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A Report on the Fireworks Accident at Carmel, Western Australia

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ABSTRACT

The investigation into an accident at Carmel, Western Australia in March 2002 found that the magnitude of explosions occurring in licensed and unlicensed storage areas was significantly greater than would have been expected from the UN hazard classification of items stored within them. Use of revised UN default classification tables for the items in storage, instead of the previous classification, goes toward accounting for the violence of the explosions. The official report into the accident makes a number of recommendations that are of direct international relevance, such as a minimum safety distance of 400 m (from residential housing or defined vulnerable facilities) for licensed UN Hazard Division 1.1 magazines regardless of mass of contents (above 50 kg minimum), removal of a concession that allows for the temporary storage of fireworks in unlicensed areas for up to 14 days prior to a display, the adoption of the UN default classification table throughout Western Australia and the importation of incorrectly classified fireworks to be made an offence.

Keywords : Carmel explosion, UN hazard classification, safety distance, unlicensed storage

Introduction

On 6th March 2002, a fireworks storage facility at Carmel, near Perth in Western Australia, was severely damaged by a number of explosions and fires. There were three major explosions, occurring over a period of 14 minutes, which resulted in the total destruction of some storage units and serious damage to a number of others. Significant damage was caused to several houses and structures in the vicinity of the site, and shrapnel pieces produced by the explosions were found several hundreds of metres away from the explosion sites. The incident did not result in death or injury, but this can only be regarded as being fortunate.

The incident was thoroughly examined by the statutory investigatory body (the Department of Mineral and Petroleum Resources (MPR), Western Australia), which published a detailed report[1] of the incident in a commendably thorough, well documented and timely manner (the report was published in July 2002). In addition to containing a description of the events at the facility and in its vicinity, the report makes a number of recommendations, the implementation of which may have significant consequences for the worldwide pyrotechnic community.

This paper briefly describes the events at Carmel and also briefly examines the recommendations made by the investigatory body. Some of the nine main recommendations made in the MPR report are intended for introduction within the state of Western Australia, some are directed toward federal implementation across Australia and a number are of potential worldwide applicability. This report of the incident and presentation of the recommendations arising from an incident at Carmel is consistent with this Journal's commitment to the advancement of pyrotechnics through the sharing of information.

Brief Summary of the Carmel Incident

A comprehensive report and examination of the incident is contained in an official MPR report.[1] The description in this paper is a brief summary of those events. However, it should be acknowledged that much of the information in this summary and in the MPR report relies heavily on statements provided by the operators of the facility. In some instances, record keeping was not sufficiently detailed to confirm the statements from the operators. In other instances, the physical evidence is contrary to the statements of the operators. The net result is that the conclusions presented in this article and MPR report cannot be considered absolutely reliable. Also, while one of the authors of this paper has had discussions with one of the on site investigators of this incident, it must be acknowledged that the authors have neither inspected the site nor participated in the investigation of the incident.

The facility at Carmel was operated by a fireworks importer and display company. As such, the main business activity of this company was the storage and preparation of fireworks intended for public displays. Pyrotechnic items for those displays were imported into Australia for storage at Carmel; from there, they would be taken to display sites throughout the country. The first firework storage license for the Carmel site was issued in 1985, and this was subsequently altered and added to several times prior to the incident.

There were four licensed storage magazines (termed M1 to M4) present on the site. The details of these magazines are given in Table 1, and their distribution around the site is presented in Figure 1.

The normal practice in the days prior to a display was to remove the required items from magazine storage to temporary preparation areas for sorting, assembly, preparation and dispatch to the display venue. The temporary preparation areas used consisted of freight containers, termed FC1 to FC4 in Figure 1. Use of such temporary areas for processing and storage was permitted at the time of the incident, although the incident report notes that the regulatory body was unaware of the placement on-site of container FC4.

The trigger for the chain of events that led to the explosions at Carmel reportedly started in Shed 2. Container FC3 was primarily used for the storage of mortars and the preparation of various display pieces. The shed in which FC3 was located was used for the storage of unfired ground pack tubes, full ground packs (also called cakes or cake items), rolls of quick match, lances and portfires. On the morning of 6th March 2002, it is estimated that Shed 2 contained a range of items, such as confetti bombs, quick match, fountains and a quantity of electric fuseheads (electric matches).

Reportedly, as a 25-shot ground pack was placed on a bench within Shed 2, a shot initiated. This initiated the rest of the shots within the pack. Within a few seconds, burning stars ejected from the ground pack initiated other items stored within the container and the shed. The staff pre-

Table 1. Licensed Magazines at Carmel Site.

Magazine	Description[a]	Licensed Capacity[b]	Estimated Content (NEQ)[c] on 6 March 2002
M1	10 t steel container	5000 kg HD 1.4	700 kg ground-level items
M2	10 t steel container	5000 kg HD 1.4	725 kg ground packs
M3	Steel container	300 kg HD 1.3	941 kg aerial shells (up to 300 mm) and salutes (up to 75 mm)[d]
M4	Steel container	1500 kg HD 1.3	1626 kg (aerial shells, up to 400 mm)

a) t = metric ton.

b) HD = hazard division.

c) NEQ = Net Explosive Quantity (mass of explosive material in items, excluding packaging).

d) The initial contents estimate is given. The contents were later reported to be 300 kg.[1]

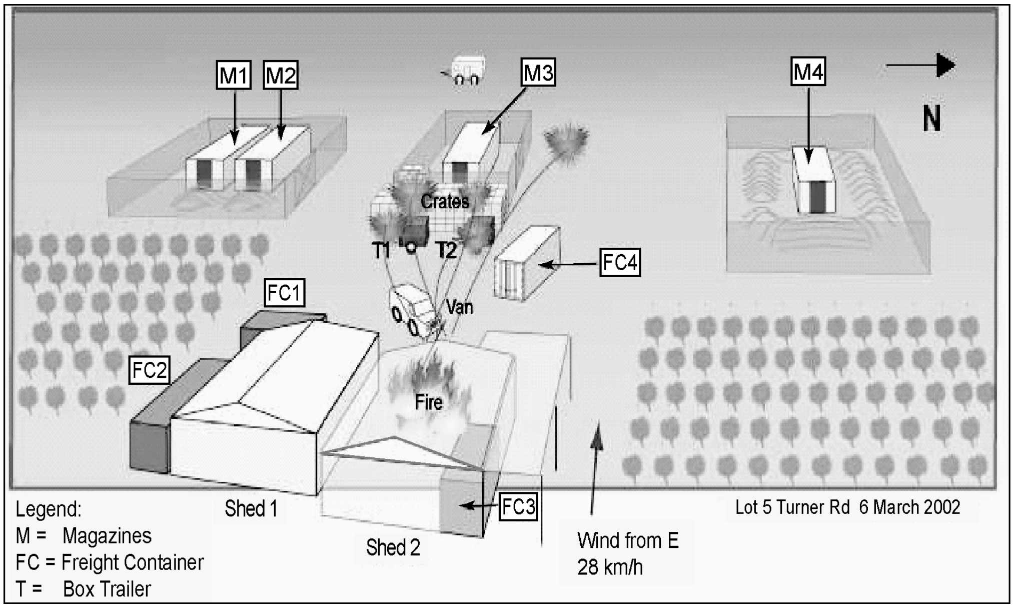

Figure 1. Outline plan of Carmel site (during initial phase of incident).

sent within the shed quickly assessed the situation as being out of control and left the building. Many burning items were observed coming out of the shed through the open door in the direction of container FC4. Soon the adjacent shed was also ignited by the fire, which spread to containers FC1 and FC2, eventually completely destroying them.

Witnesses reported seeing effects from ground packs being fired through the roller door of the shed towards container FC4. This container, the placement of which was unknown to the licensing authority, was positioned 16 m from the door of Shed 2 with the doors of FC4 opening in the direction of Shed 2. There were plastic crates, empty cardboard boxes and a quantity of wooden stakes stored close to the container walls. It is likely that stars from the ground packs struck and ignited the combustible material. Based on witness statements that the doors of FC4 were closed at the time, the ignition of the contents of FC4 would seem to have been as a result of the ignition of its contents from the heat conducted through the steel walls of the container. This is known to be sufficient to ignite the contents of such containers, and the effects of external fires on fireworks stored in steel ISO containers have been recently described in this Journal.[2] However, there is physical evidence that suggests one of the doors of FC4 was at least partially open at the time. If that was the case, the fairly rapid ignition of the contents of FC4 is even more understandable.

Shortly after the ignition of materials inside FC4, it exploded violently, sending a large quantity of steel shrapnel pieces toward magazines M2 and M3. These magazines were penetrated by the shrapnel pieces, and their contents were initiated by impact, friction or heat from the impacting fragments or, more likely, from a combination of these mechanisms. Around 5 minutes after the explosion in FC4, the contents of M2 underwent a partial detonation or a rapid deflagration. There was insufficient evidence to determine which of these explosion mechanisms was responsible for the resultant pressurization of the steel container, which failed at its welded seams. Some parts of the structure, such as roof panels and doors, were projected a short distance, and the remaining burning contents were ejected from the container.

Eleven minutes after the partial destruction of M2, magazine M3 was completely destroyed by a large explosion of unexpected violence. The investigation attributed this explosion to the partial detonation or rapid deflagration of the contents. Witnesses reported a large fireball (approximately 100 m in diameter), and a large cloud of smoke following this explosion. Small pieces of hot shrapnel were projected several hundred meters from the magazine site by the explosion in M3. Only the floor of M3 remained – the door (weighing 170 kg) was projected 370 m and the roof (380 kg) was found 295 m away. The rest of the magazine had fragmented.

Hot fragments from the explosion of M3 penetrated magazine M1, initiating its contents. No explosion occurred in this magazine, but its contents were consumed by fire. The air blast from the explosion of M3 toppled M1 over by 90 degrees.

Magazine M4, which was protected by a surrounding earth mound, was unaffected by fire or explosion. It is considered that this was due to

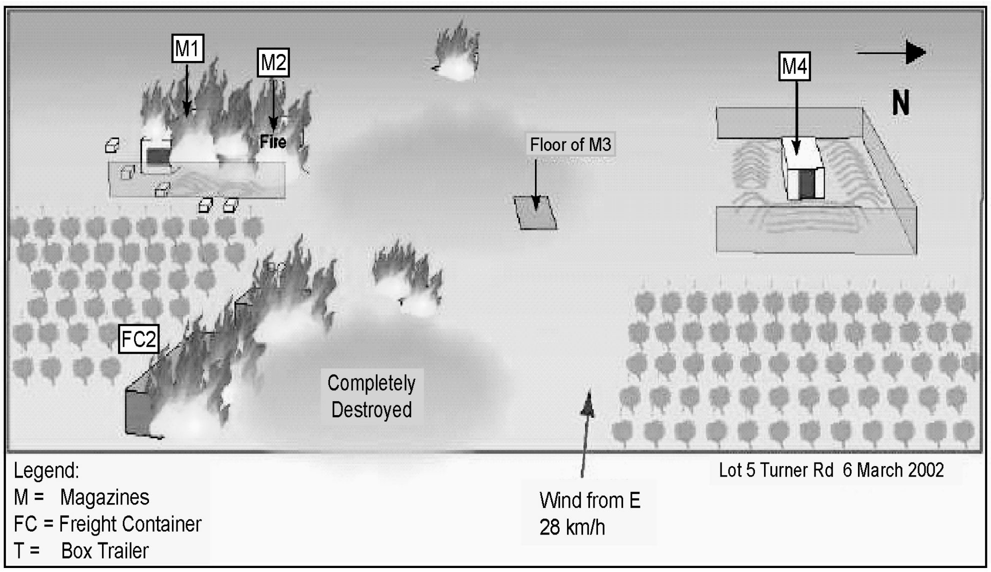

Figure 2. Location of structures following explosions.

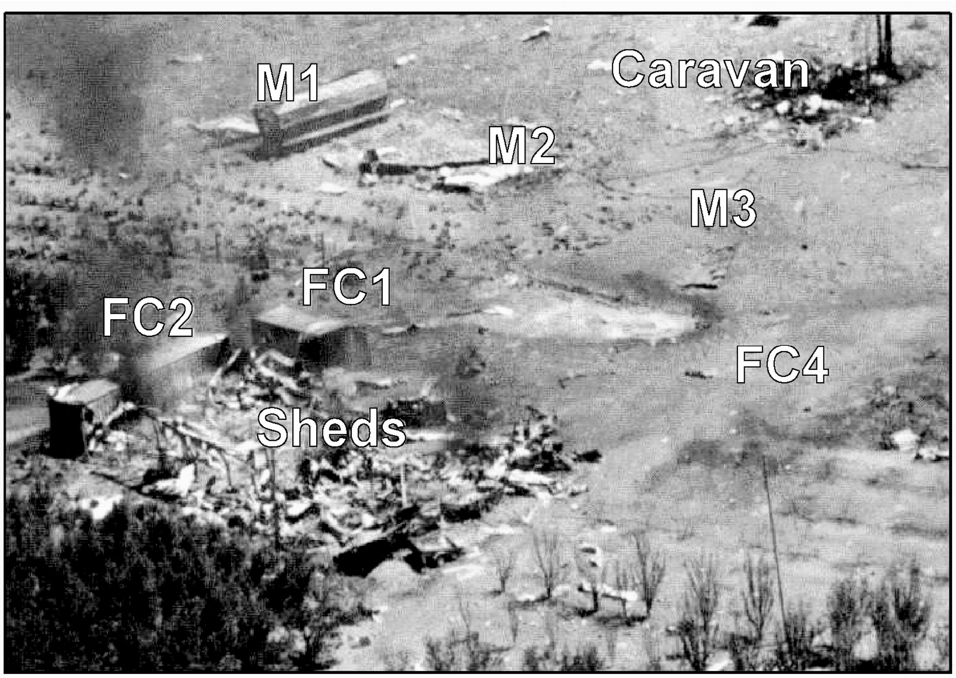

Figure 3. Aerial photograph of site following explosions.

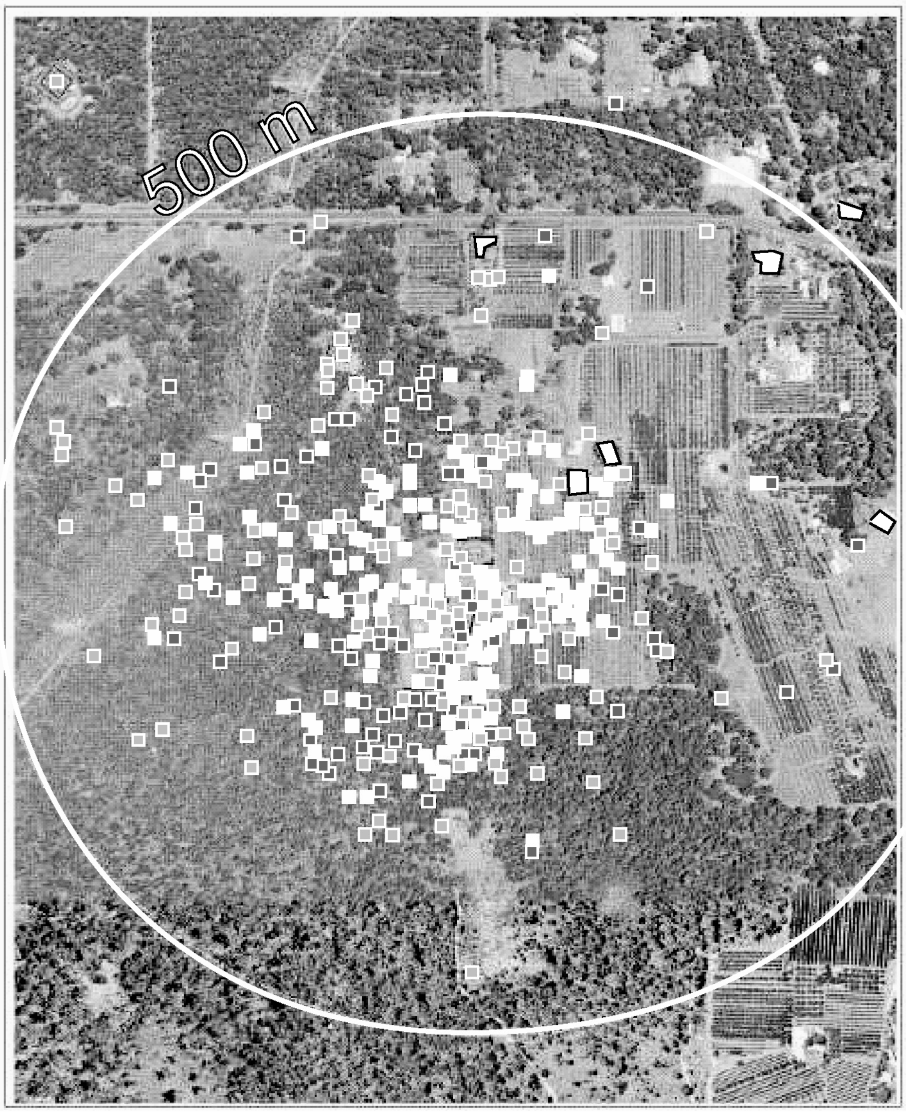

Figure 4. Combined distribution of shrapnel pieces.

the protection from flying shrapnel afforded by the earth mound.

Several bush fires started in the locality as a result of shrapnel and burning fireworks. The local fire service did not fully extinguish all fires started by the incident until the following day.

The remaining structures at the site are shown in Figure 2. A photograph of the damage is shown in Figure 3.

In addition to the damage at the site of the facility, damage to houses and other structures was reported up to a distance of 4.5 km from the facility. Most of the shrapnel was within 500 m of the facility. Figure 4 shows the distribution of fragments produced in the course of this incident.

Cause of Initiation of the First Ground Pack

The sequence of events culminating in the series of explosions at the site reportedly began with the ignition and firing of a single tube in a 25-shot 30-mm ground pack. The circumstances leading to this event merits a closer examination, since there was no obvious means of initiation.

The ground pack in question was one of a batch that had failed to fire at a previous display.

The packs were intended to be fired electrically, but they had failed to do so. The reason for failure at these displays is not known. Reportedly the packs were being adapted for hand-firing at a future display, and a key part of the modification process was the removal of the electric fusehead from the main fuse.

An operator would remove the metallic foil from the top of the ground pack tubes and then remove the electric fusehead from the ground pack. The pack would then be picked up by a second operator, who would transport the pack to another part of the working area, prior to re-fusing. Reportedly the pack in question ignited at the point when it was placed onto the ground by the second operator.

The investigation was not able to determine the reason why the shot initiated. Fuseheads are known to be quite sensitive to accidental ignition; however, most of the various possible modes of ignition involving the fusehead would be eliminated since reportedly no electric fusehead was present in the pack at the time of its initiation. Electrostatic discharge from the operator was considered to be unlikely in the belief that any such charge would likely have been dissipated during the handling of previous packs, and a discharge would have been expected at the point of picking up the pack, not when it was set down.

One possibility for the ignition of the ground pack is that there was displacement of some composition from within the ground pack, possibly caused by removal of the fusehead or disintegration of some of the several clay plugs present in the pack. This composition could then have become trapped between other materials (such as tissue paper and cardboard) within the pack. The impact from placing the pack onto the bench may then have been sufficient to ignite the composition.

The Subsequent Fires and Explosions

Following the ignition of the first shot in the first ground pack, the rest of the shots in the pack fired, projecting burning stars throughout Shed 2. This shed, which was not a licensed magazine, contained a considerable amount of pyrotechnic and other flammable material. There were at least 144 75-mm diameter aerial shells, some 15 to 20 ground packs, 25 cases of confetti bombs, 2000 electric fuseheads, some boxes of surplus quick match and assorted tubes from small ground pieces. There was also a substantial quantity of empty cardboard boxes and other combustibles in the shed at the time.

There are contradictory witness statements as to the contents of container FC4. Some state that there were no fireworks at all stored inside the container and that only packaging material was stored there. One witness statement suggests that a moderate quantity of pyrotechnic material (about 450 75-mm shells and 30 100-mm aerial shells) was stored in FC4, and that these shells were close packed instead of being in their original packaging. The violent explosion which destroyed the container within a few minutes of the incident starting in Shed 2 would suggest that the latter statement is a better reflection of the true situation.

The explosion that destroyed container FC4 was a mass explosion characteristic of high explosives of hazard division (HD) 1.1 rather than an event in the manner expected of fireworks of HD 1.3 (i.e., a minor blast and/or projection hazard but no mass explosion hazard). Previous tests described in this Journal[2] have illustrated the expected results from the initiation of a considerable quantity of HD 1.3 material inside a steel freight container, where mass explosion was not observed.

That a mass explosion did occur inside FC4 might be explained by (a) the 75-mm shells present in the container being close-packed (108 shells per box instead of 72), and (b) there may have been some salutes (which are now considered to exhibit HD 1.1 behavior) amongst the shells, as was normal company practice.[1] However, the absence of definitive information on the contents of the container makes it difficult to accurately establish the cause of the mass explosion, and the reported contents of FC4 seems inconsistent with the power of the explosion. This stresses the need for accurate record keeping if post-incident investigations are to produce reliable recommendations to prevent future incidents.

The explosion that resulted in the structural failure of magazine M2 was somewhere between the behaviors expected for HD 1.1 and HD 1.3. The magazine was known to contain mainly boxed ground packs (HD 1.4) and had an overall NEQ estimated at 725 kg. One of the firework types stored in M2 had a report as its main effect, and it is now accepted that such items can exhibit HD 1.1 behavior.[3] This may explain the unexpected violence of the event that partially destroyed the magazine.

Magazine M3 was destroyed by a very large explosion, characteristic of a detonation of a large quantity of HD 1.1 material. The magazine had an estimated 941 kg (NEQ) of up to 300-mm aerial shells and up to 75-mm salutes. According to the incident report, the blast took the authorities and the industry by surprise, since the items stored in M3 were all considered to be in HD 1.3 display fireworks.

The classification of some firework types was investigated following the Enschede disaster in the Netherlands in May 2000, and it was found that some high energy firework types tested as HD 1.1 under the UN testing regime[3,4,5] rather than HD 1.3. If these findings, which are summarized in Table 2, are applied to the contents of M3, then the hazard classification of the contents changes significantly.

Under the revised classification scheme given in Table 2, the contents of M3 would have been regarded as HD 1.1. The size of the explosion, which was thought to be from an estimated 941 kg of HD 1.3 material, is perhaps less surprising if it is thought to have come from 941 kg of HD 1.1 material. It should be stated that the firework company provided an NEQ estimate of 941 kg for magazine M3 early in the investigation, but this was revised downwards to 300 kg at a later date.[1]

Magazine M1, which reportedly contained material, mostly ground packs, with a NEQ of 700 kg classified as HD 1.4, was severely damaged by fire during the incident, but it was not destroyed by an explosion. The report considers it likely that a mild deflagration, consistent with HD 1.3 behavior, occurred within M1 as a result of its contents being initiated by hot fragments from M3. The magazine was licensed for the storage of HD 1.4 material, but reference to Table 2 shows a revised classification of HD 1.3 for ground packs, and the events within M1 are consistent with this revised classification.

Magazine M4, which contained much more material than M3, was left relatively unscathed by the events on the rest of the site. The earth mound around it reduced the likelihood of fragment impact. One wall of the magazine was struck by shrapnel, but the wall was not penetrated and the contents did not ignite.

In summary, the magnitude of the explosions came as something of a surprise to the regulatory authorities. The classifications of the items stored at the site were HD 1.3 and 1.4, for which no mass explosion would have been expected. However, if the revised classifications and the conditions of storage are taken into account, then the observed mass explosions may be explained. According to the classifications given in Table 2, magazines M1 and M2 would have had a classification of HD 1.3 (rather than HD 1.4) and magazines M3 and M4 would have had a classification of HD 1.1 (rather than HD 1.3).

The revised UN classification scheme alluded to in Table 2 is subject to revision, and it is not expected to be published until late 2004 at the earliest.

Table 2 Revised Firework Classifications Arising from Enschede Investigation Findings.[1,3,5]

Firework Type	"Old" UN Classification	Revised UN Classification
Report shells (all sizes)	1.3	1.1
Color shells (200 mm or greater diameter)	1.3	1.1
Color shells (below 200 mm diameter)	1.3	1.3
Roman candles (less than 50 mm diameter)	1.4	1.3
Boxed ground packs – report as primary effect	1.3	1.1
Boxed ground packs – color as primary effect	1.3	1.3

Report Recommendations

Nine specific recommendations were made in the incident report. Those recommendations and brief comments by this paper's authors follow:

Recommendation 1: Fireworks operators worldwide note the unforeseen explosions witnessed at the Carmel facility and conduct risk assessments of all their activities in preparing fireworks for displays and prepare Safe Operating Procedures for these activities.

Risk assessment is a key part of reducing the risk associated with any activity to a level which is as low as reasonably practicable (ALARP). This approach has been adopted in a number of countries.[6,7] The initiation of the ground pack, which triggered the whole sequence of events described in this paper, illustrates that the unexpected may occur at any time, so proper and thorough risk assessment should always incorporate such events. In addition, the consequences of unexpected initiation should be taken into consideration during the assessment of risk – in this case, the positioning of freight container FC4 may have been changed if the risk assessment had considered the possibility of an initiation of the type experienced.

Recommendation 2: That fireworks operators worldwide store all their fireworks in licensed magazines and not in preparation areas.

Short-term storage in unlicensed areas was permitted in Australia at the time of the incident. The incident report makes it clear that storage in unlicensed areas (Shed 2 and container FC4) was the major contributory factor in the escalation of the incident.

Recommendation 3: MPR considers what action, if any, is warranted in relation to compliance issues at the storage facility.

This recommendation is particular to the incident in question, and allows potential legal action (if any) to be taken. While the results of any legal action taken may be of interest to the pyrotechnic community in Australia and elsewhere, comment upon them is outside the scope of this paper.

Recommendation 4: That for the purpose of storage and transport, fireworks in Western Australia be classified in accordance with either UN testing, or by analogy of type using the UN default classification table.

This recommendation deals with the manufacturer self-classification of fireworks that are imported into Western Australia. Such classifications need to be carefully checked as a result of the incident. The notes to the recommendation make it clear that Western Australia should make use of the UN default classification table in its revised form, rather than relying on self-classification from manufacturers. The UN transport classifications for fireworks are not necessarily the same as their storage classifications. This has been addressed in the United Kingdom by the introduction of Hazard Types (HT's),[8] but this approach has not yet been applied in most other countries.

Recommendation 5: For the purpose of licensed storage of fireworks of HD 1.1, separation distances to off-site residential housing shall be in accordance with vulnerable facilities as per Table 3.2.3.2 of Australian Standard 2187.1 – 1998 "Explosives – Storage, Transport and Use Part 1: Storage", except that a minimum separation distance of 400 meters shall apply at all times.

The quantity-distance concept is consistent with common practices for establishing separation distances, and the table cited in this recommendation is similar to those cited elsewhere.[9] However, the minimum distance of 400 meters is the separation distance for 731 kg NEQ of HD 1.1 material. Failing to accept the lesser hazard posed by smaller quantities of HD 1.1 fireworks is tantamount to declaring fireworks to be significantly more hazardous than other HD 1.1 explosives. This is a position that must be hard to defend, especially in this case where the accuracy of statements of the operators regarding the quantities of fireworks present at the Carmel site is in serious question. As a matter of comparison, it might be of interest to compare this 400 meter distance with the amount of HD 1.1 material allowed for storage under the American Table of Distance for Storage of Explosives,[10] which is 4000 pounds (approx. 1820 kg) for unbarricaded magazines and 40,000 pounds (approx 18,200 kg) for barricaded magazines.

Recommendation 6: That MPR develops a Safety Bulletin to inform fireworks operators world-

wide of requirements based on revised classification of fireworks.

The changes to various regulations that are proposed by the recommendations made in the incident report need to be communicated to the industry. This recommendation proposes a mechanism for doing so.

Recommendation 7: That WA (Western Australia) takes a leadership role in discussions with other jurisdictions to adopt a nationally consistent approach to the revised classification of fireworks.

Each State within Australia has its own set of regulations. This recommendation proposes that these regulations are revised to ensure consistency. This approach is likely to be of benefit to the industry, since it can be expensive and time-consuming to deal with, for example, having different regulatory requirements at the place of importation and the place of storage.

Recommendation 8: That MPR amends the Firework Permit application form to enable the checking of safety controls for temporary storage at a display.

It is a requirement in Western Australia that display operators have to apply in advance for a permit for each separate display. This recommendation proposes that the application form is adjusted to incorporate the identification of revised requirements for the temporary storage of fireworks based on changes in classification.

It should be noted that in Western Australia, the use of fireworks by the general public has been prohibited since 1967.

Recommendation 9: That Government gives a high priority to the development of both the Dangerous Goods Safety Bill and associated explosives (incorporating fireworks) and dangerous goods regulations for a number of reasons, in part to put in place appropriate controls for the preparation and assembly of fireworks and to make it an offence to import incorrectly classified fireworks.

At the time of the incident, the main pieces of legislation governing the use and storage of explosives in Western Australia were the Explosives and Dangerous Goods (Explosives) Regulations 1963 and the earlier Explosives and Dangerous Goods Act of 1961. The report recommends a complete revision of these pieces of legislation, since it considers both to be out of date.

Conclusions

There is some uncertainty about the precise cause of the initiation of the first ground pack, the ignition of the contents of FC4, and the quantities of fireworks being stored. That not withstanding, the nature of the explosions in FC4, M2 and M3 surprised many. The magnitude of the explosions was unexpected from material of HD 1.3 and 1.4, but use of a revised UN classification table, in which many items previously considered as showing HD 1.3 behavior have been reclassified to HD 1.1, goes some way to explaining why the magazine contents behaved as they did.

Use of the revised classifications is likely to have significant consequences for the worldwide pyrotechnic community. Such reclassification will place additional restrictions on the storage and transport of a significant proportion of the items in use. This is very likely to adversely affect the business position of the commercial pyrotechnic community, since added expense is inevitable.

Some other aspects of the incident are familiar to the pyrotechnic community. The storage of flammable material near or beside a magazine or storage area is again shown to be incompatible with safe practice. The use of unlicensed and inappropriately located storage areas is shown to be a major contributory factor in the escalation of the incident from a fire in a small area to the final situation described. Finally, some unwise work practices are likely factors in the initiation and spread of the fire and explosions.

Acknowledgements

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