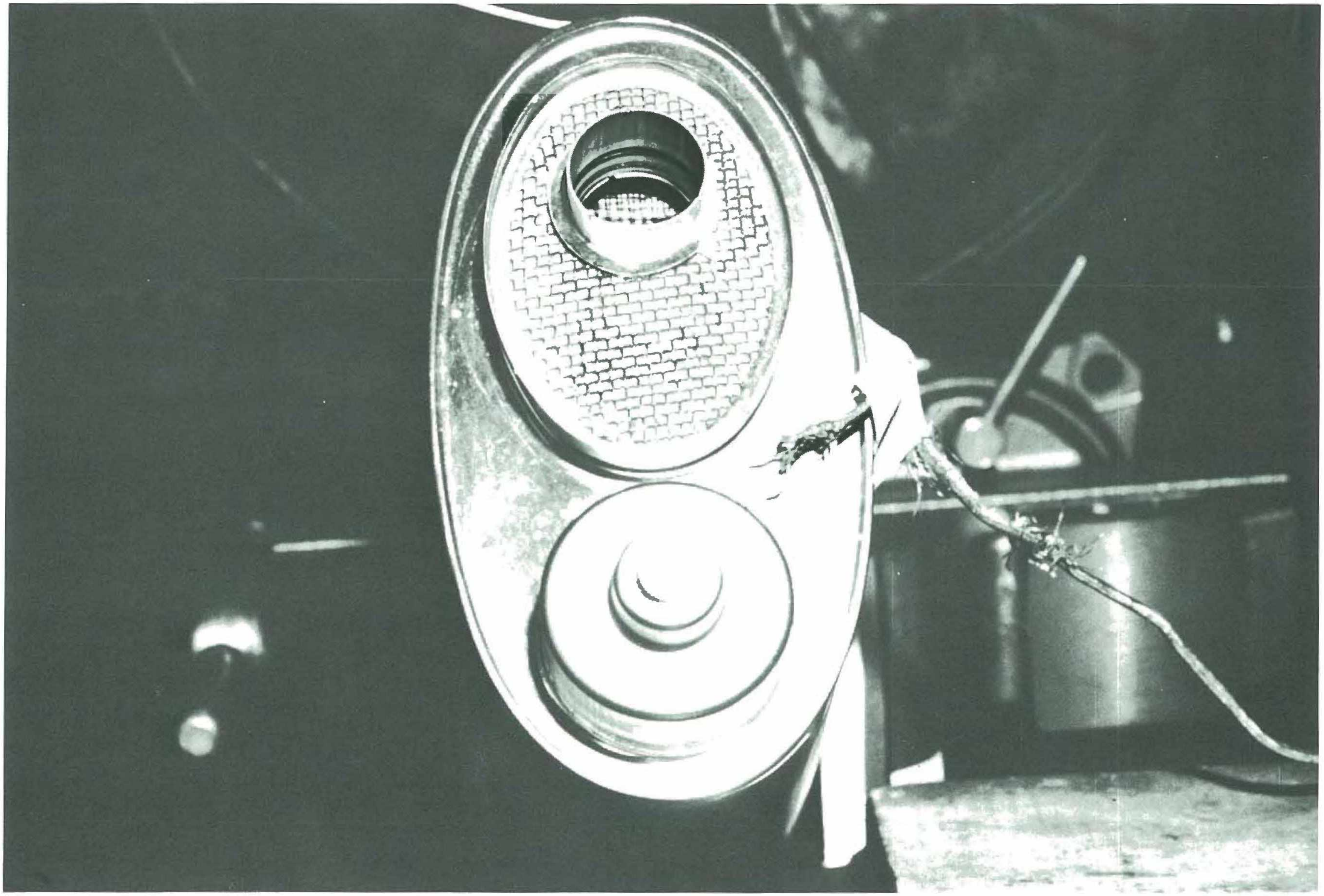
Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	23	270	267
15	98	285	264
30	166	300	260
45	206	315	257
60	234	330	253
75	254	345	249
90	265	360	246
105	272	375	243
120	277	390	240
135	283	405	237
150	283	420	233
165	286	435	230
180	284	450	227
195	282	465	224
210	280	480	220
225	277	495	217
240	274	510	214
255	271	525	210
		540	207

Special Investigation: Dragerwerk Breathing Apparatus

Date: 3/7/80 Test Sheet No.: 2

Comments: This test was conducted with a complete canister assembly. The starter assembly was sealed to the canister. The canister was filled with potassium dioxide (KO_2). Eight and six-tenths percent methane in air mixture was supplied to the gallery; no coal dust and the temperature measurement was made at 0 degrees as shown in figure numbers 1 and 2, pages 4 and 5.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	22.2	270	
15	60	285	
30	102	300	
45	165	315	
60	208	330	
75	221	345	
90	222	360	
105	216	375	
120	209	390	
135	203	405	
150	197	420	
165	192	435	
180	186	450	
195		465	
210		480	
225		495	
240		510	
255		525	
		540	



PHOTOGRAPH 4. **Temperature measurement on canister lid surface**

Special Investigation: Dregerwerk Breathing Apparatus

Date: 3/6/80 Test Sheet No.: 1

Comments: This test was conducted with a complete canister assembly. The starter assembly was sealed to the canister. The canister was filled with potassium dioxide (KO_2). Eight and six-tenths percent methane in air mixture was supplied to the gallery; no coal dust and the temperature measurement was made on the flat surface of the canister.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	23.4	270	
15	24.8	285	
30	25.6	300	
45	44.2	315	
60	82.6	330	
75	116.2	345	
90	124.6	360	
105	127.0	375	
120	126.2	390	
135	124.6	405	
150	123.6	420	
165	120.0	435	
180	120.6	450	
195	Temperature probe became disconnected from canister when cotter pin was extracted. Experiment was completed without temperature measurement data.	465	
210		480	
225		495	
240		510	
255		525	
		540	

APPENDIX NUMBER 1

EQUIPMENT LIST

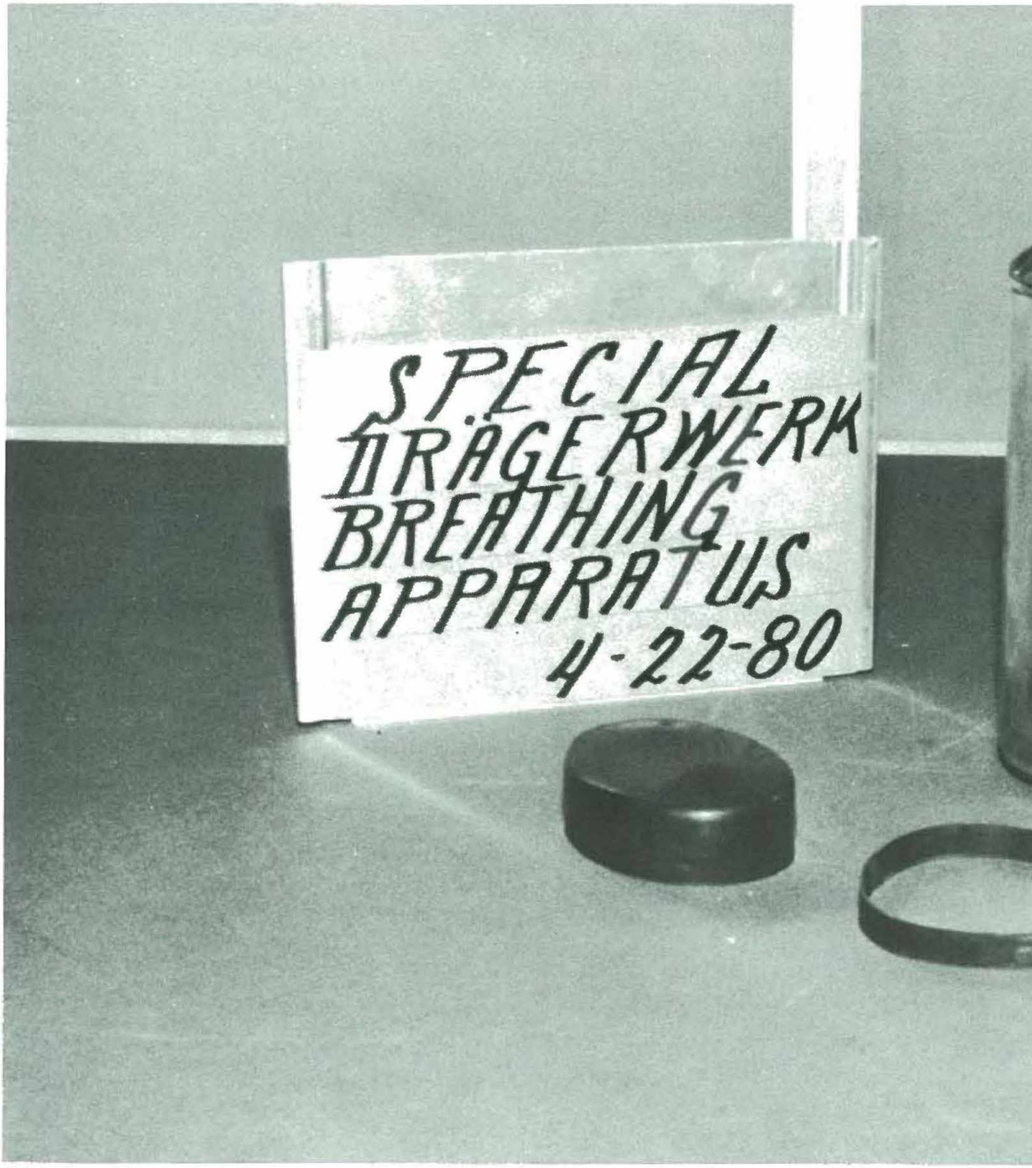
Stop watch, Wakmann, 60 second

Thermometer, Digital, Fluke, Model 2170A, ^{o}C

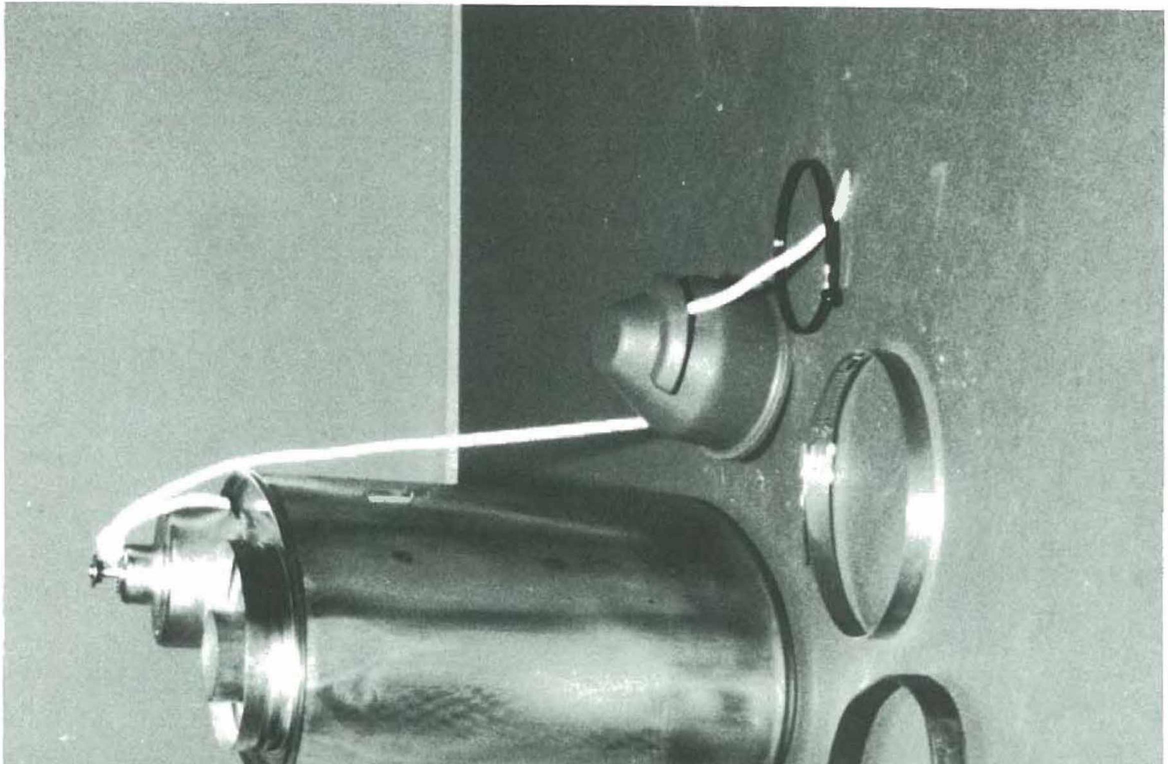
Analyzer, Infrared, Beckman, Model 864

Recorder, Brush, Gould, 220

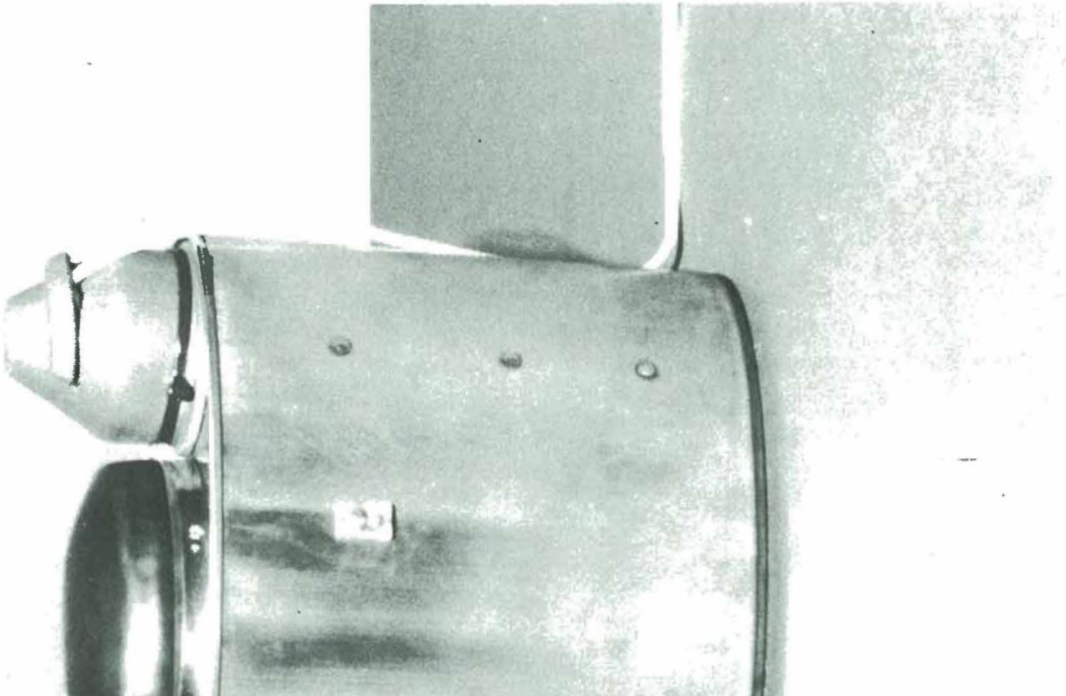
Gallery, auxiliary, modified, BOM drawing C1009, dated 5/8/39



PHOTOGRAPH 3. **Self rescuer**



PHOTOGRAPH 2. **Self rescuer**



PHOTOGRAPH 1. **Component Layout**

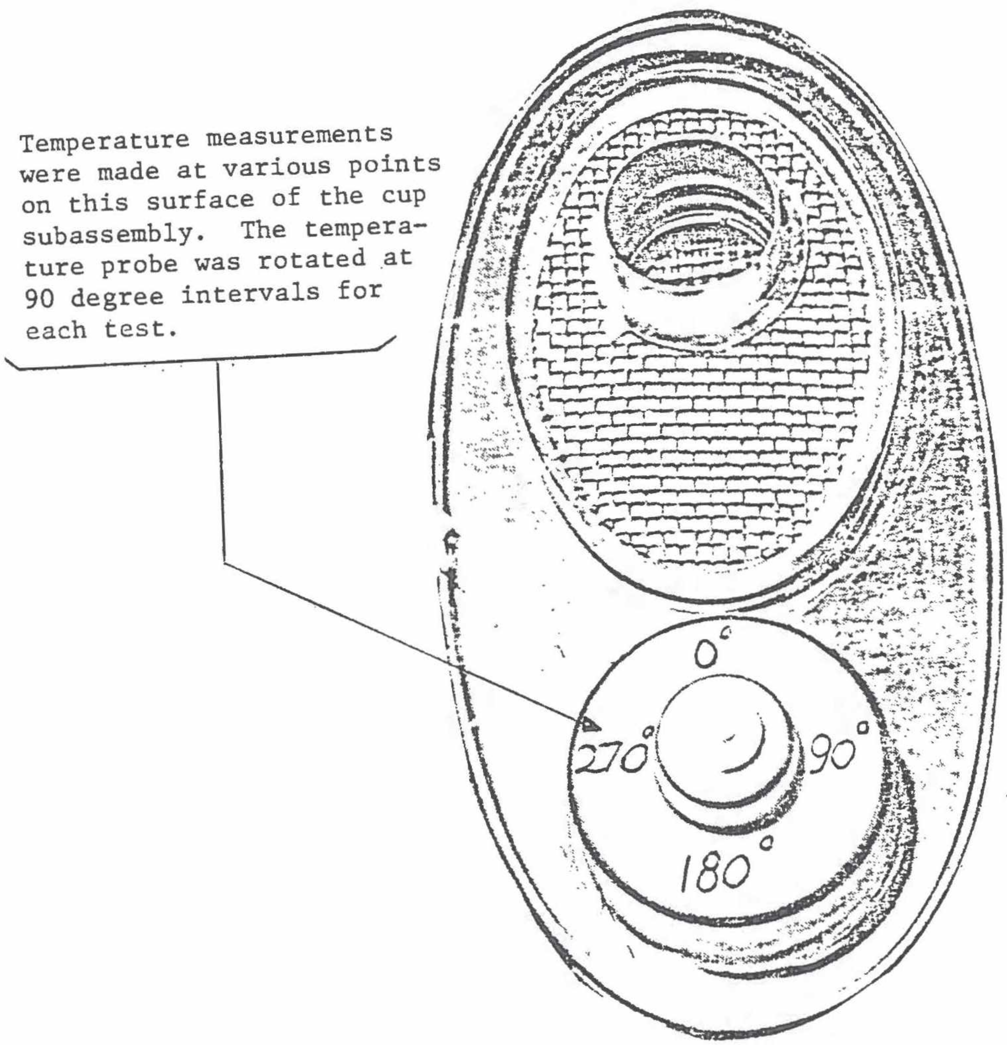
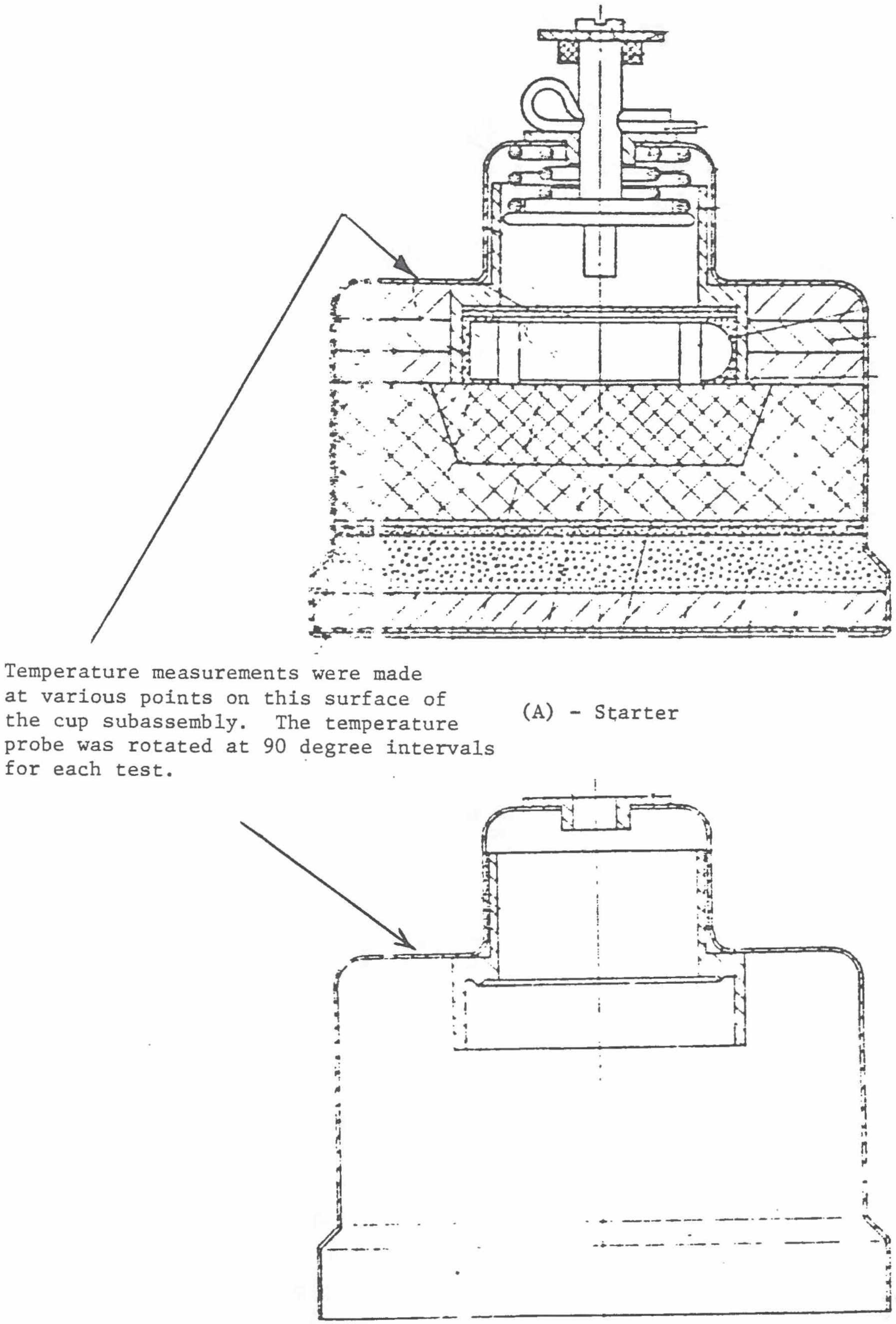


Figure #2

Temperature Probe Location



(A) - Starter

(B) - Cup Subassembly

Figure #1
Temperature Probe Location

Conclusions

This investigation provides preliminary data that shows no ignitions occured when either an empty canister or a canister filled with KO_2 is started in the presence of 8.6 percent methane or 7.0 percent methane. Experiments performed with coal dust layered on the inside and outside of the canister had no effect on the explosion tests.

Recommendations

The Dragerwerk self-rescuer appears to be of durable construction and no construction flaws were detected. The construction appeared to be of high quality based upon a visual inspection.

The explosion tests did not produce an ignition of the methane mixture. I would recommend that these tests results and observations be compared with the tests performed and results obtained by the Institute for Explosion Safety and Blast Technique in Dortmund, West Germany.

the candle within a mixture (7.0 or 8.6 percent) of methane in air the test gas would be ignited. Six tests were performed on March 7, 1980, and eight tests were conducted on April 22, 1980. All of the tests were performed in the small gallery. Each test was performed by placing the entire canister in the gallery. The starter was initiated by extracting the cotter pin via a cord attached to the pin passing through a small opening in the gallery. The investigator pulled the cord to remove the cotter pin. Various methane concentrations were used during the tests and are indicated on each data sheet. Temperature measurements were made on the surface of the cup subassembly as shown on Figures Number 1 and 2, Pages 4 and 5. Photographs 1, 2, and 3, Pages 6 through 8 show the component layout of the complete self-rescuer package and the canister.

March 7, 1980 Tests 1 Through 6

These tests consisted of explosion testing six self-rescuers. The self-rescuers were received from Mr. Dick Watson completely assembled and ready for use. Each unit was filled with potassium dioxide (KO_2). Three tests were conducted with 8.6 percent methane in air mixture and three with 7.0 percent. As shown on the data sheets and photographs Pages 10 through 19, Appendix Number 2, temperature measurements were made at various locations on the cup subassembly (Ref. Figures 1 and 2). This is true with the exception of Test Number 1 in which the temperature measurement was made on the canister lid surface. The maximum temperature measurement recorded in these tests was 305°C. No ignition occurred during these tests. It should be noted that coal dust was not used in the first six tests, but was added in the April 22, 1980 tests.

April 22, 1980 Tests 1 Through 8

These tests were conducted with an empty canister (KO_2 eliminated). The procedures were the same as in the March 7, 1980 tests except that coal dust was added in four of the tests. The maximum temperature observed during these tests was 339.2°C and was recorded at the 270 degree location (Ref. Figures 1 and 2) on the cup subassembly. This location also produced the hottest point in the March 7, 1980 tests. The test sheets and photographs on Pages 20 through 31 provide detailed characteristics of each test. No ignitions occurred.

Introduction

This report describes a special investigation made by the Electrical Testing Laboratory personnel to determine the potential explosion hazards associated with the Dragerwerk, 60-Minute self contained self-rescuer. This investigation was performed at the request of Mr. Frank Lee, Supervisory Electrical Engineer, Approval and Certification Center. Mr. Lee's request for technical assistance was initiated at a meeting held March 4, 1980. In attendance at this meeting were:

MSA Representatives: Mr. R. McIntyre, Mr. Elmer S. McKee — MSA Representatives were present to discuss tests of the MSA 60-Minute Self-Rescuer.

MSHA-A&CC Representatives: Mr. Frank Lee

MSHA-Special Projects Representative: Mr. Robert Peluso

Electrical Testing Lab personnel: Mr. Richard Metzler
Mr. W. Gilbert
Mr. Hugo Alicandri

U.S. Bureau of Mines Representative: Mr. Dick Watson

Dragerwerk or their sales representatives (National Mine Service Company) were not present.

For a list of the equipment used in these tests, see Appendix Number 1, Page Number 9.

Inspection

A visual inspection was made of the fourteen self-recuers. No deficiencies were observed in construction. All seams appeared to be good welds. Attachment Number 1 is a drawing list of the drawings being retained at the Electrical Testing Laboratory in the special investigation files.

Explosion Tests

Fourteen explosion tests were conducted on the Dragerwerk self-rescuers. These tests were performed to determine whether by starting

ELECTRICAL TESTING LABORATORY
INVESTIGATIVE REPORT NUMBER 0002

EXPLOSION TEST REPORT
DRAGERWERK 60 MINUTE SELF RESCUER

BY
RICHARD W. METZLER

MAY 7, 1980

DIVISION OF ELECTRICAL SAFETY
ELECTRICAL TESTING LABORATORY
4800 FORBES AVENUE
PITTSBURGH, PENNSYLVANIA 15213

APPENDIX I

ELECTRICAL TESTING LABORATORY
INVESTIGATIVE REPORT NUMBER 0002

EXPLOSION TEST REPORT
DRAGERWERK 60 MINUTE SELF RESCUER

BY

RICHARD W. METZLER

MAY 7, 1980

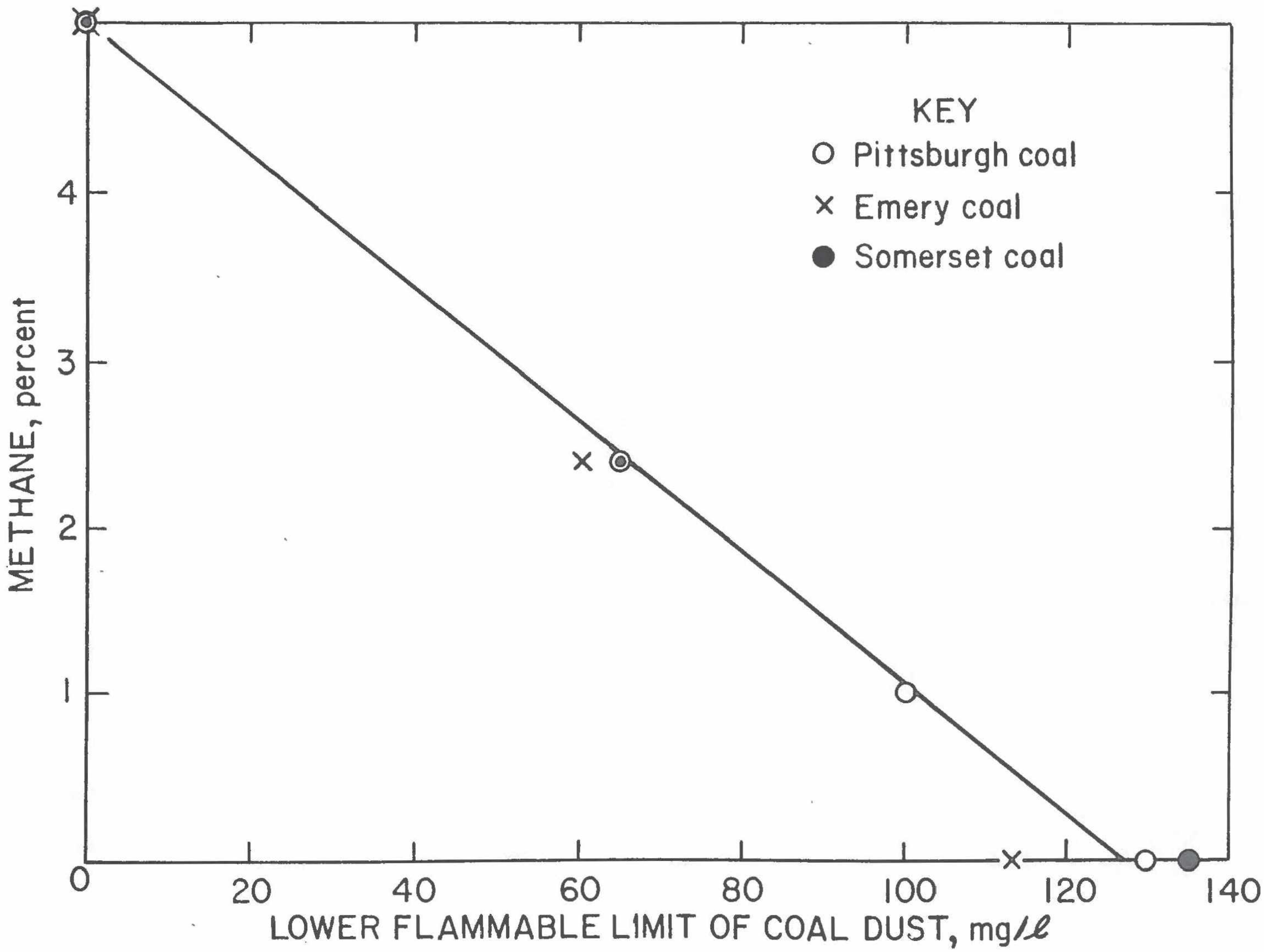


FIGURE 43. - Lower flammable limits for coal dust-methane-air mixtures.

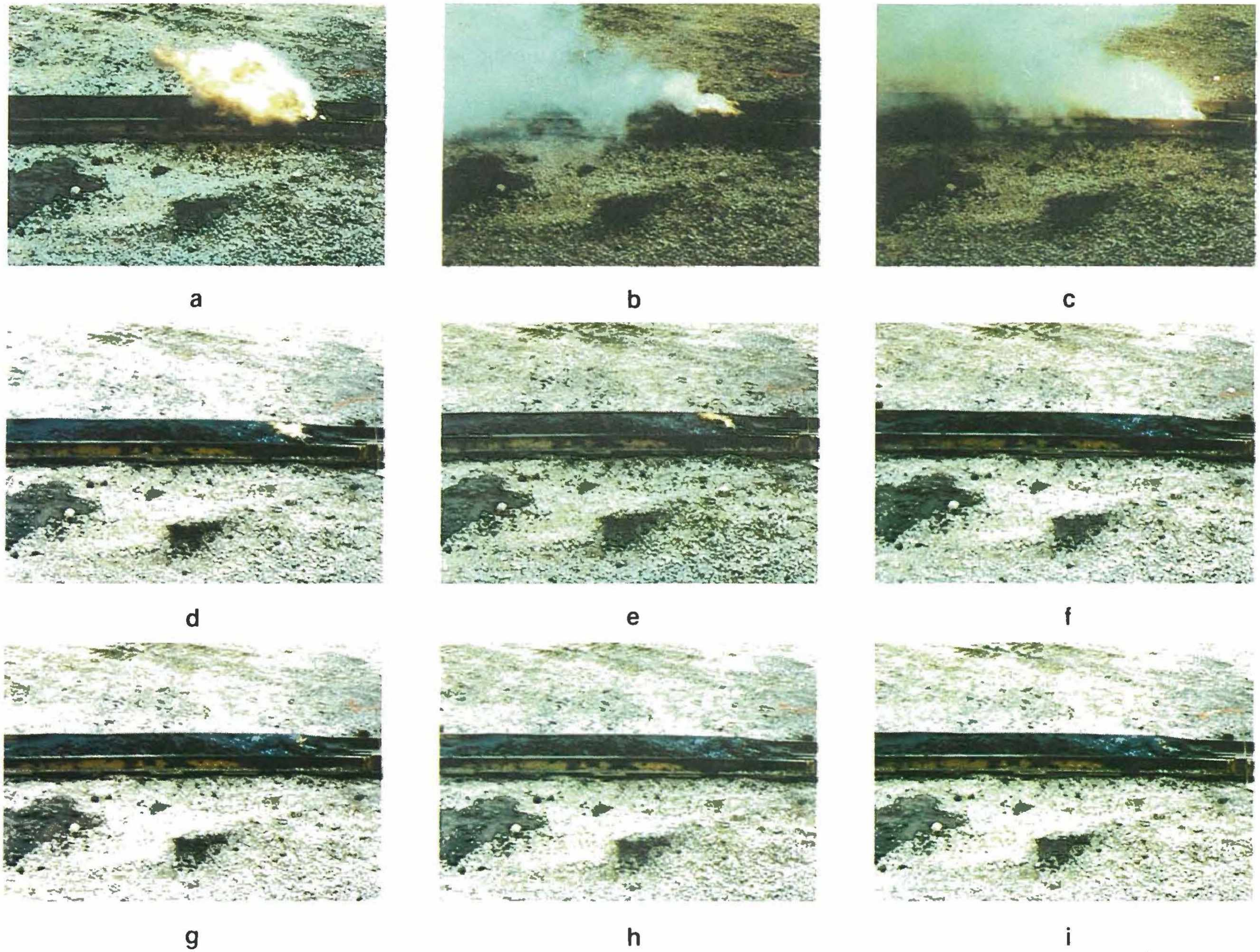


FIGURE 42. - Scenes from a simulated conveyor belt fire.

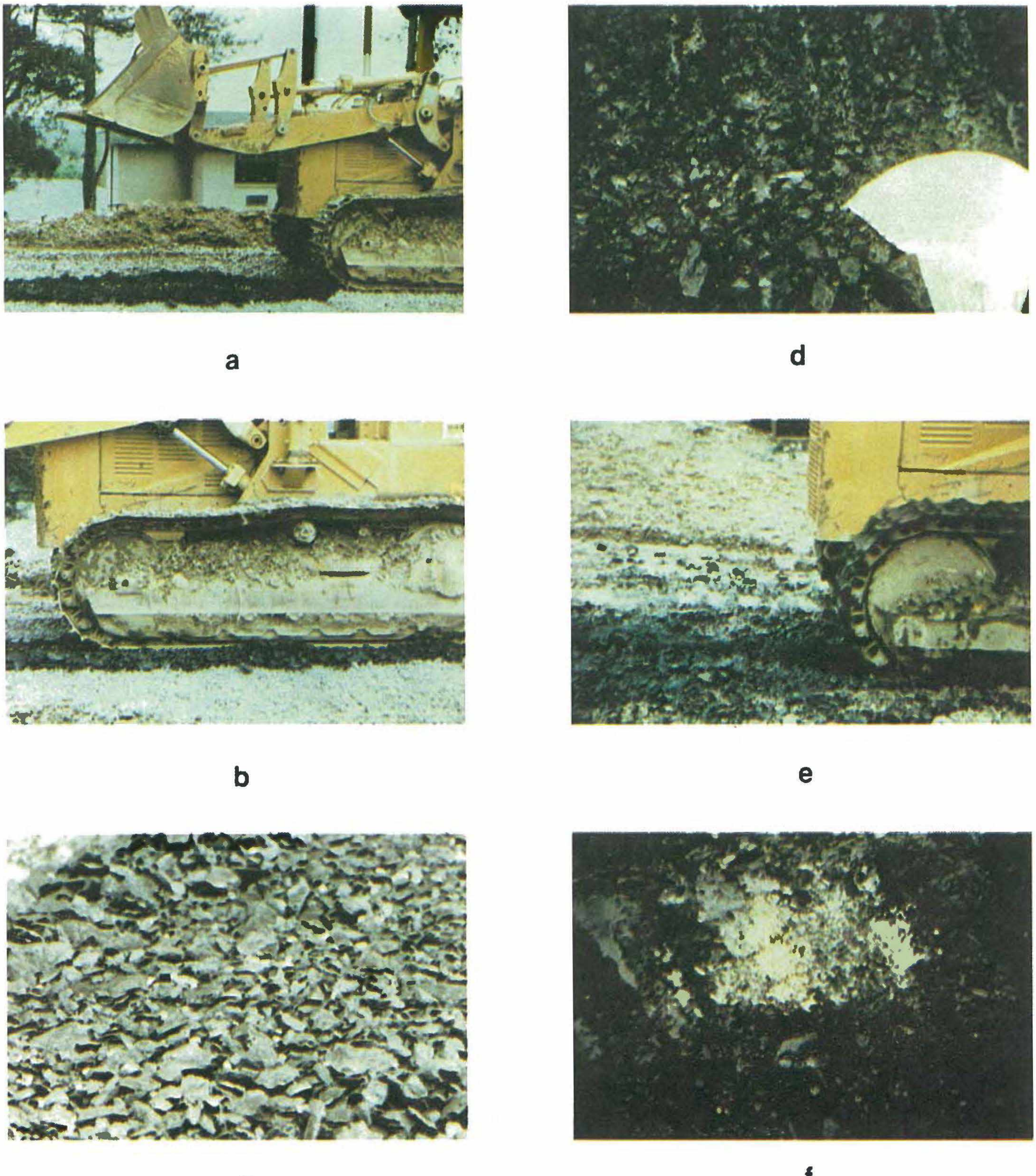


FIGURE 41. - Scenes from runover trails with raw KO_2-coal mixtures.

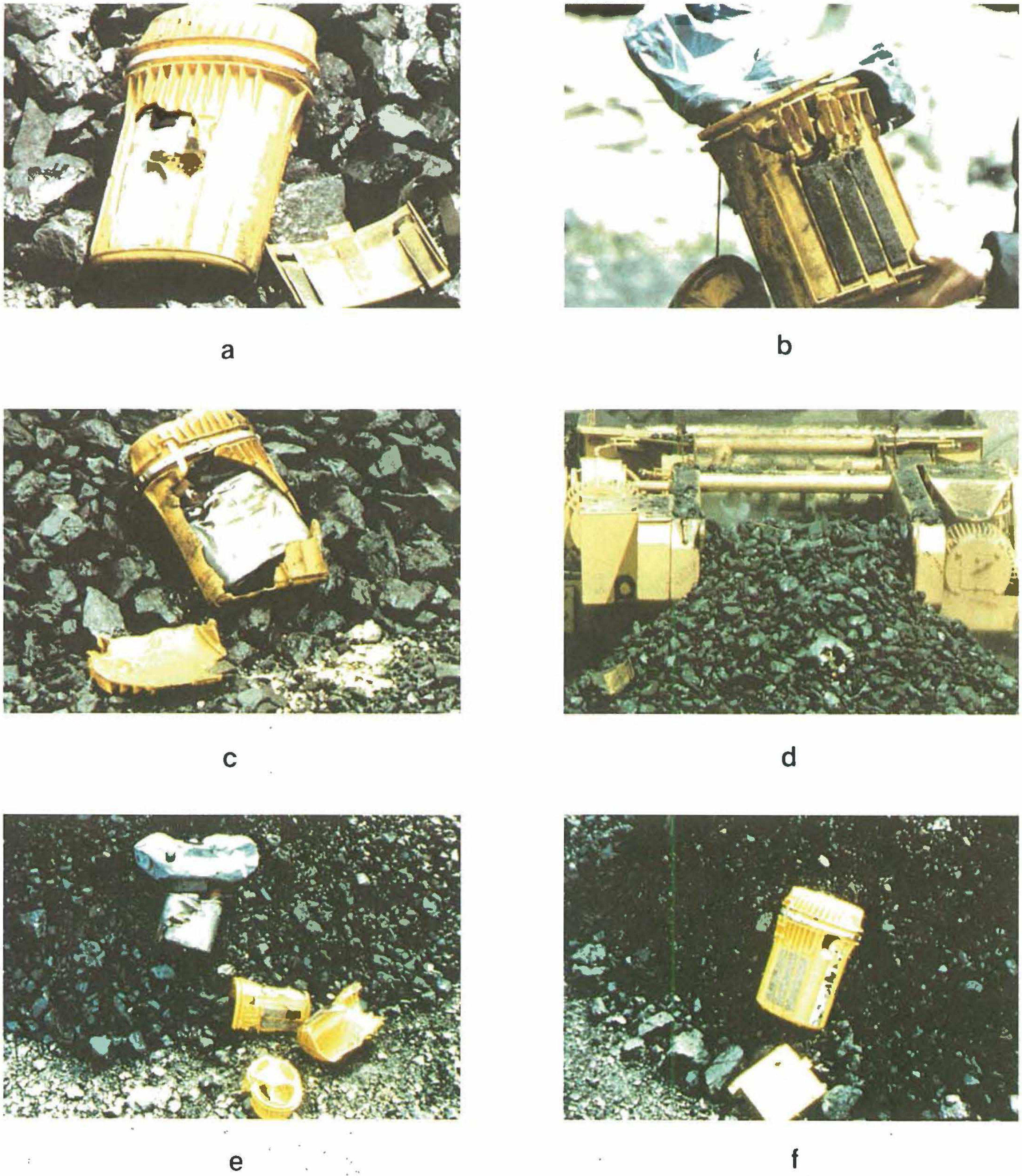


FIGURE 40. - Damage resulting from feeder-breaker tests with Emery and Somerset coals.

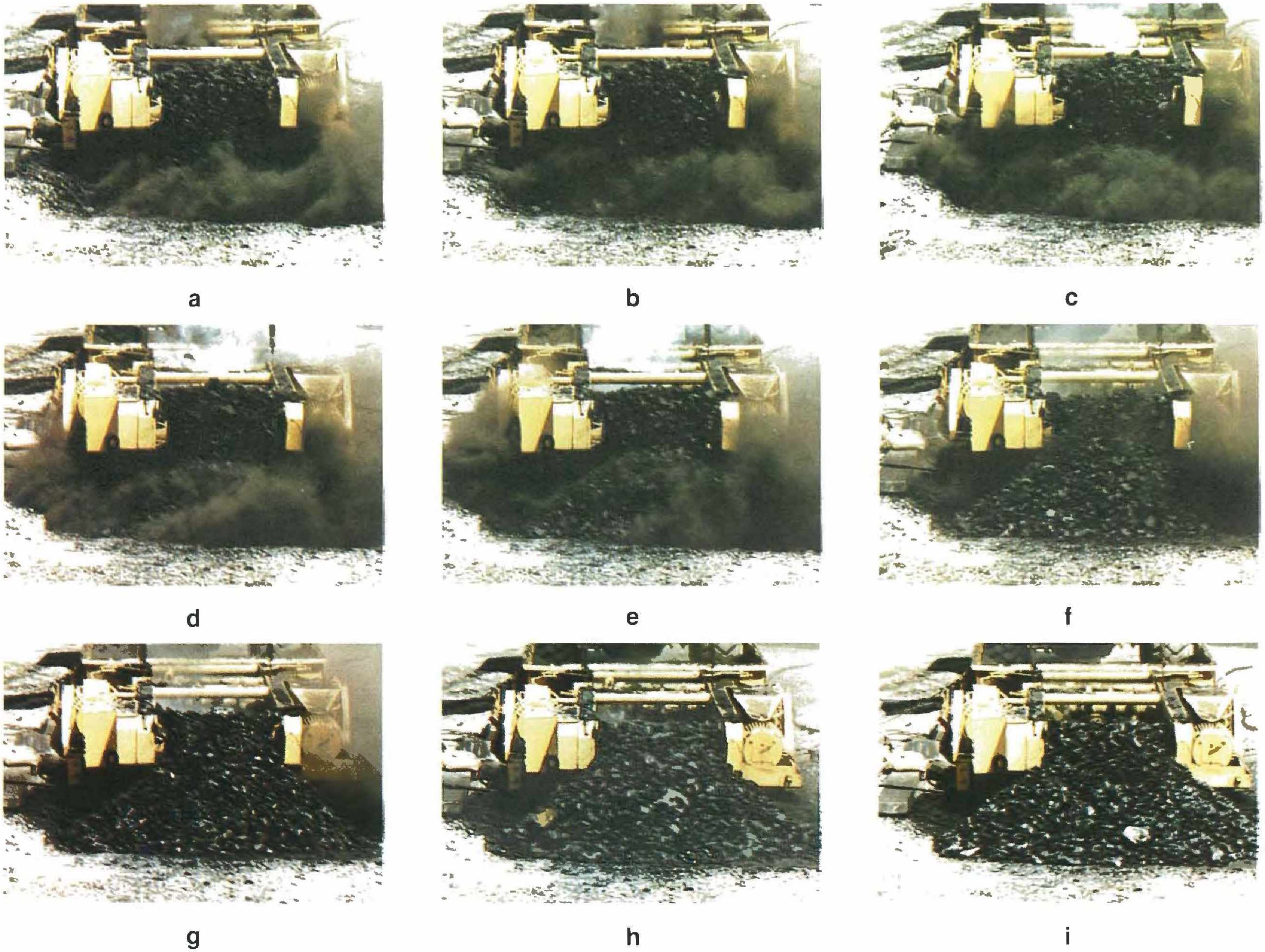
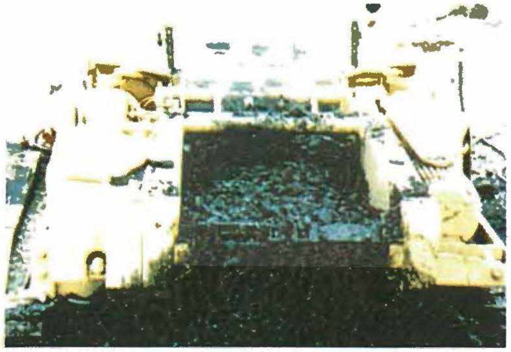


FIGURE 39. - Scenes from a feeder-breaker test with Emery coal.



a

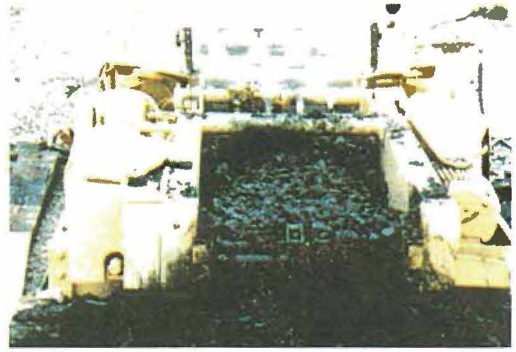


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FIGURE 38. - Scenes from a feeder-breaker test to determine effectiveness of water sprays in preventing ignitions.

FIGURE 37. - Long-Airdox feeder-breaker equipped with simple water spray system.

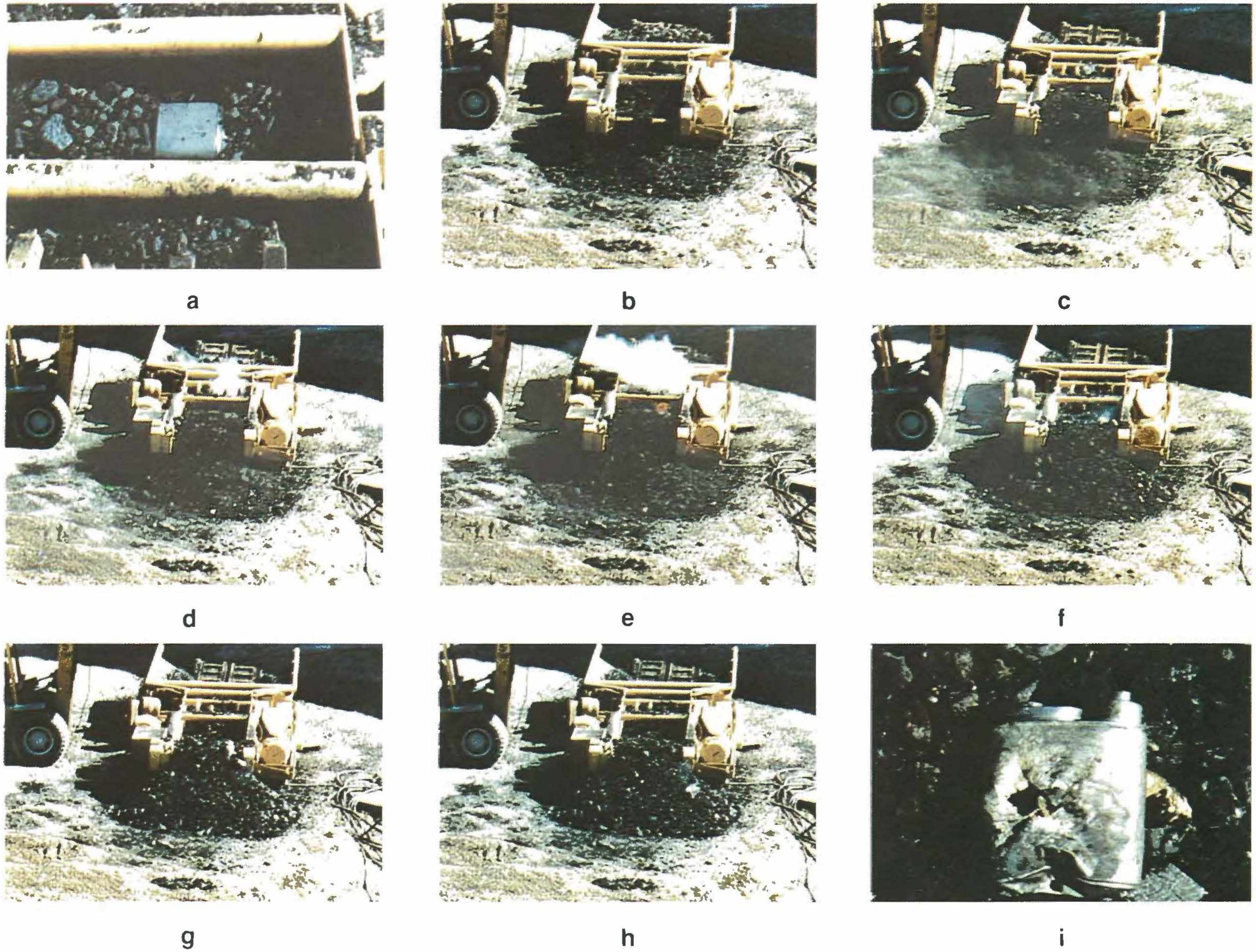


FIGURE 36. - Scenes from a feeder-breaker test with a stripped unit which resulted in a fire.

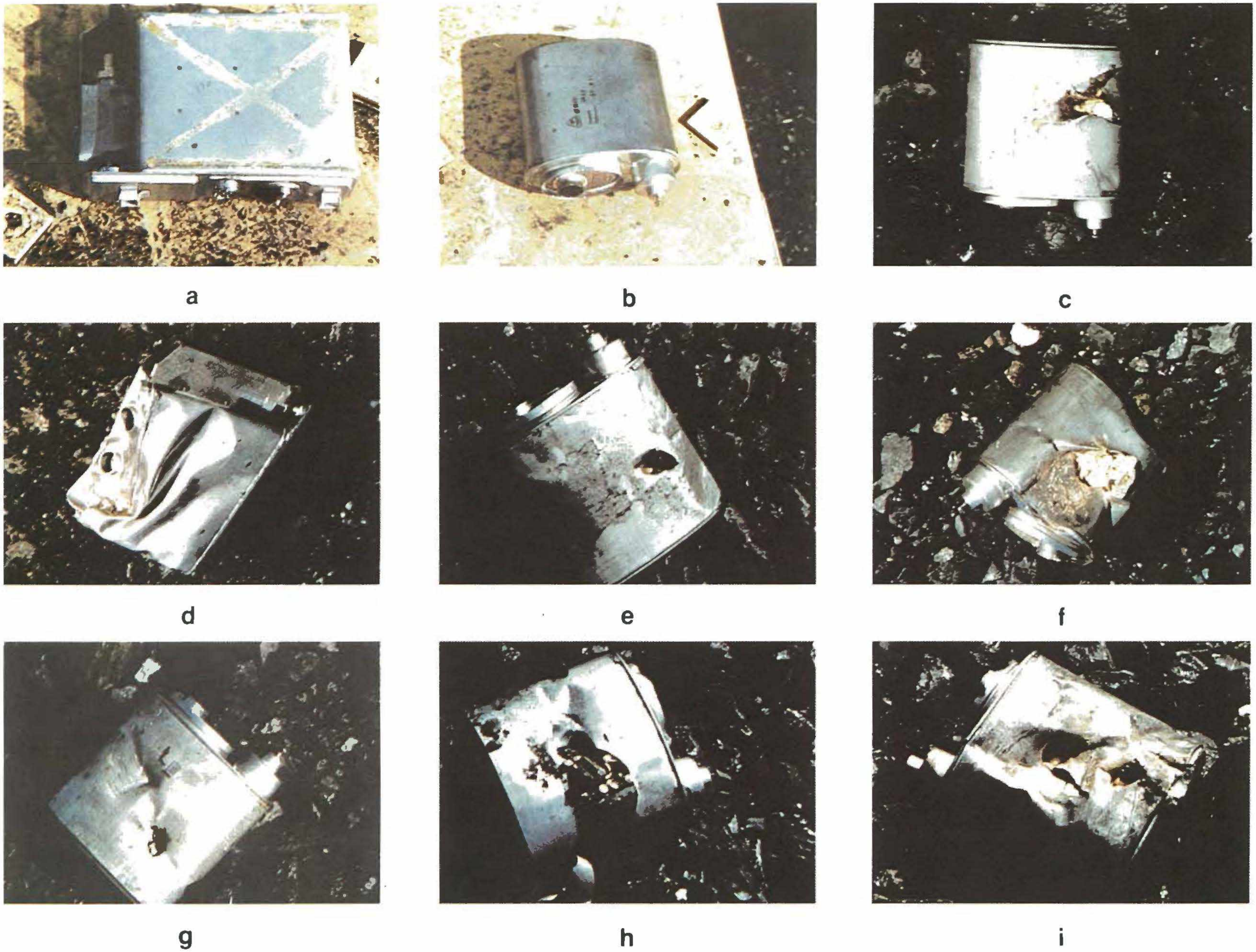


FIGURE 35. Stripped self rescuers (KO_2 canisters) used in feeder-breaker tests (a, b); damage resulting from tests with stripped units (c-i).

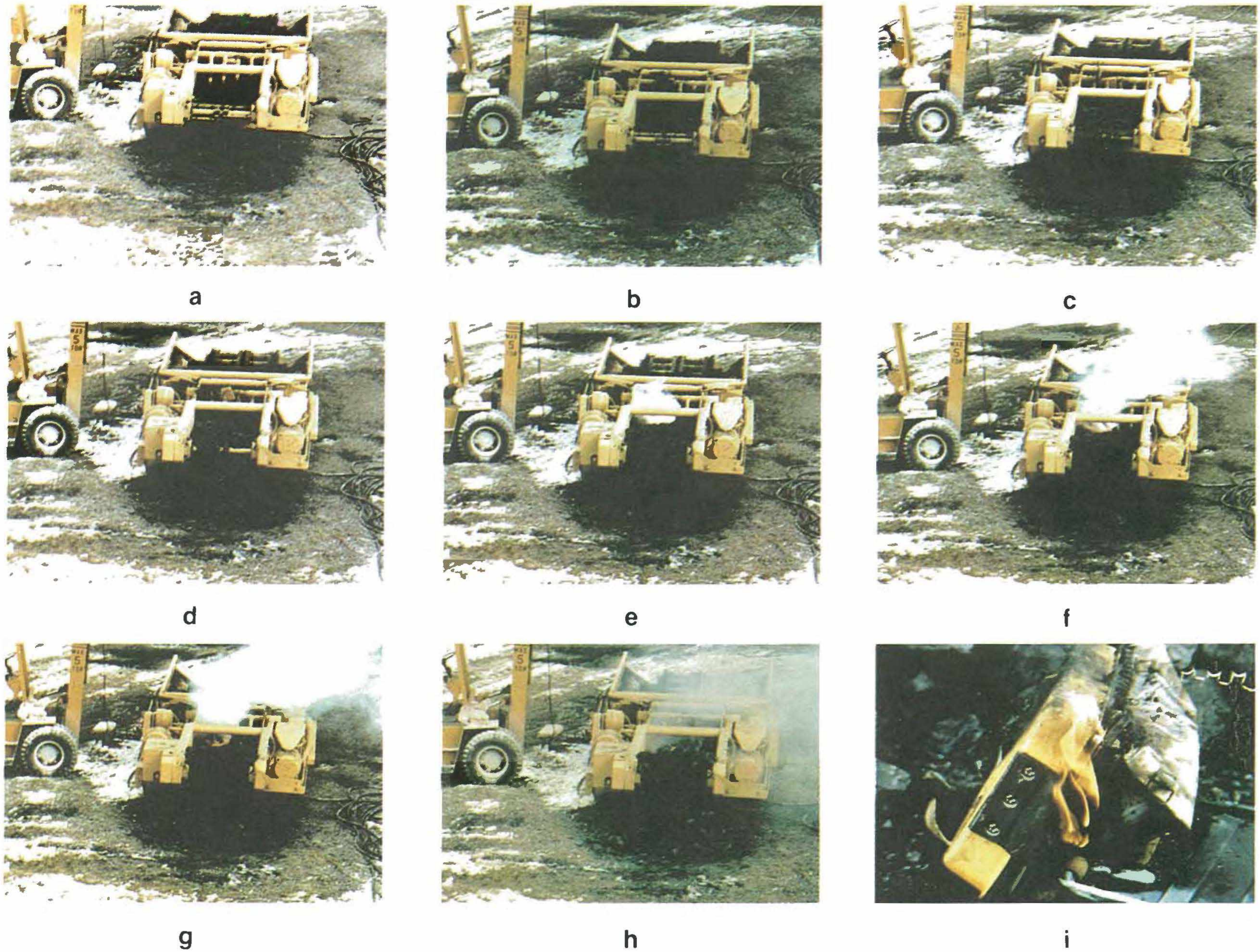


FIGURE 34. - Scenes from a feeder-breaker test resulting in a fire which consumed a composition hinge used in the construction of a MSA self rescuer.

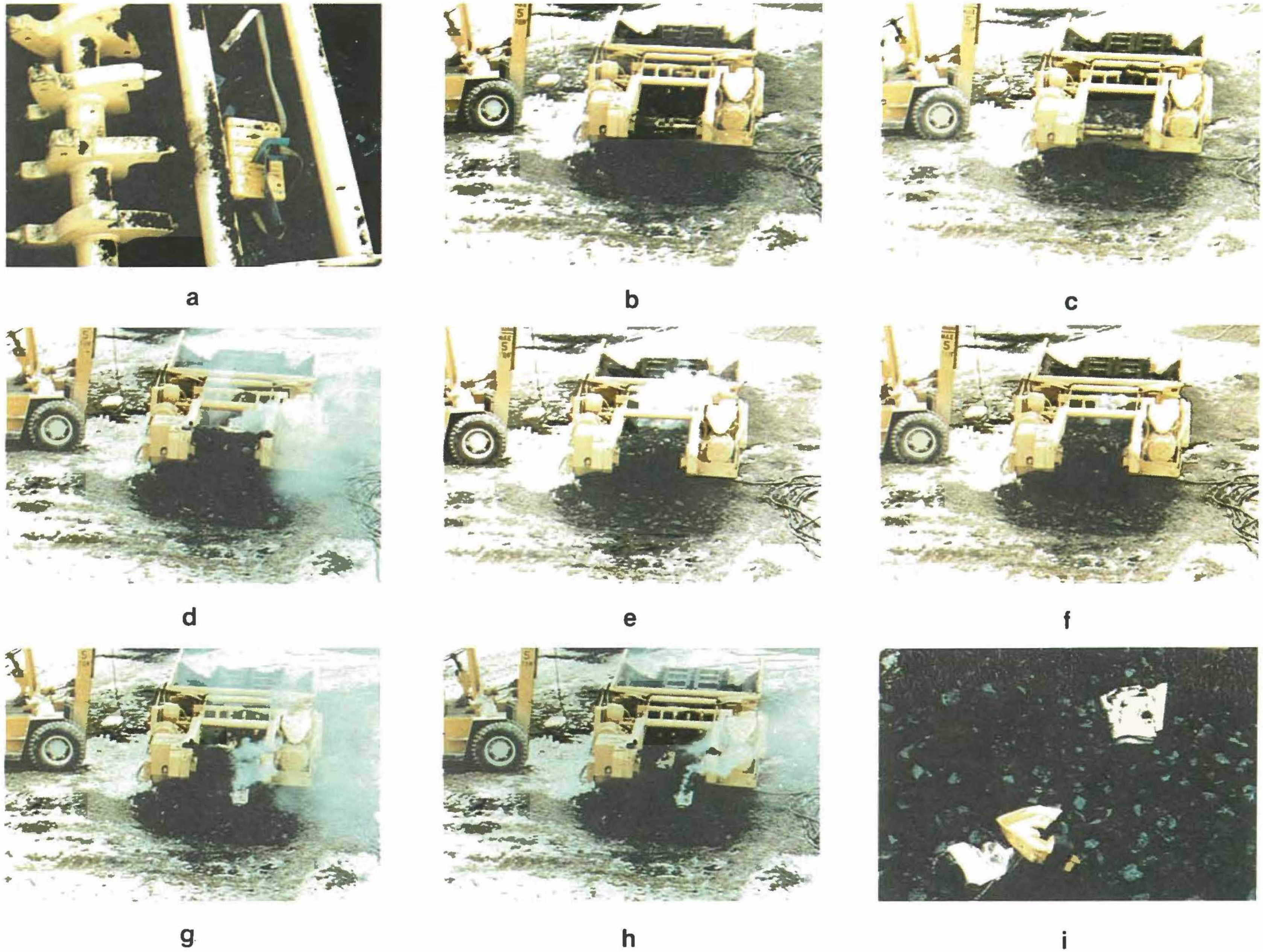
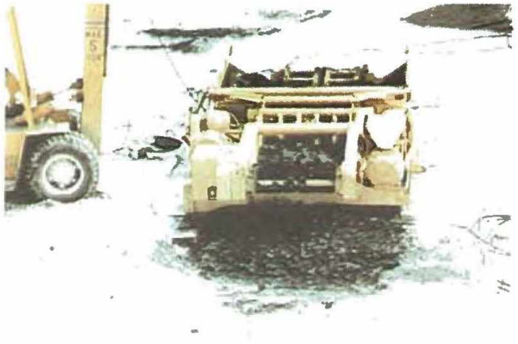
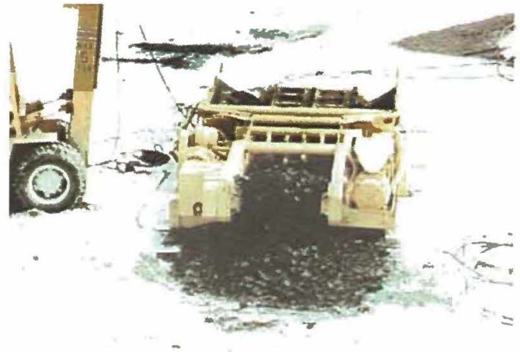


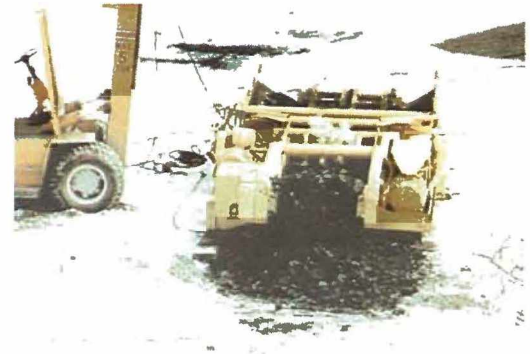
FIGURE 33. - Scenes from a feeder-breaker test resulting in a short-lived fire.



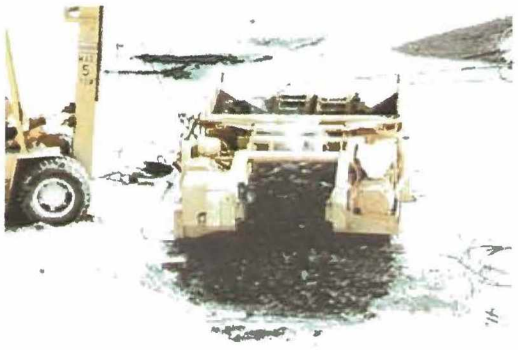
a



b



c



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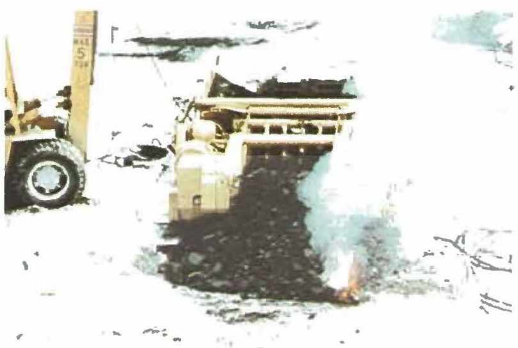

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FIGURE 32. - Scenes from a feeder-breaker test resulting in fire.

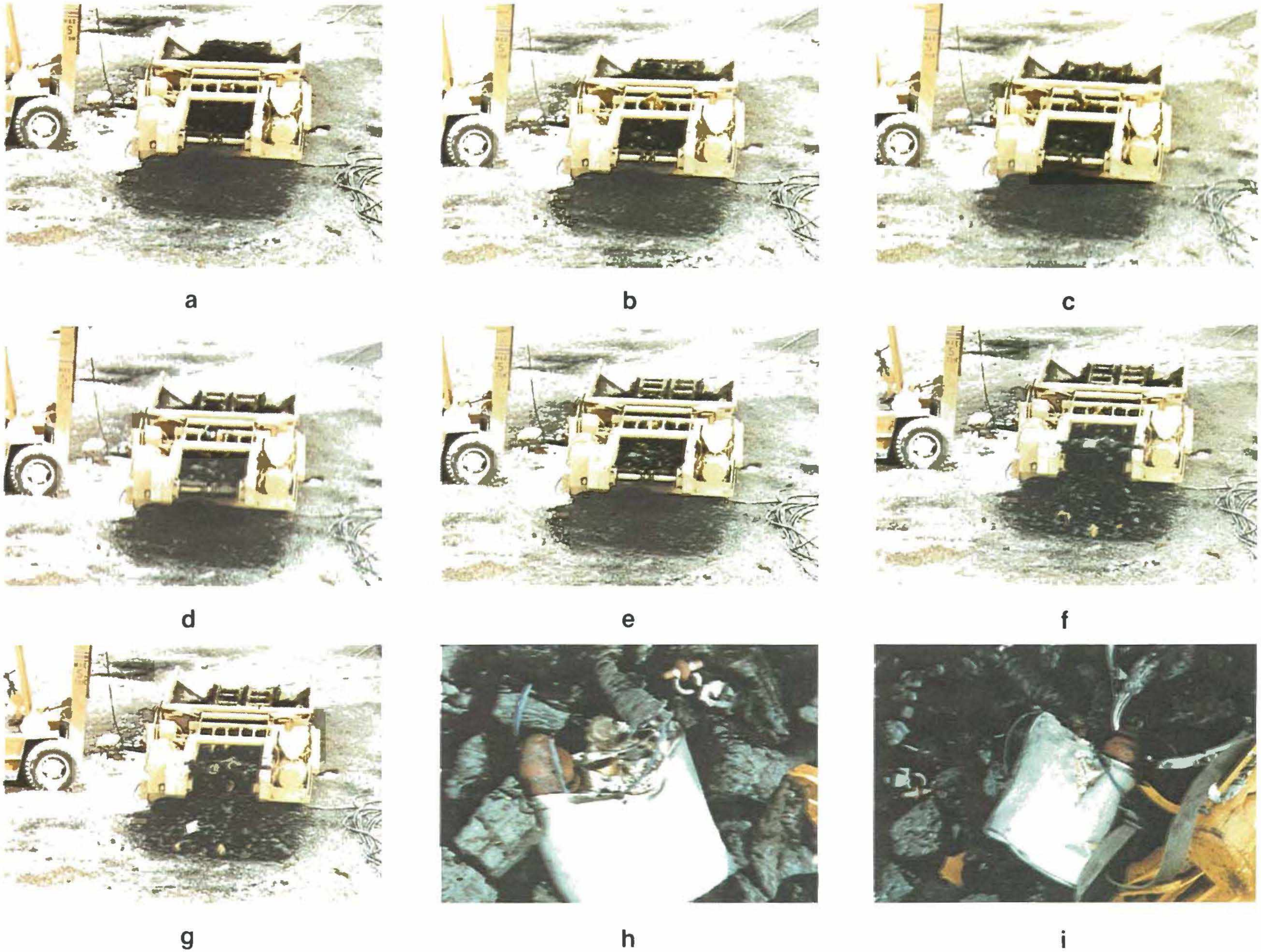


FIGURE 31. - Scenes from a feeder-breaker test resulting in severe damage to a self rescuer but no fire.

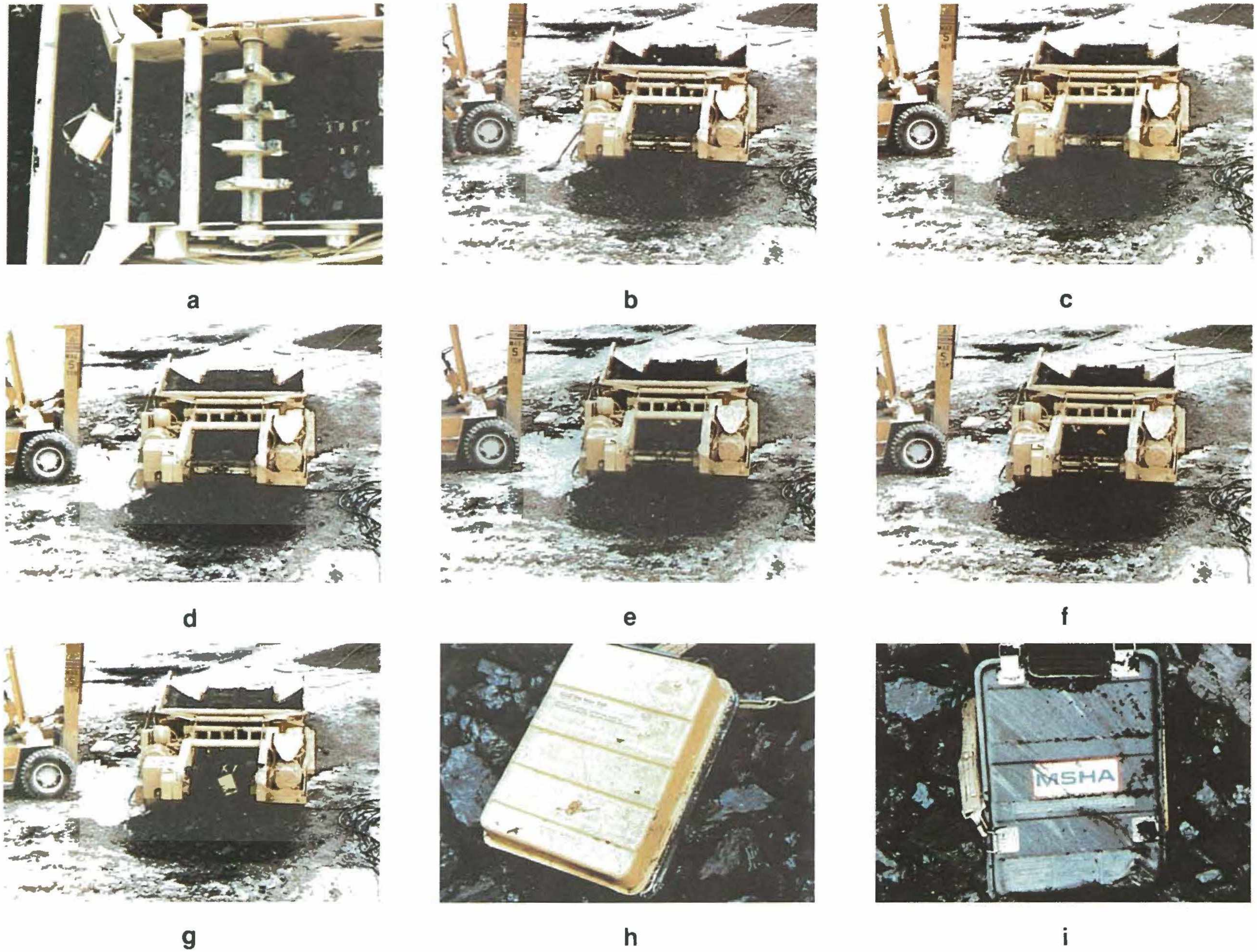
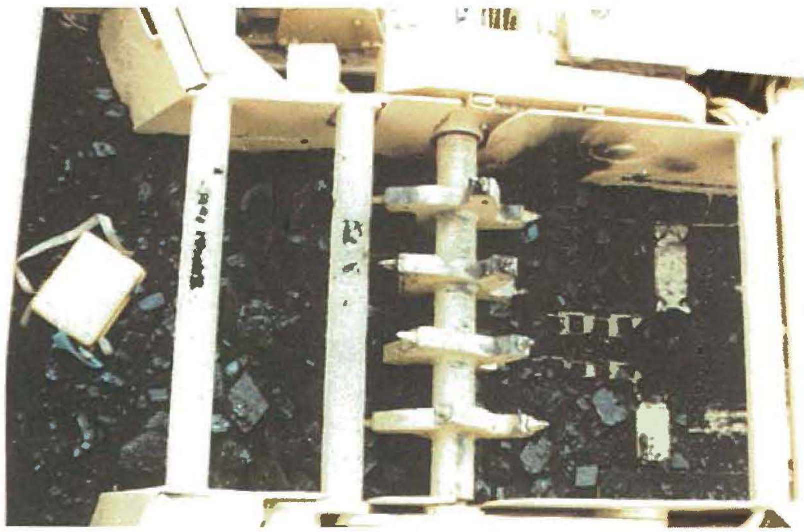
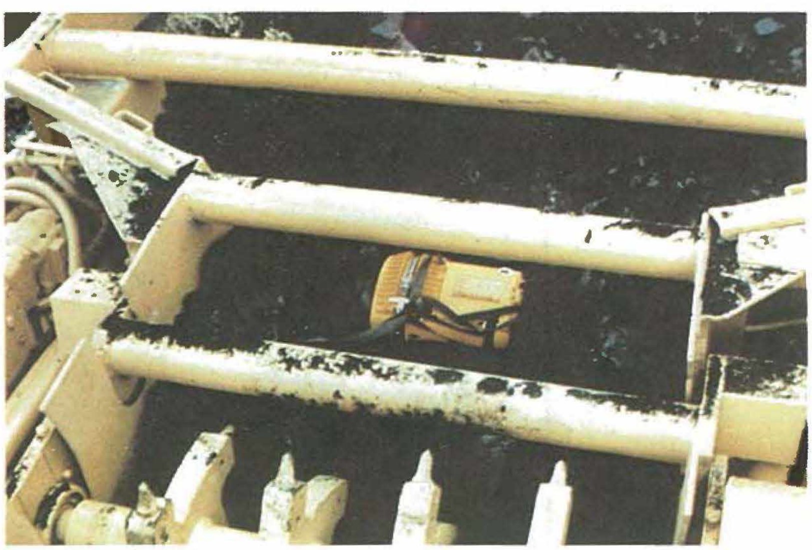


FIGURE 30. - Scenes from a feeder-breaker test resulting in minimal damage to self rescuer.

a



b



c

FIGURE 29. - (a) Feeder-breaker; (b) rotating pick assembly; (c) self rescuer arranged to maximize chance of being impaled.

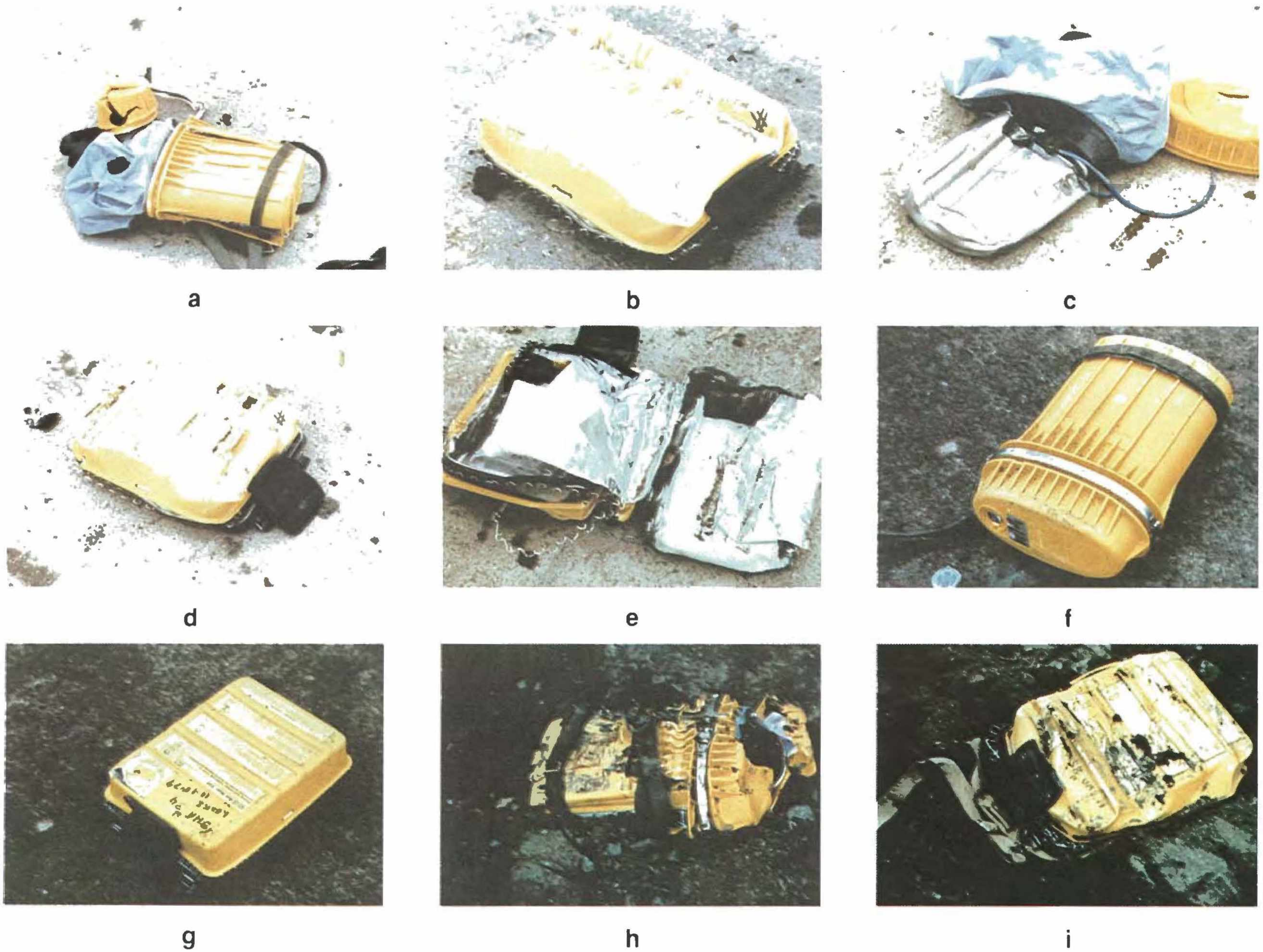
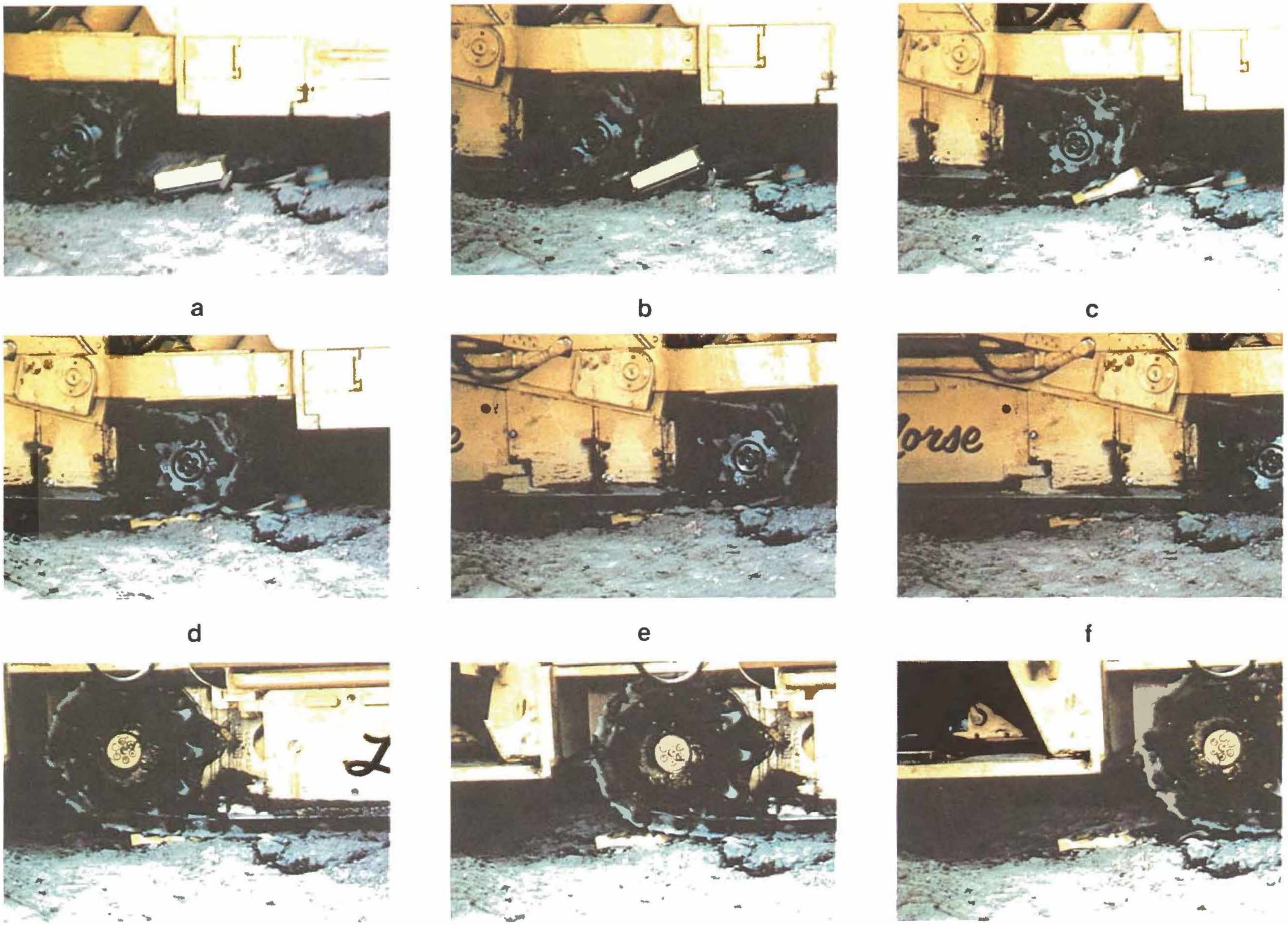


FIGURE 28. - Damage to self rescuers resulting from runover tests.



a b c

d e f

g h i

FIGURE 27. · Runover test with a 96,000 lb continuous mining machine.

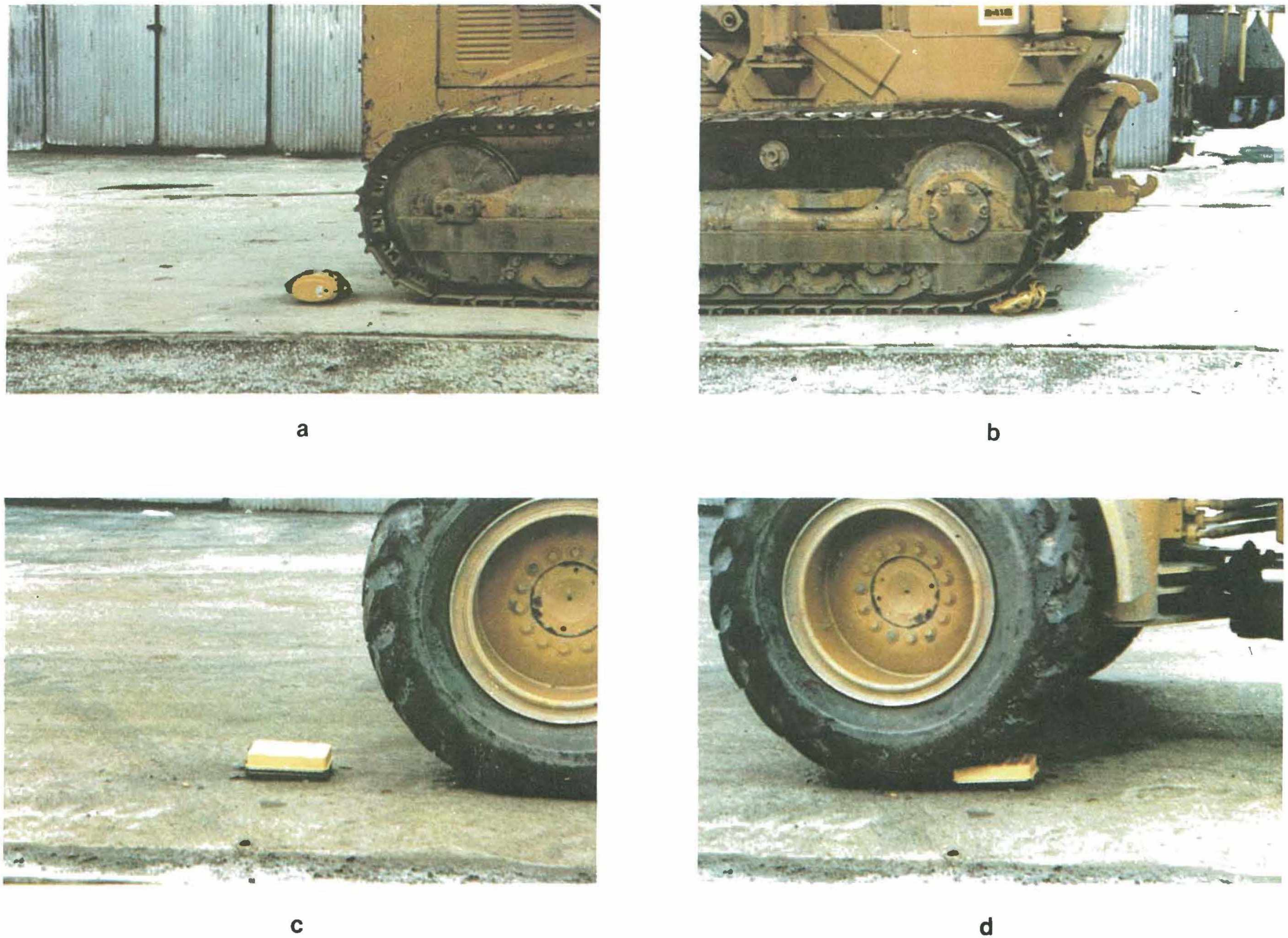


FIGURE 26. - Runover test with a 24,000 lb high lift (a, b) and a 20,000 lb front-end loader (c, d).

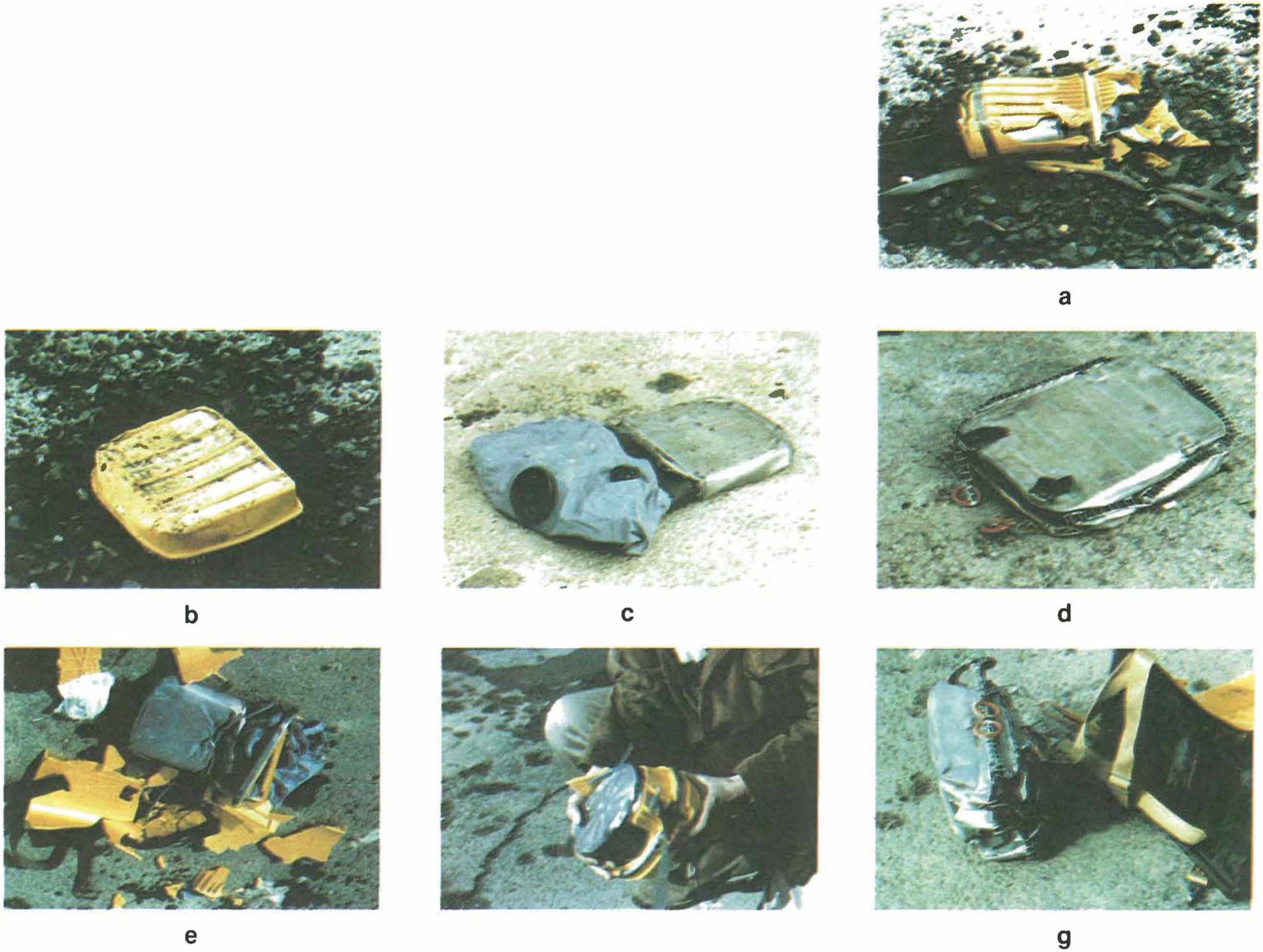


FIGURE 25. - Damage resulting from 1000 lb drop weight impact tests on self rescuers.

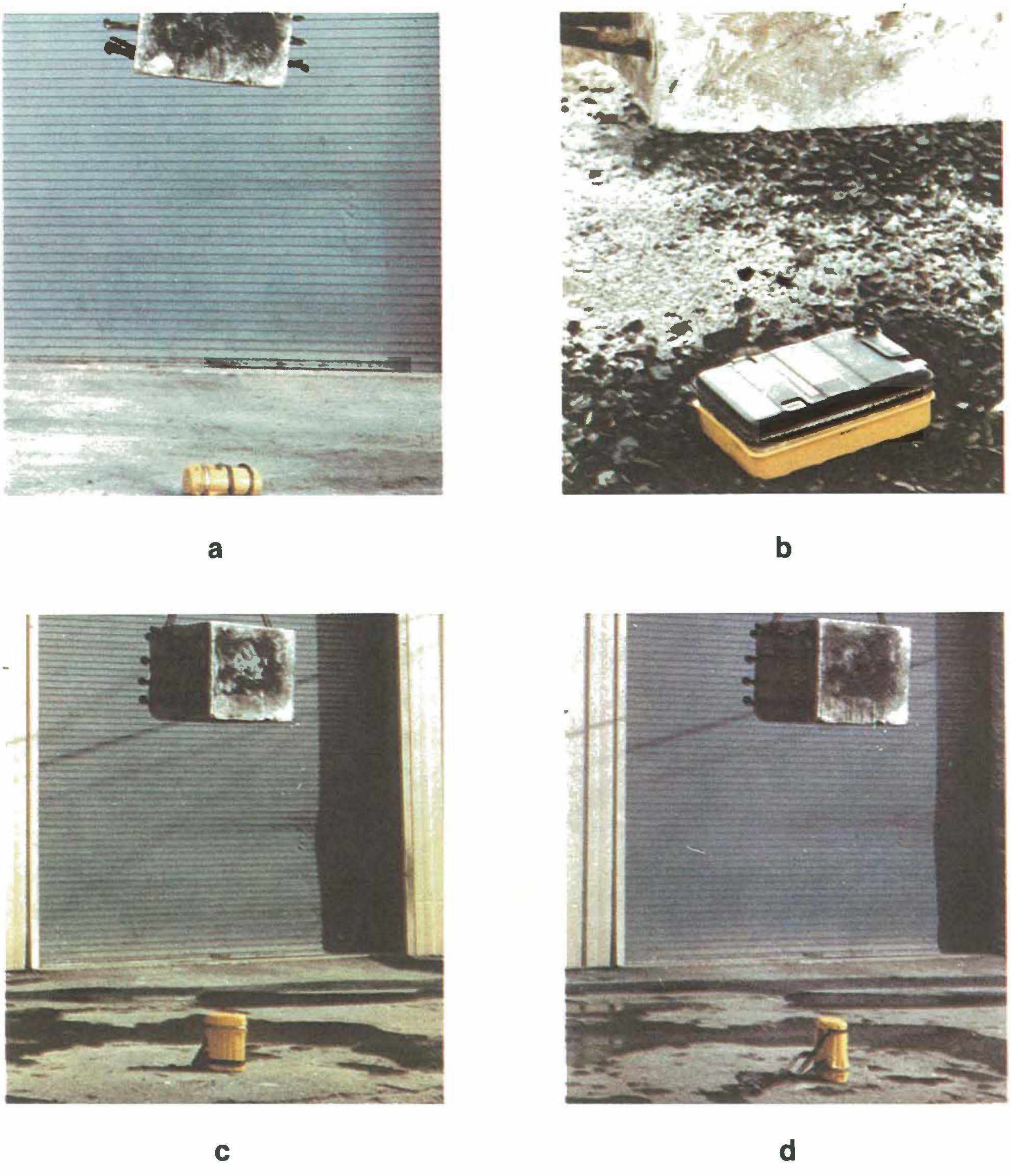
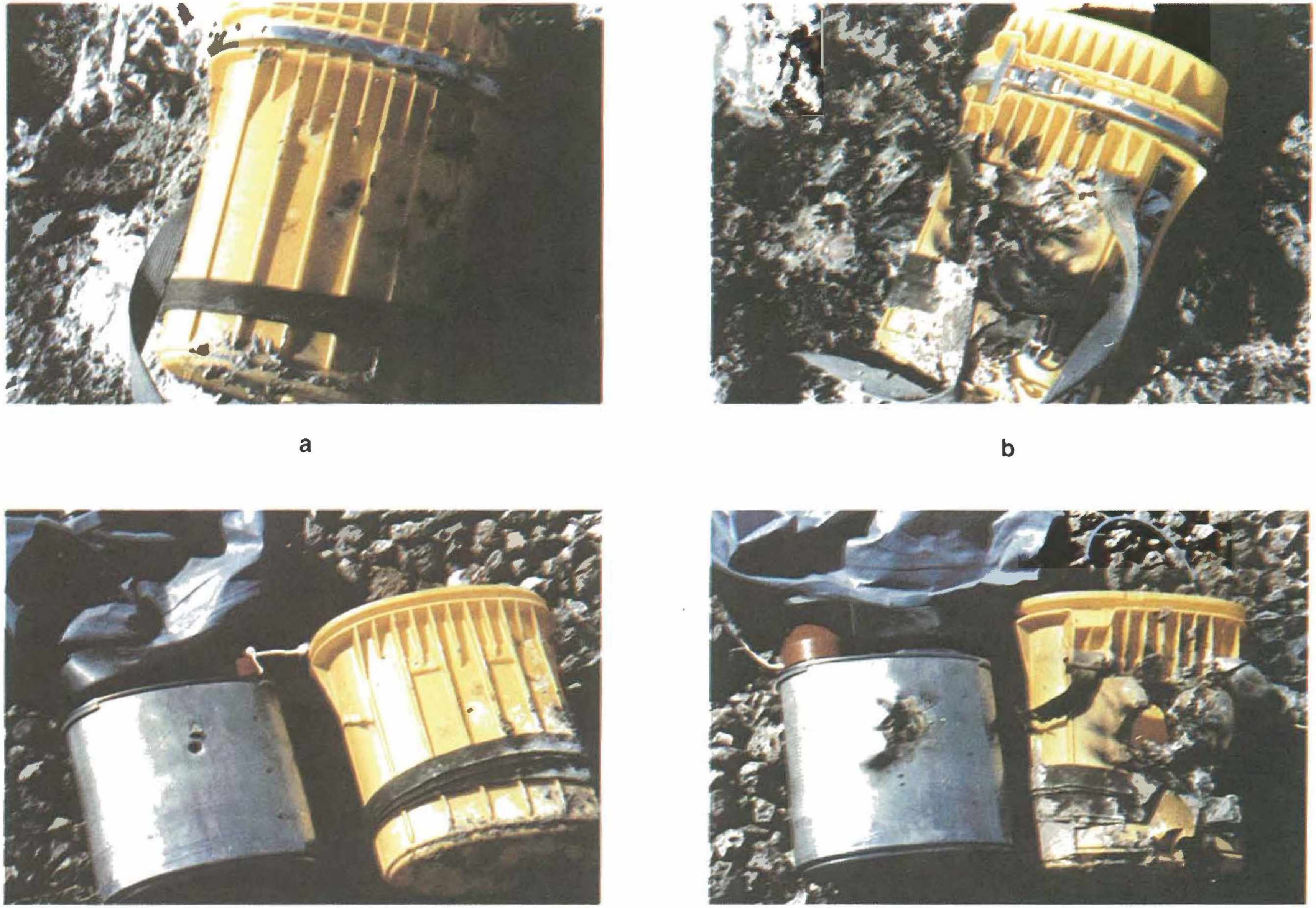


FIGURE 24. - Various configurations used in 1000 lb drop weight impacts tests with self rescuers.



a b c d

FIGURE 23. - Damage resulting from bullet impact on a Drager self rescuer.

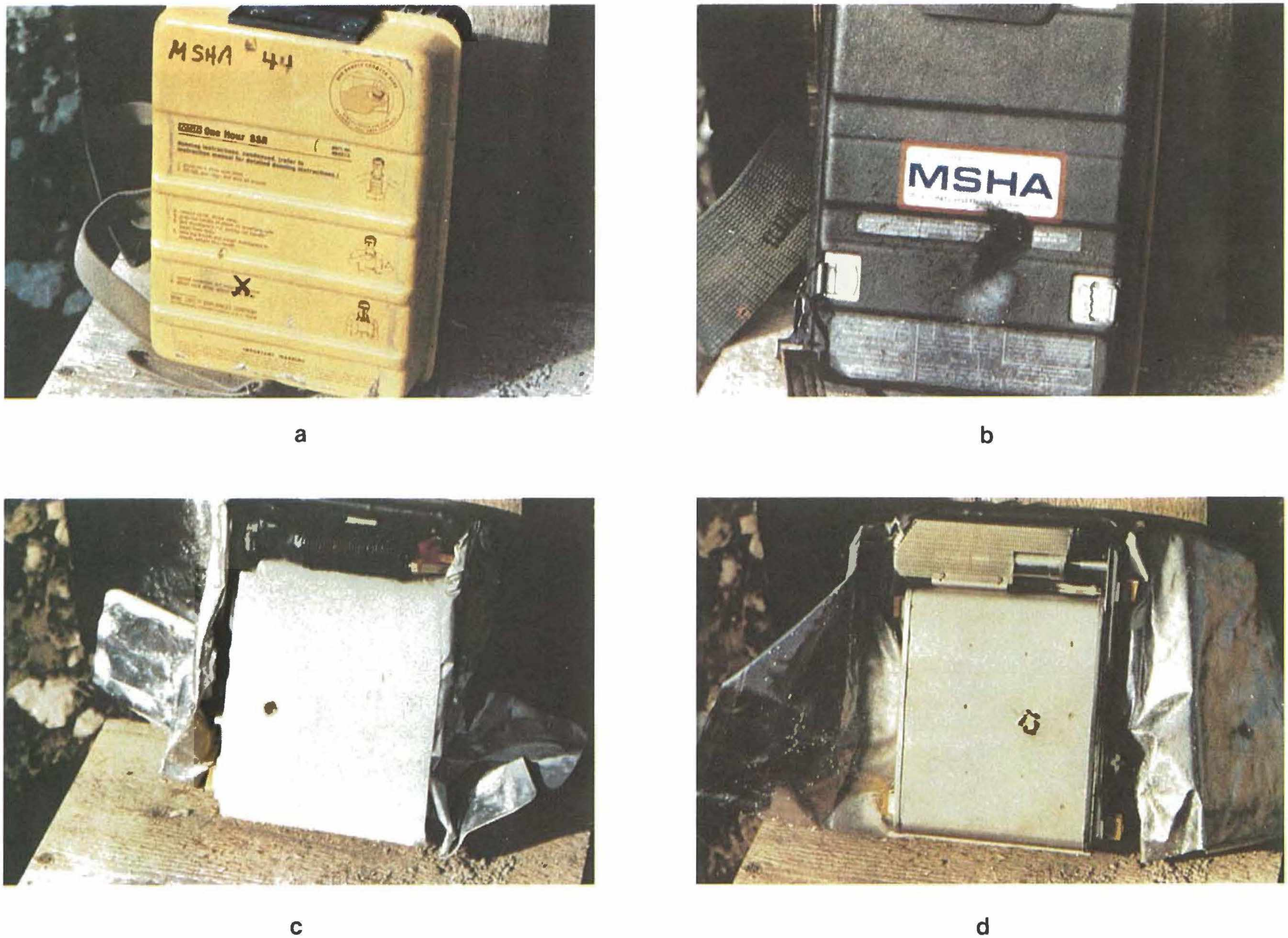


FIGURE 22. - Damage resulting from bullet impact on a MSA self rescuer.

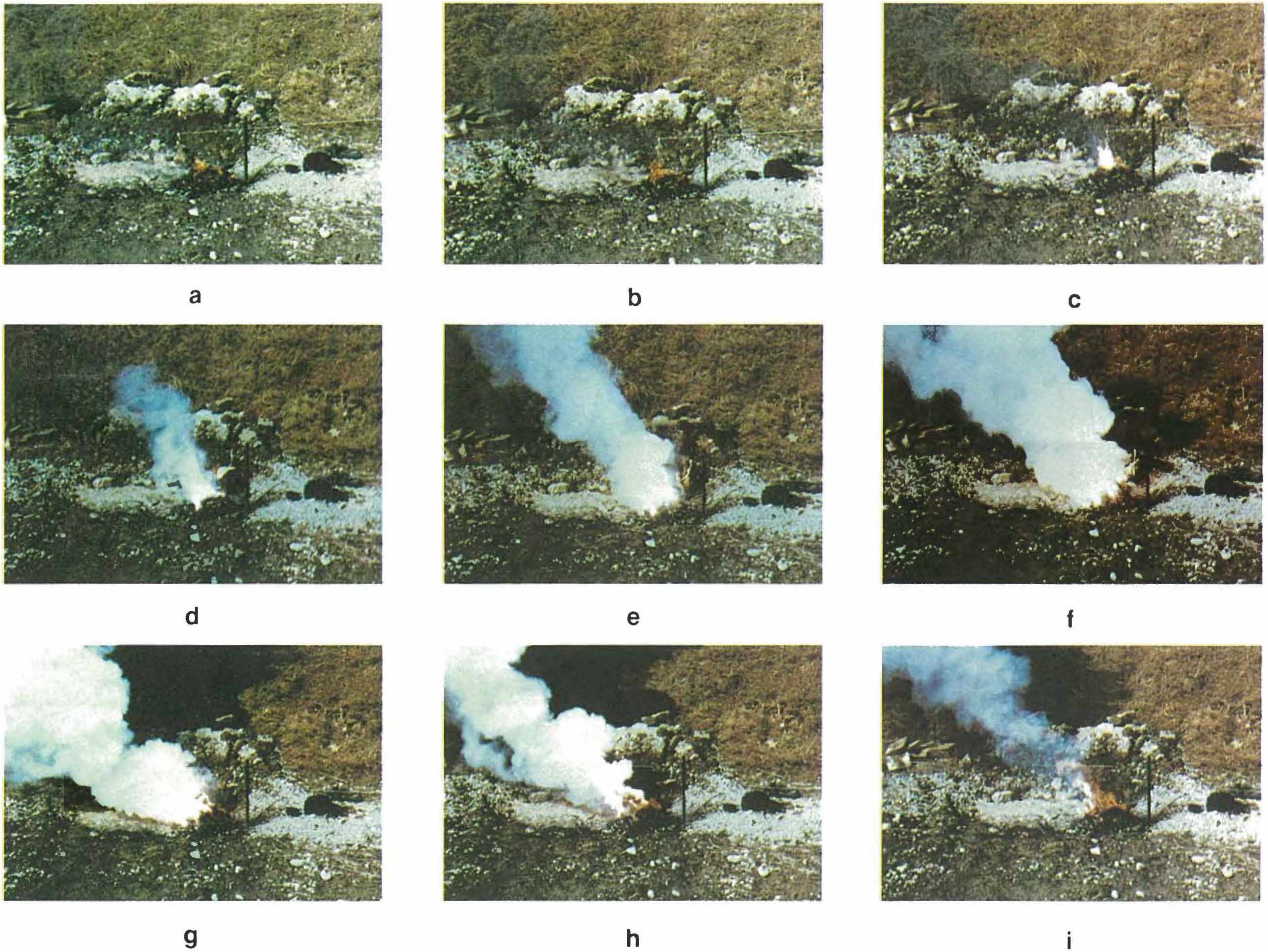


FIGURE 21. · Scenes from a bonfire test with 500g of lump KO_2.

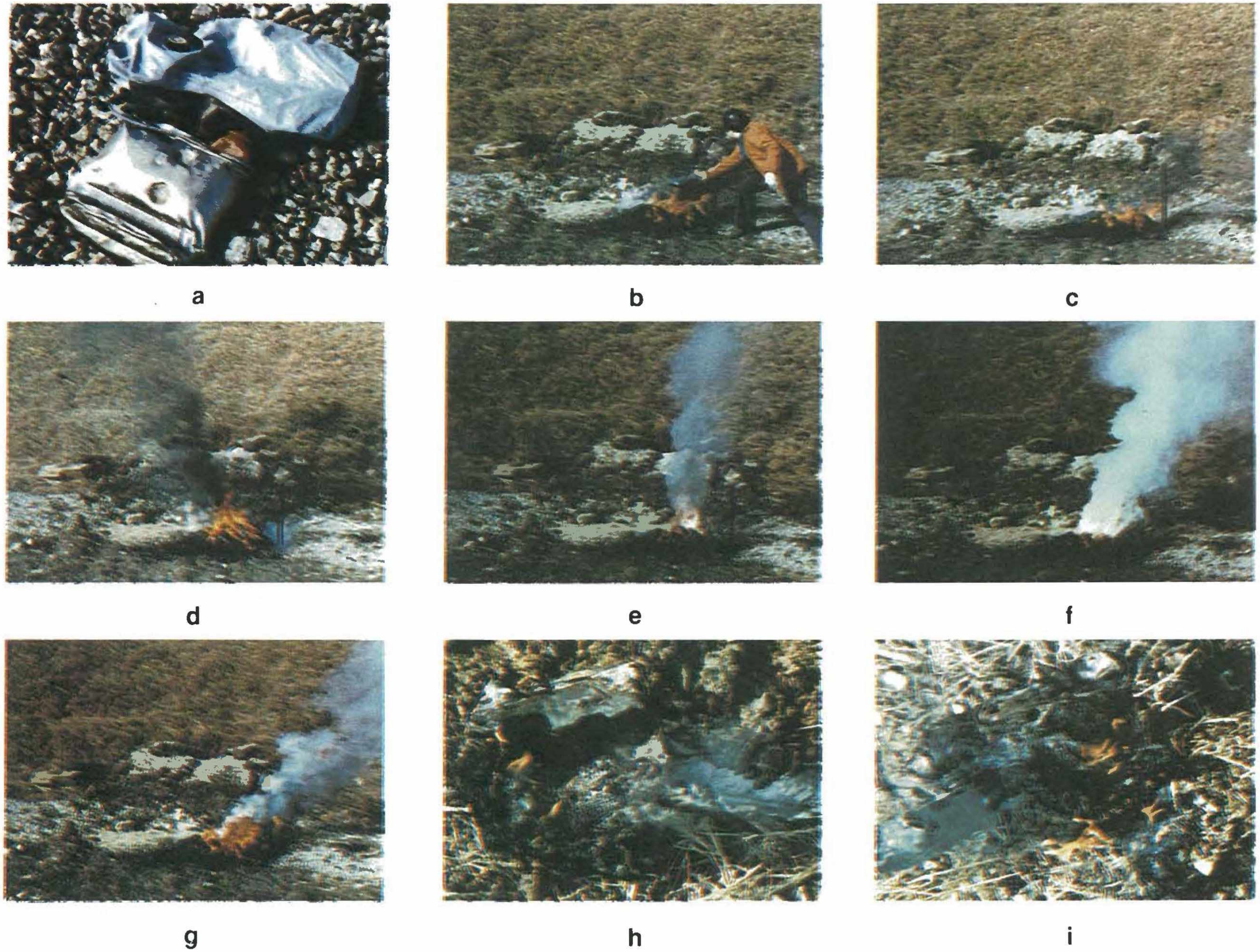


FIGURE 20. - Scenes from a bonfire test with a damaged Drager self rescuer.

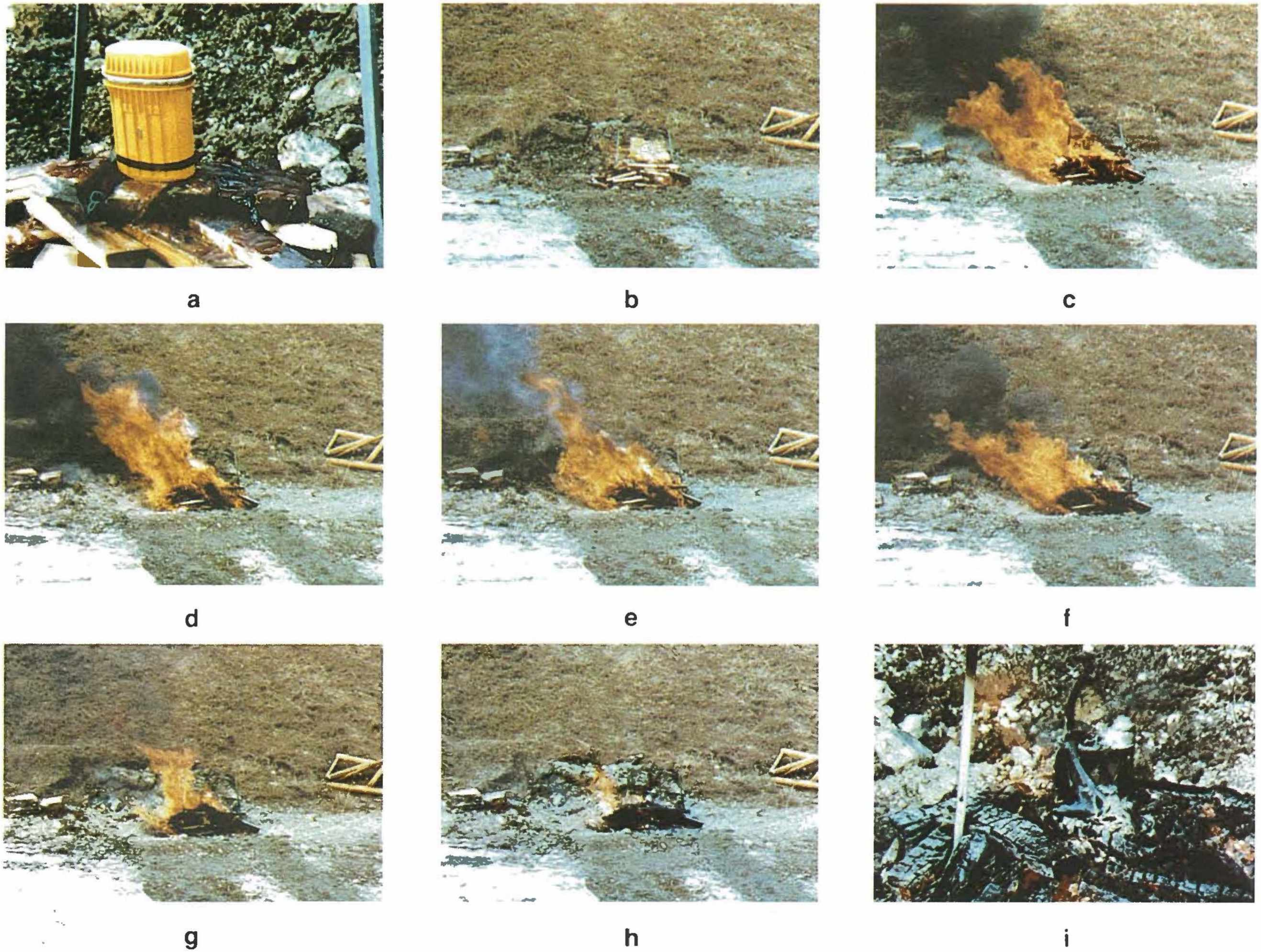


FIGURE 19. - Scenes from a bonfire test with a Drager self rescuer.

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FIGURE 18. · Scenes from a bonfire test with a MSA self rescuer.

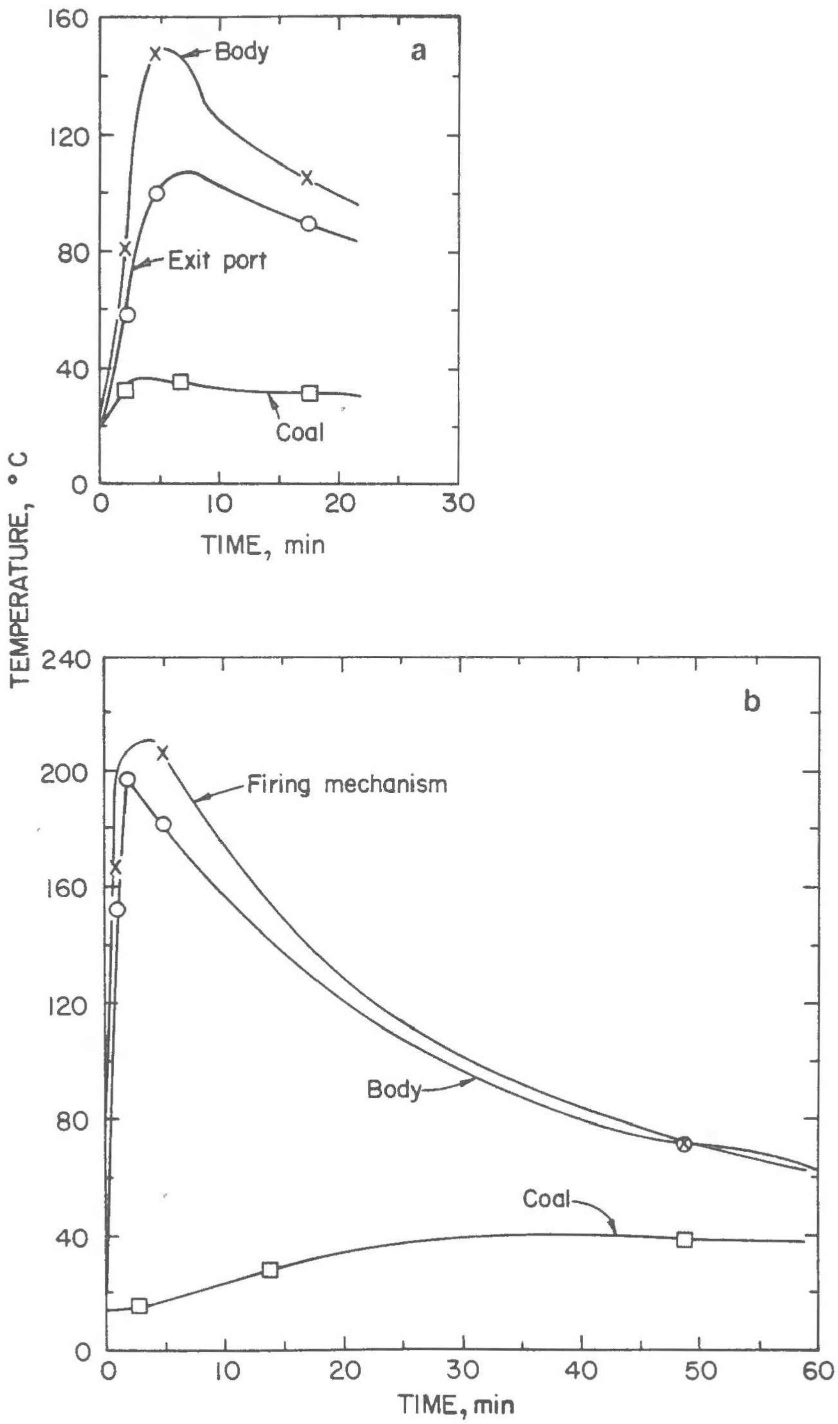


FIGURE 17. - Thermal records from: (a) MSA oxygen candle and (b) Drager oxygen candle.

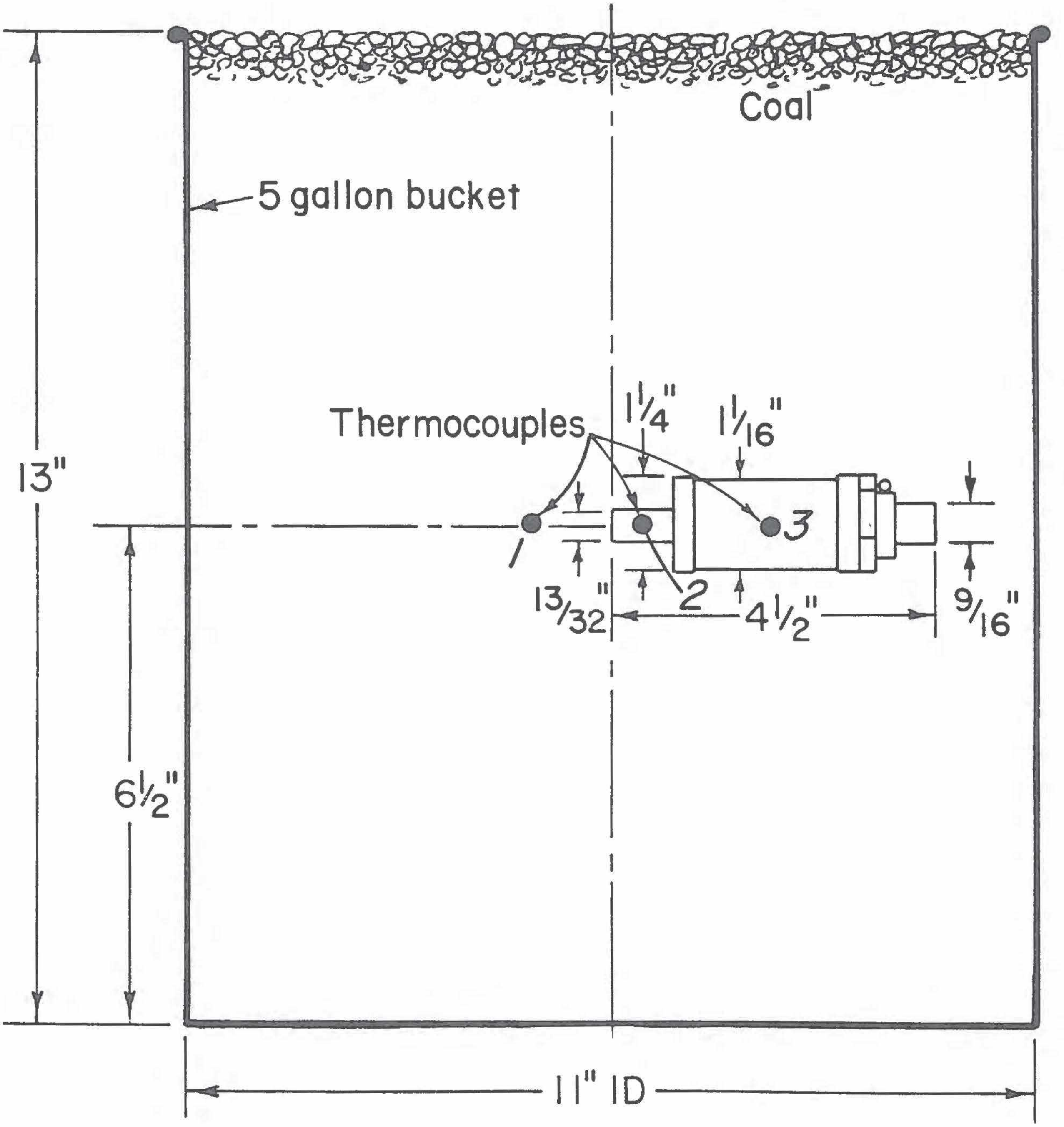


FIGURE 16. - Arrangement used in coal ignition studies with oxygen candles.

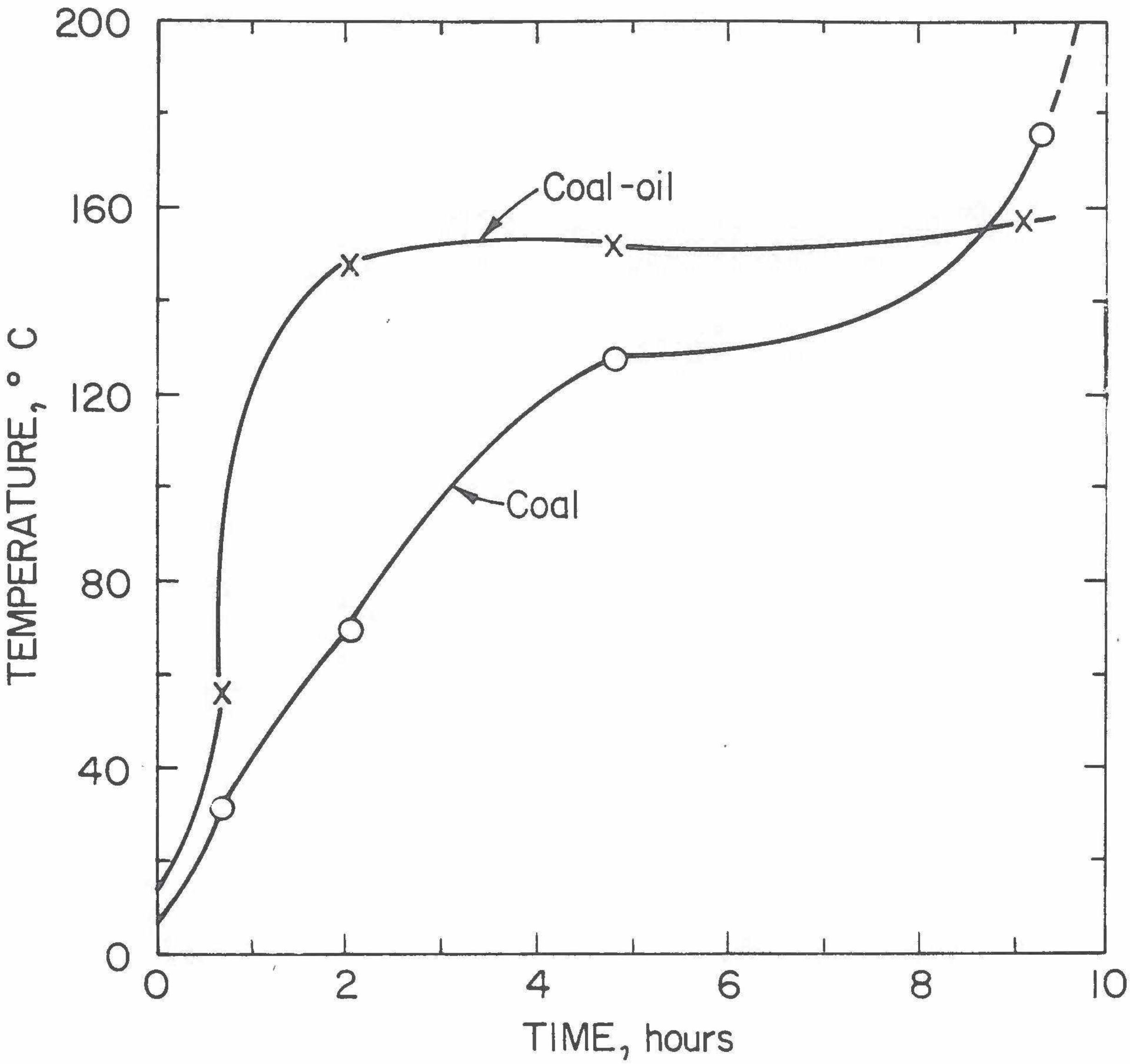


FIGURE 15. - Thermal records from 150°C simulator runs with dry coal and coal wetted with hydraulic fluid.

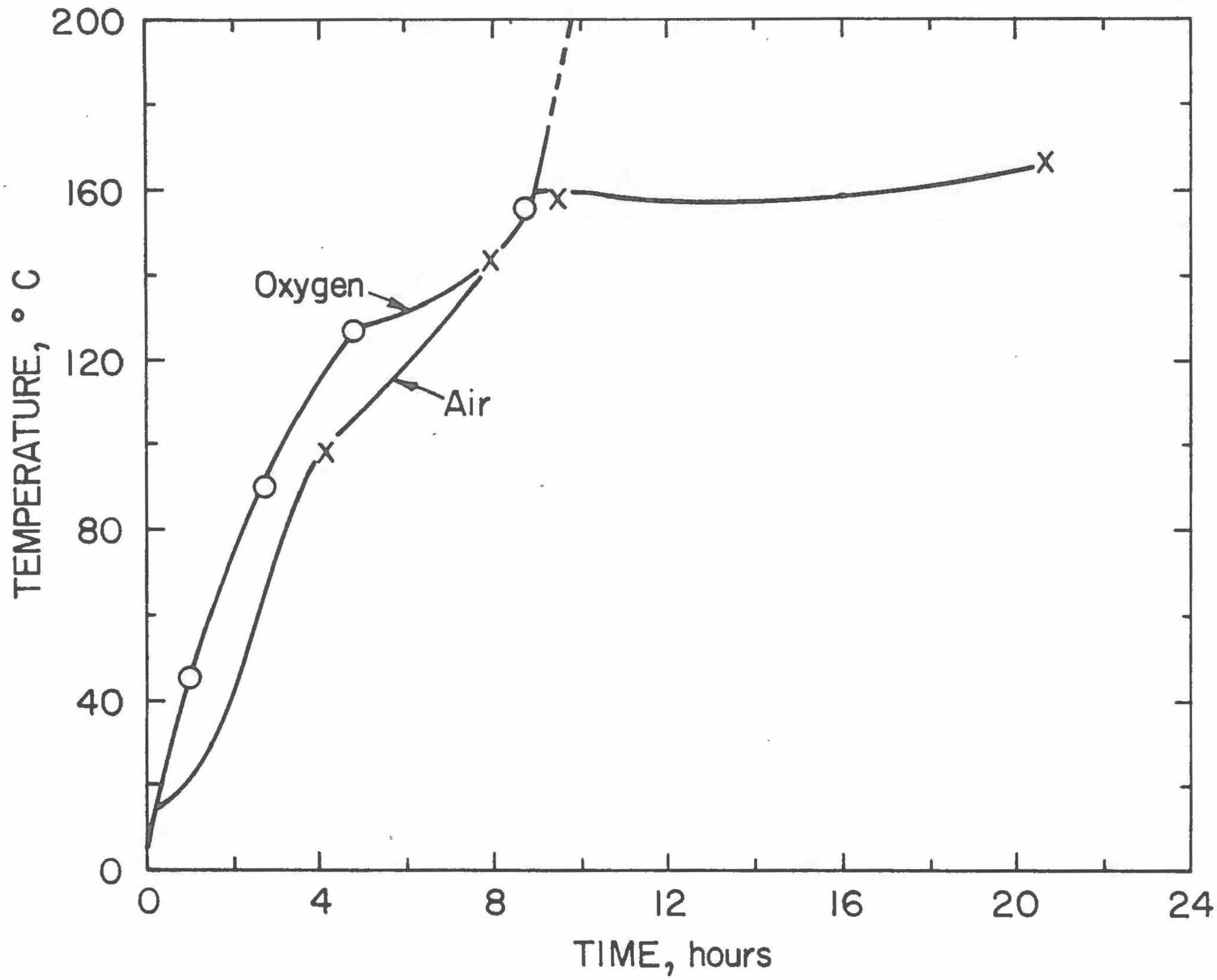


FIGURE 14. - Thermal records from a 150°C simulator run with oxygen compared to a run with air.

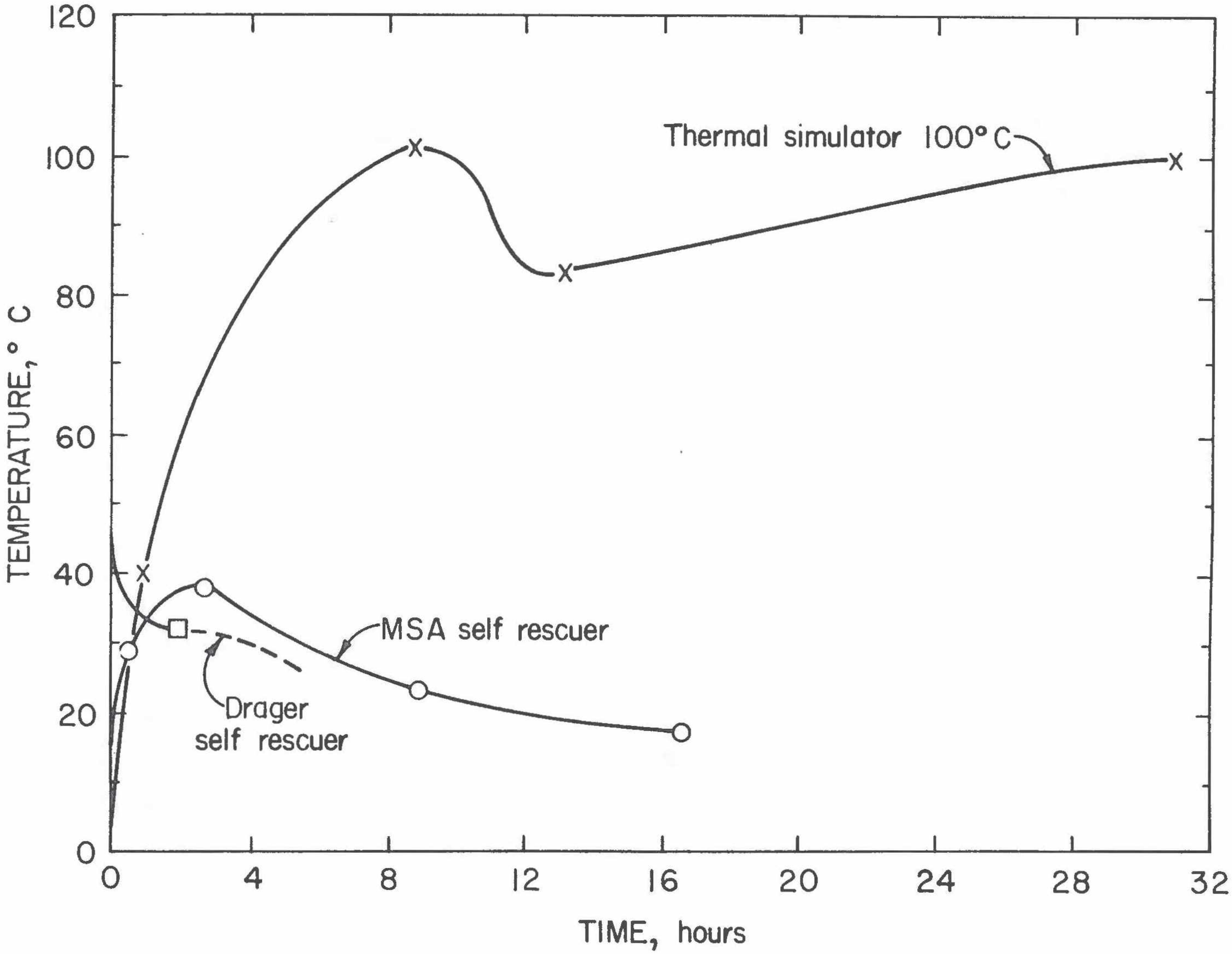


FIGURE 13. - Thermal records from 100°C simulator run compared with records from water activated KO_2 canisters.

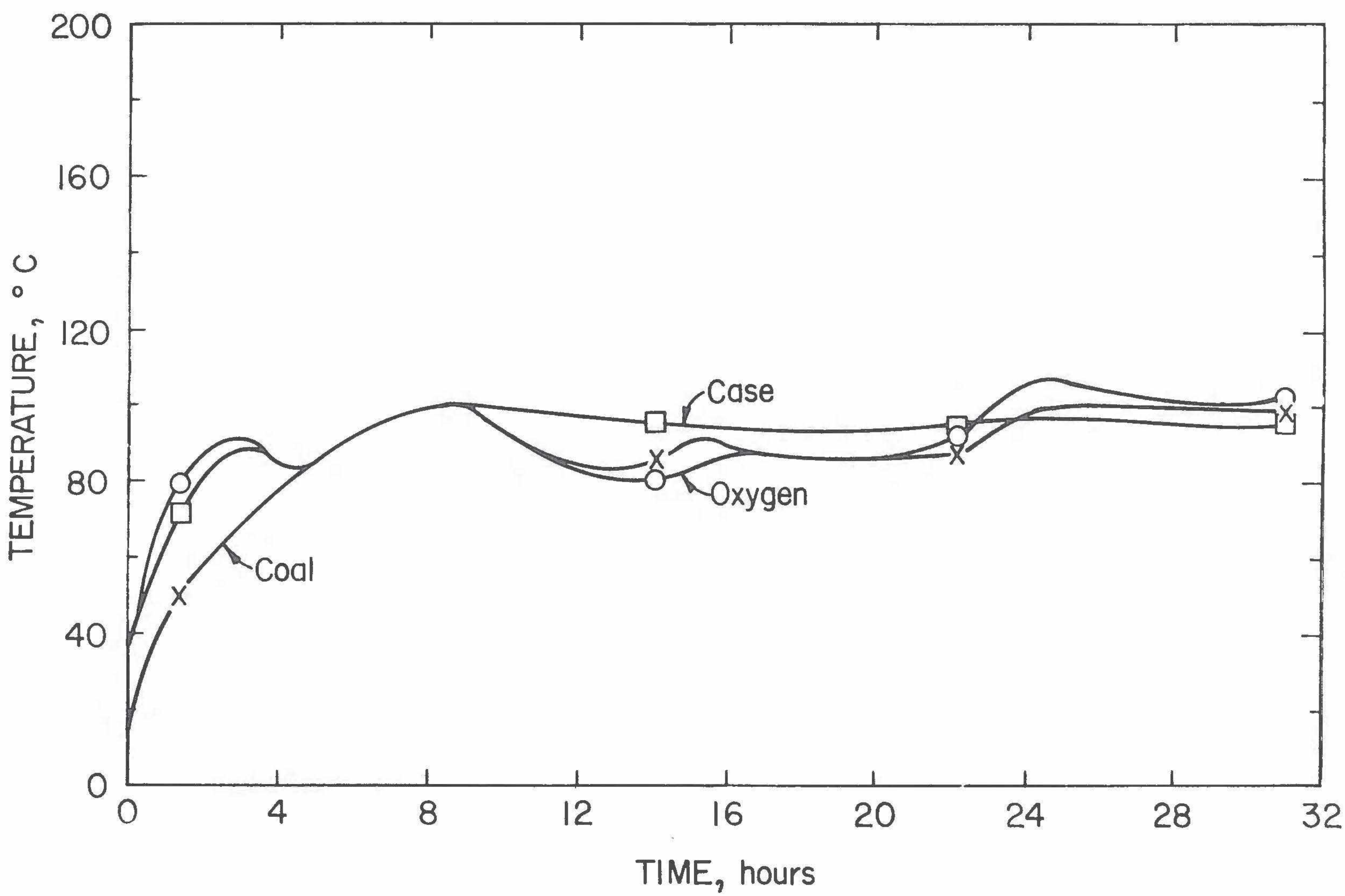


FIGURE 12. - Thermal records from 100°C simulator run in crushed Emery coal.

Time (Sec)	Temperature (° C)
555	202.4
570	199.4

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 5

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas tight weld. The test was conducted in 7.0 percent methane in air mixture with coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple - 270 degrees.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	30.8	270	213.6
15	81	285	209.8
30	140	300	206.2
45	174	315	202.4
60	202	330	198.6
75	241	345	
90	249	360	
105	250	375	
120	249.6	390	
135	247.6	405	
150	244.6	420	
165	241.6	435	
180	237.8	450	
195	234.2	465	
210	230	480	
225	226	495	
240	222	510	
255	217.6	525	
		540	

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 6

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas tight weld. The test was conducted in 7.0 percent methane in air mixture with coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple - 270 degrees.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	30.6	270	266.4
15	97.0	285	258.6
30	157	300	253.3
45	190	315	245.4
60	220	330	237.2
75	257.8	345	228.4
90	280.0	360	222.6
105	297.4	375	217.4
120	312.6	390	212.8
135	325.2	405	208.4
150	333.0	420	204.6
165	339.2	435	200.8
180	334.5	450	197.4
195	319.2	465	
210	302.4	480	
225	292.7	495	
240	283.6	510	
255	274.8	525	
		540	

Special Investigation: Dragerwerk Breathing Apparatus

Date: 4/22/80 Test Sheet No.: 7

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas tight weld. The test was conducted in 8.6 percent methane in air mixture with coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple - 270 degrees.

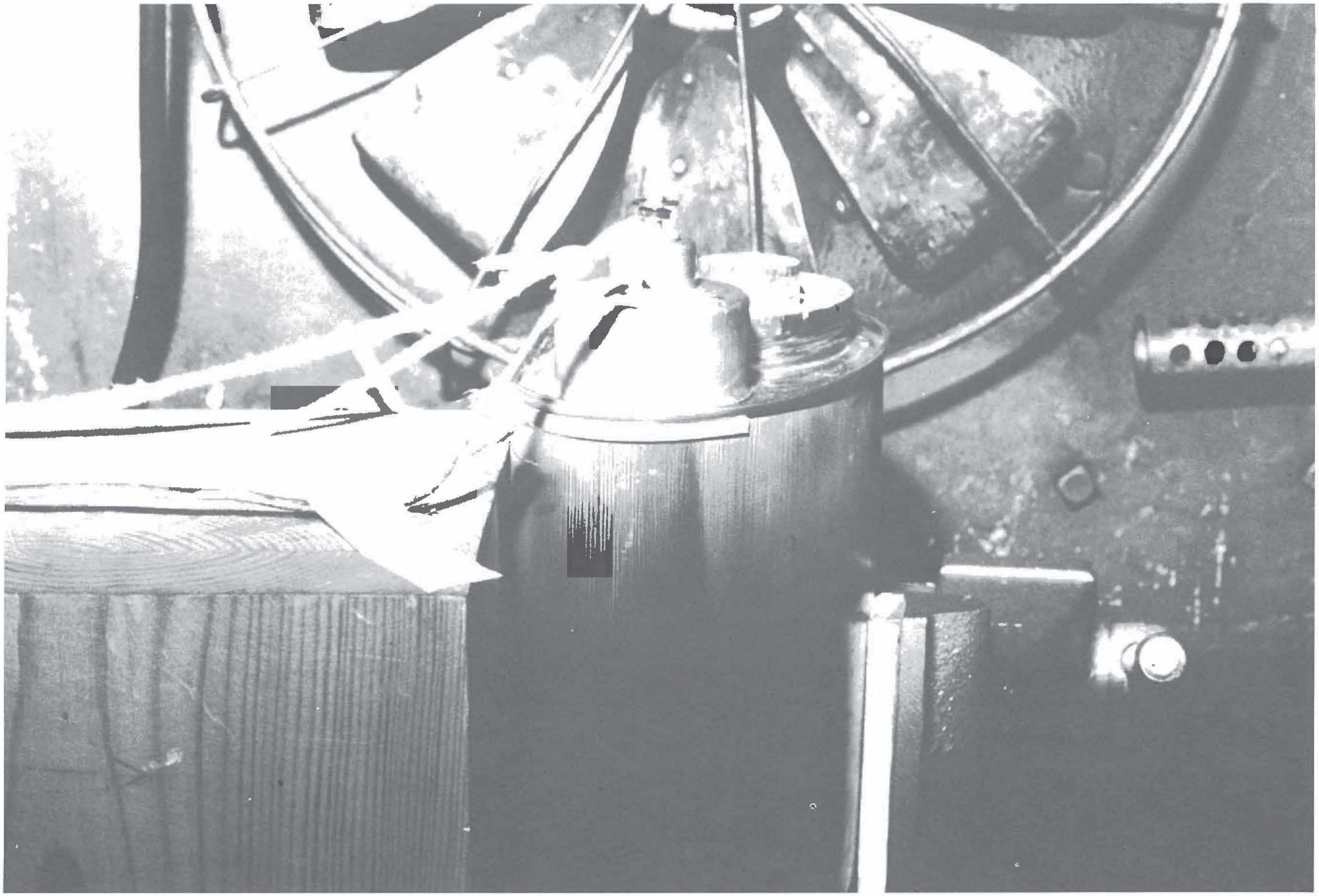
Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	30.6	270	247.4
15	152.4	285	243.6
30	178	300	239.2
45	198	315	235.2
60	213.7	330	230.6
75	236.0	345	227.8
90	251.8	360	226.2
105	262.6	375	219
120	272.4	390	215.2
135	280.8	405	211.2
150	278.6	420	207.5
165	278.2	435	204.2
180	271.2	450	201.7
195	266.8	465	197.6
210	264.2	480	
225	259.2	495	
240	254.8	510	
255	251.4	525	
		540	

Special Investigation: Dragerwerk Breathing Apparatus

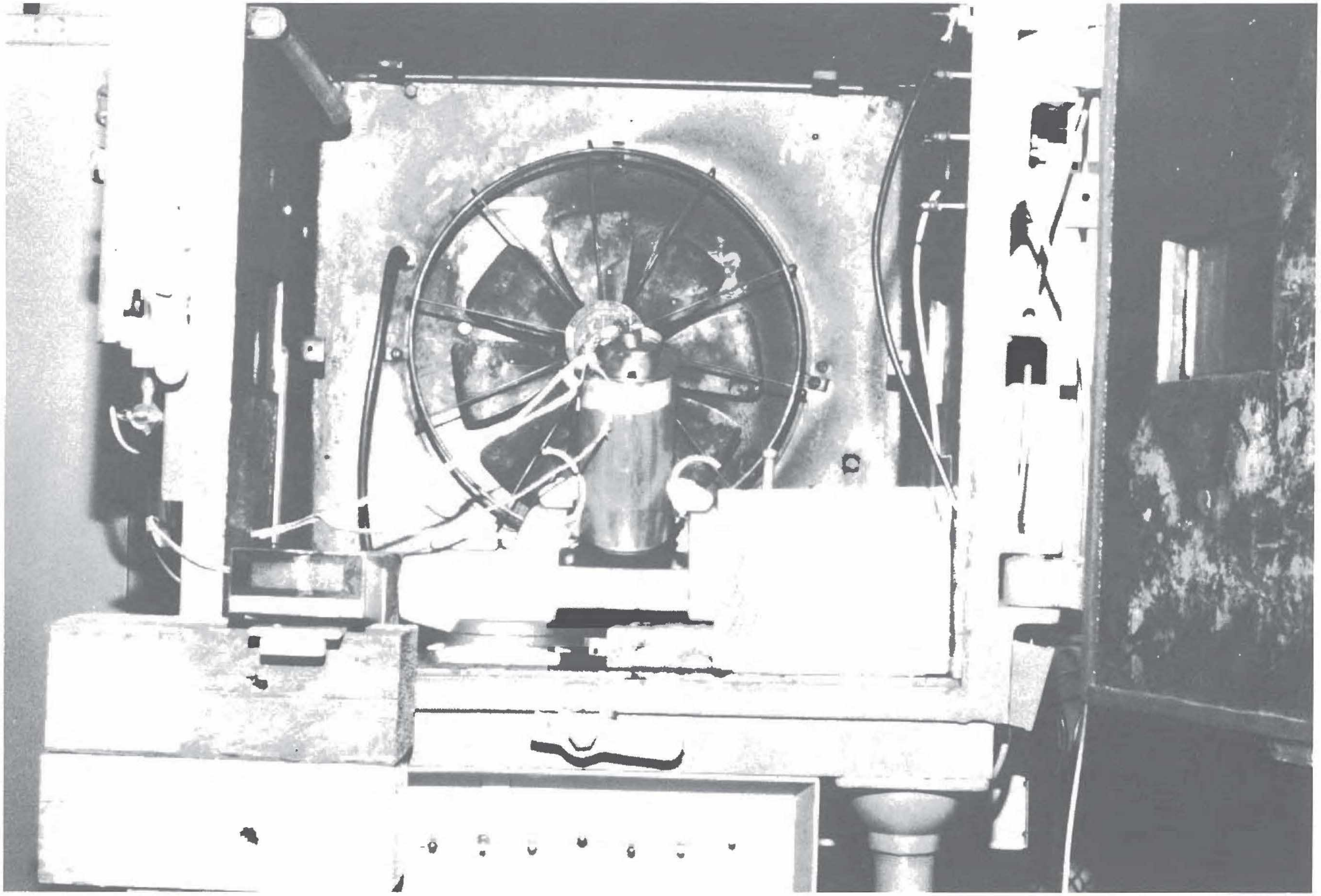
Date: 4/22/80 Test Sheet No.: 8

Comments: This test was conducted with the starter sealed to the empty canister. The seal appeared to be a gas tight weld. The test was conducted in 8.6 percent methane in air mixture with coal dust added. Temperature measurement was made as shown in figure numbers 1 and 2, pages 4 and 5. Placement of thermocouple - 270 degrees.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	30.2	270	243
15	120	285	239.2
30	181	300	235.4
45	214	315	231.8
60	239	330	227.6
75	254.6	345	224
90	266.8	360	221
105	273.8	375	217.2
120	278.4	390	213.6
135	283.2	405	210.4
150	280.2	420	207.2
165	275.6	435	204
180	270.1	450	201.4
195	264.6	465	197.8
210	259.8	480	
225	255.6	495	
240	251.4	510	
255	247.2	525	
		540	



PHOTOGRAPH 6. **Test set-up without coal dust**



PHOTOGRAPH 7. **Test set-up with coal dust**

ATTACHMENT NUMBER 1

DRAWING LIST

DRAGERWERK

BREATHING APPARATUS

TITLE	DRAWING NO.	QUALITY ASSURANCE DATE
Heat Protection Cap	67 30891	7-23-79
Starter	67 30732	7-23-79
Cup, Subassembly	67 30733	7-23-79
Lid with Starter	67 29656	9-8-78
Start Cone (Inspection Report)	67 29133	4-1-77
Start Powder Cup (Insp. Rep.)	67 29019	9-8-78
Start Mixture (Insp. Rep.)	67 27636	4-1-77
Actuator Pin (Insp. Rep.)	67 27561	9-8-78

APPENDIX II

ELECTRICAL TESTING LABORATORY
INVESTIGATIVE REPORT NUMBER 0001

EXPLOSION TESTS OF MSA - 60 MINUTE SELF RESCUERS

BY

RICHARD W. METZLER

APRIL 29, 1980

ELECTRICAL TESTING LABORATORY
INVESTIGATIVE REPORT NUMBER 0001

EXPLOSION TESTS OF MSA - 60 MINUTE SELF RESCUERS

BY
RICHARD W. METZLER

APRIL 29, 1980

DIVISION OF ELECTRICAL SAFETY
ELECTRICAL TESTING LABORATORY
4800 FORBES AVENUE
PITTSBURGH, PENNSYLVANIA 15213

Introduction

This report describes a special investigation made by the Electrical Testing Laboratory personnel to determine the potential explosion hazards associated with the Mine Safety Appliances Company, 60 Minute-Self Contained-self rescuer. This investigation was performed at the request of Mr. Frank Lee, Supervisory Electrical Engineer, Approval and Certification Center. Mr. Lee's request for technical assistance was initiated at a meeting held March 4, 1980. In attendance at this meeting were:

MSA Representatives: Mr. R. McIntyre
Mr. Elmer S. McKee

MSHA-A&CC Representatives: Mr. Frank Lee

MSHA-Special Projects Representative: Mr. Robert Peluso

Electrical Testing Lab personnel: Mr. Richard Metzler
Mr. W. Gilbert
Mr. Hugo Alicandri

U.S. Bureau of Mines Representative: Mr. Dick Watson

This investigation included both a physical inspection of the canister assembly including the firing mechanism and candle, and explosion tests.

For a list of the equipment used in these tests, see Appendix Number 1.

Inspection

The inspection consisted of measuring the physical dimensions of the firing mechanism and candle. Several drawings were acquired from Mr. Al Davis of MSA on March 10, 1980. Attachment Number 1 is a drawing list of the drawings that are being retained at the Electrical Testing Laboratory in the special investigation files. Two drawings are also attached. These show the dimensions measured for the candle and firing mechanism.

It should be noted that during the inspection of approximately 25 firing mechanisms, it was observed that the cotter pins of many of the firing mechanisms had a small burr on the pin tip. This later proved to cause difficulty in extracting the pin from the firing mechanism during the explosion tests.

Explosion Tests

Twenty-one explosion tests were conducted on the MSA self rescuer and its components. Each test is briefly described below and the test data (temperature measurements) is shown in Appendix Number 2. Photographs Number 1 through 5, pages 1 through 5 in this Appendix show the general components layout.

Test Number 1

Explosion test Number 1 was conducted with the firing mechanism in the small gallery. This component was tested in an 8.6 percent methane in air mixture by itself. This test was performed to determine the potential explosion hazard of the firing mechanism as shown in the data sheet page 6, Appendix Number 2. An explosion occurred immediately upon removal of the cotter pin. Photograph of this is shown on Page 7, Appendix Number 2.

This result was expected since the firing mechanism contains explosives and flame was seen discharging from the threaded end that mates with the candle assembly.

Tests Numbers 2 and 3

These tests were conducted with the firing mechanism and candle assembled with the washer installed and the two components torqued to 25 in.-lbs. in 8.6 percent methane in air mixture. As shown in the data sheets and photograph on pages 8 through 10. These components were not installed in the test canister. The temperature measurement was made between the firing mechanism and candle on the surface of the candle. During the two tests a maximum temperature of 297.3^{o}C was observed. This did not ignite the methane mixture in the gallery.

Tests Numbers 4 through 7

These tests were conducted to determine the explosion hazard of the complete self-rescuer assembly. These tests results and photographs of the experimental set-up are shown in Appendix Number 2, pages 11 through 15. The tests were conducted with the firing mechanism and candle installed in the canister. The canister was sealed by fastening the cover to the canister using the wing nuts provided on the canister. The firing mechanism was torqued to 25 in.-lbs. and the complete assembly was tested in 8.6 percent methane in air mixture. The temperature measurements were made at various points between the firing mechanism and canister surface.

The maximum surface temperature recorded for these tests was 244.2°C. No ignition occured. It should be noted that test Number 6 was performed twice. The first attempt at firing the canister (removing the cotter pin) resulted in a misfire. This means that the cotter pin was removed from the firing mechanism but the ball bearing failed to dislodge. This prevented the candle from being initiated. The methane was evacuated from the gallery and the mechanism was disassembled from the candle and tapped lightly with a hammer in an attempt to dislodge the ball bearing. This also failed to remove the ball bearing.

In Test Number 7 the cotter pin was very difficult to remove due to a small burr on the tip of the cotter pin. The cotter pin was also slightly bent. Although the pin was difficult to remove, it did pull out of the firing mechanism and the test was completed.

Test Number 8 through 12

These tests were conducted similar to test Numbers 4 through 7 except that the complete assembly was tested in 7.0 percent methane in air mixture. These tests are shown on pages 16 through 21. The firing mechanism and candle were installed in the canister and torqued to 25 inch-pounds. The canister was sealed by installing the canister cover on the canister and tightening the wing nuts provided with the canister. Temperature measurements were made at various points between the firing mechanism and canister surface.

The maximum surface temperature recorded for these tests was 249.2°C. No ignition occured during these tests. But it should be noted that test Number 10 resulted in a misfire. This misfire appeared to be due to a defective candle. Although the firing mechanism functioned properly, the candle failed to heat. The firing mechanism was heard when it fired and a residual was evident on the threaded end.

Test Numbers 13 and 14

These tests were performed to determine the explosion hazard that would exist if the firing mechanism became loosened. These tests were performed with the firing mechanism and candle only. No washer was installed between these components, and the two components were fastened together with one thread engagement only. The temperature measurement was made on the candle between the candle and the firing mechanism.

Test Number 13 does not include temperature data since the temperature probe fell off during the experiment. However, the test was allowed to run for 10 minutes. Although temperature data is not available. The test was completed and no ignition occured.

The maximum temperature measured in test number 14 was 328.2^{o}C. No ignition occured. Flame was observed being discharged during both tests.

These test results are shown on pages 22 through 24, Appendix Number 2.

Test Number 15

This test was conducted similar to tests 13 and 14 except that 8.6 percent methane in air mixture was substituted in place of 7.0 percent methane. The test data and photograph of the experimental set up are shown on pages 25 and 26 of Appendix Number 2. This test was performed with the firing mechanism and candle only. These components were fastened together without the washer and engaged by one thread. The maximum temperature observed was 316.0^{o}C. No ignition occured. It should be noted that flame was observed discharging from the firing mechanism when it was fired.

Test Number 16

This test was performed with 8.6 percent methane in air mixture, with the firing mechanism and candle only. No washer was installed, and the two components were engaged by only one thread. In this test coal dust was layered over the assembled components and temperature probe. As shown on page 27 the coal dust ignited at 174.4^{o}C and caused the methane to ignite. The explosion occured at approximately 45 seconds into the test. This test is shown in the Photograph on Page 28, Appendix Number 2.

Test Numbers 17 through 20

These tests were conducted to determine if coal dust layered on the canister surface would ignite and cause the methane to explode. The firing mechanism and candle were installed in the canister and torqued to 25 inch-pounds. The washer was in place between the firing mechanism and canister. The gallery was filled with 8.6 percent methane. The temperature measurement was made between the firing mechanism and canister. The test data sheets and photograph of the experimental set-up are shown on pages 29 and 33, Appendix 2.

The maximum surface temperature observed during these tests was 239.0^{o}C. No ignition occured. Although this surface temperature exceeded the ignition temperature of layered coal dust (160^{o}C) the coal dust did not ignite.

Test Number 21

This test was performed similar to tests 17 through 20 except that the firing mechanism was not torqued and the washer was not installed. The firing mechanism was finger tight only (backed-off 1 turn). The test was conducted at 8.6 percent methane in air mixture and the temperature measurement was made on the canister surface between the firing mechanism and canister. The maximum temperature reached 152.6°C. This lower temperature was due to the loose fit between the candle and the canister. No ignition occured. This test and Photograph are shown on Pages 34 and 35.

Observations

Several observations were made during these experiments that should be noted.

1. Quality Control

Two experiments out of 22 resulted in misfires either due to the firing mechanism or candle (one misfire due to each component). This is 9.09 percent. In two additional experiments the tests had to be temporarily interrupted because burrs or bent cotter pins prevented the pin from being extracted from the firing mechanism. In these tests the pins were straightened and burrs removed. The tests were then continued. In numerous other tests it was difficult to remove the cotter pins, but the pins did pull free of the firing mechanism.

This means that in approximately 20 percent of the experiments either a misfire or extreme difficulty was encountered in extracting the cotter pin from the firing mechanism.

The quality control program at MSA should be reviewed. Further data should be made available to substantiate the pull force required to activate the firing mechanism.

2. Explosions

a. Two explosions were observed. The firing mechanism alone provides incendiary flame and when activated in the controlled methane atmosphere did cause a methane ignition. The second explosion occured with the firing mechanism engaged a single turn into the candle. Both components were covered with coal dust. (These components were not installed in the canister). It appeared that the explosion occured after the coal dust ignited. This would require further tests to confirm.

b. In all tests performed with the firing mechanism and candle completely installed in the canister under a variety of conditions (coal dust, finger tight-etc.) no ignitions occured.

Conclusion

This investigation provides preliminary data that show:

1. No ignitions occured with the complete unit properly assembled and sealed.

2. The firing mechanism alone is a potential explosion hazard.

3. The firing mechanism and candle alone engaged only one thread with coal dust is a potential explosion hazard.

4. Quality control of the firing mechanism and candle assembly appears to be deficient.

Recommendations

These tests have provided preliminary data that substantiates the need for further investigation of quality control and assurance in the construction and assembly of the MSA self-rescuer.

1. Additional tests should be conducted to ascertain data to show the quality of construction of the firing mechanism and candle assembly. Test data must be available to verify the confidence level for activating the candle. These tests should also substaniate the pull force or tension required to extract the cotter pin from the firing mechanism.

2. A means should be provided to the self rescuer enclosure to insure that the firing mechanism remains properly installed.

APPENDIX NUMBER 1

EQUIPMENT LIST

Stop watch, Wakmann, 60 second

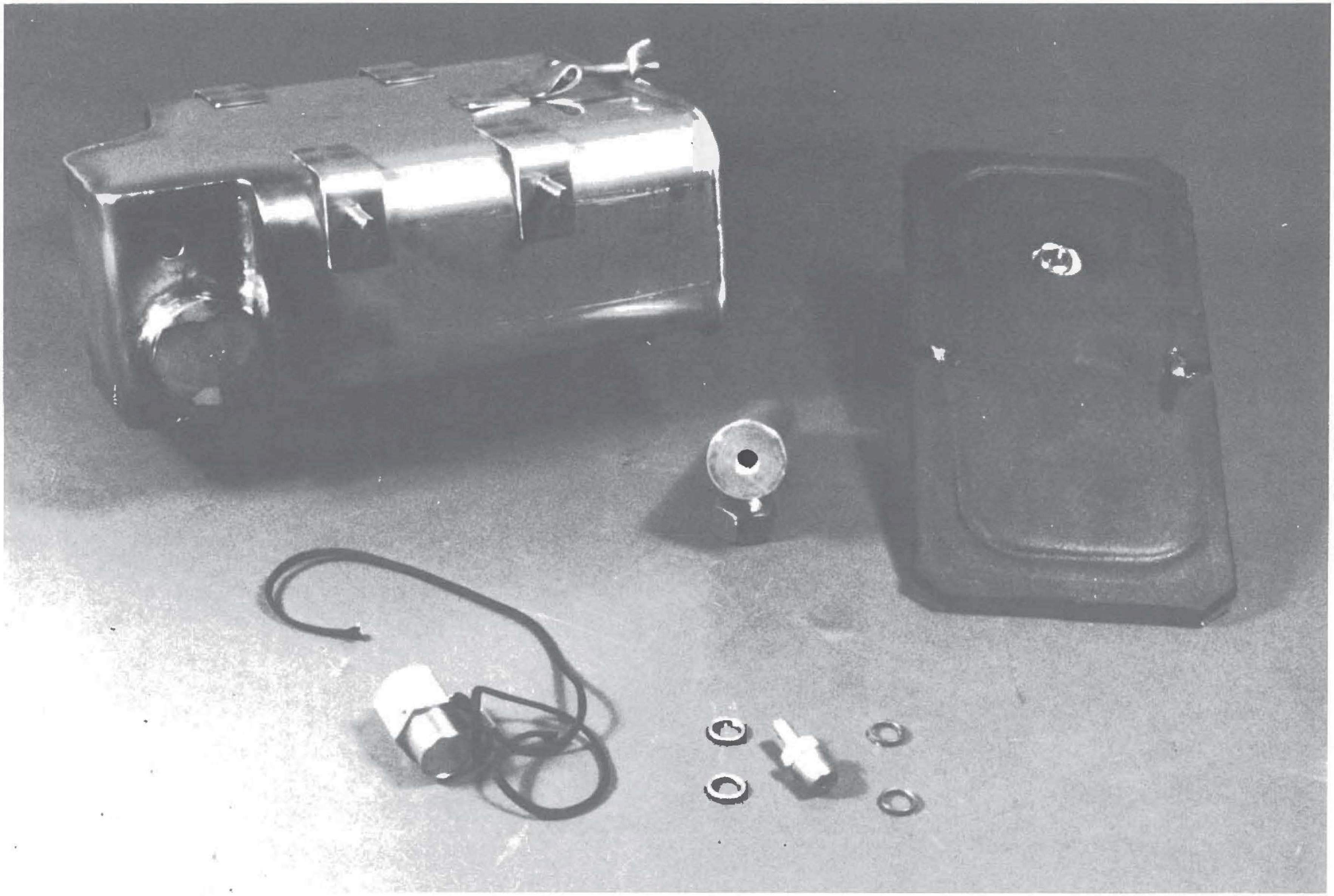
Torquemeter, torque wrench, Snap-On 0 to 150 inch/lbs, Model TE-12A

Thermometer, Digital, Fluke, Model 2170A, ^{o}C

Analyzer, Infrared, Beckman, Model 864

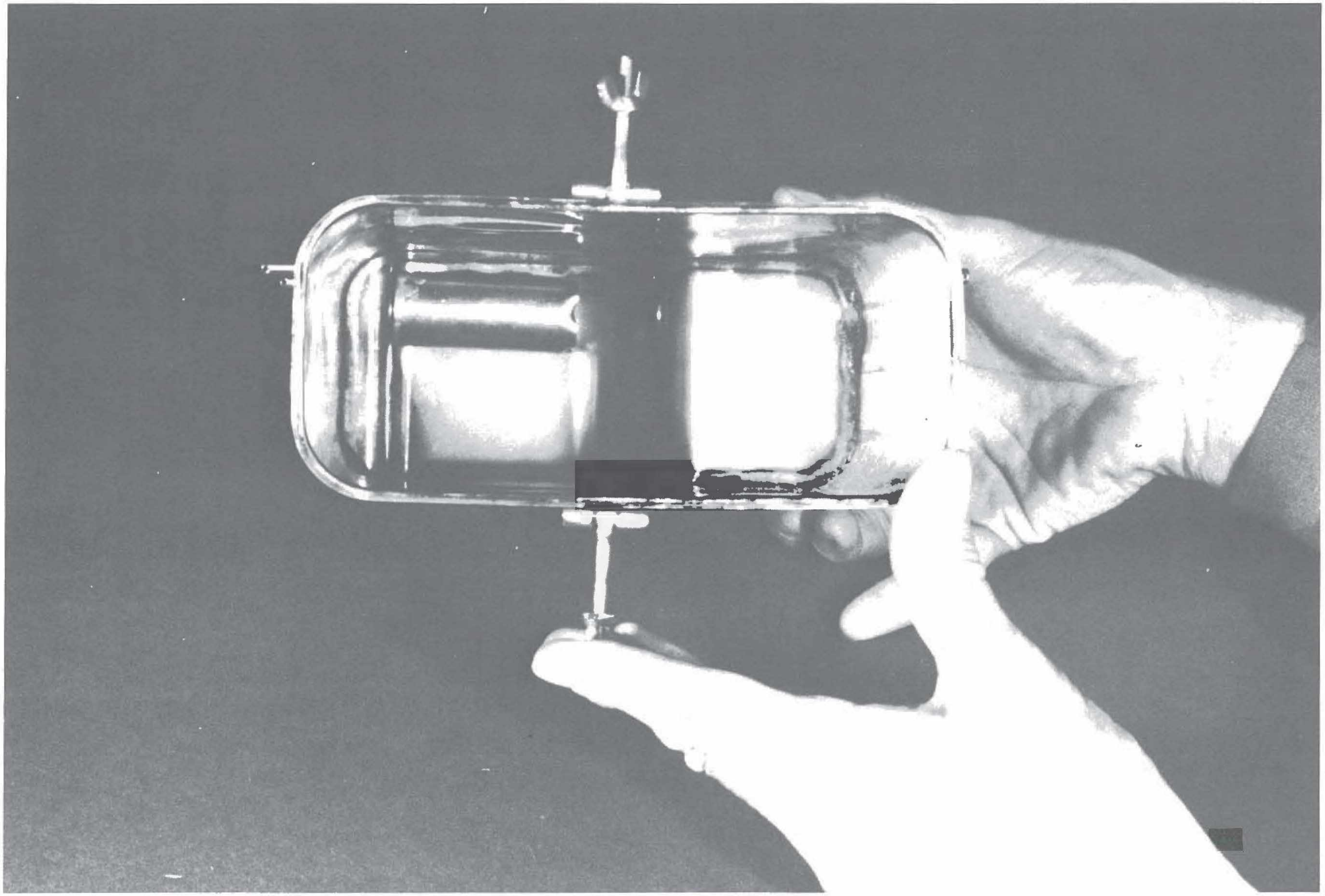
Recorder, Brush, Gould, 220

Gallery, auxiliary, modified, BOM drawing C-1009, dated 5-8-39

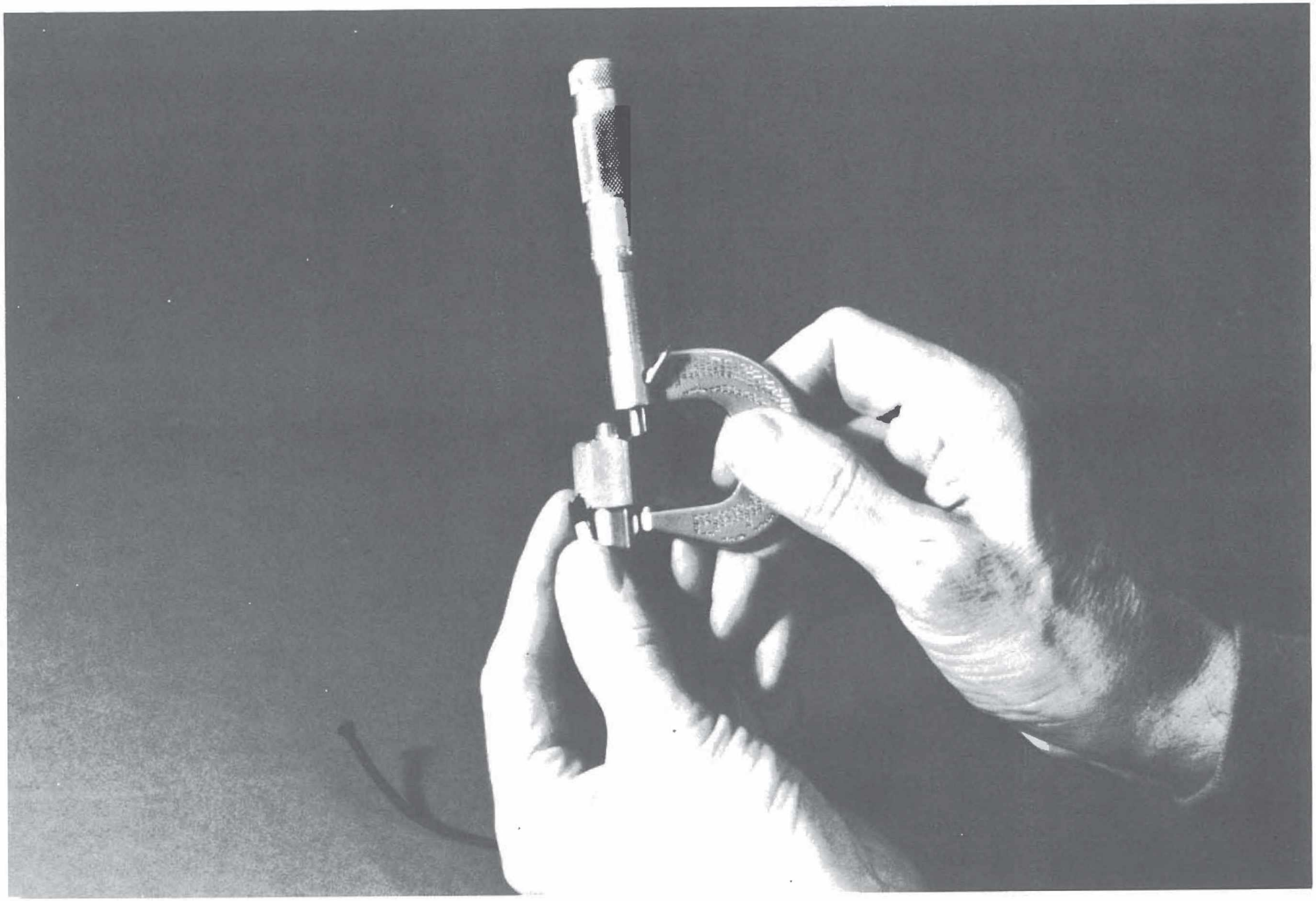


PHOTOGRAPH 1.

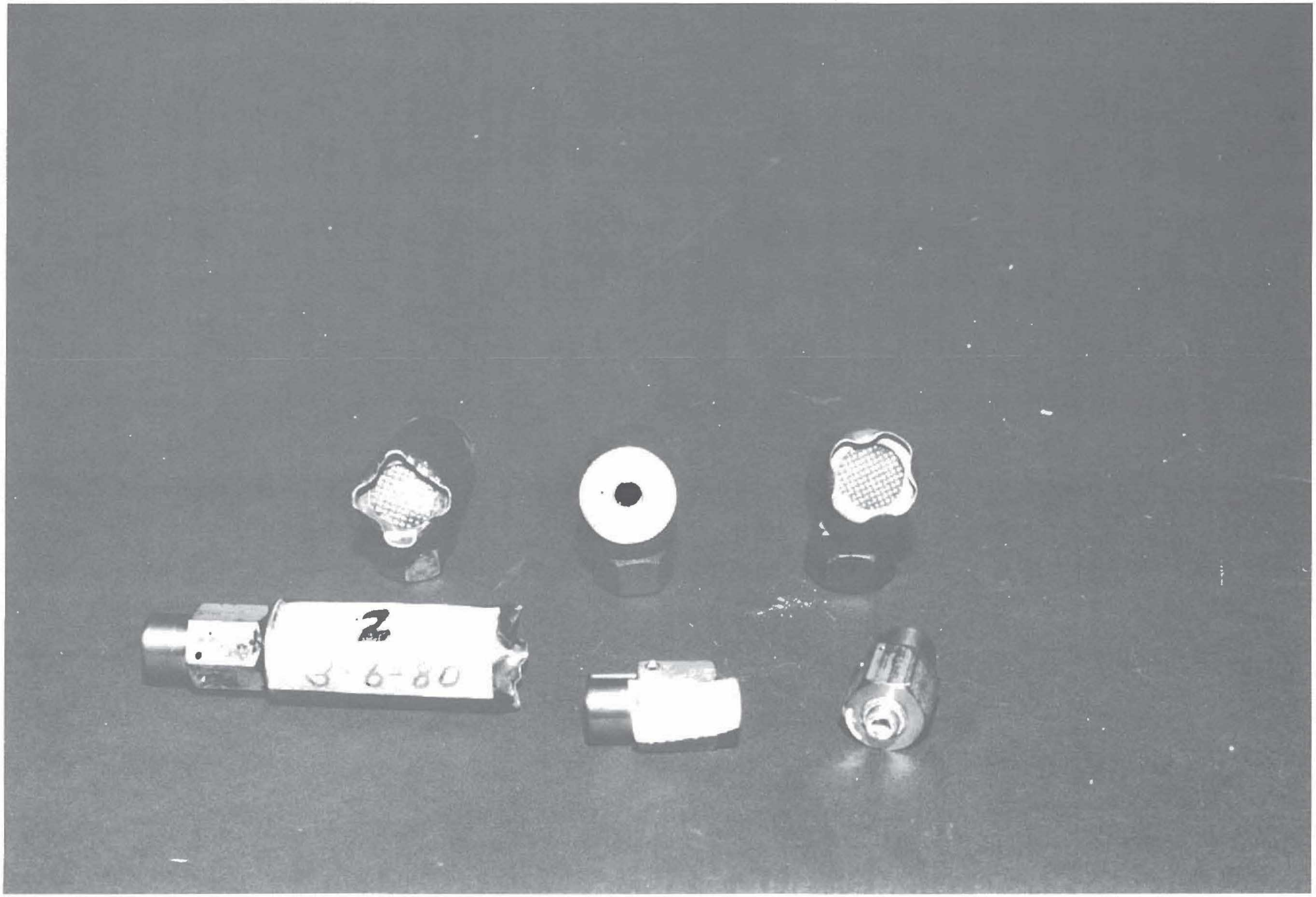
MSA - 60 minute self rescuer test canister and components



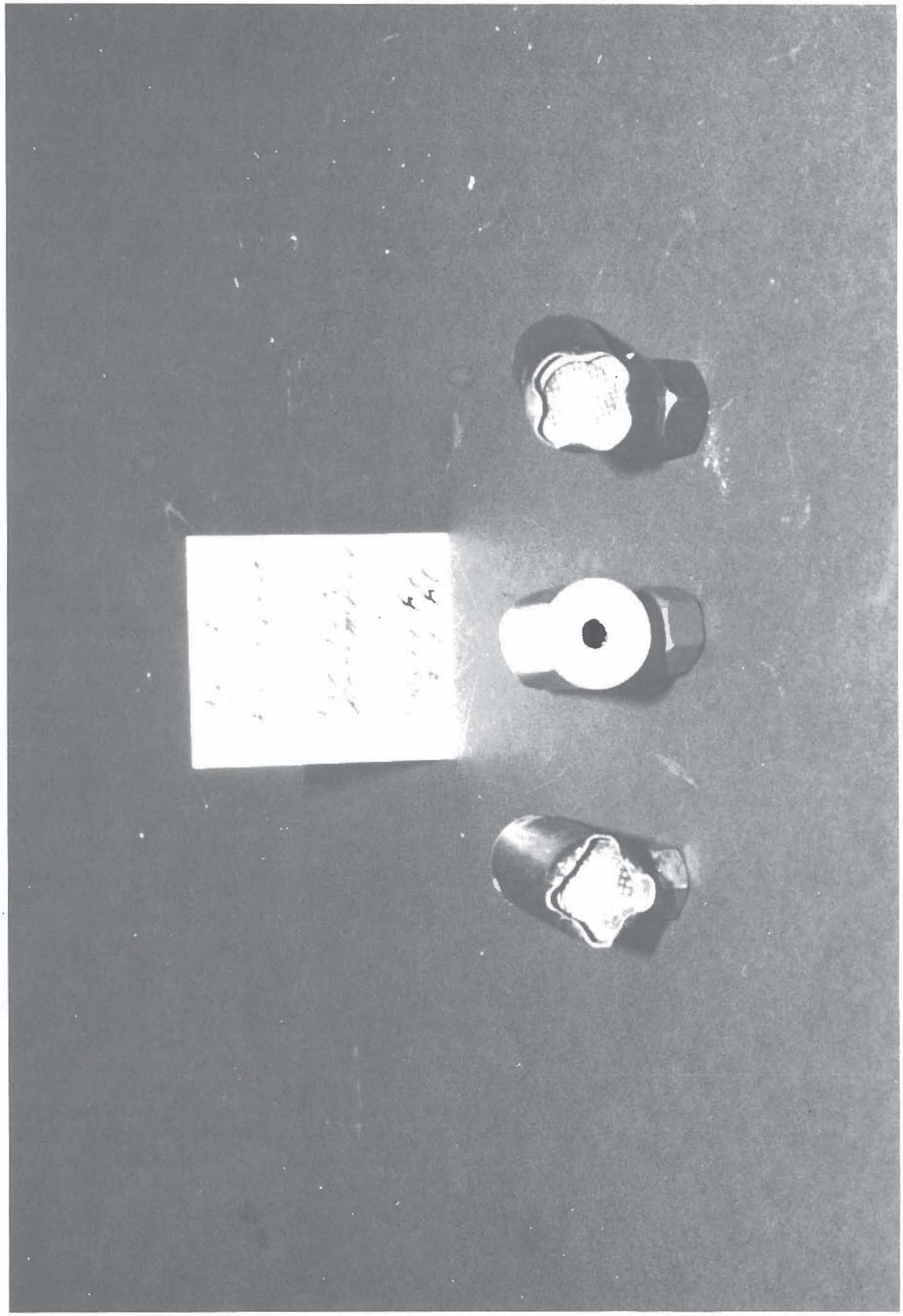
PHOTOGRAPH 2. **Inside view of test canister and candle**



PHOTOGRAPH 3. **Firing mechanism**



PHOTOGRAPH 4. **Firing mechanism and candle**



PHOTOGRAPH 5. **Candle**

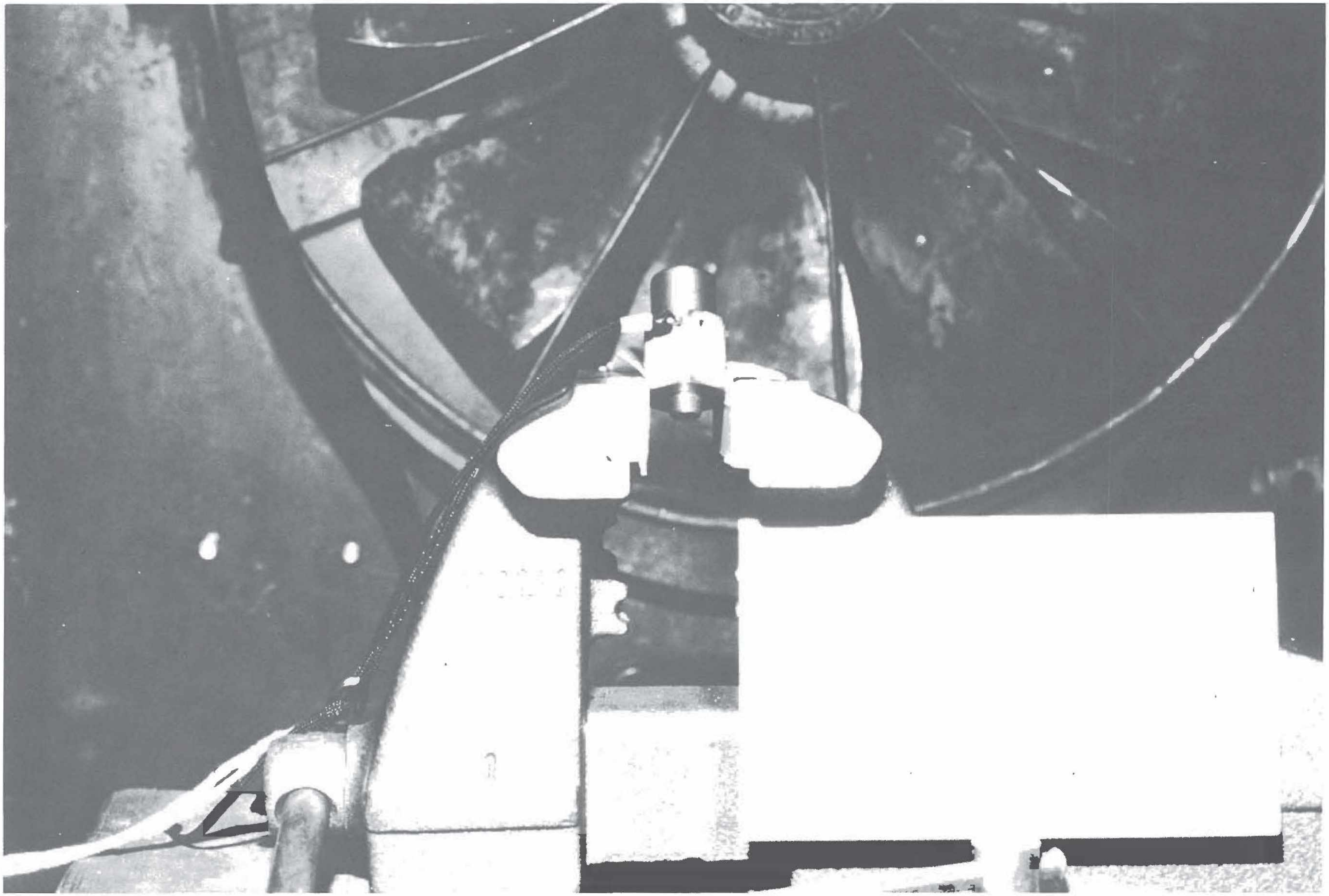
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 6, 1980　　Test Sheet No.: 1

Comments: This test was conducted with the firing mechanism only; (See photograph on next page) 8.6 percent methane. Ignition occured immediately.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0		270	
15		285	
30	SEE COMMENT ABOVE.	300	
45		315	
60		330	
75		345	
90		360	
105		375	
120		390	
135		405	
150		420	
165		435	
180		450	
195		465	
210		480	
225		495	
240		510	
255		525	
		540	



PHOTOGRAPH 6. **Firing mechanism**

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 6, 1980 Test Sheet No.: 2

Comments: Test #2 was conducted with the firing mechanism and candle only. Washer installed; torqued to 25 in.-lbs.; 8.6 percent methane; temperature measurements made between junction of firing mechanism and candle. See photograph following test #3 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	23.6	270	276.4
15	23.6	285	270.6
30	61.4	300	263.3
45	110.8	315	256.8
60	160.6	330	250.0
75	193.3	345	243.2
90	217.4	360	236.4
105	235.6	375	230.0
120	248.8	390	217.3
135	259.9	405	211.0
150	269.9	420	204.8
165	281.8	435	199.0
180	292.4	450	
195	297.3	465	
210	297.2	480	
225	294.0	495	
240	289.4	510	
255	283.2	525	
		540	

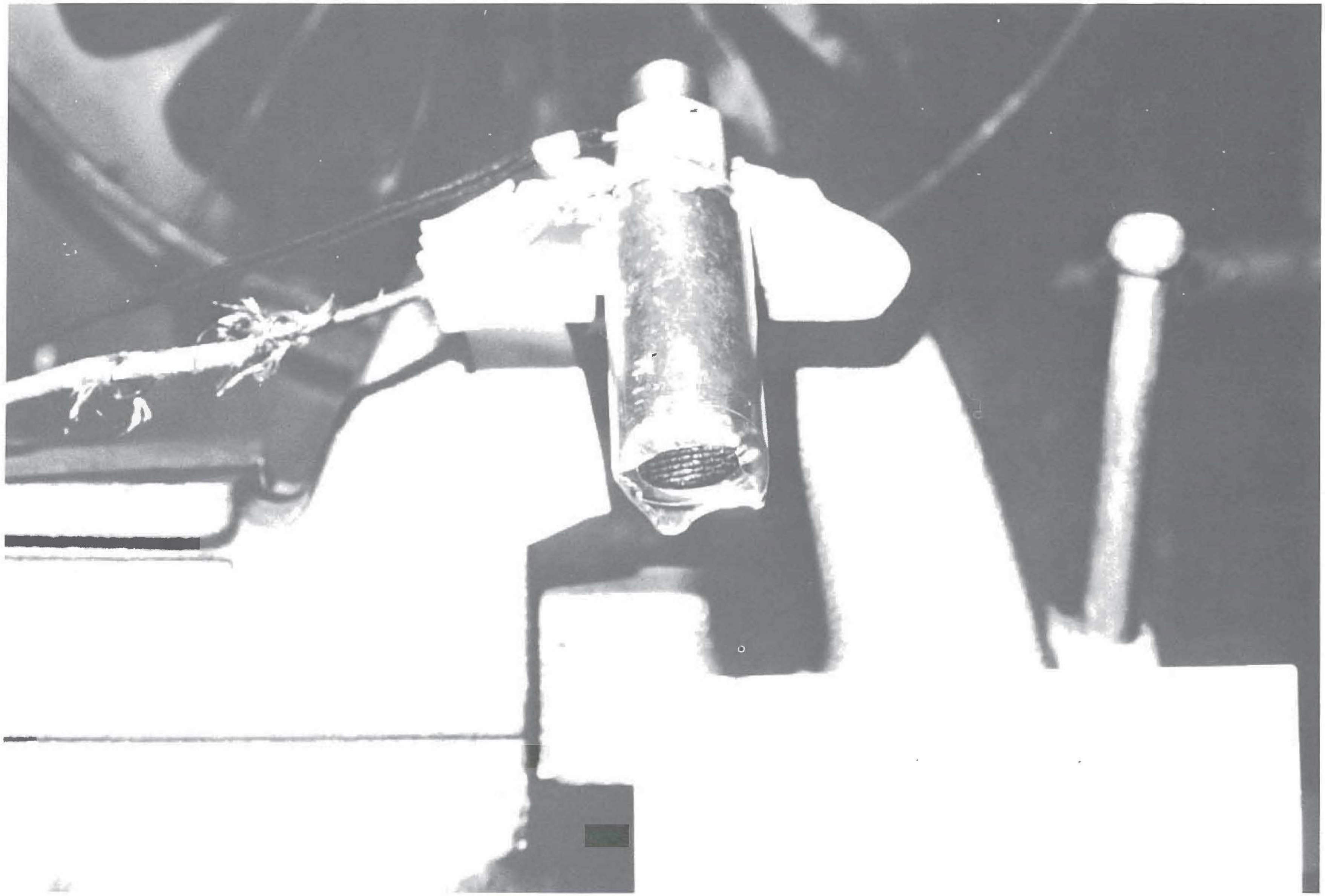
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 6, 1980 Test Sheet No.: 3

Comments: Test #3 was conducted with the firing mechanism and candle only. Washer installed; torqued to 25 in.-lbs.; 8.6 percent methane; temperature measurement made between junction of firing mechanism and candle. See photograph following test #3 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	23.6	270	265.8
15	23.6	285	260.2
30	70.2	300	254.2
45	114.4	315	248.6
60	156.6	330	240.6
75	186.6	345	236.5
90	206.8	360	229.4
105	220.6	375	223.6
120	230.8	390	217.1
135	239.3	405	211.8
150	249.2	420	205.8
165	259.8	435	200.2
180	269.9	450	194.4
195	278.0	465	
210	280.6	480	
225	279.4	495	
240	276.4	510	
255	271.4	525	
		540	



PHOTOGRAPH 7 **Firing mechanism and candle**

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 4

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 8.6 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #7 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	23.6	270	202.1
15	29.8	285	202.0
30	44.6	300	201.2
45	63.8	315	200.2
60	85.6	330	198.5
75	103.8	345	197.0
90	119.2	360	195.0
105	132.8	375	
120	144.8	390	
135	155.6	405	
150	167.6	420	
165	177.6	435	
180	185.8	450	
195	191.6	465	
210	195.2	480	
225	197.6	495	
240	200.2	510	
255	200.8	525	
		540	

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 5

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 8.6 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #7 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	34.5	270	215.8
15	66.6	285	215.0
30	89.8	300	213.8
45	110.2	315	212.2
60	126.6	330	210.2
75	139.8	345	208.0
90	150.8	360	205.6
105	160.0	375	203.0
120	169.6	390	200.6
135	179.4	405	198.0
150	190.2	420	
165	198.6	435	
180	204.8	450	
195	209.6	465	
210	212.8	480	
225	214.8	495	
240	215.8	510	
255	216.0	525	
		540	

Special Investigation: Explosion Test -MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 6

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 8.6 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #7 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	21.8	270	237.4
15	32.4	285	237.8
30	50.8	300	237.8
45	70.0	315	237.0
60	92.6	330	235.3
75	112.6	345	233.2
90	129.4	360	231.8
105	143.2	375	229.6
120	155.2	390	227.4
135	166.4	405	225.0
150	177.4	420	222.4
165	188.4	435	219.0
180	199.2	450	216.6
195	210.6	465	213.4
210	219.8	480	210.4
225	228.4	495	207.6
240	233.0	510	204.4
255	235.8	525	201.2
		540	198.4

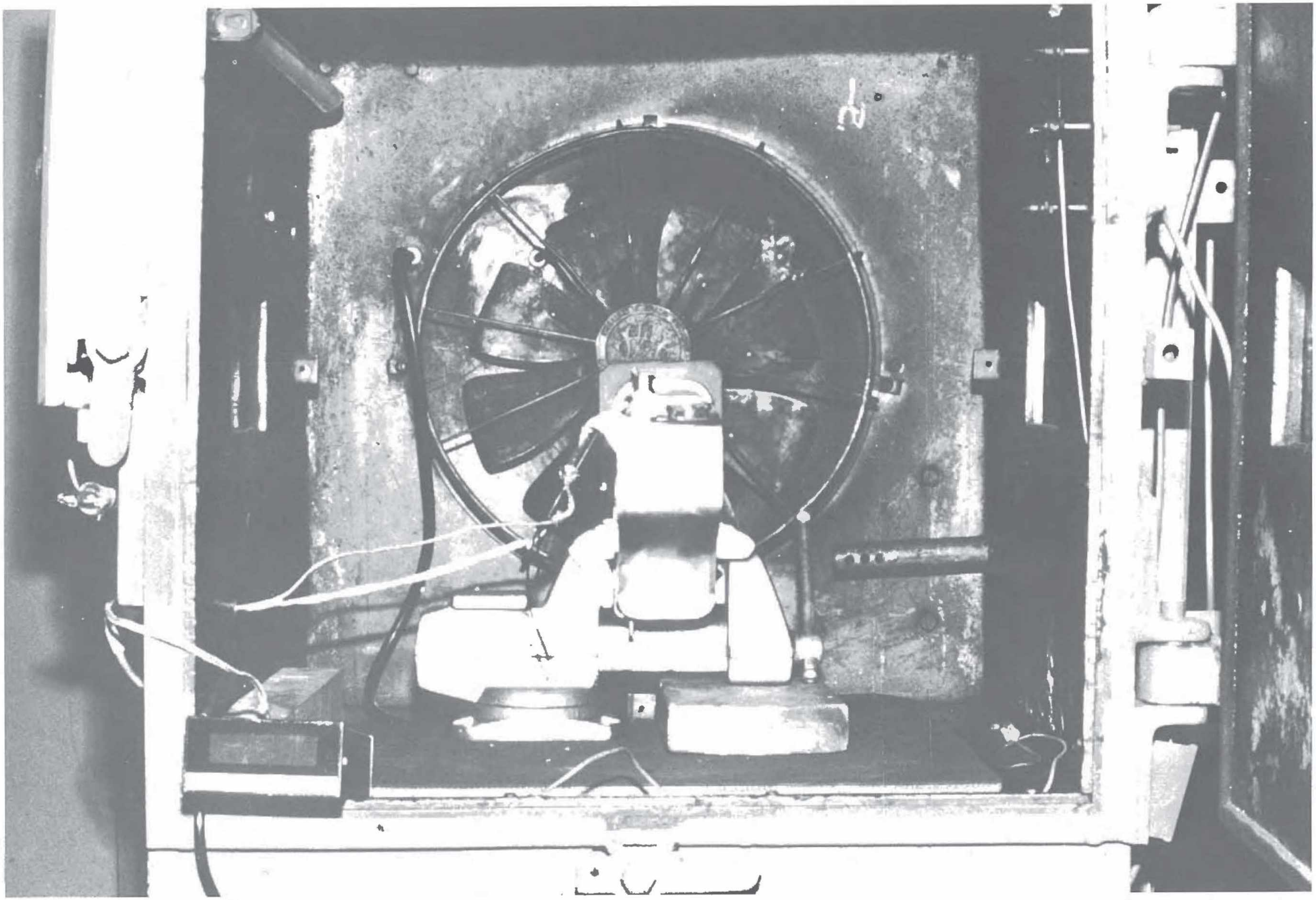
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 7

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 8.6 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #7 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	26.0	270	243.2
15	56.8	285	242.2
30	72.4	300	240.8
45	98.2	315	239.0
60	122.8	330	236.8
75	144.6	345	234.2
90	159.4	360	231.6
105	176.2	375	228.2
120	190.8	390	225.4
135	202.6	405	222.4
150	216.8	420	219.2
165	227.0	435	216.2
180	234.2	450	213.8
195	238.8	465	209.4
210	241.6	480	206.2
225	243.6	495	202.6
240	244.2	510	199.0
255	244.2	525	
		540	



PHOTOGRAPH 8. **Firing mechanism and candle installed in sealed canister**

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 8

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued t 25 in.-lbs.: 7.0 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #12 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.6	270	239.2
15	42.4	285	237.0
30	64.6	300	236.2
45	95.4	315	233.8
60	121.6	330	231.6
75	142.8	345	229.2
90	162.2	360	226.4
105	176.6	375	223.6
120	190.2	390	220.6
135	202.6	405	217.6
150	215.6	420	214.8
165	225.8	435	211.6
180	230.2	450	208.2
195	236.6	465	205.2
210	239.0	480	202.0
225	240.2	495	198.8
240	240.6	510	
255	240.2	525	
		540	

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 9

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 7.0 percent methane; NO coal dust: temperature measurement made between firing mechanism and canister. See photograph following test #12 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.8	270	211.0
15	45.0	285	210.2
30	69.4	300	209.0
45	95.0	315	207.2
60	117.2	330	205.2
75	135.6	345	203.0
90	148.4	360	201.2
105	159.0	375	198.6
120	168.2	390	
135	178.8	405	
150	188.2	420	
165	196.0	435	
180	194.0	450	
195	201.6	465	
210	206.6	480	
225	209.2	495	
240	210.0	510	
255	211.2	525	
		540	

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 10

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 7.0 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #12 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	26.2	270	
15	26.8	285	
30	26.8	300	
45	26.8	315	
60	26.8	330	
75	26.6	345	
90	26.6	360	
105	26.6	375	
120		390	
135		405	
150		420	
165		435	
180		450	
195		465	
210		480	
225		495	
240		510	
255		525	
		540	

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 11

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 7.0 percent methane; NO coal dust: temperature measurement made between firing mechanism and canister. See photograph following test #12 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.6	270	201.6
15	28.8	285	201.6
30	40.0	300	200.0
45	57.4	315	198.2
60	76.4	330	195.2
75	93.2	345	194.6
90	109.8	360	191.0
105	123.2	375	
120	135.0	390	
135	146.2	405	
150	156.4	420	
165	167.0	435	
180	176.2	450	
195	181.8	465	
210	185.2	480	
225	189.0	495	
240	192.6	510	
255	198.5	525	
		540	

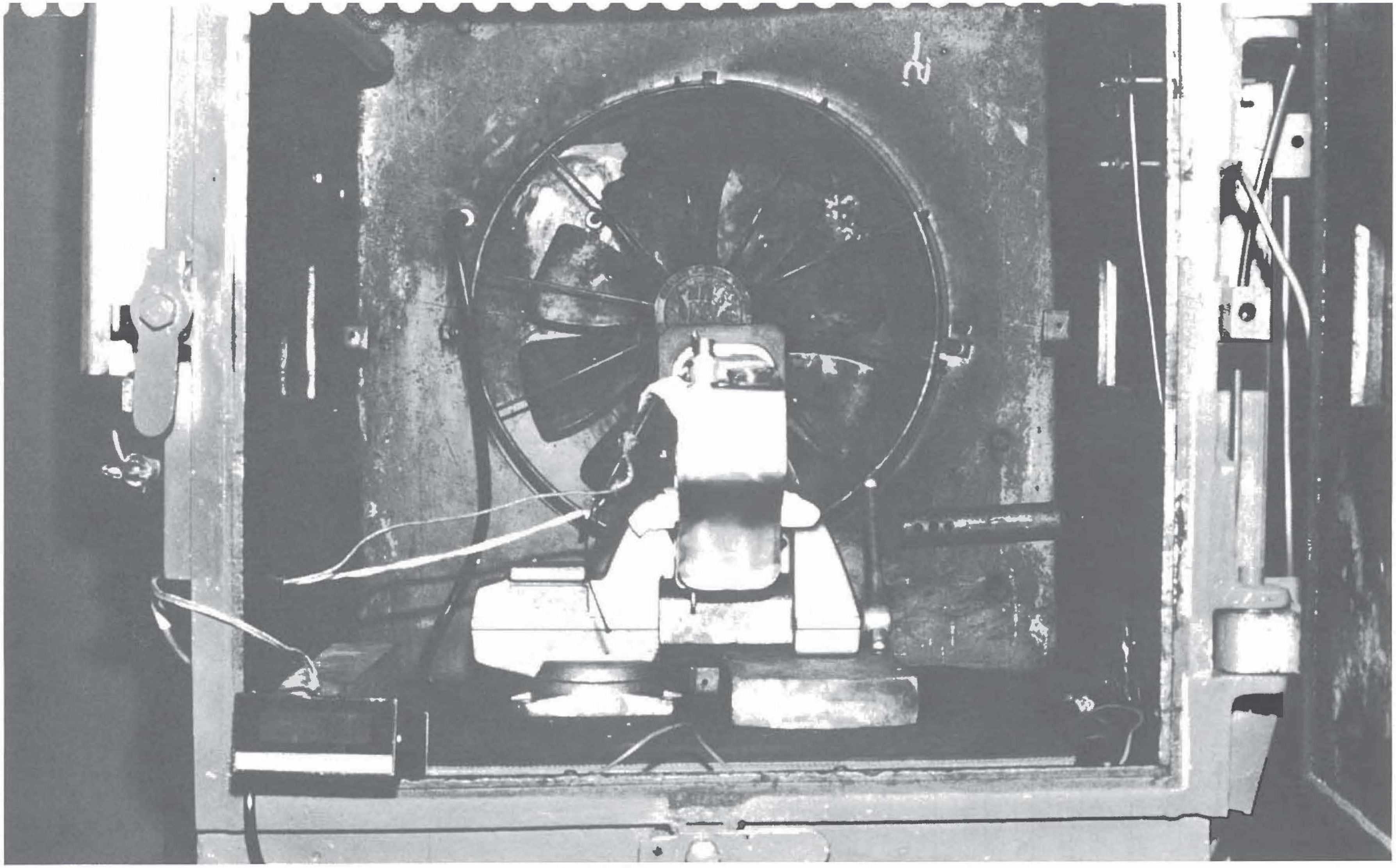
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 7, 1980 Test Sheet No.: 12

Comments: This test was conducted with the firing mechanism and candle installed in the sealed canister. Washer in place between firing mechanism and canister; torqued to 25 in.-lbs.; 7.0 percent methane; NO coal dust; temperature measurement made between firing mechanism and canister. See photograph following test #12 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	26.4	270	248.2
15	40.6	285	247.0
30	65.4	300	245.2
45	96.2	315	243.2
60	122.6	330	241.2
75	148.0	345	238.8
90	170.0	360	236.0
105	183.3	375	233.0
120	200.1	390	230.6
135	214.8	405	227.0
150	226.2	420	223.8
165	235.4	435	220.4
180	240.8	450	217.4
195	244.8	465	214.0
210	247.4	480	210.8
225	248.8	495	207.4
240	249.2	510	204.2
255	249.0	525	200.8
		540	



PHOTOGRAPH 9. **Firing mechanism and candle installed in sealed canister**

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 13

Comments: This test was conducted with the firing mechanism and candle only; no washer; one thread engagement; not torqued. 7.0 percent methane; temperature measurement made on candle between candle and firing mechanism. See photograph following test #14 data sht.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.8	270	
15	27.2	285	
30		300	
45		315	
60		330	
75		345	
90		360	
105		375	
120		390	
135		405	
150		420	
165		435	
180		450	
195		465	
210		480	
225		495	
240		510	
255		525	
		540	

TEMPERATURE PROBE FELL OFF DURING TEST. THE TEST WAS COMPLETED WITHOUT TEMPERATURE DATA.

Special Investigation: Explosion Test - MSA

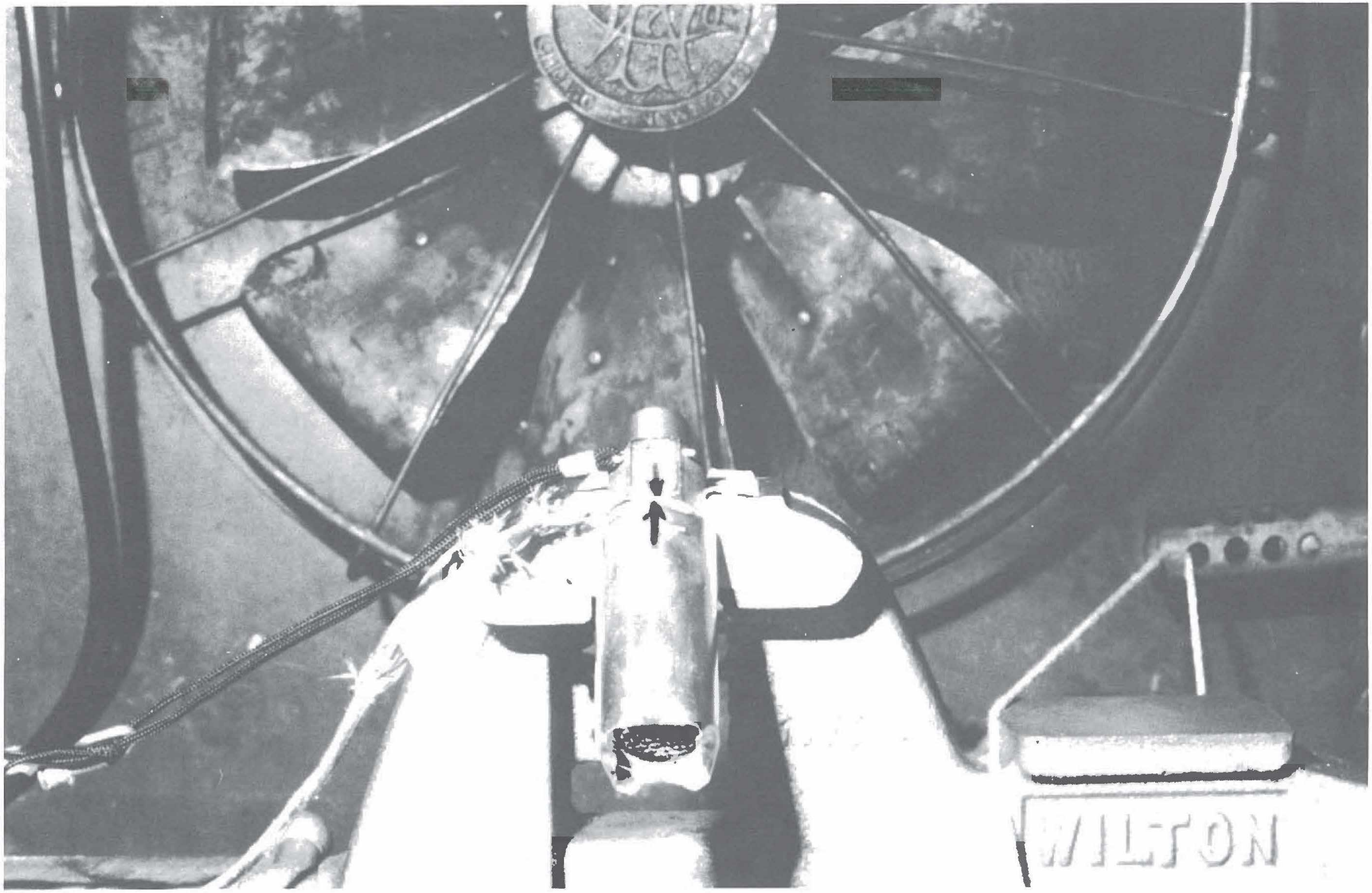
60 Minute Self Rescuer

Date: March 10, 1980

Test Sheet No.: 14

Comments: This test was conducted with the firing mechanism and candle only; no washer; one thread engagement; not torqued. 7.0 percent methane; temperature measurement made on candle between candle and firing mechanism. See photograph following test #14 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	26.6	270	296.6
15	71.8	285	288.8
30	124.6	300	282.0
45	167.6	315	274.6
60	210.2	330	266.6
75	243.8	345	259.4
90	267.4	360	252.2
105	283.4	375	246.4
120	294.0	390	239.8
135	304.8	405	233.6
150	316.8	420	227.6
165	326.4	435	222.2
180	328.2	450	216.0
195	325.6	465	210.6
210	320.8	480	205.6
225	317.8	495	198.8
240	312.4	510	
255	305.8	525	
		540	



PHOTOGRAPH 10. **Firing mechanism and candle**

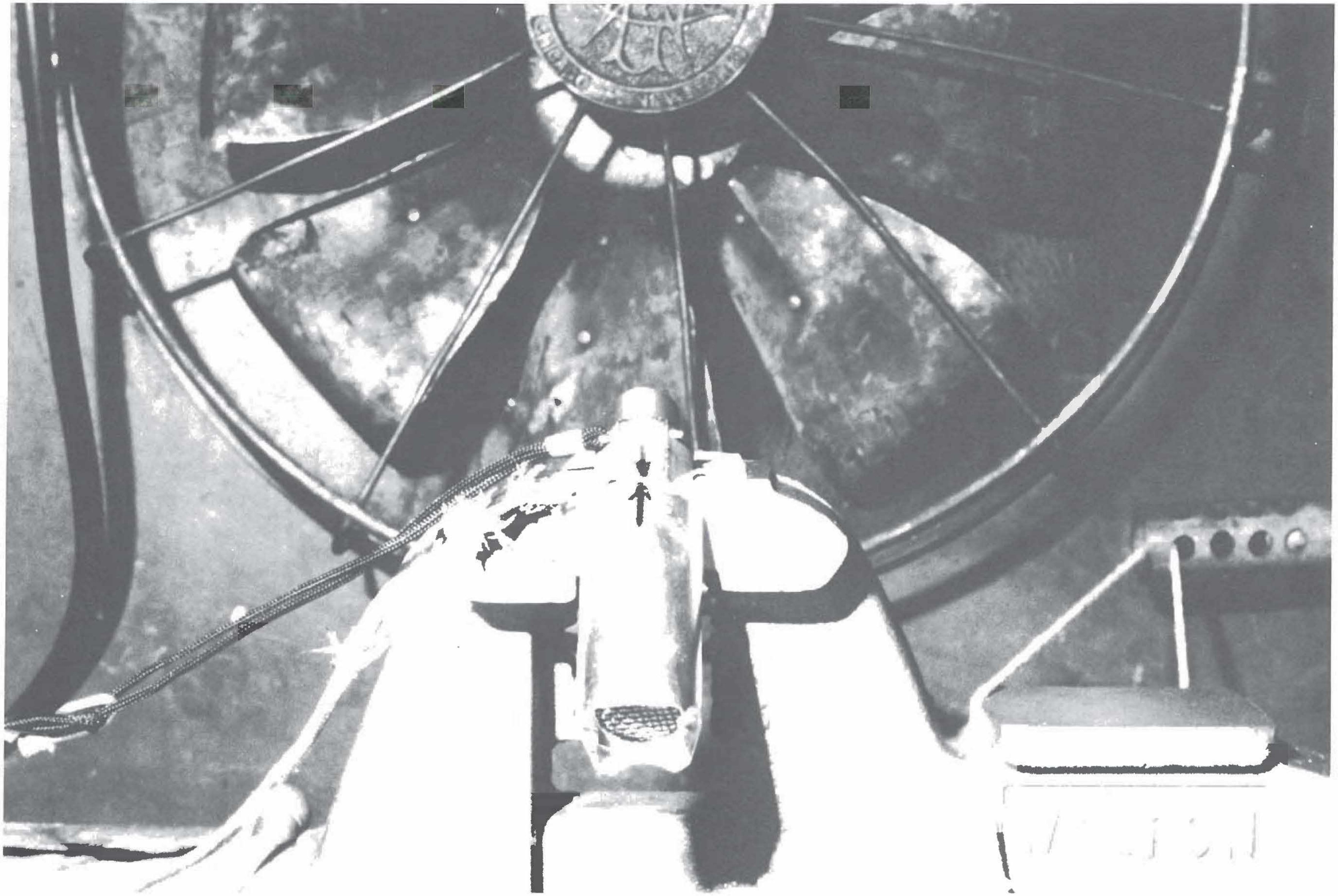
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 15

Comments: This test was conducted with the firing mechanism and candle only; no washer; one thread engagement; not torqued. 8.6 percent methane; temperature measurement made on candle between candle and firing mechanism. See photograph following test #15 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	27.2	270	287.0
15	57.2	285	279.8
30	97.2	300	272.0
45	146.0	315	265.4
60	193.2	330	257.6
75	226.6	345	250.2
90	250.0	360	244.4
105	267.8	375	237.4
120	279.4	390	231.2
135	290.0	405	225.0
150	301.4	420	219.0
165	310.6	435	213.6
180	315.4	450	208.4
195	316.0	465	202.4
210	312.4	480	197.2
225	307.4	495	
240	301.0	510	
255	294.0	525	
		540	



PHOTOGRAPH 11. **Firing mechanism and candle**

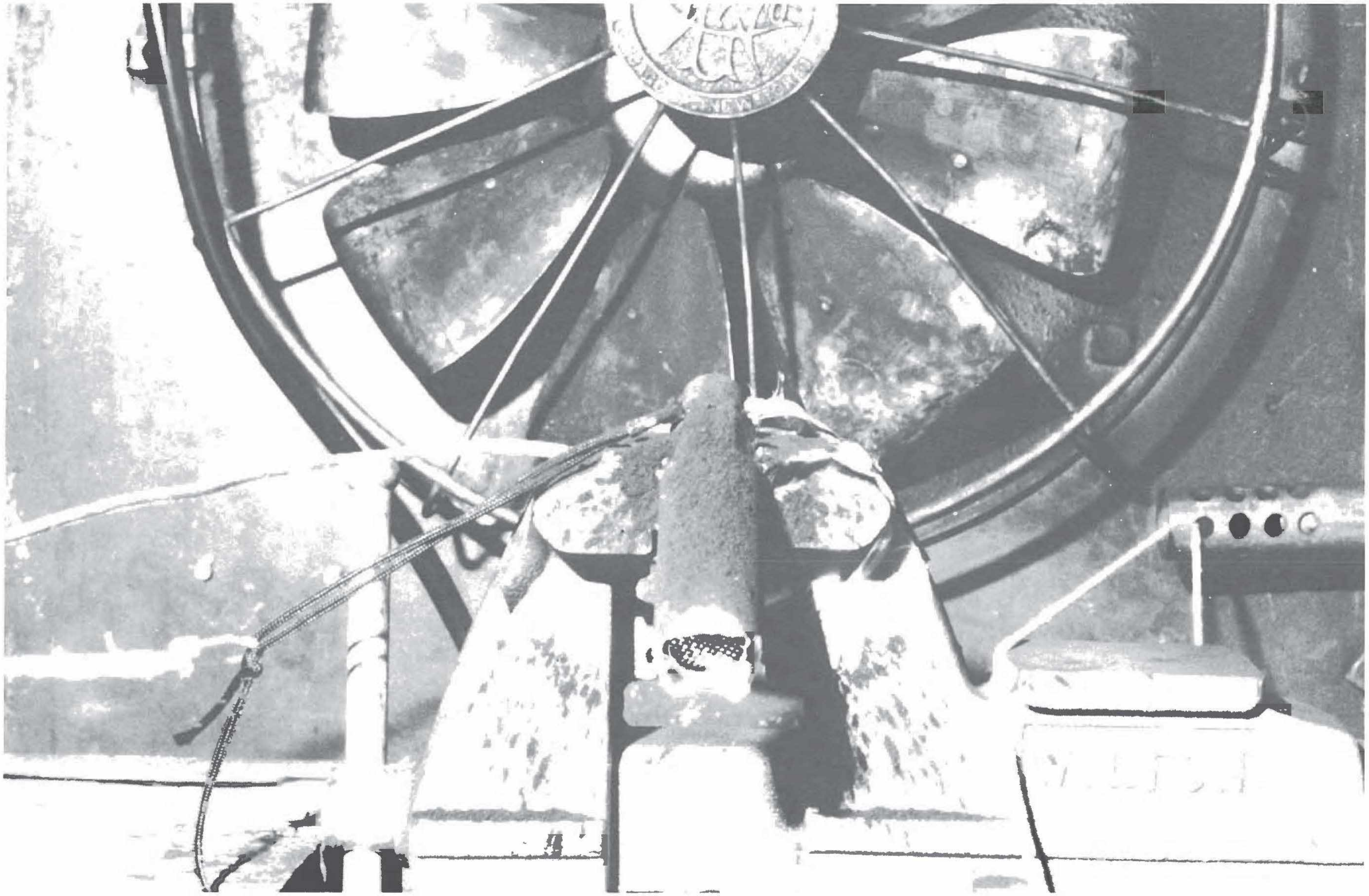
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 16

Comments: This test was conducted with the firing mechanism and candle only; no washer; one thread engagement; not torqued. 8.6 percent methane; Coal dust layer over firing mechanism and candle assembly; temperature measurement made on candle between candle and firing mechanism. See photograph on next page.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	27.4	270	
15	68.6	285	
30	118.6	300	
45	174.4	315	
60		330	
75	IGNITION OCCURED.	345	
90		360	
105		375	
120		390	
135		405	
150		420	
165		435	
180		450	
195		465	
210		480	
225		495	
240		510	
255		525	
		540	



PHOTOGRAPH 12. **Firing mechanism and candle**

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 17

Comments: Test conducted with firing mechanism and candle installed in sealed canister; 8.6 percent methane; washer in place; torqued to 25 in.-lbs. Coal dust layered over firing mechanism and canister; temperature measurement made between firing mechanism and canister. See photograph following test #20 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.6	270	168.2
15	32.4	285	169.2
30	41.8	300	169.6
45	56.6	315	169.2
60	70.2	330	168.2
75	82.2	345	167.8
90	94.2	360	166.2
105	100.6	375	164.8
120	108.2	390	163.0
135	116.2	405	161.6
150	124.4	420	159.2
165	132.8	435	157.0
180	140.8	450	155.0
195	150.0	465	152.8
210	156.8	480	150.6
225	160.8	495	148.6
240	164.4	510	146.2
255	166.8	525	144.0
		540	141.8

Time (Sec)	Temperature (° C)
555	139.6
570	137.4
585	131.2
600	127.4
615	124.8
630	122.2
645	120.2
660	118.2
675	116.4
690	114.0
705	112.0
720	110.0
735	108.2
750	106.6
765	105.0
780	103.4
795	101.8
810	100.2
825	98.6
840	97.2
855	95.8
870	94.4
885	93.0
900	91.8

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 18

Comments: Test conducted with firing mechanism and candle installed in sealed canister; 8.6 percent methane; washer in place; torqued to 25 in.-lbs. Coal dust layered over firing mechanism and canister; temperature measurement made between firing mechanism and canister. See photograph following test #20 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	22.8	270	238.2
15	31.8	285	239.0
30	50.1	300	239.0
45	73.8	315	238.2
60	98.2	330	237.2
75	118.4	345	235.4
90	135.6	360	233.6
105	151.4	375	231.4
120	163.8	390	229.2
135	175.7	405	226.6
150	187.6	420	223.8
165	200.6	435	221.0
180	211.8	450	218.2
195	220.4	465	215.0
210	227.2	480	212.0
225	231.4	495	208.8
240	234.6	510	205.8
255	236.8	525	202.6
		540	199.8

Time (Sec)	Temperature (^{o} C)
555	196.8
570	193.6
585	190.6
600	187.4

Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 19

Comments: Test conducted with firing mechanism and candle installed in sealed canister; 8.6 percent methane; washer in place; torqued to 25 in.-lbs. Coal dust layered over firing mechanism and canister; temperature measurement made between firing mechanism and canister. See photograph following test #20 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	22.4	270	236.2
15	41.4	285	235.0
30	66.2	300	233.4
45	95.1	315	231.6
60	121.2	330	229.4
75	143.6	345	227.0
90	161.8	360	224.2
105	176.6	375	221.4
120	187.4	390	218.6
135	198.2	405	215.4
150	210.6	420	212.2
165	220.6	435	209.0
180	226.8	450	205.6
195	231.6	465	202.4
210	234.6	480	198.8
225	236.2	495	195.6
240	237.0	510	192.4
255	237.0	525	189.0
		540	185.8

Time (Sec)	Temperature (o C)
555	182.2
570	179.6
585	176.6
600	173.6

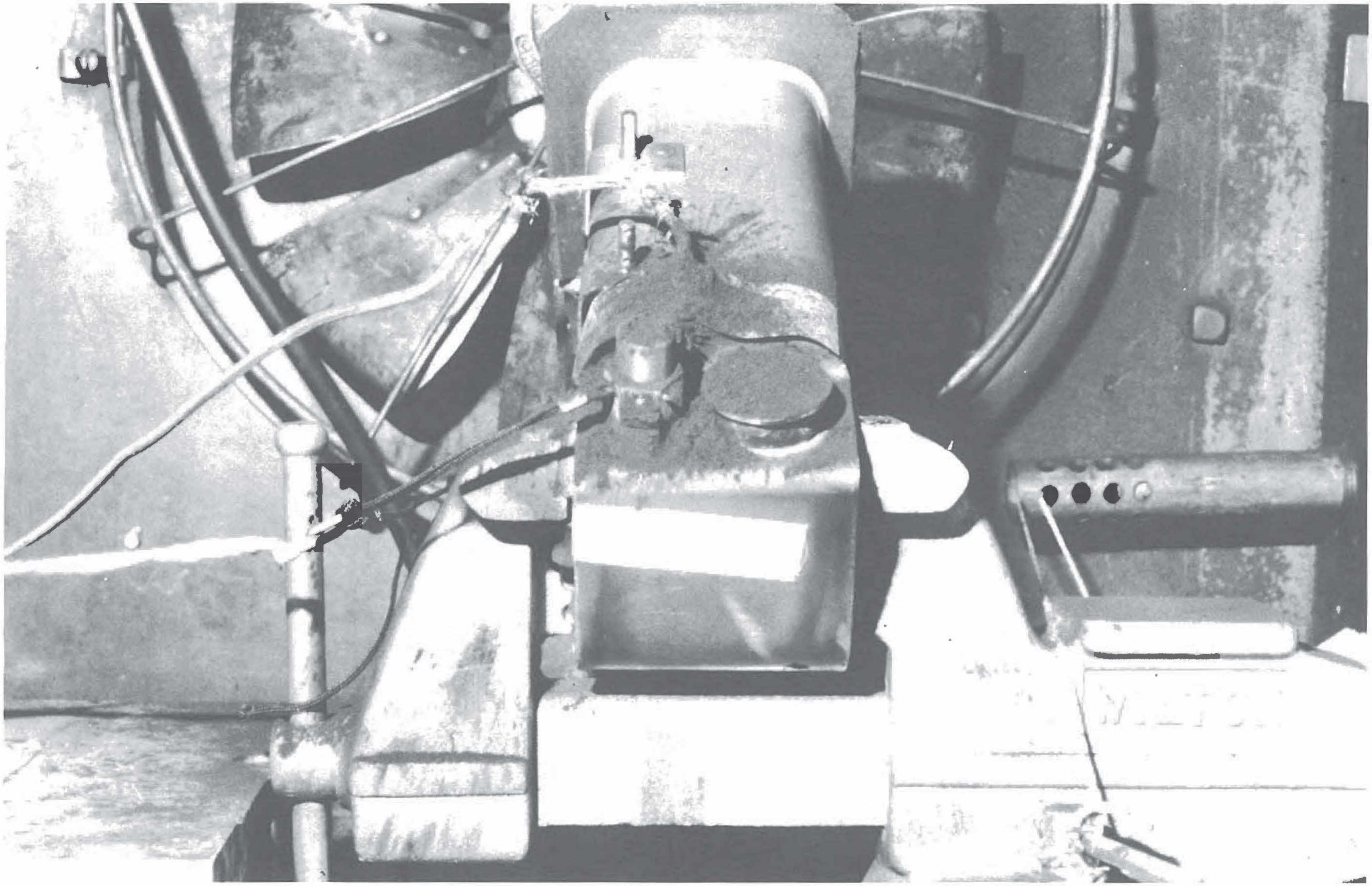
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 20

Comments: Test conducted with firing mechanism and candle installed in sealed canister: 8.6 percent methane: washer in place: torqued to 25 in.-lbs. Coal dust layered over firing mechanism and canister: temperature measurement made between firing mechanism and canister. See photograph following test #20 data sheet.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	24.4	270	225.2
15	42.3	285	225.2
30	59.8	300	224.6
45	77.6	315	223.4
60	99.6	330	222.0
75	118.7	345	220.2
90	135.4	360	218.0
105	147.6	375	215.6
120	159.4	390	212.8
135	169.2	405	210.6
150	181.6	420	207.6
165	193.1	435	204.8
180	203.6	450	201.6
195	211.2	465	198.8
210	216.8	480	195.6
225	220.8	495	192.8
240	223.2	510	189.8
255	224.8	525	186.7
		540	184.0



PHOTOGRAPH 13. **Firing mechanism and candle installed in sealed canister**

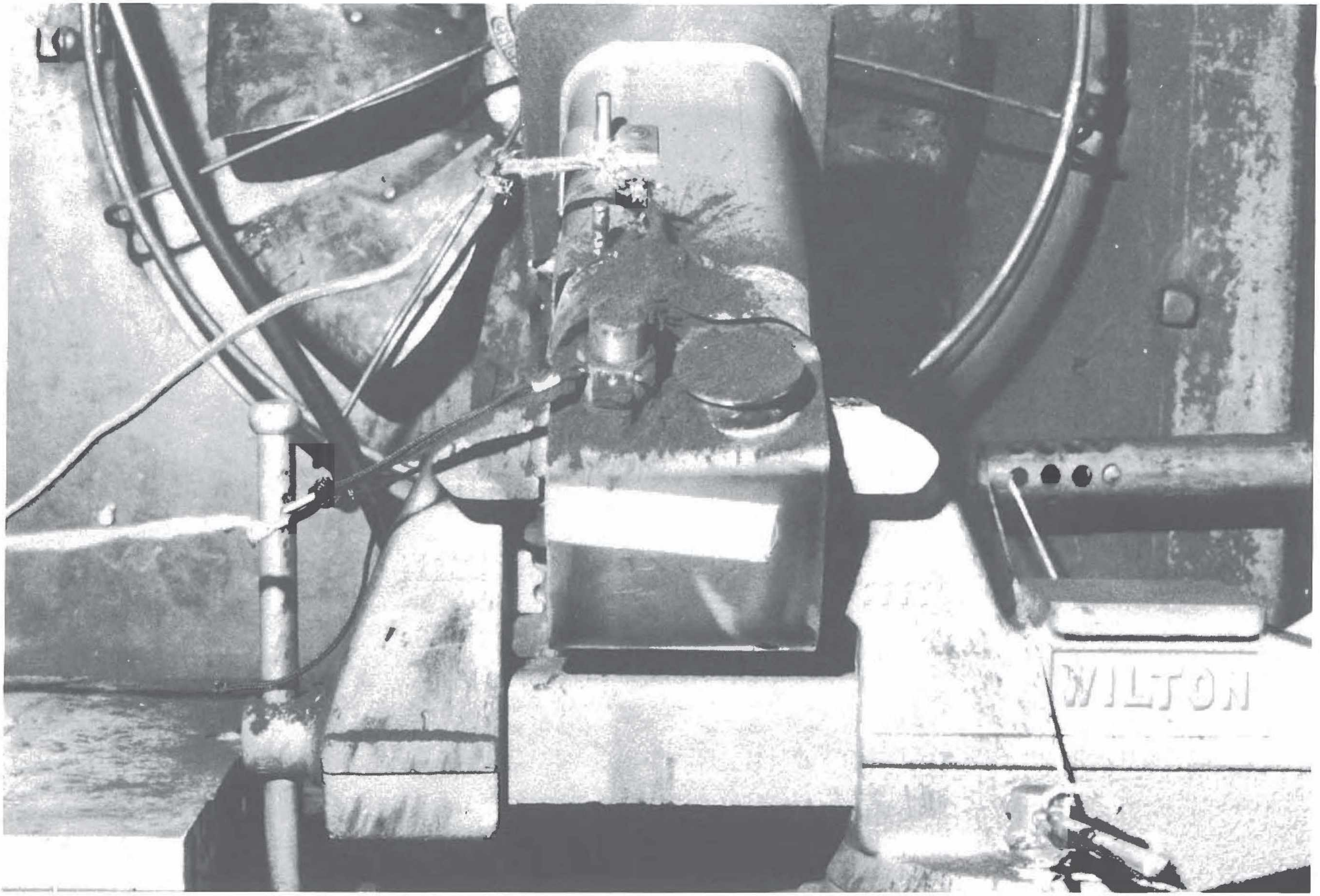
Special Investigation: Explosion Test - MSA

60 Minute Self Rescuer

Date: March 10, 1980 Test Sheet No.: 21

Comments: Test conducted with firing mechanism and candle installed in sealed canister; 8.6 percent methane; no washer; firing mechanism finger tight only. (backed-off 1-turn); coal dust layered on canister and firing mechanism; temperature measurement made between firing mechanism and canister. See photograph on next page.

Time (Sec)	Temperature (° C)	Time (Sec)	Temperature (° C)
0	25.6	270	148.6
15	26.8	285	150.2
30	31.6	300	151.4
45	38.8	315	152.4
60	49.4	330	152.6
75	59.6	345	152.6
90	71.8	360	152.4
105	83.8	375	151.8
120	93.2	390	150.8
135	103.2	405	149.8
150	107.8	420	148.6
165	114.4	435	147.4
180	122.4	450	145.8
195	130.4	465	144.4
210	137.7	480	142.8
225	142.6	495	140.8
240	146.6	510	139.0
255	147.0	525	138.0
		540	136.0



PHOTOGRAPH 14. **Firing mechanism and candle installed in sealed canister**

ATTACHMENT NUMBER 1

DRAWING LIST

MINE SAFETY APPLIANCES COMPANY

60 MINUTE SELF RESCUER

TITLE	DRAWING NO.	REVISION
Candle Assembly	C466686	12-4-78
Firing Mechanism Assembly	C466690	12-5-78
Lanyard	B466997	1
Part Number Specifications	628154	2
Disc	B466688	10-28-78
Plunger	B466687	1
Part Number Specifications	24941	3
Screen, Filter, Candle	D458747	2
Part Number Specification	22097	2
Part Number Specification	57868	-
Primer, M-42C2	D57372	2
Part Number Specification	628156	1
Part Number Specification	601563	-
Part Number Specification	628762	-
Part Number Specification	53255	1
Candle	C466685	11-8-78
Housing	C466689	3
Cone	B466676	11-8-78
Specification	163	5-6-75

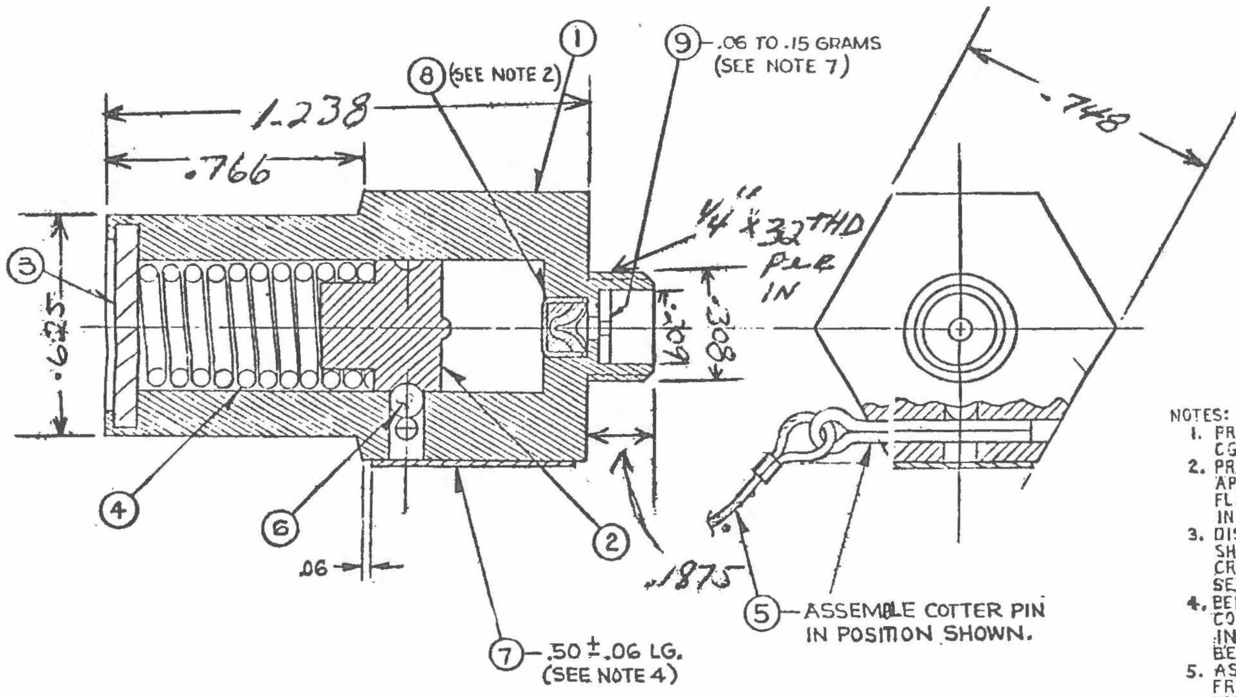
TITLE	DRAWING NO.	REVISION
Screen, Disc, Candle	B466683	1
Part Number Specification	25866	1
Disc, Fiber	B466681	1
Part Number Specification	304344	-
Washer, Retaining	B466684	10-26-78
Ring, Retaining	B466680	11-8-78
Case Assembly, Candle	B466679	11-8-78
Tube, Case	B466678	10-26-78
Part Number Specification	20430	2
End, Case	B466677	10-26-78
Part Number Specification	20941	-
Washer, Fiber	B466682	1
Part Number Specification	600686	-

PARTS LIST

ITEM NO.	PT. NO. DWG. NO.	REQ'D	DESCRIPTION
1	C466689	1	HOUSING
2	B466637	1	PLUNGER
3	B466638	1	DISC
4	628154	1	SPRING
5	B466997	1	LANYARD
6	628156	1	BALL, STAINLESS STEEL, 3/32" DIA.
7	601553	—	TAPE, 3/8" WIDE
8	057372	1	PRIMER.
9	25202		POWDER, FLASH

REVISIONS

DEC 5 1978



NOTES:

1. PRIOR TO ASSEMBLY CLEAN ITEMS 4 AND 6 PER CGA PAMPHLET G-4.1.
2. PRIMER (ITEM 8) SHALL BE SEATED BY APPLYING 200 LB. LOAD TO A $.173^{+.000}_{-.001}$ DIA. FLAT BOTTOM PUNCH, THEN RING STAKED IN PLACE.
3. DISC (ITEM 3) TO BE HELD FLAT AGAINST SHOULDER PORTION OF HOUSING (ITEM 1) DURING CRIMPING OPERATION TO INSURE PROPER SPRING SETTING.
4. BEFORE APPLYING TAPE (ITEM 7) INSURE COTTER PIN (ITEM 5) IS COMPLETELY INSERTED AND ACROSS BORE. TAPE MUST BE FLAT.
5. ASSEMBLY (C466690) TO BE PROTECTED FROM WATER VAPOR. PACKAGE PER CGA PAMPHLET G-4.1.
6. (A) FORCE REQ'D. TO PULL OUT COTTER PIN SHALL BE 7 LB. ± 3 LB. WHEN PULLED IN LINE WITH THE COTTER PIN ±5° AT A RATE OF 12 ± .5 IN/MIN.
7. PACK POWDER (ITEM 9) INTO POSITION (1000 TO 1300 LB. COMPRESSION) WITH A .040 DIA. HOLE IN CENTER.

MINE SAFETY APPLIANCES COMPANY
PITTSBURGH, PA. 15208 U.S.A.

MSA STANDARD SHOP PRACTICES APPLY

DO NOT SCALE DWG.

CODE SYMBOLS: CRITICAL A, MAJOR A A, MAJOR B A, MINOR

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL ±
2 PL. DEC. ±
3 PL. DEC. ±
ANGULAR ±
SEE MSA STANDARD SHOP PRACTICES FOR DRILLED HOLE TOLERANCES

DRAWN BY: J.T. McVEIGH DATE: 8-19-78
CHECKED BY: R.J. SHEPPARD
PROJECT ENGINEER: R.K. McINTYRE 11-29-78
MGR. QUALITY ASSURANCE: J.B. Brown
MGR. NEW PRODUCT INTRO.:

JOB NO. ER550071 SCALE 48"=1'-0"

NIOSH	BMA	FED	STATE	UL	FM		

FIRING MECHANISM ASSEMBLY

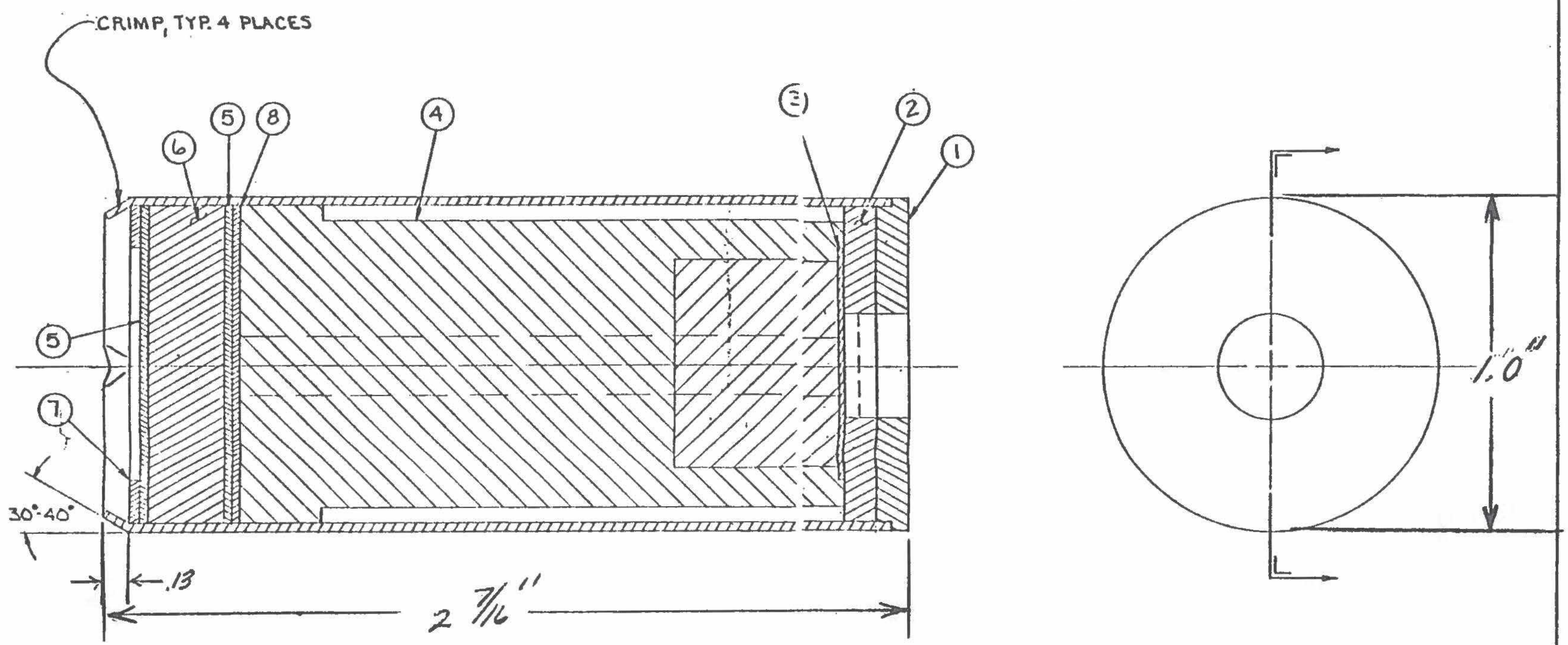
C 466690

REVISIONS CONT.

REVISIONS
DEC 4 1978

PARTS LIST

ITEM NO.	PT. NO. DWG. NO.	REQ'D.	DESCRIPTION
1	B466679	1	CASE ASSEMBLY
2	B466682	1	WASHER, FIBER
3	D458747	1	SCREEN, FILTER
4	C466685	1	CANDLE.
5	B466683	2	SCREEN, DISC
6	B466681	1	DISC
7	B466684	1	WASHER, RETAINING
8	B466680	1	RING



NOTE:
△A 1. MUST MEET MSA SPEC. # 224.

CODE SYMBOLS
CRITICAL [illegible] MAJOR A [illegible]
MAJOR B [illegible]

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL ±
2 PL. DEC. ±
3 PL. DEC. ±
ANGULAR ±
[illegible] MSA STANDARD [illegible]
[illegible] TOLERANCES

DRAWN BY: CPB DATE: 9-20-78
CHECKED BY: RJ SHEPPARD 11-27-78
PROJECT ENGINEER: RJ SHEPPARD 11-27-78
MGR. QUALITY ASSURANCE: JR BROWN [illegible]
[illegible]

JOB NO. ER 550071 SCALE 4 X.

NIOSH	BMA	FED	STATE	UL	FM		
X							

CANDLE ASSEMBLY

C 4 [illegible] 6 5 6

APPENDIX III

REPORT ON THE POTENTIAL HAZARDS OF THE MSA CHLORATE CANDLE PRIMER (FIRING MECHANISM) IN GASSY ENVIRONMENTS

BY

W. C. PETERS

JULY 18, 1975

Report on the Potential Hazards of the MSA Chlorate Candle Primer (Firing Mechanism) in Gassy Environments

TEST METHODS:

The tests were conducted in the 45 cubic feet illustrated in figure 1. Since the chlorate candle primer did not ignite 8% natural gas-air, a more flammable atmosphere was used, consisting of 8% natural gas and up to 37% oxygen enriched air. The primers were not modified for the tests; however, the striker assembly was modified by adding tension to the spring, a more ridged striker arm, and a sharp striker point to insure perforation of the primer assembly in each test. A spent chlorate candle was used to simulate the flash suppression effect of the actual chlorate candle. The modified striker assembly and the mounting plate are shown in figure 2.

The entire chlorate candle assembly was tested in 8% natural gas-air using the same mounting plate and modified striker arrangement. In all the tests, the test item was suspended in the center of the gallery. The concentration of natural gas was monitored in each test using a LIRA gas analyzer to within $\pm$ .30%.

A very low strength detonating cord (4 gr PETN per foot) was used as a control ignition device. Previous tests have shown that a single, one foot long strand of the cord, suspended in the gallery in 8% natural gas, has a very low probability of ignition. The number of bundled 1-foot strands required for 50% probability of ignition of 8% natural gas is 9.4. Ignition by one strand with 50% probability requires an O_2 concentration of 24%.

RESULTS:

An ignition with an initiated primer assembly was obtained in 37% oxygen enriched 8% natural gas-air. An ignition was also obtained at the 33% enrichment level with a primer which was not initiated after repeated perforations by the striker. The ignition at 33% O_2 is tentatively attributed to the striker action rather than primer flashback. Seven non-ignitions were observed at enrichment levels greater than 33%, up to 37% O_2, with initiated primers. An oxygen index ($\%O_2$) for which five ignitions are obtained in five trials was not determined due to the very high level of enrichment required for ignition. The test results are summarized in Table 1.

One ignition in ten trials with the complete chlorate candle in 8% natural gas (no O_2 enrichment) was obtained. The data on the complete candle are listed in Table 2. Since the ignition occurred several seconds ($\simeq$ 15 seconds) after the primer was fired, it is tentatively attributed to the burning chlorate candle, not to perforated primer flashback. The candle which caused the ignition is shown in figure 3 along with a spent candle and an unfired candle for comparison. The hot slag visible near the perimeter of the candle probably contributed to the ignition of the natural gas. Four holes were drilled through the fiberglas filter media (See figure 4) in an effort to deliberately create exposed hot slag. The experiment failed and the natural gas was not ignited by the modified candle.

TABLE 1. - PERFORATED CHLORATE CANDLE PRIMER TEST RESULTS IN OXYGEN ENRICHED 8% NATURAL GAS-AIR MIXTURES

Enrichment Level	Results
$\%O_2$	+ = ignition; o = nonignition
37	o, +
36	o, o
35	o, o, o
34	o
33	(+)1/, o, o
32	o, o, o, o
28	o
27	o

1/ Ignition occurred without initiating the primer mix.

TABLE 2. - RESULTS FOR COMPLETE CHLORATE CANDLE ASSEMBLY IN 8% NATURAL GAS-AIR MIXTURE

Shot #	Result (+ = ignition; o = nonignition)
75	o
76	o
77	o
78	o
79	o
80	+
81	o
82	o
83	o[1/]
84	o

1/ Candle modified by drilling holes through fiberglas filter media.

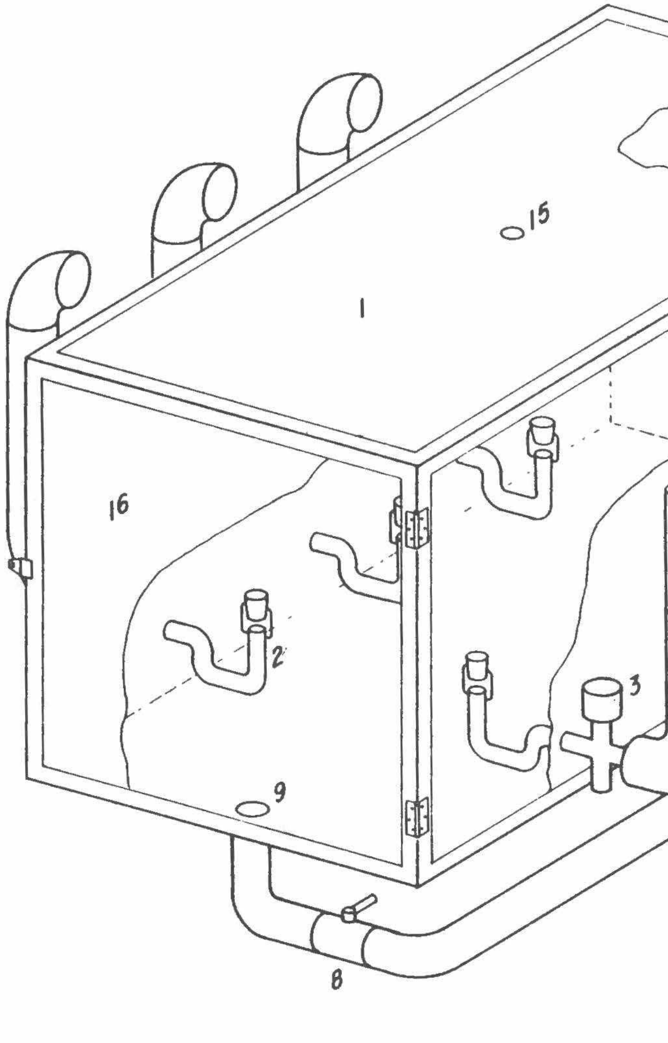
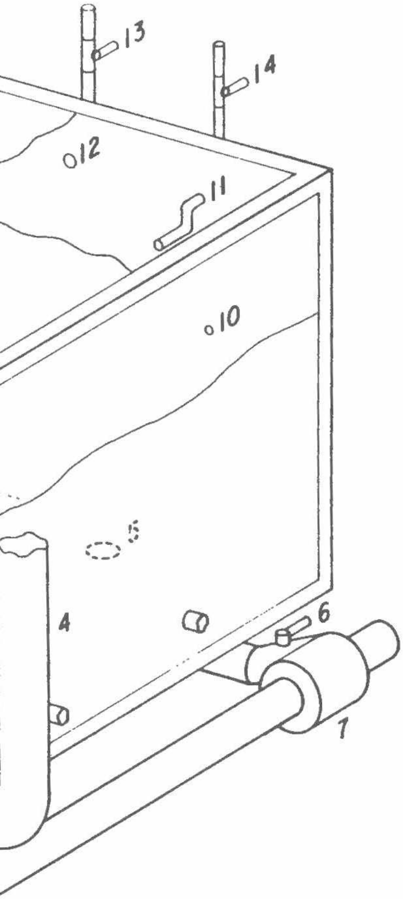


FIGURE 1



1 $\frac{1}{2}$" steel walls
2 Coal dust disperser
3 Solenoid valve (air pressure)
4 Air reserve chamber
5 Gas circulator input port
6 Circulator input shutoff
7 Gas circulator
8 Circulator output shutoff
9 Gas circulator output port
10 Thermometer port
11 Lira sample tube
12 Gas inlet
13 Gas shutoff
14 Lira shutoff
15 Detonator port
16 Paper diaphragm

. - Modified 45 cu ft gallery.

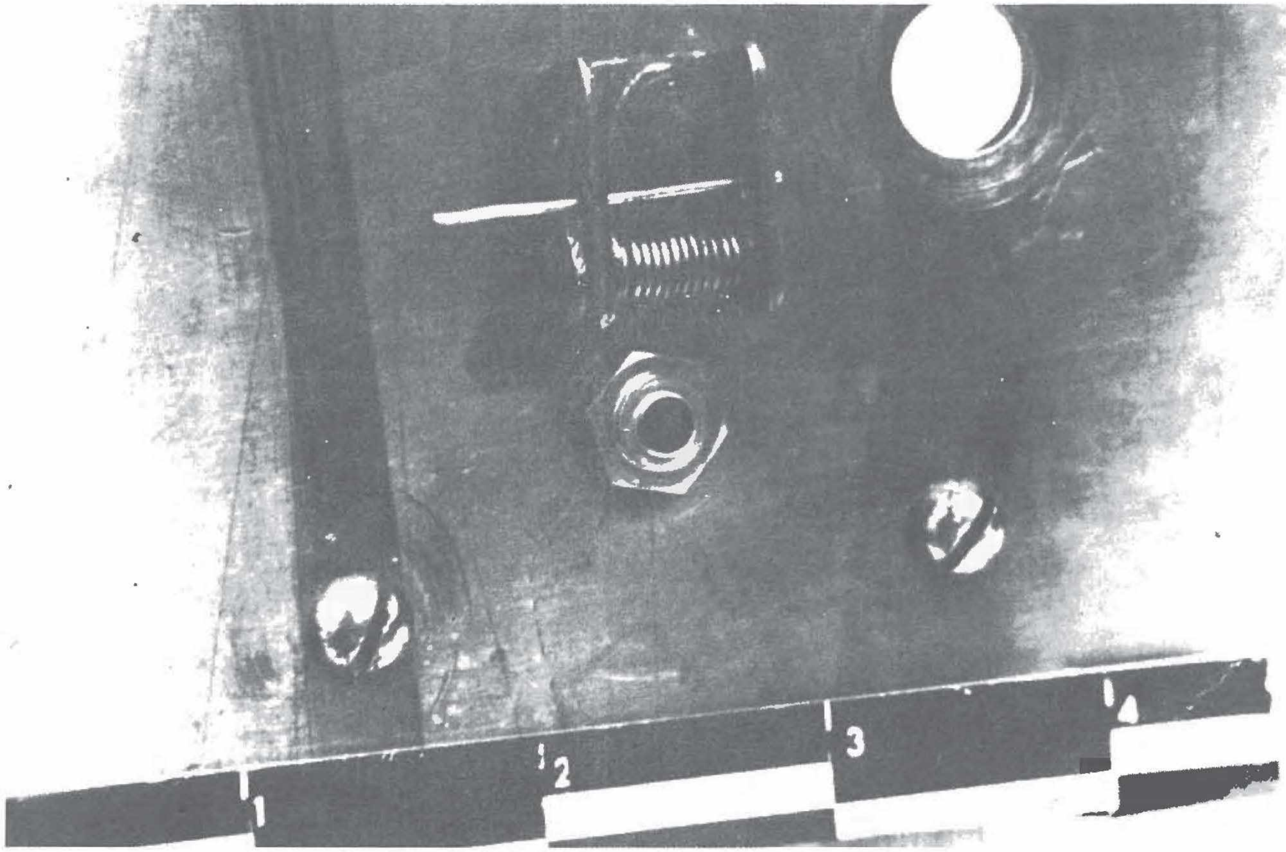


FIGURE 2. - Modified striker assembly and mounting plate.

FIGURE 3. - Left to right: unfired candle, spent candle which caused ignition, spent candle with no ignition.

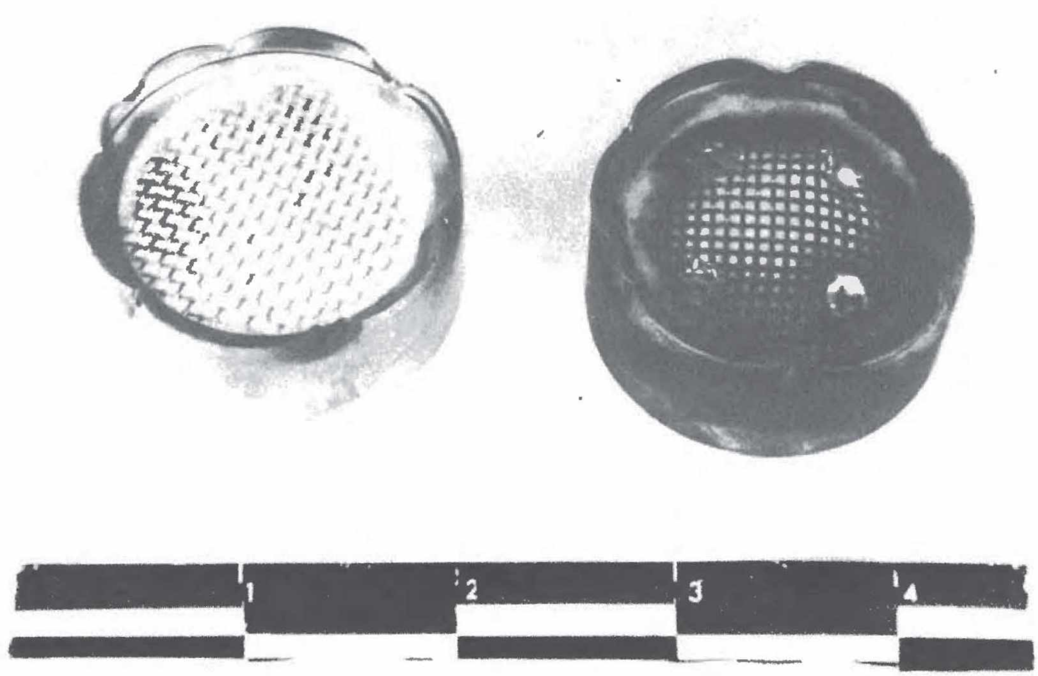


FIGURE 4. - Left, unfired candle; right, spent candle modified to expose slag.