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ABSTRACT

The Canadian Explosives Research Laboratory (CERL), is evaluating the status of the Schedule IV explosives container as it presently pertains to the industry. The Schedule IV container serves the same purpose in Canada as the IME 22 container does in the United States. That is, to transport detonators on the same vehicle which is carrying explosives.

In this paper, the results of preliminary burn trials on Schedule IV containers or their equivalent are reported. All tests were fully instrumented and video-taped. The study evaluates the effect of full and partially full containers, the packing density of detonators, and electric versus non-electric detonators. Some comparisons are also made between Schedule IV container and IME 22 container burn test data. In view of the results obtained from this study and the availability of new insulating materials, suggestions are made for improving this type of container.

INTRODUCTION

Trials on fire resistant containers were initiated as part of a general investigation designed to determine the precautions necessary to permit safe transport of detonators and explosives in the same vehicle. Traditionally, such transportation has been permitted in Canada, provided that "They are separated by a barrier 'equivalent' to 15 cm of wood." A regulation to this effect has existed in the Canada Explosives Act since 1946.

In the mid 1970's, CERL evaluated various combinations of materials to find a suitable replacement for the 15 cm wood partition used to separate detonators from high explosives in the cargo box of some type of explosives transport vehicles. A laminate barrier consisting of layers of steel, glass fibre insulation and plywood was found to prevent transmission of detonation from detonators to adjacent dynamite cartridges. This barrier laminate was subsequently incorporated into the Canada Explosives Act as Schedule IV.

Subsequent developments resulted in containers being fabricated from this laminate construction and subjected to fire tests. Times of one hour or more of protection were obtained for small containers before the first detonator(s) functioned. Containers using this construction, so-called Schedule IV containers, are used for simultaneously shipping, on the same vehicle, detonators of Class 6, Division 3, and explosives from other Classes. In the event of a fire, the container should prevent the detonators from initiating the explosive. Ideally, the container must protect the contents or its effects for the maximum time period required for the load of explosive to be consumed.

Observations made in the field indicate that after being in service for some time, it would be doubtful if some of these containers would survive a fire test. The transport process subjects these containers to formidable stresses and may cause misalignment of hinges and locks and result in gaps around the door. It has also been found that wood filler used within the container is often disturbed leaving the screws or bolts exposed, thereby providing highly thermal conductive paths. Concerns have also arisen regarding the conformity of the manufacturing process as it pertains to the published construction details.

Burning trials (1) and accident data have indicated that explosive loads of 10 tonnes are consumed within 30 minutes of ignition. If detonators can be prevented from functioning during this consumption, then their subsequent explosion will not assist in any crossover to detonation of the burning load.

BURN TRIALS

DESCRIPTION OF FIRE TESTS

The burning trials on the containers were performed in two available configurations. The first facility is shown in Fig 1. A steel tank 2 m in diameter, 2 m long and having a wall thickness of 2.5 cm is surrounded by 25 cm of reinforced concrete and is on its side in an earth mound. In the tank is a steel grating on which the sample container being tested is placed. Wood to fuel the fire is located underneath the grating and piled around the sample. Since the fire has to be maintained for at least one hour and since it cannot be approached to add more wood, an 8 mm copper tube is used to deliver diesel fuel to the fire. The fuel is pumped from the control building to a steel pan placed under the grating in the tank. Thus, whenever the fire temperature drops, fuel is pumped so as to re-establish the previous temperature.

An alternate set-up for performing burn trials at a remote field site is shown in Fig 2. A strong steel frame in the form of a bench was placed inside a steel pan. The frame top was reinforced with steel angles and heavy gauge expanded steel mesh. The sample container was placed on the stand and wood was placed in the pan and all around the container. As in the other set-up, an 8 mm tube was used to feed fuel oil into the pan to maintain the required fire temperature.

In both set-ups, thermocouples were used to monitor the fire temperature at the grating just below the sample and to monitor the temperature at any other point in the sample. The thermocouple outputs were fed to a multichannel recorder from which were obtained hard copy records of the temperature histories. All the trials were also videotaped.

Some of the early work presented in this report was performed sometime between 1976 and 1981 and is reported in reference (2).

TEST 1 - INITIAL TESTS

As indicated in reference (2), containers were constructed in the form of chests by laminating, from the outside to the inside, the following thicknesses of materials: 12 mm plywood, 3 mm steel plate, 25 mm rigid glass fibre insulation, and 10 mm plywood. The burn trial reported was on a container with dimensions of 41 cm high by 41 cm deep by 61 cm long. Inside this container was placed a fiberboard carton containing 300, 2 m safety fuse assemblies in four separate paperboard cartons as prepared for normal shipment. The tight-fitting, laminated lid was then simply placed on the container which was thus considered to be air-tight.

Figure 3 shows the temperature profiles at different locations of the container. At a time of about 00:30:00 the outside wood layer had burned away exposing the steel surface. The thermocouple at the steel surface indicated a temperature of 700°C while those within the container did not indicate any increase in temperature. At this time the heat caused the lid to warp and lift at one corner. The lid remained open until a time of 00:54:00. At 01:07:00, when the maximum temperature detected within the container was 350°C, the detonators began to function. A large explosion, apparently of one third of the detonators was followed by 10 or 15 smaller ones. The explosion caused the projection of the lid and the container to bulge.

TEST 2 - SCHEDULE IV CONTAINER

The Schedule IV container tested had previously been in use for two years. It was cubical in shape, having 120 cm long sides and was constructed along the guidelines given in the Explosives Act (1986). This container is shown in Fig 4. Information from the manufacturer indicated that the laminated construction, from the outside to the inside, consisted of 12.5 mm fir plywood, 3 mm (11 gauge) mild steel, 25.4 mm rigid glass fibre insulation (Fiberglass AF-545, RSI = 0.72), and 12.5 mm fir plywood. The door was of the same construction, with the steel laminate overlapping the container opening by 2.5 cm. Three welded hinges secured the door on the right, and a metal clasp on the left provided for a padlock closure.

The container was loaded with five cases of approximately 1200 electric detonators. The results from this burn trial are reported in detail in reference (3). The detonators began to function at 00:25:30 when the maximum inside temperature was 330°C and continued to a time of 00:39:57. Figure 5 shows some of the temperature profiles associated with this test. Observations after the burn indicated that the metal container had maintained its integrity. The door had warped on the clasp side but otherwise held. Close inspection revealed a 3 cm tear on the bottom, left hand corner. The bottom panel had many bulges and several perforations. It was evident from this test that the closure (door and lock mechanism) could be improved. Some of these observations can be seen in Fig 6.

TEST 3 - SCHEDULE IV-TYPE CONTAINERS

This series of tests is based on a container that could be tightly sealed and constructed along the guidelines given in the Explosives Act (1986). The tests were designed to evaluate several factors such as the effect on the container of electric versus non-electric detonators, full containers versus partially filled containers and high density packaged detonators versus low density packaged detonators. The series of burn trials performed were as follows:

Trial 1 - Container filled with electric detonators packaged 500/case.
Trial 2 - Container partially filled with electric detonators packaged 500/case.

Trial 3 - Container filled with electric detonators packaged 80/case.
Trial 4 - Container partially filled with electric detonators packaged 80/case.

Trial 5 - Container filled with non-electric detonators packaged 250/case.
Trial 6 - Container partially filled with non-electric detonators packaged 250/case.

Trial 7 - Container filled with non-electric detonators packaged 25/case.
Trial 8 - Container partially filled with non-electric detonators packaged 25/case.

For the purpose of this series of tests it was decided to manufacture, as economically as possible, eight identical containers. The most readily available basic structures were 200 litre steel drums 82 cm high and having an inner diameter of 57 cm. The removable lids had a foam seal and were secured to the drum via a steel band that was tightened with a nut and bolt arrangement. The drums were manufactured from 1.6 mm thick steel. Since the requirement for a Schedule IV container is for a 3.2 mm steel wall thickness, two discs, one for the bottom and the other for the top, and one cylinder were manufactured from 1.6 mm thick steel plate to fit snuggly inside the drum.

Rigid, 2.5 cm thick, glass fibre board insulation was used to line the inside of the container. However, due to the cylindrical shape that it had to conform to, slits were cut longitudinally to a depth of 2 cm and 5 cm apart. This allowed easy rolling of the insulation to an outside diameter equal to that of the inside of the drum. In the rolling process the slotted area would close and a continuous insulating barrier would result.

The construction of a Schedule IV container requires that the innermost layer be 12.7 mm thick plywood. Discs of such a material were cut for the top and bottom of the drum. Unfortunately, it was very difficult to roll this thickness of plywood to conform to the inner diameter of the insulation layer. As an alternative, the required thickness of wood was achieved using layers of 3.2 mm thick masonite.

It must be emphasized that great care was taken in ensuring that all the individual materials formed a continuous layer within the container.

It was also decided not to attempt wrapping the drum with the 1.27 cm of plywood as required. Initially, this layer would provide some thermal insulation, but as the burn test proceeded, the wood would ignite and contribute as a heat source. It was felt that these two effects would negate each other and in view of the hot fires that were obtained, little, if any effect on the time to the first detonator functioning would be discernible.

Five thermocouples were used to monitor the temperatures in these burn trials. Three thermocouple fittings were installed on the side of each drum. Once through the fittings, the stainless steel-sheathed thermocouples (exposed junction) were placed on the axis of symmetry of the drum; the first on the bottom, the second on top of the first case of detonators and the third just below the lid. The fourth thermocouple used to monitor the fire temperature was placed just below the centre of the drum. The fifth thermocouple was placed away from the fire to register the ambient temperature.

What follows is a description of each trial and the corresponding observations. Each pair of trials was performed on the same day, with the eight trials completed in four consecutive days. The ambient conditions during this period were all very similar.

Trial 1 - The number 4 delay electric detonators used in this test had 2 m long leg wires and were packaged 50/box (500/case). The case was modified to hold 8 boxes (400 detonators) so as to fit in the container. Three modified cases were loaded in the test container for a total of 1200 detonators.

The temperature profiles for this test are shown in Fig 7. At a time of 00:30:00 small flames could be seen at the top of the drum at the clamp closure. The first explosion occurred at a time of 00:51:00 when the maximum inside temperature was also at 300°C this simply caused the drum to tip on its side on the grating. The next explosion 3 s later caused the drum to fall onto the ground. Three other major explosions occurred 9 s, 15 s, and 46 s after the original. Inspection of the container revealed that both the bottom and lid were missing. Figure 8 shows some of this damage.

Trial 2 - The number 2 delay electric detonators used in this test had 2 m long leg wires and were packaged 50/box (500/case). The case was modified to hold 8 boxes (400 detonators) so as to fit in the container. One such case was placed on the bottom of the test container for a total load of 400 detonators.

The temperature profiles for this test are shown in Fig 9. At a time of 00:30:00, as in the above test, small flames could be seen at the top of the drum at the clamp closure. The first explosion occurred when the maximum inside temperature was 300°C at a time of 00:50:00. The remaining detonators functioned during the next two minutes. The lid was blown off the drum and the bottom was driven into the burn stand. The drum remained in an upright position. Figure 10 shows some of this damage.

Trial 3 - The number 4 delay electric detonators used in this test had 25 m long leg wires and were packaged 8/box (80/case). The case was modified to hold 6 boxes (48 detonators) so as to fit in the container. Three modified cases were loaded in the test container for a total of 144 detonators.

The temperature profiles for this test are shown in Fig 11. Small flames could be seen burning at the top of the drum at the clamp closure from a time of 00:38:00 to well over two hours. At a time of 00:43:00, these flames became torch-like and remained so for about 30 min. The first detonator functioned at a time of 00:47:00 when the maximum inside temperature was 350°C. The remainder of the detonators functioned in a pop-corn fashion for the next hour. The bottom and top of the container were slightly bulged but otherwise no other damage was noticeable. Inspection of the interior revealed that the wood and insulation binder had been consumed and that the glass wool had melted.

Trial 4 - The number 4 delay electric detonators used in this test had 25 m long leg wires and were packaged 8/box (80/case). The case was modified to hold 6 boxes (48 detonators) so as to fit in the container. One case was loaded in the test container for a total of 48 detonators.

The temperature profiles for this test are shown in Fig 12. At a time of about 30 min. small flames could be seen at the top of the drum at the clamp closure. When the maximum inside temperature was 300°C at a time of 00:34:53 several detonators functioned and were followed by an explosion 10 seconds later that caused half the lid to pop open. Shortly after, the inside of the container ignited and burned until the test was deemed completed one hour later. Individual detonators functioned thereafter with the bulk of them exploding between times of 00:50:00 and 01:20:00. The last of the detonators functioned at a time of 01:36:00. Inspection of the container revealed that the bottom had bulged and the lid was partly opened. Figure 13 shows some of this damage.

Trial 5 - The selection of number 1,2 and 3 delay non-electric detonators used in this test had 2 m long tubing and were packaged 25/box (250/case). The case was modified to hold 6 boxes (150 detonators) so as to fit in the container. Three modified cases were loaded in the test container for a total of 450 detonators.

The temperature profiles for this test are shown in Fig 14. At a time of 00:35:00 small flames could be seen at the top of the drum at the clamp closure. At a time of 00:43:00 the lid of the container began to bulge and the flames began jetting. The jetting continued to the end of the test with it becoming very violent at times. An explosion occurred at a time of 01:02:00 causing the container to fall from the burn stand. The maximum inside temperature at this time was 400°C. Detonators were dispersed with some functioning during the next two minutes. Inspection of the container revealed that the lid had been blown off and the bottom had been driven onto the burn stand. Figure 15 shows some of this damage. A search of the area revealed that about 20% of the detonators survived the explosion. It is interesting to note that the tubing of many of these detonators was either charred, completely deteriorated, or missing and yet the detonators had not functioned. Some of these detonators are shown in Fig 16.

Trial 6 - The number 0 delay, non-electric detonators used in this test had 2 m long tubing and were packaged 25/box (250/case). The case was modified to hold 6 boxes (150 detonators) so as to fit in the container. One modified case was loaded in the test container for a total of 150 detonators.

The temperature profiles for this test are shown in Fig 17. At a time of 00:43:00 small flames could be seen at the top of the drum at the clamp closure. Three minutes later the flame began jetting vigorously. The jetting continued to the end of the test with it becoming very violent at times. An explosion occurred at a time of 01:05:00 causing the container to fall from the burn stand. The maximum inside temperature at this time was 280°C. Some detonators were dispersed with two functioning during the next minute. Inspection of the container revealed that, as in the previous test, the lid had been blown off and the bottom had been driven onto the burn stand. Figure 18 shows some of this damage. When the area was searched, a few detonators were found to have survived the explosion.

Trial 7 - The number 3 delay, non-electric detonators used in this test had 25 m long tubing and were packaged 25/case. There were no inner boxes. The case was modified to hold 15 detonators. Three modified cases were loaded in the test container for a total of 45 detonators.

The temperature profiles for this test are shown in Fig 19. At a time of 00:25:00 small flames could be seen at the top of the drum at the clamp closure. A jet of gases released from this area at a time of 00.37:00. Continuous jetting began at 00:52:00 and continued to the end of the test. Several detonators functioned at about 00:59:00 when the maximum inside temperature was 280°C and again at 01:03:00. Individual detonators functioned between this time and 01:36:00. Inspection of the container revealed that it was intact except that the bottom had bulged and part of it had detached at the seam over a distance of about 20 cm. Figure 20 shows some of this damage. All the detonators had functioned.

Trial 8 - The number 3 delay, non-electric detonators used in this test had 25 m long tubing and were packaged 25/case. There were no inner boxes. The case was modified to hold 15 detonators. One such case was loaded in the test container for a total of 15 detonators.

The temperature profiles for this test are shown in Fig 21. Due to the fire engulfing the container it was difficult to determine when flames appeared at the top of the drum at the clamp closure. A jet, although not fully visible, could be heard at a time of about 00:35:00. At 00:43:00, when the maximum inside temperature was 210°C, the first detonator functioned. The jetting became quite vigorous at 00:45:00 and remained so for the next 25 minutes. After this time, only a small flame remained in this area. The detonators all functioned individually until a time of about 01:40:00. Inspection of the container revealed that it was intact except that the bottom had bulged. All the detonators had functioned.

TEST 4 - COMMERCIAL VAULTS

The following two tests made use of commercially-available fire resistant vaults. In the first trial the container was loaded with delay number 4 electric detonators packaged 500/case (2 m wire length). Three boxes of detonators were used for a total load of 150 detonators. The three boxes were encased in cardboard to simulate the standard packaging, and then placed in the container. A thermocouple was inserted in the centre of the bottom of the container to monitor the inside temperature. The vault was then locked and strapped using two 10 mm wide steel bands. The vault was then subjected to a fire having the temperature profile shown in Fig 22.

The temperature within the vault rose slowly to about 100°C. It remained at this level for about 50 minutes until the water bound to the insulating material evaporated. The temperature then rose to 295°C at a time of 01:34:00 when the detonators functioned en masse. A few detonators that survived the initial blast functioned within the next minute and the test was deemed to be completed at a time of 01:35:00. The container was completely destroyed as seen from Fig 23.

The setup for the second test was identical to that described above except that non-electric detonators packaged 250/case (2 m tube length) were used. Two boxes of delay number 0 for a total of 50 detonators were loaded into the vault. The container was subjected to a fire having the temperature profile shown in Fig 24. From this figure, it can be seen that the temperature within the container followed the same trend as in the previous test. The detonators again functioned en mass at a time of 01:04:00 and at a temperature of 240°C. The result of the explosion on this container is shown in Fig 25. There was slightly less damage to the container but then fewer detonators were involved.

A third burn trial was performed with non-electric detonators. They were tested in a vault, similar to the above but that had previously undergone two burn trials and survived. This test would indicate the effect that the water deficient insulation of this vault would have on the results. The vault was loaded with 0-delay detonators that were packaged 150/case (4 m tube length). Two boxes were placed in the vault for a total of 30 detonators. Since the lock had been damaged in the previous burns, the lid was closed and the vault was strapped as in previous tests.

The vault and contents were subjected to a fire having the temperature profile shown in Fig 26. Also shown in this figure is the temperature measured within the vault. The first detonators functioned at a time of 00:57:29 when the maximum inside temperature was 300°C. The remaining detonators functioned within the next 53 seconds to a time of 00:58:22.

The explosions caused the steel straps to break, the vault sides to bulge and the bottom to burst open. The insulation from the bottom of the vault was very dry and crumbled easily. Figure 27 shows the condition of the vault after the burn.

TEST 5 - IME 22 CONTAINERS

Two burn trials were performed on the American equivalent of Schedule IV containers, the IME - 22 container.

The first of these trials involved a container which had external dimensions of 61 cm (24 in) in length, 43 cm (17 in) in width and 46 cm (18 in) in height. It was manufactured according to the IME Safety Library Publication No. 22, Part J and Appendix D. The laminate construction from inside to outside consisted of 6.4 mm (0.25 in) plywood, 25.4 mm (1 in) hardwood, 12.7 mm (0.5 in) plywood, 12.7 mm (0.50 in) sheetrock, and 22 gauge sheet metal. The container is shown in Fig 28.

This container was loaded with delay number 4 electric detonators packaged 500/case (2 m wire length). Nine boxes of detonators were used for a total load of 450 detonators. The nine boxes were encased in cardboard to simulate the standard packaging, and then placed in the container. Thermocouples were located in the centre of the bottom and at the top of the container to monitor the inside temperatures. The vault was then padlocked and subjected to a fire having the temperature profile shown in Fig 29.

With the firewood packed so tightly underneath the container, it took some time for the fire temperature (underneath the container) to attain the level of that in previous tests. As a result, although the fire was well established on the surface of the wood pile and on top of the container, the thermocouple did not indicate so immediately. This, and the fact that the bottom thermocouple was underneath the case of detonators while the top thermocouple was in open space, resulted in a temperature gradient within the container as is evident from the temperature profiles. An en masse detonation occurred at 01:38:00 when the top thermocouple read 210°C and the bottom registered 108°C. The explosion caused some detonators to be scattered with some functioning to a time of 01:44:00. The container was damaged to the extent indicated in Fig 30. After the trial, 18 detonators that had not functioned were recovered.

The second container tested was, as measured externally, 92.7 cm (36.5 in) long, 41.9 cm (16.5 in) wide, and 62.2 cm (24.5 in) high. It was manufactured according to the IME Safety Library Publication No. 22, Part B and Appendix C. The laminate construction from inside to outside consisted of 12.7 mm (0.5 in) plywood, 12.7 mm (0.5 in) sheetrock, 3.2 mm (0.125 in) low-carbon steel, and 6.4 mm (0.25 in) plywood. This container is shown in Fig 31.

The container was first loaded with 10 boxes of non-electric detonators (2 boxes delay no. 0, 4 boxes delay no. 1, and 4 boxes delay no. 2) having 2 m long tubes and packaged 25/box and 250/case. On top of these boxes were placed 40, delay no.3, non-electric detonators having 25 m long tubes. The container was thus loaded with 290 detonators.

Due to its length, this container was set longitudinally in the burning tank and completely covered with wood except for the end at the tank opening which was left partly exposed. Since the fire was initiated on the surface of the pile, the thermocouple detecting the fire temperature was 'thermally' isolated. This is reflected in the fire temperature profile shown in Fig 32.

By a time of 00:25:00 the outside layer of plywood that had been visible was completely consumed and the flames became well established in the back of the container by 00:45:00 and completely engulfed it by 00:55:00. The first explosion occurred at 01:05:00 when the maximum inside temperature detected was 90°C. This was followed by individual functioning of approximately 60 detonators to a time of 01:08:00 when a second lesser explosion occurred. The functioning of approximately 30 additional detonators followed to 01:10:00 with a few more exploding after this time.

The first explosion caused the visible end of the container and the lid to be blown off. The lid was flung approximately 30 m and on its way struck the camera tripod. The slightly bulged remnant of the container remained on the grating in the fire. Some of the aluminum components used in the construction were almost completely melted. The container was slightly bulged and completely void of its inner liners of plywood and sheetrock. Figure 33 shows some of this damage.

TEST 6 - PROTOTYPE CONTAINERS

The following two tests were performed to evaluate an insulating material that would not collapse as glass fiber insulation does when heated. The characteristics of this substitute insulation and other similar materials have been transcribed from reference (4) and are listed in Table 1. The construction of these units was the same as that required for a Schedule IV container except that the 2.5 cm thick rigid glass fiber insulation was replaced with an equivalent layer of the ceramic fiber insulation. The containers measured 61 cm (24 in) long, 46 cm (18 in) wide and 46 cm (18 in) high. The laminated lid was not hinged but was simply placed on the container and strapped with four, 1 cm wide steel bands. This configuration provided an 'air-tight' container.

In the first test, the container was loaded with a case of non-electric detonators. The case contained 8 boxes of number 0 period delay with 4 m tube lengths and packaged 15/box for a total of 120 detonators plus 4 boxes of number 3 period delay detonators with 2 m tube lengths and packaged 25/box for a total of 100 detonators, and a combined total load of 220 detonators.

The temperature profiles for this test are shown in Fig 34. At the start of the burn, the front and top of the container were slightly exposed, however, they were engulfed by flame. The outside plywood layer burned within the first 30 minutes. At this time, the metal lid was seen lifting on the left side and remained opened with a 3 cm gap for the remainder of the test. Flames could be seen around the lid opening and by 00:36:00 minutes the flames were burning all around the lid. At a time of 01:15:00 the flames became more vigorous and one minute later it began to jet. The first detonator functioned at 01:18:00 when the maximum inside temperature was 170°C. A few seconds later multiple detonators functioned causing the steel bands to break and the steel lid to be projected. The explosions that followed during the next few minutes caused the lid material to be ejected along with detonator components. At 01:21:00 the detonators were functioning at a rate of 2/s, while at 01:22:00 at 1/s, with the last functioning at 01:24:00.

Inspection of the container revealed that the sides and bottom were slightly bulged and although there were 'lumps' from detonators exploding close to the steel, there were no through holes. The insulation that was not damaged from the explosions, remained intact with no signs of melting or decomposition. Fig 35 shows these results. A few detonators survived this test.

In the second test, the container was loaded with a case of electric detonators. Six boxes of number 4 period delay detonators with 2 m long leg wires and packaged 50/box were placed in the bottom of the case. The remainder of the case was filled with seven boxes of number 1 period delay with 25 m long leg wires and packaged 8/box. The total load was 356 detonators.

The temperature profiles for this burn are shown in Fig 36. The fire did not develop as well in the early stages of this test as in the previous test. The outside layer of plywood was burned within the first 35 minutes. At 00:36:00 flames appeared at the left side of the lid and spread to the other side by 00:45:00 at which time the lid lifted at the right side, front corner. The lid remained in this position until the end of the burn. At 01:00:00 the flames were burning all around the lid. Although it was a little difficult to discern, it is believed that the first detonator functioned at 01:34:00 when the maximum inside temperature detected was 230°C. Six more functioned within the next two minutes. At 01:36:00 an explosion caused the container to rip open and to be flung 10 m from the burn site. About thirty more detonators functioned after this explosion with the last one occurring at 01:40:00.

As shown in Fig 37, the two welded sides were blown off and the remainder of the container flattened. The inner insulation and plywood were completely destroyed. A few detonators survived the event.

TEST 7 - COMMUNICATION TESTS

Several tests were performed to evaluate the behaviour of a case of detonators when one of them was functioned.

The first of these tests concerned a case of delay no. 3, non-electric detonators having 25 m tube length and packaged 25/case (no interior boxes). One high strength electric detonator was placed in the centre of the case and the case was re-sealed with glass fiber reinforced adhesive tape. On functioning the electric detonator, a series of other detonators exploded. The case ripped open and complete bundles, including detonator, and pieces of tubing were strewn over an area having a diameter of about 4 m. These results can be seen in Fig 38. Fifteen of the 25 detonators (60%) functioned. Of those remaining intact, it was noticed that some of the tubes did sustain damage although the detonator had not functioned.

The second test was performed on a case of non-electric detonators having 2 m tube length and packaged 25/box and 250/case. One, high strength electric detonator was placed in the bottom of the top, center box. The case was re-sealed with glass fiber reinforced adhesive tape. On initiating the electric detonator, a series of other detonators exploded. The case shredded into small pieces but the bottom was virtually left intact at the original position. Short pieces of tubing and parts of detonators were found as far as 40 m from the source. Very few long pieces of tubing remained. A few intact units were found in the direction of one end of the case. The result of this test can be seen in Fig 39. Of the 250 detonators, 213 functioned (85%).

DISCUSSION OF RESULTS

The two communication tests performed with non-electric detonators indicate that a higher percentage of detonators can be expected to function sympathetically in higher density packaging. This is probably due to more individual detonators/tubing being close to the initiator. With a packing density of 25 detonators/case, 60% functioned sympathetically, whereas, with a packing density 10 times higher, that is 250 detonators/case, 85% functioned sympathetically.

The results of all the burn tests to date are listed in Table 2. What does not appear on this table is the extent of damage suffered by the containers in the tests. Although this is not a measurable parameter, it should be considered in the overall assessment of the containers. Note that the 'Mass of Load' does not mean the amount of explosive but simply the 'gross weight'. The column having the heading 'Total Load' indicates the number of detonators loaded and tested in the container. The figures in this column can be used as a guide for the mass of explosive loaded. The last column lists the thermocouple code and the temperature detected when the first detonator(s) functioned. This is not necessarily the temperature at the location where the first explosion occurred.

A difficulty arises when comparing the method in which the detonators functioned, whether 'en masse' or in a 'pop-corn' fashion. In general, what does detonators functioning 'en masse' mean? As far as the human ear can discern, simultaneity of the event (functioning of detonators) can arise either when the critical temperature is achieved throughout the load at the same time or when the detonators are so located that when one functions it effects immediately cascades to the surrounding detonators. Therefore, when in a burn test, instantaneous detonators function in a pop-corn fashion, the detonators are probably subjected to different temperatures due to temperature gradients within the container and they are in a configuration that does not allow easy communication of the blast stimulus.

The initial work that started in the mid 70's led to the development of a Sched-IV container in Canada. At the time, Canada chose to use glass fibre insulation instead of sheetrock or asbestos as used in the IME-22 container used in the United States. This decision was based on CERL's unpublished work on laminated wall sections which indicated that glass fibre insulation was the better shock wave energy attenuator. The early containers manufactured at CERL withstood fire temperatures for about one hour before the detonators began to function.

The time to first explosion of the 120 cm cubical Schedule-IV container is rather short but considering the severity of the fire and the poor door arrangement this is understandable. This was also the only container tested that had a door on the side (3). Subjected to a normal fire, and with slight improvements to the door, the time to first explosion could certainly be extended by ten to fifteen minutes.

The eight trials performed on the Schedule IV-Type containers can be used to determine the effects from different types of detonators, packing densities and loads. The following conclusions can be drawn from these trials.

a. Times to first explosion for both volume ratios are approximately the same for both types of detonators having low packing densities. (Compare 3.3 and 3.4 to 3.7 and 3.8)

b. Except for the low packing density electric detonators, there seems to be very little difference in the times to first explosion between the different mass loads. (Compare 3.1 to 3.2) Obviously, there is a vast difference in the damage sustained by the containers arising from different mass loads.

c. Each pair of tests for the same packing density (Dets/case), resulted in very similar times to first explosion with higher packing density pairs having longer times to first explosion.

Comparison of the first two trials on commercial vaults, filled approximately to the same volume ratio, indicate that the load of electric detonators takes longer to explode. The fire temperature profiles for both burns are very similar so that the only possible explanation for these differences is the higher thermal mass of the electric detonator assemblies, although one would expect their higher thermal conductivity to also have an effect.

The increase on the time to first explosion due to the water in the insulation of these vaults would be expected to range from about six to twelveminutes as seen from Figures 22 and 24. Although there is a slight difference in the loads of the last two trials, the time to first explosion for the used vault is approximately seven minutes.

As already explained, the location of the thermocouple in both IME-22 container burn trials, caused the recording of the fire temperature profile to be somewhat distorted. Both records suffered from the thermocouples being thermally isolated. However, proof that sufficient heat was being generated by the fire is reflected in the temperature profiles recorded within the vault. They are very similar to other tests.

An indication that the temperature achieved in the fire was at least 850°C, was witnessed by the aluminum rivets and lock fixtures that were almost completely melted. In actual fact, the temperature profile experienced by the container was very similar to that of the first trial. Both containers performed well, with the first detonator functioning in the one-hour-plus range. Slightly more damage was caused by the electric detonators as in the commercial vault trials. Although, the detonator load was lower with the non-electrics, the reduced damage could also be due to the tubing of the non-electric detonators which may be absorbing some of the blast energy.

The results obtained on the prototype containers were quite satisfactory. The insulation has a very high melting point and thus retains its structure during a fire. again, the time to first explosion was longest for the electric detonators which were also the most destructive as they functioned 'en masse'.

It is interesting to note that the results for electric versus non-electric detonators from tests 4, 5 and 6 are better defined than those from tests 1, 2 and 3. The difference between these two test groups is that the former consists of containers manufactured with 'solid' types of insulating materials whereas, the latter were manufactured with rigid, glass fibre insulation. Tests with containers constructed with glass fibre insulation has shown that when the binder melts, the insulation collapses slightly and causes a reduction in the insulating value. Laboratory tests have indicated that the glass fibre insulation melts between 650°C and 700°C. As indicated by the results from both groups of data for the electric and non-electric detonators, this naturally leads to shorter times to first explosion.

The results from these series of tests do not dictate an obvious type of construction. In the discussion that follows, it must always be kept in mind that the detonator load to container volume determines the extent of damage. Two extreme construction philosophies are described below.

A container can be manufactured from purely insulating materials which would provide very long times to first explosion and possibly no explosions at all. Such a well insulated container would allow the inside temperature to rise slowly and thus keep any temperature gradients very small. Then, if a critical temperature is reached, all the detonators would function. Were such a container in a fire with explosive that had not yet been consumed, the results could be catastrophic. Thus, although, insulating material is crucial to the construction of such containers, too much of it could be detrimental.

Another scenario that could arise in a fire situation with the above container, occurs when the load of explosives has been consumed, the fire has extinguished but the detonators have not yet functioned. When can one safely approach the site? It is possible that heat is still being generated and transferred to the detonator container. This situation may give a false sense of security that could lead to complications. A judgement must eventually be made as to when to approach and open and/or destroy the container and contents.

A container could also be constructed with little or no insulation but would be manufactured with sufficient strength to contain the effects from the simultaneous functioning of all the detonators. Such a container would naturally be quite heavy and the inside would experience varying thermal gradients that could cause the detonators to function in a 'pop-corn' fashion. Again, if the packing density is high, the result could be an en masse detonation.

Having thus established two extreme construction types, a compromise must be reached where the detonators will survive a fire for a reasonable length of time and when the detonators do begin to function, their effect should be contained so as not to initiate an adjacent explosives load.

From the point of view of the extent of damage sustained by the containers, it is advisable not to have a container that can legally be completely filled with high density packed detonators. This would be the worst possible situation. It is best to have excess volume when detonators are to be shipped.

It would be ideal to be able to define a detonator load (taking into account delay and leg wire or tube length) per volume of container, however, this is not feasible at this time.

With regard to commercial vaults, their advantage lies in the consistency of construction. However, larger units must be tested to determine if they survive detonators functioning in a pop-corn fashion. They may require steel re-enforcing of the inner layer.

Future work in this area will include more communication tests, a series of burn trials on small Schedule IV containers, a burn trial on a large commercial vault and on other prototype containers. Non-electric detonator tubing will also be assessed to determine its role in a fire situation.

ACKNOWLEDGEMENTS

The authors wish to thank members of the Technical Services Division of CANMET for the timely supply of the burn stands and related equipment, and M. Hamel and W. Quigley from the Mining Research Laboraories for the editing and processing of this report.

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3. Contestabile, E. et al., Burning trial on schedule IV container, Canadian Explosives Research Laboratory, MRL 87-72, 1987.

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Table 1 Characteristics of ceramic insulation

Physical Properties and Chemical Analysis

Physical Properties	**M**	**S**	**Block**	**HS**	**MB-823**	**MB-830**	**12C**	**14C**	**2600**	**15C**	**3000**	**17C**
Thickness, inches (mm)	¼-3" (6.35-76.2)	½-3" (12.7-76.2)	½-3" (12.7-76.2)	½-3" (12.7-76.2)	.125" (3.18)	.15" (3.81)	¼-3" (6.35-76.2)	¼-3" (6.35-76.2)	¼-3" (6.35-76.2)	¼-3" (6.35-76.2)	¼-3" (6.35-76.2)	¼-3" (6.35-76.2)
Color	beige	lt. brown	white	beige	white	tan	yellow	green	blue	lavender	pink	orange
Density, lb./cu. ft. (Kg/m^3)	14-16 (224-256)	18-22 (288-352)	18-20 (288-320)	26-30 (416-480)	45 (720)	35-37 (560-592)	14-16 (224-256)	14-16 (224-256)	12-14 (192-224)	11-13 (176-208)	11-13 (176-208)	13-15 (208-240)
Modulus of Rupture $lbf/in.^2$ (N/m^2)	90-110 ($6.2x10^5$-$7.6x10^5$)	200-230 ($13.8x10^5$-$15.8x10^5$)	220-250 ($15.2x10^5$-$17.3x10^5$)	250-290 ($17.3x10^5$-$19.9x10^5$)	440 ($30.3x10^5$)	—	120-160 ($8.3x10^5$-$11x10^5$)	90-110 ($6.2x10^5$-$7.6x10^5$)	80-100 ($5.5x10^5$-$6.9x10^5$)	70-90 ($4.9x10^5$-$6.2x10^5$)	60-80 ($4.1x10^5$-$5.5x10^5$)	120-160 ($8.3x10^5$-$11x10^5$)
Use Limit, °F (°C)	2300 (1260)	2300 (1260)	2300 (1260)	2300 (1260)	2300 (1260)	2300 (1260)	2200 (1204)	2300 (1260)	2500 (1371)	2700 (1482)	2800 (1538)	3000 (1649)
Chemical Anaylsis %												
Alumina (Al_2O_3)	41.0	48.4	30.6	19.1	30.0	30.0	38.4	46.5	56.0	65.0	75.0	82.5
Silica (SiO_2)	51.2	48.9	69.4	79.7	61.0	55.0	52.5	44.0	38.0	35.0	19.0	17.4
Loss on Ignition (LOI)	4.7	5.8	4.8	4.7	7.2	15.0	9.1	7.9	7.9	7.9	7.9	6.9

Thermal Conductivity
($Btu \cdot in./hr. \cdot ft.^2 \cdot °F$)

Mean Temp. °F (°C)	**M Board**	**S Board**	**HS Board**	**Expansion Joint Board**	**Millboard 823**	**Millboard 830**	**12C Board**	**2600 Board**	**3000 Board**
500 (260)	0.47	0.48	0.55	0.43	0.72	0.50	0.45	0.48	0.38
1000 (538)	0.70	0.76	0.70	0.68	0.78	0.73	0.72	0.68	0.54
1500 (816)	1.04	1.14	0.85	0.95	0.85	0.93	1.08	0.95	0.80
2000 (1093)							1.40	1.34	1.19
2400 (1316)								1.80	1.68

Table 2 - Compilation of burn test results

Test/ Trial No	Container	Volume of Container m^3	Detonator Type	Number of Dets/Case	Total Load	Mass of Load Kg	Volume of Load m^3(a)	Approx. Ratio of Volumes	Time of First Explosion	Time of Last Explosion	% Dets that Funct'	Temp at First Explosion
1/1	Sched-IV Type	0.049	Safety Fuse Assemblies	200	300	20.5	0.049	0.7	01:07:00	--------	66	TC-28-350
2/1	Schedule-IV	1.331	EBC	5 cases	1200	50.0	0.025	0.2	00:25:30	00:39:57	100	TC-330(d)
3/1	Sched-IV Type	0.125	EBC	500	1200	25.2	0.078	0.6	00:51:00	00:51:46	70	TC-2-300
3/2	Sched-IV Type	0.125	EBC	500	400	8.4	0.026	0.2	00:50:00	00:52:00	90	TC-3-300
3/3	Sched-IV Type	0.125	EBC	80	144	36.9	0.078	0.6	00:47:00	01:47:00	100	TC-2-350
3/4	Sched-IV Type	0.125	EBC	80	48	12.3	0.026	0.2	00:34:53	01:36:00	100	TC-2-300
3/5	Sched-IV Type	0.125	N-EBC	250	450	16.5	0.075	0.6	01:02:00	01:04:00	80	TC-2-400
3/6	Sched-IV Type	0.125	N-EBC	250	150	5.5	0.025	0.2	01:05:00	01:06:00	98	TC-3-280
3/7	Sched-IV Type	0.125	N-EBC	25	45	16.5	0.057	0.5	00:59:00	01:36:00	100	TC-2-280
3/8	Sched-IV Type	0.125	N-EBC	25	15	5.5	0.019	0.2	00:43:00	01:40:00	100	TC-4-210
4/1	Commer Vault	0.011	EBC	500	150	3.1	0.007	0.6	01:34:00	01:35:00	100	TC-2A-295
4/2	Commer Vault	0.011	N-EBC	250	50	2.0	0.008	0.7	01:04:00	01:04:00	100	TC-2B-240
4/3	Commer Vault(b)	0.011	N-EBC	150	30	1.6	0.008	0.7	00:57:29	00:58:22	100	TC-2-300
5/1	IME-22	0.056	EBC	500	450	9.4	0.030	0.5	01:38:00	01:38:00	96	TC-4-210
5/2	IME-22	0.201	N-EBC	250/25(c)	290	21.8	0.140	0.7	01:05:00	01:10:00	95	TC-4-90
6/1	Prototype	0.061	N-EBC	250/150(c)	220	10.2	0.050	0.8	01:18:00	01:24:00	90	TC-2-170
6/2	Prototype	0.061	EBC	500/80(c)	356	20.4	0.043	0.7	01:34:00	01:40:00	90	TC-2-230

EBC - Electric blasting caps
N-EBC - Non-electric blasting caps
(a) Obtained from case volumes given in literature
(b) Previously burned vault - See text
(c) See text

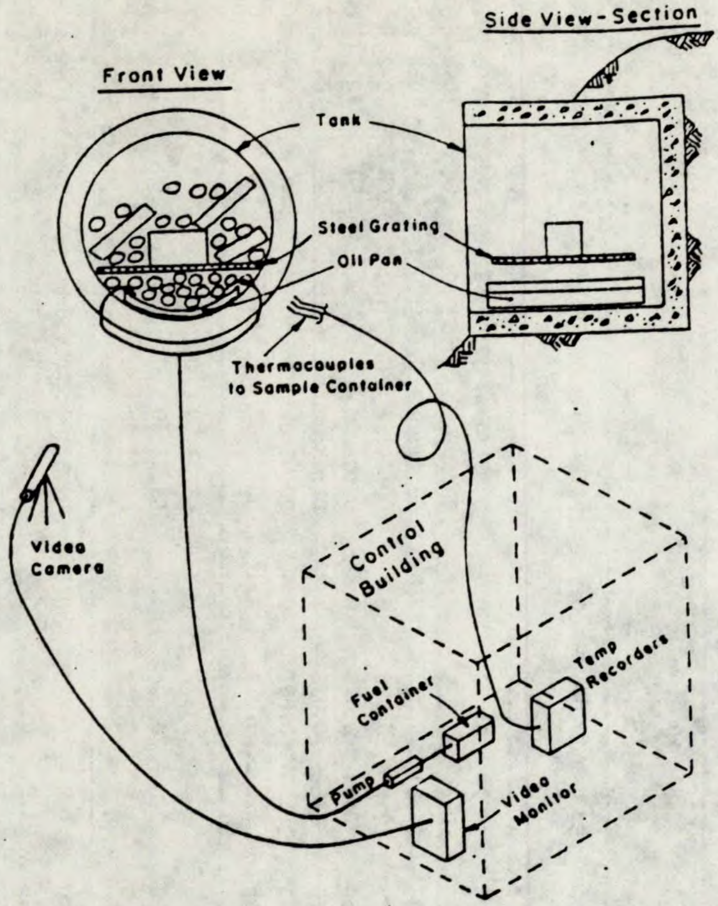

Fig. 1 - Fire test facility (CERL)

Fig. 2 - Fire test set-up (Field)

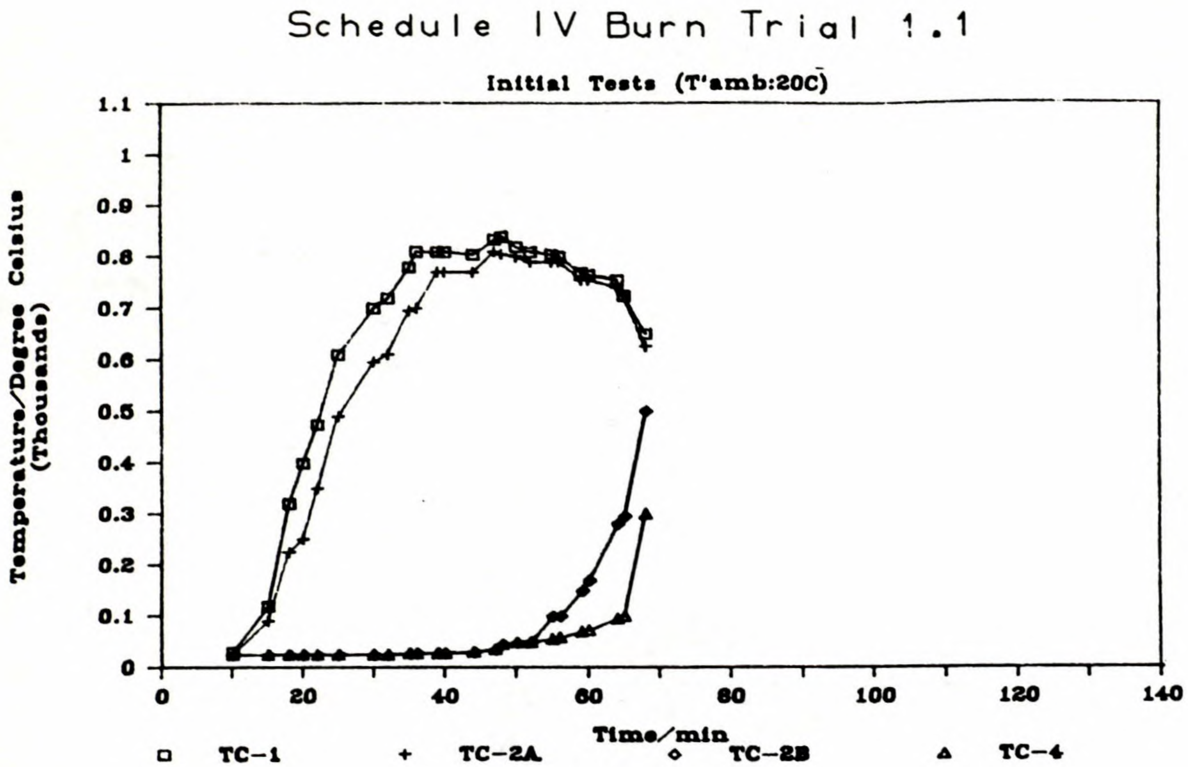

Fig. 3 - Temperature profiles of fire and inside temperatures

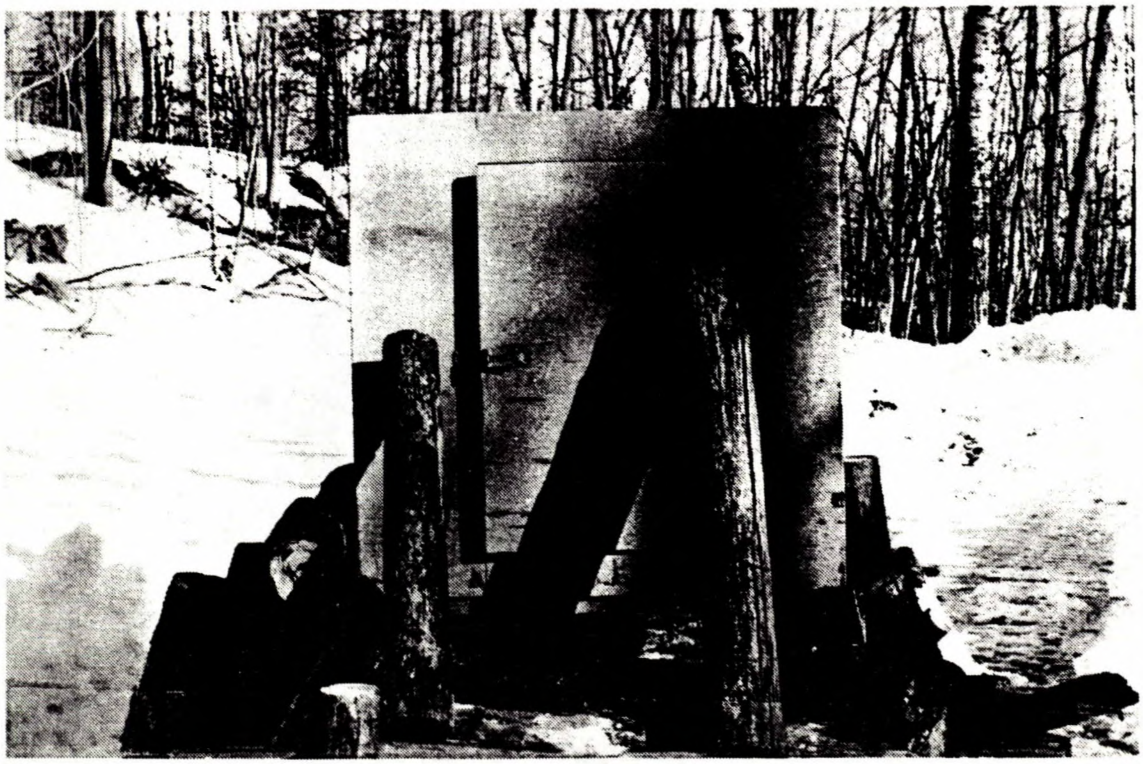

Fig. 4 - Schedule IV Container before burn

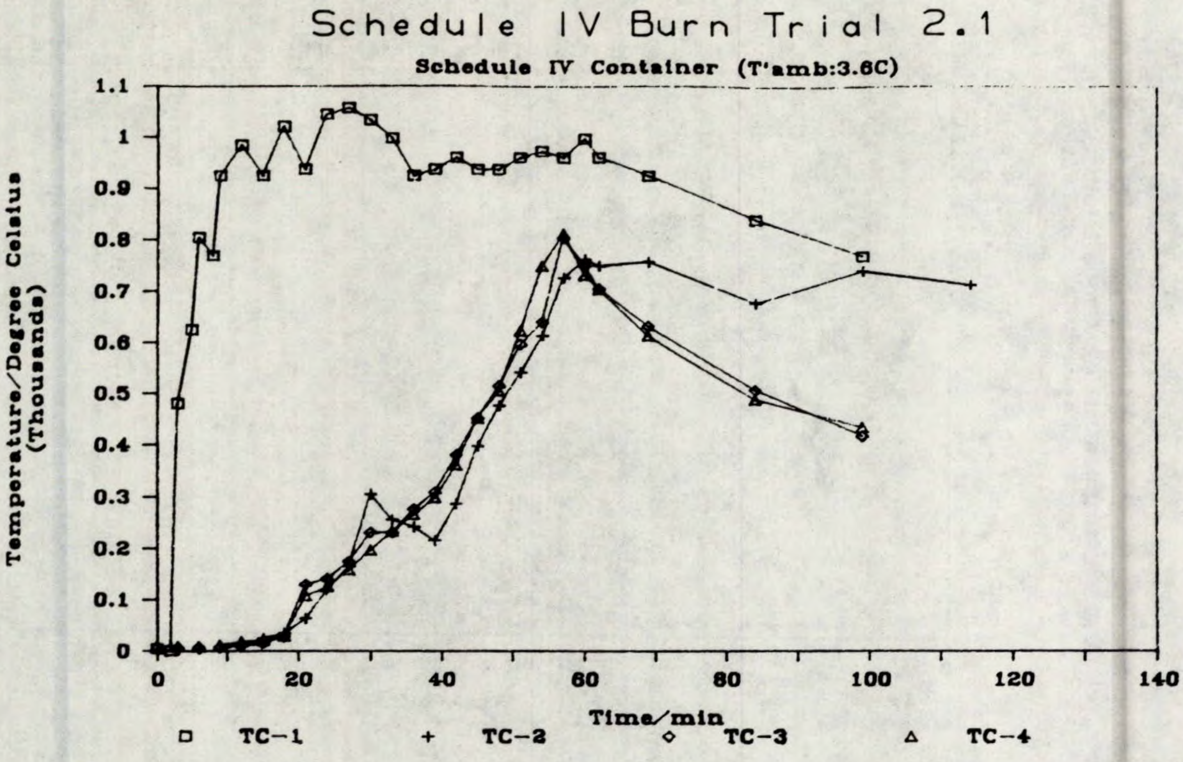

Fig. 5 - Temperature profiles from Schedule IV Container burn

Fig. 6 - Schedule IV Container after burn

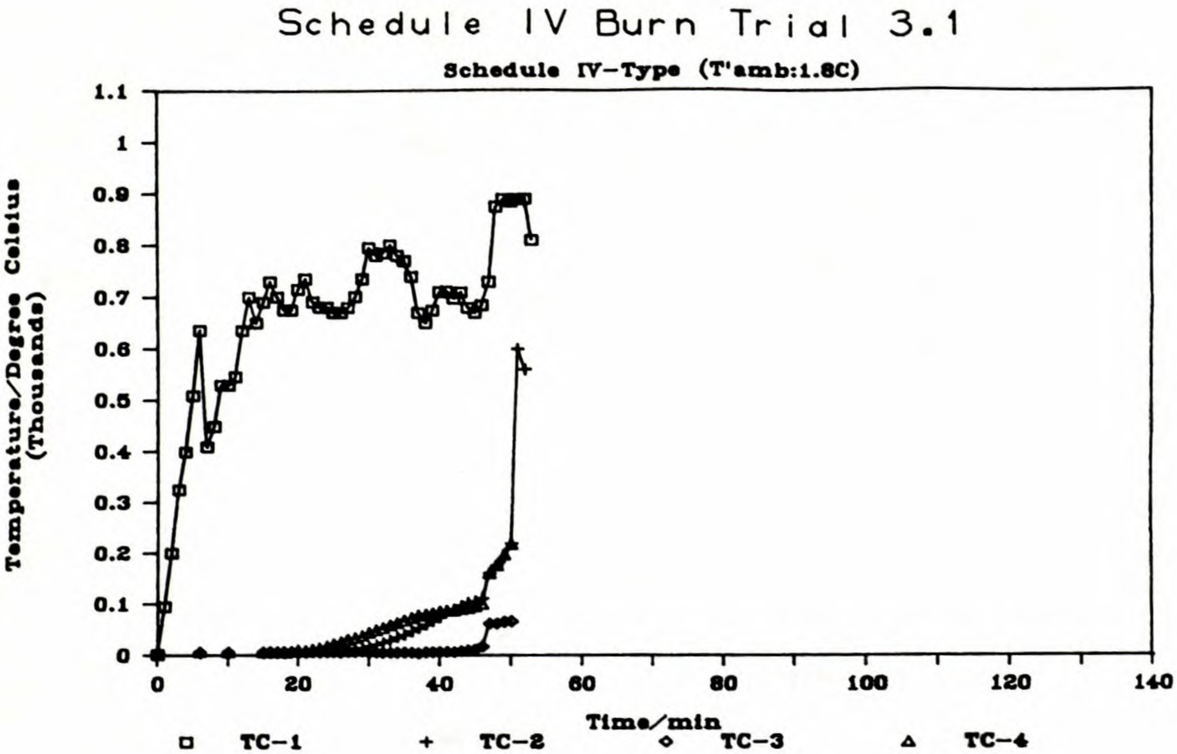

Fig. 7 - Temperature profiles from burn Trial 1

Fig. 8 - Results from burn Trial 1

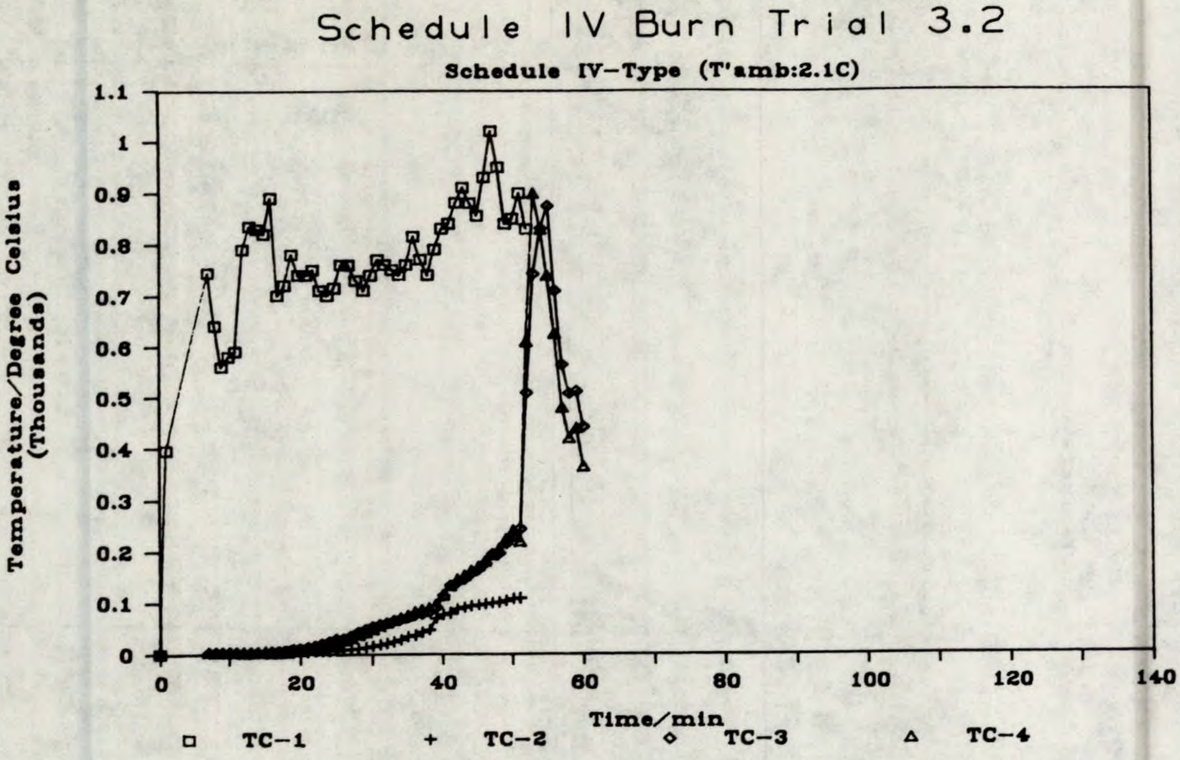

Fig. 9 - Temperature profiles from burn Trial 2

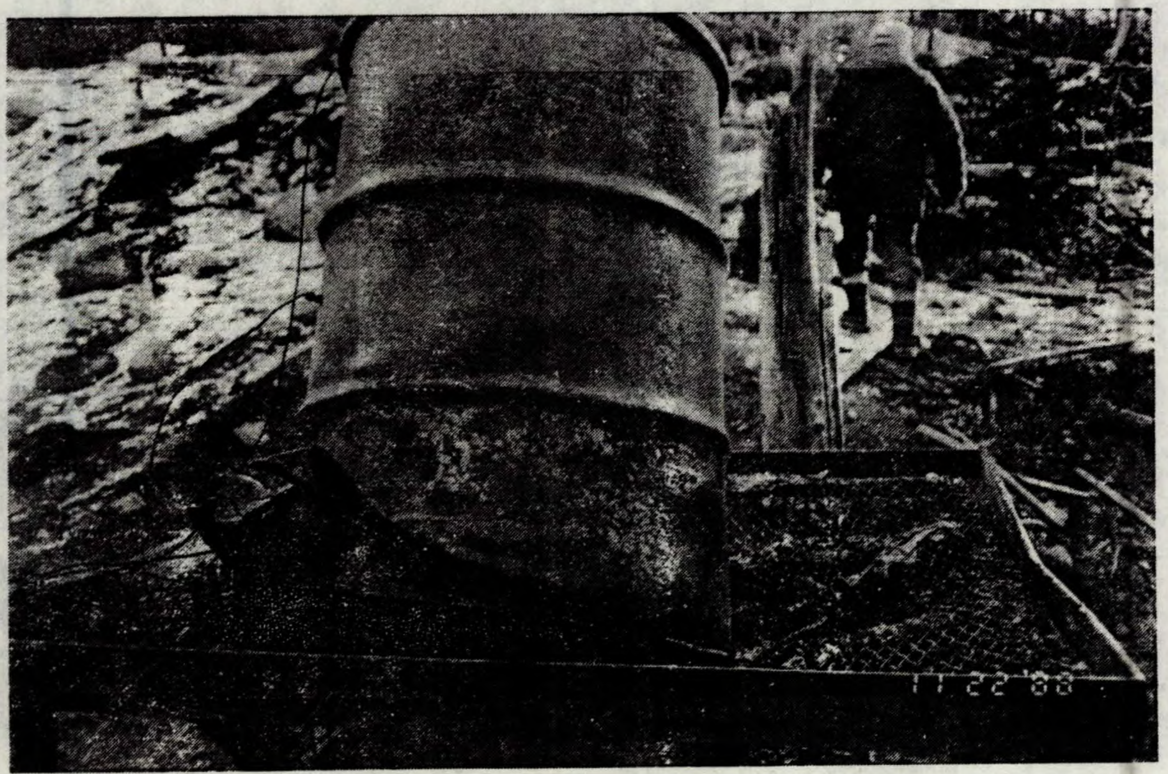

Fig. 10 - Results from burn Trial 2

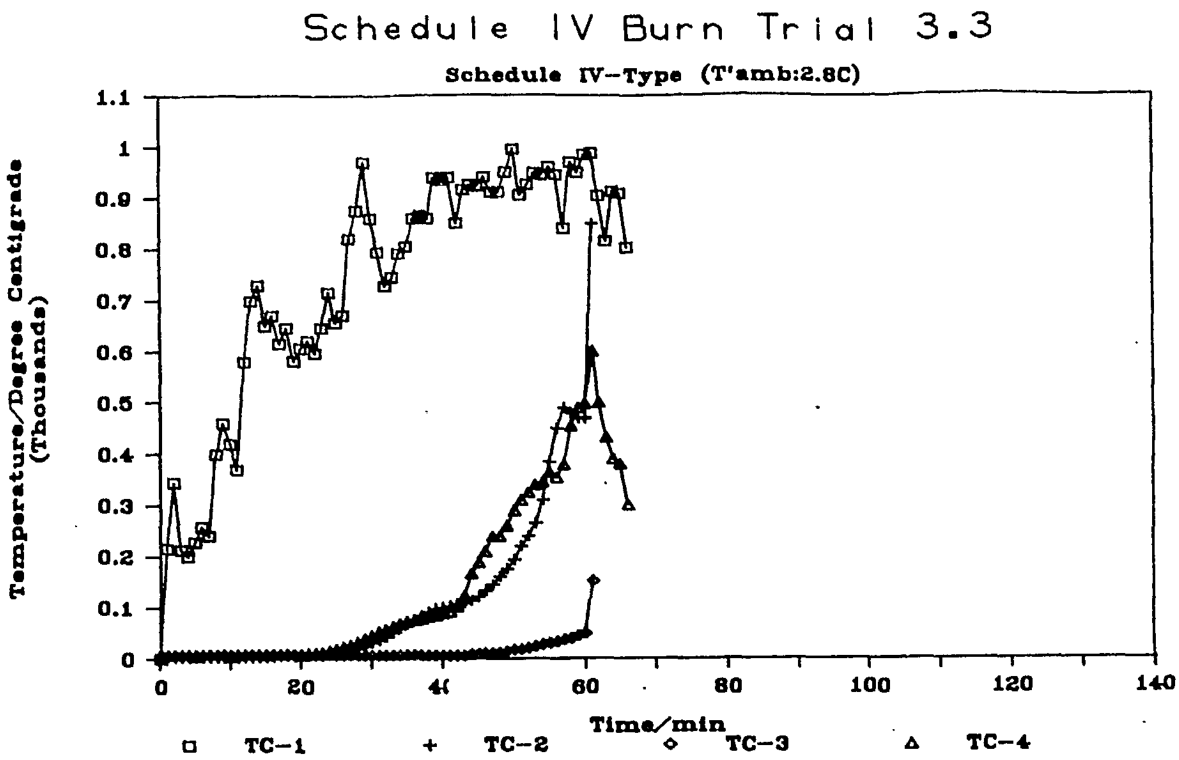

Fig. 11 - Temperature profiles from burn Trial 3

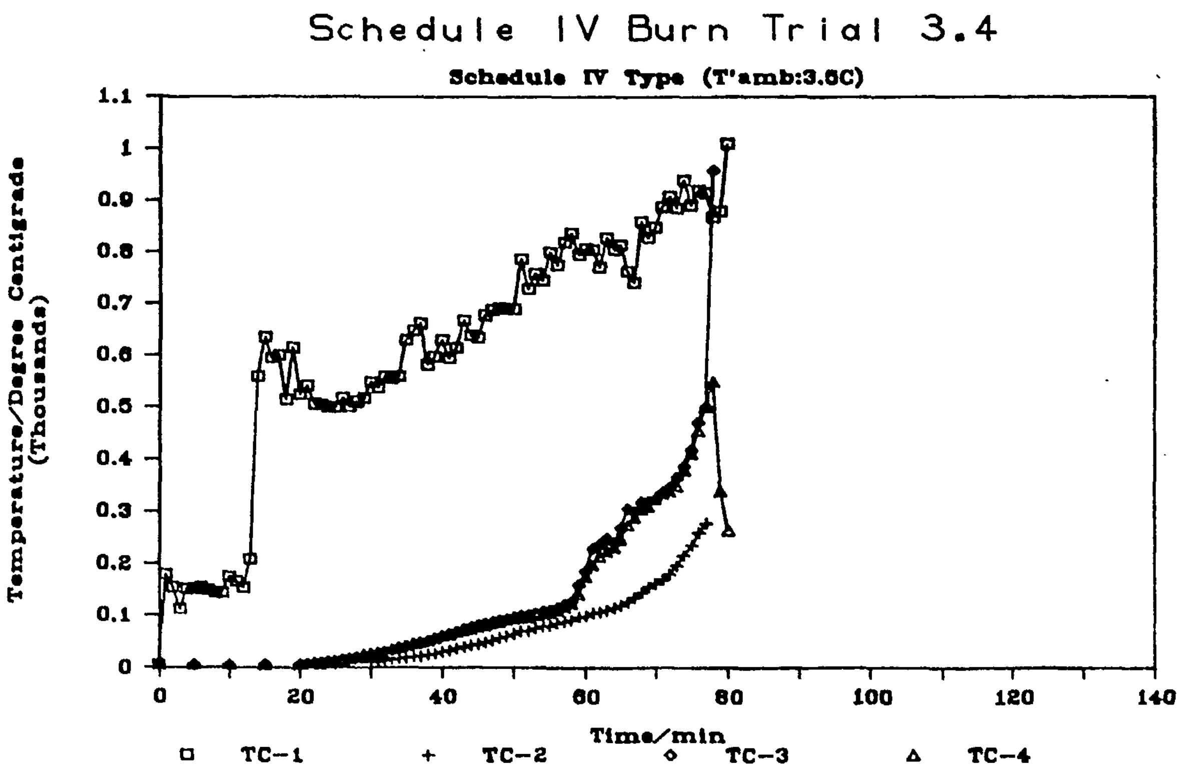

Fig. 12 - Temperature profiles from burn Trial 4

Fig. 13 - Results from burn Trial 4

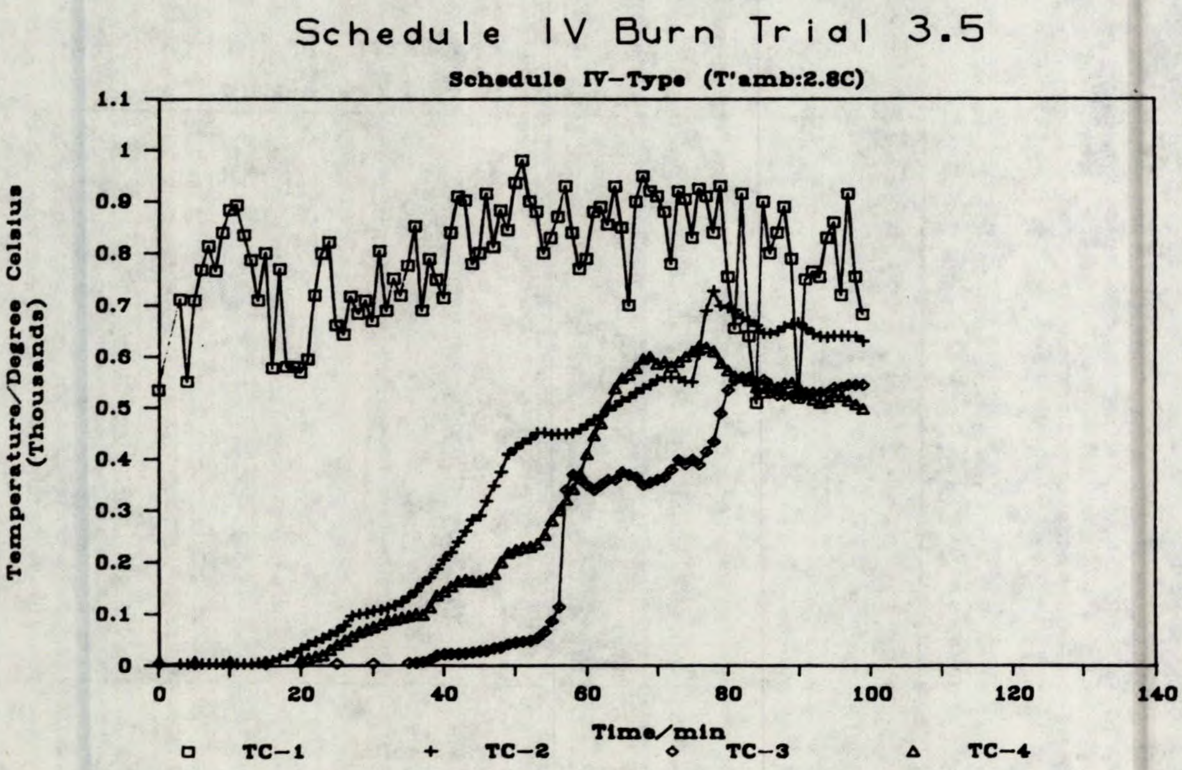

Fig. 14 - Temperature profiles from burn Trial 5

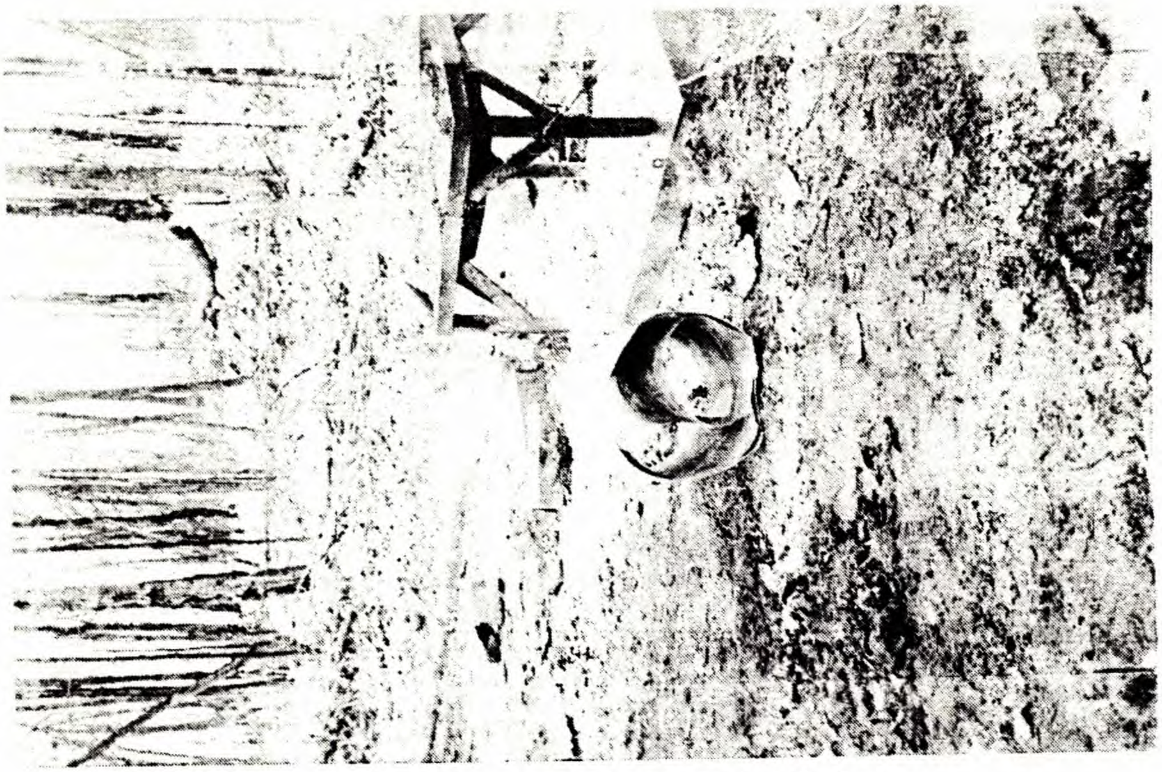

Fig. 15 - Results from burn Trial 5

Fig. 16 - Results from burn Trial 5

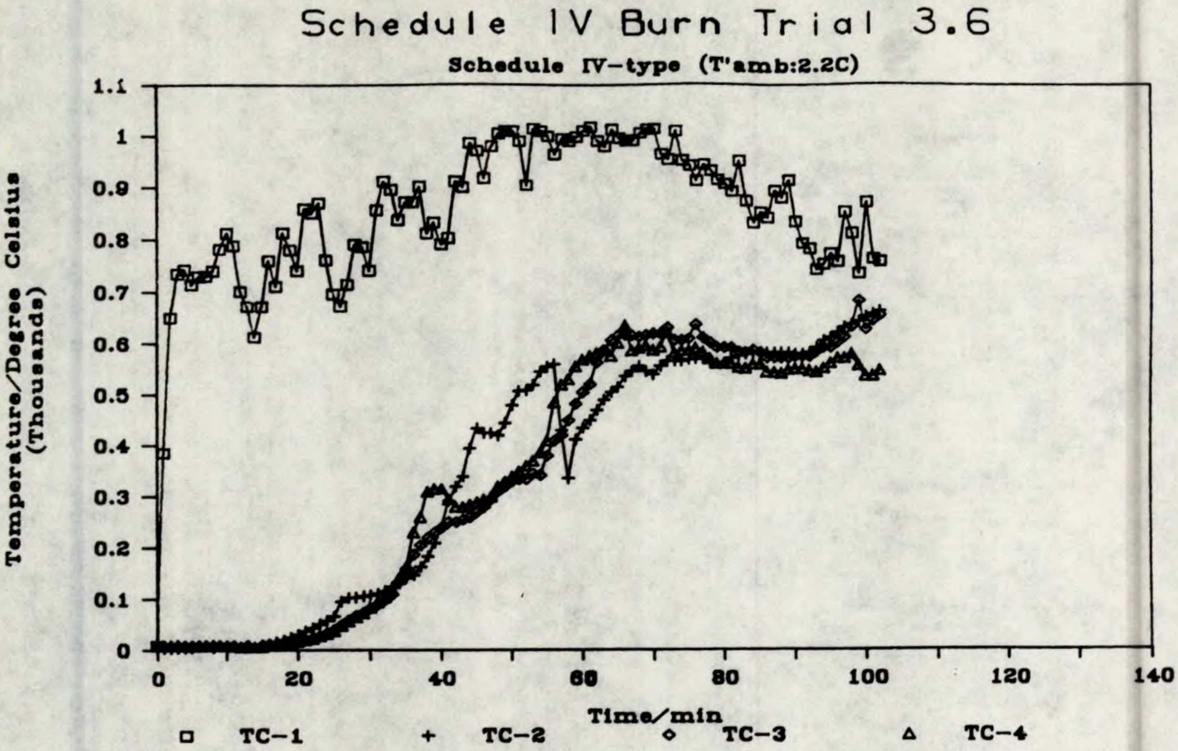

Fig. 17 - Temperature profiles from burn Trial 6

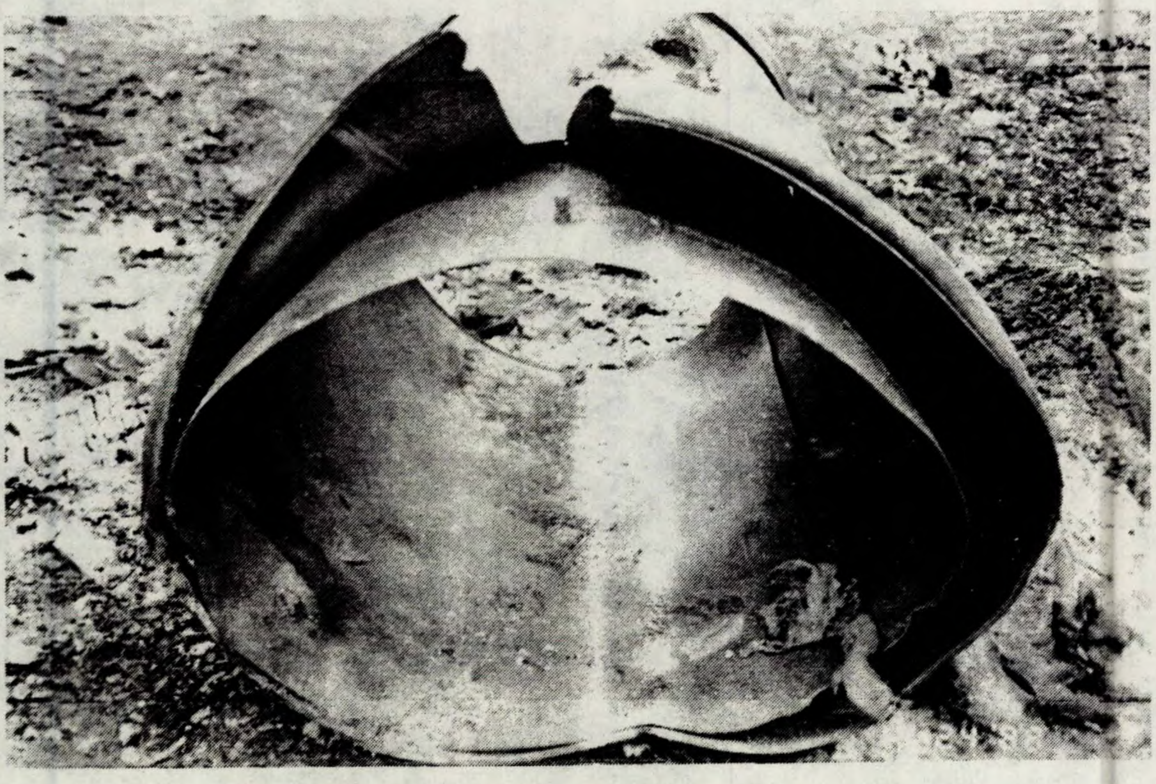

Fig. 18 - Results from burn Trial 6

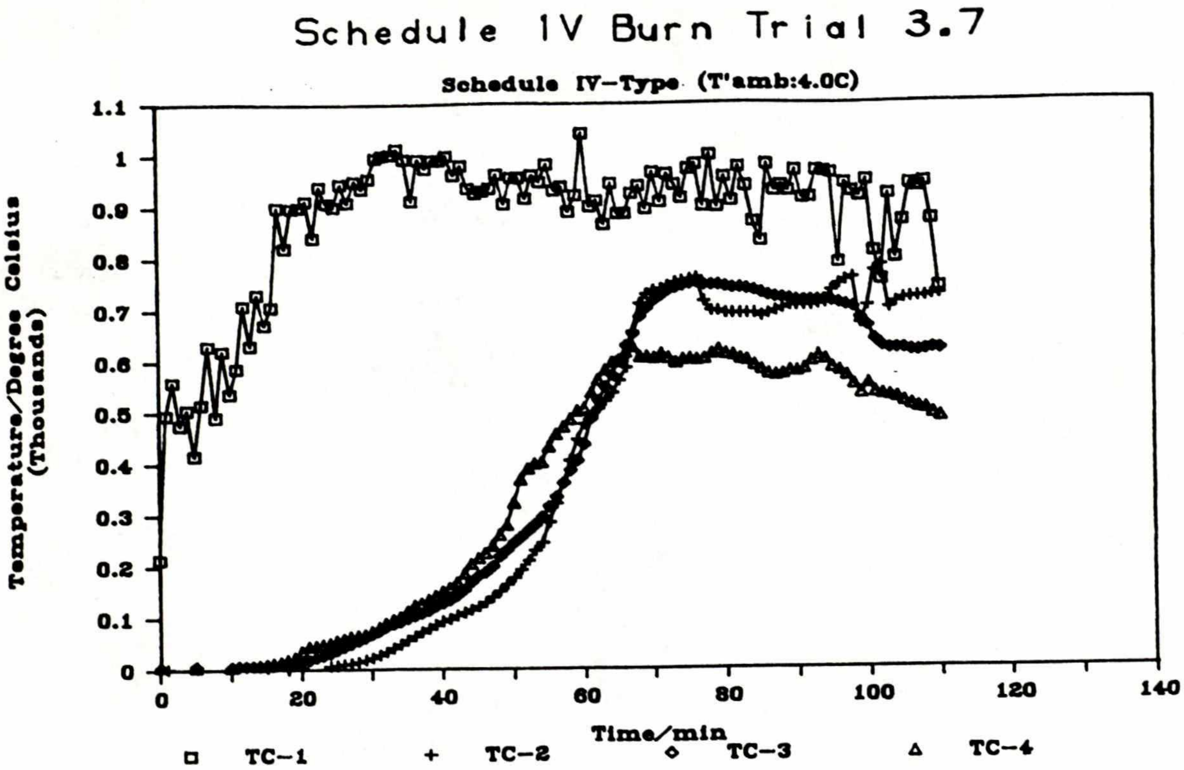

Fig. 19 - Temperature profiles from burn Trial 7

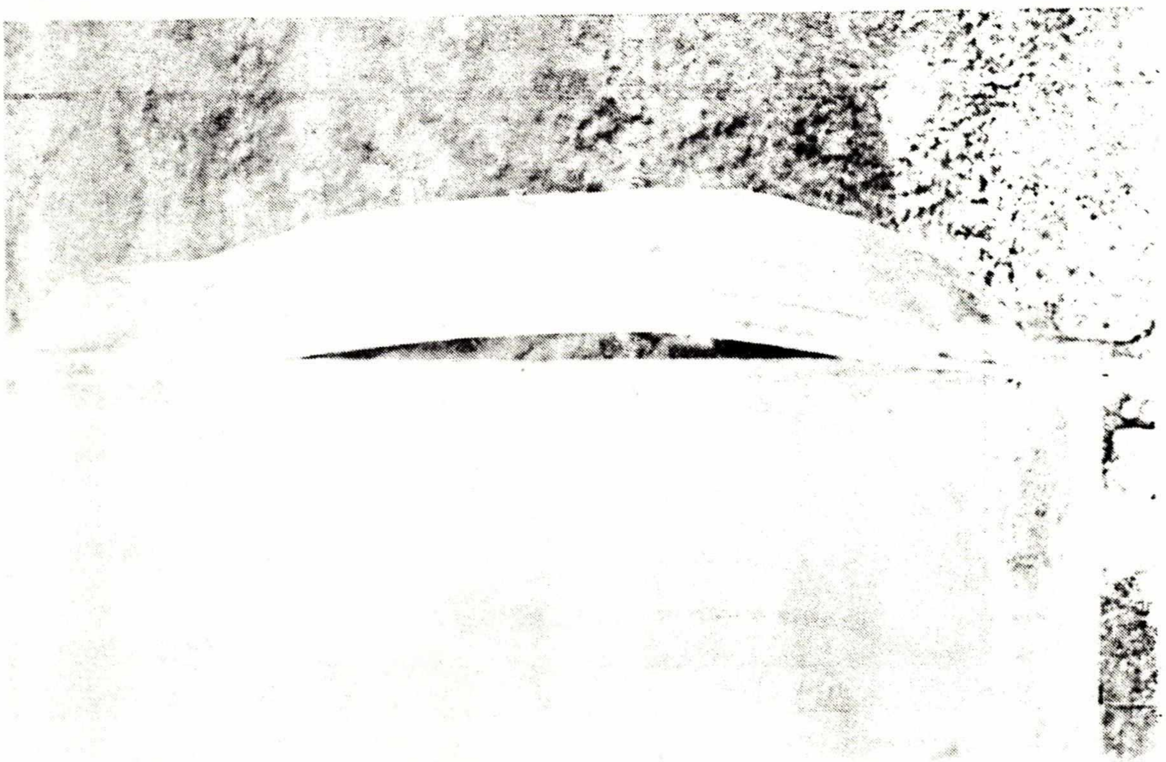

Fig. 20 - Results from burn Trial 7

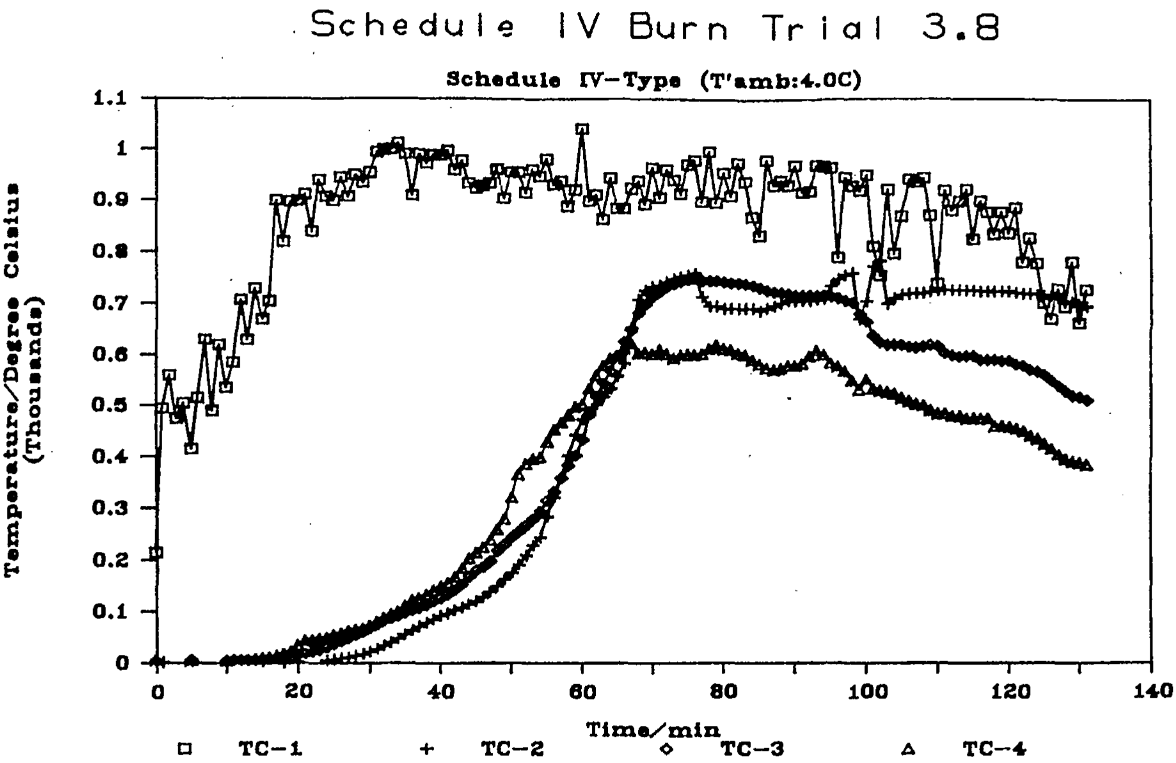

Fig. 21 - Temperature profiles from burn Trial 8

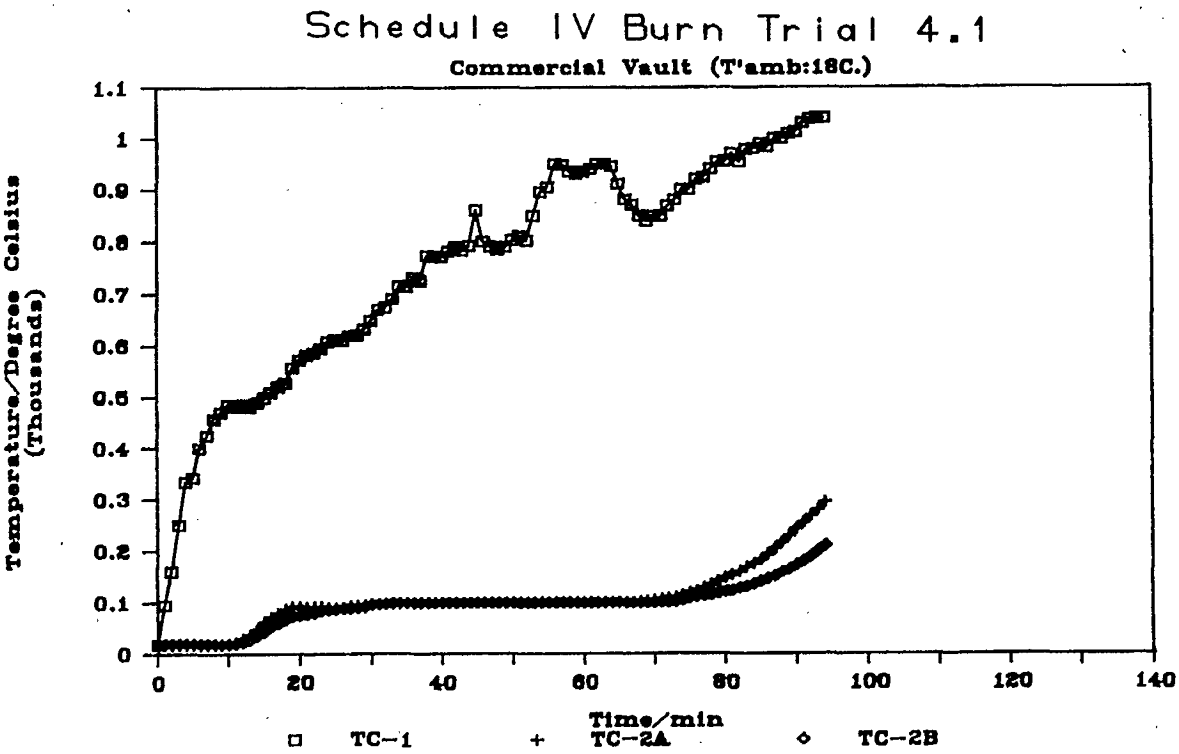

Fig. 22 - Temperature profiles from a burn trial on a commercial vault

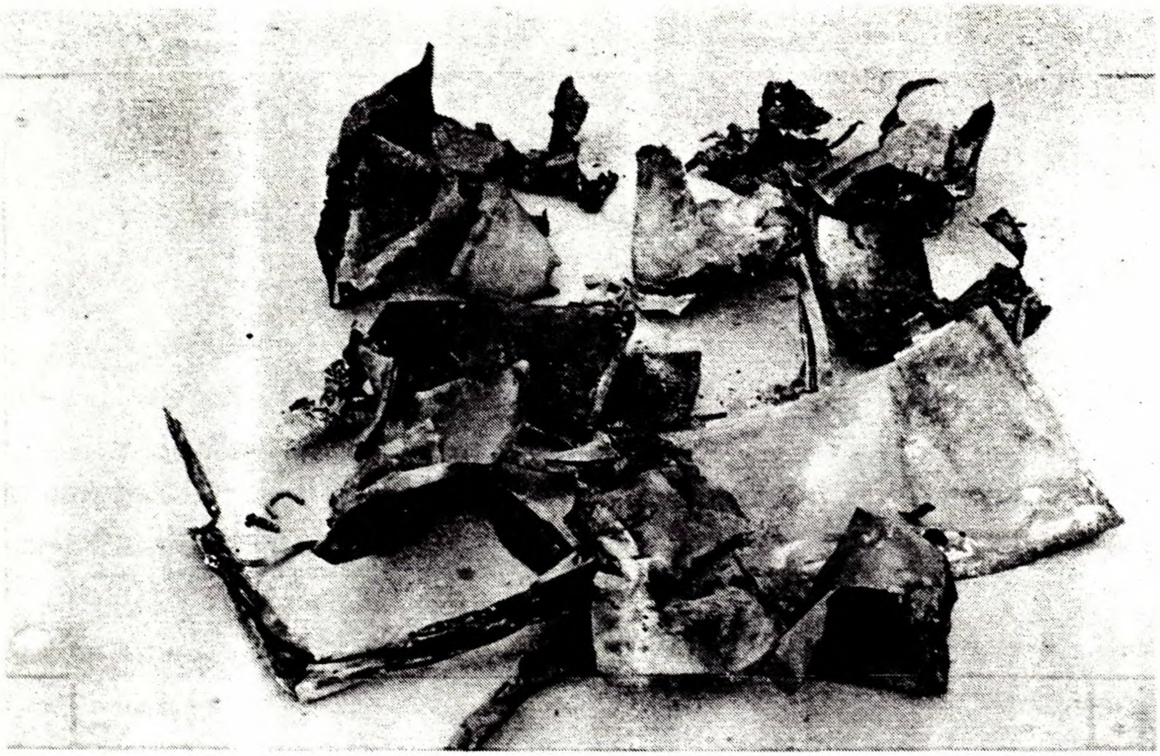

Fig. 23 - Damage sustained by the vault loaded with electric detonators

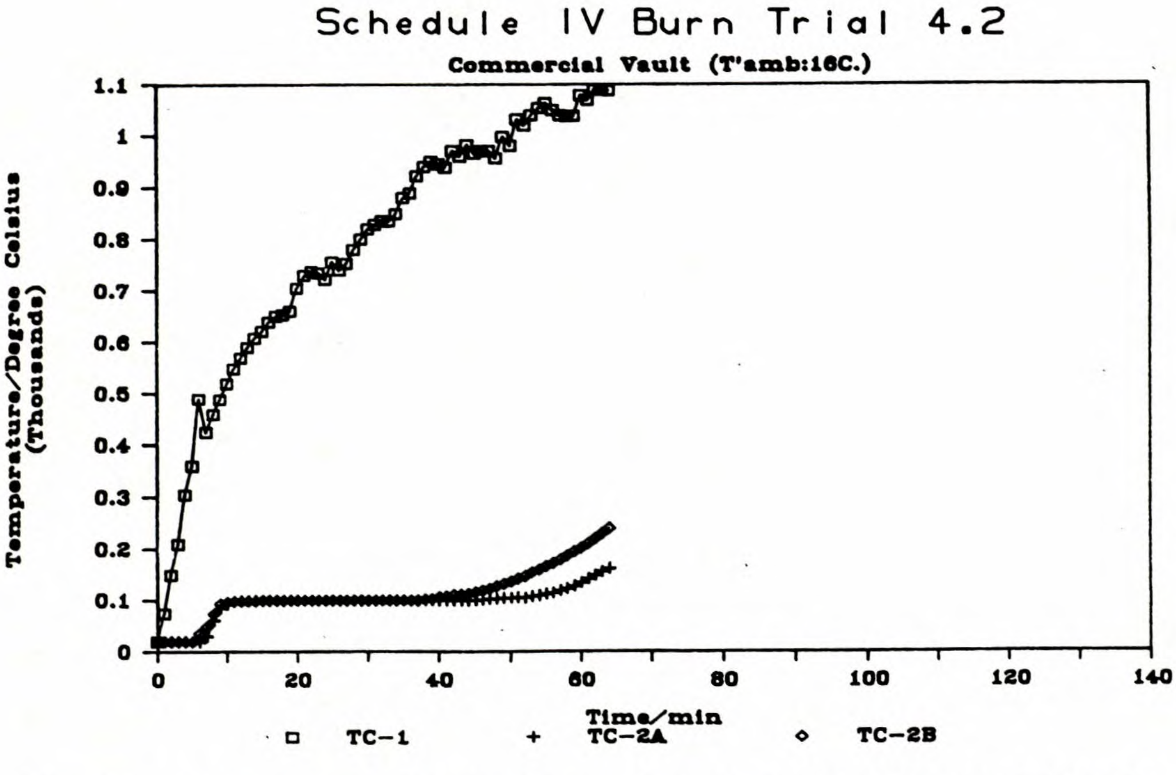

Fig. 24 - Temperature profiles from a burn trial on a commercial vault

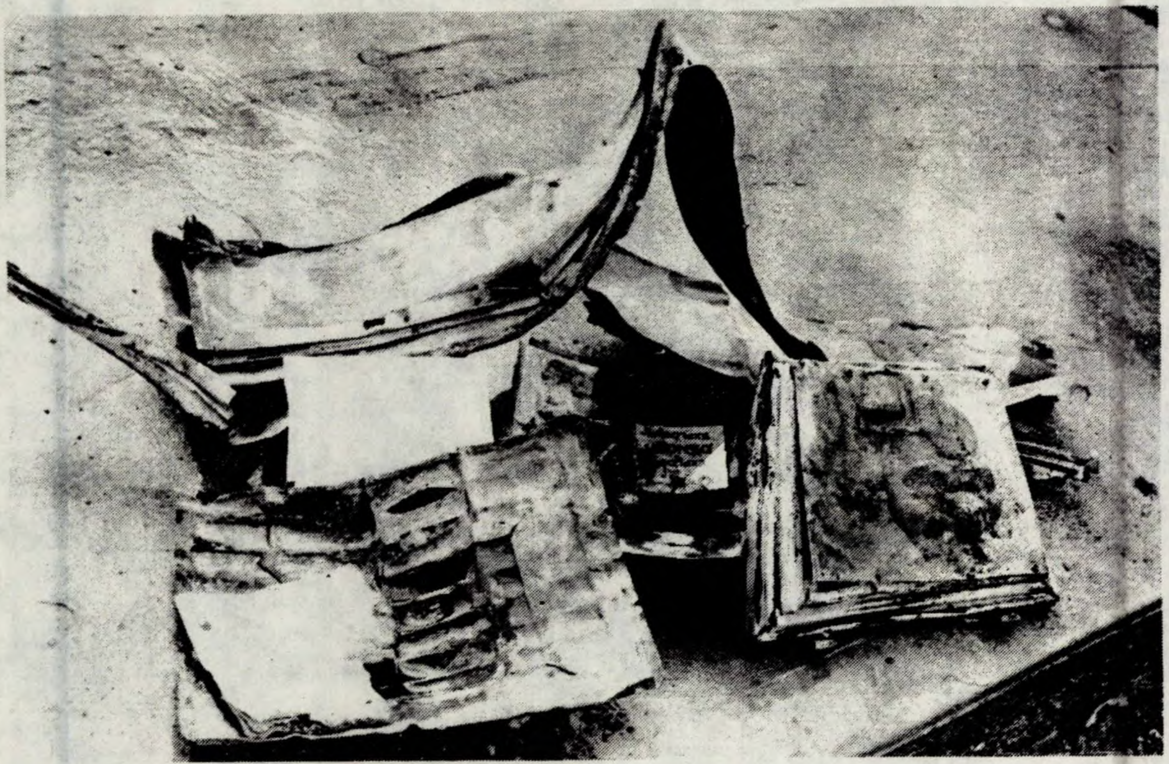

Fig. 25 - Damage sustained by the vault loaded with non-electric detonators

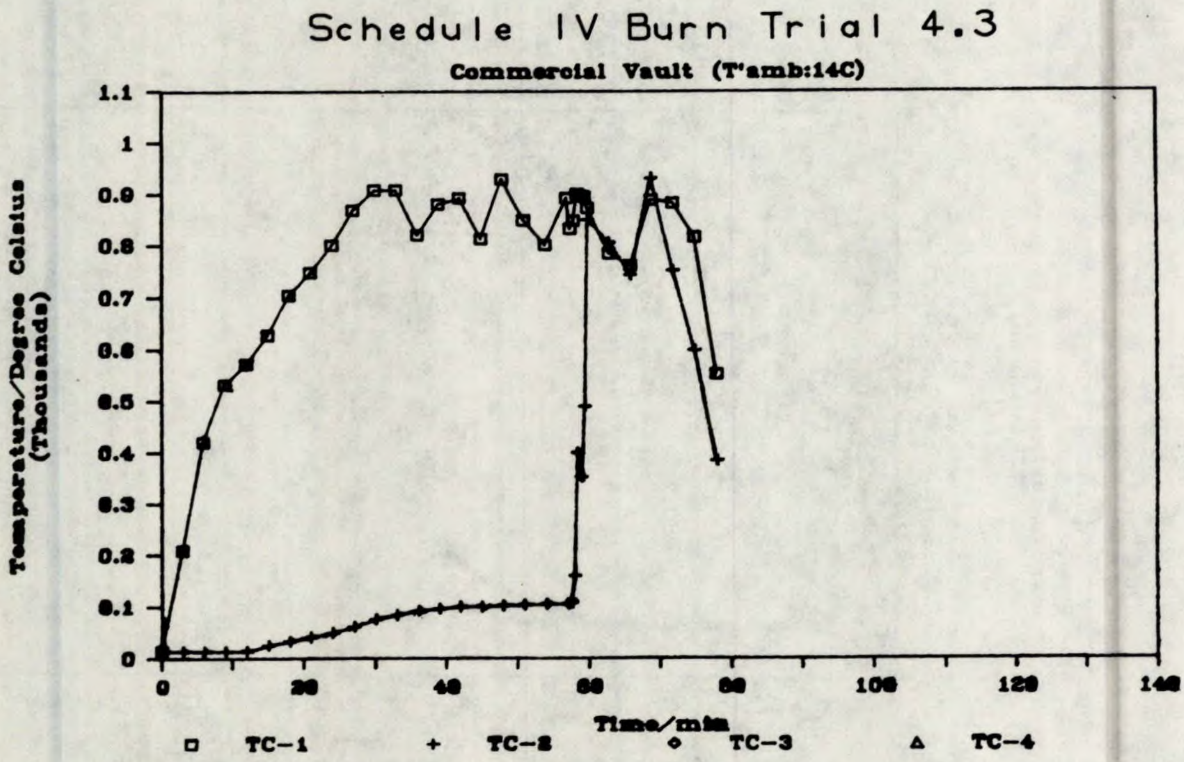

Fig. 26 - Temperature profiles from a burn trial on a previously used commercial vault

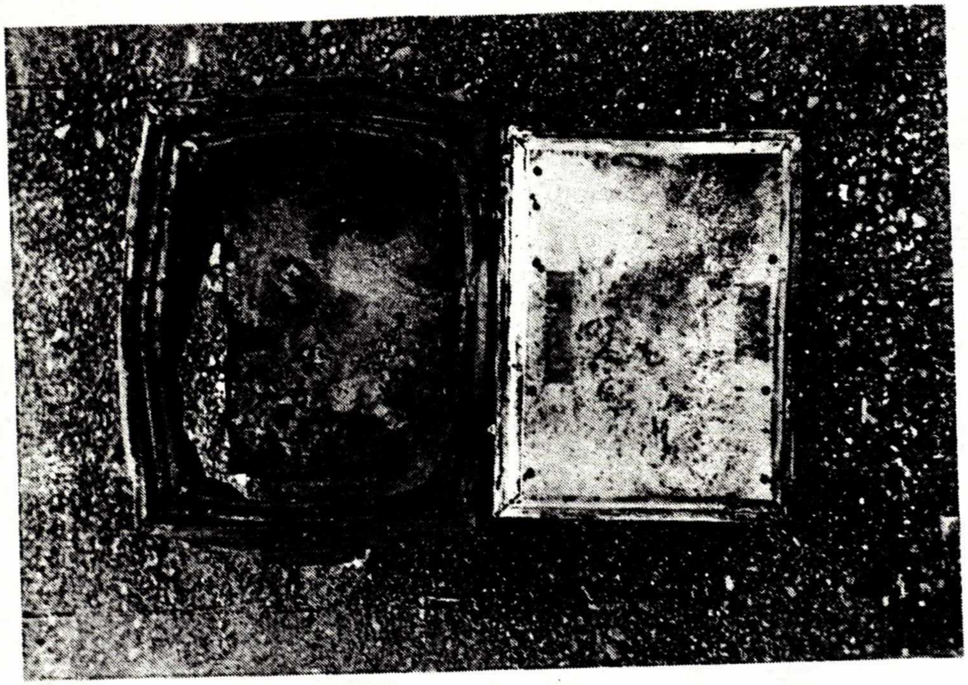

Fig. 27 - Damage sustained by the used vault loaded with non-electric detonators

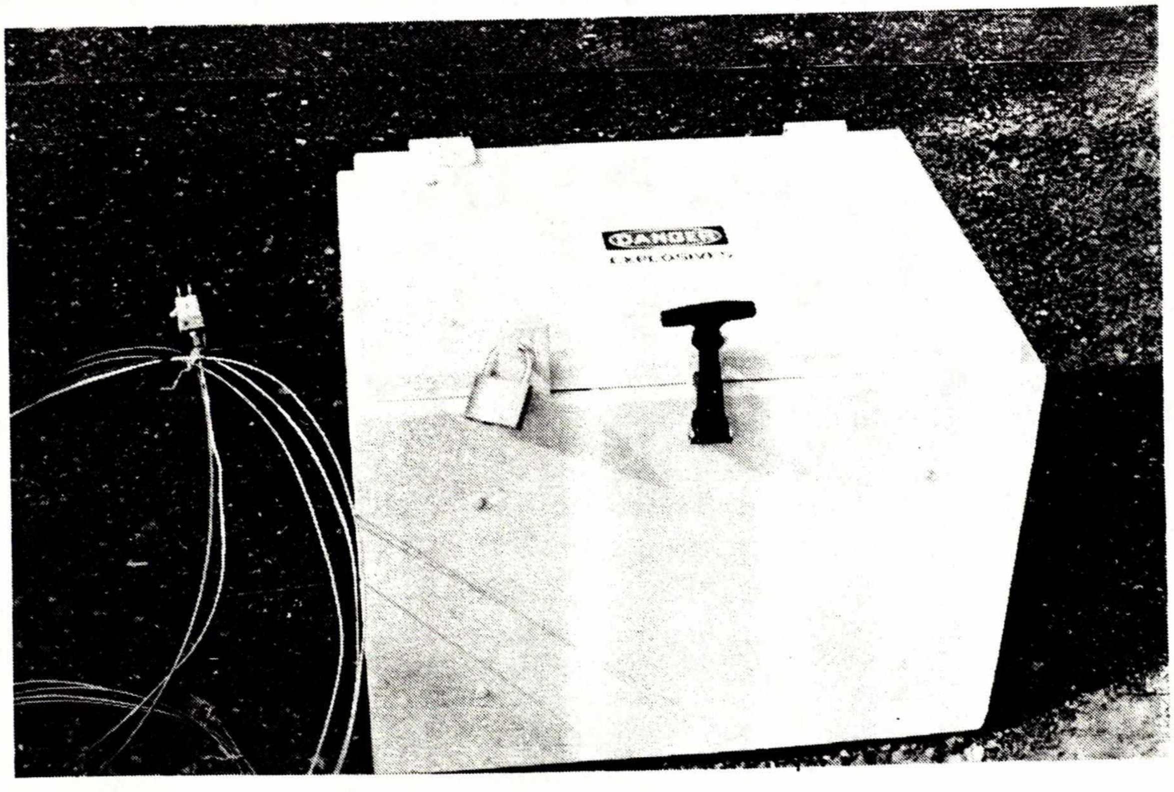

Fig. 28 - The first IME 22 Container tested

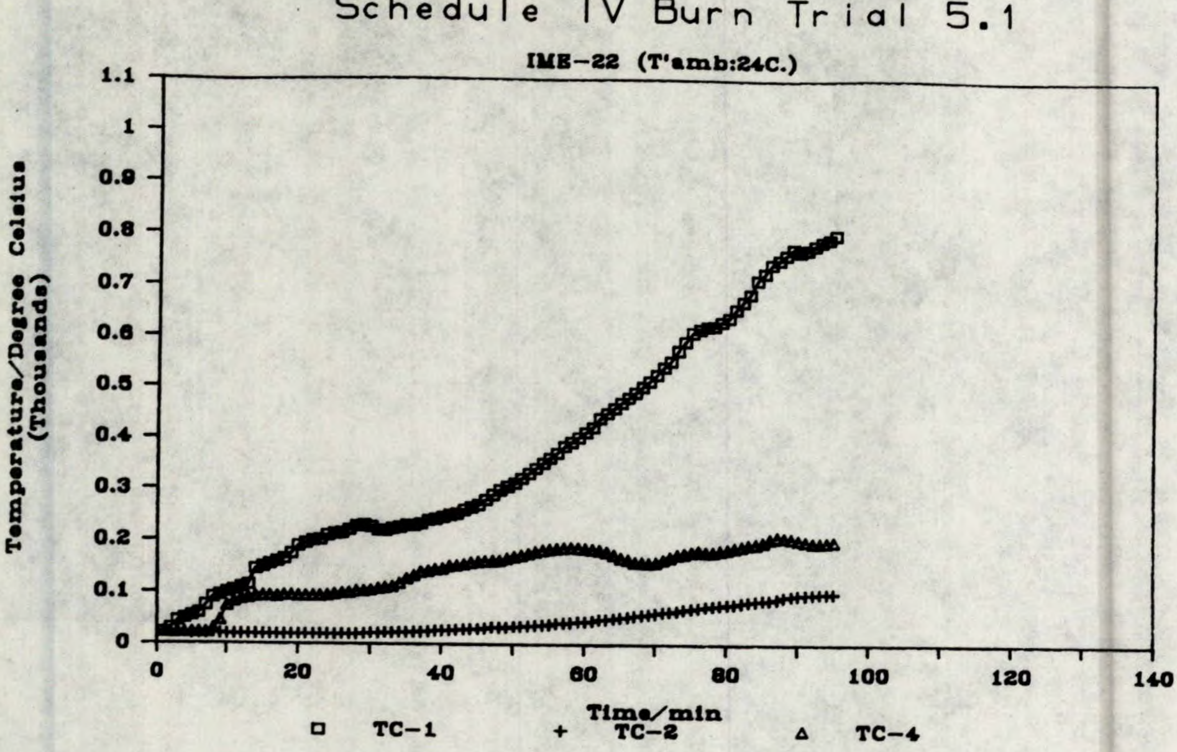

Fig. 29 - Temperature profiles from the burn trial on the first IME 22 Container

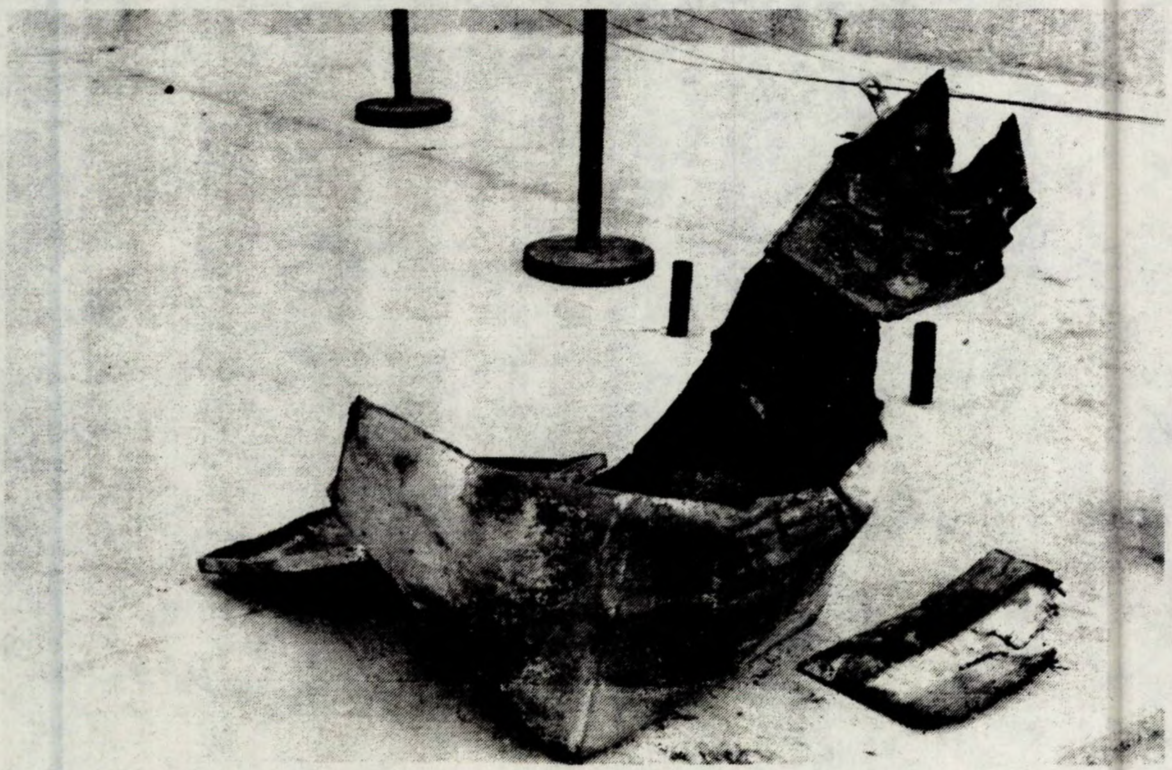

Fig. 30 - Damage sustained by the first IME 22 Container tested

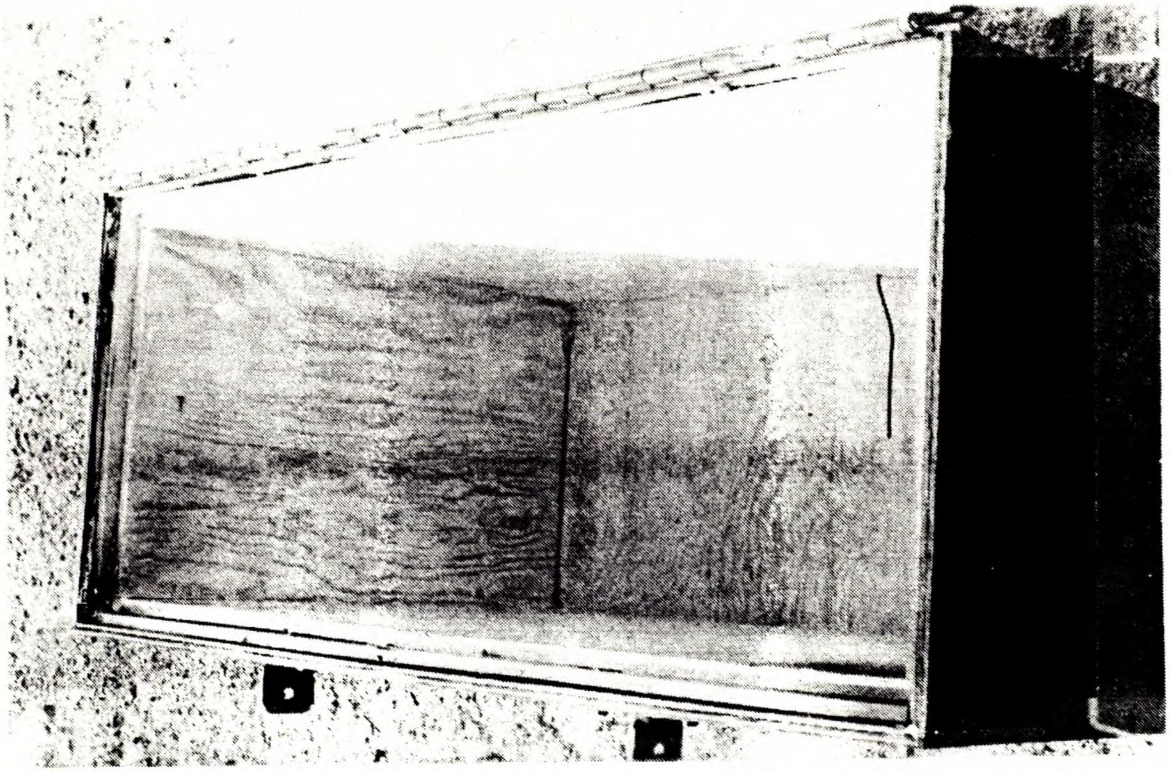

Fig. 31 - The second IME 22 Container tested

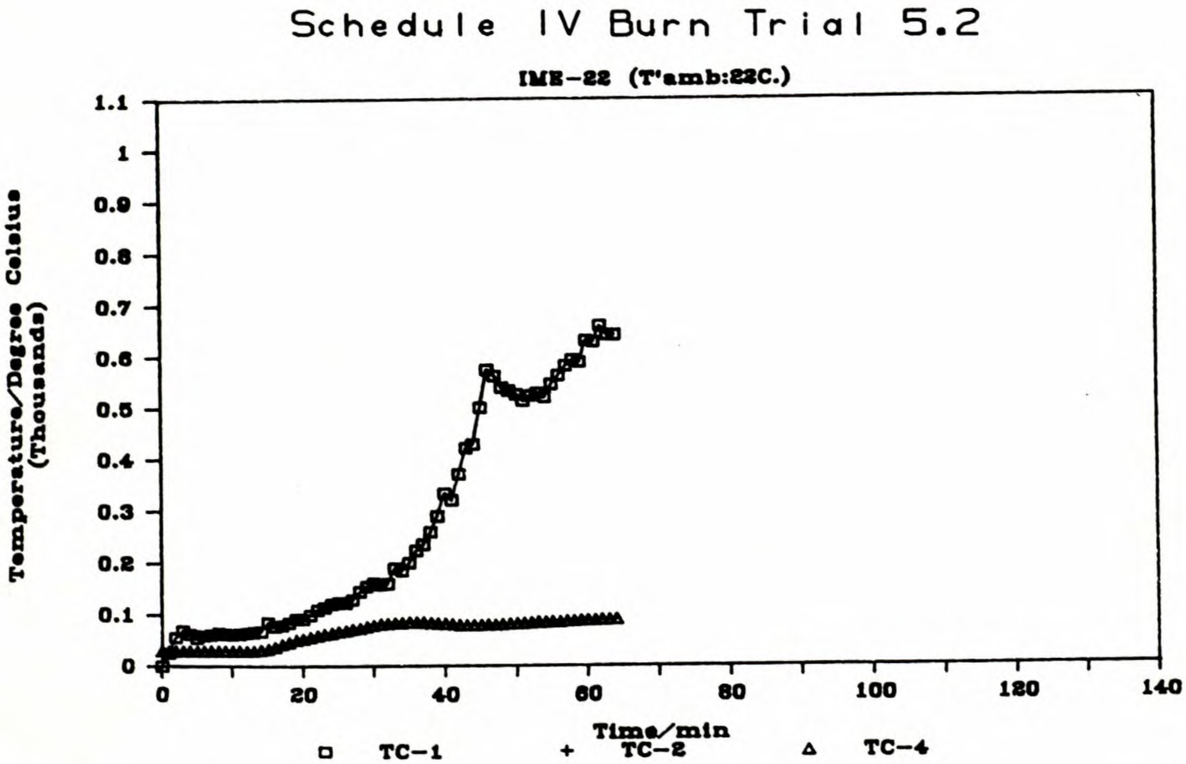

Fig. 32 - Temperature profiles from the burn trial on the second IME 22 Container

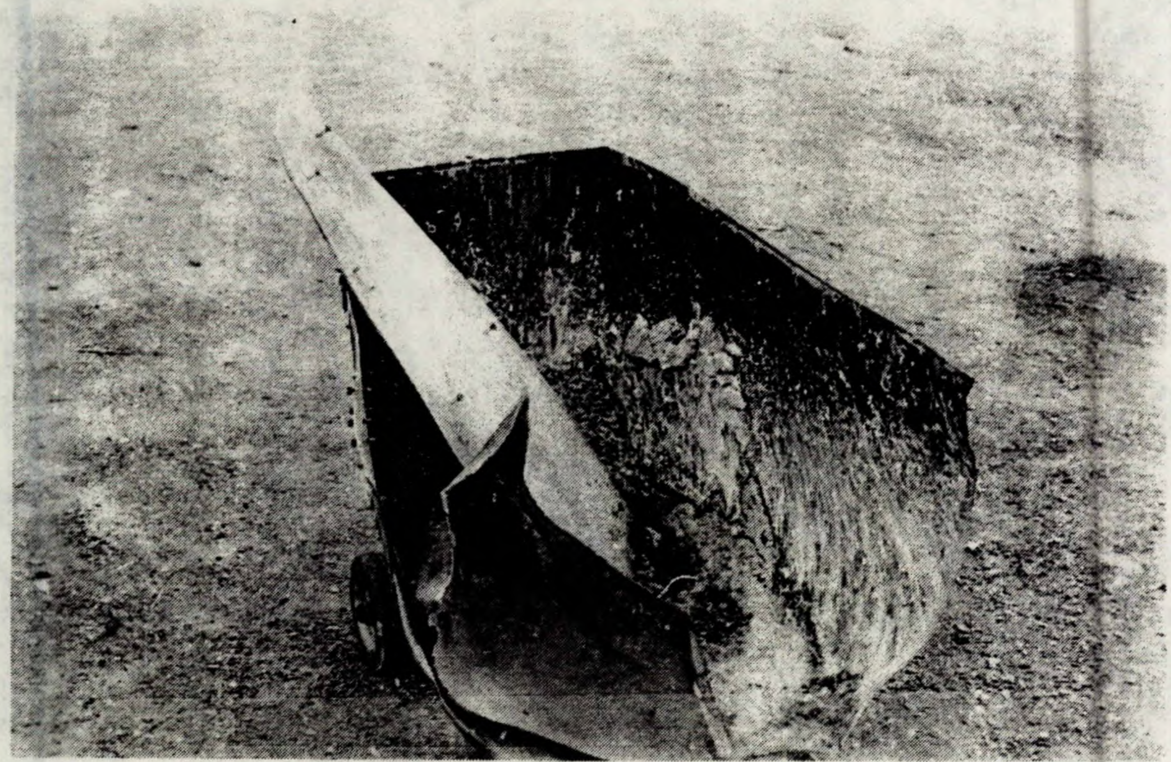

Fig. 33 - Damage sustained by the second IME Container tested

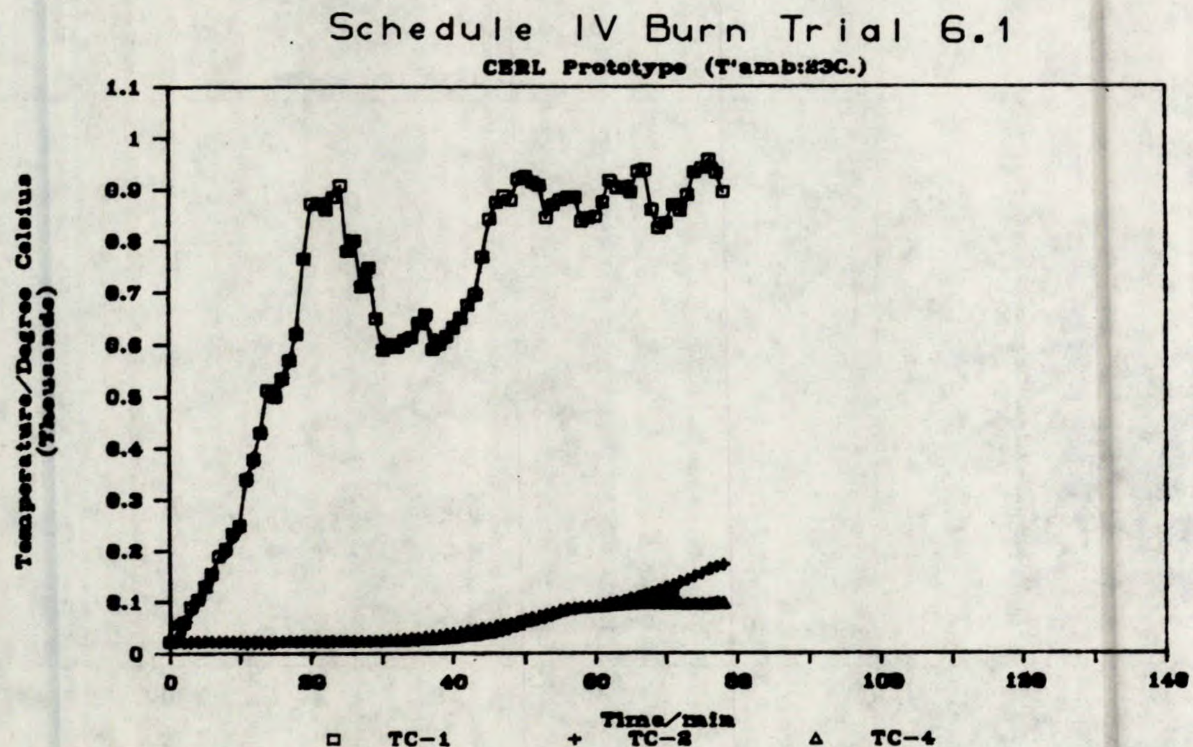

Fig. 34 - Temperature profiles from the burn trial on the first prototype loaded with non-electric detonators

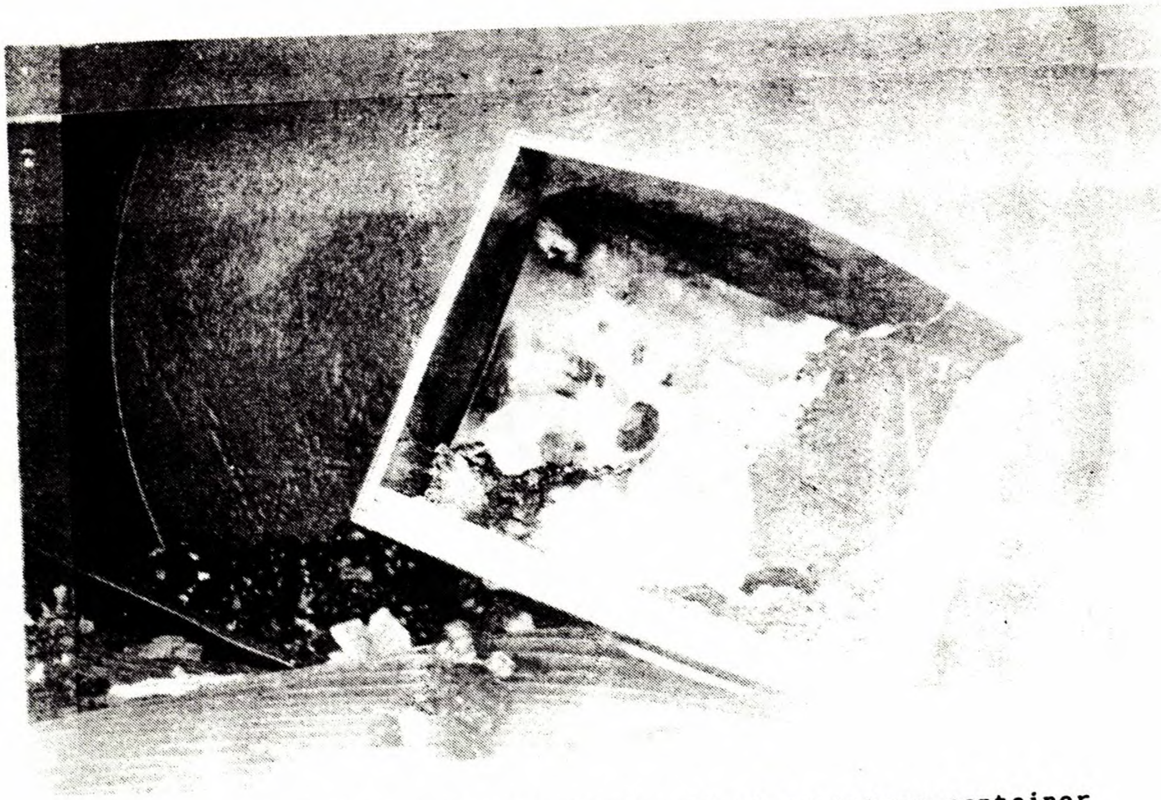

Fig. 35 - Damage sustained by the first prototype container

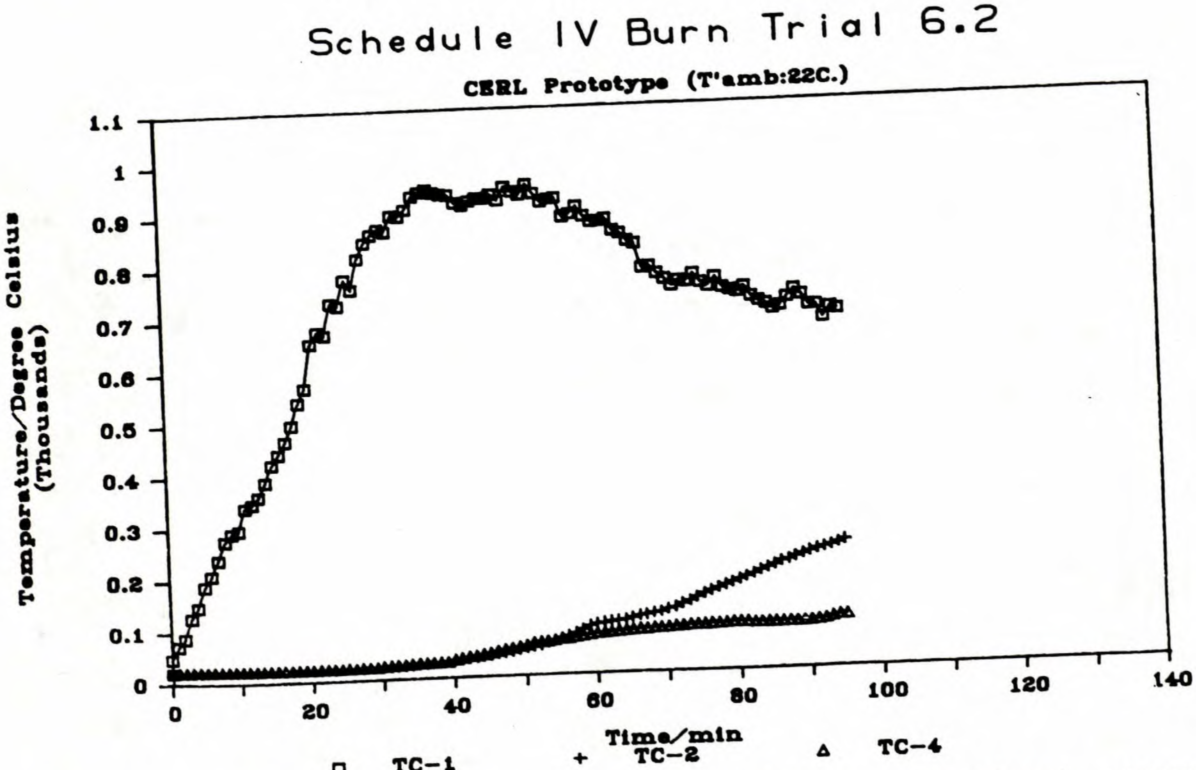

Fig. 36 - Temperature profiles from the burn trial on the second prototype container loaded

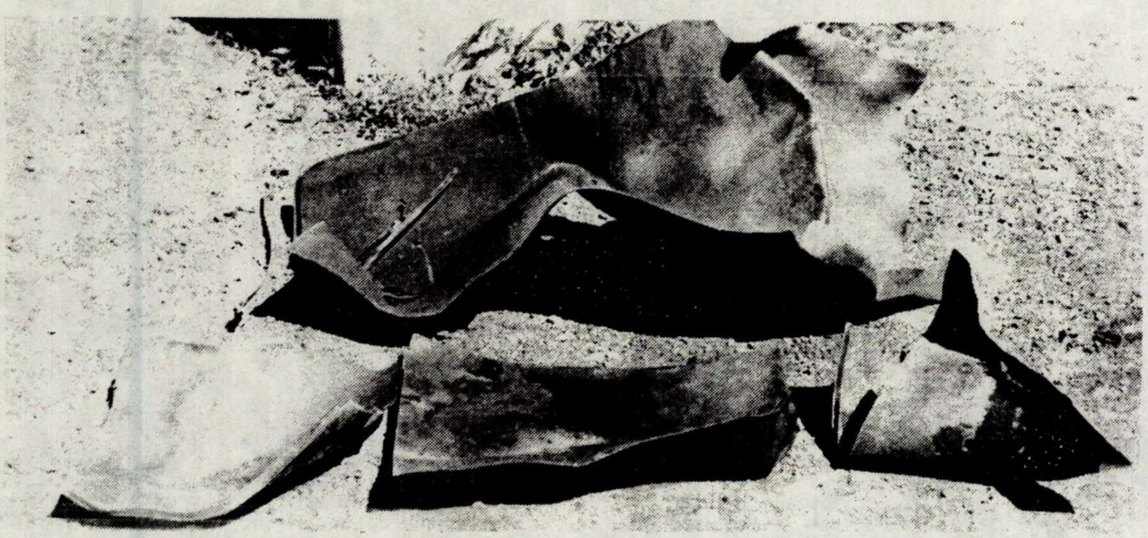

Fig. 37 - Damage sustained by the second prototype container

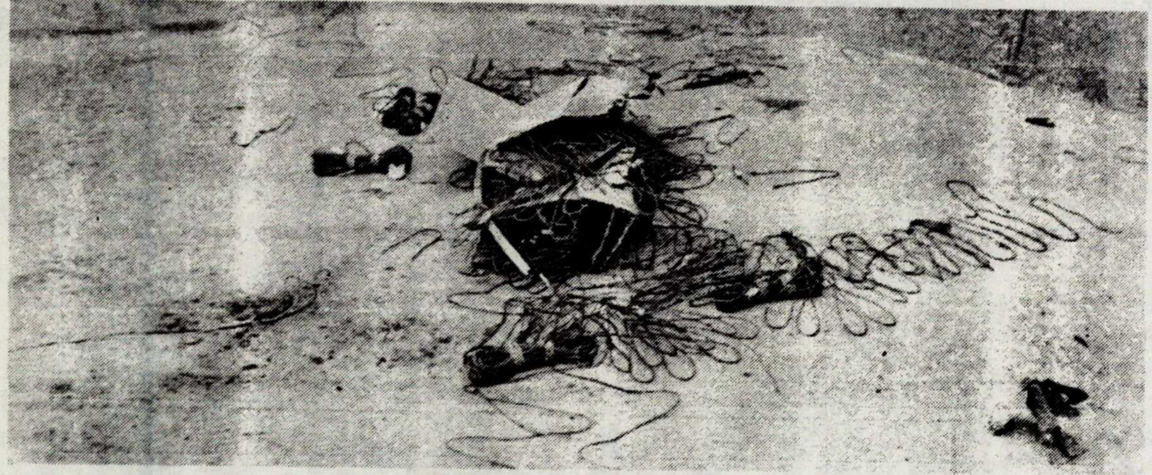

Fig. 38 - Results of the communication test on a case of non-electric detonators packaged 25/case (25 m tube length)

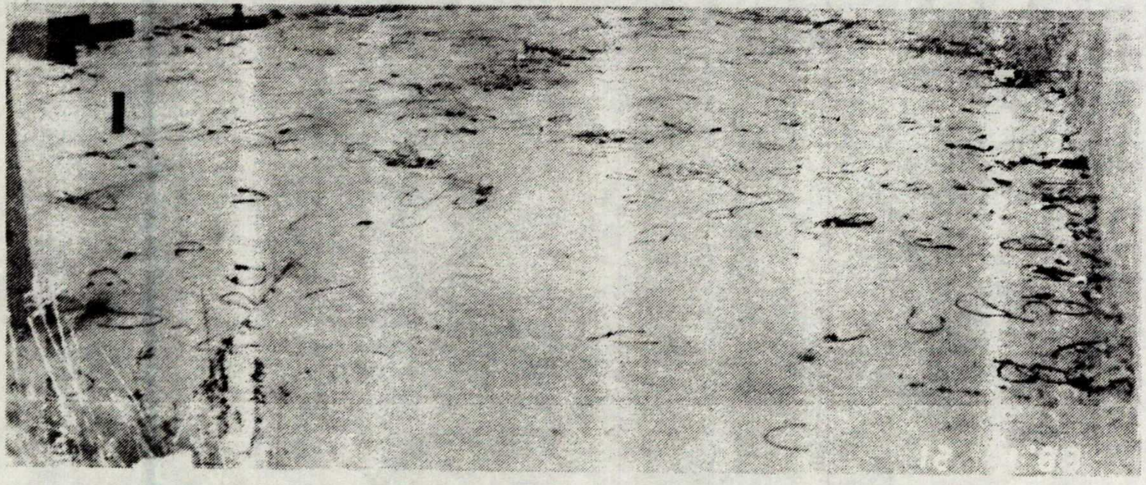

Fig. 39 - Results of the communication test on a case of non-electric detonators packaged 250/case (2 m tube length)