FIRE PROTECTION PROVIDED BY DETONATOR CONTAINERS

by
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The Code of Federal Regulations Title 30, Parts 56, 57, 75, and 77 require that detonators and explosives be separated by four inches of hardwood or equivalents when transported together in mines. This standard was developed to protect the explosives from initiation by the more sensitive detonators. The research reported here is an attempt to quantify the fire protection offered by four inches of red oak and other materials. Boxes with a volume of 6.75 cubic feet were made from four-inch thick rough green oak (RGO), two-inch thick RGO plied, two-inch thick #1 common (dried) red oak plied, and a metal/plywood composite. These and boxes meeting the Institute of Makers of Explosives' (IME) Safety Library Publication No. 22 were tested in bonfires. The boxes were instrumented with thermocouples, filled with detonators, and placed over a kerosene fire imparting about 16 kilowatts per square meter heat flux for up to 3 hours. Tests showed that the wood boxes protected the detonators for over an hour with variations between the different trials. In the IME 22 container tests, detonators began exploding in as little as 17 minutes in one test and not for 2-1/2 hours in another test. Detonators in the metal/plywood boxes began to explode in about 15 minutes but with minor alterations, were able to contain the detonators. The test results show that the exterior of an IME 22 container significantly affects its thermal properties. Defects in the form of cracks and the manner in which the container is closed have a significant effect on the performance of a detonator container in a fire.

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Introduction

The Code of Federal Regulations (CFR) Title 30, Parts 56.6201, 57.6201, 75.1311(b)(2), and 77.1302(e), require that detonators and explosives be separated by four inches of hardwood or the equivalent when transported together on the same vehicle in mines. Parts 56, 57 and 75, call for four inches of hardwood, a laminated partition, or the equivalent. The laminated partition is defined as a minimum of, from detonator side to explosive side, ½-inch plywood, ½-inch gypsum wallboard, 1/8-inch steel, and ¼-inch plywood. This is also the minimum requirement listed in the Institute of Makers of Explosives (IME) Safety Library Publication (SLP) No. 22 when explosives can contact the outside (1)[2]. Part 77, the surface coal mine regulations, calls for "four inches of hardwood or the equivalent" with no definition of equivalent. The Mine Safety and Health Administration's (MSHA) policy has been to require the mine operator to prove the equivalency of other partitions prior to use. The mining law also requires that the detonators be kept in their original packaging if more than 1,000 are transported.

The CFR Title 49 Part 177.835(g) impacts vehicles which transport detonators and explosives together over public highways. The only compartmental method listed in 49 CFR is use of a container as described in IME SLP 22. There are also limitations on the quantity and hazard class of detonators allowed in an IME 22 container. As recognized in these regulations, detonators with a mass detonation hazard (shipping Class 1.1) can render any box construction worthless. If Class 1.1 detonators were involved in a fire, it would be expected that all of them would explode at once. If explosives were also on board, they would likely be initiated through direct shock or impact from flying debris.

There are two hazards when Class 1.4 detonators and explosives are transported on the same vehicle. The first is a single detonator accidentally exploding and initiating the explosive load. Here, a shock-attenuating barrier is needed. The second occurs when the vehicle is in a fire which involves the detonators or explosives; at which point all fire fighting measures should stop. In theory, the explosives should burn without detonating, but measures must be taken in case they do. The critical aspect now is that there be enough time to secure the area before the detonators pose a threat to initiating the explosives. As this takes place, the detonators must not be expelled from their container or else they could initiate the explosive. Even if the load is only blasting agent, it would be a risky assumption to believe a stray detonator could not set it off. Consider that the test to determine an explosives' blasting cap sensitivity uses a detonator with a base charge of 500 milligrams, a paper container for confinement of the small charge, and is performed at 25°C (2). In a transportation fire, larger base charge detonators are likely to be involved and the explosive may be confined, hot, and in larger diameter.

The length of time a detonator container should protect the detonators can be approached two ways. The first is to determine the time needed to block access and ensure all personnel are in a safe location away from the fire. A second approach, used by Darling (3), is to determine how long the explosives will burn. A number of minutes that applies to all situations is impossible to arrive at with either approach. The first approach depends on conditions at the scene of the fire. The second approach may work well for high explosives which burn vigorously but, explosives with very high water content could take several hours to burn. Ideally, the most effective detonator container would not allow detonators to escape the box in a fire, rendering the time it takes to secure the area or to burn the explosives immaterial.

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[2] Numbers in parentheses refer to references listed at the end of this report.

It is clear the mining law only considers the hazard of an accidental initiation of a detonator. When first promulgated in the 1969 Mine Safety Act, a single box with a divider to separate the explosives and detonators exemplified the four inch hardwood requirement. This was typical of the time, especially in underground coal mines and others where relatively small amounts of explosive were used. Today however, large amounts of explosive are transported requiring separate containers for the explosives and detonators. Boxes with dividers are still used today, and no history of accidents with 4 inches of hardwood as a divider exists. The critical features of this type of box would be its thermal properties and the condition or effectiveness of the barrier while the detonators exploded. For example, if the barrier did not meet the lid flush, exploding detonators would likely toss live detonators over the barrier into the explosives. The results of this testing are directly applicable to the thermal properties. The effectiveness of the barrier would depend on factors such as its ruggedness, the extent of thermal damage, and the detonator load.

According to the IME, their design is mainly intended for protection in a fire. Prior US Bureau of Mines research showed the IME 22 laminate provides an adequate shock attenuator also. (4)

The primary hazard is a fire situation. The author knows of no case where a commercial detonator exploded inside a container during transport other than in a fire. Perhaps a bullet could penetrate the magazine and strike a detonator, but the magazine has now been damaged and may not perform as intended. Radio energy presents practically no threat to electric detonators if the legwires are in their original shipping configuration. However, vehicle fires do occur in mining. According to the Accident/Injury/Illness database generated from MSHA's Form 7000-1, there were at least 189 mobile equipment fires which lasted more than 30 minutes in US mines from 1990 to 1995. Although most of these incidents involved heavy equipment, 23 involved compressors, forklifts, mancars, or nonhaulage trucks.

Test Parameters

Boxes with a volume of 6.75 cubic feet were made from 4-inch by 6-inch rough green oak (RGO), 2-inch by 6-inch RGO plied, two-inch thick #1 common (dried) red oak plied, and a metal/plywood composite. These and boxes meeting the requirements of IME SLP 22 were placed in kerosene fires for up to 3 hours. The boxes were fabricated by professionals, thus assuring good construction. Each box was filled with inner boxes of Austin[3] Rock-Star detonators with 16 foot (ft) copper legwires. These detonators were packaged 60 to an inner box and varied only in the length of the delay element. The detonators had a base charge of 750 milligrams (mg) PETN and an initiating charge of 200 mg lead azide. Table 1 summarizes the parameters of each test. For comparison, data from the original IME 22 container tests (5) and a test from which the Canadian standard was based (3) are included in Table 1.

Some explanation of terms used in Table 1 is necessary for clarity. The column "Test" lists an abbreviation for the type of box followed by the trial number if more than one was performed. The column "Closure Method" lists the type of hardware used to seal the lid or door of the box. The column "Condition" lists the observed general state of the box before the test. The term "Good" means the box had not been exposed to weather and had tight fitting joints. The term "Cracks" refer to boxes in which

[3] Reference to specific manufacturers does not indicate endorsement by NIOSH.

the joints did not meet flush. In test Com#2, the term "Vented" indicates a 2 inch diameter vent hole was drilled in the top of the box. In test IME#1, the term "Weathered" indicates the box had been exposed to the weather for about 7 years. In test M/P#3, the cracks were "Filled" with common stove pipe caulking. The column "Pan Size" lists the plan view size of the pan used to contain the kerosene. The column "Spacers" lists type of spacer placed in the pan to reduce the burning surface area. The term N/A means not applicable.

The heat source was kerosene floated on 6 inches of water in all the tests. The variations in size of pan, fuel feed rate, and type of spacer had no significant effect on the data. Analysis of the data from the bottom outside thermocouple of tests 4x6#1, Com#2, 2x6#1, 2x6#2, and 2X6#3 indicate a thermal flux of between 14.6 and 17.6 kilowatts per meter squared. The outsides of the boxes reached 300°C within a few minutes and temperatures as hot as 1,000°C were recorded.

Each test was video recorded and instrumented with eight type K thermocouples. The thermocouple leads were insulated from the fire with 1-1/2 inches of ceramic fiber insulation assuring no thermal damage to the thermocouples. Each test had a thermocouple in the airspace of the box. Each test except 4x6#1 had a thermocouple on the outside and inside center of the bottom, and on the outside and inside center of one side. Thermocouples were also placed in the walls, in the detonator packages, and on joints or in cracks.

The thermocouple data were recorded with a personal computer based data acquisition system. Each channel was sampled at 40 hertz through a low pass (80 hertz) filter. A software program then averaged every 160 data points, converted this voltage into degrees Celsius (°C), and stored the temperature value with a time stamp every 4 seconds for all 8 channels.

Test Results

The time from the start of the fire to when the first detonator went off (1^{st} det time) and when detonators were expelled from the box were the two events of interest during the tests. Figure 1 is a bar graph showing these two times for each test. Again, data from the original IME 22 container tests and a Canadian test are included in Figure 1. Bars extending to the top of the graph indicate no detonators escaped from the box. Since test 4x6#1 used only one detonator, the time when detonators escaped the box was not applicable.

Except for test Com#3 and 4x6#1, the wood boxes prevented detonators from going off from between 85 and 138 minutes. The average for these 7 tests was 104 minutes with a standard deviation of 19 minutes. All the wood boxes fell apart allowing detonators to fly about within a few minutes after detonators started to go off.

Craftsmanship was critical as seen in the variability of the 2x6 RGO tests in Figure 1. Here, the three tests yielded 1^{st} det times of 84, 109, and 138 min. Figure 2, the air temperatures during these tests, shows a spike in the air temperature in the first ten minutes of 2x6#3. This could be caused by influx of hot gasses from the fire through cracks between the boards which were quickly plugged by combustion byproducts, wood excretions, or swelling. These same defects allow a quicker overall temperature rise as seen in the graph. A thermocouple placed in a 1/8-inch crack in the corner of the 2x6#3 box recorded temperatures of nearly 150 °C only 25 min into the burn. No cracks that wide were present in the 2x6#1&2. The same trend was noticed in the 4x6 RGO tests shown in Figure 3.

Other temperature data from the tests suggest imperfections in the construction of detonator containers influence when detonators start to explode. In the test with one detonator suspended, it exploded at 172°C while the air temperature was 200°C. The average temperatures at the 1st det time in the other tests were as follows. The air in the 16 boxes was 171°C with a relatively high standard deviation of 51. The center of the detonators was only 67°C with a relatively low standard deviation of 8 in the 7 measurements taken. The temperature of joints varied from 43°C to over 726°C (in 2x6#3) at the 1st det time depending on the tightness of the joint. The average temperature of the bottom inside wall fell into two sets but was always well below the temperature of joints which did not meet flush. For the wood boxes, it was 57°C with a standard deviation of 16 in 8 tests (excepting 4x6#1). For the metal/plywood and IME 22 composites, it was 119°C with a standard deviation of 20 in 6 tests.

The M/P#1 test yielded a 1st det time of 16 min. Despite the heavy steel latch, the lid flew open on this box in 25 min. This was prevented in the next two tests by putting a ¼-inch bolt through the latch and bolt to prevent it from pulling out under the pressure of detonators exploding. In M/P#2, a detonator went off in 21 min. Then, 38 min into the burn, one of the welded seams split and allowed a few detonators to escape. Although a detonator went off in 12 minutes in M/P#3, it was the only test in which detonators never escaped the box. Along with the improved latch, the interior joints of this box were filled with common stove pipe caulking.

The boxes in M/P#1 and M/P#3 had gaps as wide as ¼-inch where the plywood sheets met. The box in Metal#2 had tight fitting joints. The effect is apparent in Figures 4 and 5, the air and crack temperatures. The crack temperature in the M/P#2 test roughly followed the air temperature. In M/P#1&3, the crack temperature was hotter than the metal shell from about 5 minutes on. The stove pipe caulking reduced the crack temperature somewhat and may have kept the air temperature from continuing to rise in M/P#3. Histograms of the number of exploding detonators per minute up to when the box's lid opened are shown in Figure 6. Figures 6a-c show detonators were going off at a rate of over 1 per second just before the lid opened in M/P#1 and the seam split in M/P#2. However, in test Metal#3, detonators never went off at a rate faster than 45 per minute. Whether or not the application of caulking was the reason for this is undetermined.

The IME 22 boxes showed great variability in their significant event times. The 1st det time varied from 17 min in IME#3 to 165 min in IME#1. Detonators were expelled in about 50 min in IME#2&3 and 165 min in IME#1. The different exteriors mentioned earlier are mainly responsible for this. Why a detonator went off in 17 minutes in IME#3 is undetermined.

Figure 7 shows the temperature of the metal in the IME 22 box tests. The insulating effects of the different exteriors (1/4-inch plywood, ½-inch plywood, and ½-inch plywood coated with 1/16-inch fiberglass) are apparent. Two hours into IME#1, the metal temperature had not yet reached 200°C. In IME#2&3, the metal reached 200°C in just over 10 and 20 minutes. This carried over to the air temperatures as seen in Figure 8.

Figure 6d shows the number of exploding of detonators each minute after the test was started for IME#3. More research is needed to explain why a detonator exploded 17 min into the test and 6 more exploded in the next 20 minutes This event did show that having a detonator container securely closed can be critical. The latch on this box was wired shut but gave way when the first detonator exploded allowing the lid to open and at least one other detonator to come out. This detonator exploded in the burn pan in the next few seconds. Since a padlock would have prevented the box from opening, this event was not considered a threat to explosives. Surprisingly, the lid opened slightly when the next detonator exploded but did not open again until it was blown off its hinges 24 minutes later.

Other observations showed that the type of closure hardware affects the safety of detonator containers. In IME#2&3, the lid latch and hinge were made from aluminum. Common aluminum alloys melt between 600-700°C. When the detonators began to explode in rapid succession in tests IME#2&3, the lid was thrown off since the only thing holding it down was its own weight. These boxes may have opened sooner if they had side opening doors instead of top opening lids. The IME#1 box came open as soon as detonators started to go off. Even though the latch and hinges were heavy duty steel, they were not attached to the metal shell and had no strength since the wood they were attached to was burned away when the detonators started to go off.

The closure mechanism is definitely an issue with less insulated boxes like the metal/plywood composite boxes. In M/P#1, the ¾-inch steel bolt, which extended over an inch into the latch, was bent and pulled out of the latch by the force of the exploding detonators. The addition of a ¼-inch machine bolt through the ¾-inch steel bolt and latch prevented this in M/P#2&3. In field use, a heavy cotter pin could serve the same purpose.

Conclusions

The following conclusions can be drawn from the results of the research.

- The craftsmanship as well as the material used in detonator containers have significant impact on the time and rapidity in which detonators explode in the box in a fire.
- Well constructed boxes with walls of four inches of red oak provide over an hour of protection against a kerosene fire.
- With proper latch reinforcing and tight fitting or sealed joints, the metal/plywood composite boxes tested can provide about 30 minutes of protection and have the potential to eliminate the threat of detonators escaping from the box in a fire.
- The exterior of an IME 22 container has significant influence on its thermal properties.
- The material and method used to close a detonator container have significant influence on when and if detonators present a threat to nearby explosives.

Acknowledgments

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References

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(2) The United Nations, Recommendations on the Transport of Dangerous Goods, Test and Criteria, 2nd edition, Labelmaster, Chicago, IL., 1990, p. 126.

(3) Darling, J.A., "Burning Trials of a Test Container Protecting Detonators from Fire", Canadian Explosives Research Laboratory, CANMET report MRP/MRL 81-104(OP), September, 1981, 7 pp.

(4) Becker, K.R., "Status Report-Effectiveness of Barriers and Containers", U.S. Bureau of Mines' Pittsburgh Research Center Report No. 4304, December 2, 1980, 11 pp.

(5) Dowling, T.P., Trojan - U.S. Powder Co. Memorandum on "Testing of Containers for Combination Electric Blasting Cap/High Explosive Shipments", October 11, 1971, 11 pp.

Table 1. Test Parameters

TEST	WALL (inches inside to outside)	SIZE (inches inside)	CLOSURE METHOD	CONDITION	NO. OF DETS	PAN SIZE (feet)	FUEL (8)	SPACERS
2x6#1	4 Red Oak	18x36x18	8 inch Lag Screws	Good	1140	8x8	1.4	Fire Bricks
2x6#2	4 Red Oak	18x36x18	8 inch Lag Screws	Good	1140	8x8	1.6	Fire Bricks
2x6#3	4 Red Oak	18x36x18	8 inch Lag Screws	Cracks	1140	8x8	1.6	Steel Cylinders
4x6#1	4 Red Oak	18x36x18	8 inch Lag Screws	Cracks	1140	6x6	1.2	none
4x6#2	4 Red Oak	18x36x18	8 inch Lag Screws	Good	1140	8x8	1.6	Fire Bricks
4x6#3	4 Red Oak	18x36x18	8 inch Lag Screws	Good	1140	8x8	1.6	Steel Cylinders
Com#1	4 Red Oak	18x36x18	8 inch Lag Screws	Good	1140	6x6	1.2	none
Com#2	4 Red Oak	18x36x18	8 inch Lag Screws	Vented	1140	8x8	1.2	Fire Bricks
Com#3	4 Red Oak	18x36x18	8 inch Lag Screws	Large Cracks	1140	8x8	1.6	Steel Cylinders
IME#1	IME+1/2 fc ply (1), (2), (3)	20x20x18	Heavy Duty Commercial	Weathered	540	8x8	1.6	Fire Bricks
IME#2	IME+1/2 ply	12x16x12	Aluminum Latch	Small Cracks	300	8x8	1.6	Steel Cylinders
IME#3	IME+1/4 ply	22x36x22	Aluminum Latch	Small Cracks	1620	8x8	1.6	Steel Cylinders
M/P#1	3/4 ply+1/4 steel	18x36x18	Heavy Steel	Cracks	1140	6x6	1.2	none
M/P#2	3/4 ply+1/4 steel	18x36x18	Enhanced Heavy Steel	Good	1140	8x8	1.6	Fire Bricks
M/P#3	3/4 ply+1/4 steel	18x36x18	Enhanced Heavy Steel	Filled Cracks	1140	8x8	1.6	Steel Cylinders
1-3/4 in	1-3/4 hw+1/8 steel+1/2 fc ply (4)	18x18x24	Steel Latch	Weathered	600	8x8	1.6	Fire Bricks
Orig IME#1	IME+1/4 ply	16x16x16 (7)	Heavy Steel	Good	100	N/A	Wood	N/A
Orig IME#2	Optional IME (5)	16x16x16 (7)	Heavy Steel	Good	100	N/A	Wood	N/A
Canada	CERL (6)	N/A	None-Lid Rested on Top	Good	300	N/A	Wood	N/A

(1)IME = 1/2 ply+1/2 gypsum board+1/8 steel
(2)fc = fiberglass coated
(3)ply = plywood
(4)hw = hardwood
(5)Optional IME = 1/4 ply+1 hardwood+1/2 ply+1/4 asbestos+22 gauge steel
(6)CERL = 1 cm ply+3 cm semi-rigid glass fiber+3 mm steel+?? ply
(7) = estimated
(8) = gallons of kerosene per minute except for wood

Figure 1. Significant Event Times

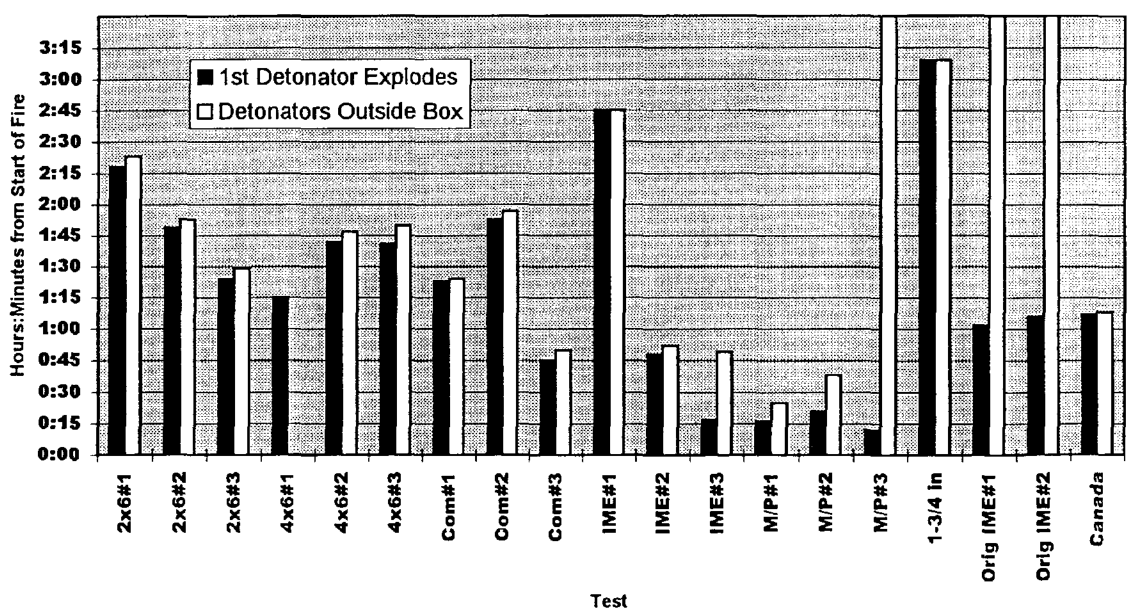


Figure 2. 2x6 RGO Air Temperatures

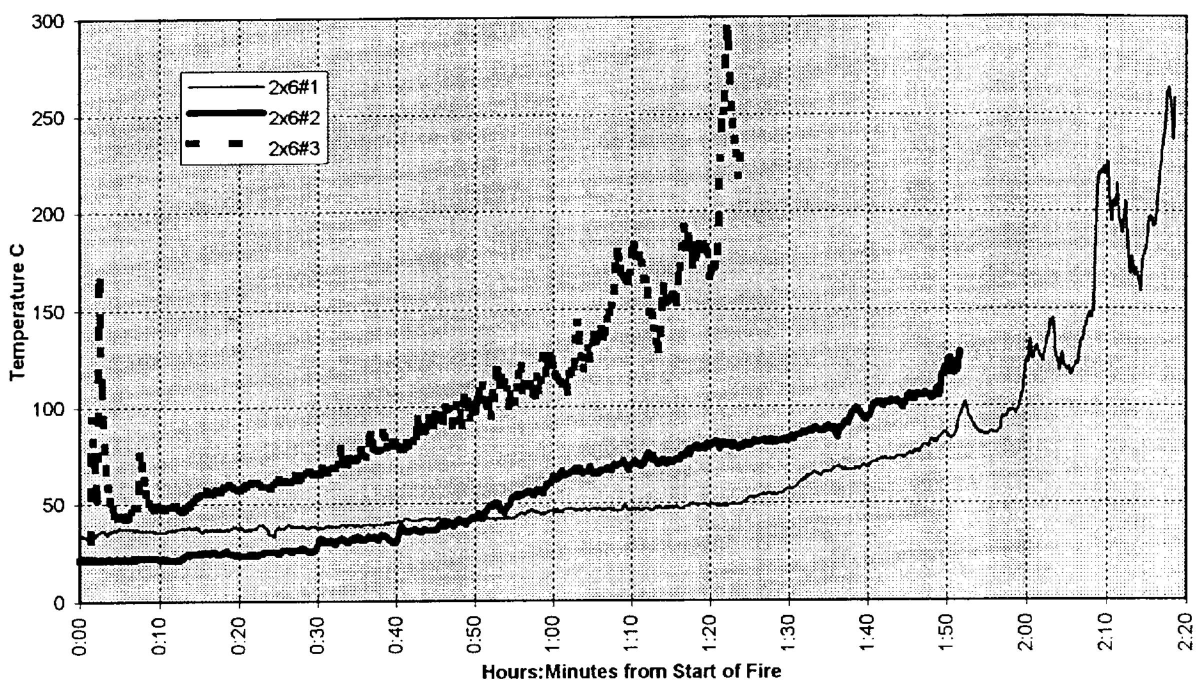
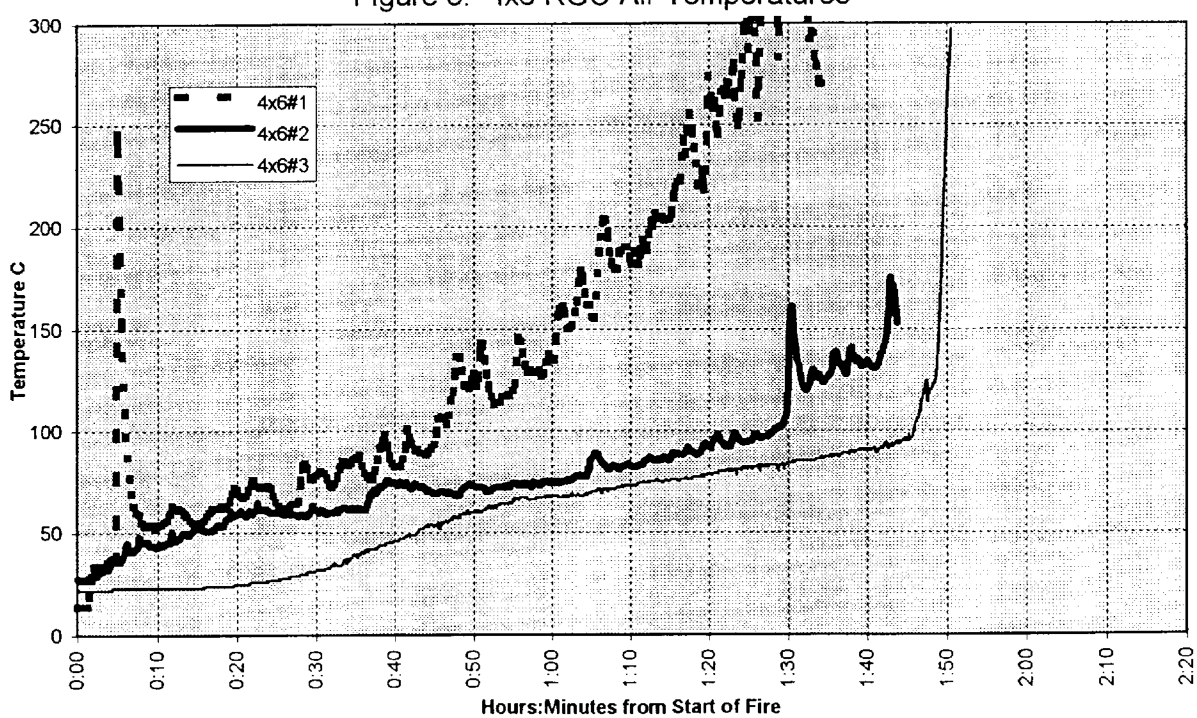


Figure 3. 4x6 RGO Air Temperatures



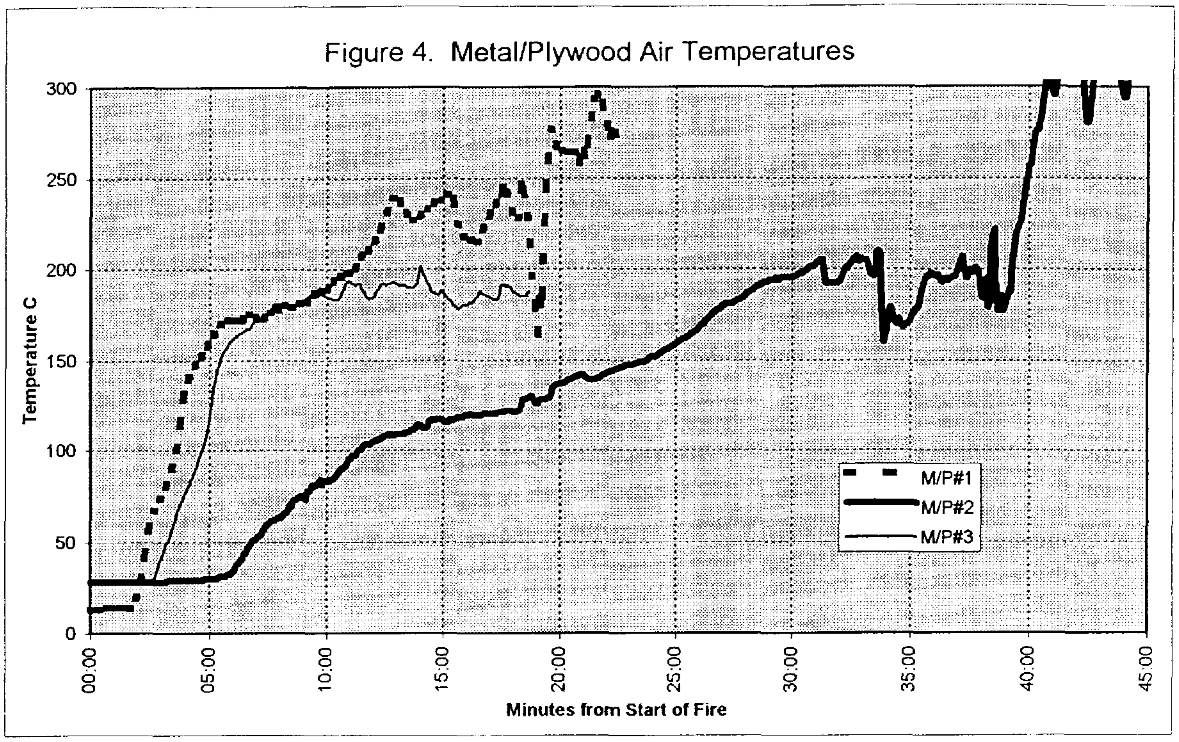


Figure 4. Metal/Plywood Air Temperatures
Temperature C
0
50
100
150
200
250
300
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
45:00
Minutes from Start of Fire
M/P#1
M/P#2
M/P#3

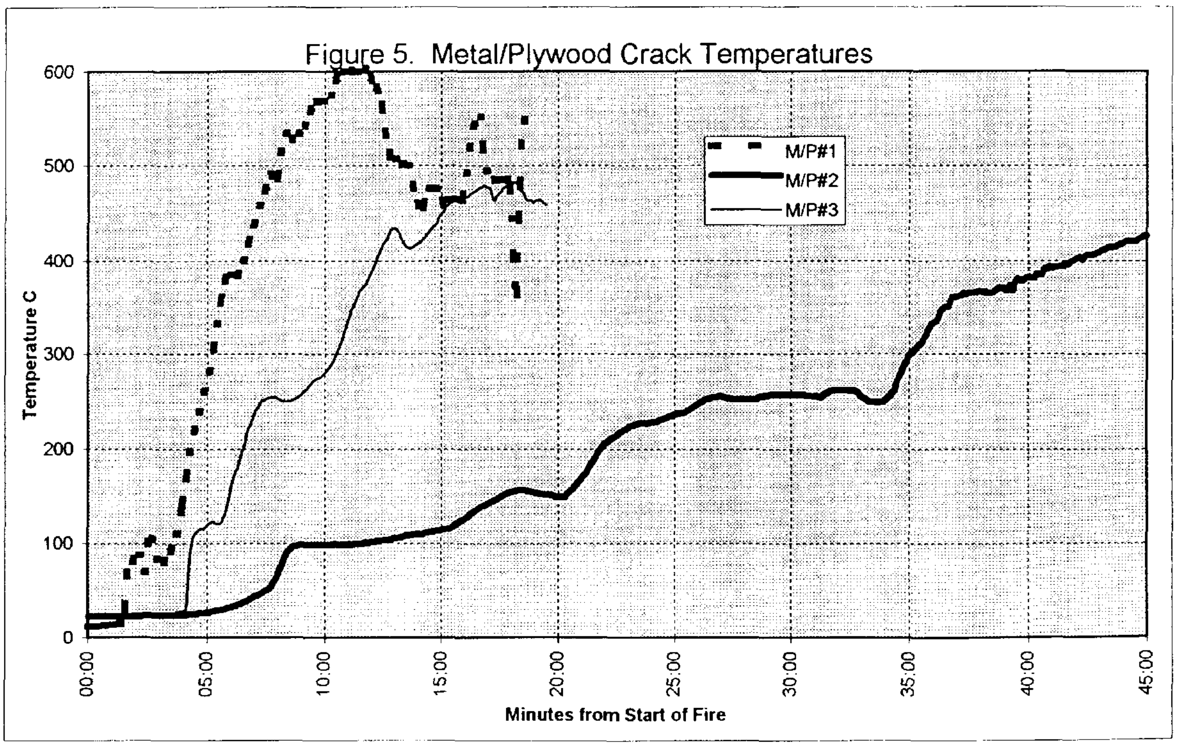


Figure 5. Metal/Plywood Crack Temperatures
Temperature C
0
100
200
300
400
500
600
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
45:00
Minutes from Start of Fire
M/P#1
M/P#2
M/P#3

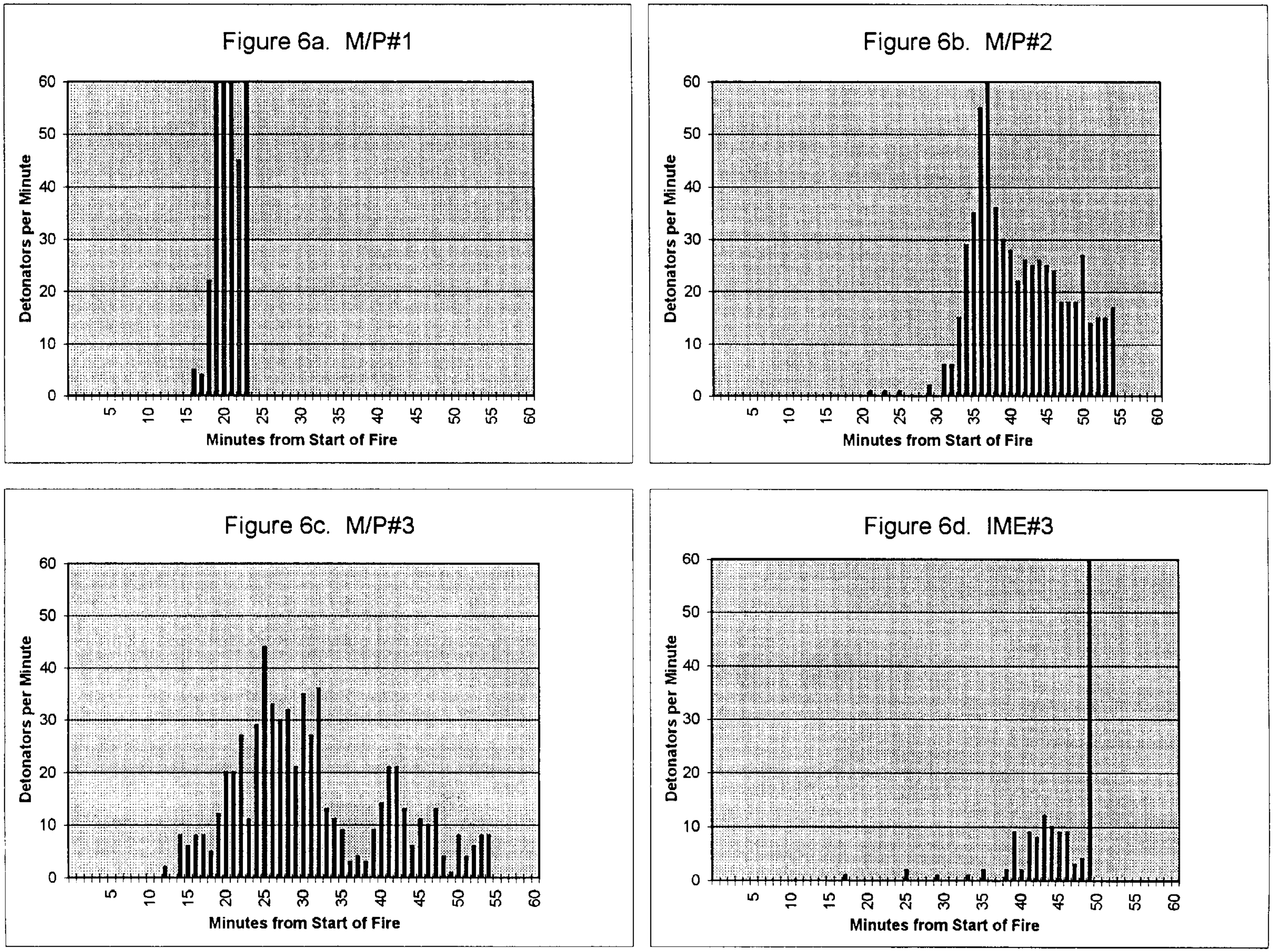


Figure 6. Detonator Function Times until Lid Opening

Figure 7. IME 22 Metal Shell Temperatures

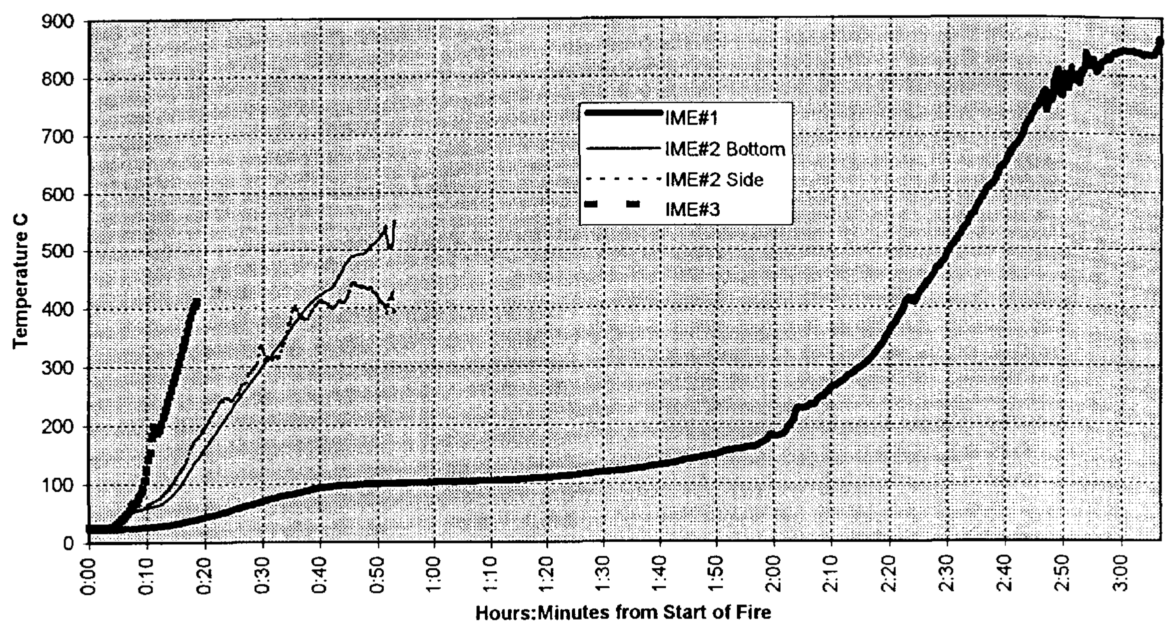


Figure 8. IME 22 Air Temperatures