35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Electrical Safety of Conducted Electrical Weapons Relative to Requirements of Relevant Electrical Standards

Dorin Panescu[1], Ph.D., FIEEE, Max Nerheim[2], M.S.E.E., Mark Kroll[3], Ph.D., FIEEE

[1]Intuitive Surgical, Inc., Sunnyvale, CA, [2]TASER International, Inc., Scottsdale, AZ,[3]University of Minnesota, Minneapolis, MN

Introduction: **TASER® conducted electrical weapons (CEW) deliver electrical pulses that can inhibit a person's neuromuscular control or temporarily incapacitate. TASER X26, X26P, and X2 are among CEW models most frequently deployed by law enforcement agencies. The X2 CEW uses two cartridge bays while the X26 and X26P CEWs have only one. The TASER X26P CEW electronic output circuit design is equivalent to that of any one of the two TASER X2 outputs. The goal of this paper was to analyze the nominal electrical outputs of TASER X26, X26P, and X2 CEWs in reference to provisions of several international standards that specify safety requirements for electrical medical devices and electrical fences. Although these standards do not specifically mention CEWs, they are the closest electrical safety standards and hence give very relevant guidance.**

Methods: **The outputs of two TASER X26 and two TASER X2 CEWs were measured and confirmed against manufacturer and other published specifications. The TASER X26, X26P, and X2 CEWs electrical output parameters were reviewed against relevant safety requirements of UL 69, IEC 60335-2-76 Ed 2.1, IEC 60479-1, IEC 60479-2, AS/NZS 60479.1, AS/NZS 60479.2 and IEC 60601-1. Prior reports on similar topics were reviewed as well.**

Results and Conclusion: **Our measurements and analyses confirmed that the nominal electrical outputs of TASER X26, X26P and X2 CEWs lie within safety bounds specified by relevant requirements of the above standards.**

Keywords—**Cardiac, Fibrillation, Safety, Standards, TASER, CEW.**

I. INTRODUCTION

The use of conducted electrical weapons (CEW) is an increasingly popular less-lethal choice for law enforcement. These weapons, such as TASER® CEWs, deliver trains of brief, low-charge electrical pulses designed to temporarily inhibit a person's neuromuscular control primarily through motor-nerve mediated neuromuscular activation. TASER CEWs utilize compressed nitrogen to propel two small probes to distances of 4.5, 6.5, or 7.5 m at a speed of about 48 m/s [1]. Paintball guns used for recreational play are metered at about 60 m/s. An electrical signal is transmitted through trailing wires to probes which make contact with the body or clothing, resulting in an immediate inhibition of a suspect's neuromuscular control, with the initial reaction often being postural collapse and loss of ability to perform coordinated action for the duration of the train of pulses. The incapacitation is caused by the activation of skeletal muscle tissue innervated by peripheral nerves exposed to electric fields created by CEWs [1, 2]. The stimuli from a CEW will override the motor nervous system and block the command and control of the human body. Conventional stun devices stimulate sensory neurons for pain compliance and can be overridden by a focused individual. TASER CEWs directly stimulate pre-endplate motor nerve tissue, causing incapacitation regardless of subject's mental focus, training, size, or drug-induced dementia [1, 2, 3]. TASER X26, X26P, and X2 are among CEW models most frequently deployed by law enforcement agencies [3]. The X2 CEW uses two cartridge bays while the X26 and X26P CEWs have only one. The TASER X26P electronic output circuit design is equivalent to that of any one of the two TASER X2 outputs [3]. Table I provides a summary of measured electrical output parameters for these CEWs. A 600 Ω non-inductive load was connected to the device output. Their typical output waveforms are shown in Figs. 1 and 2, respectively. Additional electrical output data was measured by Dawes *et al.* [4].

Table I. Output parameters of TASER X26 and X2 CEWs.

Parameter	X26	X2
Open-circuit peak voltage [kV]	57	52
Peak voltage in typical load [kV]	1.75	1.4
Peak output current in typical load [A]	2.9	3.5
Energy delivered in typical load [J/pulse]	0.1	0.09
Power into typical load [W]	1.75	1.7
Absolute charge in the main phase [μC]	99	79
Net charge in the main phase [μC]	97	63
Impulse duration [μs]	126	56
Pulse rate [pulse/s]	18.45	19.15
Aggregate average current (net charge*pps) [mA]	1.79	1.21
Total delivery duration [s]	5	5
On-demand delivery termination	Yes	Yes

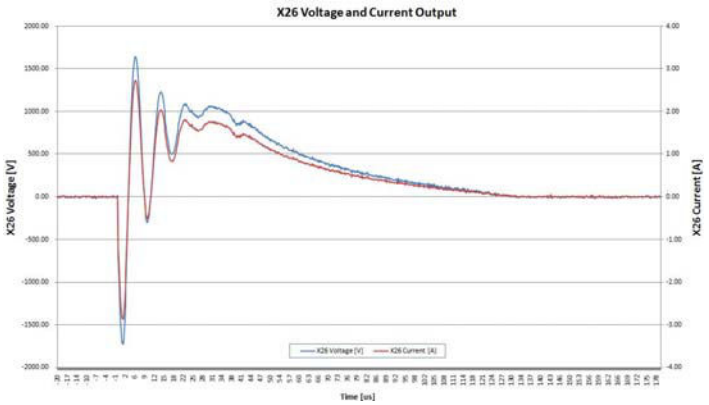


Fig. 1. TASER X26 CEW output for 600 Ω load.

The TASER X26 and X2 electrical output parameters were reviewed against relevant safety requirements of UL 69, IEC 60335-2-76 Ed 2.1, IEC 60479-1, IEC 60479-2, AS/NZS

60479.1, AS/NZS 60479.2 and IEC 60601-1 [5 – 12]. Prior reports on similar topics were reviewed as well [14 – 19]. The UL 69 requirements cover electric-fence controllers used only for the control of animals [5]. The IEC 60335-2-76 Ed 2.1: 2006 standard deals with the safety of electric fence energizers, the rated voltage of which is not more than 250 V, and with means by which wires in agricultural, domestic or feral animal control fences may be electrified or monitored [6]. Standards IEC 60479-1, IEC 60479-2, AS/NZS 60479.1, AS/NZS 60479.2 describe effects of electrical current on human beings and livestock [7 – 10]. The 60479-1 series (IEC or AS/NZS) describes the effects of DC and of sinusoidal alternating currents with frequencies between 15 Hz and 100 Hz passing through the human body [7, 9]. The effects of non-sinusoidal currents of higher frequencies are covered by the 60479-2 series (IEC or AS/NZS) [8, 10]. The IEC 60601-1 standard stipulates accepted regulatory requirements for the safety of electrical medical devices [11]. The corresponding European Norm (EN) version has similar scope and requirements [12].

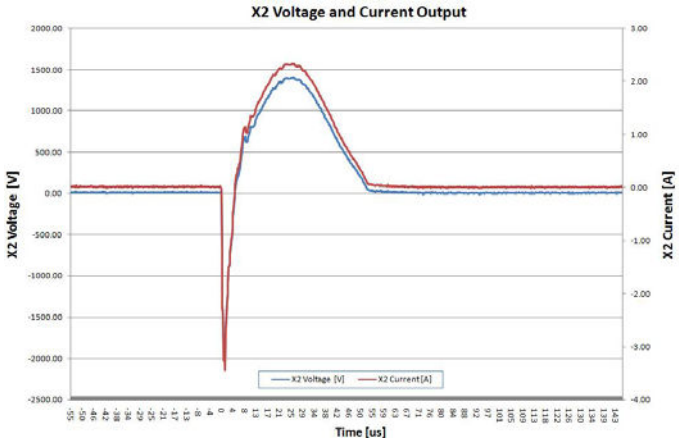


Fig. 2. TASER X2 CEW output for 600 Ω load.

II. METHODS

1. *Underwriters Laboratories (UL) Standard for Electric-Fence Controllers, UL 69 10th Ed, 2009.*

The UL 69 requirements cover electric-fence controllers used only for the control of animals [5]. Requirements of earlier UL 69 editions are consistent with those cited in this section. UL 69 also covers portable and permanently mounted electric-fence controllers with peak-discharge or sinusoidal-discharge output for indoor or outdoor use, including battery-operated controllers intended to operate from battery circuits of 42.4 V or less, line-operated controllers intended to operate from circuits of 125 V or less, combination controllers intended to operate from either a battery or a line circuit, and photovoltaic module battery operated controllers. These requirements do not cover electric-fence controllers for the continuous (uninterrupted) current type or intermediate equipment, such as a converter, a rectifier, or the like, that is sometimes used between the primary source of supply and an electric-fence controller and that is investigated only as part of a complete controller.

The UL 69 standard load consists of a non-inductive 500 Ω resistor with a parallel capacitor of less than 2 μF. In its Fig. 22.1, the standard shows the relationship between current (mA) versus impulse duration (ms) (see Fig. 3 for details). UL 69 defines the impulse duration as the interval of time which contains 95% of the overall energy. The equation indicating this relationship is:

$$\text{Current (mA)} = 2000 \times (\text{Duration (ms)})^{-0.7}$$

For an impulse with a duration of 0.1 ms, the equation yields:

$$I_{\text{impulse\_UL\_limit}} = 10023\ \text{mA}_{\text{rms}}$$

Abnormal operation restrictions are specified as:

$$\text{Current (mA)} = 2000 \times (\text{Duration (ms)})^{-0.7} \times (\text{pps})^{-0.5}$$

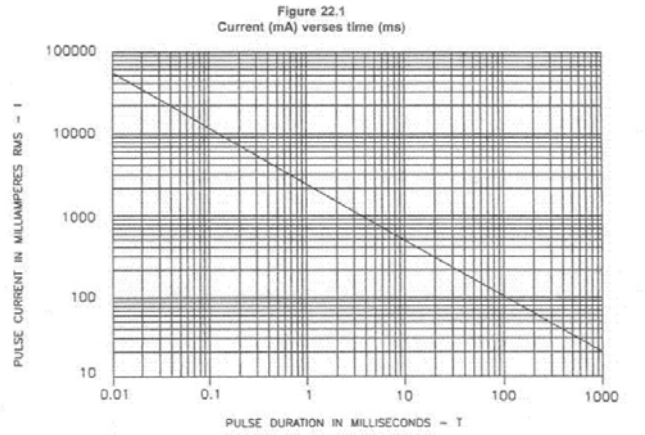


Fig. 3. UL 69: Current vs. impulse duration graph.

The variable *pps* represents the pulse repetition rate, expressed in pulses per second (pps). Section 23.2.3 of the standard specifies these restrictions when the interval between adjacent pulses drops below 0.75 s and requires that the device shall interrupt the output within 3 min. For an impulse with duration of 0.1 ms and a repetition rate of 19 pps:

$$I_{\text{repetitive\_UL\_limit}} = 2300\ \text{mA}_{\text{rms}}$$

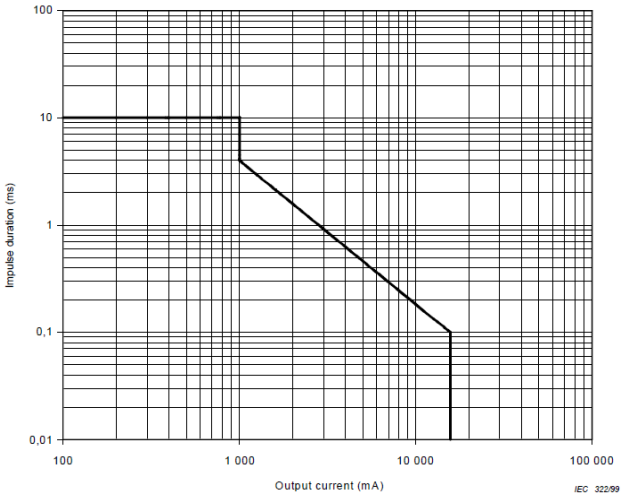
2. *IEC 60335-2-76, Ed 2.1: Household and Similar Electrical Appliances—Safety—Part 2—76: Particular Requirements for Electric Fence Energizers, 2006.*

The IEC 60335-2-76 standard deals with the safety of electric fence energizers, the rated voltage of which is not more than 250 V [6]. It also covers the means by which wires in agricultural, domestic or feral animal control fences and those in security fences may be electrified or monitored. In section 3.118, the standard defines "standard load: load

consisting of a non-inductive resistor of 500 ± 2.5 Ω resistor."

In section 22.108, the standard calls out that an energizer output characteristic shall be such that (see Fig. 4 for details):

- The pulse repetition rate shall not exceed 1 Hz;
- The duration of the impulse shall not exceed 10 ms;
- For energy-limited energizers, the energy/pulse in the 500 Ω load shall not exceed 5 J/pulse;
- For current-limited energizers the output current in the standard load shall not exceed 15,700 mA_{rms} for impulse duration of not greater than 0.1 ms;
- If the pulse repetition rate becomes greater than 1.34 Hz, the discharge energy per second into a load consisting of a non-inductive resistor of 500 Ω shall not exceed 2.5 J/s for a period not exceeding 3 min, within which the device shall interrupt its output.



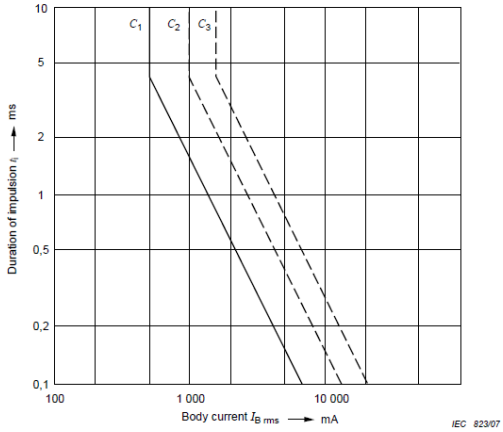
NOTE The equation of the line relating **impulse duration** (ms) to **output current** (mA) for 1 000 mA < **output current** < 15 700 mA, is given by **impulse duration** = 41,885 × 10^3 × (**output current**)$^{-1,34}$

Fig. 4. IEC 60335-2-76, Ed 2.1: Impulse duration vs. output current.

3. *IEC 60479-1 & -2: Effects of Current on Human Beings and Livestock, General & Special Aspects, 2005 – 2007.*

The IEC 60479 standard deals with effects of electrical current on human beings and livestock [7 – 10]. IEC 60479-1 describes the effects of sinusoidal alternating currents with frequencies between 15 Hz and 100 Hz and of direct currents passing through the human body, respectively [7, 9]. The effects of non-sinusoidal currents of higher frequencies are covered by IEC 60479-2 [8, 10]. Section 11.4 of IEC 60479-2 describes the thresholds of ventricular fibrillation (VF) for impulses of short duration. It states that "for 50% probability of fibrillation, Fq is of the order of 0.005 As." Fq is defined as the charge of the impulse. Figure 20 of section 11.4 of IEC 60479-2 describes requirements for region C1, which the standard lists as "no fibrillation" (shown in Fig. 5). Section 11.2.2 and Fig. 18 of IEC 60479-2 define I_{Brms} as being $I_{peak}/\sqrt{6}$ for currents approximated as being mostly unidirectional impulses of short durations.

The requirements of standards AS/NZS 60479.1 and AS/NZS 60479.2 are similar to those of the corresponding IEC versions, IEC 60479-1 and IEC 60479-2 [9, 10].



The curves indicate the probability of fibrillation risk for current flowing through the body from the left hand to both feet. For other current paths, see 5.9 in IEC 60479-1.

Below C_1:	no fibrillation;
Above C_1 up to C_2:	low risk of fibrillation (up to 5% of probability);
Above C_2 up to C_3:	average risk of fibrillation (up to 50% of probability);
Above C_3:	high risk of fibrillation (more than 50% probability).

Fig. 5. IEC 60479-2: Risks of ventricular fibrillation.

4. *IEC 6060-1: Medical electrical equipment. General requirements for basic safety and essential performance. 2005, including corrigenda up to August 2012.*

The 60601-1 international standards stipulate accepted regulatory requirements for the safety of electrical medical devices [11, 12]. Among many other requirements, the standard also sets the allowed threshold for the patient leakage current for medical devices that have direct contact to patients' heart. Citing from the standard, we learn that:

> "The allowable value of PATIENT LEAKAGE CURRENT for TYPE CF APPLIED PARTS in NORMAL CONDITION is 10 µA which has a probability of 0.002 for causing ventricular fibrillation or pump failure when applied through small areas to an intracardiac site.
>
> Even with zero current, it has been observed that mechanical irritation can produce ventricular fibrillation. A limit of 10 µA is readily achievable and does not significantly increase the risk of ventricular fibrillation during intracardiac procedures."

While the 10 μA_{rms} limit does not apply to TASER X26, X26P, or X2 CEWs, as they are not medical devices and do not deliver an intracardiac charge, the rationale behind the 0.002 probability of VF induction is relevant to CEW applications. Although a 10 μA_{rms} CF patient-leakage current is deemed to have a 0.002 probability (1 out of 500) of causing VF or pump failure in humans, the standard accepts this value as being safe. Regulatory agencies, such as the US FDA or the Germany-based Technischer Überwachungs-Verein (TUV), certify electrical medical devices as being

safe for use in intracardiac clinical procedures if they comply with this patient leakage current limit. Intracardiac procedures carry the highest risk for patients. Therefore, by accepting requirements of IEC 60601-1, or the equivalent BS EN 60601-1, these regulatory agencies accept that a 0.002 probability of causing VF represents an extremely low risk.

III. RESULTS

1. *Underwriters Laboratories (UL) Standard for Electric-Fence Controllers, UL 69 10th Ed, 2009.*

Although UL 69 covers electric-fence controllers used for the control of animals, some of its requirements are relevant to CEW functionality. Table II presents relevant output parameters of the TASER X26 and X2 CEWs with respect to previously discussed requirements of UL 69. As discussed above, the parameters of TASER X26P are equivalent to those of a single cartridge bay of the X2.

Table II. X26 and X2 CEWs parameters and UL 69 limits.

	X26 CEW	X2 CEW
Duration [ms] (at 95% of impulse energy)	68 μs	40 μs
UL limit $I_{impulse\_UL\_limit}$	10023 mA_{rms}	10023 mA_{rms}
Measured $I_{impulse\_max}$	2950 mA	2350 mA
UL limit $I_{repetitive\_UL\_limit}$	2300 mA_{rms}	2300 mA_{rms}
Measured $I_{repetitive\_rms}$	1424 mA_{rms}	1871 mA_{rms}

2. *IEC 60335-2-76, Ed 2.1: Household and Similar Electrical Appliances—Safety—Part 2—76: Particular Requirements for Electric Fence Energizers, 2006.*

Table III presents relevant output parameters of the X26 and X2 CEWs with respect to previously discussed requirements of IEC 60335-2-76, Ed 2.1. The parameters of X26P are equivalent to those of a single cartridge bay of the X2. All three CEWs deliver about 0.09 J/pulse, which is an energy/pulse level significantly below the 5 J/pulse limit required by the standard.

Table III. X26 and X2 CEWs parameters vs. relevant limits of IEC 60335-2-76.

	X26 CEW	X2 CEW
Duration [ms] (at 95% of impulse energy)	68 μs	40 μs
IEC limit $I_{impulse\_IEC\_limit}$	15,700 mA_{rms}	15,700 mA_{rms}
Measured $I_{impulse\_max}$	2950 mA	2350 mA
IEC limit Energy $_{repetitive\_IEC\_limit}$	2.5 J/s	2.5 J/s
Measured $Energy_{repetitive}$	1.61 J/s	1.69 J/s

3. *IEC 60479-1 & -2: Effects of Current on Human Beings and Livestock, General & Special Aspects, 2005 – 2007.*

The main phase net charge of X26 and X2 CEWs was measured to be 97 μC and 63 μC, respectively. These values are at least 50 times lower than the threshold indicated by IEC 60479-2 for a 50% probability of VF induction. Even if considering I_{Brms} equal to the peak output current of the X26 and X2, 2.9 A and 3.5 A, the output operating point continues to fall within the "no fibrillation" region C1 (Fig. 5). But, as explained above, the actual I_{Brms} can be approximated as 2.9 A/√6 and 3.5 A/√6 or 1.18 A and 1.43 A, for the X26 and X2 CEWs, respectively. At impulse durations of 0.126 ms, for the X26, or 0.056 ms, for the X2, IEC 60479-2 specifies the limit of the C1 region at approximately 6 A (Fig. 5). Consequently, the electrical parameters of X26 and X2 CEWs are well within the "no fibrillation" region C1, as specified by IEC 60479-2. The X26P CEW is expected to comply too, given that its output is equivalent to that of X2 CEW. Even the peak electrical currents delivered by X26, X26P and X2 CEWs fall in the "no fibrillation" region C1. For clarification, when delivered to a 600 Ω load, the actual root-mean-squared (RMS) value of the output current of an X26 CEW was measured at 52 mA_{rms}. Similarly, for the X2 CEW the output current RMS value was measured at 53 mA_{rms}. Thus, according to the IEC 60479-2 criteria, an impulse from an X26 or X2 CEW has very remote chances, if any, of directly inducing VF in a human. With a sequence of pulses, the VF threshold may decrease (see section 9.2 of IEC 60479-2) [8, 10]. Example 1, shown in Fig. 14 section 9.2,2, page 26, discusses the VF risk of a train of four very short current pulses, similar to those put out by TASER CEWs. The IEC 60479-2 concludes that "the risk of ventricular fibrillation in this case could be considered low [8]." In light of this Example, considering the narrow impulse duration (126 μs and 56 μs) and short duty cycle (< 0.2%) of X26 and X2 CEWs, the IEC 60479-2 standard confirms that a series of X26, X26P or X2 CEW pulses would not increase the risk of VF relative to that associated with an impulse.

We conclude that the X26, X26P, and X2 CEWs electrical outputs are within the "no fibrillation" region, as defined by IEC 60479-2, even for applications that last several seconds.

4. *IEC 6060-1: Medical electrical equipment. General requirements for basic safety and essential performance. 2005, including corrigenda up to August 2012.*

By accepting IEC 60601-1, or the equivalent BS EN 60601-1, regulatory agencies accept that a 0.002 probability of causing VF, or of 1 in 500 cases, represents an extremely low risk. The reported VF risk with CEWs is much lower. It has been reported that as of December 31, 2011, CEWs were used approximately on 1,351,891 ± 7% human volunteers, and, as of January 23, 2013, on 1,800,100 ± 2% human subjects during actual law enforcement field deployments [1, 3]. In any of these situations, no reliable scientific or medical evidence was provided that would support the notion that

TASER CEWs directly caused fatal cardiac rhythm disturbances [13, 14, 15]. As such, the VF risk with TASER CEWs is estimated at less than 1/(1,351,891 + 1,800,100) = 0.00000032, or less than 1 in 3,151,991 cases. In summary, the IEC 60601-1-accepted VF risk of 0.002 is more than 6000 times higher than the observed theoretical risk for TASER CEW-induced VF.

IV. Conclusion

Other groups have investigated the output of stun guns or TASER CEWs with respect to relevant requirements of the standards discussed above [14, 15, 17 – 19]. Southwell analyzed the safety of X26 and M26 CEWs [14, 15]. He concluded that the current output of the X26 CEW is significantly below the fibrillation threshold set out in the AS3859, AS/NZS 60479.1 and AS/NZS 60479.2 standards [14, 16]. Similar conclusions were reached after inspecting the output of M26 CEWs [15, 16]. The short pulses of the X26 and M26 CEWs make cardiac and breathing arrest very unlikely. No reports were found of cardiac arrest or breathing arrest solely from pulsed high frequency current at the levels produced by the X26 and M26 CEWs [14, 15]. Southwell opined that "from an electrical safety viewpoint the device presents an acceptable risk when used by trained law enforcement officers in accordance with the manufacturer's directions for use [14, 15]."

In 2009, Nimunkar and Webster also determined that the X26 CEW electrical parameters fall within relevant safety limits of UL, IEC and AS/NZS [20]. Recognizing that there are no standards for CEWs, Nimunkar and Webster proposed a new electrical standard for testing the safety of pulsed electric devices [20]. The proposed new standard would require: (1) construct a physical RC circuit with a time constant of about 2 ms, which is similar to that of cardiac cells, (2) discharge the device under test into this RC circuit and record the maximum output voltage, (3) if the maximum output voltage exceeds a specified voltage limit, the device would fail the test due to risk of VF. To model the cardiac cells, Nimunkar and Webster used an RC circuit with R = 9.08 Ω and C = 200 μF, which resulted in a time constant of 1.82 ms [20]. According to their investigation, a device should pass the test only if the maximum voltage developed across the capacitor did not exceed 0.5 V [20]. Their test data showed that the X26 CEW met the proposed safety standard for CEWs. When the X26 CEW was energized, the maximum voltage across the capacitor was 0.469 V, a lower value than the proposed 0.5 V limit. They also tested two commercial electric fences and determined that these devices failed their proposed safety standard [20].

Adler et al. described a detailed methodology for testing TASER CEWs [21]. Their protocol was based on experience of testing 6000 TASER CEWs in affiliated labs. They referenced the IEC 60479-2 electrical safety standard [8] and used it to compare the measured TASER CEW electrical output parameters. According to their results, even after accounting for device-to-device variability, the measured TASER CEW output parameters fell well within the safety limits prescribed by IEC 60479-2 [21].

The safety standards above address current through thoraxes without consideration for the depth of penetration of the CEW probe through the skin. However, when a probe tip is within a few millimeters from the epicardium then the charge of TASER CEWs may be sufficient to capture the heart [22]. Under probe penetration conditions unlikely to be experienced during real-life use, induction of VF has also been reported in simplified animal models [23]. Such observations may correlate with thresholds for VF induction reported in humans when rapid pulses were delivered [24, 25]. Close probe tip proximity to the epicardium requires rare circumstances and an unusually thin chest wall. Even under such conditions, echocardiography imaging reported an extremely low corresponding cardiac-capture risk [22, 26]. Cardiac effects have not been reported when CEW probes penetrated the skin at regions away from the chest [22]. Thus, the incremental risk offered by probe penetration does not affect the interpretation of the above safety standards as it relates to their applicability to TASER CEW performance.

Several reports associated induction of VF with use of CEWs. Kim and Franklin reported one such alleged event in 2005 [27]. Their evidence, associating the cardiac event with the actual use of a CEW, was rebuked by other medical experts [28]. A more recent case claimed that a teenager had VF induced by a CEW [29]. Emergency physicians from the same hospital refuted this report by publishing that the subject presented with asystole — not VF — consistent with his extreme levels of ethanol and presence of tetrahydrocannabinol [30]. Other incidents of alleged temporal association between sudden cardiac arrest and use of TASER CEWs were reported in a case series [31]. In all these incidents, the respective Medical Examiner reports established the cause of cardiac arrest as being different than direct electrical stimulation produced by TASER CEWs. Furthermore, case series provide weak evidence of causality because they are particularly prone to bias and confounding [32]. The controversial reports reviewed above [27, 29, 31], included ten cases of alleged association between induction of VF and use of TASER CEWs. Even if hypothetically accepting them, the observed theoretical VF risk with TASER CEWs would become 10 in 3,151,991 cases, which would still be 600 times lower than the IEC 60601-1-accepted VF risk of 1 in 500 [11, 12].

Concluding, the analyses above confirmed that the nominal electrical outputs of TASER X26, X26P and X2 CEWs lie within safety bounds specified by relevant requirements of UL, IEC, AS/NZS, EN, and BSI standards.

V. Disclosure

Dr. Panescu is paid consultant to TASER International, Inc. (TASER). Dr. Kroll is a member of TASER's Scientific and Medical Advisory Board and Board of Directors. Mr. Nerheim is TASER's Technical Fellow and Vice President of Research.

VI. REFERENCES

[1] TASER International: TASER Technology Summary. Available at http://www.taser.com/research-and-safety/science-and-medical

[2] Smith PW, Hand-held stun gun for incapacitating a human target, US Patent 6,636,412, October 21, 2003.

[3] TASER International: Law Enforcement Technology. Available at http://www.taser.com/products/law-enforcement

[4] D. M. Dawes, J. D. Ho, M. W. Kroll and J. R. Miner, "Electrical Characteristics of an Electronic Control Device Under a Physiologic Load: A Brief Report," *PACE*, pp. 1–7, 2009.

[5] Underwriters Laboratories, UL Standard for Electric-Fence Controllers, UL 69 10th Ed, 2009, Northbrook, IL: UL Laboratories.

[6] International Electrotechnical Commission, Household and Similar Electrical Appliances—Safety—Part 2—76: Particular Requirements for Electric Fence Energizers IEC 60335-2-76, Ed 2.1, 2006, Geneva: IEC.

[7] International Electrotechnical Commission, Effects of current on human beings and livestock: Part 1 – General aspects, IEC 60479-1, 2005, Geneva: IEC.

[8] International Electrotechnical Commission, Effects of current on human beings and livestock: Part 2 – Special aspects, IEC 60479-2, 2007, Geneva: IEC.

[9] Australian/New Zealand Standard™, Effects of current on human beings and livestock: Part 1: General aspects. AS/NZS 60479.1:2010.

[10] Australian/New Zealand Standard™, Effects of current on human beings and livestock: Part 2: Special aspects. AS/NZS 60479.2:2002.

[11] International Electrotechnical Commission, Medical electrical equipment - Part 1: General requirements for basic safety and essential performance, IEC 60601-1:2005+A1:2012, Geneva: IEC.

[12] BSI British Standards. BS EN 60601-1:2010 Medical electrical equipment. General requirements for basic safety and essential performance. 2010.

[13] W. P. Bozeman, E. Teacher and J. E. Winslow, "Transcardiac conducted electrical weapon (TASER) probe deployments: incidence and outcomes," *J. Em. Med.*, on line at doi:10.1016/j.jemermed.2012.03.022.

[14] J. Southwell, "Taser X-26 safety analysis," Biomedical Engineering Department of The Alfred Hospital, Victoria, Australia, 2004. Referenced at http://www.police.qld.gov.au/Resources/Internet/news and alerts/campaigns/taser/documents/ReviewoftheQPSTasertrial.pdf

[15] J. Southwell, "Advanced Taser M-26 safety analysis," Biomedical Engineering Department of The Alfred Hospital, Victoria, Australia, 2003. Referenced at http://www.police.qld.gov.au/Resources/Internet/news and alerts/campaigns/taser/documents/ReviewoftheQPSTasertrial.pdf

[16] Australian Standard, Effects current flowing through the human body. AS 3859: 1991.

[17] M. N. Robinson, C. G. Brooks, G. D. Renshaw, "Electric Shock Devices and their Effects on the Human Body," *Med. Sci. Law*, vol. 30(4), pp. 285-300, 1990.

[18] C. Sherry, C. Beason, G. C. Brown, et al., "Variable Taser Parameters: Effectiveness (Muscle Contraction) and Cardiac Safety (Ventricular Fibrillation)," *United States Air Force Research Laboratory. AFRL-HE-BR-TR-2004-0094*, July 2004.

[19] J. Kenny, B. Murray, W. Sebastianelli, et al., "Report of Findings: Sticky Shocker Assessment," *Penn State Applied Research Laboratory*, July 29 1999.

[20] A. J. Nimunkar and J.G. Webster, "Safety of pulsed electric devices," *Physiol Meas.*, vol. 30(1), pp. 101-114, 2009.

[21] A. Adler, D. Dawson and R. Evans, "Toward a Test Protocol for Conducted Energy Weapons," *Modern Instrumentation*, Vol. 2(1), pp. 7-15, 2013.

[22] D. M. Dawes, J. D. Ho, J. C. Moore and J. R. Miner, "An evaluation of two conducted electrical weapons and two probe designs using a swine comparative cardiac safety model," *Forensic Sci Med Pathol.* DOI 10.1007/s12024-013-9422-x. Published online March 30, 2013.

[23] J. Y. Wu, H. Sun, A. P. O'Rourke, et al., "Taser blunt probe dart-to-heart distance causing ventricular fibrillation in pigs," *IEEE Trans. Biomed. Eng.*, vol. 55(12), pp. 2768-2771, 2008.

[24] G. Walcott, M. Kroll and R. Ideker, "Ventricular Fibrillation Threshold of Rapid Short Pulses," *Conf. Proc. IEEE Eng. Med. Biol. Soc.,* vol. 2011, pp. 255-258, 2011.

[25] L. N. Horowitz, J. F. Spear, M. E. Josephson, J. A. Kastor and E. N. Moore, "The effects of coronary artery disease on the ventricular fibrillation threshold in man," *Circ.*, vol. 60(4), pp. 792-7, 1979.

[26] M. W. Kroll, D. Lakkireddy, P. S. Rahko, D. Panescu, "Ventricular fibrillation risk estimation for conducted electrical weapons: critical convolutions," *Conf. Proc. IEEE Eng. Med. Biol. Soc.*, vol. 2011, pp. 271-277, 2011.

[27] P. J. Kim and W. H. Franklin, "Ventricular fibrillation after stun-gun discharge," *N. Engl. J. Med.*, vol. 353(9), pp. 958-959, 2005.

[28] J. Roberts, "Medical Effects of TASERs." *Emergency Medicine News*. vol. 30(2), pp. 12-15, 2008.

[29] R. S. Naunheim, M. Treaster and C. Aubin, "Ventricular fibrillation in a man shot with a Taser," *Emerg. Med. J.*, vol. 27(8), pp. 645-646, 2010.

[30] E. S. Schwarz, M. Barra and M. M. Liao, "Successful resuscitation of a patient in asystole after a TASER injury using a hypothermia protocol," *Am. J. Emerg. Med.*, vol. 27(4), pp. 511-512, 2009.

[31] D. P. Zipes, "Sudden Cardiac Arrest and Death Following Application of Shocks From a TASER Electronic Control Device," Circ., vol. 125(20), pp. 2417-2422, 2012.

[32] M. P. Ho, P. N. Peterson and F. A. Masoudi, "Evaluating the Evidence: Is There a Rigid Hierarchy?" *Circ.*, vol. 118, pp. 1675-1684, 2008.