Electrical Testing of TASER X2 and TASER X26P Conducted Energy Weapons

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Executive Summary

This work seeks to inform policy makers on the results of tests performed on the new TASER X26P and TASER X2 models of conducted energy weapons (CEWs). The TASER X2 and TASER X26P deliver an electrical waveform marketed as TASER International's "Precision Shaped Pulse". In this study, the functional and electrical characteristics of 30 TASER X26P and 30 TASER X2 models were documented. Testing was done in accordance with the procedure recommended in 2013 by DRDC-CSS.

All of the weapons passed the electrical tests. In all cases, the weapons produced electrical pulses that were well-defined in amplitude and in duration. No anomalies were noted during the electrical tests. Although previous studies have shown that the pulse rate has been a failure mechanism for older models of TASER CEWs, the pulse rates of the new weapon models were found to be very stable under laboratory conditions.

A statistical analysis of the recorded waveforms revealed only small differences between the TASER X2 and the TASER X26P. On average, the total charge delivered by the TASER X26P was 7% higher than that of the TASER X2. On average, the duration of each pulse produced by the TASER X26P was approximately 10% longer than that of the TASER X2. This being said, all of the weapons were well within the recommended limits. The charge delivered by the weapons was found to be within ±5% of the manufacturer's claim.

TASER International has addressed two of the concerns regarding the TASER X2 that were raised in a previous report. At that time, the safety switch of the TASER X2 could be slid into the Armed or Safe position quite easily, making it susceptible to being inadvertently armed or disarmed. A stop has been added to the safety switch of the latest TASER X2, which requires the application of a more significant force to throw the switch. This same feature is also present on the TASER X26P. The second concern that has been addressed by TASER International is with regards to the Smart Cartridges, which deploy the probes from a TASER X2 when it is fired. Previously, the blast doors did not separate cleanly from the cartridge when the weapon was fired. The blast doors of the new Smart Cartridge have been redesigned and separated cleanly during a test firing of the weapon.

However, a single test firing of a TASER X2 revealed that parts of the Smart Cartridge cracked and broke, a problem that was noted in a previous study. Bits of broken plastic slid out of the weapon when the spent cartridge was removed. There is a concern that the broken pieces may get lodged and interfere with the reloading of the weapon. As previously noted, such breakage could lead to a misfiring of the TASER X2. This issue, which is particular to the TASER X2, should be addressed by the manufacturer. The TASER X26P uses a different cartridge type and no cartridge damage was evident when the TASER X26P was fired.

Both weapon models can be connected to a computer running the Evidence Sync software. Evidence Sync can load the most recent firmware release onto the weapon via the internet. Evidence Sync also downloads the firing events stored by the weapon and displays that information to the user. Although the software ran reliably, a number of small deficiencies were noted.

Significance for Defence and Security

This work is timely and important to Canadian law enforcement agencies for two reasons.

First, TASER International has announced that, as of December 2014, it will discontinue sales of the TASER X26E, which is the most widely held conducted energy weapon (CEW) in Canadian law enforcement inventories. As such, law enforcement agencies will be forced to adopt new CEWs in the coming years. This report contains operational and technical information concerning two next-generation CEWs manufactured by TASER International, namely the TASER X26P and the TASER X2, which may be chosen to replace the older TASER X26E CEWs. The information in this report serves to inform policy makers on the some of the merits and shortcomings of both weapons.

Second, this report serves as a follow-up to an earlier report in which operational safety concerns were raised regarding the TASER X2. Some of these issues have been addressed by the manufacturer whereas others have not, and these are documented herein.

Résumé

Le présent rapport vise à informer les décideurs des résultats des essais qui ont été menés sur les nouveaux modèles d'armes à impulsions (AI) TASER X26P et TASER X2. Le TASER X2 et le TASER X26P produisent une forme d'onde électrique commercialisée par TASER International sous le nom de « Precision Shaped Pulse ». Dans cette étude, nous avons documenté les caractéristiques fonctionnelles et électriques de 30 exemplaires du modèle TASER X26P et de 30 exemplaires du modèle TASER X2. Nous avons mené les essais conformément à la procédure qui avait été recommandée en 2013 par RDDC CSS.

Toutes les armes ont réussi les essais électriques. Dans tous les cas, les armes ont produit des impulsions électriques qui étaient bien définies en amplitude et en durée. Nous n'avons observé aucune anomalie pendant les essais électriques. Alors que des études précédentes ont démontré que la fréquence des impulsions causait des défaillances dans les modèles plus anciens d'armes à impulsions TASER, l'étude a permis de constater que la fréquence des impulsions des nouveaux modèles est très stable dans des conditions de laboratoire.

Une analyse statistique des formes d'ondes enregistrées a révélé de très petites différences entre le TASER X2 et le TASER X26P. En moyenne, la charge totale produite par le TASER X26P était plus élevée de 7 % que celle du TASER X2. En moyenne, la durée de chaque impulsion produite par le TASER X26P durait 10 % plus longtemps que celle du TASER X2. Cela dit, toutes les armes se trouvaient bien à l'intérieur des limites recommandées. L'étude a permis de constater que la charge produite par ces armes se situait à moins de □5 % de la déclaration du fabricant.

TASER International a corrigé deux des préoccupations concernant le TASER X2 qui avaient été soulevées dans un rapport précédent. À l'époque, le verrou de sécurité du TASER X2 pouvait basculer très facilement entre la position « Armed » (armé) ou « Safe » (sécurité), ce qui rendait l'arme très susceptible d'être armée ou désarmée par inadvertance. Le fabricant a ajouté un cran au verrou de sécurité du dernier modèle TASER X2, qui requiert l'application d'une plus grande force pour faire basculer le verrou. Cette même caractéristique est maintenant présente sur le modèle TASER X26P. La deuxième préoccupation qui a été corrigée par TASER International concerne les cartouches « Smart », qui déploient les sondes du TASER X2 lorsqu'on utilise l'arme. Précédemment, les portes ne se détachaient pas nettement de la cartouche quand on faisait feu avec l'arme. Les portes de la nouvelle cartouche « Smart » ont été redessinées et se détachent maintenant nettement dans les tirs d'essai.

Toutefois, dans un essai de tir unique du TASER X2, le plastique de la cartouche « Smart » a cassé, un problème que nous avions noté dans une étude précédente. Des éclats de plastique sont tombés de l'arme quand la cartouche utilisée a été enlevée. Nous sommes préoccupés par des éclats de plastique qui pourraient rester logés dans le réceptacle de la cartouche et entraver recharge de l'arme. Comme nous l'avions noté précédemment, un bris de la sorte pourrait mener à un tir raté du TASER X2. Ce problème, qui est particulier au modèle TASER X2, pourrait être corrigé par le fabricant. Le modèle TASER X26P utilise des cartouches différentes et aucune de ces cartouches n'a montré de bris quand le TASER X26P a été mis à l'essai.

Les deux modèles d'arme peuvent être branchés à un ordinateur sur lequel est installé le logiciel Evidence Sync. Ce logiciel permet de télécharger la plus récente version du micrologiciel dans l'arme par l'entremise d'Internet. Evidence Sync peut aussi télécharger vers l'ordinateur les données de tir qui sont enregistrées dans l'arme et les afficher. Même si le logiciel fonctionnait de manière fiable, nous avons noté certaines petites lacunes.

Importance pour la défense et la sécurité

Ces travaux sont considérés comme importants et à propos pour les forces de l'ordre du Canada pour deux raisons.

Tout d'abord, la société TASER International a annoncé qu'à compter de décembre 2014, elle cessera la vente du modèle TASER X26E, le modèle le plus courant d'arme à impulsions dans les stocks d'armes des forces de l'ordre au Canada. Les organismes qui détiennent ces armes seront obligés d'adopter de nouvelles armes dans les années à venir. Ce rapport contient des informations techniques et opérationnelles qui concernent deux prochaines générations d'armes à impulsions fabriquées par TASER International, à savoir le TASER X26P et le TASER X2, qui font partie des choix de remplacement pour les anciennes armes TASER X26E. L'information dans ce rapport sert à informer les décideurs des mérites et des lacunes de ces deux armes.

Deuxièmement, le rapport sert de suivi à un rapport publié plus tôt, dans lequel des préoccupations de sécurité opérationnelles avaient été soulevées concernant le TASER X2. Certaines de ces préoccupations ont été réglées par le fabricant, alors que d'autres ne l'ont pas été, et sont signalées dans ce nouveau rapport**.**

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1 Introduction

The TASER X26E is the mostly widely held CEW approved for use by Canadian law enforcement agencies. However, TASER International has announced that sales of the TASER X26E will cease as of December 31, 2014. As such, new CEW models are being considered to replace the TASER X26E.

This study investigates the electrical and functional performance of two of the next-generation CEW models sold by TASER International, namely the TASER X26P and TASER X2. Whereas shipments of the TASER X2 began in June of 2011, the TASER X26P was announced in January 2013 and is TASER International’s most recent CEW at the time of writing [1].

The objective of this study is to verify and to compare the functional and electrical performance of a population sample of new TASER X26P and TASER X2 CEWs. To this end, 30 TASER X26P and 30 TASER X2 CEWs were secured from the Canadian supplier, MD Charlton Company Ltd. All of the tested weapons were likely manufactured in November 2013, based on the earliest records that appear in the weapon logs

As part of the functional tests, a limited number of live cartridges were fired from both CEW models. In addition, the TASER International software known as Evidence Sync was evaluated by connecting the weapons to the computer. Firmware upgrades to the weapons were performed via the internet.

Electrical testing of the weapons was done in accordance with the recommended Canadian test procedure known as DRDCVer1 [2]. The weapons were validated against the Canadian acceptance limits found in DRDCVer1.

In addition, the electrical pulses produced by the weapons were characterized and compared on a pulse-by-pulse basis, on a weapon-by-weapon basis, and on a model basis. The pulses produced by the left- and right-side bays of the TASER X2 will also be characterized and compared.

This report is divided into 5 chapters. Chapter 2 introduces the two weapon models that are considered in this study and summarizes the functional tests. Chapter 3 describes the test equipment that was used. Chapter 4 presents the analysis of the electrical data and Chapter 5 presents the conclusions and lists possible future work.

2 Introduction to the TASER X26P and TASER X2

The TASER X26P and TASER X2 CEWs are described in this chapter. Section 2.1 begins by comparing the physical features of both weapon models. In Section 2.2, physical features that are common to both weapon models are described, as is the TASER International software package that is used with both weapons, known as Evidence Sync. A critical examination of the Evidence Sync software is also included. Sections 2.3 and 2.4 present features that are unique to the TASER X26P and TASER X2, respectively. Finally, Section 2.5 examines a number of previous concerns that were raised in a previous report regarding the TASER X2 to see if any progress has been made in addressing them.

2.1 Physical Description of the Weapons

The TASER X26P and TASER X2 are both shaped like a lopsided pistol, with the TASER X2 being the larger of the two. The TASER X2 has been described previously in detail in [3]. The TASER X26P closely resembles the earlier TASER X26E model. Both weapons consist of three main components, namely: the body, the power magazine, and the cartridge, as shown in Fig. 1. All of the parts are made from high-impact molded plastic. The dimensions and mass of the weapon components are compared in Table 1.

Figure 1: Disassembled TASER X26P (left) and TASER X2 (right)

Table 1: Dimensions and mass of the TASER X26P and TASER X2 components

	TASER X26P (Rev. X3)	**TASER X2**
Length with a standard power magazine	16.0 cm (19.2 cm with cartridge)	19.8 cm [4] (same with cartridges)
Width with a standard power magazine	4.4 cm	4.3 cm [4]
Height with a standard power magazine	10.4 cm	10.7 cm [4]
Mass (body only)	214 g	286 g [3]
Mass of standard 25-foot cartridge	56 g (model 22403 Rev. G)	39 g (model 22151 Rev. A)
Mass of standard power magazine	69 g (model 22010 Revision A)	

The measured dimensions and mass of the TASER X26P are in agreement with [5] and are similar to those of the earlier TASER X26E model [6], although the front part of the TASER X26P body is slightly wider than the earlier model. Although the unloaded TASER X26P is shorter than an unloaded TASER X2, their lengths are approximately the same once they are loaded with cartridges because the TASER X2 cartridges mount flush with the front of the weapon whereas those of the TASER X26P extend beyond the front of the weapon. The maximum width of both weapons corresponds to the edges of the safety levers. When loaded with a standard power magazine and a 25-foot cartridge, the TASER X26P weighs approximately 340 g whereas the TASER X2 (with two 25-foot cartridges) weighs approximately 430 g (about 25% heavier). The maximum thickness of the grip is approximately 32.5 mm for both weapons.

2.2 TASER X26P and TASER X2 Shared Characteristics

Both models share a number of features and operating characteristics. The right-side view of both weapons is shown in Fig. 2 (not exactly to scale).

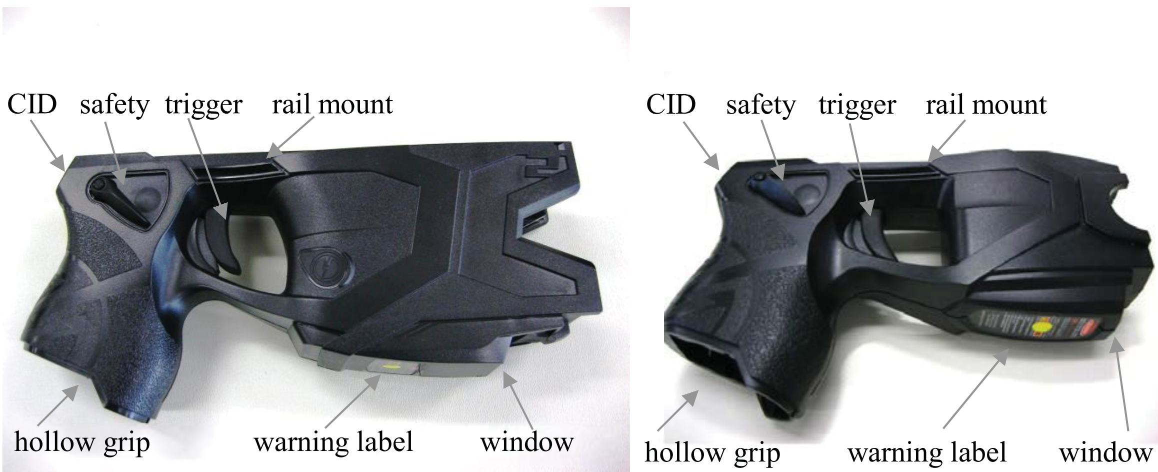

Figure 2: Right-side of the TASER X2 (left) and TASER X26P (right) weapon bodies

Both models have a hollow grip into which a power magazine must be inserted to operate the weapon. The locations of the Central Information Display (CID), ambidextrous safety lever, trigger, rail mount slots, warning labels, and front window are also the same. The rear view of the TASER X26P is shown in Fig. 3.

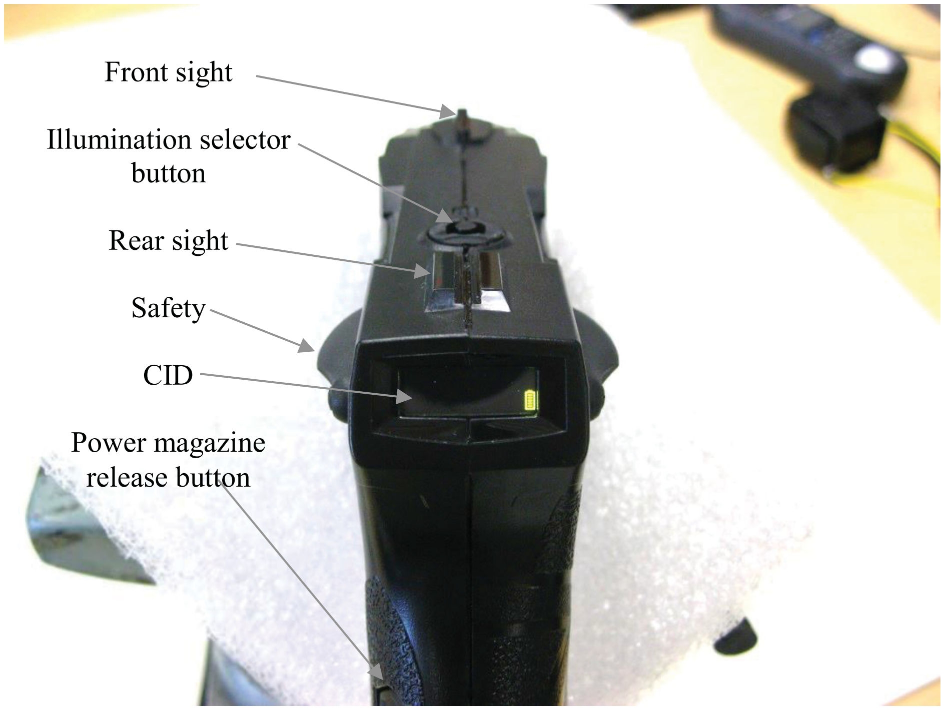

Figure 3: Rear view of the TASER X26P

Both models have fin-and-blade mechanical sights and an illumination selector button along the top of the weapon. The power magazine release button is located on the left-hand side of the grip on both weapons. Both models use the same type of power magazine, known as the Performance Power Magazine (PPM), shown in Fig. 4.

Figure 4: TASER X26P and TASER X2 power magazines: PPM, APPM and TPPM

The power magazines used in the earlier TASER X26E are incompatible with the newer TASER X26P. There are different types of PPM, including the Audible PPM (APPM) and the Tactical PPM (TPPM), in addition to the standard PPM. The optional audio-video recorder TASER CAM can also be inserted into the hollow grip of both weapons.

Events, such as the arming the weapon and trigger pulls, are recorded internally by both models. The event data can be uploaded to a computer running the TASER International software program Evidence Sync by inserting a USB adaptor into the hollow grip of the weapon and connecting it to the computer. Fig. 5 shows the USB adaptor and the CID display when the weapon is connected to the computer.

Figure 5: USB adapter (left) and CID showing of the weapon's serial number when it is connected to the computer (right)

The weapon's most recent firmware can be downloaded via the internet and installed onto the weapon when it is connected to Evidence Sync. At the time of writing, the most recent version of Evidence Sync (2.9.2) is significantly different from the earlier version (1.31) evaluated in [3]. The user interface is less crowded, having been accomplished by removing certain information, such as the warranty, subcomponent firmware revision numbers, firmware history, and weapon options. In the upper left-hand side of the Evidence Sync main window are shown the weapon model, serial number, assignee, firmware revision and an option to print a PDF report. The main Evidence Sync window has two tabs: Logs and Device Settings, as shown in Fig. 6.

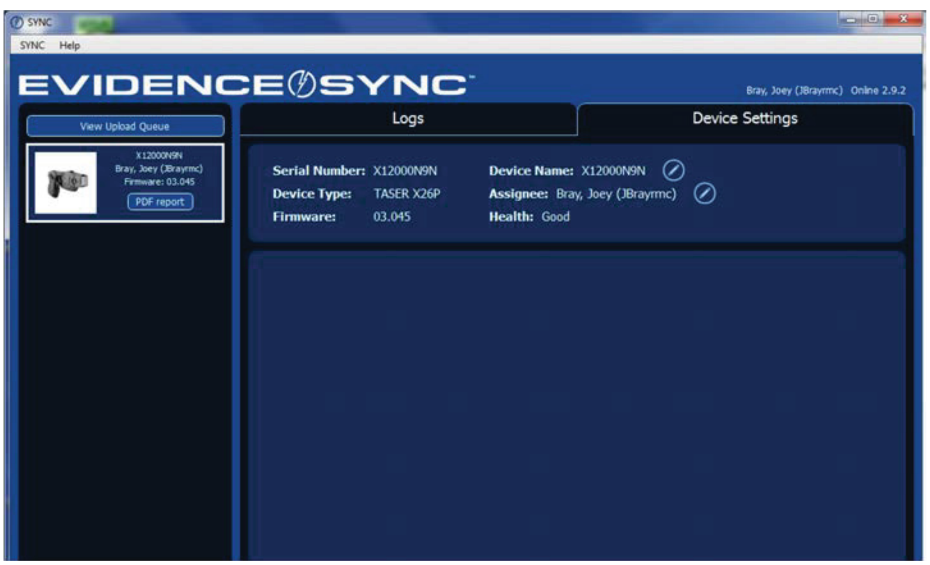

Figure 6: Evidence Sync Device Settings tab

The Device Settings tab again lists the weapon model, serial number, firmware revision and officer assignee, the latter being editable. It also allows the user to create a name for the weapon. The “health” of the weapon is also listed (shown as Good in Fig. 6).

The Logs tab, shown in Fig. 7, contains the event log of the weapon, including buttons that generate graphs of the pulse logs that are recorded when the weapon is fired.

Figure 7: Evidence Sync Logs tab with a TASER X26P connected

Pressing a Graphs button next to a trigger event yields a Pulse Log graph shown in Fig. 8.

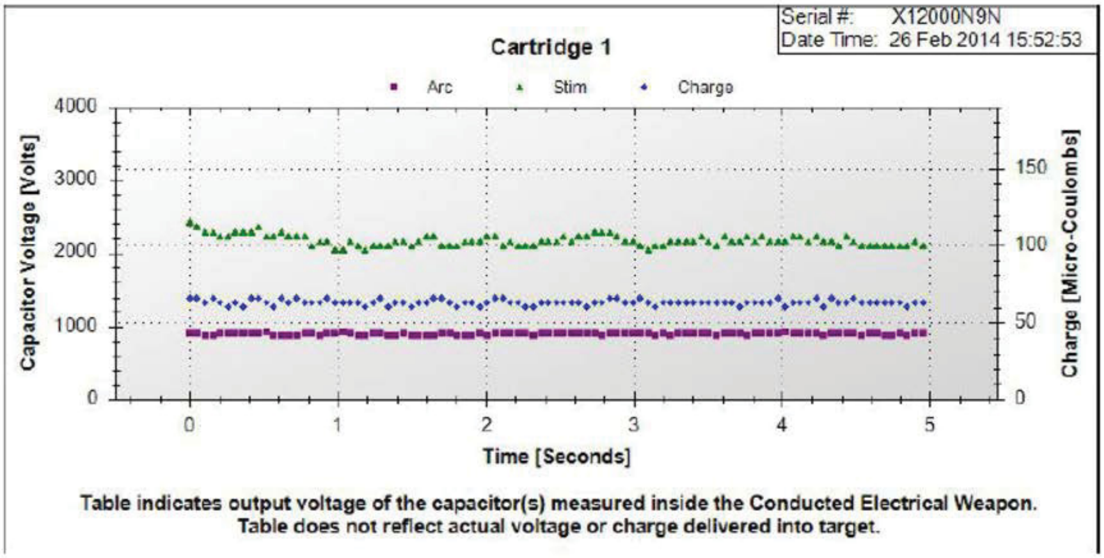

Figure 8: Pulse Log graph of a TASER X26P

The Pulse Log displays the voltages in the weapon's internal capacitors – one capacitor is associated with the Arc Phase whereas the other is for the Stimulation Phase. Note that these voltages are *not* the same voltages associated with testing – rather, they are the voltage levels of the internal components of the weapon. A charge parameter is also overlaid on the same graph, but the definition of this charge parameter is not disclosed by TASER International. **Although the Pulse Log may be useful as a qualitative measure of the electrical connection with a subject, the lack of any manufacturer definition and the disclaimers listed at the bottom of the graph limit its usefulness in any other context. As previously noted in [3], the Pulse Logs still only record 97 pulses despite there being 98 pulses at times. The reason for this discrepancy is unknown and should be addressed by the manufacturer.**

In the Evidence Sync main window, pressing the PDF Report button generates another event listing in PDF format, as shown in Fig. 9 for a TASER X26P weapon. Oddly, the Health of the weapon is listed in the PDF as "Active" instead of "Good" as in the Evidence Sync Device Settings tab (this discrepancy exists only for the TASER X26P).

In Fig. 10, the beginning and end of the Evidence Sync Logs tab window is shown. The reader should compare the event numberings shown in Figs 9 and 10.

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Taser Information		Report Generated by	
Dept.	ROYAL MILITARY COLLEGE OF CANADA	Name	Bray, Joey
Serial	X12000N9N	Badge ID	JBrayrmc
Model	TASER X26P	Local Timezone	Eastern Standard Time (UTC -05:00)
Firmware Version	Rev. 03.045	Generated On	07 Mar 2014 10:11:41
Device Name	X12000N9N		
Health	Active		

Device (X26P)

Seq #	Local Time [dd:mm::yyyy Hr:min:Sec]	Event [Event Type]	Duration [Seconds]	Temp [Degrees Celsius]	Batt Remaining [%]
1	25 Nov 2013 19:12:38	Armed		29	70
2	25 Nov 2013 19:12:43	Trigger	5		70
3	25 Nov 2013 19:12:48	Trigger	5		70
4	25 Nov 2013 19:12:54	Trigger	5		70
5	25 Nov 2013 19:12:59	Trigger	5		70
6	25 Nov 2013 19:13:05	Trigger	5		70
7	25 Nov 2013 19:13:11	Trigger	5		70
8	25 Nov 2013 19:13:16	Trigger	5		70
9	25 Nov 2013 19:13:22	Trigger	5		70
10	25 Nov 2013 19:13:27	Trigger	5		70
11	25 Nov 2013 19:13:33	Trigger	5		70
12	25 Nov 2013 19:13:39	Trigger	5		70
13	25 Nov 2013 19:13:44	Trigger	5		70
14	25 Nov 2013 19:13:50	Trigger	5		70
15	25 Nov 2013 19:13:56	Trigger	5		70
16	25 Nov 2013 19:14:02	Trigger	5		70
17	25 Nov 2013 19:14:08	Trigger	5		70
18	25 Nov 2013 19:14:14	Trigger	5		70
19	25 Nov 2013 19:14:20	Trigger	5		70
20	25 Nov 2013 19:14:26	Trigger	5		70
21	25 Nov 2013 19:14:31	Trigger	5		69
22	25 Nov 2013 19:14:37	Safe	118	40	69
23	25 Nov 2013 19:59:42	USB			Unknown
24	11 Dec 2013 12:48:36	Time Sync	From '11 Dec 2013 12:48:36' to '11 Dec 2013 12:49:13'		
25	11 Dec 2013 12:49:18	Armed		29	90
26	11 Dec 2013 12:49:19	Trigger	5		90
27	11 Dec 2013 12:49:25	Safe	6	29	90
28	26 Feb 2014 15:45:06	USB			Unknown
29	26 Feb 2014 15:45:08	Time Sync	From '26 Feb 2014 15:45:08' to '26 Feb 2014 15:48:56'		
30	26 Feb 2014 15:50:59	Armed		32	75
31	26 Feb 2014 15:51:14	Trigger	1		75
32	26 Feb 2014 15:51:15	Safe	15	33	75
33	26 Feb 2014 15:52:48	Armed		31	75
34	26 Feb 2014 15:52:53	Trigger	5		75
35	26 Feb 2014 15:52:59	Safe	11	32	74
36	26 Feb 2014 15:59:23	USB			Unknown
37	26 Feb 2014 15:59:25	Time Sync	From '26 Feb 2014 15:59:25' to '26 Feb 2014 15:59:25'		
38	07 Mar 2014 09:34:58	Armed		26	92
39	07 Mar 2014 09:35:09	Safe	11	27	92
40	07 Mar 2014 09:36:57	Armed		28	92
41	07 Mar 2014 09:39:06	Safe	129	35	92
42	07 Mar 2014 09:39:17	Armed		34	92
43	07 Mar 2014 09:39:47	Safe	30	34	92
44	07 Mar 2014 09:42:03	Armed		31	92
45	07 Mar 2014 09:42:35	Safe	32	33	92
46	07 Mar 2014 09:56:39	USB			Unknown
47	07 Mar 2014 09:56:43	Time Sync	From '07 Mar 2014 09:56:43' to '07 Mar 2014 09:57:05'		

Figure 9: Evidence Sync PDF Report for TASER X26P serial number X12000N9N

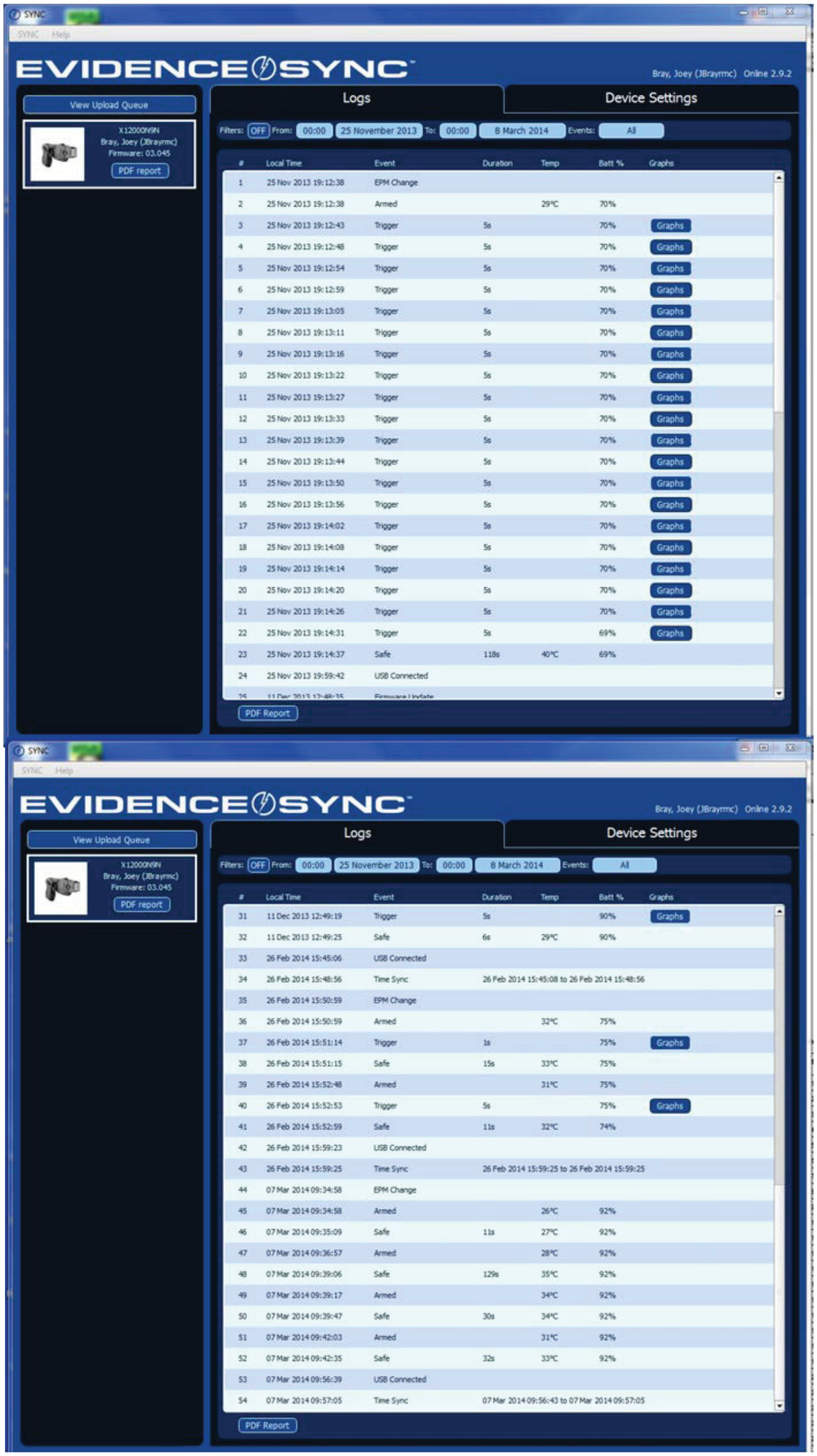

Figure 10: Evidence Sync Logs tab for the same TASER X26P serial number X12000N9N

Note that the event numbering is different depending on whether the data is viewed in the Logs tab or in the PDF Report. This is because the PDF Report contains more events, such as power module changes, that are not captured in the Logs tab. **This discrepancy may lead to confusion, since the same event will have a different event number depending on whether the Logs tab or the PDF Report is used as the source of the information.**

The most significant difference between the (soon to be discontinued) TASER X26E and the TASER X26P is with regards to the pulse waveform that is delivered to the subject: the newer TASER X26P uses the same "Precision Shaped Pulse" technology as the TASER X2. A qualitative comparison of the old and new waveforms is shown in Fig. 11.

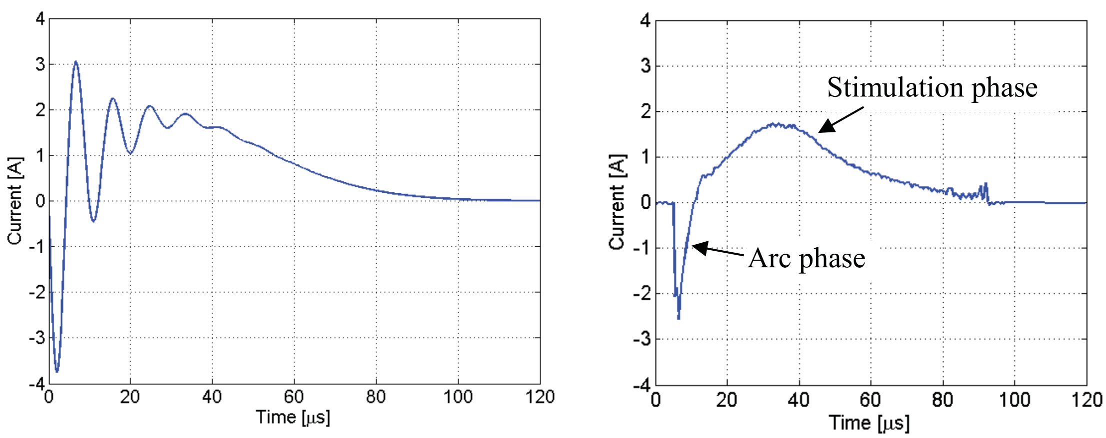

Figure 11: Typical current pulse of a TASER X26E (left) and of a TASER X26P or TASER X2 (right)

The "Precision Shaped Pulse" that is common to the TASER X26P and TASER X2 has two distinct lobes. The pulse begins with a brief, high amplitude lobe known as the Arc Phase that establishes the electrical connection. It is followed by the longer Stimulation Phase that is responsible for neuromuscular incapacitation. The duration of both of the pulses in Fig. 11 is approximately 100 µs. The oscillations associated with the earlier TASER X26E waveform have been eliminated in the Precision Shaped Pulse and the peak current of the Stimulation Phase has been reduced significantly. The nominal pulse repetition frequency (PRF) is 19 pulses per second for the TASER X26E, TASER X26P and TASER X2.

There are a number of functional similarities between the TASER X26P and TASER X2. The arming of the weapons is accomplished by flipping the safety lever, which also illuminates the LED flashlight and/or the laser sight depending on the weapon's illumination settings. Depressing the Illumination selector button while the weapon is armed places the weapon in *stealth mode*, in which the laser and flashlight are turned off and the CID display is dimmed. Without a cartridge, depressing the trigger fires the weapon, which creates arcs between the recessed arc points at the front of the weapon (when the weapon is not placed on a subject). The weapon can also be used a *drive-stun* mode if it is pushed against a subject and the trigger is pulled. After a trigger pull, the CID counts and displays the duration of the discharge cycle, which is nominally 5-seconds long.

2.3 Unique Characteristics of the TASER X26P

The most significant difference between the TASER X26P and the TASER X2 is with respect to the cartridges that fire the probes. The TASER X26P uses the same “Standard Cartridge” that is used with the TASER X26E. At the time of writing, 15-foot, 21-foot, 25-foot and 35-foot cartridges are available for field use.

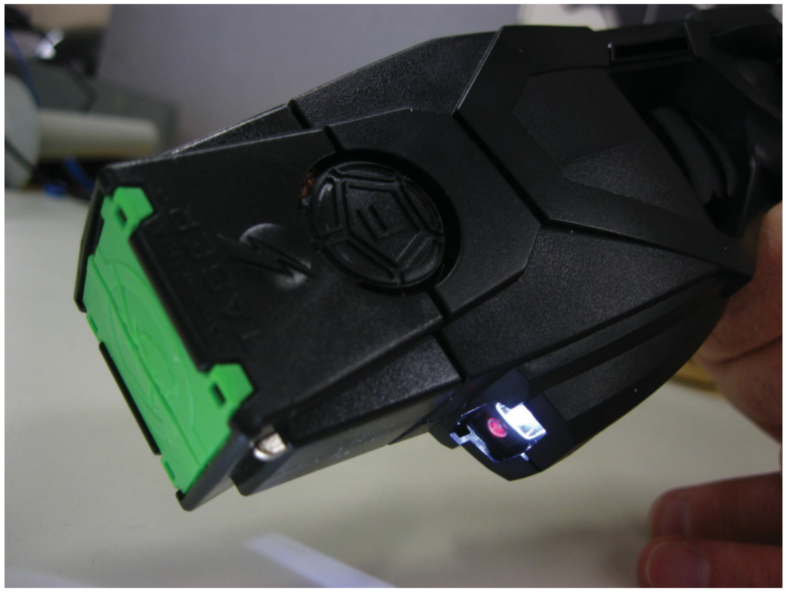

Figure 12: TASER X26P with a 25-foot cartridge loaded (model 44203)

Once the TASER X26P is loaded with a cartridge, a trigger pull of the TASER X26P will fire the probes, followed by a 5-second discharge cycle. **There is no way of producing a warning arc with a loaded TASER X26P. The TASER X26P can be loaded with only a single cartridge at a time.** After firing, the spent cartridge must be removed and a new one inserted before the weapon can fire another set of probes. A power module known as the Extended PPM (XPPM) holds a spare cartridge and is available for the TASER X26P.

The TASER X26P has a single laser sight, which is visible along with the flashlight below the cartridge in Fig. 12. Whether or not the laser and/or flashlight illuminate when the weapon is armed depends on the illumination settings that are chosen by pressing the Illumination Selector button while the weapon is in safe mode.

As shown earlier in Fig. 3, when the TASER X26P is armed, the CID displays only the battery status when used with a PPM under normal operating conditions. **In a TASER X26P, the type of cartridge loaded into the weapon must be identified visually by the colour of its blast doors.**

2.4 Unique Characteristics of the TASER X2

The TASER X2 uses a different, more slender type of cartridge known as the “Smart Cartridge” and the weapon can be loaded with up to two cartridges simultaneously, allowing for Semi-Automatic firing of two sets of probes if the trigger is pulled twice. The TASER X2 has many more features than the TASER X26P, including the immediate availability of the backup shot. At the time of writing, Smart Cartridges are available in 15, 25 and 35-foot lengths. As shown on the left of Fig. 13, the front window of the TASER X2 has two laser sights in addition to the flashlight: one laser estimates the impact site of the top probe whereas the other estimates the impact site of the bottom probe when using a 25-foot cartridge.

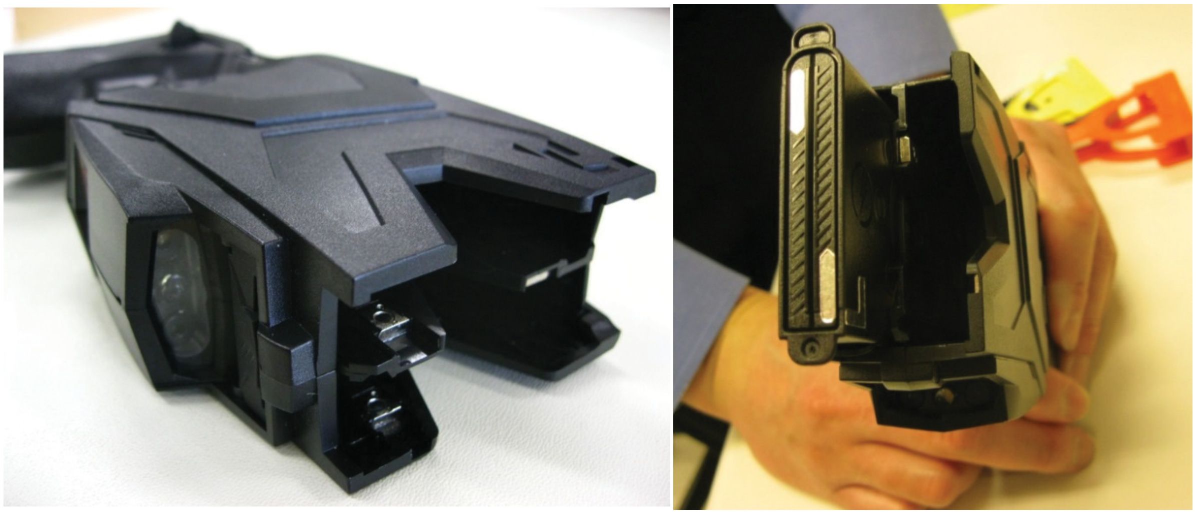

Figure 13: Empty bays of a TASER X2 (left) and with one cartridge partially inserted (right)

The internal firing mechanism of a Smart Cartridge is different from that of a Standard Cartridge, in that the high voltage pulse generated by the weapon does *not* initiate the firing. Additional electrical contacts are present on the Smart Cartridge, shown on the bottom right-hand side of Fig. 14. These contact allow it to communicate with the TASER X2, and it is along these contacts that the firing signal is sent. **Given the different firing mechanism, the Smart Cartridge is marketed as being much less susceptible to accidental firing when exposed to static electricity than is the Standard Cartridge.**

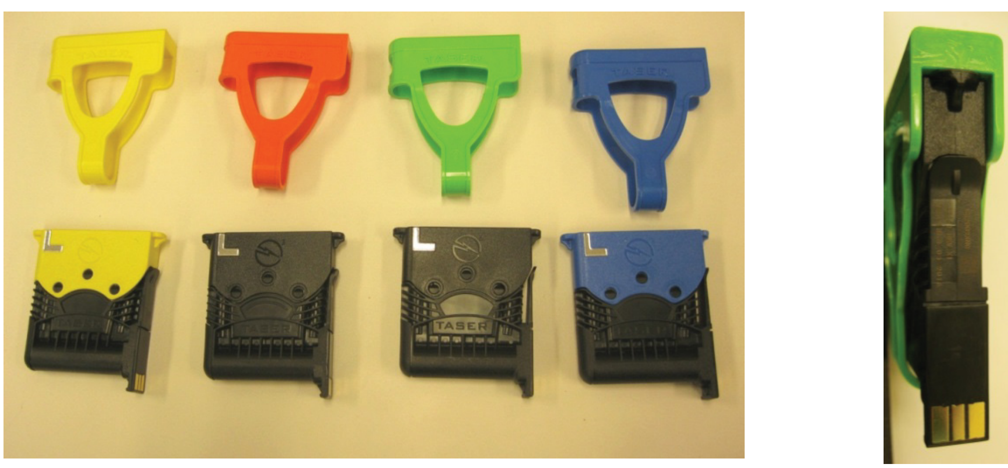

Figure 14: Smart Cartridges compatible with the TASER X2, and view of the electrical contacts

The type of cartridge and whether or not it has been deployed are also detected by the TASER X2, which displays this information to the user on the CID along with the battery status under normal operating conditions with a PPM, as shown in Fig. 15.

Figure 15: TASER X2 CID indicating two loaded 25-foot cartridges, left side set to fire first

On the CID, the underlined cartridge is the next one to fire. The CID also counts the duration of the discharge cycle after the trigger is pulled. **The default firing sequence of the two cartridge bays is the Semi-Automatic Mode in which the left bay fires upon the first trigger pull, followed by the right bay upon the second trigger pull. A Manual Mode of bay selection also exists: if the user wishes to fire a particular bay, or if a previously-fired bay needs to be re-energized, an operation known as a "cartridge advance" must be performed, in which one of the Arc buttons must be momentarily depressed. The TASER X2 has two Arc buttons on either side of the front of its body, whereas the TASER X26P has no such additional buttons.** One of the Arc buttons is shown on the left of Fig. 16.

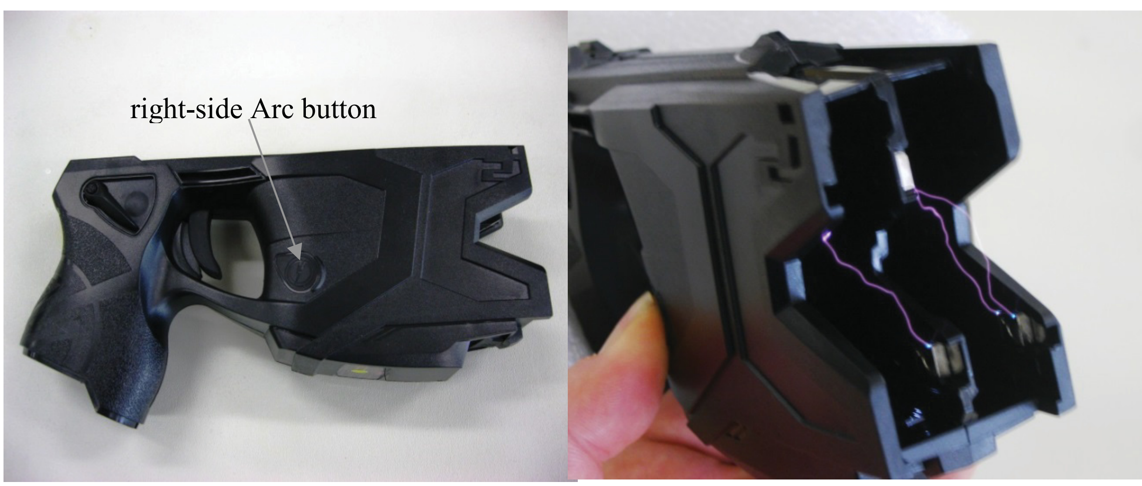

Figure 16: TASER X2 right-side view and warning arcs

If either of the Arc buttons is held down while the weapon is armed, a warning arc will be produced across both bays of the TASER X2 until the button is released, as shown on the right of Fig. 16. **The Arc buttons of the TASER X2 can be used to produce warning arcs even while**

it is loaded with cartridges. The reason for this is because the high voltage pulses are no longer associated with firing the weapon in a TASER X2. The warning arc is displayed across the oblong metallic tabs on the blast doors at the front of the cartridge shown on the right of Fig. 13. If probes are deployed, pressing the Arc button will re-energize the probes.

As described in [3], the TASER X2 has many different combinations of cartridge status, trigger pull and Arc button actions, **requiring more training than would the TASER X26P.**

Also described in [3], the top Illumination selector button, when depressed in safe mode, displays a menu on the CID, in which items are scrolled and selected using the Arc buttons once again. Among these options are the flashlight and laser illumination settings similar to the TASER X26P.

2.5 Previous Concerns Regarding the TASER X2

Operational safety concerns were raised in an earlier study of the TASER X2 [3]. At that time, the TASER X2 model 22002 Revision X10 was considered whereas the newer TASER X2 model 22002 Revision C was considered herein.

One of the concerns was that the safety lever slid too easily between the safe and armed positions. As shown in Fig. 17, the throw of the safety lever of the Revision X10 weapon was smooth, whereas it contains a raised dimple in Revision C. This raised dimple serves as a stop, requiring more effort to throw the lever into the other position and which produces a more satisfying click. **This issue appears to have been addressed by the manufacturer.**

Figure 17: TASER X2 safety lever on older Revision X10 (left) and newer Revision C (right)

A further concern mentioned in [3] was that it was difficult to lock the PPM into the hollow grip of the Revision X10 TASER X2. With the newer Revision C TASER X2, a significant squeezing force was required between the thumb (resting on the base of the PPM) and the index finger (resting on the front sight) to lock the PPM. However, a good lock was always achieved and was confirmed by the sudden popping-up of the cartridge release button, which generated a satisfying 'click' sound not previously heard from the older version of the TASER X2 [3]. This issue appears to have been addressed by the manufacturer.

Another concern raised in [3] was that **the blast doors of the Smart Cartridge did not separate cleanly** from the cartridge when fired, which had the potential of adversely affecting the ballistics. At the time, the revision code of the Smart Cartridges was X1, whereas newer cartridges (model 22151 Rev A) were tested in the present study. The different cartridge revisions are shown in Fig. 18.

Figure 18: Newer Revision A (left) and older Revision X1 (right) Smart Cartridges

From the outside, the cartridges are nearly identical except for their blast doors. The earlier Revision X1 blast doors are ribbed whereas the newer Revision A blast doors are smooth. A TASER X2 (Revision C) was loaded with both revisions of the 25-foot model 22151 Smart Cartridge and fired. Only one test was conducted. Fig. 19 shows the fragments of the blast doors that were recovered.

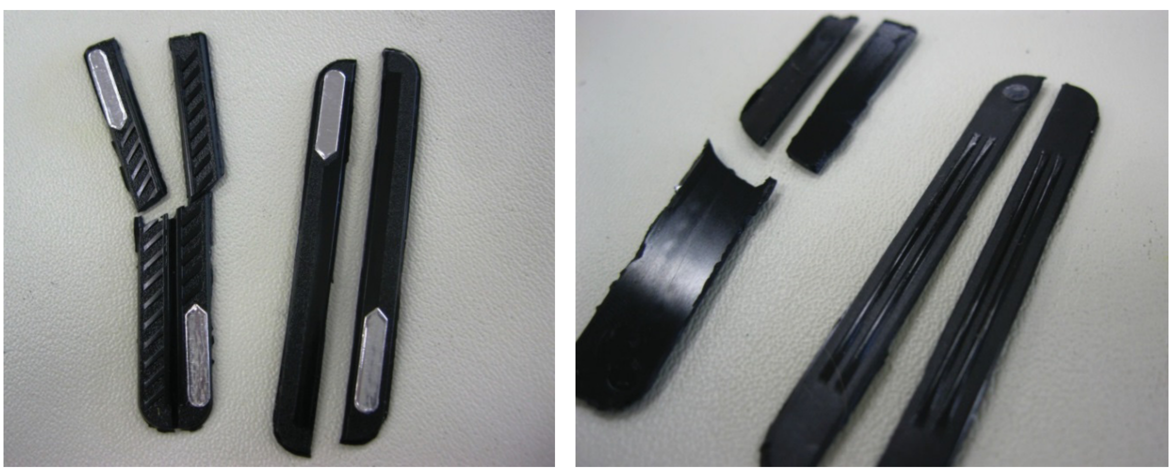

Figure 19: Outside surface of Smart Cartridge blast doors (left) and inside surface (right)

Once again, the Revision X1 blast doors did not break cleanly – the edges of the plastic were jagged and the breakage did not occur along the entire length of the seam. **The newer Revision A doors separated cleanly along the seam.** Note that the inside surface of the Revision A blast doors have lengthwise ridges whereas the Revision X1 doors were smooth. Also of note are the white sabots or *ejectors* that were expelled by the two cartridges, which are shown in Fig. 20. The two-part sabots shroud the barb of each probe while it is in the cartridge's bore and fly away from the probe as it is expelled.

Figure 20: White plastic sabots of the old Rev X1 (left) and newer Rev A (right) Smart Cartridges

The white sabots of the earlier Revision X1 Smart Cartridge are identical to the sabots used in the Standard Cartridges (for use with the TASER X26P) – they resemble small white plastic dumbbells. The sabots of the Revision A Smart Cartridge have a rounded tip that resembles a nosecone. **These design changes suggest that the blast door issue has been addressed by the manufacturer.**

The final TASER X2 concern raised in [3] that will be examined herein is the **cracking and breakage of the plastic housing of the Smart Cartridges when they are fired**. As explained in [3], the body of the Smart Cartridge has two parts that are held together by 6 rings on one part that snap over 6 support pins on the other part. The rings on the Rev X1 Smart Cartridges broke, posing a risk that the two parts could separate completely, which could lead to a misfiring of the cartridge. The spent older Revision X10 and Revision A Smart Cartridges were examined after the single test firing in a TASER X2 Revision C, as shown in Fig. 21.

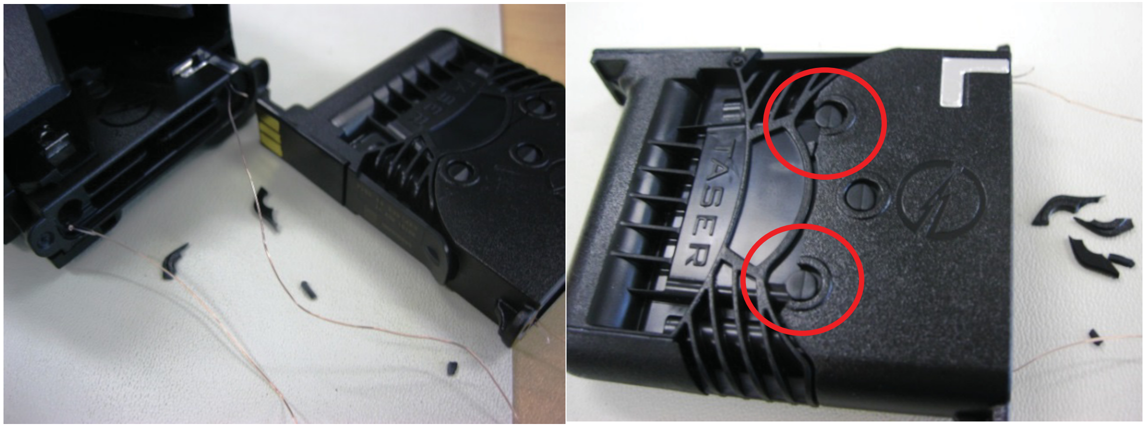

Figure 21: Broken parts of the older Revision X1 Smart Cartridge after firing

As shown in Fig. 21, small pieces of broken plastic came out of the cartridge bay when the Rev X1 cartridge was removed. As expected, the older Rev X1 cartridge was damaged, with a number of broken support rings around the support pins. The newer Rev A Smart Cartridge was then examined, as shown in Fig. 22.

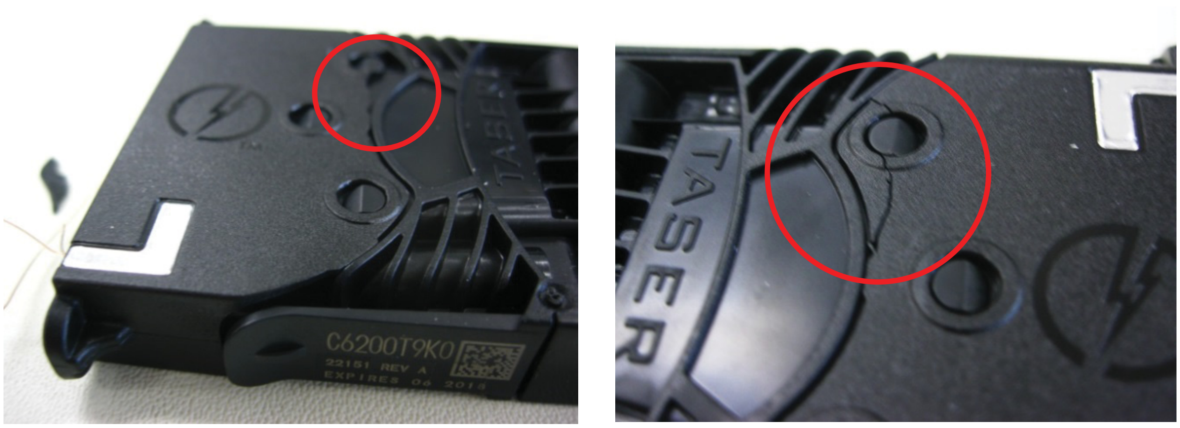

Figure 22: Breakage and cracking on both sides of the newer Revision A Smart Cartridge

Breakage and cracking are apparent in the newer Revision A cartridge, indicating that this issue has not been addressed by the manufacturer. There are two risks associated with this problem. First, the cartridges may leave broken plastic pieces behind in the cartridge bay of the weapon, which could either: interfere with reloading, interfere with the electrical contacts, or damage the weapon. Second, as indicated in [3], if all 6 support rings break, there is a possibility that the front portion of the cartridge body could be ejected from the weapon when it is fired, which could interfere with the wires. This issue should be addressed by the manufacturer.

Note that this cracking defect is not likely covered by the cartridge's warranty, given the statement contained therein: "…Smart cartridges that are expended are deemed to have operated properly" [7].

3 Electrical Test Procedure and Instrumentation

Electrical testing of the 30 TASER X2 and 30 TASER X26P CEWs was conducted in accordance with the test procedure described in [2], known as DRDCVer1. Section 3.1 provides an overview of the testing procedure, Section 3.2 identifies the equipment and software that were used, and Section 3.3 explains the minor divergences that were required from the DRDCVer1 test procedure.

3.1 Testing Overview

The flowchart shown in Fig. 23 provides an overview of the testing procedure. The subsections included below summarize the operations that are performed in each numbered step shown in the figure. Slight departures from the DRDCVer1 test procedure were required, as will be described in Section 3.3.

3.1.1 Set Up and Verify Test Environment

Before testing occurs, the operator ensures that the equipment is operational and that all software is functional, including the TASER International software Evidence Sync and the custom-written computer script that guides the operator. The custom script was written in Matlab [8]. For reporting purposes, the operator confirms the following information: Public Agency Identification Number, weapon owner, name of the operator, name of supervising engineer, name of test procedure followed, and the date of the test.

3.1.2 Conduct Physical Inspection of CEW

The operator then selects a particular weapon from the inventory, records the weapon's model and revision numbers, performs a visual inspection of the weapon, and records the result.

The following steps, which are in addition to DRDCVer1, are then performed. The operator then connects the weapon via USB to the host computer. At this stage, Evidence Sync is used to download the latest firmware from TASER International, if applicable. The operator then records the firmware version. The operator then records whether or not Evidence Sync is properly recognizing the weapon model and serial number. Using the Evidence Sync Logs, the operator then estimates the date of manufacture of the weapon by recording the date of the first log entry. The operator then counts the number of previous trigger pulls (and arc events, if the weapon is a TASER X2) and records this number. The operator then verifies the Health of the weapon as listed by Evidence Sync (usually Good). Finally, the operator saves a copy of the weapon's PDF Report for archival purposes using the file name `XX_SERIAL_DD-Mon-YYYY.PDF` where `XX` is the TASER model (X2 or X26P), `SERIAL` is the serial number of the weapon, and `DD-Mon-YYYY` is the date, such as 26-Mar-2014. Another PDF Report will be saved from the weapon after testing to ensure that the weapon properly recorded the trigger events. The weapon is then disconnected from the computer.

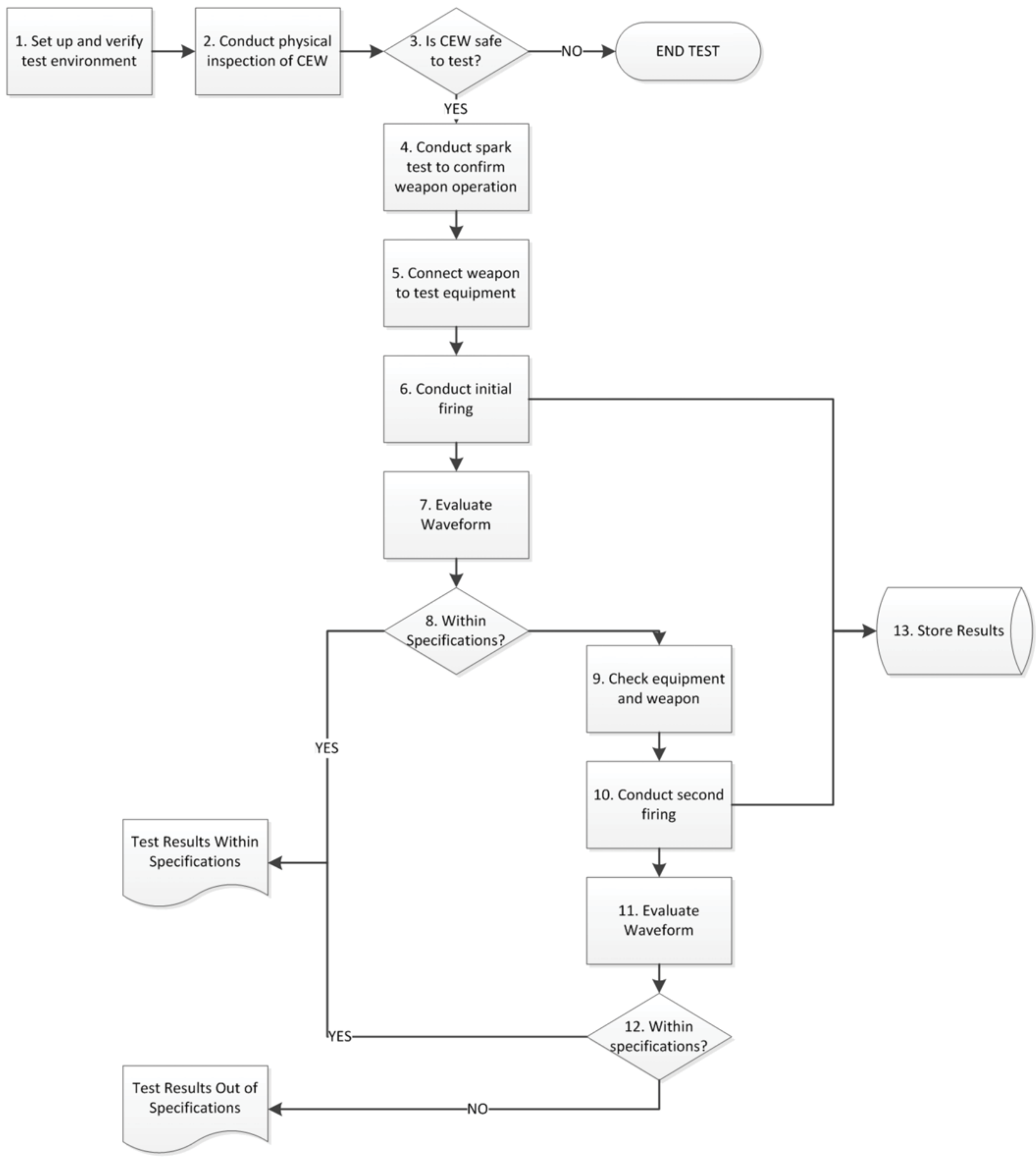

Figure 23: DRDCVer1 electrical testing flowchart

3.1.3 Is the Weapon Safe to Test?

If the weapon passes the physical inspection, it is deemed safe to test.

3.1.4 Conduct Spark Test to Confirm Weapon Operation

A power magazine is then inserted into the grip of the weapon, and the operator records whether or not it seated properly. The weapon is then armed. Before performing the spark test, the operator ensures and records that the power magazine has a charge of 20% or greater by examining the number of bars indicated on the battery icon on the CID; if not, the power magazine is removed and a fresh one is inserted. The operator then checks and records that the laser and flashlight are operational. A spark test is then performed and the result is recorded. The weapon passes the test if arcs are produced across its empty cartridge bay(s).

3.1.5 Connect Weapon to Test Equipment

Before the weapon is connected to the test jig, the operator records: the measured resistance of the resistor (nominally 600 Ω), the time at which the resistor was last measured, the ambient temperature (°C) and humidity (%) of the laboratory, and the atmospheric pressure (kPa) as listed by Environment Canada's website for Kingston, Ontario. The weapon is then connected to the test jig. If the weapon is a TASER X2, the left bay is selected first. The weapon is then armed. The operator then records the battery level (number of bars from 0 to 5) of the power magazine.

3.1.6 Conduct Initial Firing

The operator pulls the trigger and records a 5-second discharge on the oscilloscope. The weapon is placed in Safe mode, and the recorded data is transferred to the host computer for analysis. In this study, the raw data from the oscilloscope was stored in Comma-Separated-Values (CSV) format using the filename convention `XX_SERIAL_DD-Mon-YYYY_NM.CSV`, where `XX` is the TASER model number (X2 or X26P), `SERIAL` is the serial number of the weapon, `DD-Mon-YYYY` is the date, such as 26-Mar-2014, `N` is the number of the test firing (either 1 or 2 according to DRDCVer1), and `M` indicates the bay that was fired, if the weapon is a TASER X2 only (R for Right, L for Left). If the weapon only has one cartridge bay, such as the TASER X26P, the `M` field is omitted. An example data file name would be `X2_X29001PR5_23-Apr-2014_1L.CSV`. Note that the uncompressed file size of each CSV file is quite large, approaching 410 MB per trigger pull.

3.1.7 Evaluate Waveform

The recorded waveform is then analyzed according to the definitions and parameters in DRDCVer1 using the Matlab script. Two reports are automatically generated by the script: the first is the succinct, comma-delimited text file required by DRDCVer1 and the second is a more complete and verbose test report that summarizes all of the measurements and recorded data, and which indicates whether or not the weapon has passed the Canadian acceptance tests recommended in DRDCVer1. An example of the Canadian acceptance test report is shown in Annex A.

3.1.8 Within Specifications?

If the firing of a TASER X26P passes the Canadian acceptance test, no other test firing is required. If the firing of a TASER X2's Left bay passes the Canadian acceptance test, the test is repeated for the Right bay. If the first firing of the weapon's bay fails, a second firing is conducted and recorded following steps 9 through 12 in the flowchart.

Once the firings are completed, the weapon is placed in Safe mode and re-connected to Evidence Sync. The operator verifies and records that the spark test and trigger pull(s) were logged by the weapon. The post-firing PDF Report is then saved for future reference. Finally, the operator saves an image (PNG format) of each Evidence Sync Pulse Log that was recorded by the weapon for each of the trigger pulls associated with the test. Only an image could be saved of a Pulse Log, as TASER International does not allow the user to save the Pulse Log data directly.

3.2 Test Equipment

In accordance with DRDCVer1, the CEW is connected to a standard 600 Ω resistor by way of a modified spent cartridge. The voltage across this resistor is measured using a high-voltage probe and recorded by the oscilloscope to which the probe is connected. A picture of the test bench is shown in Fig. 24.

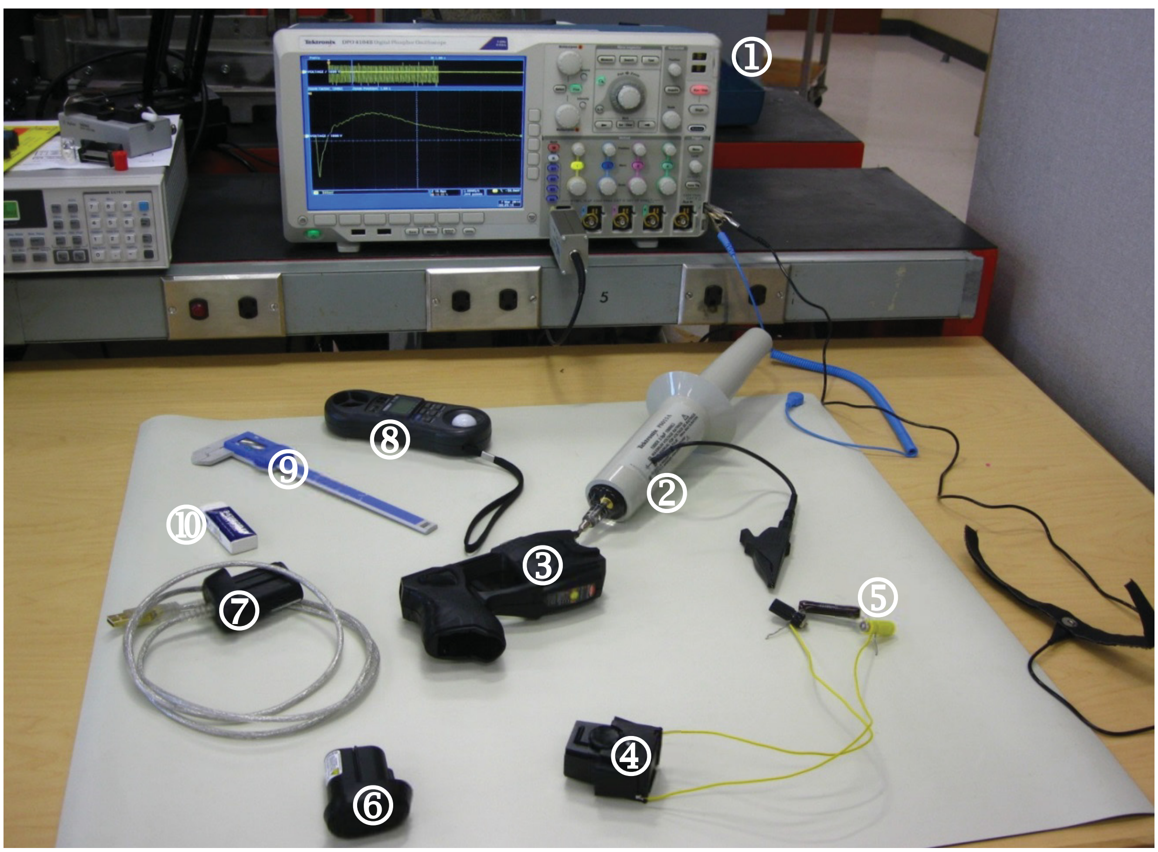

Figure 24: Typical test bench (LCR meter and computer not shown)

The numbered items are described in the text below. Consult Annex B for a detailed listing of the equipment and settings used.

1. Oscilloscope – records the voltage waveforms
2. High voltage probe – measures the voltage across the resistor
3. TASER X26P under test
4. Test jig – a modified spent X26P Standard Cartridge is shown
5. Non-inductive 600 Ω resistor
6. Power magazine for the weapon (Model 22010 Rev A)
7. USB adapter for connecting the weapon to the computer
8. Thermometer and hygrometer
9. Calipers used for measuring spark gaps (used for the TASER X2 test jig)
10. Soft white eraser used for removing carbon deposits from the test jig

3.2.1 TASER X2 Test Jig

A spent Smart Cartridge served as the test jig for the TASER X2, as shown in Fig. 25.

Figure 25: TASER X2 alongside its test jig

The test wires are approximately 30 cm long and are made of insulated 22-gauge solid core copper conductors. Each wire enters near the middle of the spent cartridge and then loops back such that its stripped end emerges from the probe bore, just beside the L-shaped foil pad. This is very similar to the wires of a live cartridge are arranged. No direct connection exists between the wires of a live cartridge and the terminals of the cartridge – an arc must bridge the gap between the wire and the L-shaped foil pad, as shown on the image to the left of Fig. 26.

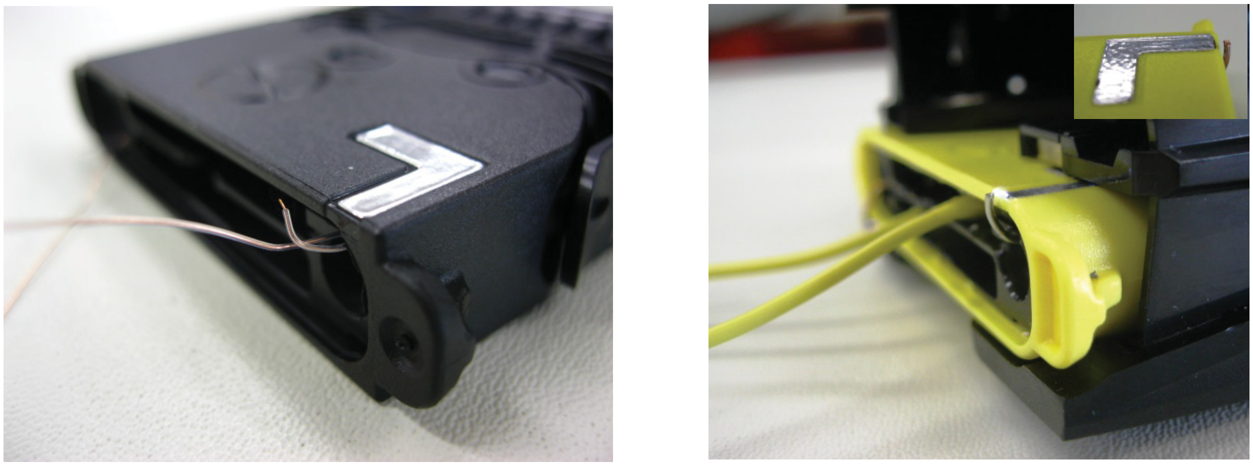

Figure 26: Deployed wire of a live cartridge next to the L-shaped foil pad of the cartridge (left) and test jig inserted into the cartridge bay of a TASER X2 (right)

On the right of Fig. 26 is a picture of the test jig and the inset image in the upper right-side corner shows the gap between the test wire and the pad, which was set to approximately 1-mm during testing. The image to the right of Fig. 26 actually shows an arc (white) leaping from the edge of the L-shaped pad to the wire, which approximates the action of the TASER X2 when a live cartridge is deployed during live firing. For testing, the electrical signal is sent down the yellow wires to the resistor, where the voltage is ultimately measured.

3.2.2 TASER X26P Test Jig

The construction of the TASER X26P test jig is simpler, in that a pair of 30-cm, 22-gauge wires is soldered directly to the exposed metallic arc points of a spent cartridge, as was shown earlier in Fig. 24. The metallic arc point to which the wire is soldered is visible on the image to the left of Fig. 27.

Figure 27: Metallic arc point and internal connection to the probe wire in a Standard Cartridge

A soldered connection is appropriate for the TASER X26P because in a Standard Cartridge, the wires of a live cartridge are tightly crimped under a solid L-shaped steel bar that forms the arc point, which likely produces a direct contact. The exposed L-shape bar and the exposed probe wire of a dismantled Standard Cartridge are shown on the centre and on the right of Fig. 27. The L-shaped bar is not usually visible to the user.

3.3 Divergence from DRDCVer1

In a few instances, it was necessary to diverge from the testing recommendations presented in DRDCVer1. This section explains these instances and why they were necessary.

3.3.1 Pulse Low Voltage

In DRDCVer1, the recommended acceptance limit for the lowest pulse voltage is –2600 V [2]. **This limit was ignored during testing**. Most of the recorded pulses satisfy this limit, for example, as shown by the left-side graph of Fig. 28.

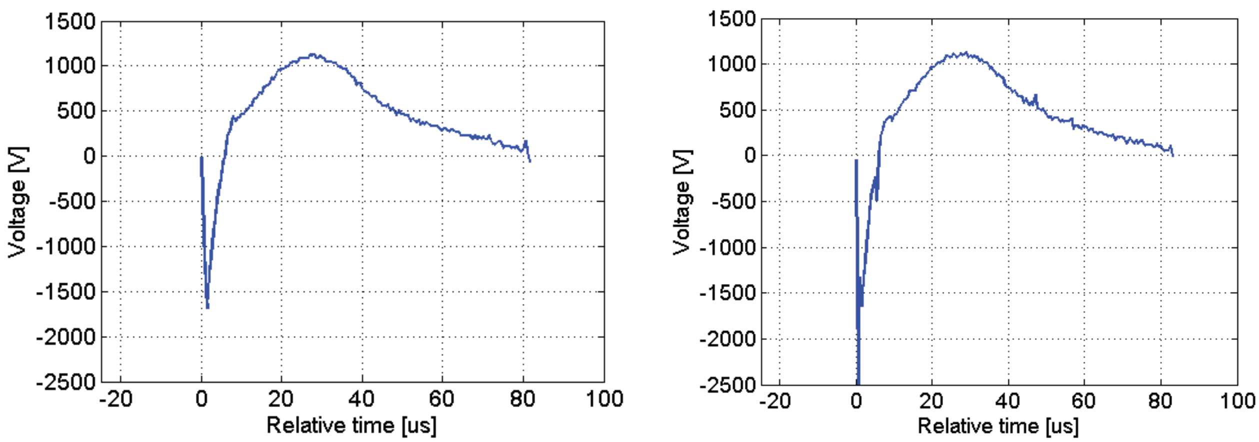

Figure 28: Unclipped and clipped TASER X2 voltage pulses sampled at 2 MSa/s

However, for all trigger pulls, a small number of pulses were observed that displayed a very strong and very brief (lasting no more than one sample period) negative voltage spike at the beginning of the pulse, as shown by the graph on the right-hand side of Fig. 28. Upon further investigation, it was discovered that **this strong negative spike always occurs** at the beginning of the pulse; however, it is so very brief that the 2 MSa/s sampling rate is unable to detect it reliably. By increasing the sampling rate of the oscilloscope to its limit of 5 GSa/s, the first 10 μs of the pulse was revealed, as shown in Fig. 29.

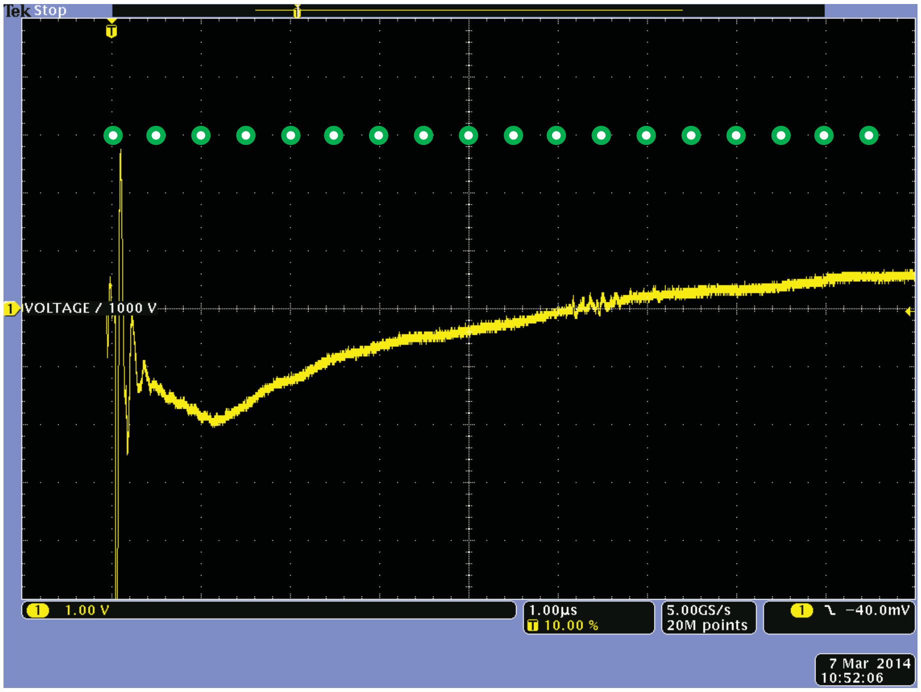

Figure 29: First 10 µs of the pulse recorded at 5 GSa/s

In this graph, the vertical scale of the oscilloscope is 1000 volts per division and the horizontal scale is 1 µs per division. This represents a zoom-in of the negative portion of the pulse shown earlier in Fig. 28**. The start of the pulse actually oscillates between strong negative and positive values – something that had not been observed** in earlier reports such as DRDCVer1 [2]. The green circles represent the samples that would have been taken of this waveform if the sampling rate was the recommended 2 MSa/s. As shown, that sample rate can easily miss the very rapidly-varying part of the waveform at the beginning of the pulse, which is why it only periodically appears as a clipped voltage spike in the measurements. Although it would be desirable to record the entire 5-second waveform at the high sampling rate of 5 GSa/s, the memory limit of the oscilloscope would permit only 4 milliseconds of the discharge cycle to be recorded as opposed to the full 5-seconds. **Hence there is an inherent compromise that must be made**: either the entire 5-second discharge cycle is saved at a sampling rate of 2 MSa/s, which causes the rapidly-varying part of the pulse to be missed, or only a small portion of the 5-second discharge can be recorded at the high sampling rate of 5 GSa/s in which the beginning of the pulse is captured properly.

Because of the need to record all of the pulses, the recommended sampling rate of 2 MSa/s was chosen in this work, meaning that the entire 5-second discharge cycle was recorded. Because DRDCVer1 was based on this sampling rate, **the recommended negative limit of –2600 V is false. As such, the Low Pulse Voltage limit was ignored during testing**, and this is clearly indicated in the Canadian acceptance text file reports that were generated by the Matlab script, as shown in Annex A. It is recommended that the Low Pulse Voltage parameter be amended in DRDCVer1.

Further investigation revealed that the actual Low Pulse Voltage peaks at approximately −6500 V and that the rapidly-varying part of the pulse lasts for approximately 0.5 μs. Because of its brief duration, there is not a significant amount of charge associated with it.

One segment of the rapidly-varying part of the pulse varies so rapidly that it exceeds the 75 MHz bandwidth of the high voltage probes used in the measurement (consult Annex B). This means that the fidelity of that segment's measurement is poor. A detailed analysis of the Arc Phase using higher-bandwidth probes is beyond the scope of the current work, and so it is recommended that a further study be done to more accurately characterize the rapidly-varying part of the pulse. The results of the recommended work could then be used to update the voltage limits found in DRDCVer1.

3.3.2 Trigger Level

The oscilloscope's trigger was set to the value specified by DRDCVer1 (−50 VDC). However, within the Matlab script, a pulse-finding routine is used to identify the pulses within the 5-second recording. The pulse-finder will detect the beginning of a new pulse whenever the recorded voltage exceeds a certain threshold (software trigger). The recorded data is so noisy that setting the software trigger level to −50 VDC resulted in the detection of false pulses caused by noise. To remedy this, the software trigger level was raised to −120 VDC. The definition of the Null Period in DRDCVer1 was also altered to use this new software trigger level value.

3.3.3 Lobe Definitions

In Fig. 28, the positive part of the waveform, called the Stimulation Phase by TASER International or the Peak Charge Lobe in DRDCVer1, delivers the most charge. Identifying the beginning of the Peak Charge Lobe is difficult because the zero-crossing at the beginning of the lobe is quite oscillatory owing to noise. For this reason, the beginning of the Peak Charge Lobe is defined as the zero-crossing after which the next 20 μs contains purely positive values.

3.3.4 Pulse High Voltage

The maximum positive pulse voltage may, in fact, occur during the rapidly-varying portion at the beginning of the pulse, which is not sampled adequately to be measured. As such, Pulse High Voltage is redefined in this work to represent the maximum positive voltage of the Peak Charge Lobe (Stimulation Phase) only.

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4 Data Analysis

This chapter summarizes the electrical testing results. Section 4.1 presents the inventory of the weapons that were tested and Section 4.2 presents the results of the Canadian acceptance tests. In Section 4.3, the electrical parameters of the weapons are characterized statistically on a pulse-by-pulse basis and on a weapon-by-weapon basis. The results from the TASER X26P are then compared to those of the TASER X2 to determine if any significant difference exists between the models. Finally, Section 4.4 investigates whether the pulses produced by the two weapon bays of the TASER X2 are related to each other.

4.1 Weapon Inventory

The weapons listed in Table 2 were secured from MD Charlton Company Ltd. for the purposes of testing. The weapons were delivered to the Royal Military College of Canada in January 2014 and returned to the company in March 2014. The hardware revision numbers were 'C' for the TASER X2 CEWs and 'X3' for the TASER X26P CEWs. The firmware revision number was 03.045 for all of the weapons.

Table 2: Inventory of TASER X2 and TASER X26P weapons tested

TASER X2, Rev. C Firmware Rev. 03.045			**TASER X26P, Rev. X3 Firmware Rev. 03.045**	
FIN	**Serial**		**FIN**	**Serial**
12202436	X29001RVT		12202474	X12000NC8
12202438	X29001RVY		12202463	X12000N89
12202439	X29001RW1		12202459	X12000N70
12202440	X29001RW3		12202450	X12000N43
12202441	X29001RWC		12202470	X12000N9N
12202442	X29001RWK		12202454	X12000N5M
12202443	X29001RWM		12202449	X12000N3X
12202445	X29001RWR		12202471	X12000NAC
12202418	X29001PNH		12202465	X12000N8W
12202419	X29001PNN		12202455	X12000N63
12202420	X29001PNW		12202468	X12000N94
12202422	X29001PRN		12202466	X12000N92
12202423	X29001PRV		12202458	X12000N6T
12202424	X29001PRX		12202461	X12000N87
12202427	X29001PTM		12202457	X12000N69
12202432	X29001RN2		12202477	X12000NCV
12202433	X29001RN6		12202464	X12000N8K
12202434	X29001RPE		12202460	X12000N76
12202435	X29001RT0		12202452	X12000N46

12202437	X29001RVX		12202448	X12000N14
12202444	X29001RWP		12202456	X12000N65
12202446	X29001RX2		12202467	X12000N93
12202447	X29001RY2		12202469	X12000N9D
12202421	X29001PR5		12202451	X12000N44
12202425	X29001PT0		12202473	X12000NC0
12202426	X29001PTD		12202472	X12000NAD
12202428	X29001REM		12202462	X12000N88
12202429	X29001RF7		12202476	X12000NCA
12202430	X29001RKP		12202475	X12000NC9
12202431	X29001RM2		12202453	X12000N4R

The Firearm Identification Number (FIN) is included to assist in identifying the weapon in the RCMP Canadian Firearms Program (CFP) database.

The first log entry of every Evidence Sync PDF Report was recorded in November 2013, which suggests that all of the weapons were manufactured during that month. The weapons were also fired on December 11th 2013, which is likely when the weapons were shipped from TASER International.

4.2 Compliance with Canadian Acceptance Test Standard

All of the weapons passed the physical inspection and fired in a reliable manner. All of the weapons passed the Canadian acceptance test standard, with the exception of the Pulse Low Voltage parameter, which was ignored, as explained earlier in Section 3.3.1.

4.3 Statistical Analysis of Selected Parameters

A complete 5-second discharge cycle was recorded for each weapon in which 97 or 98 pulses are usually present. Thus $30 \times 98 \approx 3000$ pulses were captured from the TASER X26P CEWs, 3000 pulses were captured from the left bay of the TASER X2 CEWs, and another 3000 pulses were captured from the right bay of the TASER X2 CEWs. Statistical analyses were applied to four pulse parameters, namely: Peak Charge Lobe High Voltage (same as peak Stimulation Phase voltage), Total Charge, Pulse Repetition Frequency, and Pulse Duration.

Four assumptions are made prior to applying the analysis:

1. Pulses could vary within a single trigger pull of a single weapon (pulse-to-pulse)
2. Pulses could vary from weapon-to-weapon
3. Pulses could vary from model-to-model
4. Pulses could vary from trigger-to-trigger pull of the same weapon

Of the assumptions made, cases 1 to 3 were analyzed in this study. Case 4 could not be assessed due to a lack of time, although data from multiple firings from 5 randomly chosen TASER X26P and 5 TASER X2 CEWs were collected. The intent was to gather the information so that a future study could determine how much variation was associated with multiple firings of a same weapon.

4.3.1 Assumed Statistical Distribution of the Measured Data

Given the large quantity of data that was collected during testing, statistics were used to characterize the weapons' parameters. For the statistical analyses to be meaningful, assumptions must be made on the nature of the data, otherwise known as the *distribution* of the data. For measurements such as these, it is often assumed that the data will be *normally* distributed, that is, that most of the data points will be centrally grouped around a mean value, with progressively less data points away from that mean value.

So-called *normality tests* are used to verify whether or not the data is well-modelled by a normal distribution. A summary of the normality tests performed on three of the parameters (Peak Charge Lobe High Voltage, Total Charge, and Pulse Repetition Frequency) may be found in Annex D. **The results show that all three parameters are indeed well-modelled by normal distributions.** Thus the use of terms such as the mean and standard deviation will be meaningful in the sections that follow.

4.3.2 Peak Charge Lobe High Voltage

Before grouping all of the pulses in the database together, it is meaningful to assess the pulse-to-pulse and weapon-to-weapon variability of the parameters. Fig. 30 shows a so-called 'box-and-whisker' plot of the measured Peak Charge Lobe High Voltage parameter of the 30 TASER X26P weapons. A detailed description of how to interpret such a plot is provided immediately below.

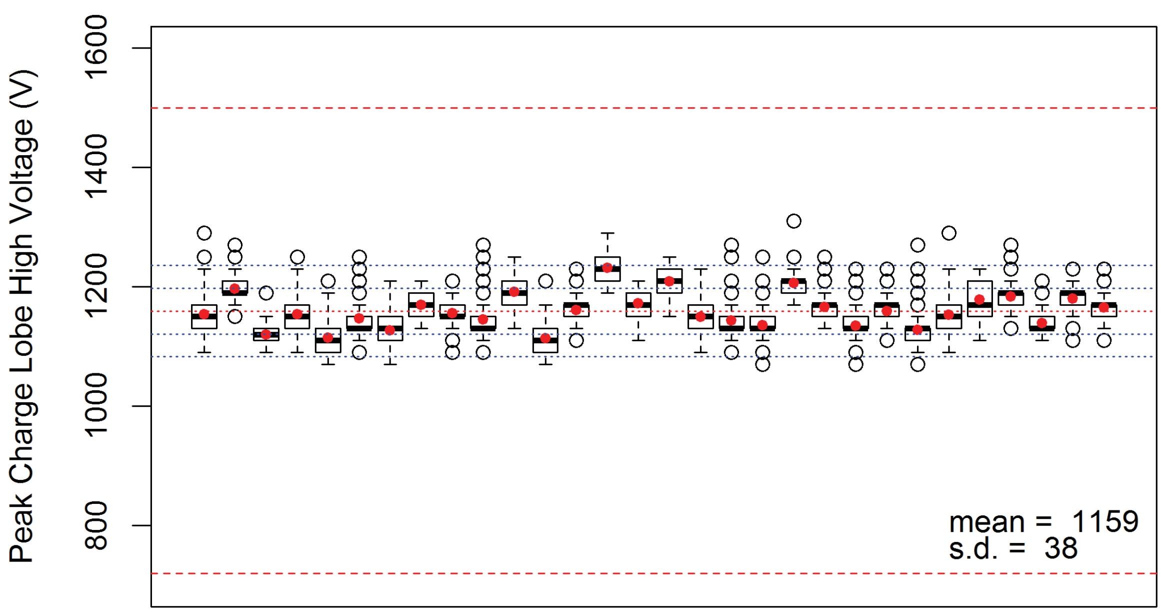

Figure 30: Peak Charge Lobe High Voltage for 30 different TASER X26P serials

A box-and-whisker plot such as the one shown in Fig. 30 is commonly used with a group of data to get a general impression of how the values are distributed. First, counting from left-to-right, note how there are 30 groups of symbols that are spread vertically: each spread of symbols represents the test firing of one TASER X26P weapon (different serial). For each weapon test firing, there is a red dot that represents the mean value of the 97 or 98 pulses and a heavy horizontal black bar that represents the median value of the pulses, from a single trigger pull. The lower and upper extent of the black rectangular 'box' around the median indicates the first and third *quartile* respectively, thus the box shows the inter-quartile range (IQR). The vertical black dashed lines that extend above and below the box (terminated by T or ⊥) are called 'whiskers' and extend to 1.5 times the IQR on either side of the median, or to the maximum or minimum measured value if it is within that range. If there are any observations outside of this range they are plotted individually as small circles (the outliers). If the box for the IQR is off-centre compared to the median, or if significantly more or less outliers are above the upper "whisker" than below, this would be an indicator that the distribution of data is not symmetrical.

The dashed red horizontal lines at the top and bottom of the graph indicate the tolerance limits for the Canadian acceptance standards. **All measurements of Peak Charge Lobe High Voltage were well-within the tolerance limits**, which was the case for all of the parameters to follow.

The overall mean of all of the pulses is represented by the horizontal dotted red line across the middle of the plot, and its numerical value is inscribed in the bottom-right hand corner of the graph. Standard deviations from the overall mean are shown by dotted blue lines above and below the overall mean, and the standard deviation's numerical value is also inscribed in the bottom-right hand corner of the graph.

The mean Peak Charge Lobe High Voltage of each TASER X26P weapon is slightly different, although the means are indeed clustered around the overall mean (only 5 are more than 1 standard deviation away).

It is also noted that the distribution is different for each weapon, with some showing a slightly skewed distribution and some with a handful of outliers (6 of the 30 have 5 or more measurements outside of the whiskers). Note how more of the outliers (circles) are above the whiskers than below. **Upon further analysis, it was found that these outliers are usually associated with the first pulses of the TASER X26P discharge cycle**. In all but 4 of the weapons, the pulse-by-pulse graph of the Peak Charge Lobe High Voltage resembled the one shown in Fig. 31.

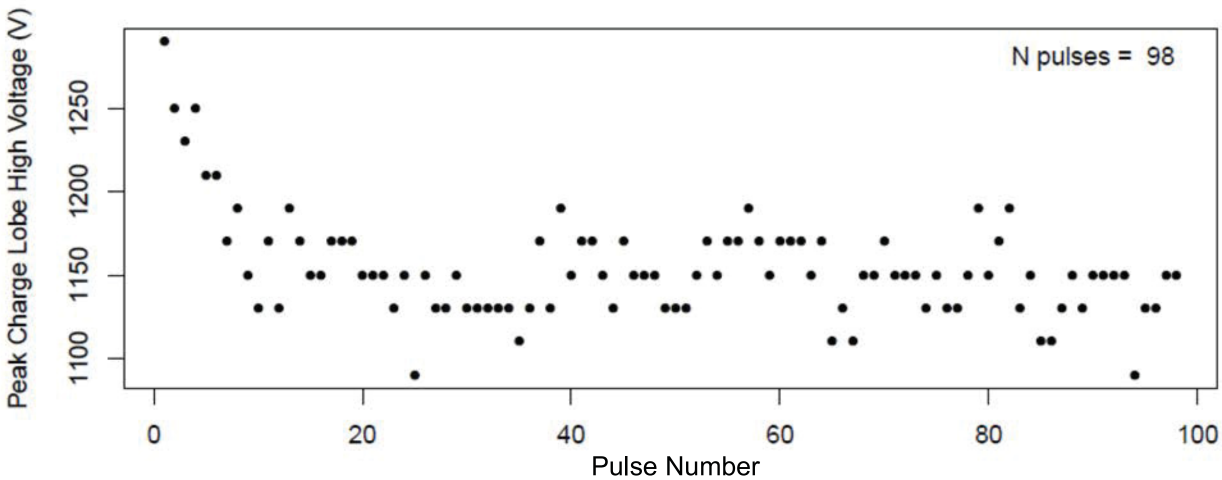

Figure 31: Pulse-per-pulse value of the Peak Charge Lobe High Voltage parameter for the TASER X26P serial number X12000N14

Note the high values of the first few pulses, which are the high outliers of the distribution. The observed gradual reduction of the voltage may be due to the weapon's "charge metering" feature, which "…constantly adjust the output levels for precise charge delivery" [9-11]. Unlike its earlier CEWs, TASER International claims that the internal circuitry of the TASER X26P and TASER X2 monitors and automatically adjusts the amount of charge delivered by the weapon. Regardless**, the first few pulses of the TASER X26P were consistently high**. These values would be missed completely if the TASER International recommended test procedure was followed [12], which further justifies the use of DRDCVer1 instead.

A comparison was conducted of the means of the first five pulses versus all of other pulses in the discharge cycle, first for the TASER X26P weapons, and, for comparison, for the TASER X2 left and right bays. The mean values and standard deviations are listed in Table 3.

Table 3: Mean Peak Charge Lobe High Voltage for the first 5 pulses and for the remaining pulses

Mean Peak Charge Lobe High Voltage (V)	**X26P**		**X2 Left**		**X2 Right**	
	First Five	**Others**	**First Five**	**Others**	**First Five**	**Others**
Mean	1212	1157	1127	1124	1140	1145
Standard Deviation	34	36	34	42	38	43

From this it is evident that there is a large difference between the mean of the first five pulses and the other pulses for the TASER X26P (1212 V – 1157 V = 55 V), but very small differences (no more than 5 V) were found between the means for the TASER X2, whether from the left or the right bay. An analysis of variance (ANOVA) [16] test on the equality of the means indicates that the difference for the TASER X26P is significant, but the differences for the TASER X2 left and right bays are not.

The box-and-whisker graphs of the Peak Charge Lobe High Voltage for the Left and Right cartridge bays of the TASER X2 are shown in Figs. 32 and 33.

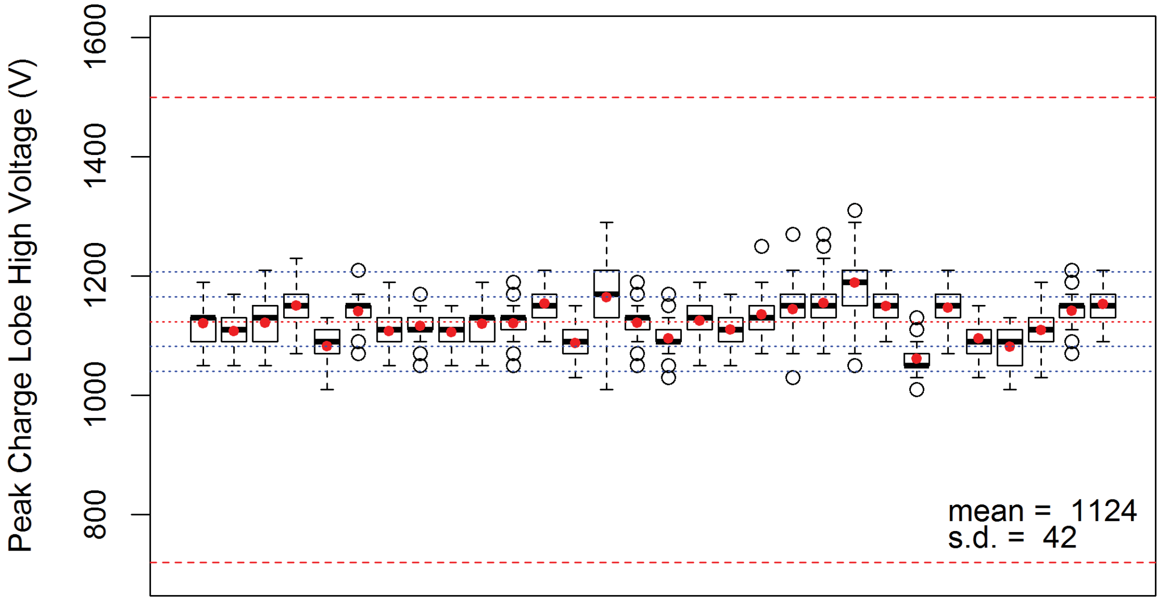

Figure 32: Peak Charge Lobe High Voltage for the left bay of 30 different TASER X2 serials

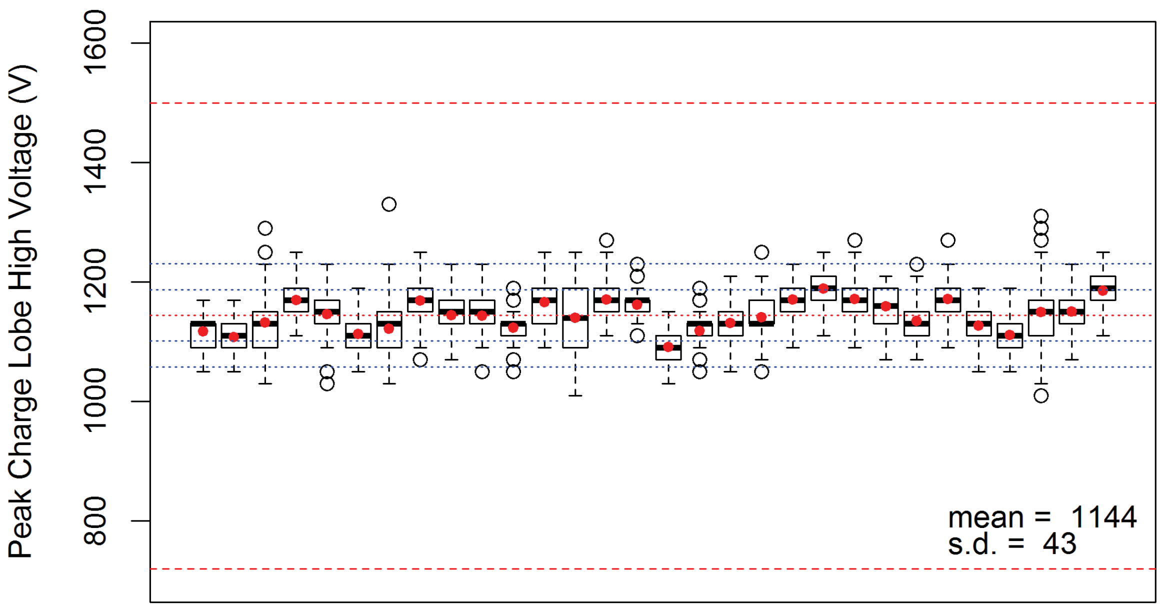

Figure 33: Peak Charge Lobe High Voltage for the right bay of 30 different TASER X2 serials

Compared with the outliers in Fig. 30 (for the X26P model), the plots for the X2 model (Figs. 32 and 33) suggest a better balance to the outliers: about the same number above as below.

As with the X26P weapons, the X2 plots for the left and right bays show that each weapon is different from the others: the means and medians are all close to the overall mean, but the 30 box-and-whisker plots in each figure show a different dispersion, although all pulses measured well within the tolerance limits.

The overall mean, standard deviation and extrema of the Peak Charge Lobe High Voltage parameter are compared in Table 4 for all pulses.

Table 4: Comparison of the Peak Charge Lobe High Voltage between models

Peak Charge Lobe High Voltage (V)	**TASER X26P**	**TASER X2 Left Bay**	**TASER X2 Right Bay**
Overall mean	1159	1124	1144
Standard Deviation	38	42	43
Highest Value	1310	1310	1330
Lowest Value	1070	1010	1010

The box-and-whisker plot of the 30 means of Peak Charge Lobe High Voltage for the TASER X26P and TASER X2 (Left and Right bays) are shown in Fig. 34.

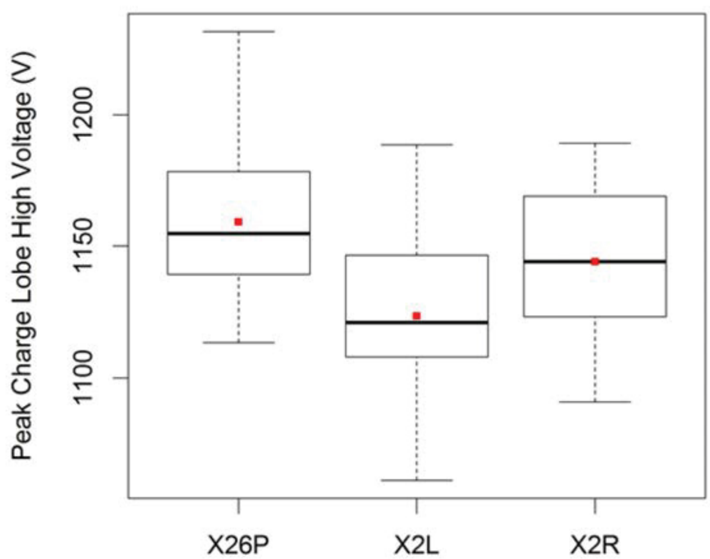

Figure 34: Box-and-whisker graph of the Peak Charge Lobe High Voltage parameter for the 30 mean values

Given that both the TASER X26P and TASER X2 use the same “Precision Shaped Pulse” technology, the natural question that arose is whether the mean values for the X26P, the X2 left bay, and the X2 right bay were about the same, or not. An ANOVA test will be used to determine, with an appropriate significance level, whether we can reject the hypothesis that all three means for a given parameter are equal. If they are found to be unequal, the Tukey Honest Significant Difference test can be applied pair-wise to determine the pairs of datasets where the means of the parameters can be taken to be different [16]. The ANOVA and Tukey tests are useful in distinguishing when there are real differences from cases where there may appear to be a difference, but where it is not significant.

When the Tukey test gives a range, this is essentially a confidence interval on a difference; if the range does not include 0, i.e., if the lower and upper values are both positive or both negative, the Tukey test is indicating that there is a noticeable difference (one that is statistically significant).

For the ANOVA and Tukey tests, the confidence level was set at 95% (equivalent to a p-value < 0.05). In layman's terms, this means that if, from data like this, we conclude that there is a difference in the comparisons, we can anticipate that we would be making an error (detecting a difference where none really exists) less than 5% of the time, or a chance of less than 1 in 20. A confidence level of 95% (similar to an opinion poll being "right, 19 times out of 20") or p-value of 0.05 is widely used in this type of statistical testing.

The p-value for the ANOVA test was less than 0.05, the typical threshold; so we may conclude that the means were not the same. The Tukey test of the pairs at the same threshold (0.05) indicates that TASER X26P and TASER X2 left bay differed by 35.6 V (with a range of 18.7 V to 52.5 V) and that the TASER X2 right bay and left bay differed by 20.4 V (with a range from 3.5 V to 37.3 V). However, the difference between the TASER X2 right bay and the TASER X26P was not significant.

4.3.3 Total Charge

The box-and-whisker graph of the Total Charge measured from the TASER X26P is shown in Fig. 35, whereas the graphs for the TASER X2's left and right bays are shown in Figs. 36 and 37, respectively.

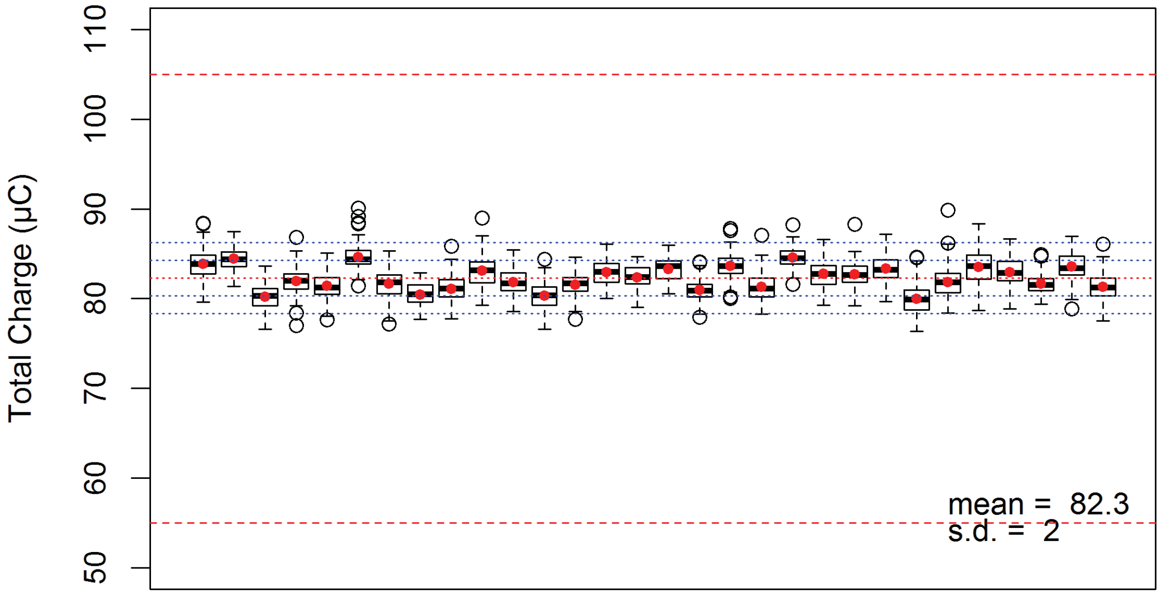

Figure 35: Total Charge for 30 different TASER X26P serials

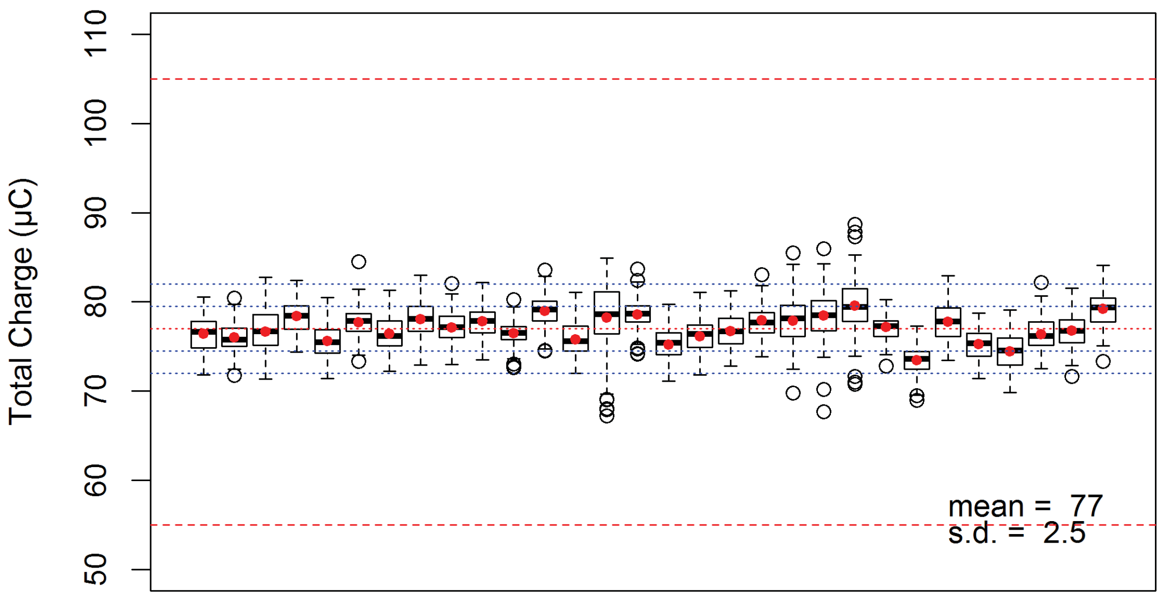

Figure 36: Total Charge for the left bay of 30 different TASER X2 serials

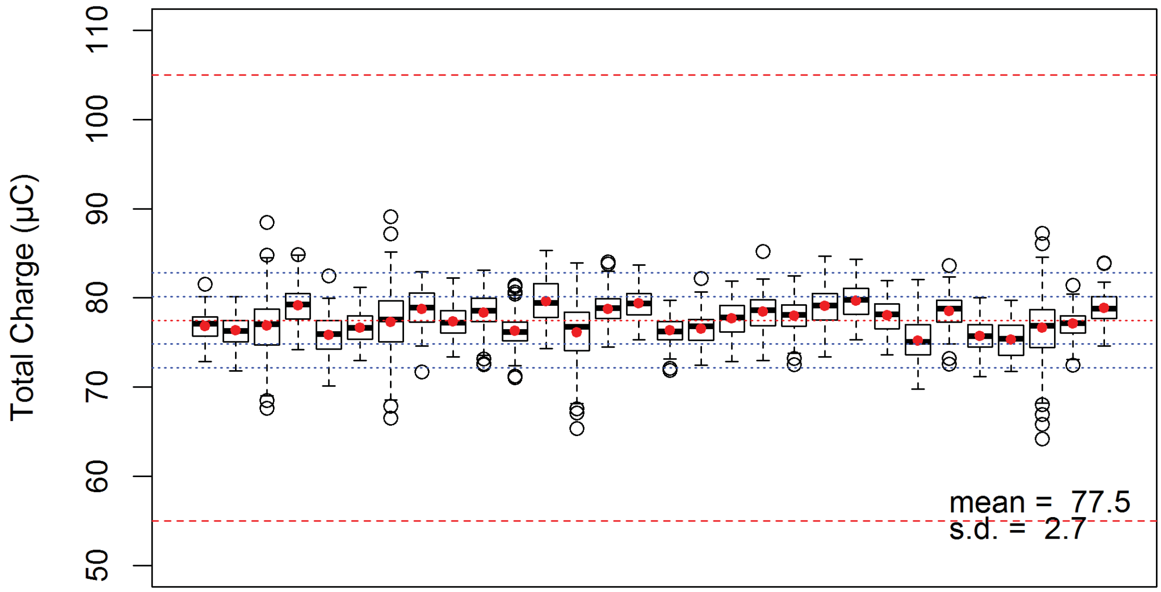

Figure 37: Total Charge for the right bay of 30 different TASER X2 serials

The overall mean, standard deviation and extrema of the Total Charge parameter are compared in Table 5.

Table 5: Comparison of the Total Charge Between Models

Total Charge (μC)	**TASER X26P**	**TASER X2 Left Bay**	**TASER X2 Right Bay**
Overall mean	82.3	77.0	77.5
Standard Deviation	2.0	2.5	2.7
Highest Value	90.1	88.7	98.1
Lowest Value	76.3	67.2	64.2

The box-and-whisker plot of the 30 means of Total Charge for the TASER X26P and TASER X2 (left and right bays) are shown in Fig. 38.

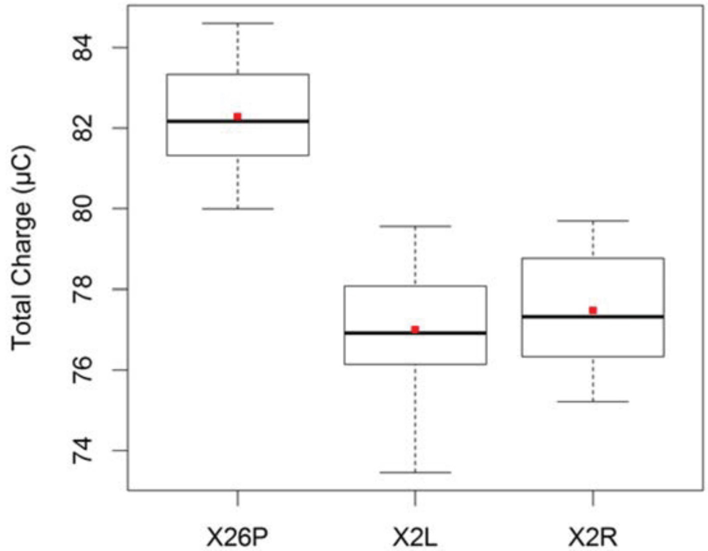

Figure 38: Box-and-whisker graph of the Total Charge parameter for the 30 mean values

The *p*-value for the ANOVA test was again less than 0.05 indicating that the means are not the same. Here the differences between the TASER X26P and the TASER X2 left bay (5.3 µC with a range from 4.4 to 6.1) and between the TASER X26P and the TASER X2 right bay (4.8 µC with a range from 4.0 and 5.6) were both significant. However, the differences between the X2 left bay and right bay were not significant.

How does this compare to what has been previously reported by TASER International? According to [9,13-14], the Net Charge should be 63 µC. It is difficult to measure the precise quantity of charge associated with the Peak Voltage Lobe (Arc Phase) because it is undersampled, as previously explained in Section 3.3.1. However, a reasonable estimate is 8 µC based on our findings. The overall mean Net Charge for the TASER X26P, TASER X2 left bay and TASER X2 right bay would therefore be 66.3 µC, 61.0 µC and 61.5 µC, respectively. These values are +5% and −3% of the nominal value of 63 µC, very close to what is quoted by the manufacturer.

4.3.4 Pulse Repetition Frequency

The box-and-whisker graph of the measured PRF of the TASER X26P is shown in Fig. 39, whereas the graphs of the PRF for the TASER X2's left and right bays are shown in Figs. 40 and 41, respectively.

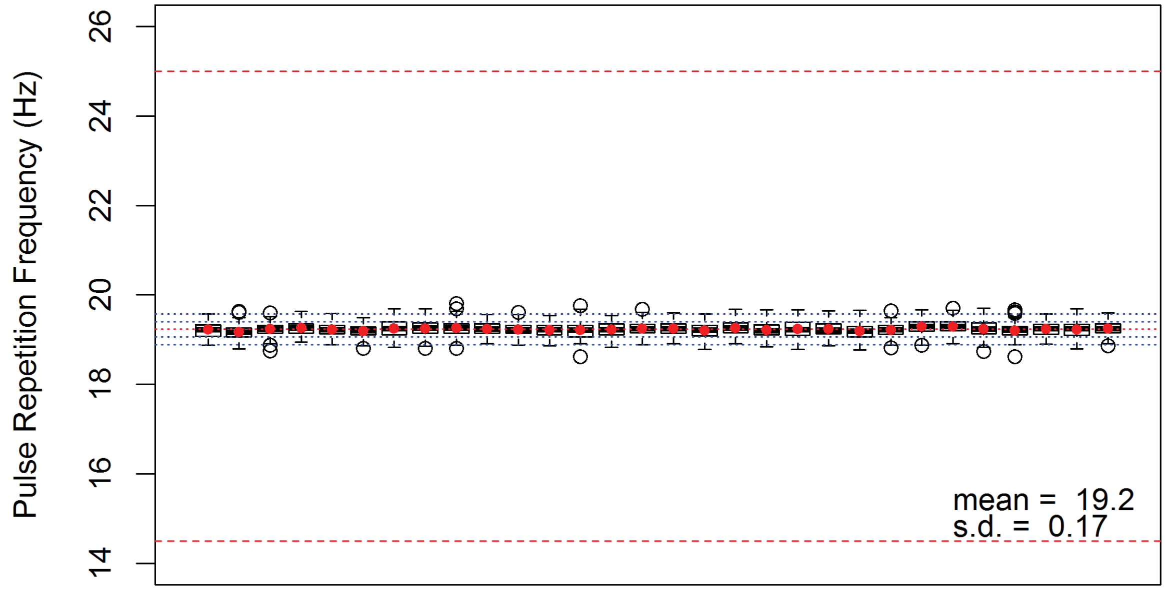

Figure 39: Pulse Repetition Frequency for 30 different TASER X26P serials

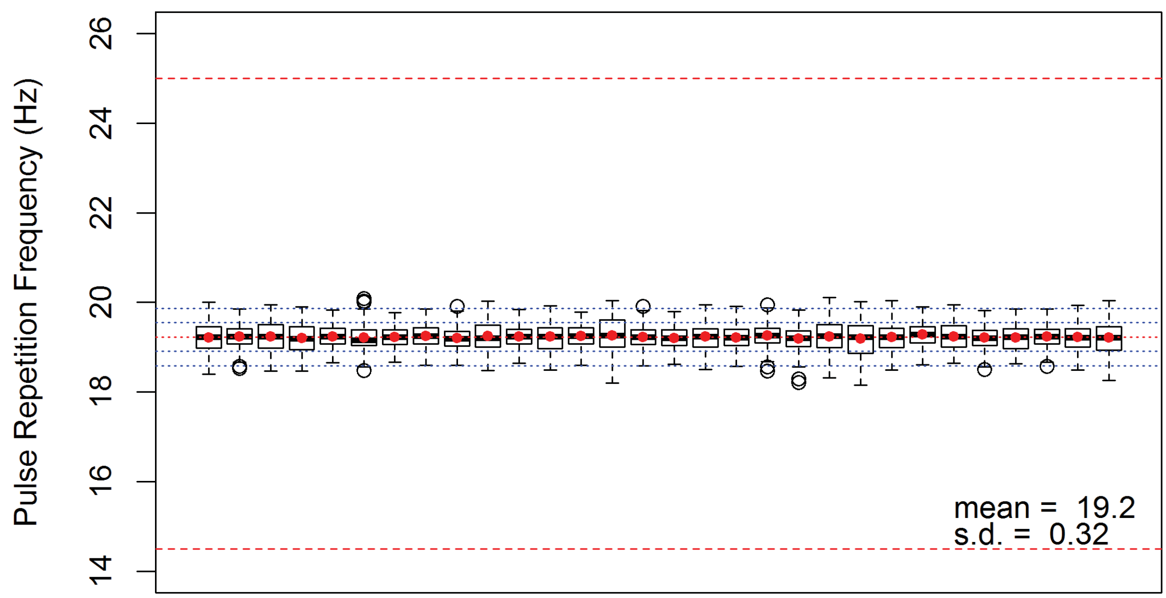

Figure 40: Pulse Repetition Frequency for the left bay of 30 different TASER X2 serials

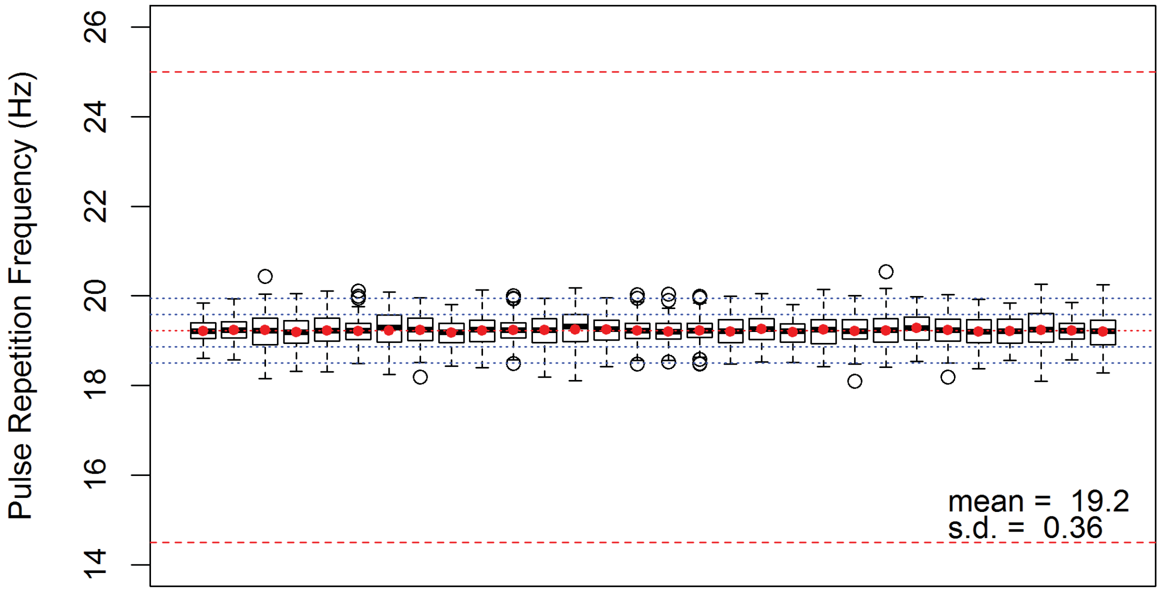

Figure 41: Pulse Repetition Frequency for the right bay of 30 different TASER X2 serials

The overall mean, standard deviation and extrema of the PRF are compared in Table 6.

Table 6: Comparison of the Pulse Repetition Frequency between models

PRF (Hz or pulses per second)	**TASER X26P**	**TASER X2 Left Bay**	**TASER X2 Right Bay**
Overall mean	19.2	19.2	19.2
Standard Deviation	0.17	0.32	0.36
Highest Value	19.8	20.1	20.5
Lowest Value	18.6	18.2	18.1

The box-and-whisker plot of the 30 means of the PRF for the TASER X26P and TASER X2 (left and right bays) are shown in Fig. 42.

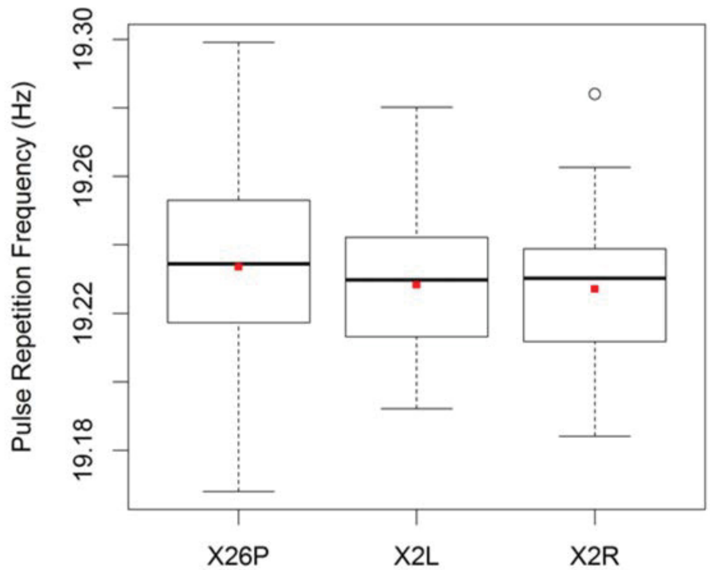

Figure 42: Box-and-whisker graph of the Pulse Repetition Frequency for the 30 mean values

The PRF has a much tighter distribution relative to the Canadian acceptance standard. **As with the other data, all pulse measurements are within the lower and upper tolerance limits in the Canadian acceptance standard.** It appears that the variation around the mean is smaller for the TASER X2.

The mean values for the pulse repetition frequency in all three figures is essentially the same when rounded to four significant digits: 19.23 Hz. The ANOVA test indicated that any difference in means of the PRF was not significant.

4.3.5 Pulse Duration

The box-and-whisker graph of the measured Pulse Duration of the TASER X26P is shown in Fig. 43, whereas the graphs of the Pulse Duration for the TASER X2's left and right bays are shown in Figs. 44 and 45, respectively.

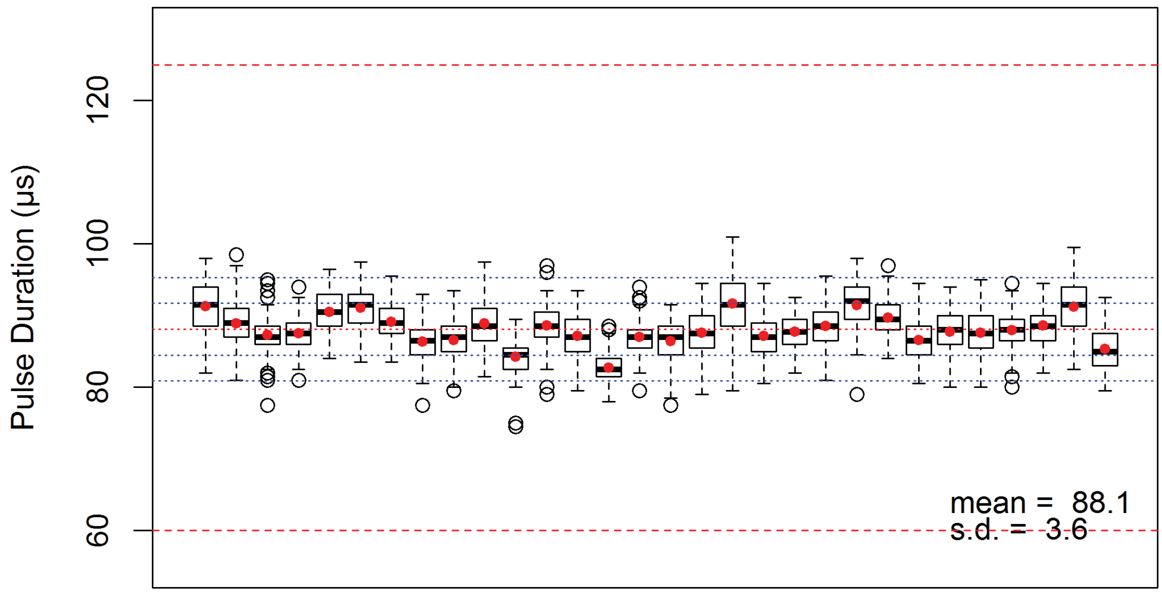

Figure 43: Pulse Duration for 30 different TASER X26P serials

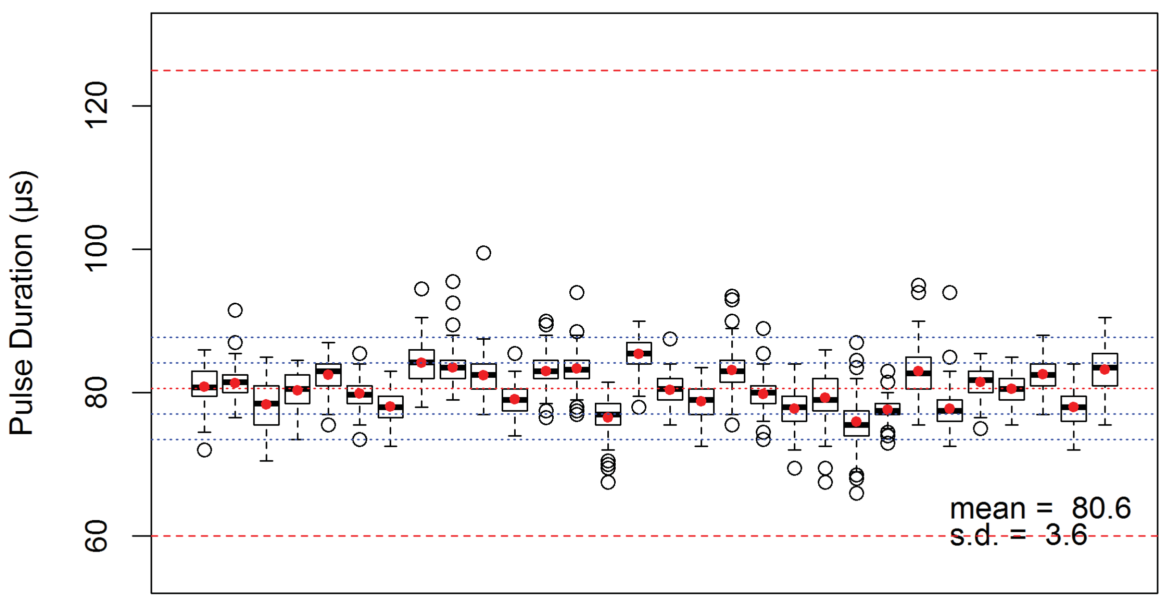

Figure 44: Pulse Duration for the left bay of 30 different TASER X2 serials

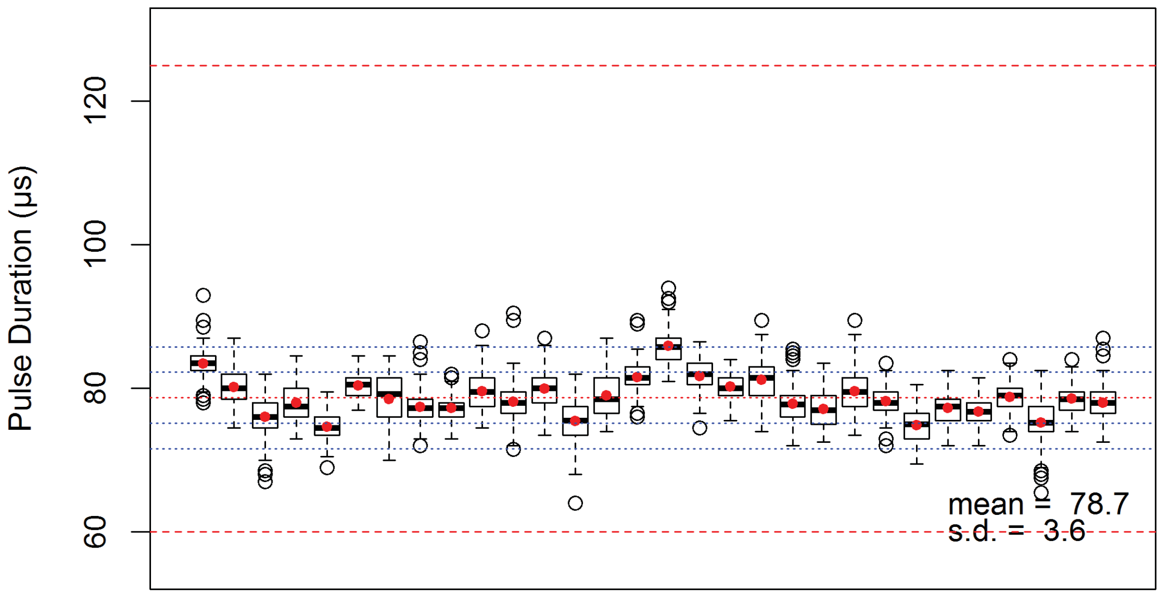

Figure 45: Pulse Duration for the right bay of 30 different TASER X2 serials

The overall mean, standard deviation and extrema of the Pulse Duration are compared in Table 7.

Table 7: Comparison of the Pulse Duration between models

Pulse Duration (µs)	**TASER X26P**	**TASER X2 Left Bay**	**TASER X2 Right Bay**
Overall mean	88.1	80.6	78.7
Standard Deviation	3.6	3.6	3.6
Highest Value	101	99.5	94
Lowest Value	74.5	66.0	64

The box-and-whisker plot of the 30 means of the Pulse Duration for the TASER X26P and TASER X2 (left and right bays) are shown in Fig. 46.

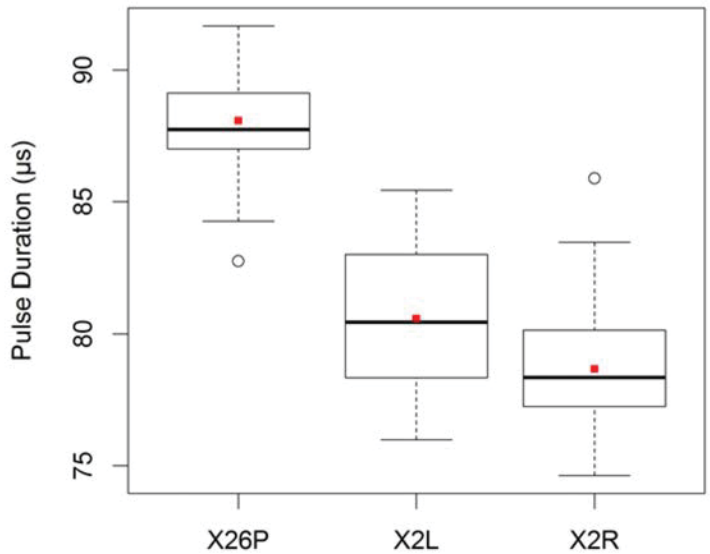

Figure 46: Box-and-whisker graph of the Pulse Duration for the 30 mean values

For pulse duration, the distribution of values relative to the range permitted by the Canadian acceptance standard is wider than for pulse repetition frequency. Given that the end of the waveform is prone to noise, it is not surprising that this parameter is dispersive. **Regardless, all of the weapons passed the Canadian acceptance test for the Pulse Duration.**

The overall mean value for the TASER X26P appears to be higher than for the means for either bay of the TASER X2. The ANOVA test indicates these means were not the same. According to Tukey's test for pair-wise differences, the means of the TASER X26P and TASER X2 left bay differed by 7.5 µs with a range of 6.0 to 9.0 µs; the means of the TASER X26P and TASER X2 right bay differed by 9.4 µs with a range from 7.9 to 10.9 µs, and the TASER X2 left and right bays differed by 1.9 µs with a range of 0.4 to 3.4 µs and all three of these were significant at the 5% level.

A summary of the TASER X26P and TASER X2 measurements may be found in Annex C, along with previously-taken measurements of the TASER X26E.

4.4 Are the Left and Right Bays of the TASER X2 Related?

It takes nearly twice as long to test a TASER X2 compared to a TASER X26P because the former has two cartridge bays. It would be beneficial to know if a relationship exists between the two bays. Given that it is likely that the same circuitry is used within the TASER X2 regardless of which bay is being fired, it is reasonable to suggest that some similarity exists.

The analysis in this section was performed on the mean values of the left and right cartridge bay firings for the 30 weapons tested. A so-called F-test is performed on the resulting linear relationship to judge whether or not it should be considered significant, and when it is, the corresponding relationship will be given. The one-way analysis of variance (ANOVA) tables for the linear regression are given in Annex E.

Based on the means for each weapon, the results indicated that we may assume that the mean Peak Charge Lobe High Voltage from the firing in one bay **is** linearly related to that the other bay. The mean value for the right-side bay is given by 0.55-times the mean value for the left-side bay, plus 524.6 volts. This linear relationship is graphed in Fig. 47, where circles represent the 30 weapon means, the left-side bay Peak Charge Lobe High Voltage is on the horizontal axis and the right-side bay voltage is on the vertical axis. The grey dashed lines show +/- 1 and +/- 2 standard deviations around that line based on the standard error of the estimate.

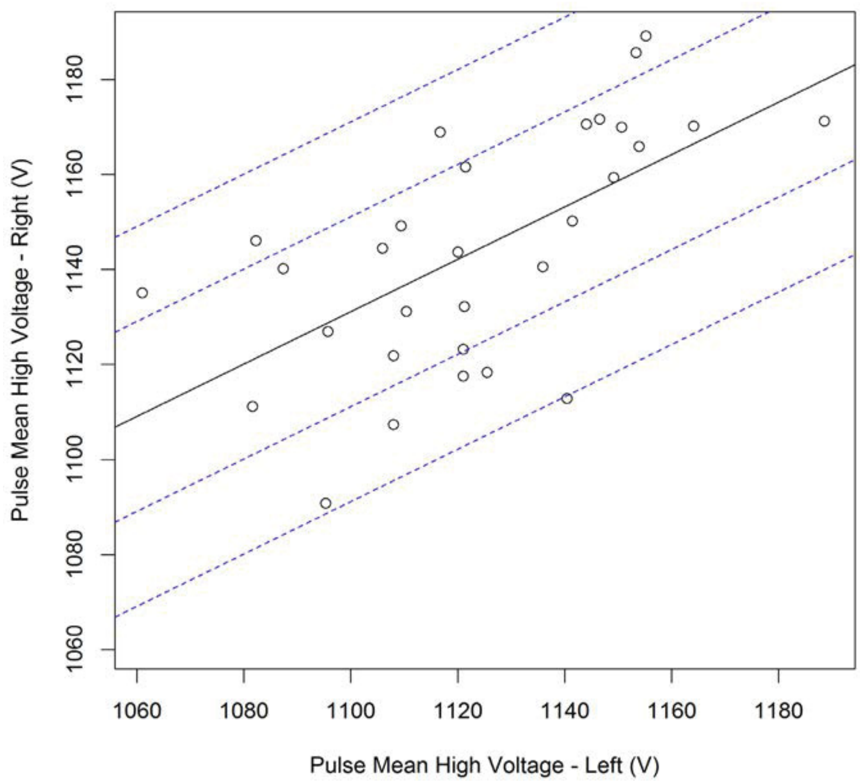

Figure 47: Linear regression results for the mean Peak Charge Lobe High Voltage of the TASER X2 bays

Although this linear relationship is deemed to be statistically significant, the improvement factor (coefficient of determination, commonly called the R-squared factor) is only 0.39 (out of a possible 1.0), which is considered low, so independent testing of the two bays should continue as standard practice for this parameter.

The poor fit of the mean Peak Charge Lobe High Voltage may be due to the fact that it represents an extreme value taken from each pulse record – it is a single data point that has not benefitted from any averaging or integration, unlike the Total Charge parameter, which is considered next.

For the mean Total Charge parameter, analysis shows that we may once again assume that the value in one bay **is** linearly related to the value in the other bay. The mean value for the right-side bay is given by 0.872-times the mean value for the left-side bay, plus 10.4 μC. The model and data points are graphed in Fig. 48.

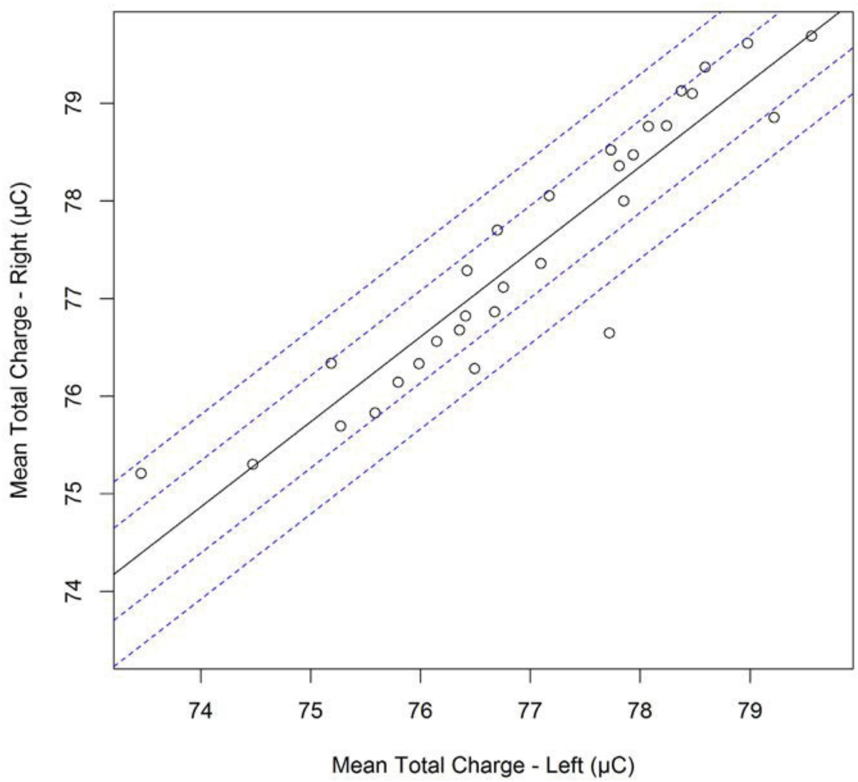

Figure 48: Linear regression results for the mean Total Charge of the TASER X2 bays

The improvement factor (R-squared = 0.88) is high for this parameter, indicating that the linear model is quite good. One possible reason for this improvement compared to the Peak Charge Lobe High Voltage is that the Total Charge represents an integration procedure applied to many measurements across a pulse; thus the impact of irregularities (assumed to be random and somewhat symmetrical) would offset each other during this integration process. This may be the reason for the stronger correlation between left and right bay for Total Charge.

The next parameter of interest is the Pulse Repetition Frequency for both bays. Given that the PRFs of both bays were very similar, this parameter also admits a linear relationship, being that the mean PRF of the right-side bay is 0.942-times the mean value of the left-side bay, plus 1.108 pulses-per-second. The model and the data points are graphed in Fig. 49. The improvement factor (R-squared = 0.89) is again quite high, indicating that the model is again quite good.

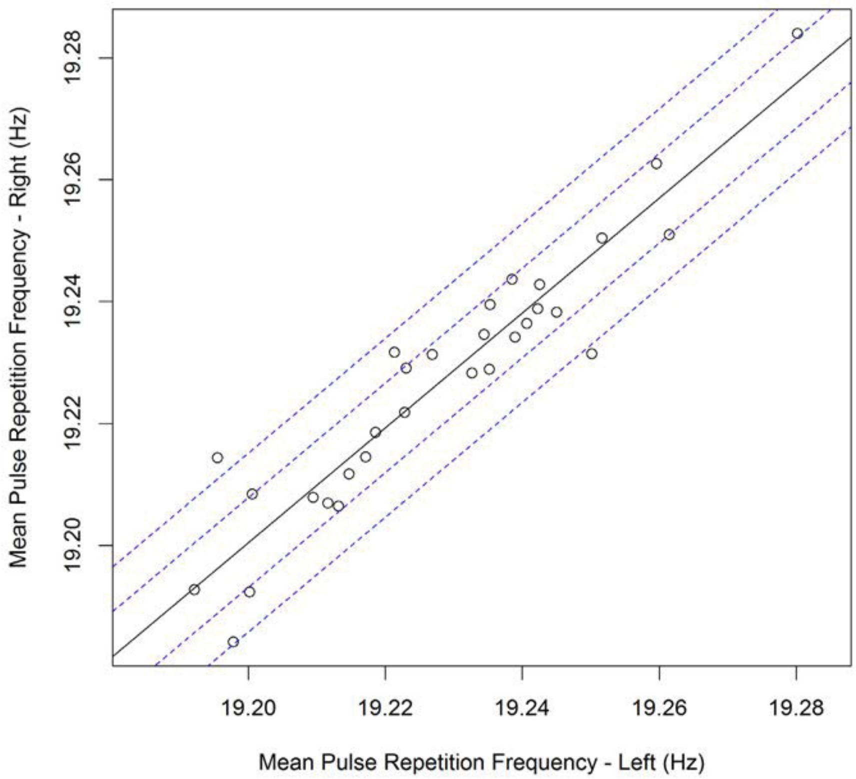

Figure 49: Linear regression results for the mean PRF of the TASER X2 bays

For the pulse repetition frequency, the same mechanism for controlling pulse rate may be used in the weapon design for both bays, and that may be the reason for the high level of the correlation.

The final parameter of interest is the mean Pulse Duration in both bays. For the Pulse Duration, it was found that no correlation exists between the left and right bays. The reason for this may be the difficulty in determining exactly when a pulse ends. If the length of a pulse is subject to a random error factor that is not correlated between the results from the two bays, a lack of correlation between the results from the two would be expected. For the mean Pulse Duration, a linear relationship is not statistically significant: from the ANOVA table, the p-value > 0.05.

To summarize, some of the parameters of the left and right side bays of the TASER X2 did admit a linear relationship. However, the relationship between the bays is not sufficiently strong to accurately predict the output of one bay based solely on the measurement of the other bay. For this reason, it is recommended that separate testing of the left and right bays should continue.

5 Conclusion and Future Work

5.1 Conclusion

All of the 30 TASER X26P and 30 TASER X2 CEWs passed the physical inspection and they easily passed the (modified) Canadian acceptance tests. The weapons were found to be of good quality and no problems were encountered during the electrical testing. The weapons connected successfully with the Evidence Sync software and firmware upgrades performed successfully and easily via the internet. The event logs recorded by the weapons and displayed in Evidence Sync were reliable. That being said, the Pulse Log graphs produced by Evidence Sync are still of limited practical use, and the event numbering in Evidence Sync can sometimes be confusing depending on which report is being viewed.

From an electrical point of view, the TASER X26P and TASER X2 CEWs are very similar, although slight differences in their pulses were detected. The first five pulses of most of the TASER X26P weapons deliver significantly higher charge than the subsequent pulses in the discharge cycle. This phenomenon was not present in the TASER X2. As a result, the average total charge delivered by a TASER X26P is higher than that delivered by a TASER X2. However, charge is well within the Canadian acceptance limits and is within ±5% of the value claimed by the manufacturer.

The mean maximum pulse voltage (Stimulation Phase) of the weapons was similar, ranging from 1124 volts for the TASER X2 (left bay) to 1159 volts for the TASER X26P. The mean pulse repetition frequency (PRF) of the weapons was very consistent at room temperature, being exactly 19.23 pulses per second for the TASER X26P and both bays of the TASER X2.

From an operational point of view, although some improvements have been made to the TASER X2, concerns remain with regards to its cartridges. The safety switch on the TASER X2 has been improved, and the blast doors of the Smart Cartridges now separate cleanly. However, the Smart Cartridges still crack and break when they are fired, which could pose a risk. No such concerns were noted with the Standard Cartridges used with the TASER X26P.

Finally, this work revealed that the Arc Phase of the waveform contains a very brief, high voltage oscillatory period that was hitherto ignored. Its duration is so brief that it is often missed completely using the sampling rate recommended in the DRDCVer1 test procedure. The DRDCVer1 test procedure should be revised to take this into consideration, and the limit of the Lowest Pulse Voltage parameter in DRDCVer1 (which was ignored in this work) should be modified to better reflect the true value produced by the weapons.

5.2 Future Work

This section serves to highlight work that was not within the scope of the current study but that could provide more insight into the performance of the TASER X26P and TASER X2 CEWs.

As shown in Section 2.5, a single test firing of a TASER X2 revealed that the support rings of the new Smart Cartridge cracked and broke. Although this was noted in an earlier study [3], it is unknown if it is a widespread problem and so further testing is recommended.

As mentioned in Section 4.3, the trigger-to-trigger variability of the pulses from a same weapon was not analyzed, although the data has been collected. It would be of interest to determine if the trigger-to-trigger variability is similar to the weapon-to-weapon variability noted in the present study.

The fixed, 1-mm gap introduced between the test wires and the TASER X2 approximates the gap that exists between the wires fired from a live cartridge and the cartridge. Given that this gap is not tightly controlled during the firing of a live weapon, an investigation into the effect of the gap length on the pulse parameters would be useful to justify the continued use of the 1-mm gap during testing.

A fixed-value 600-ohm resistor was used in this study, in accordance with the DRDCVer1 test procedure. In reality, the resistance encountered by the deployed probes of a live cartridge is likely to vary significantly depending on their separation, the clothing worn by the subject, and other parameters. In 2013, a CEWSI-sponsored report from QETE reported that the pulses of the TASER X26E CEW did not vary significantly when the resistance value was varied between 250 ohms and 850 ohms [17]. It is unknown if this observation also applies to the TASER X26P and TASER X2, and so further testing is recommended. In addition, the "charge metering" feature of the weapon could also be tested by varying the value of the resistance during a discharge cycle.

All of the measurements documented in this report were taken at the ambient temperature of the laboratory. In 2013, QETE indicated that the Pulse Repetition Frequency of TASER M26 and TASER X26E CEWs was susceptible to failure at cold temperatures [17]. It is unknown if this is still the case for the TASER X26P and TASER X2. Given the Canadian climate, it is highly recommended that the temperature variability be determined for these weapons.

Finally, it should be noted that a single type of high voltage probe was used during testing. Given the plethora of possible probe types that could be used, a comparison of the results for various probe types would be useful to determine the most cost effective solution.

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Annex A Canadian Acceptance Test Report

The data below, saved in a text file, is an example of the detailed Canadian acceptance test report that is automatically generated by the Matlab script upon the conclusion of a weapons test.

Canadian Acceptance* Test Report
==============================+

*ignores minimum voltage, tests only maximum voltage in max charge lobe

Overall Test Result: PASSED

Test Agency:	Royal Military College of Canada
Date:	26-Feb-2014
Test Procedure:	DRDCVer1
Technician:	Fred Cameron
Engineer:	Joey Bray
Uncertainty	

Laboratory Test Conditions
========================

Temperature:	24 deg. Celsius
Humidity:	24 %
Pressure:	101 kPa
Resistor:	603 Ohms
Resistor Measured at:	14:12

Weapon Specifications
===================

Manufacturer:	TASER
Model:	X26P
Serial:	X12000N9N
Hardware Version:	X3

Evidence Sync Data
=================

Connection:	PASS
Laboratory Time of First Connection:	15:49
Firmware Version:	03.045
Manufactured (estimate):	25-Nov-2013
Prior Firings:	21
Health Status:	PASS
Shows Correct Model and Serial:	GOOD

Waveform Testing Pass/Fail

========================

Discharge Cycle Duration	PASS
Number of Pulses:	PASS
Maximum Pulse Duration:	PASS
Minimum Pulse Duration:	PASS
Mean Pulse Repetition Interval:	PASS
Maximum Pulse Repetition Interval:	PASS
Mean Pulse Repetition Frequency:	PASS
Maximum Pulse Repetition Frequency:	PASS
Minimum Pulse Repetition Frequency:	PASS
Highest Pulse Voltage:	PASS
Weakest Pulse High Voltage:	PASS
Lowest Pulse Voltage:	IGNORED
Weakest Pulse Low Voltage:	PASS
Mean Total Charge:	PASS
Maximum Total Charge:	PASS
Minimum Total Charge:	PASS
Peak Charge Lobe Mean Charge:	PASS
Peak Charge Lobe Max Charge:	PASS
Peak Charge Lobe Min Charge:	PASS

Calculated Waveform Parameters

============================

Discharge Cycle Duration:	5.05e+000 seconds
Number of Pulses:	98
Maximum Pulse Duration:	9.70e-005 seconds
Minimum Pulse Duration:	8.40e-005 seconds
Mean Pulse Repetition Interval:	5.20e-002 seconds
Maximum Pulse Repetition Interval:	5.31e-002 seconds
Mean Pulse Repetition Frequency:	1.92e+001 Hertz
Maximum Pulse Repetition Frequency:	1.96e+001 Hertz
Minimum Pulse Repetition Frequency:	1.88e+001 Hertz
Highest Pulse Voltage:	1.23e+003 Volts
Weakest Pulse High Voltage:	1.11e+003 Volts
Lowest Pulse Voltage:	-2.50e+003 Volts
Weakest Pulse Low Voltage:	-1.75e+003 Volts
Mean Total Charge:	8.33e-005 Coulombs
Maximum Total Charge:	8.72e-005 Coulombs
Minimum Total Charge:	7.97e-005 Coulombs
Peak Charge Lobe Mean Charge:	7.50e-005 Coulombs
Peak Charge Lobe Maximum Charge:	7.91e-005 Coulombs
Peak Charge Lobe Minimum Charge:	7.16e-005 Coulombs
Peak Voltage Lobe Mean Charge:	8.38e-006 Coulombs
Peak Voltage Lobe Maximum Charge:	1.01e-005 Coulombs
Peak Voltage Lobe Minimum Charge:	7.62e-006 Coulombs

Auxiliary Weapon Testing Parameters

====================================

Physical Inspection:	PASS
PPM Seated Correctly:	PASS
Laboratory Time of First Arming:	15:51
Laser and Flashlight	PASS
Laboratory Time of Spark Test:	15:51
Spark Test result:	PASS
Battery Bars:	4
Laboratory Time of Trigger Pull:	15:52
PDF Filename:	X26P_X12000N9N_26-Feb-2014
CSV Filename:	X26P_X12000N9N_26-Feb-2014_1

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Annex B Test Equipment

This annex documents the equipment that was used and indicates the settings that were chosen.

Table B.1: Oscilloscope

Make	Tektronix
Model	DPO4104B
Serial	C021569
Age	Arrived Oct 2012
Calibration	Tektronix Certificate PCXPT1L7BH Sept 17 2012
Analog bandwidth	Set to 20 MHz
Sample rate	Set to 2 million samples per second
Record length	Set to 20 million samples
Horizontal time step	0.5 µs/sample
Vertical scale	500 mV/division
Resolution	8 bits per sample
Coupling	DC
Trigger	Edge, DC, –50 mV level, normal mode
Input impedance	1 MΩ
Conditioning	None, raw data recorded

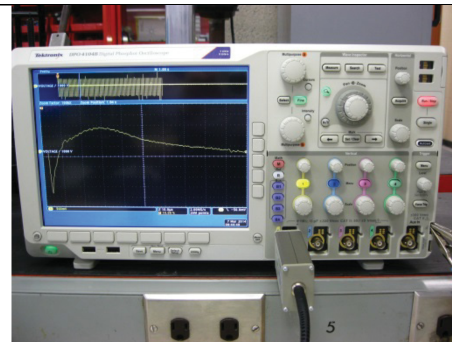

Table B.2: High voltage probe

Make	Tektronix
Model	P6015A
Serial	C066270
Age	Arrived Oct 2012
Calibration	Tektronix Certificate PCXPS73VWQ Dec 20 2011
Compensation	Automatically applied by the oscilloscope
Maximum voltage	20 kV DC / 40 kV peak (100 ms pulse width)
Voltage reduction	1000:1
Bandwidth	75 MHz

Table B.3: LCR-meter

Make	Agilent	
Model	4263B	
Test Fixture	16047D	
Serial	MY40112581	
Age	New. Arrived Jan 2014	
Calibration	Agilent Certificate 4069687-4831487-1 Oct 16 2013	

Table B.4: Power resistor

Make	Ohmite	
Series	200 Brown Devil vitreous enamel, ceramic core	
Model	B12NJ600R	
Resistance	600 ±5%	
Wattage	12 watts RMS	
Winding	Non-inductive	

Table B.5: Thermometer and hygrometer

Make	TENMA	
Model	72-7595	
Age	Unknown	
Calibration	Not calibrated	

Table B.6: Additional information

Test dates	February 2014 through March 2014
Test location	Sawyer 5100 laboratory, Royal Military College of Canada
Bench surface	non-conducting anti-static mat over wood laminate
Mass measurements	OHAUS TS400S balance

B.1 Note Regarding Quantization Error

Peak voltages in excess of 2000 volts are expected from the TASER X2 with the 600 Ω resistor attached. This dictates the use of the 500 mV/division vertical scale, which actually represents 500 V/division after multiplying by the probe's 1000-times multiplication factor. The oscilloscope has 10.24 vertical divisions, and an 8-bit resolution yields a least-significant bit voltage of 10.24 divisions × 500 V/division / 28 bits = 20 V/bit. This means that the voltage resolution of the measurements is no better than 20 volts.

Annex C Summary of Measured Parameters

This annex summarizes the measurements of the TASER X26P and TASER X2 CEWs. Also shown are the benchmark measurements of the TASER X26E as reported in [17].

C.1 TASER X26P Pulses

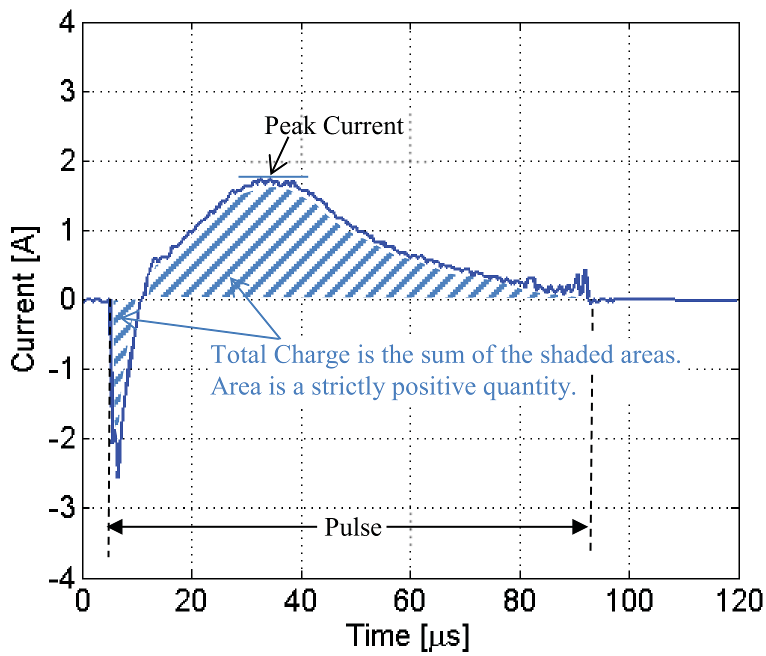

Figure C.1: Typical "Precision Shaped Pulse" of the TASER X26P

Table C.1: Measured Parameters of the TASER X26P

Parameter	Mean Value	Standard Deviation
Peak Current* [A]	1.93	0.06
Peak Voltage [V]	1159	38
Total Charge [µC]	82.3	2.0
Pulse Repetition Frequency [Hz]	19.2	0.2
Pulse Duration [µs]	88.1	3.6

*based on measured Peak Voltage, assuming a 600-ohm resistor

C.2 TASER X2 Pulses

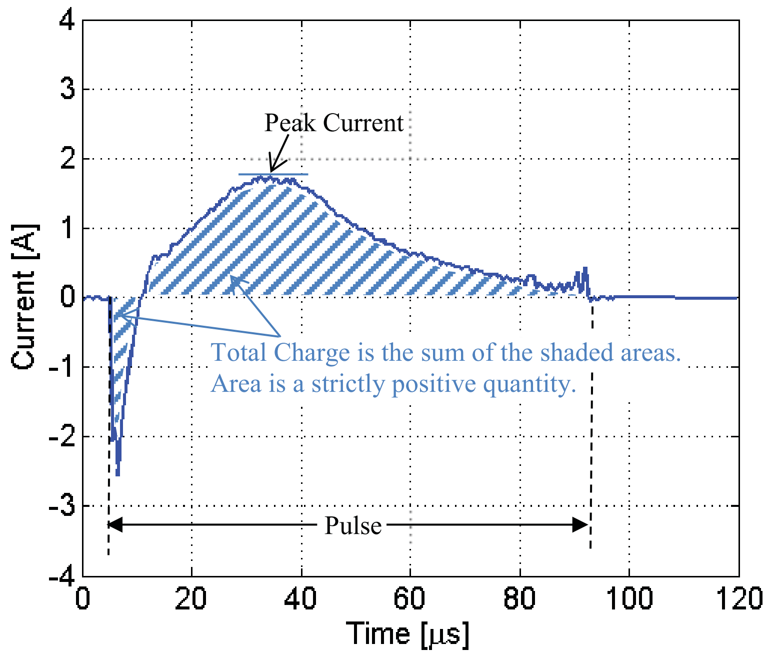

Figure C.2: Typical "Precision Shaped Pulse" of the TASER X2

Table C.2: Measured Parameters of the TASER X2

	TASER X2 LEFT BAY		**TASER X2 RIGHT BAY**	
Parameter	**Mean Value**	**Standard Deviation**	**Mean Value**	**Standard Deviation**
Peak Current* [A]	1.87	0.07	1.91	0.07
Peak Voltage [V]	1124	42	1144	43
Total Charge [µC]	77.0	2.5	77.5	2.7
Pulse Repetition Frequency [Hz]	19.2	0.3	19.2	0.4
Pulse Duration [µs]	80.6	3.6	78.7	3.6

*based on measured Peak Voltage, assuming a 600-ohm resistor

C.3 TASER X26E Pulses

The following data is presented as information only and is taken from [17].

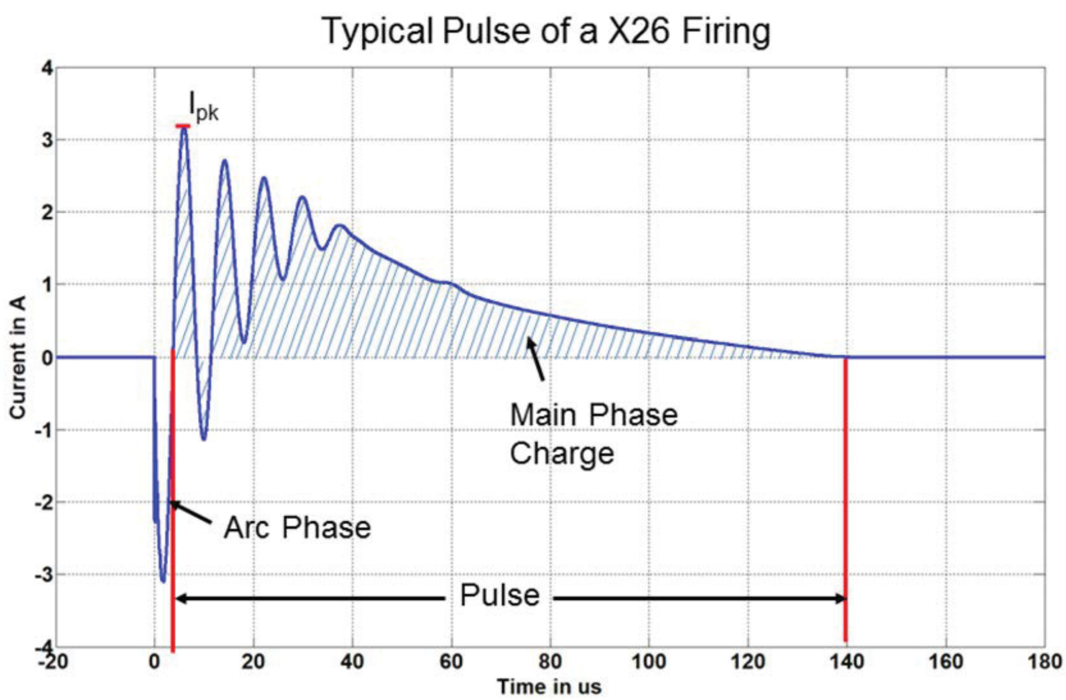

Figure C.3: Typical "Shaped Pulse" of the TASER X26E [17]

Table C.3: Measured Parameters of the TASER X26E [17]

Parameter	**Mean Value**	**Standard Deviation**
Peak Current* [A]	3.33	0.10
Peak Voltage [V]	1996	58
Main Phase Charge [µC]	109	3
Pulse Repetition Frequency [Hz]	18.4	0.03
Pulse Duration [µs]	132	5

*based on measured Peak Voltage, assuming a 600-ohm resistor

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Annex D Normality Tests

This annex summarizes the normality tests that were applied to the measured parameters of Peak Charge Lobe High Voltage, Total Charge, and Pulse Repetition Frequency (PRF). In all three cases, one numerical test and two visual normality tests were used.

The Shapiro-Wilk normality test was the numerical test used on the three parameters. It indicated that only the Total Charge and PRF could be considered as coming from a normal distribution, whereas the Peak Charge Lobe High Voltage was rejected. The reason for this rejection, along with a correction that leads to the parameter being accepted, is given in Section D.1.

The first visual test used on the three parameters is the *kernel density plot*, which is inspected visually in terms of its appearance to assess the normality. In the second visual test, the data are plotted on a normal *quantile-quantile plot* (QQ plot). If the data approximate a diagonal line on the QQ plot, they are likely normally distributed.

Based on the information presented below, we conclude that it is reasonable to assume that the Peak Charge Lobe High Voltage, Total Charge, and PRF are well-modelled by a normal distribution.

D.1 Normality of Peak Charge Lobe High Voltage

A representative measurement of the Peak Charge Lobe High Voltage versus the pulse number (1 to 97) for a TASER X26P, serial X12000N3X, is shown in Fig. D.1, along with the kernel density plot and QQ plot in Fig. D.2.

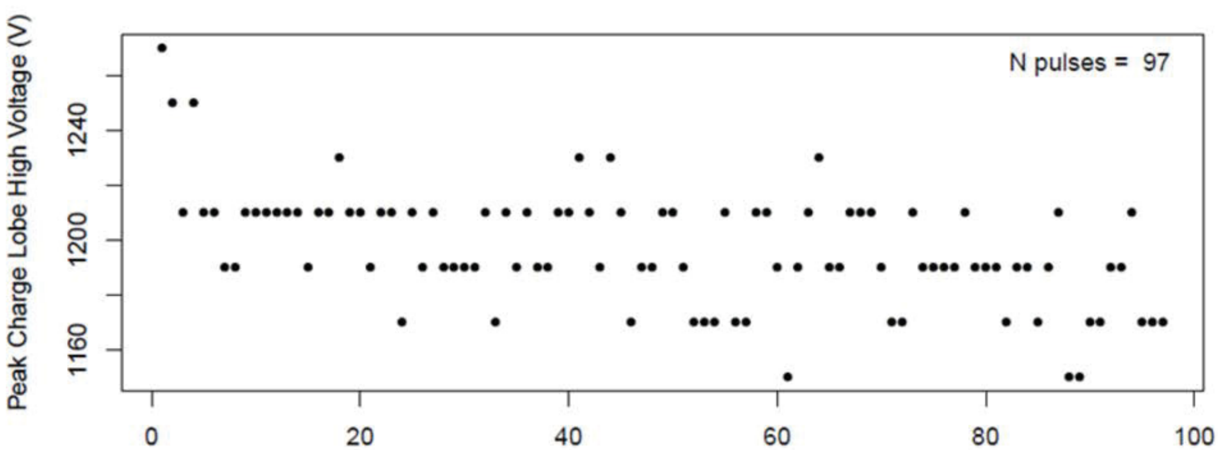

Figure D.1: Measured Peak Charge Lobe High Voltage for the 97 pulses of the firing of a TASER X26P

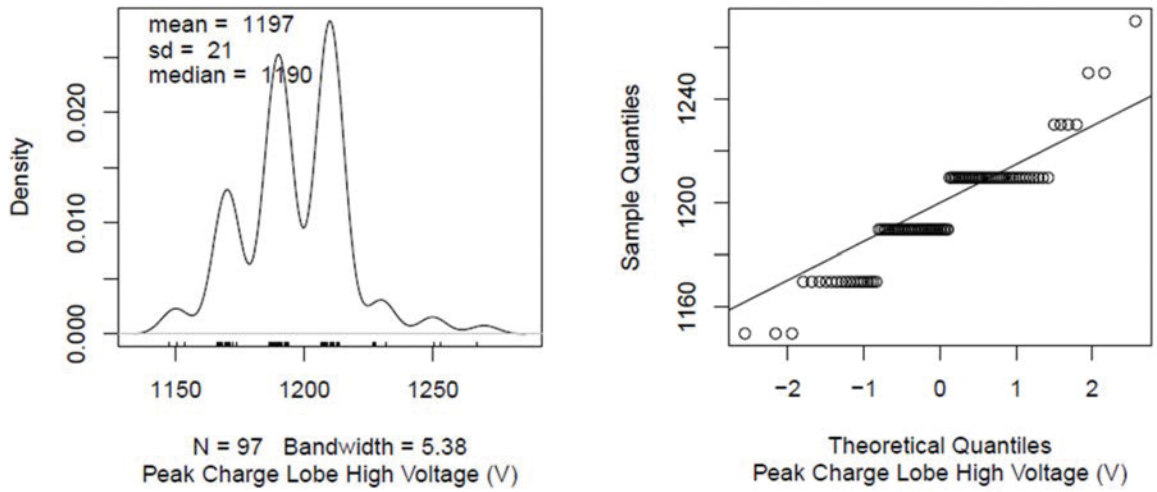

Figure D.2: Kernel density plot (left) and QQ plot (right) of the data shown in Fig. D.1

For the QQ plot, the diagonal line represents the best linear fit to the data. Inspection of Fig. D.2 suggests that the Peak Charge Lobe High Voltage is *not* normally distributed – there are three peaks instead of one in the kernel density plot, and the QQ plot follows the diagonal in a step-wise manner instead of being evenly distributed around the diagonal. However, inspection of the data in Fig. D.1 shows that the oscilloscope's resolution is limited to 20-volt increments. Hence it is *likely* that the actual voltages are interspersed between these 20-volt increments but the equipment cannot measure voltage to that resolution. If a random *jitter* of ±10-volts is added to the measured data, the measured values will fluctuate randomly between the 20-volt quantized levels and will likely better represent the actual voltage. The resulting kernel density and QQ plots, with jitter added, are shown in Fig. D.3.

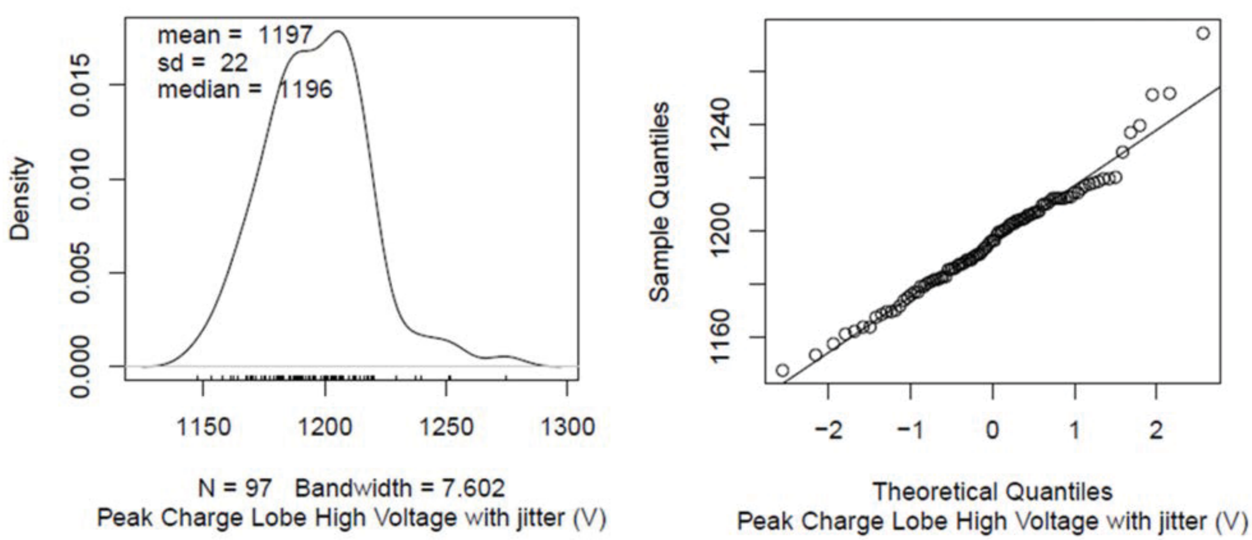

Figure D.3: Kernel density plot (left) and QQ plot (right) of the data shown in Fig. D.1 with a ±10-volt random jitter added

As can be seen from the graphs in Fig. D.3, the addition of the jitter has not significantly changed the mean, median or standard deviation of the data, but it now closely resembles a normal distribution, with the QQ plot indicating only a few outliers on the high-voltage side (some of which we know are caused by the first few pulses of the TASER X26P). Based on this observation, it is reasonable to assume that Peak Charge Lobe High Voltage is well-approximated by a normal distribution. As a further note, the jitter needed only to be added for the purposes of assessing the normality of the Peak Charge Lobe High Voltage – it was not added to the data for subsequent analysis purposes.

D.2 Normality of Total Charge

As an example, the Total Charge calculated from the measured pulses from the right bay of a TASER X2, serial X29001PR5, is shown in Fig. D.4. Fig. D.5 shows the associated kernel density and QQ plots.

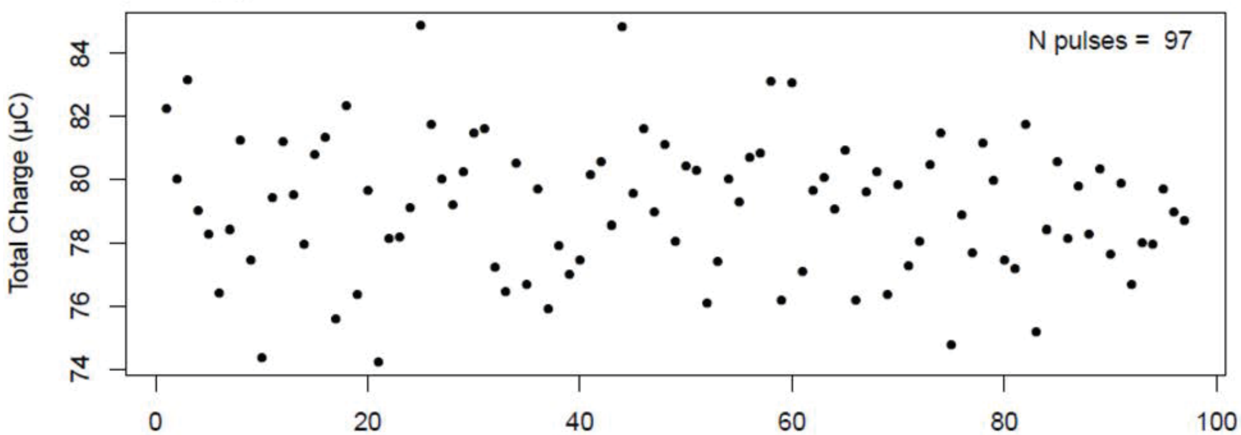

Figure D.4: Calculated Total Charge of the 97 pulses of the right bay firing of a TASER X2

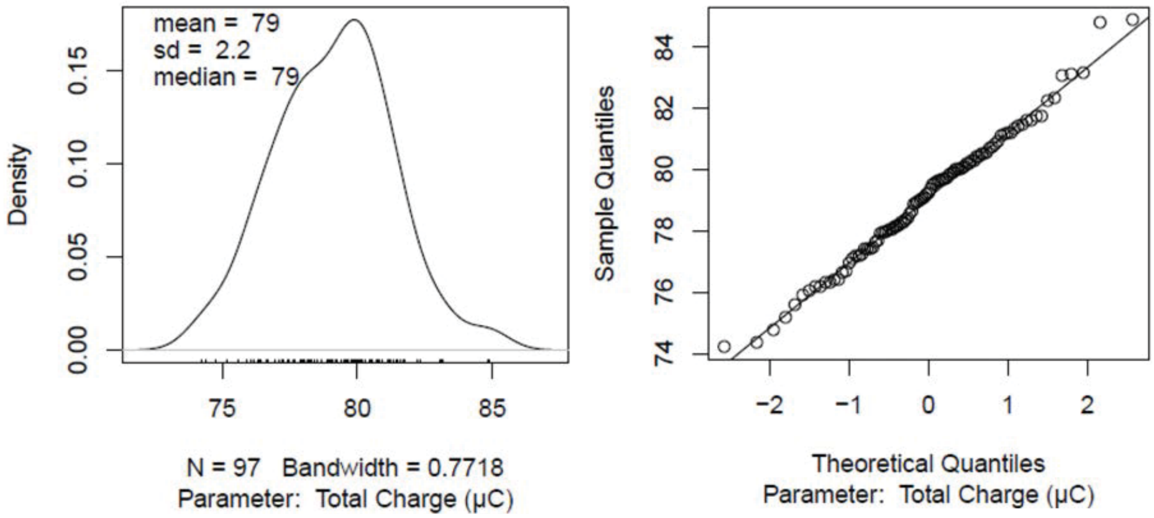

Figure D.5: Kernel density plot (left) and QQ plot (right) of the data shown in Fig. D.4

The results indicate that the Total Charge is well-modelled by a normal distribution, as is evidenced by the tight grouping of the data points about the diagonal in the QQ plot, with very few outliers.

D.3 Normality of Pulse Repetition Frequency

The Pulse Repetition Frequency, measured in pulses per second (or Hertz) is the reciprocal of the so-called Interpulse Period, measured in seconds. The Interpulse Period is simply the time elapsed between the beginning of each pulse. The normality test was applied directly to the Interpulse Period. The Interpulse Period measured from the left bay of a TASER X2, serial X29001PNH, is shown in Fig. D.6. The kernel density and QQ plots are shown in Fig. D.7.

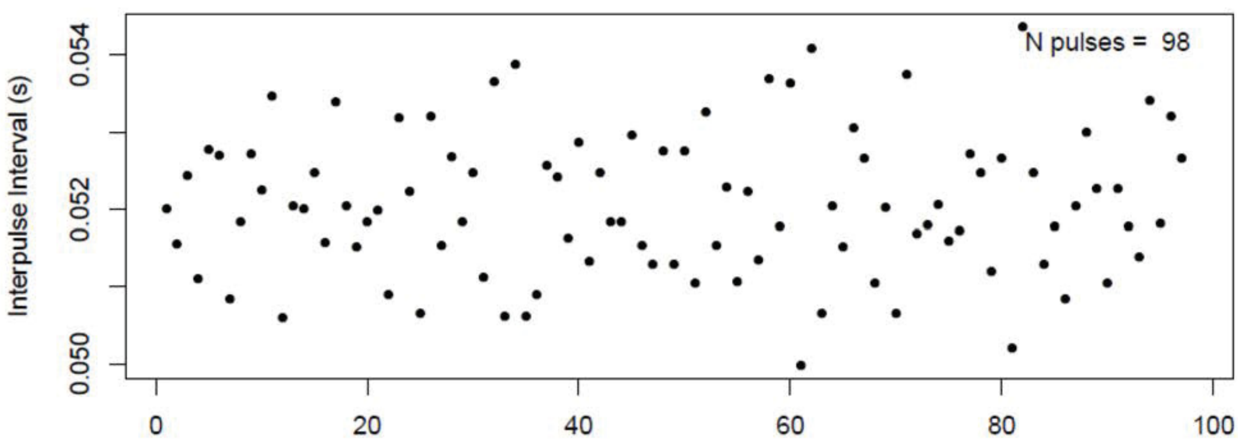

Figure D.6: Interpulse Interval of the 98 pulses of the left bay firing of a TASER X2

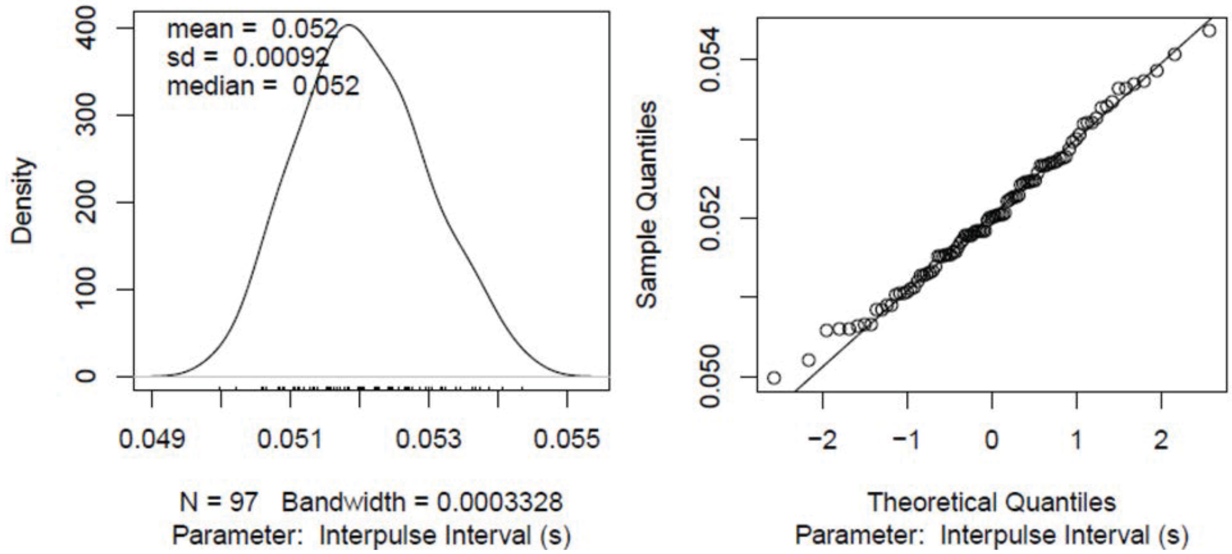

Figure D.7: Kernel density plot (left) and QQ plot (right) of the data shown in Fig. D.6

The majority of the Interpulse Period data points follow the diagonal very closely on the QQ plot, with only a few obvious outliers on the low-side. It is therefore reasonable to assume that the Interpulse Period is also well-modelled by a normal distribution.

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Annex E ANOVA Tables for Linear Regression

The statistical details regarding the linear regression performed on the data collected from the TASER X2's left and right bays are given in the form of one-way analysis of variance (ANOVA) tables. The tables are meaningful to those who are well-versed in statistics. They are provided here for sake of rigour.

Table E.1: Linear regression for mean Peak Charge Lobe High Voltage

Mean Peak Charge Lobe High Voltage (V)	**Estimate**	**Standard Error**	**t-value**	**Pr(>|t|)**
Intercept	524.6	147.28	3.6	0.001
Slope	0.55	0.13	4.2	0.0002
Residual standard error	20 on 28 degrees of freedom			
Multiple R-squared	0.39			
Adjusted R-squared	0.37			
F-statistic	18 on 1 and 28 DF		p-value	0.00024

Table E.2: Linear regression for mean Total Charge

Mean Total Charge (μC)	**Estimate**	**Standard Error**	**t-value**	**Pr(>|t|)**
Intercept	10.366	4.695	2.2	0.04
Slope	0.872	0.061	14.3	2.0E−14
Residual standard error	0.47 on 28 degrees of freedom			
Multiple R-squared	0.88			
Adjusted R-squared	0.88			
F-statistic	200 on 1 and 28 DF		p-value	2.1E−14

Table E.3: Linear regression for mean Pulse Repetition Frequency

Mean Pulse Repetition Frequency (Hz)	**Estimate**	**Standard Error**	**t-value**	**Pr(>|t|)**
Intercept	1.108	1.228	0.9	0.4
Slope	0.942	0.064	14.8	1.0E−14
Residual standard error	0.0073 on 28 degrees of freedom			
Multiple R-squared	0.89			
Adjusted R-squared	0.88			
F-statistic	220 on 1 and 28 DF		p-value	9.8E−15

Table E.4: Linear regression for the mean Pulse Duration

Mean Pulse Duration (s)	**Estimate**	**Standard Error**	**t-value**	**Pr(>|t|)**
Intercept	8.70E−5	1.50E−5	5.6	5.00E−6
Slope	−9.90E−2	1.90E−1	−0.5	0.6
Residual standard error	2.6E−6 on 28 degrees of freedom			
Multiple R-squared	0.0095			
Adjusted R-squared	−0.026			
F-statistic	0.27 on 1 and 28 DF		p-value	0.61

Annex F Glossary

This annex contains the definitions of selected technical terms.

Arc
Commonly known as an electrical spark. A lightning bolt is an example of an arc. A picture of an arcing TASER X2 is shown in Fig. 16.

Arc Phase
A TASER International term that refers to the first part of the pulse generated by the TASER X26P and TASER X2. The Arc Phase is brief and provides a very high voltage. See also Stimulation Phase.

Box-and-whisker plot
A graph type for displaying large quantities of data. Instead of showing all of the data points, which would clutter a graph, it just shows a box around the area where most of the data points are.

Cartridge Bay
The TASER X2 can accommodate up to two cartridges, and a cartridge bay refers to one of the two slots (either left or right) at the front of the weapon into which the cartridge is inserted.

Charge
An electrical term that refers to a quantity of electrons. The unit of charge is the Coulomb (C). Conducted energy weapons deliver charge into a subject. An analogy would be to a quantity of water, measured in litres. Similar to water flowing in a pipe, charge flows in an electrical circuit.

Current
An electrical term that refers to the rate of flow of electrons, measured in Coulombs-per-second. One Coulomb-per-second is defined as one Ampere (A). One-thousandth of an Ampere is a milliampere (mA) and one-millionth of an ampere is a microampere (μA). An analogy would be to the flow rate of water, measured in litres-per-second. Just like water in a pipe, current can flow in a positive direction or a negative direction.

Inter-Quartile Range (IQR)
A statistical term that refers to a range of values in which 50% of the data points lie, grouped around the median-value.

Net Charge
An electrical term that refers to a quantity of electrons, measured in Coulombs. It describes a difference: how much more charge that flowed in one direction compared to the other direction. A note of caution: if a quantity of charge flows first in one direction, then reverses and the same quantity of charge flows in the other direction, the Net Charge will be zero, so this parameter can be deceptive. See also Total Charge.

Oscilloscope
A common electrical apparatus that records voltage as a function of time.

Peak Charge Lobe
An electrical term formally defined in DRDCVer1 [2] that refers to a portion of a pulse. Given that electrical current can flow in positive and negative directions during a pulse, a lobe is defined as a portion of a pulse in which current if flowing only either in the positive or negative direction. A single pulse can have many lobes. The Peak Charge Lobe is the lobe that delivers the most charge to the subject. It usually corresponds with what TASER International calls the Stimulation Phase of the pulses generated by the TASER X26P and TASER X2.

Peak Charge Lobe High Voltage
An electrical term formally defined in DRDCVer1 [2] that refers to the highest measured voltage of the Peak Charge Lobe.

Peak Voltage Lobe
An electrical term formally defined in DRDCVer1 [2] that refers to a portion of a pulse. Given that electrical current can flow in positive and negative directions during a pulse, a lobe is defined as a portion of a pulse in which current if flowing only either in the positive or negative direction. A single pulse can have many lobes. The Peak Voltage Lobe is the lobe that produces the strongest voltage during the pulse. It is usually contained in what TASER International calls the Arc Phase of the pulses generated by the TASER X26P and TASER X2.

Probe
There are two contexts where the term 'probe' is used. In the first, the barbed darts that are fired from a TASER cartridge are called probes. In the second, probes refer to the contact points where measurement equipment connections are made.

Pulse Duration
An electrical term that refers to time, measured in seconds. TASER International CEWs deliver a series of electrical pulses into a subject. The Pulse Duration is the time duration of one of these pulses. One thousandth of a second is a millisecond (ms) and one millionth of a second is a microsecond (μs).

Pulse Repetition Frequency (PRF)
An electrical term that refers to the rate of pulses produced by a CEW, measured in units of pulses-per-second or Hertz (Hz).

Pulse Repetition Interval
An electrical term that refers to the elapsed time between the start of one pulse and the start of the next pulse, measured in seconds. One thousandth of a second is a millisecond (ms) and one millionth of a second is a microsecond (μs).

Quartile
A statistical term that refers to a range of values in which 25% of the data points lie.

Resistance
An electrical term that refers to a circuit's reluctance to permit the flow of current, measured in units of Ohms (Ω). A resistor provides a fixed, known value of resistance. A unit of voltage will cause more current to flow in a circuit having low resistance, compared to a circuit having high resistance.

Sabot
A munitions term that refers to parts that hold a projectile in its bore before it is fired. Upon firing, the sabots help to guide the projectile as it is accelerated in the bore. Sabots are of no use once the projectile has exited the bore and so they usually detach from the projectile and are expelled. The TASER International term for the sabots that shroud the probes are 'ejectors'.

Sampling Rate
An electrical term that refers to the number of discrete electrical measurements made during a period of time, measured in samples-per-second (Sa/s). Digital electrical apparatus only take measurements (known as samples) at finite time intervals. Quickly-varying events require high sampling rates. One million samples-per-second is a megasample-per-second (MSa/s) and one billion samples-per-second is a gigasample-per-second (GSa/s).

Stimulation Phase
A TASER International term that refers to the second part of the pulse generated by the TASER X26P and TASER X2. The Stimulation Phase delivers the most charge to the subject and is responsible for neuromuscular incapacitation. See also Arc Phase.

Total Charge
An electrical term that refers to a quantity of electrons, measured in Coulombs. Total Charge is formally defined in DRDCVer1 [2]. Total Charge is an absolute measurement of charge that does not rely on the direction of flow. For example, if a quantity of charge 'Q' flows first in one direction, then reverses and the same quantity 'Q' of charge flows in the other direction, the Total Charge will be twice the value of 'Q'. See also Net Charge.

Voltage
An electrical term, measured in Volts (V), that refers to the amount of energy in a charge. An analogy would be to the pressure of water in a pipe.

List of abbreviations

ANOVA	ANalysis Of VAriance
APPM	Audible Performance Power Magazine
CEW	Conducted Energy Weapon
CEWSI	Conducted Energy Weapon Strategic Initiative
CID	Central Information Display
CSS	Centre for Security Science
CSV	Comma Separated Values
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DRDCVer1	c.f. Ref. [2]
FIN	Firearm Identification Number
HSD	Honest Significant Difference
IQR	Inter-Quartile Range
LCR	Inductance, Capacitance, Resistance
LED	Light Emitting Diode
PDF	Portable Document Format
PNG	Portable Network Graphics
PPM	Performance Power Magazine
PRF	Pulse Repetition Frequency
QETE	Quality Engineering Test Establishment
QQ plot	Quantile-Quantile plot
RCMP	Royal Canadian Mounted Police
TPPM	Tactical Performance Power Magazine
USB	Universal Serial Bus
XPPM	Extended Performance Power Magazine

List of units

A	ampere, a unit of electric current
cm	centimetre, a unit of length
g	gram, a unit of mass
GSa/s	gigasamples per second, a unit of sampling rate
Hz	hertz, a unit of frequency (pulses per second)
kPa	kilopascal, a unit of atmospheric pressure
mm	millimetre, a unit of length
mV	millivolt, a unit of electric potential
MB	megabyte
MSa/s	megasamples per second, a unit of sampling rate
V	volt, a unit of electric potential
VDC	volts direct current, a unit of electric potential
μC	microcoulomb, a unit of electric charge
μs	microsecond, a unit of time