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Static Fires at Retail Petrol Stations:

An examination of the myths and facts about fires caused by static electricity and exploding mobile phones

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This report was produced by the Australian Transport Safety Bureau (ATSB), PO Box 967, Civic Square ACT 2608.

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1. EXECUTIVE SUMMARY

There have recently been a number of media reports about the ability of static electricity to ignite fires while motorists have been refuelling at petrol stations. Although the reports have raised awareness among motorists about the hazards of static electricity, they have also led to considerable speculation about the potential for mobile phones to explode. The purpose of this paper was to examine the risks associated with static ignited fires at petrol stations. Specifically, the paper:

- explored the myths and facts about exploding mobile phones and static ignited fires during refuelling;
- examined the findings of studies on static-related fires;
- described the hazards of container fires;
- explored the physical science of static electricity; and
- provided an overview of the chemistry of petrol combustion.

A review of the literature revealed that, between 1993 and 2004, there were 243 reported incidents of fires breaking out at petrol stations around the world. Although the fires were claimed to be caused by exploding mobile phones, experts have subsequently revealed that not one of the incidents was associated with telecommunication equipment. Instead, many of the fires were ignited by the discharge of static electricity from the human body.

Static electricity is a common phenomenon with motor vehicles. The static shock which motorists experience when exiting a car is predominantly caused by friction between the motorist and the seat. The static electricity that has been generated usually discharges when the motorist touches the metal car door on exiting. However, if the first point of contact with metal happens to be the fill point of the fuel dispenser nozzle, the spark can ignite the petrol vapours and cause a brief flash fire. The likelihood of this occurring is higher when the person re-enters their vehicle during refuelling.

In contrast to refuelling a vehicle, the risk of a fire igniting from a static charge is higher when an unearthed container is being filled with fuel. The risk is particularly high when the fuel is spilt or being 'splash filled'. Evidence suggests that refilling containers (either metal or plastic) on the back of a pick-up truck is especially hazardous. This is because the friction between the surfaces of the moving vehicle and the container can build up sufficient energy to cause a spark between the container and the dispenser nozzle, resulting in ignition of the fuel vapours in the air.

In recognition of the potential for fires to ignite at petrol stations due to static electricity, the report provides a number of safety tips for motorists. These include safety tips to minimise the build up of static charge and strategies to control the effects of static discharge.

2. INTRODUCTION

Can static electricity ignite a fire at a retail petrol station? According to media reports, there have been a number of incidents in Australia and overseas where static electricity has started a fire while the motorist was refuelling their vehicle. Although the reports have raised concern among the public about the possibility for static-ignited fires to occur, they have also led to considerable speculation about the potential for mobile phones to explode. The purpose of this paper is to examine the risks associated with static ignited fires at petrol stations. Specifically, the paper:

- explores the myths and facts about exploding mobile phones and static ignited fires during refuelling;
- examines the findings of studies on static-related fires;
- describes the hazards of container fires;
- explores the physical science of static electricity; and
- provides an overview of the chemistry of petrol combustion.

3. EXPLODING MOBILE PHONES

Between 1993 and 2004, there were 243 reported incidents of fires breaking out at petrol stations due to mobile phones. However, according to Dr Adam Burgess from the University of Kent, not one of these incidents occurred as a result of a sparking mobile phone. In fact, there is no evidence to indicate that any petrol station fire has been ignited from electrical equipment.

If the dangers of using mobile phones in petrol stations appear unfounded, why do retailers continue to warn motorists against using them? According to Burgess, mobile phone warnings developed as part of a global drive to increase safety in the late 1980’s. This was largely in response to the Piper-Alpha oil rig disaster just off the Scottish coast in 1988, in which 167 oil-workers lost their lives. The accident triggered a number of safety precautions across the British oil industry, and subsequently led to a proliferation of mobile phone warning labels at retail petrol stations.

Perpetuated by the rise of the Internet, warnings about the potential for mobile phones to explode or ignite in the presence of petroleum fumes were in circulation by the late 1990's. Included among the hoax warnings was an allegedly official e-mail from the major oil company, Shell. The email described a number of incidents that occurred as a result of mobile phones ringing at retail petrol stations (see http://urbanlegends.about.com/library/bl-cellphone-gas-fires.htm).

The e-mail was originally sent to a Shell employee based in Jamaica as an e-mail attachment. Without checking the authenticity of the incidents, the e-mail was forwarded on to various employees and external agencies.

In response to the e-mail, Shell Malaysia denied having issued the warning (see http://www.shell.com/home/Framework?siteId=my-en&FC2=&FC3=/my-en/html/iwgen/news_and_library/press_releases/2004/fakeshellon_internet_0531.html). In addition, Shell UK issued an e-mail to the mobile phone industry, stating that:

> "…the email is from a non-Shell source and that the originating email was an Internet hoax. This would indicate that the three cases being referred to are completely fictitious…Shell has no knowledge of any specific incident of ignition that occurred as a result of using a mobile phone on forecourts."

A review of the scientific literature suggests that there is no demonstrated evidence to support the theory that mobile phones can ignite at petrol stations. In fact, prior to the distribution of the hoax e-mail, Shell UK had initiated a study on the risks of a radio frequency spark from mobile phones. In its final report, Shell UK concluded that:

> "…portable cell phones properly used do not represent a meaningful hazard on the retail forecourt. Without doubt, apart from the human acts of smoking and

> striking a match, the thing that represents the greatest hazard on the retail forecourt is the motorcar!"[1]

A number of other studies were conducted by phone manufacturers and researchers to determine whether the allegations were genuine. In line with the findings determined by Shell UK, the results provided no evidence to suggest that mobile phones can explode. According to a research paper prepared for the Motorola Corporation[2], the auto-ignition temperatures needed for ignition are much higher than the normal operating temperatures of mobile phone components. The report states that hot surfaces would only be an ignition concern during a malfunction of the phone or battery.

Similarly, research conducted by the School of Industrial Engineering at the University of Oklahoma found no relationship between exploding mobile phones and fires at retail petrol stations. In 1999, the school conducted a subjective assessment of the potential for a mobile phone to cause an explosion based on historical evidence and expert opinion. The report determined that mobile phones do not pose a safety hazard at petrol stations. Furthermore, it concluded that no recommendations for further research or action are required from the mobile phone or petroleum industries. A copy of the report can be obtained at http://urbanlegends.about.com/gi/dynamic/offsite.htm?site=http://www.ou.edu/engineering/emc/projects/GS1%5FX.html.

Despite scientific evidence to the contrary, countries around the world continue to caution customers about the dangers of using mobile phones in the vicinity of petrol pumps. This includes Australia, where petrol pumps display stickers that caution motorists to turn off their mobile phones while refuelling. Without any supportive evidence, however, such precautionary action raises the question as to why service stations continue to provide warnings against mobile phones.

The answer is provided by Mobil Oil Australia. In 2004, the oil company issued a memo to all retail site staff to explain the need for mobile phone warnings. It stated that, while Mobil has no experience of fires being caused in this manner, most mobile phone manufacturers do not certify their equipment as safe to use in hazardous areas. It explained that, in accordance with dangerous goods regulations[3], it is a requirement that electrical equipment used within hazardous areas be certified intrinsically safe and that this is not the case with most mobile phones. In addition, the memo explained that mobile phone warnings are used to reduce the chance of fuel spill and fire caused by motorist inattention.

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1 Millington, K. S. (1991, July). Radio telephones in cabs – avoiding the big bang. Petroleum Review, pp 337-339.

2 Exponent Failure Analysis Associates (1999, December). Cell Phone Usage at Gasoline Stations. Available at http://www.sfowler.com/esdjournal/cellphonereport.pdf

3 For an example of regulations, see Section 95 (Electric apparatus and wiring) in NSW Dangerous Goods Regulation 1999, available at http://www.legislation.nsw.gov.au/fullhtml/inforce/subordleg+453+1999+FIRST+0+N

4. STATIC IGNITED FIRES DURING REFUELLING

Fires caused by static electricity at retail petrol stations are uncommon. This is because the open air environment of petrol stations is not conducive to the conditions required for static to ignite the fuel vapours. However, there have been a small number of cases that have demonstrated that static-ignited fires at petrol stations do occur. According to investigations conducted by the oil company BP, the fires have been caused by a discharge of static from the motorist's body (see http://news.bbc.co.uk/2/hi/uk_news/england/kent/4366337.stm).

Static electricity is a common phenomenon with motor vehicles. The build up of electricity is often noticed by passengers and drivers when they receive a mild electric shock as they exit their vehicle. The shock is caused by friction between the person's body and the seat, and effectively causes both the person and vehicle to be electrically charged. Typically, the static electricity is discharged when the person touches the metal car door on exiting. However, if the first point of contact happens to be the metal fill point of the dispenser nozzle, the spark may ignite the surrounding fuel vapours and cause a brief flash fire.

The risk of static igniting a fire is higher when the motorist re-enters the vehicle during refuelling. Motorists may return to the car for a number of reasons, such as to retrieve their wallet or purse, shelter from the cold, or take an odometer reading. As the motorist slides over the seat, the interaction between their clothing and the seat fabric can generate a fresh charge of static electricity. If the motorist returns to the fuel dispenser without having touched any metal, the electricity may discharge from their body on contact with the nozzle. As demonstrated by the link below, this sequence of events can seriously jeopardise the safety of the motorist.

For video footage of a static-ignited fire at a refuelling site go to **http://www.pei.org/static/index.htm**. Note the compounding of static build-up by the motorist rubbing her clothes.

It is important to note that the risks of static electricity fires caused by the motorist re-entering the vehicle during refuelling are likely to be low in Australia. This is because the legislation in Australia does not permit open-hold latches on the dispenser nozzles[4]. Motorists are therefore encouraged to continuously hold the handle of the dispenser nozzle until refuelling is complete. A risk may remain, however, if the motorist jams an object into the handle of the dispenser nozzle and re-enters the vehicle during refuelling.

♦ The statistics on static-ignited fires

The exact number of static-related fires in Australian retail service station outlets remains unclear. Some indication of the prevalence of static electricity fires can be determined, however, from the Petroleum Equipment Institute (PEI) in the United States. According to their website, there were 36 reports of ignitions of gasoline vapours during the refuelling process between September 1999 and January 2000. Investigations into the incidents revealed that all ignitions occurred during dry weather, in the absence of open flames, and when the vehicle engines were turned off. PEI concluded that static electricity was the source of ignition in all cases.

To examine this issue further, PEI published an article in its newsletter asking readers to report on their experience of refuelling fires presumably caused by static electricity. Specifically, readers were asked to provide details of their car (e.g. type of tyres, model, year) and action while refuelling. A total of 161 reports of refuelling fires attributed to static electricity were received between 2000 and 2004. The findings revealed that:

- there were no occurrences involving open flames, running motors, or electrical continuity problems;
- conventional and vacuum-assisted vapour recovery nozzles were used in all occurrences;
- there were no reports of occurrences involving balance system nozzles;
- driveway surfaces included concrete, asphalt, stone, crushed rock and dirt;
- fires occurred with a variety of nozzle types, hoses, breakaways and dispensers;
- no mobile phones were involved;
- a wide variety of clothes were worn by motorists; and
- in 94% of the occurrences, rubber-soled shoes were worn by the motorists.

In 78 of the occurrences, fires occurred when the motorist returned to the vehicle during the refuelling process and then touched the nozzle after leaving the vehicle. In addition, 37 reports described fires before the refuelling process began, when the motorist touched the

[4] Australian Standard 1940-2004: The storage and handling of flammable and combustible liquids.

fuel cap or the area close to it after leaving the vehicle. PEI is continuing to collect reports of fires associated with the refuelling process. For further information on the findings, go to http://www.pei.org/static/fire_summary.htm.

5. CONTAINER FIRES

Fires ignited by static at petrol stations are not limited to incidents involving vehicles. In fact, empirical evidence suggests that the condition most likely to lead to a spark discharge is filling an unearthed metal container or tank with fuel. Such fires can be particularly dangerous due to the high risk of fuel spillage. The article below describes a container fire that resulted in serious burns to a track machine operator in Western Australia.

Worker Burned by Container Fire

A worker in the process of refuelling a petrol engine on a track machine using a plastic jerry can and funnel received serious burn injuries when the fuel ignited. Ignition is believed to have occurred as a result of a static electrical discharge in the form of a spark that ignited petrol vapours. His injuries were exacerbated when he dropped the fuel container spilling fuel onto his limbs. The burning fuel ignited the spilled fuel causing burns to the worker's arms and legs. The injuries were severe enough to require the worker to be hospitalised.

Contributing Factors:

- The injured person was standing on a wheel of the machine and was not earthed.
- The fuel container was an approved plastic type and had anti-static properties. The funnel used was not a dedicated item and did not have the same anti-static properties.
- Petrol has a low electrical conductivity. This can cause a charge of static electricity to build up as it flows through a pipe.

Source: Department of Consumer and Employment Protection, Western Australia. Article available at http://www.safetyline.wa.gov.au/pagebin/injrsign0126.htm.

Containers used to store fuel may accumulate a static charge due to the friction caused between the surfaces of a moving vehicle and the container. The charge can also be generated as the petrol flows through the container. In both cases, it is possible for the charge to build up sufficient energy to cause a spark between the container and the dispenser nozzle and ignite the fuel vapours in the air.

One of the few organisations to examine the characteristics of container fires in petrol stations is PEI. Between 1990 and 1995, the institute received 20 first-hand reports of fires involving the filling of portable fuel containers. The fires were predominantly associated with containers located on the back of a pick-up truck. The breakdown of the 20 incidents is presented below:

Number of Incidents	Type of Container	Location of Container
12	Metal	On-plastic-lined bed of pick-up truck
4	Plastic	On-plastic-lined bed of pick-up truck
1	Metal	On carpeted bed of pick-up truck
1	Metal	On carpeted floor of automobile
1	Plastic	Removed from plastic-lined bed of pick-up truck and placed on pavement
1	Plastic	On pavement

Source: Petroleum Equipment Institute

According to PEI, the fires may have resulted from static charge generated by the container sliding on the bed of the pick-up truck or the air flow around the container when the vehicle was moving. PEI suggests that the charge was prevented from being unearthed because of the insulating (i.e. non-conductive) effect of the plastic bed-liner, floor mat, or carpet. It is therefore likely that the charge resided either on the surface of the container or in the fuel itself. For further information on the findings, see http://www.pei.org/FRD/gascan.htm.

The potential for static fires to ignite when refuelling containers is increased when the fuel is being ‘splash filled’ (i.e. free falling). According to Dermody Petroleum in South Australia, it is unsafe to splash fill any container over 20 litres with petroleum products because it can cause a major static and ignition hazard. For instructions on filling containers exceeding 20 litres, see http://www.dermody.com.au/Static_policy.doc.

♦ Warnings about container fires

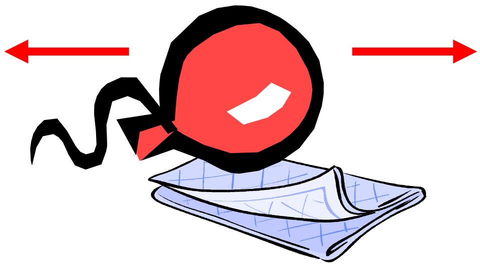
In response to the hazards associated with refuelling containers, many petrol stations display warnings about filling containers. These include warnings about:

- Filling containers greater than 25 litres due to the risk of fire from static electricity and the possibility of spillage. In fact, in some Australian states this is illegal.
- Using glass and plastic containers not approved for hazardous goods due to the risk of containers breaking, leaking or melting. Many containers may break, leak or melt when holding petrol.
- Filling containers in a confined space, such as the back of a utility, due to the risk of static build up.

THE SCIENCE OF STATIC ELECTRICITY

What causes static electricity?

Static electricity is generally caused when certain materials are rubbed against each other, such as wool on rubber or the soles of your shoes on carpet. The friction between the two materials disturbs the molecular construction of the surfaces. This disturbance causes electrons to be pulled from the surface of one material and relocated on the surface of the other material.



The friction caused by rubbing a balloon on a blanket creates charges on both surfaces

The material that loses electrons ends up with an excess of positive (+) charges on its surface. Conversely, the material that gains electrons ends up with an excess of negative (-) charges on its surface.

Conductivity

The ability of a material to either lose or gain electrons is determined by the conductivity of the material. For example, a pure conductor such as copper will not permit its electrons to move around freely. In contrast, a non-conductive material such as plastic will allow the material to charge with minimal friction, heat or pressure.

There are a number of non-conductive materials that motorists may be exposed to that may contribute to an electric charge. These include:

- plastic car interiors
- synthetic clothing
- woollen clothing
- rubber-soled shoes

When combined with certain activities, non-conductive materials can result in a static charge. Examples of routine activities involving non-conductive materials include:

- brushing your hair
- patting a dog
- rubbing your shoes on the carpet
- removing a nylon shirt

The characteristics of static electricity

According to the Australian Department of Consumer and Employment Protection, there are a number of characteristics of static electricity that make it dangerous. These include:

- It is silent, invisible, unpredictable and therefore dangerous.
- It can cause ignition in the presence of flammable materials.
- It can discharge in the form of a spark.
- It is common because it is found where friction exists between any two unlike materials.
- It is a natural phenomenon. The generation, accumulation and discharge of static electricity are natural occurrences that cannot be prevented. Control measures, however, can be implemented.

Further information on the characteristics of static electricity can be found at http://www.safetyline.wa.gov.au/pagebin/injrsign0126.htm.

Static and fuel

Petroleum fuel has a low electrical conductivity, such that it does not conduct electricity well. However, a charge of static electricity can build up on the fuel as it flows through a pipe or hose. Generally, the charge takes several seconds to several minutes to dissipate after the fuel has reached a tank or a container. If the charge discharges as a spark from a tank or container to the grounded metal nozzle of the gasoline dispenser hose, the fuel may ignite. For this to occur, the spark needs to discharge near the tank opening where the fuel vapour is in the flammable range. It is also possible for a spark to discharge directly from the surface of the gasoline to the grounded nozzle. Normally, though, this will not result in ignition because the concentration of fuel vapour near the liquid is above the flammable limit.

For further information on the relationship between static fires and fuel, see http://www.awtrucks.com/bedliner_warning.htm - one#one.

6. THE CHEMISTRY OF PETROL COMBUSTION

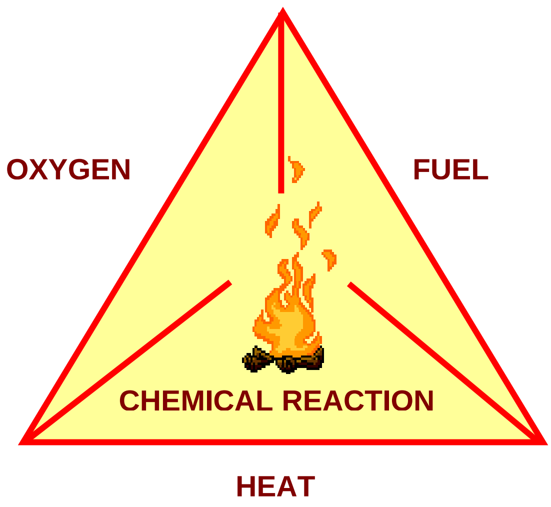
This section examines the chemistry of petrol combustion. To understand this process, it is useful to know about the basic properties of fire.

♦ What is fire?

Fire is uncontrolled burning. Burning, or combustion, is the chemical reaction between fuel and oxygen. When the burning is slow, without any flames, it is often called smouldering. When it is extremely fast, such as when a gas leak mixes with air, an explosion can occur. Between these two extremes are flaming fires.

The process of burning is a continuous chemical reaction between fuel particles and oxygen. The fire spreads due to the transfer of heat. The key properties of fire – fuel, oxygen, heat, and chemical reaction – are often represented by the fire tetrahedron. Take away one property and the fire will be extinguished.

THE FIRE TETRAHEDRON



♦ Balancing fuel and oxygen

In the environment of a retail petrol station, the property of fuel in the fire tetrahedron may be emitted as petrol vapours during the refuelling process or evaporated as a fuel spill. For combustion to occur, however, the concentration of fuel in the gas mixture needs to be appropriately balanced with the oxidising atmosphere. The primary measures for determining whether a particular mixture of fuel and air is combustible are flammability (explosive) limits.

There are two flammability limits for fuel-air mixtures. One is the lower explosion limit (LEL), where the concentration of fuel is too low to allow the propagation of flames. The other is the upper explosion limit (UEL), where the concentration of fuel is too high, such that the available oxygen is too low to enable flame propagation. The flammability limits determine whether a particular mixture is combustible. Though values may vary for different grades and formulations of fuel, the National Fire Protection Agency (NFPA) in the United States quotes the lower and upper flammability limits of 1.4% and 7.6% by volume in air at ambient conditions[5].

♦ The ignition source

A competent ignition source is required to initiate the combustion of the flammable fuel-air mixture. The source may be a spark or an extremely hot surface. For a hot surface to ignite a flammable mixture, its temperature needs to be above the auto-ignition temperature of the mixture. According to Failure Analysis Associates, the hot surface temperature required for ignition may be significantly hotter than the auto-ignition temperature. This is because the gases in contact with the surface heat and convect away prior to attaining a suitable temperature for ignition (see http://www.sfowler.com/esdjournal/cellphonereport.pdf).

The auto-ignition temperature and the flash point vary for different types of fuels[6]. In general, the auto-ignition temperature for petrol is higher than the auto-ignition temperature for diesel fuel. This is because petrol is designed for use in an engine which is driven by a spark. The fuel is premixed with air within its flammable limits and heated above its flash point. It is then

[5] NFPA (2001). Fire Protection Guide to Hazardous Materials.

[6] The auto-ignition temperature is the lowest temperature at which a substance will spontaneously combust in a normal atmosphere, without an external source of ignition. The flash point is the minimum temperature at which a substance produces enough vapour to ignite (flash) on application of an ignition source. Generally, the lower the flash point the greater the danger of explosion.

ignited by the spark plug. The fuel should not pre-ignite in the heated engine. Therefore, this type of engine requires that petrol has a high auto-ignition temperature and a low flash point.

In contrast, diesel fuel is designed for use in a high-compression engine. Air is compressed until it is heated above the auto-ignition temperature. The fuel is then injected as a high pressure spray, keeping the fuel-air mixture within the flammable limits of diesel. This process requires no ignition source. Diesel is therefore required to have a low auto-ignition temperature and a high flash point (see http://www.answers.com/topic/flash-point).

The table below provides the auto-ignition and flashpoints for the major fuels sold by Caltex and Shell in Australia. Further information on the properties of fuels available to motorists in Australia is available from the Department of the Environment and Heritage, at http://www.deh.gov.au/atmosphere/cleaner-fuels/petrol-diesel/setting.html.

	Petrol	Unleaded Petrol	Lead Replacement Petrol	Premium Unleaded Petrol	Diesel	Diesolines
Flash point	**< –40°C**	**–40°C**	**–40°C**	**–40°C**	**80°C**	**> 61.5**
Auto-ignition temperature	**> 250°C**	**370°C**	**370°C**	**370°C**	**350°C**	**> 250°C**

Source: Australian Department of the Environment and Heritage

For any given fuel-air mixture, there is a minimum quantity of spark energy which must be available to trigger ignition. This quantity is often referred to as the 'minimum spark ignition energy'. Below this level, a spark will be incapable of igniting the mixture. The minimum spark ignition energies vary, depending on the specific type of fuel-air mixture and the atmospheric conditions. According to Irvin Glassman, the minimum spark energy required to ignite flammable petrol vapours is 0.2 microjoules at the optimum mixture ratio [7].

For further information on the chemistry of petrol combustion see http://www.cs.ntu.edu.au/homepages/jmitroy/sid101/oil/gasoline.html
http://www.sfowler.com/esdjournal/cellphonereport.pdf

[7] Glassman, I. (1987). Combustion, 2nd Edition. Academic Press, pp. 486-489.

7. SAFETY TIPS FOR REFUELLING

To minimise the build up of static charge and to control the effects of static discharge:

- **Switch off your engine**

Turn your vehicle engine off and disable any other auxiliary sources of ignition (e.g. camper or trailer heater, pilot lights, cooking units) to avoid the generation of sparks.

- **Do not smoke**

Do not smoke, light matches or lighters while refuelling at the pump or in the vicinity of the pump.

- **Do not get in and out of your car**

Stay outside the vehicle while refuelling. This will reduce the potential for any build-up of static electricity to be discharged at the nozzle.

- **Discharge static build-up**

If you need to re-enter your vehicle during refuelling, discharge any static build-up before reaching the nozzle. Static can be discharged by touching metal, such as the vehicle door, with a bare hand.

- **Do not jam the refuelling trigger**

Do not use any object to jam the refuelling trigger on the nozzle in order to keep it open.

- **If a static fire occurs…**

If a static-ignited fire occurs when refuelling, leave the nozzle in the fill pipe of the vehicle and step away from the vehicle. Notify the station attendant immediately.

For more information, see the Australian Institute Petroleum website at http://www.aip.com.au/industry/safety.htm

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