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Advanced Taser M-26 Safety Analysis

Executive Summary

Dr David Vissenga and Inspector Bruce Thomas from Victoria Police commissioned The Alfred to perform an electrical safety analysis of the Advanced Taser M-26 "stun gun". Since the project was only to examine the electrical safety aspects of the Taser it cannot be taken as a product endorsement. This report presents the results of our testing of a sample Taser unit supplied by the Australian agents (FBIS International Group). Law enforcement officers in several countries have used the Taser for up to 30 years. The Advanced Taser is designed to disarm or incapacitate a suspect without causing death or serious injury to the suspect, law enforcement officer or bystander, and is currently used by over 1,700 law enforcement agencies.

The first stage of the project was to conduct a literature search, including web-sites. This showed that although several fatalities have occurred after using the Taser there is no proven connection between use of the Taser and the subsequent death. At a November 2002 Conference, Taser International CEO, Rick Smith, gave a statistical analysis of 2,050 field uses of the Advanced Taser M26 and claimed a 94.2% success rate.

The second stage was to calculate the theoretical power output of the M26 and compare with two medical devices accepted as safe for use on humans by trained operators. Devices chosen for comparison were an electro-surgical unit (ESU) and an electro-convulsive therapy unit (ECT). Both these devices have been in regular, routine use in Hospitals and clinics for well over 50 years. We also compared the Taser output to that of an electric fence.

The last stage was to do a practical test of the device operating into a dummy load to confirm our theoretical calculations. Results were compared with limits specified by Australian Standard AS3859 - 1991 - "Effects of current flowing through the human body".

The conclusion reached is that the current output of the Advanced Taser M26 is below the fibrillation threshold set out in the Standard. From an electrical safety viewpoint the device presents an acceptable risk when used by trained law enforcement officers in accordance with the manufacturers directions for use.

Included in the report is a letter from Dr Archer Broughton, Specialist Cardiologist from the Heart Centre at The Alfred. Dr Broughton recommends that a person who has been "Tasered" be admitted to the Emergency Department of a Hospital for observation. The purpose of the medical observation period is to minimise harm to the offender.

Since completing the above evaluation a fourth generation of the Taser has been released - the X-26 Taser. This new model has advantages of significantly reduced size, weight and power while retaining the non-lethal incapacitation properties of the previous model. We have neither seen nor tested this unit but, if the manufacturer's data is correct, it is likely to be a superior unit in terms of useability while still maintaining the effectiveness of the M-26 model.

Advanced Taser M-26 Safety Analysis

Background

Dr David Vissenga and Inspector Bruce Thomas commissioned The Alfred to perform an electrical safety analysis of the Advanced Taser M-26 "stun gun" or "electro-muscular disruption - EMD" device. Following an initial meeting between Dr David Vissenga and The Alfred staff on 9 December 2002 the scope of the proposed analysis was confirmed in e-mails between David Vissenga of Victoria Police and Simon Brewin from The Alfred.

The Taser "non-lethal weapon" is the latest design from a company involved in the manufacturer of these devices for 30 years. [1] (The word Taser is an acronym for "Thomas A. Swift electric Rifle".) The Taser device is growing in popularity with law enforcement officers' worldwide as an effective way of disarming violent persons in a non-lethal manner. The electrical output of the device can be compared with an electric fence or a motor vehicle ignition system. Taser International claims that "Most importantly, with over 20 years of field testing there has never been a death attributed directly to Taser technology".

The Taser uses compressed nitrogen to fire two small probes at distances up to 6.4 metres (21 feet). These probes will pierce clothing and/or tissue. The probes are fired at a velocity of approximately 6.1 metres per second (200 feet/second) and will penetrate the body to a depth of no more than 6.5 mm (¼ inch).[1] The Taser will be effective if used anywhere on the body but it is obviously important that the Taser not be fired at the face or neck of a person in order to prevent possible eye damage. The Taser output voltage will vary with contact impedance. Taser output may exceed 50,000 volts when the probes are contacting fabric; dropping to 3,000 volts or less when directly contacting skin or tissue.

The aim of this project is to undertake an electrical safety analysis of the Advanced Taser M-26 EMD device. We are not conducting tests on, or checking the accuracy of, the firing mechanism. The project is restricted to:

(a) a literature review

(b) theoretical calculation of output and verification that this complies with Australian medical device standards

(c) practical test of Taser output into known test resistances. This is a device test only - the firing mechanism and probes were not checked

(d) comparison of actual measured Taser output to calculated outputs of common high electrical output medical devices and domestic equipment

(e) medical recommendations concerning post-use checks on a person after being Tasered

1. Literature review

Law enforcement officers in several countries have used the Taser for up to 30 years. The Advanced Taser is designed to disarm or incapacitate a suspect without causing death or serious injury to the suspect, law enforcement officer or bystander, and is currently used by over 1,700 law enforcement agencies. Although several fatalities have occurred after using the Taser there is no proven connection between use of the Taser and the subsequent death. At a November 2002 Conference, Taser International CEO, Rick Smith, gave a statistical analysis of 2,050 field uses of the Advanced Taser M26 that showed a 94.2% success rate.[2]

A comprehensive report on testing of the Taser dated 16 May 2001 was produced by Bodycote Materials Testing in Ontario, Canada. S/Sgt Peter Sherstan commissioned this report on behalf of the Royal Canadian Mounted Police. This testing included applying Taser pulses to various barriers including synthetic insulated jackets, RCMP storm coats and RCMP body armour. Their testing indicted that effective pulses would be produced when clothing layers were less than 50-mm compressed barriers. For 58-mm compressed barriers results were intermittent and for 69-mm barrier clothing the device failed to operate effectively. [3]

All tests on human beings in the reports/ studies have been conducted on fit and healthy people with normal heart rate and blood pressure conditions. None of the large scale studies examines the effects on aggravated / violent person who may have high heart rate and blood pressure conditions, abnormal heart conditions and/or low skin impedance due to high perspiration.

None of the reports obtained analyses the direct effect on people under the influence of PCP, alcohol, amphetamines or any other drugs. A case study published in a March 1991 JFS article describes 16 fatalities, after Taser shocks[4]. In a letter to Chief Neil Ferdelam, of the Hamilton Police Department, USA, Dr Robert Stratbucker, Medical Director of Taser International, denied any suggestions that the Taser contributed to the deaths. Dr Stratbucker pointed out that the case study did not apply to the Taser M-26 but analysed cases from another manufacturer's products built in the 1970's. He also said ".. it is important to note that the authors found sufficient evidence to rule out the Taser as having playing a causal role in all the 16 fatalities".[5]

The TASER International company has a 35-page Medical Safety Information document on its website.[6] The document states that in-depth animal testing has been undertaken at the University of Missouri and "this is the most extensive medical safety testing of any less-lethal weapon known to me."[7]

The one reported case of a 8-10 weeks pregnant woman miscarrying the foetus after being 'Tasered' indicates that safety on pregnant women is not proven. [8] It should be noted that this report does not involve the M-26 Taser currently under evaluation. The M-26 pulse width, current amplitude and pulse frequency is different to that of the earlier device that is the basis of the report. Dr Stratbucker wrote to Taser International refuting the claim made in the journal that "The sequence of events suggests a causal link between (Tasering) and miscarriage". [9] Again Dr Stratbucker affirms in an affidavit date 15 June 2001 to the State of Indiana superior court that "it (the Taser) cannot cause the loss of a fetus". [10]

The use of electric weapons has been linked to torture and interrogation. [11] There is therefore some potential to make a claim against the police after being 'Tasered' in support of claims of torture or post-traumatic stress disorder. [12]

Injury thresholds, the effects of Tasers on the nerves, methods of satisfying people of the risk of respiratory or cardiac arrest as well as the degree of blood-gas correction required to minimise these risks are unknown. [12]

Mr Bleetman, a consultant at Birmingham's Heartland Hospital conducted a review of all medical literature on electric weaponry for the Northamptonshire Police. [13] As part of his research he was shot with a Taser. "I had concerns about the barbs being discharged into people's bodies at high velocity and I have concerns that barb strikes to eyes and other sensitive area of the body do carry inherent risks" said Bleetman. He also believes that police should use the weapon. [13]

A report of permanent damage to the spinal cord and brain following discharge of an anti-theft device in a person with a spinal cord stimulator implanted has been recorded.[14] However this anti-theft device output is not directly comparable to the Advanced Taser.

Armed or non-armed violet offenders frequently have altered mental status due to ingestion of drugs and or psychiatric illness. The use of a Taser on top of this may cause paranoid delusions. [12]

However, the Schizophrenia Digest, September/October 2000 stated that the British Colombia Schizophrenia Society voted to support the Taser "as an less lethal option for police dealing with the mentally ill". [15]

When analysing any possible deleterious effect of the Taser the issues to be considered are:

(a) electric shock due to device current and

(b) tissue heating effects from the power output.

Note that voltage is not highlighted as an issue. Applying a high voltage with negligible current can be disregarded in most situations. Walking on carpet wearing rubber shoes on a day with low humidity can easily generate a "static" voltage of over 20,000 volts. This will provide a nasty shock when touching an earthed object, but is not inherently dangerous.

Fatal or dangerous electric shock is due to current flow through the body. Significant current from a high voltage source will result in tissue heating. A common example of high voltage and high current resulting in tissue damage is a lightning strike. However even low voltages can be hazardous in certain circumstances. There are cases where hearts have stopped beating effectively with only 9-volts applied directly to the heart. This is due to the current flow through the heart. The level of current likely to cause electrocution, or excessive tissue heating, is dependent on amplitude, pulse shape and the length of time that this current is applied.

An Australian Standard (AS3859:1991) has been published to provide guidance on the effects of current passing through the body. [16] This standard is basically identical to two International standards (IEC-479-1 and IEC-479-2) published by the International Electrotechnical Commission (IEC), but AS3859:1991 includes additional notes and appendixes for Australia.

The Standard relies on tests carried out in the 1960s and 1970s. A Biomedical Engineer, Alex Watson, coordinated much of the initial human research in Sydney, Australia. The tests were carried out on a large number of elderly patients undergoing

open-heart surgery. It can be argued therefore that the research data is very much "worst case" and has a large factor of safety built in compared with the normal population. This work was published in the Medical Journal of Australia in 1973. [17]

This standard was written to identify currents in the range likely to cause ventricular fibrillation. Ventricular fibrillation (VF) is a critical heart rhythm that, unless treated, will cause death in minutes.

The current that is required to cause VF is dependent on the length of time for which the current is applied and the frequency of the current. The graphs provided are for frequencies of 15 to 100 Hertz or duration greater than 10 milliseconds. At the 10 mS level a current of up to 500 milliAmp is considered safe, or in the words of the standard "Usually no organic damage to be expected." [16]

For frequencies above 1,000 Hz there is little data. The initial work assumed that causes of VF would result from alternating current electrical mains (AC) - 50 Hz in Australia and Europe and 60 Hz in the USA - or direct current (DC) from batteries or AC-DC converters. It was assumed at that stage that high frequency current was not an issue when considering causes of VF. The heating effect was well known from high frequency electro-surgical units but was not raised as a possible cause of VF. This has not changed significantly as the Australian / IEC Standard states that, for frequencies above 100,000 Hz there "is neither experimental data nor reported incidents concerning the threshold of ventricular fibrillation". [16]

The measured and calculated frequency for the Taser is between 45,000 to 50,000 Hz. The Standards graphs indicate that the current required to cause VF is 14 times greater at 1000 Hz than at 50 Hz. This means that at least 7,000 mA is required to cause VF at 1,000 Hz. Extrapolating to 45,000 Hz gives a VF value of at 70,000 mA - several times the "worst case" current of 20,000 mA delivered by the Taser.

There are other physiological effects of Taser to be considered in addition to VF. Cardiac arrest, breathing arrest and heavy burns may result from excessive current over a significant time. The short pulse length of the Taser output makes cardiac and breathing arrest very unlikely. Respiratory arrest difficulties are reduced by the automatic 1-second de-activation after 7.5 seconds, which is then repeated for each subsequent 6.5 seconds of use. No reports were found of cardiac arrest or breathing arrest solely from pulsed high frequency current at the levels produced by the Taser.

To evaluate possible harm due to heating effects from the power delivered by the Taser we compared the Taser output to that of an electro-surgical unit (ESU) and an electro-convulsive therapy (ECT) unit.

ESUs have been used in surgical procedures for many years. Early types using "spark gaps" were in regular use by the late 1920s. [18,19] The ESU is now an essential tool in any major surgery. High-frequency current is used to "cut" or "coagulate" tissue. ESUs are used in open-heart surgery and have no deleterious effect on heart operation.

In the "cut" mode high frequency current is applied continuously to tissue and cuts it like a scalpel. In the "coagulate" mode the high frequency current is applied in pulses to "seal" the cut or to stop blood vessels from bleeding. The pulsed nature of the Taser means it operates closer to the "coagulate" mode than "cut" mode. The shallow penetration of the Taser probe and relatively low total power output makes any significant tissue burns very unlikely.

ECT has been used regularly since the late 1930s to treat severe debilitating mental disorders.[20] ECT has a chequered history - for many years it was used to control behaviour and not as a medical treatment. It is a device that applies high current

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pulses across the brain by placing an electrode above each temple, or between one temple and the middle of the forehead. In 1938 Ugo Cerletti and Lucio Bini were reputedly the first to use electric current to induce a seizure. In a delusional, hallucinating, schizophrenic man. [20]

With ECT the current pulses are applied for around 30 to 60 seconds – considerably longer than the 7 seconds that the Taser is normally activated.

Comparison with non-medical devices was also undertaken. There is an Australian Standard (AS/NZS 60335.2.76:2003) for electric fence energisers.[21] Electric fences have been used for many years to prevent unwanted access to restricted areas, usually by animals. Obviously the fence needs to be safe if accidentally contacted by human beings from children to adults. Typical output voltages on commercial units are around 10,000 volts.[22] The Australian standard does not specify voltage, but provides current limits of 15,700 mA or 5 joules per impulse. The single pulse specification is similar to that of the Taser. The major difference is that while electric fences have a maximum pulse repetition rate of 1 pulse per second, the Taser is set to 15 pulses per second.

Finally, the effect on implanted devices needs to be considered.

The possible effects on an offender fitted with a pacemaker include malfunctioning of the device during delivery of shocks – if the pacemaker detects these pulses as cardiac abnormalities. It may inhibit bradycardia pacing, or treat sensed events as electrical noise, resulting in the delayed detection of a potential tachycardia arrhythmia. There is also the potential of physical damage to a pacemaker or lead by the point of the Taser, and the energy delivered could reset the programmed parameters of the pacemaker.[23]

Papers published by Roy & Podgorski in 1989[24] and 1990[25] reported that VF had been induced in a pig with an implanted pacemaker. This occurred when the highest-power stun gun was used on saline-moistened skin of the pig. However the power stun guns tested had voltage outputs greater than 150,000 volts and currents of up to 140 amps. For comparison, the maxims we measured on the Taser were 41,000 volts and 18 amps. (A maximum voltage of 50,000 volts is specified in Taser documentation.)

Fish & Geddes acknowledged the Roy & Podgorski paper in a "Commentary note on the effects of stun guns and tasers" published in The Lancet in 2001.[26] Geddes is colloquially known as the "father" of the modern pacemakers. His comment that "Further research on what other cardiac effects tasers and related devices would have on people with pacemakers is needed" may indicate that he considers that pacemakers and Taser devices have evolved since 1989 and the earlier tests may not apply to current devices.

The pacemaker issue needs to be put into perspective. A modern pacemaker is designed to reject large amplitude noise and to still function correctly when an external defibrillator is used to deliver an energy pulse many times greater than that of the Taser. The pacemaker itself is implanted in a "pocket" more than 6 mm under the skin – that is deeper than the Taser probe will reach. Even if the Taser probe did reach the pacemaker, its titanium shell is strong enough to prevent the Taser probe penetrating the device. There is still the possibility that the Taser dart could make contact with the pulse generator lead. [23] This possibility is quite remote due to normal lead placement well below the skin, but it is enough to recommend caution when using a Taser on a subject with a pacemaker.

If the Taser probe did reset a programmable pacemaker the effect would be reduced cardiac output. The pacemaker would not stop pacing, but drop to a lower than normal rate. In his letter Dr Broughton includes this as one reason for persons who have been 'Tasered' to spend some hours under medical observation'.

The U.K. Association of Chief Police Officers states that "The evidence for the damage or disturbance to implanted electrical equipment such as pacemakers is limited and equivocal – be aware of the potential, risk of damage to the device"..[27]

The Taser website states that a pacemaker manufacturer (Cordis) tested a Taser at their Medical Laboratory in Florida and that the tests confirmed that the Taser would not damage a cardiac pacemaker.[28] This statement that Cordis testing would not damage implanted pacemakers has also appeared in other articles. [28]

Taser International has tested the output of the M-26 unit on a 70 kg (150 lb) pig. [29] The test showed that the M-26 Taser output is extremely unlikely to damage an implanted pacemaker or Implantable Cardioverter Defibrillator. The measured energy delivered to the pig for each Taser pulse was 0.29 joules. Implanted pacemakers are designed to cope with high-energy pulses from defibrillators, which are now typically 150-200 joules (biphasic models). (Older defibrillator models delivered up to 360 joules.)

The Information for General Practitioners Taser Notes advise that "The medical implications of use of the M26 Advanced Taser in the operational trial by the Police have been reviewed by an independent panel of clinicians, and their statement was part of the evidence considered by Government prior to the decision to authorise the trial". [27] These notes also state that the main physiological effect is pain and that "there is no evidence of any long term clinical effects of Taser use".

Civil rights organisations like Amnesty International,[30,31] Liberty (U.K.)[32] and The Guardian newspaper[33] have not found any significant problems to report with the Taser. Their main concerns are ensuring that the devices are "medically proven safe before introduction" and that they be used only where firearms are the only other option.[34] Despite the safety record of the Taser, 7% of citizen complaints from one area of the USA were related to the 0.2% of times Tasers were used as the restraining method. [28]

Deputy Carlos Torres of the Hillsborough sheriff's office in Tampa, Florida stated "Criminals in Orange County have become aware - and afraid - of the tool. Just the sight of the Taser's red laser scope has caused some suspects to surrender immediately."[35]

The U.K. Muslim News on 17 April 2003 reviewed the use of the Taser M-26 by police in England and Wales.[36] They referred to the opinions of Liberty and Amnesty civil rights groups as well as the Hertfordshire police.

One website includes a discussion on ways to defeat or neutralise the Taser.[37] The most significant suggestion was to wrap yourself in conductive foil. (To be effective the foil needs to be thick enough to prevent penetration by the darts.)

Another website reported results of an English test where a Taser was fired at mannequins covered in SC gas.[38] Apparently in 2 out of 7 tests the mannequins caught fire. Although this was only reported on one website it is certainly possible for a spark created by any means to ignite a flammable gas. The same precautions would apply with the Taser near flammable fluids or materials as for any other device that can produce a spark.

Summary of literature survey:

No proven connection has been reported between use of the Taser and subsequent deaths of offenders.

There are no comprehensive studies relating to long term physiological effects on subjects who have been hit by a Taser dart.

There is no comparative electro-physiology literature that indicates the Taser electrical output is beyond currently published acceptable limits.

Secondary effects such as fire, muscle spasm, falling over etc also need to be considered.

Since completing the above evaluation a fourth generation of the Taser has been released - the X-26 Taser.[39] This new model has advantages of significantly reduced size, weight and power while retaining the non-lethal incapacitation properties of the previous model. We have not tested this unit but, if the manufacturer's data is correct, it is a superior unit in terms of useability and downloading of usage information via a USB dataport. The shaped pulse discharge waveform is designed to maximise the disabling effect on humans and may not be as effective on animals. The manufacturer's trials showed the X-26 to be 5% more effective on human subjects than the M-26 model with less subject disorientation during the "stun" phase.[40]

The X-26 uses a 6v custom Lithium battery. Obviously these batteries are not as readily available as the "AA" alkaline batteries used in the M-26. However Lithium batteries have a 10-year shelf life and the manufacturer estimates that a battery will provide power for approximately 300 firings. The X-26 has a display showing the estimated battery life remaining. It is recommended that operating protocols for the X-26 includes a battery replacement procedure - for example replace the battery when capacity drops to 15% or when the battery is 8 years old.

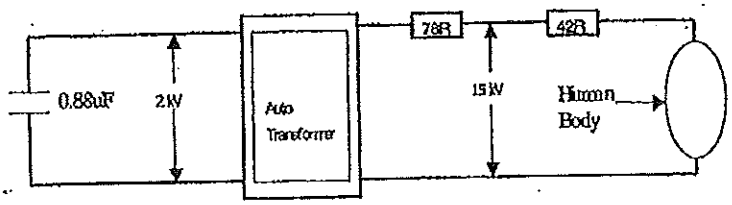
The X-26 includes "drive-stun" backup capability to deliver pulsed energy directly to the body without having to fire the air cartridge. If an air cartridge is fitted this must only be done after firing an air cartridge. The X-26 will also work in this mode with no air cartridge in place.

If the information from the manufacturer's Taser website is correct then our conclusions that the M-26 power output would comply with electrical safety standards also apply to the X-26 in the normal operating mode. We cannot comment on the use of the X-26 in the "drive-stun" direct contact mode as no measurements have been carried out using the M-26 in this mode. All our calculations assume that the power will be delivered via the normal air cartridge.

2. Theoretical power calculations using provided data

The second stage was to calculate the theoretical power output of the M26 and compare with two medical devices accepted as safe to use on humans by trained operators. Devices chosen for comparison were an electro-surgical unit (ESU) and an electro-convulsive therapy unit (ECT). Both these devices have been in regular, routine use in Hospitals and clinics for over well over 50 years. We also compared the Taser output to that of an electric fence.

2.1 Calculations



From the data available for the Advanced Taser unit, we could assume the following,
The discharge path block diagram as shown above,
Impedance of the secondary winding of the transformer 72R + 2 X 21R (impedance of the dart wire),
For our calculations it is assumed that 100% of the energy stored in the capacitor is transferred to the secondary windings of the transformer. (Neglecting losses in the transformer gives us a worst case scenario.)
The open circuit voltage of the secondary is 15 kV,
Typical Impedance of the human body is 1,000 Ω.

From earlier test data provided, the output is a damped sine half wave with peak current of 18 amps with a pulse width of 11 µSec.

Energy stored in the Capacitor $= 1/2 \times C \times V^2$
$= 0.5 \times 0.88 \times 10^{-6} \times (2000)^2$
$= \mathbf{1.76}$ Joules.

Body Current flow measured with 1K resistor = 18 amps (peak)
= 18 x 0.707 amps (rms)
= **12.7** amps (rms).

Power wasted in internal impedance and dart wires $= I^2 \times R$
$= (12.7279)^2 \times 120$
= **1,9440** watts (1,9440 Joules/sec).

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Pulse duration = 11 µSec.
So pulse energy wasted = 19440 x 11 x 10^{-6} Joules, = **0.21** Joules.

Actual power transferred to human body = 1.76 – 0.21 Joules
= **1.55** Joules/ Pulse.

2.2 Additional Calculations

If Pulse duration = 11 µSec. (half sine wave),

Then frequency = 1/ (2 x 11 x 10^{-6}) Hz = **45.5** kHz.

Firing algorithm of the Taser unit => 10 to 15 pulses per sec.

7.5 sec ON -> 1 sec OFF -> 6.5 sec ON -> 1 sec OFF -> 6.5 sec ON -> 1 sec OFF -> 6.5sec ON -> 1 sec OFF ->3 sec ON.

If the Taser outputs 15 pulses per sec then,
Total energy delivered to the body = 15 x 1.54616 Joules / sec.
= **23.2 watts** (Joules / sec)

Total body current = $I_{(rms)} = (P_{average} / R)^{½}$
= $(23.1924/(1000-120))^{½}$
= **162** mAmps (rms)

For the initial 7.5 sec ON period,

@ 15 pulses /sec → 15 x 7.5 = 112.5 pulses.
Approximately → 112 pulses.

Total power delivered to the body = 1.54616 x 112 Joules.
= **173** Joules

For the 6.5 sec ON period,

@ 15 pulses /sec → 15 x 6.5 = 97.5 pulses.
Approximately → 97 pulses.

Total power delivered to the body = 1.54616 x 97 Joules
= **150** Joules

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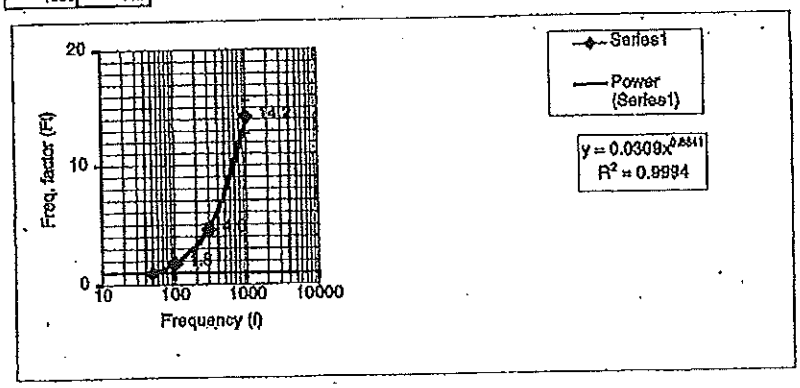
2.3 Frequency Factor (F_f)

The Standard provides graphs of the threshold current for the relevant physiological effects at frequency f compared to the threshold current at 50/60 Hz [16 - pps 20-23]. Fig 11 on page 23 of the Standard (variation of the threshold of ventricular fibrillation within the frequency range 50/60 Hz to 1000 Hz, shock – durations longer than one heart period and longitudinal current paths through the trunk of the body) is most appropriate to use in this application. The graph shows the ratio of current required to induce VF at frequencies other than 50/60 Hz. We can use the known values from the graph to create an equation that can be used to extrapolate to the Taser frequencies.

Hz	Ff
50	1
100	1.8
300	4.8
1000	14.2



The above graph is reproduced from the data on ref [16]; AS 3859 –1991, pages 20 to 23. The equation function of Excel is used to F_f at 45 kHz (the expected fundamental frequency of the Taser device discharge pulse).

Note that this analysis assumes loads that are purely resistive. Inductive and capacitive effects have not been considered.

From the graph =>

Best fit for the predicted graph for higher frequencies obtained from power series equations.

The equation predicted by Excel is → $Y = 0.0309 * X^{0.8841}$ { $F_f = 0.0309 * (\text{Frequency})^{0.8841}$ }

So if the frequency is 45000 Hz then $F_f = 0.0309 * (45000)^{0.8841} =$ **401**

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2.4 Analysis on various Electro Therapy Units

2.4.1 Electro Surgical Unit Pulses

ESU model: Force –2 -> Valley Lab -> ME 1885.[41]

In Coagulation Mode.

Coagulation frequency = 500 KHz. -> damped sine wave pulses.
Repetition Frequency = 31 KHz. Bursts.

Approximately 16 pulses per bursts
In one second 31000 bursts.
Maximum output power 120 watts.

One burst power = 120/31000 watts.
= **3.87 m Joules.**

*One burst has 16 pulses
So the pulse power = 3.871/ 16 m Joules.
= **0.24 m Joules**

2.4.2 Electro Convulsive Therapy Unit Pulses

ECT Model: Thymatron – DGx. -> Somatics -> ME 2316.[42]

ECT output – square wave pulses, pulse width of 1mSec and repetition rate of 70 Hz (14.28 mSec.)

From the graphs provided

Load current for 500 Ω load is = 0.76 amps.

Therefore the single pulse power = $(0.76)^2 * 500$
= **289 m Watts**

Energy delivered per second = $(0.76)^2 * 500 * 70$
= **20.3 Joules**

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2.4.3 Electric Fence Energisers

Electric fence energisers are used in property fences to protect the animals. These units are commercially available and can be purchased and installed. There are several Australian Standards applying to electric fences. The most relevant with respect to the comparison with Taser equipment is AS/NZS 603350.2.76:2003 [43] and the previous version AS/NZS 60335.2.76:1998 [44]

Both above standards require manufacturers to comply with the range of options to minimise the danger of electrocution and subsequent death.

Current limited energiser characteristic limit line curve is given by the following equation.

Impulse duration (mS) $= 41885 \times 10^{3} \times (\text{output current (mA)})^{-1.14}$

For 1000 mA < output current < 15700 mA.

For comparison with a Taser unit we can use the maximum specifications listed in the standard, assuming pulse duration of 1mSec and load impedance of 500 ohm.

Max Output Current allowed (calculated using above formulae) = 2.815 amps (peak) = 1.99 amps (RMS)

Max output power allowed $= I^{2} \times R = 1.99 \times 1.99 \times 500$ **=1980** Watts

Therefore single pulse energy = **1.98** Joules

Comparison of the energy delivered by each unit.

The energy delivered by the Taser unit is re calculated for the impedance of 500 Ω since available date for the two medical devices (ESU & ECT) is based on 500 Ω load impedance.

Using 500 Ω Load	Taser	ESU	ECT	Electric Fence Energiser
Single Pulse Power (in m Joules)	1,062	0.24	290	1,980
Pulse / burst Duration	22 µSec	32 µSec	1 mSec	1 mSec
Total Energy delivered to the body in 1 Sec.(Joules)	15.9	120	20.3	1.98

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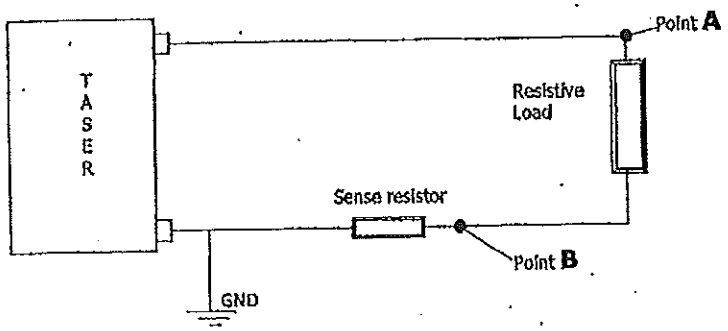
3. Measurement on supplied Taser M26 unit

The last stage was to do a practical test of the device operating into a dummy load to confirm our theoretical calculations. Results were compared with limits specified by Australian Standard AS3859 - 1991 - "Effects of current flowing through the human body". [16]

A trial unit supplied by the FBIS International Group was tested in the Biomedical Engineering Department at The Alfred hospital over three consecutive days. Tests were carried out using both batteries supplied by the company and off-the-self batteries from hospital stock. Testing including using older batteries that were near end-of-life to observe the effect of lower battery voltage on power output. The higher value test resistors were placed in an oil-filed bath to prevent voltage breakdown. Shivaparan Sivasubramaniam, B.E. (Biomedical & Communications) carried out the testing in the Biomedical Engineering Department.

3.1 Test Set-up



Initial Inspection

Advanced Taser
Model No: M26 – 06/02, S/No: P3 – 009204.
No cartridges/wires & pins/darts were supplied with the Taser unit.
The Gap between Contacts – 34.31 mm

Laser pointer
Class IIIA Laser product. (Complies with 21, CFR 1040.10 & 1040.11)
Max Output: 5mW
Wavelength: 630 – 680 nM.

011485

Batteries

- Energizer AA size, Alkaline, 1.5V (X 8 In one pack) LR6 – AM3- 1.5V
- Duracell Ultra AA size, Alkaline, 1.5V (X 8 In one pack) MX 1500 -LR6 - 1.5V
- Energizer (Industrial) AA size 2010, Alkaline, 1.5V (X 8 In one pack) EN91- LR6 – AM3- 1.5V

Note: Taser was supplied with battery packs 1 & 2 only but the voltages of those packs were 12.57 Volts and 12.10 Volts respectively. Battery type 3 was from our lab stock and with these new batteries fitted battery pack voltage measured 12.90 Volts.

Test equipment

Oscilloscope

Tektronics Model: TDS 744 – 500 MHz – 2 G.samples/sec.

HV Probe

Tektronics Model: P6015A – 70MHz -> calibrated and checked.

Normal Probe

Tektronics Model: P6139A – 500 MHz –8pF -> calibrated

Multi-meter

Summit – SDM 783.

Sense resistor

1Ω (1.2Ω) resistor used to sense the current flow through the load.

Load resistors

Various values of resistive loads were used to investigate the behaviour of the Taser unit under different load conditions.

Value (expected)	Actual Value (measured)
200 R	199.2 R
300 R	296.8 R
500 R	494.0 R
1 K	1,015 R
5 K	5,010 R
10 K	10,01 K

011486

Batteries used for the following procedures and measurements were,

Energizer (Industrial) AA size 2010, Alkaline, 1.5V (X 8 in one pack) EN91- LR6 – AM3- 1.5V

Key Observations

- Battery pack was very difficult to load and unload.
- Battery pack voltage drops very quickly (battery pack with new batteries measuring 12.90 Volts dropped to 12.11 Volts after 6 series discharges).
- Intermittent flashovers, across the terminals, observed with new batteries installed and greater than 5 KΩ load connected. Note that this was without the firing pack connected, equivalent to being used in "stun gun" mode.

3.2 Procedure & Measurements

All measurements were taken using oscilloscope at points A & B as shown in the diagram above.

Point A

Was connected to the high voltage probe, which measures the voltage across the load and it it is represented by CH –1 waveform in screen capture.

Point B

Was connected to a standard probe, which measures the voltage developed across the 1 R resistance. So the measurements are equal to the current flowing from the Taser unit. The current waveform is represented by CH –4 on the screen capture.

Math –1

Waveform on the screen capture is actually the product of CH –1 waveform (voltage) and the CH – 4 waveform (current). So Math –1 waveform can be treated as the power delivered by the Taser unit or power dissipated across the load.

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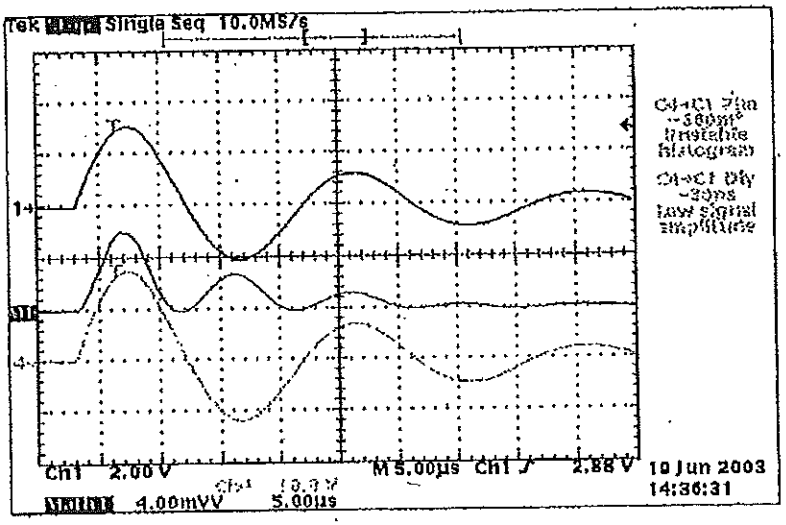
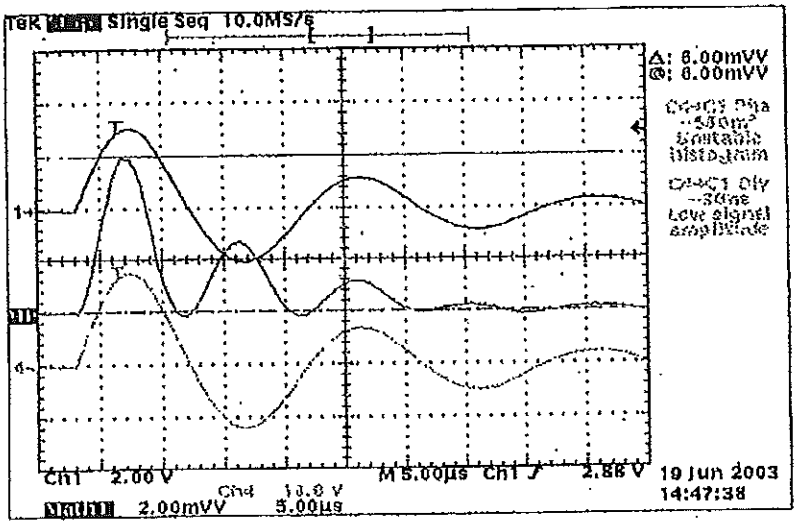
3.3 Results

200 Ω Load - CH 1 output voltage in kV (black waveform), CH 4 output current in amps (blue waveform)



300 Ω Load



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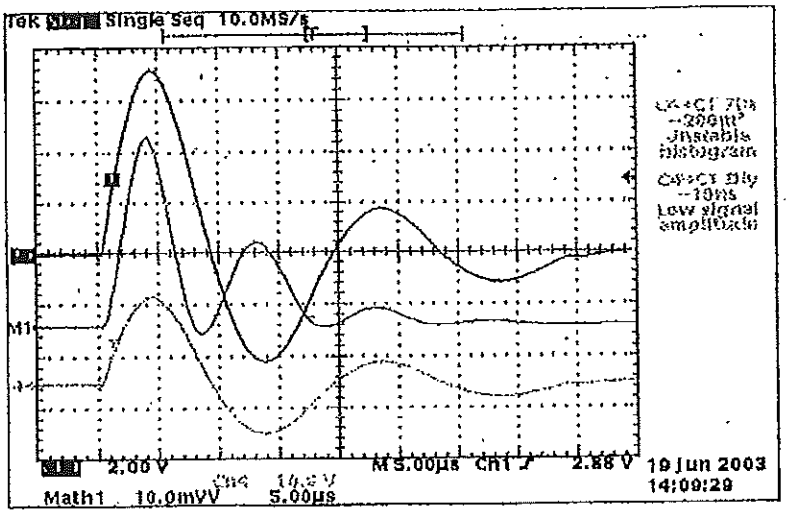
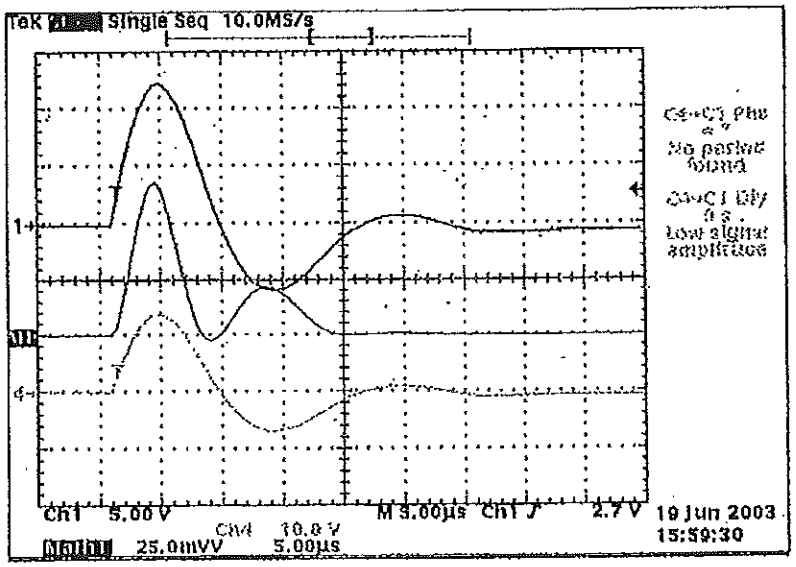
500 Ω Load - CH1 output voltage in KV (black waveform). CH4 output current in amps (blue waveform)



1 KΩ Load



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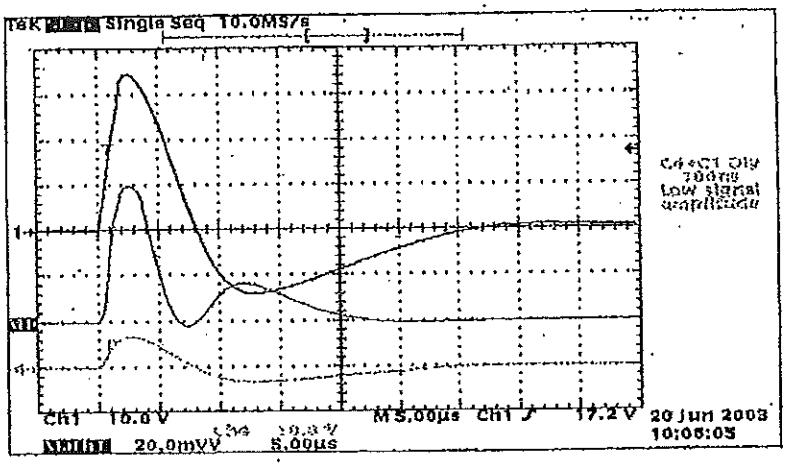
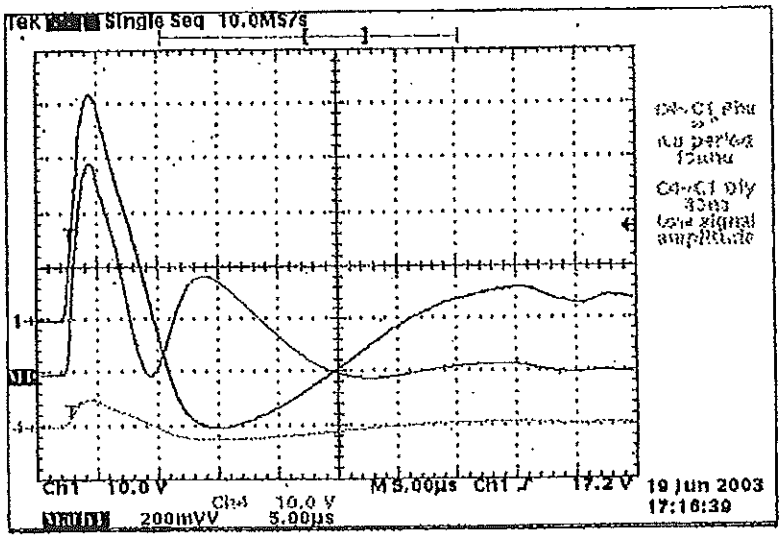
5 KΩ Load - CH 1 output voltage in KV (black waveform), CH 4 output current in amps (blue waveform)



10 KΩ Load



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3.4 Summary

Voltage Measurements

Resistance (KΩ)	0.199	0.297	0.494	1.02	5.01	10.0		5.01
Batt. Voltage (V)	12.90	12.45	12.90	12.36	12.90	12.31		12.11
Period (uS)	19.62	19.84	20.14	20.31	26.57	28.13		26.25
BrstWd (uS)	25.98	26.07	26.33	5.73	4.98	4.24		5.02
Pk-Pk (KV)	5.50	7.44	11.32	18.20	48.40	62.20		41.00
Max (KV)	3.30	4.52	7.16	12.20	34.40	41.80		28.60
Mean (V)	14	28	16	160	350	260		320
RMS (KV)	0.58	0.77	1.16	1.85	4.96	6.32		4.30

Current Measurements

Resistance (KΩ)	0.199	0.297	0.494	1.02	5.01	10.0		5.01
Batt. Voltage (V)	12.90	12.45	12.90	12.36	12.90	12.31		12.11
Period(uS)	19.58	19.87	20.14	19.06	20.00	21.88		20.00
BrstWd(uS)	26.09	26.02	26.28	5.66	4.83	4.27		4.88
Pk-Pk(A)	25.50	23.67	22.00	17.17	8.33	6.33		8.33
Max(A)	15.17	14.33	13.83	11.50	5.67	4.17		5.67
Mean(A)	0.05	0.02	0.03	0.10	0.10	0.05		0.05
RMS(A)	2.68	2.45	2.23	1.73	1.17	0.63		0.85

Power Measurements

Resistance (KΩ)	0.199	0.297	0.494	1.02	5.01	10.0		5.01
Batt. Voltage (V)	12.90	12.45	12.90	12.36	12.90	12.31		12.11
Period(uS)	9.54	9.40	9.40	4.06	3.67	4.01		3.59
BrstWd(uS)	14.56	14.46	14.55	4.06	3.67	4.01		3.59
Pk-Pk(X J)	5.97	12.36	26.94	48.61	42.64	56.11		37.78
Max(X J)	5.83	11.94	25.97	47.22	41.39	55.00		36.94
Mean(mJ)	178	322	639	972	914	1,722		806
RMS(Joules)	0.76	1.49	3.11	5.49	46.94	70.56		41.67

011491

3.5 Comparison of energy delivered by Taser unit and ESU, ECT & Electric Fence Device

Units compared are:

1. Taser - Electrical stun device (Model: M-26) - no dart supplied
2. ESU – Electro Surgical Unit. (Valleylab model: Force2)
3. ECT - Electro Convulsive Therapy Unit (Somatics model: Thymatron-DGX)
4. Commercially available Electric Fence Energiser

All measurements in the following table are based on 500Ω external resistive load. Calculated values are those derived (with noted assumptions) from data supplied by the manufacturer, or published in journals. Measured data refers to test results from our laboratory measurements.

500 Ω Load Impedance	Taser Calculated	Taser Measured [a]	Taser Measured [b]	ESU Calculated	ECT Calculated	Electric Fence Energiser Calculated
Single Pulse Power (in mJoules)	1,062	3,110	2,820	0.24	290	1,980
Total Energy delivered in 1 Sec.(Watts)	15.9	46.7	42.3	120	20.3	1.98
Pulse Width / burst Duration	22 µSec	20 µSec	20 µSec	32 µSec	1.0 mSec	1.0 mSec
Frequency	45.5 KHz	49.7 KHz	49.7 KHz	31.0 KHz	1.0 KHz	1.0 KHz
Frequency Factor (F_f)	402	438	438	289	13.9	13.9
Current $mA_{(RMS)}$ over 1 second	178	306	306	490	201	63
Current divided by F_f	0.44	0.76	0.76	1.22	0.50	0.16
Effective % of normalised current to induce VF	0.9%	1.5%	1.5%	2.4%	1.0%	0.3%

[a] - direct connection to output clips - equivalent to "stun gun" mode
[b] - after allowing for wire resistance of 42 Ω, energy delivered via Taser darts for total 500 Ω

The energy delivered by the Taser unit is re-calculated for an impedance of 500 Ω as available date for the two medical device (ESU & ECT) is based on 500 Ω load impedance.

Frequency factor $F_f = 0.0309 * (\text{Frequency})^{0.8841}$ (from earlier calculations)

011492

Conclusion

The aim of this project, in accordance with the original meeting on 9 December 2002 and subsequent e-mails, was to undertake an electrical safety analysis of the Advanced Taser M-26 EMD device and is not a product endorsement. We did not conduct tests on, or check the accuracy of, the firing mechanism. The project was restricted to:

(a) a literature review

(b) theoretical calculation of output and verification that this complies with Australian medical device standards

(c) practical test of Taser output into known test resistances. This is a device test only - the firing mechanism and probes were not checked

(d) comparison of actual measured Taser output to calculated outputs of common high electrical output medical devices and domestic equipment

(e) medical recommendations concerning post-use checks on a person after being Tasered

A thorough investigation of available information regarding Taser use was undertaken. This included correspondence with the U.S.A. manufacturers, their local agents, members of the Victorian Police Department and searches of websites that are considered conservative with respect to technology changes.

The power, voltage and current Taser outputs that were provided by the manufacturer were recalculated by basic principles. These calculated results were compared with recognised Australian/New Zealand and the International Electro-technical Commission (IEC) electrical safety standards for the application of electric current to the human body. The Taser outputs were then compared with some typical medical and domestic equipment. As shown in the table (section 3.5), the Taser output is less than 2% of the normalised current likely to produce ventricular fibrillation.

Body tissue can be damaged when electricity is applied. The damage can be caused in two ways - by heating tissue and by changing the heart rhythm and causing changes in blood flow around the body.

Tissue heating is deliberately used in devices such as electro-surgical units and diathermy machines including ultrasound. Tissue heating effects are determined by the power applied over time. The Taser delivers less power in 1 second (67 watts) than the electro-surgical unit - ESU - (120 watts), electro-convulsive therapy (ECT) unit (283 watts) or defibrillator (now typically 200 watts, but previously 350 watts). Tissue damage from the Taser is therefore expected to be less than that from other routinely used patient treatment devices. (The electric fence energiser has only one pulse per second so the heating effect is minimal at 2 watts.)

Electrical current flowing through the heart can cause more serious complications by changing the heart rhythm. The complication of most concern is called fibrillation. In this case the heart ceases to pump blood around the body. Fibrillation results from current flows within a certain range. Current amplitude and frequency determine this range. Current Australian Standards nominate a fibrillation threshold of around 50 mA for normal 240v 50 Hz mains current.

The current required for fibrillation increases with increased frequency and the Taser pulse is very short. It requires approximately 400 times more current from the Taser than from 50 Hz electric mains to cause fibrillation. Multiplying the 50 mA by 400 gives 20 amps. The current tables in section 3.4 above show that the maximum RMS current measurement is 3.2 amps. This provides a significant factor of safety of greater than 5. For comparison, the electric fence may have an output of 2 amps but at a much lower frequency and the factor of safety is less than 1 using our conservative approach.

An electric fence was used for comparison with the Taser as typical for a device in relatively common use with no requirements for operator training. The single pulse energy delivery into a normal load from an electric fence is higher than that from a single Taser pulse. However the Taser has 15 pulses per second compared with one for the electric fence to provide the disabling effect.

Practical testing of the Taser over three days confirmed the theoretical calculations. Note that the firing device was not tested - only the Taser electrical output into test loads. The effect of battery voltage on Taser output was measured and typical battery lifetime checked. This showed that a minimum of six series of discharges could be achieved from one new pack of 8 AA size alkaline batteries.

The conclusion reached is that the output of the Advanced Taser M26 is below the fibrillation threshold set out in the Standard. From an electrical safety viewpoint the device presents an acceptable risk when used by trained law enforcement officers in accordance with the manufacturers directions for use.

Thanks are expressed to Shivaparan Sivasubramaniam for the theoretical calculations and practical testing described above.

Included in the report is a letter from Dr Archer Broughton, Specialist Cardiologist. Dr Broughton recommends that a person who has been "Tasered" be admitted to the Emergency Department of a Hospital. Dr Broughton's conclusion is that "It would be prudent to routinely observe all 'Tasered' offenders for 4-6 hours in a suitably equipped hospital emergency department."

Since completing the above evaluation a fourth generation of the Taser has been released - the X-26 Taser. This new model has advantages of significantly reduced size, weight and power while retaining the non-lethal incapacitation properties of the previous model. We have neither seen nor tested this unit but, if the manufacturer's data is correct, it will be a superior unit in terms of useability and downloading of usage information via a USB dataport. The shaped pulse discharge waveform in the X-26 Taser is designed to maximise the disabling effect on humans and therefore may not be as effective on animals. The manufacturer's trials showed the X-26 to be 5% more effective on human subjects than the M-26 model with less subject disorientation during the "stun" phase.

The Denver Police Department recently obtained 90 X-26 Tasers and Michigan's city council approved 50 X-26 Tasers for the Sterling Heights Police Department. [15]

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Our thanks to Dr Vissenga for suppling much of the initial data regarding overseas experience with Tasers.

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