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A case study in forensic chemistry: The Bali bombings

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Abstract

The Bali bombings on 12 October 2002 killed 202 people and caused international outrage. The police investigation referred to as "Operation Alliance" involved the Indonesian National Police, the Australian Federal Police and others, resulted in the arrests of key personnel and exposed the link between Jemaah Islamiah (JI) and al-Queda.

This paper describes aspects of the investigation from a forensic chemists perspective. The recovery of water soluble residues from blast scenes and suspect's residences is a challenging task that requires a meticulous and methodical approach. The concept of deploying forensic chemists and setting up a "mobile laboratory" from the outset proved to be a highly effective and efficient way to process large numbers of samples and assist investigators with relevant information at the time that it was most needed. It also identified the need for a new generation of field portable instruments.

Keywords: Case study; Improvised explosives; Operation Alliance; Mobile laboratory; Bali bombing

1. Introduction

The bombings that occurred in Bali on the 12 October 2002, were the most callous act of terrorism in Australian history. It was a typical busy Saturday night in the main tourist area of Kuta when, shortly after 11.00 pm a bomb exploded in Paddy's Bar. Moments later a second and much larger bomb exploded on the roadway outside the popular Sari night club, and then a third bomb, which was small in comparison to the first two devices, exploded approximately 10 km away, near the United States and Australian Consulates. Two hundred and two people were killed of which 88 were Australians, and many hundreds more were injured.

Initial reports from that night started with a suggestion that gas cylinders had exploded. Stories of confusion, panic and destruction were relayed back to Australia. Two Australian Federal Police (AFP) forensic officers travelling to Jakarta were redirected to the scene to make an assessment. They reported massive structural damage, burning motor vehicles and buildings, emergency personnel struggling to cope and a large crater in the roadway outside the Sari Club. They immediately recognised the scene for what it was and initiated a full police investigation, which became known as Operation Alliance.

2. Operation Alliance

The Australian Federal Police (AFP) sent a team of investigative and forensic officers to Bali to assist the Indonesian National Police (INP) in their investigation. Operation Alliance became the largest investigation ever undertaken by any Australian police force and was truly an "alliance" between the Australian, Indonesian and international law enforcement communities. Although there were many forensic facets to the operation, such as the involvement of odontologists, pathologists, and police disaster victim identification specialists, this article only relates to some aspects of the chemistry component of the criminal investigation.

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3. Detail of the events of October 12

It is estimated that the Paddy's Bar explosion involved between 1 and 5 kg of TNT contained within five lengths of PVC pipe of 50 mm diameter sewn into a tartan lined black vest worn by the suicide bomber. Tiny fragments of tartan fabric were recovered from sites surrounding the blast epicentre. Numerous pieces of metal were also found amongst the debris and these were found to match fragments recovered from living and deceased victims. Connective tissue and spatter marks were visible on the ceiling above the epicentre. The common organic high explosive (HE) known as trinitrotoluene (TNT) was identified in this material. The notable absence of a crater and extrapolation of spatter indicated the position of the bomb to be between 80 and 120 cm above the floor. This was the first evidence to indicate the involvement of a suicide bomber. Later, analysis of this biological material revealed that it had all come from the one individual. A dismembered head and two lower legs were found amongst various body parts at the morgue. As samples for DNA analysis were being collected from all the significant body parts as a routine part of the Disaster Victim Identification (DVI) process, it was a simple matter to compare profiles and link those parts with the ceiling spatter. These body parts turned out to be a rich reservoir of precious trace evidence. Investigators, now aware of this DNA database and suspecting the involvement of a suicide bomber, sought out that person's parents in order to establish his true identity. To our surprise, the DNA profile of that union did not match. A further search of the database however, did in fact reveal the presence of this profile and it was in many tiny body parts that were found near the Sari Club. This observation implicated the involvement of a second suicide bomber.

The second and largest device was detonated at the nearby Sari Club at 11:08 pm, 15 s after the Paddy's Bar explosion. It is estimated that over 350 people were in the club at this time. The force of the blast was so strong that it registered on seismographs in neighbouring countries. It is estimated that an improvised explosive mixture with an estimated power equivalent of 150 kg of TNT had been used. Exhaustive analyses revealed the presence of the chlorate ion in and around the crater. When arrested the offenders stated the bomb was made from a mixture of potassium chlorate, sulphur and aluminium, boosted by TNT. It is now believed that the improvised explosive mixture, more than 1 tonne in total, was contained in 12 four-drawer plastic filing cabinets interconnected with detonating chord which is made from another organic high explosive known as pentaerythritol tetranitrate (PETN). This device was placed in the back of a Mitsubishi L300 van and parked outside the Sari Club. It was also initiated by a suicide bomber. Remarkably, some fragments from this individual survived the blast and were used to establish his identity through DNA analysis.

The third bomb, referred to in the media as the "USA Consulate Bomb", was detonated about 10 km away on a public street near the Unites States and Australian Consulates. It was made from a relatively small amount of TNT and was initiated remotely using a mobile phone about 45 s after the Sari Club bomb. No injuries were caused by this bomb, however this site was important as it was rich in physical evidence.

4. The breakthrough

The initial breakthrough came about through forensic examiners from the INP finding impressed numbers in chassis fragments that survived the main blast. Although both chassis and engine numbers appeared to have been filed away in an attempt to avoid detection, another number otherwise unknown to the general public had been stamped on the chassis rail during a routine vehicle inspection by the Indonesian authorities. Through the finding this number, the INP investigators were able to trace the vehicle back to a Javanese man named Amrozi (referred to in the media as "the smiling assassin") who was a key member of the terrorist gang. It has subsequently been determined that he purchased the van and chemicals and attended meetings to plan the crime. Amrozi confessed and named his co-conspirators Samudra, Idris, Dulmatin, Muklas and Ali Imron.

5. The chemistry

An explosion is merely an energetic reaction that results in the rapid release of gas. The rate of the reaction determines the destructive consequences [1,2]. Improvised explosives using inorganic components such as ammonium nitrate with fuel oils (ANFO) usually have relatively low velocities of detonation and are suitable for "pushing" applications such as in earthworks and mining [3]. ANFO is the most common explosive used in Australia with about 650,000 tonnes used annually [4]. Organic explosives such as TNT, PETN and RDX are characterised by high velocities of detonation (up to 9000 m/s) and have applications in detonators, boosting chargers and military ordinance [5]. Although high explosives are used to initiate and boost low explosives, they are usually totally consumed in the ensuing reaction and rarely leave traces for the forensic chemist to find.

Contrary to intuition, but accepted by most experienced practitioners, large explosions usually leave less tell-tale residue than smaller ones. Most large bombs are improvised and made of inorganic oxidizers such as nitrates, chlorates and perchlorates and fuels such as diesel oil, sugar, sulphur or reactive metals such as aluminium dust [2]. The release of such tremendous energy often causes a fire which is invariably fought with water. The bomb outside the Sari Club caused the thatched roofs over the courtyards to catch on fire and the blast broke a water main under the roadway causing the crater to fill. The quantity of post blast residual matter was reduced through dissolution and being washed away down gutters and drains. The warm and humid climate of the tropics compounded the problem as atmospheric moisture

Fig. 1. Water filled crater outside the Sari Club.

combined with the fuels and carbonaceous materials (traffic soot) to further reduce the amount of reactive chemicals to be found (see Fig. 1).

6. The incident scene

Good forensic science starts at the crime scene where careful observation is required in order to collect important evidence and reconstruct events [6]. In the case of explosion scenes the information that can be gained concerning the type of explosive, quantity and bomb architecture is vital for successful apprehension of the perpetrators [2]. It is important to ensure details such as the location of the sample and the identity of every person involved in the chain of possession is accurately recorded and it is also imperative that the risk of contamination be minimised from the outset [6]. A professional law enforcement organisation has procedures in place to ensure this occurs and that the integrity of samples is maintained from scene to court [6,7]. Crime scenes where explosions have occurred are particularly challenging to process, due to their complexity. Microscopic fragments of explosive and its residues will be spread throughout a large amount of post blast debris [2].

7. The mobile laboratory

Provision of information at an early stage in an investigation is extremely helpful in rapid identification of suspects. The AFP deployed part of its mobile laboratory to Bali to assist with the collection of trace evidence and explosive residues. AFP practice is to set it up as close to the forward command post for security and effective communications, and as close to the scene as to be convenient, yet far enough away to minimise the risk of contamination. A nearby motel room was cleared and prepared for the installation of such instruments as a microscope with camera, an ion mobility spectrometer (IMS), a portable infra-red spectrometer (FT-IR), and a range of reagents for various presumptive and other spot tests. Of particular interest were those for detecting strong oxidizers (diphenylamine reagent, modified Griess test (nitrites/nitrates), aniline hydrochloride for chlorates, and others such as Nessler's for the ammonium ion, and so on, see Table 1). From lessons learnt in Bali the AFP has since purchased a portable ion analyser, which is used for the instrumental analysis of these inorganic ions that are commonly found in improvised explosives.

The rationale behind a mobile laboratory is to produce timely, albeit tentative findings for the investigators whilst reducing the number and volume of samples to be sent to the main laboratory for more exhaustive confirmatory analyses. In such an important case as Operation Alliance, which involved victims from 22 countries and presented the possibility of a prosecution in the International Court, it was considered prudent to have findings corroborated by other reputable laboratories. On occasions, up to four samples were collected; one for the main AFP laboratory in Canberra, a duplicate for the host country, and one each for the Victoria Police Forensic Services Centre (VPFSC) and the Forensic Explosives Laboratory (FEL), Britain.

The contribution of the scientists from Britain was particularly praiseworthy, for not only did they bring a wealth of experience to the table during the early stages of the investigation, they also undertook an environmental survey to establish the background levels of various ions (including chlorate,

Table 1
Colorimetric screening methods for explosives [1,8,9]

Test	Target explosives	Colour change
Alcoholic KOH: 3% KOH in ethanol	TNT	Purple/brown
	2,4-DNT	Yellow
	2,6-DNT	Yellow
	Tetryl	Violet
Griess reagent: methanolic *N*-(1-napthyl)ethylenediamine in the presence of sulphanilic acid and zinc dust	Nitrates and nitrites	Purple
	Nitrate	Pink to red
	Nitrocellulose	Pink
	Nitroglycerin	Pink to red
	PETN	Pink to red
	RDX	Pink to red
	Tetryl	Pink to red
Diphenylamine: reaction with diphenylamine in concentrated sulphuric acid	Chlorate	Blue
	Nitrates	Blue
	Nitrocellulose	Blue-black
	Nitroglycerin	Blue
	PETN	Blue
	RDX	Blue
	Tetryl	Blue
	TATP	Blue
Aniline hydrochloride: aniline acidified with hydrochloric acid and activated with potassium chlorate	Chlorate	Blue
	Hypochlorite	Blue
	Chlorite	Blue
Nessler's reagent: mercury-iodide solution (commercially available)	Ammonium ions	Yellow/brown
	Nitroglycerin	Black
	TNT	Red

nitrate and so on). This is essential information from a scientific perspective.

8. The analytical approach

The approach taken in analysing post debris starts with a number of presumptive tests (see Table 1). These presumptive tests generally involve reactions resulting in a distinctive colour. These tests require careful use of blanks and positive controls to ensure valid results, and while rapid they are not definitive [1,2,8,9]. Samples that yield promising results are collected and packaged for further examinations and analysis in the laboratory (see Table 2) [1,9]. The level of confidence rises with each positive result. A satisfactory level of confidence in establishing the identity of a questioned sample is generally achieved after corroboration from two independent techniques. This is known as "orthogonal" testing.

Orthogonal testing is relatively easy to achieve when dealing with bulk material. For example, a very high level of confidence would be expressed in an identification based on an infra-red spectrum and a chromatogram where retention times have been shown to be precise and reproducible. The problem becomes more difficult when dealing with trace quantities, and especially so when they are from an inorganic source which may occur naturally in the environment, or if they are volatile and unlikely to persist in the area. It could be argued (and was) that although chlorates are not normally found in the environment, it may be possible in such a scene to have detected residues of unburnt matches that fell from victims during or after the blast! For this reason, elevated surfaces were preferred sites for sampling.

Some forensic explosive laboratories favour liquid chromatography in combination with mass spectrometry (LC–MS) as the principle technique [10], whilst others prefer gas chromatography with either a thermal energy analyser (GC–TEA) [11,12], which is specific for compounds containing the nitro and nitroso functional groups; or positive and/or negative ion chemical ionisation mass spectrometry (GC–nciMS) detectors [9,13].

Time of flight mass spectrometry (TOF-MS) can get past the problem of thermal instability by performing very rapid analyses using a short narrow bore column, and deconvoluting the resulting chromatogram by exceedingly rapid mass spectral analysis. This however raises the question as to whether it is truly orthogonal testing for if the chromatography does not resolve co-eluting compounds, then is it really only the one technique?

Capillary electrophoresis (CE) was viewed as the emerging technology to displace ion chromatography (IC) as the preferred method for the analysis of inorganic ions [13]. It seemed to have the greatest promise for conversion to miniaturisation to produce field-portable units. Certainly the CE technique has acceptable detection limits and the capacity to resolve ions with an extraordinary number of theoretical

Table 2
Analytical methods for explosive residue analysis [1,9–13]

Analytical method	Target explosives	Detection limit	Advantages	Limitations
TLC	Organic[a]	μg to sub-μg	Simple inexpensive rapid	Low resolution susceptible to contamination
GC–ECD	Nitrogen-containing[b]	pg	Rapid selective highly sensitive for nitrogen-containing compounds	Requires volatile analytes insensitive to hydrocarbons
GC–TEA	Nitro-containing[c]	pg	Sensitive and selective for nitro compounds	Requires volatile analytes expensive limited to nitro compounds
HPLC-UV or DA	Organic[a]	ng	Sensitive	Low selectivity
IR	Organic[a] and inorganic[d]	μg	Universal organic and inorganic compounds have characteristic spectra	Residues require separation prior to analysis
MS	Organic[a] and inorganic[d]	pg to ng	Rapid selective sensitive reliable	
GC–MS	Organic[a] (low bp) plasticizers[e] stabilisers[f]	pg to ng	Rapid selective reliable sensitive	Limited to volatiles
LC–MS	Organic[a]	pg to ng	Analysis of non-volatiles	Requires interface between HPLC and MS
SEM/EDX	Inorganic[d]		Organic and inorganic samples	Expensive, requires expert operators

[a] Organic explosives: DNT, TNT, EGDN, NG, PETN, NC, RDX, HMX, TATP, HMTD.
[b] Nitrogen-containing explosives: DNT, TNT, picric acid, EGDN, NG, PETN, NC, nitrate salts.
[c] Nitro explosives: DNT, TNT, picric acid, EGDN, NG, PETN, NC, RDX, HMX. RDX, HMX, nitrate salts, black powder.
[d] Inorganic explosives: nitrate and chlorate salts.
[e] Plasticizers: phthalate and sebacate esters.
[f] Stabilisers: diphenylamine (DPA), ethyl centralite (EC).

plates; however it has fallen out of favour with many analysts due to difficulties in obtaining reproducible migration times.

In order to mount an argument that an inorganic ion was part of the explosive mixture, the forensic analyst must demonstrate its concentration to be significantly higher in and around the crater than in the background. A large number of analyses may be required to achieve this objective. At this stage of technological development there are no instruments available on the market for such applications.

The total number of samples analysed at the AFP laboratory was in excess of 2000 (ca. 2400). Many of these were items of clothing recovered from victims as they returned to Australia. The chlorate ion was identified in a small number of samples (six in total), however this is a remarkable observation in itself as such a reactive ion is unlikely to persist in the environment. Notably, it was recovered from crevices in the bitumen surface of the blast crater, and on elevated surfaces of lamp posts facing the blast.

Scientists from the FEL searched the pitting in the soft aluminium of street signs that had been retrieved from nearby roof tops using an SEM EDX. They reported elevated levels of chloride, low levels of chlorate and but only marginally higher than background levels of potassium. Sulphur was not detected.

Soils from in and around the blast seat were analysed by scientists from the AFP using X-ray fluorescence

Fig. 2. The newspaper with a barely visible footprint on its surface.

Fig. 3. The footprint in aluminium dust on a black gelatin lift.

spectroscopy. No evidence was found to indicate higher than background levels of any of the elements implicated.

The organic explosive TNT was detected using IMS at the two other scenes and confirmation was achieved by both GC–TEA and GC–nciMS.

The findings of the AFP in relation to chlorate and TNT were corroborated by the VPFSC and the FEL using different procedures and techniques. As the police investigation progressed, confessions from the accused added further corroboration with TNT, potassium chlorate, sulphur and aluminium being volunteered as the ingredients for the main Sari Club bomb, and TNT being the main charge in both the other bombs.

It should be borne in mind that these bomb scene analyses formed part of wider investigation. About 4 months after the incident the police investigators led the forensic team to a

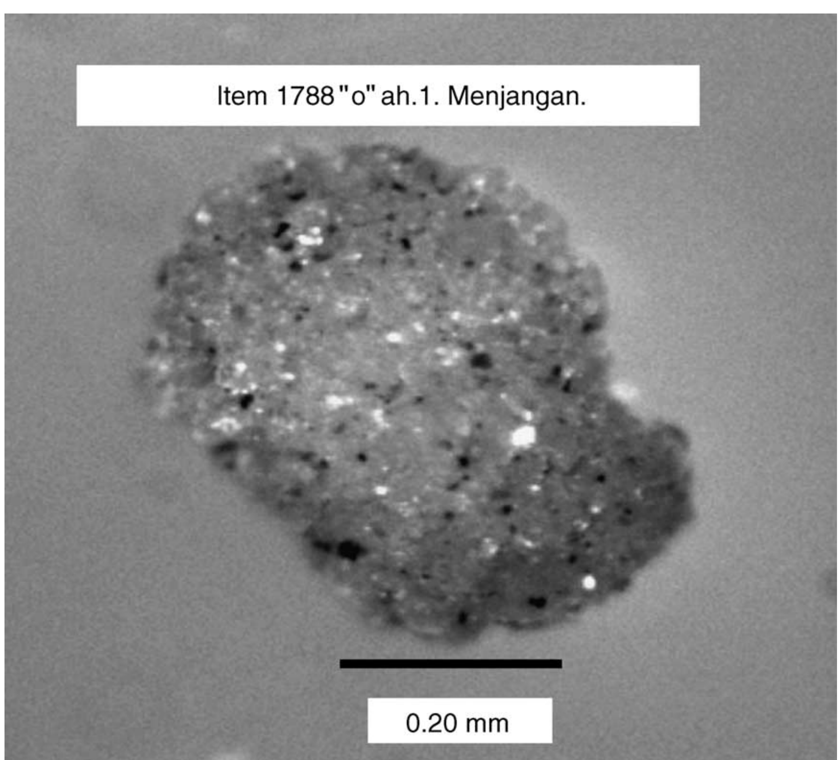

Fig. 4. A microscopic particle of potassium chlorate, sulphur and aluminium found in vacuumings from suspect premises.

suburban dwelling in Denpasar where it was alleged the bomb was constructed. Although an initial cursory inspection provided little encouragement, a mass of physical, chemical and trace evidence was harvested from this scene. To mention but two, minute particles of the explosive mixture were recovered from vacuumings taken from the gaps in the tiled floor and a barely visible footprint in aluminium dust was found on a sheet of newspaper (see Figs. 2–4).

9. Conclusion

The "mobile laboratory" concept proved to be effective in providing valuable information to the investigators at a time when it was most needed.

A multi-jurisdictional response is the most appropriate way to effectively deal with an incident involving mass casualties from many nationalities because it allowed the independent forensic strengths of each jurisdiction to be shared, whilst reducing the workload on individuals. A high level of confidence can be expressed when different laboratories from different jurisdictions arrive at the same conclusion using their own independently developed and validated methods.

The forensic chemist's contribution to Operation Alliance was significant and helped lead to the early arrests of offenders, thus thwarting another similar incident from occurring and saving countless unknown lives and suffering.

10. Personal comments (David Royds)

Participation in an investigation of this magnitude demands an intensity of purpose that normally protects one from joining in the bereavement journey of the relatives mourning their loved ones. But in its enormity there were periods of frustration caused largely by instrument failure, and tedium that made it difficult to manage until the results of our work turned those feelings of hopelessness to exhilaration.

The Bali bombings confirmed my deeply held belief that forensic scientists should aspire to develop a broad understanding of a wide range of evidence types in order to be most effective in such situations. Scientists must be able to work in the morgue to recover evidence from bodies, examine scenes and interpret the damage so as to collect material that is most likely to produce evidence, search suspect premises whilst minimising the potential for cross contamination, and conduct a wide range of analyses in the laboratory, including fibre examinations, paint and plastic analysis as well as post blast explosive residue analysis, and interpret all the scientific observations in an objective manner.

In hindsight, it was a privilege to be involved in Operation Alliance with friendships being forged between like-minded people from around the world. The unifying effect of a world outraged by the senseless acts of a religious fundamentalist minority will ensure those who use terrorism will not win.

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