Presentation to Taser International Scientific and Medical Advisory Board

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Outline

- Background
- What are our interests?
- Taser Testing in Canada
- Our “V1.1” test standard
- Results of our tests
- Opinions
  - NIST standard
  - Other testing of ESW
  - Routine testing of ESWs
  - Lessons for the next non-lethal weapon
  - Physiological tests needed

Carleton
UNIVERSITY

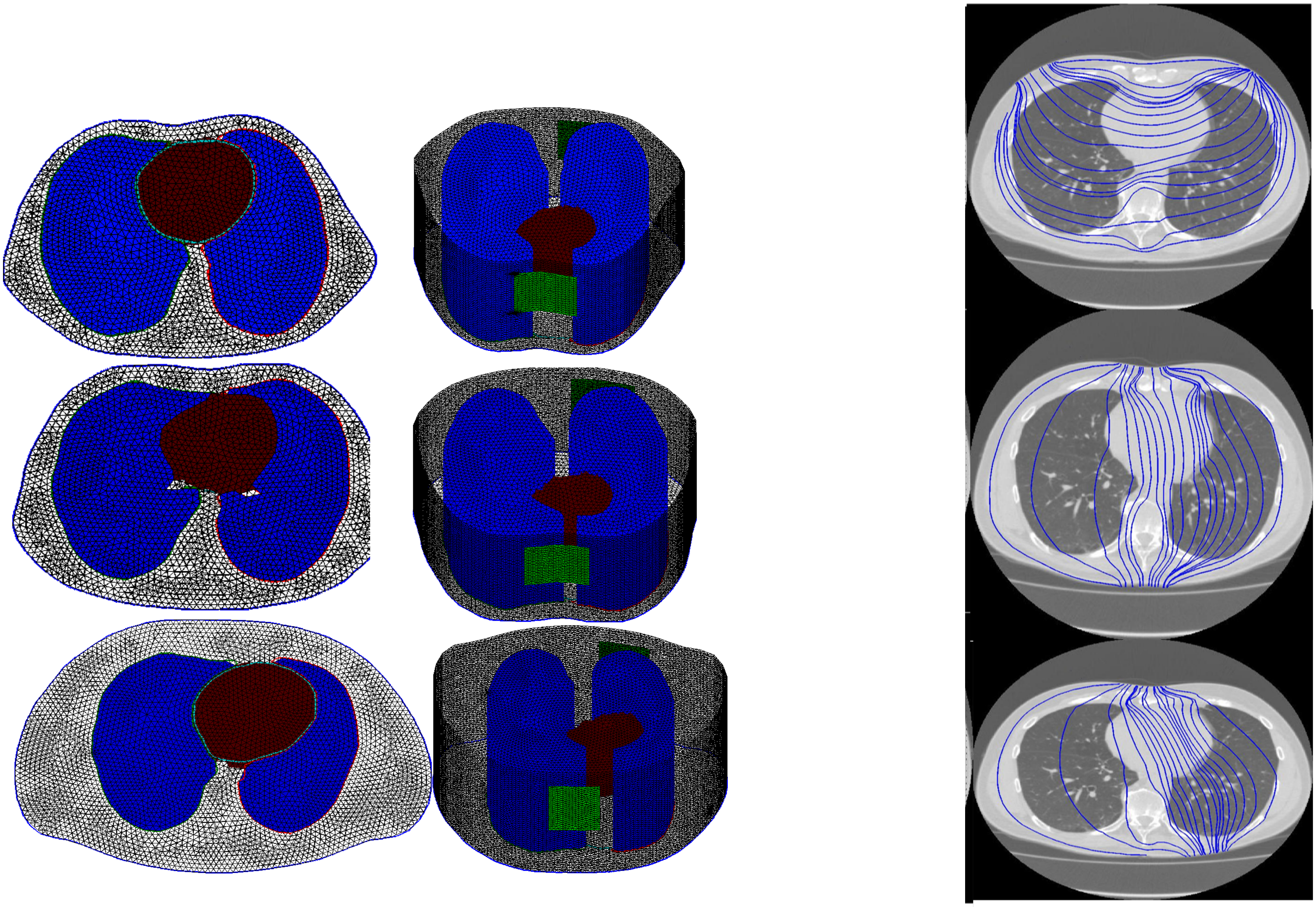
- Founded 1942
- Located in Ottawa, Ontario, Canada
- Operating Budget $327.5 Million
- 26,771 Students
- The Biomedical Engineering Program is within the Systems and Computer Engineering Department

Examples of our interests

- Biomedical measurement and instrumentation
  - Non-invasive techniques for measuring cardiac, neurological and respiratory function
  - Biometrics (face and fingerprint)
  - Imaging using applied currents
  - Electrical Impedance Tomography
    - Biomedical
    - Geophysical
- Research Collaborations
  - USA, Europe (UK, Germany, France, Switzerland), South Africa, Korea

Lab Group: Summer, 2012

Eg: Cardioversion pad placement

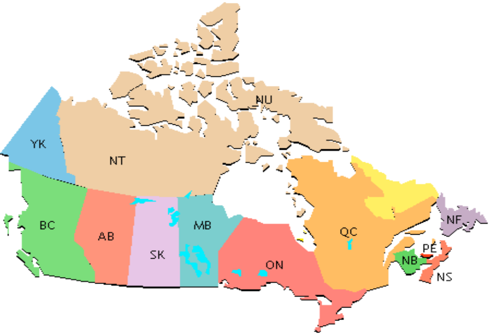


Our Goals

- Help establish a standardized test procedure
  - Useful from Taser + other ESWs
- Help establish a test database across jurisdictions
- Develop and publish analysis tools
- Expertise in ESW testing
- Get ahead of the curve on testing new ESWs
  - This includes Taser X-2

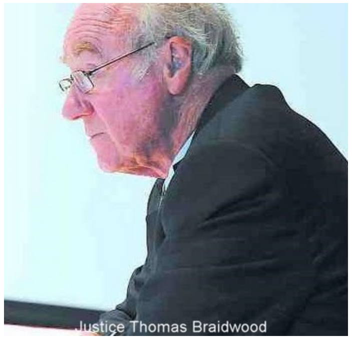
Testing of Electroshock Weapons

- Our initial involvement motivated by media concern after death of Robert Dziekanski (Vancouver airport)
- We wanted to contribute measurements electrical currents in body.
- It became clear that the first question was on variability and reliability of Taser electrical outputs.
  - Medical effects needed first to know what was input.
  - After an incident, was weapon used behaving normally?
- Large population study of the performance characteristics of the X-26
- Forensic examination of broader range of CEWs



ESW Testing in Canada

- est. 11,000 CEWs in Canada
  - of which 3,000 are regularly tested
  - Mostly X26. A few M26's are still around
- No testing before 2009
  - No Life cycle management
  - No Performance validation



- Public inquiry by Justice Braidwood drove more wide-spread testing
  - Recommendations specifically to test regularly and independently

ESW Testing in Canada

- Nationally, responsibility Defense Research Development Canada and Public Safety Canada
- Provincial Responsibility for Policing
  - Many provinces (BC, AB, NS) have adopted our “v1.1” test protocol
  - BC: tests every 2 years (via contract test lab)
  - AB: tests every year + at delivery (via contract test lab)
  - NS: tests every 2 years (via contract test lab)
  - ON: does testing internally (but now might outsource)
  - QC: does testing internally
  - RCMP: does testing via contract lab

CEW testing in Canada

- Carleton University
- Rassettica Testing Limited (Ottawa)
- Datrend (Richmond BC)
- Ontario Center for Forensic Science (Electronics Section now discontinued)
- Laboratoire de sciences judiciares et de médecine légale
- MPB Electronics Test Centers

Timeline of our tests

- 2008: Undergraduate Project, Phantom Gel
- 2009: Testing Protocol
- 2009: National Workshop on CEWs (Carleton)
- 2010: National Workshop on CEWs (Carleton)
- 2010: Consensus Testing Protocol “V1.1”
- 2011: National CEW Workshop (DRDC Canada)
- 2012: 3rd round of testing in some Jurisdictions

Test Procedure for Conducted Energy Weapons

version 1.1, 31 July 2010

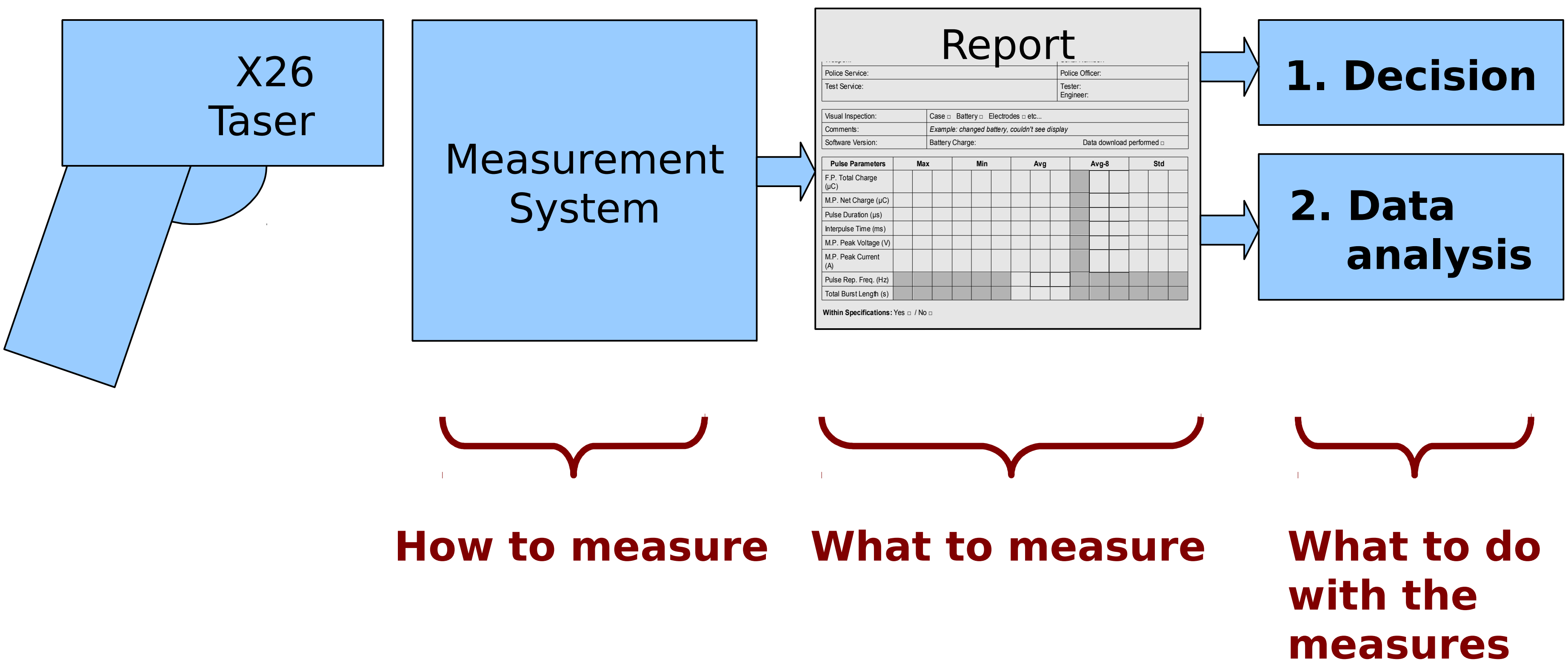
Andy Adler, Dave Dawson, Ron Evans, Laurin Garland, Mark Miller, Ian Sinclair

Why not the TI procedure?

0. Buy very specific scope and devices
1. Set up scope
2. Prepare probes and devices
    2a. Observe repetition rate
    2b. Manually calculate parameters
3. Change scope settings
    3a. Observe pulse shape
    3b. Manually calculate parameters

    ...

Summary / Overview



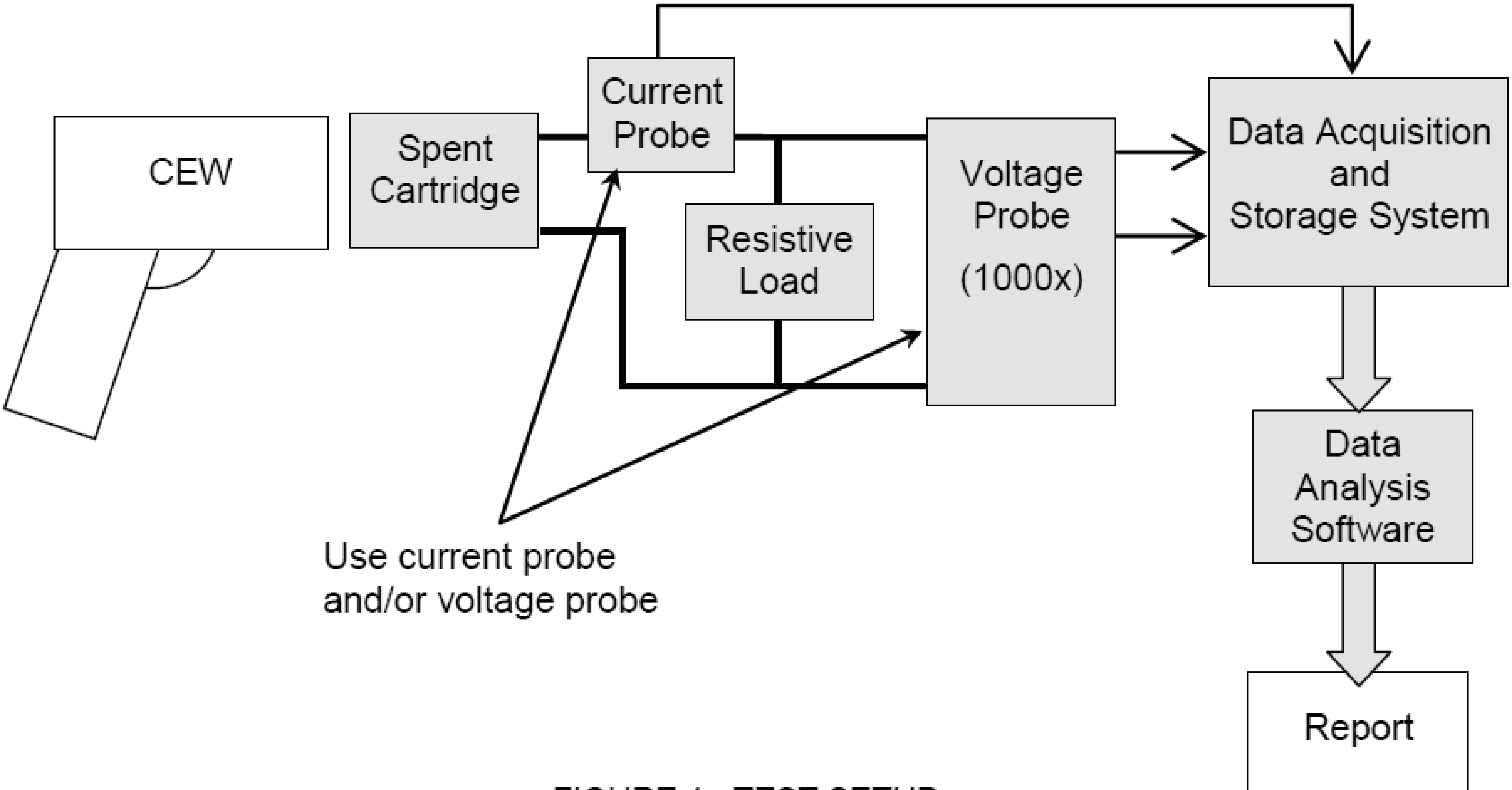
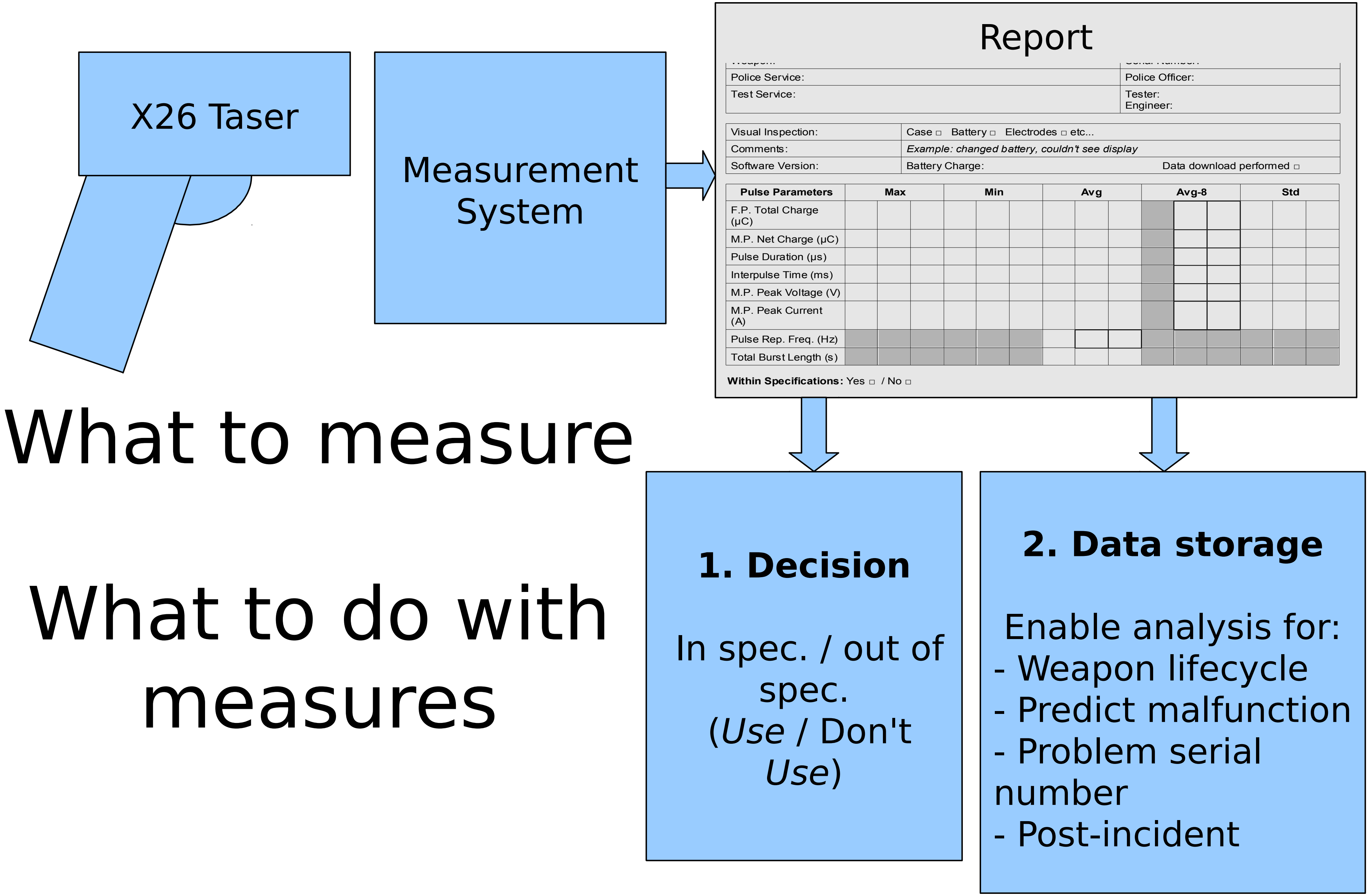


FIGURE 1: TEST SETUP

How to measure


X26 Taser
Measurement System
Report
Police Service:
Police Officer:
Test Service:
Tester:
Engineer:
Visual Inspection:
Case □ Battery □ Electrodes □ etc...
Comments:
Example: changed battery, couldn't see display
Software Version:
Battery Charge:
Data download performed □
Pulse Parameters
Max
Min
Avg
Avg-8
Std
F.P. Total Charge (μC)
M.P. Net Charge (μC)
Pulse Duration (μs)
Interpulse Time (ms)
M.P. Peak Voltage (V)
M.P. Peak Current (A)
Pulse Rep. Freq. (Hz)
Total Burst Length (s)
Within Specifications: Yes □ / No □
What to measure
What to do with measures
1. Decision
In spec. / out of spec.
(Use / Don't Use)
2. Data storage
Enable analysis for:
- Weapon lifecycle
- Predict malfunction
- Problem serial number
- Post-incident

Is weapon in spec?

- Decision: *Use* / Don't *use*

- Based on two tests:

1. Test to document from Taser International [1]
2. Test to additional specifications based on operational and safety data

[1] TASER X26TM Series Electronic Control Device Specifications (Law Enforcement X26). Version 2.0. February 6, 2009:, from "Test Concepts X26 v6"

Is weapon in spec?

- Spec from Taser International [1]
  - Fire once before testing
  - Tests against the average of the last 8 pulses of 5 parameters.
- Spec from operational/safety data
  - Tests should change as we learn more
  - *Comment:* It is important to ensure we collect the right parameters now to enable these decisions

New Safety / Operational Specs

- New Safety Specs
  - Based on IEC:
  - Max: *Monophasic Charge*

- We also probably should have new *Operational Specs*
  - Min/Max: *total burst length*
  - Min/Max: *number of pulses*
  - Min/Max: *Pulse Repetition Rate*

Principles

- Simple
- Get a draft out quickly
- Attempt to future proof
- Involve the user
- Collaborate and publish
- Allow various approaches

- For us:
  - CEW remains in control of police
  - “In/out-of-tolerance” decision is immediate

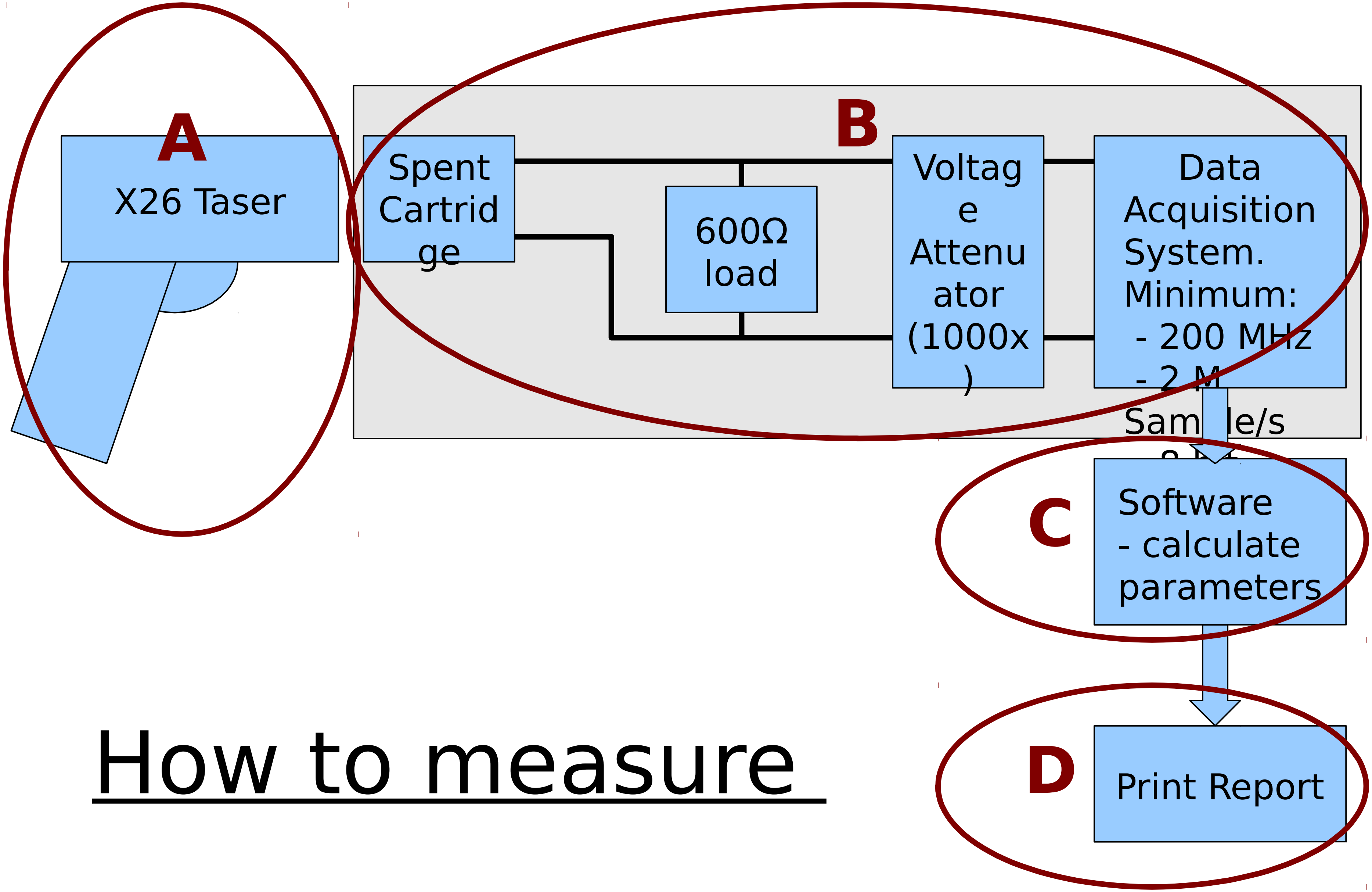
Aside: no warranty

- We were concerned to ensure that we protected ourselves from liability in cases where a CEW which passed this test was involved in an incident.
- It looks like we got taken to task for it:

Taser testing issue delays death investigation,

CINCINNATI (10/20/2011)- A Channel 9 investigation has found that more than 10 weeks after U.C. Upward Bound student Everette Howard Jr. died after he was tased by police, the Taser X26 used to subdue him has still not been tested for its electrical output.

http://www.wcpo.com/dpp/news/local_news/investigations/taser-testing-issue-delays-death-investigation

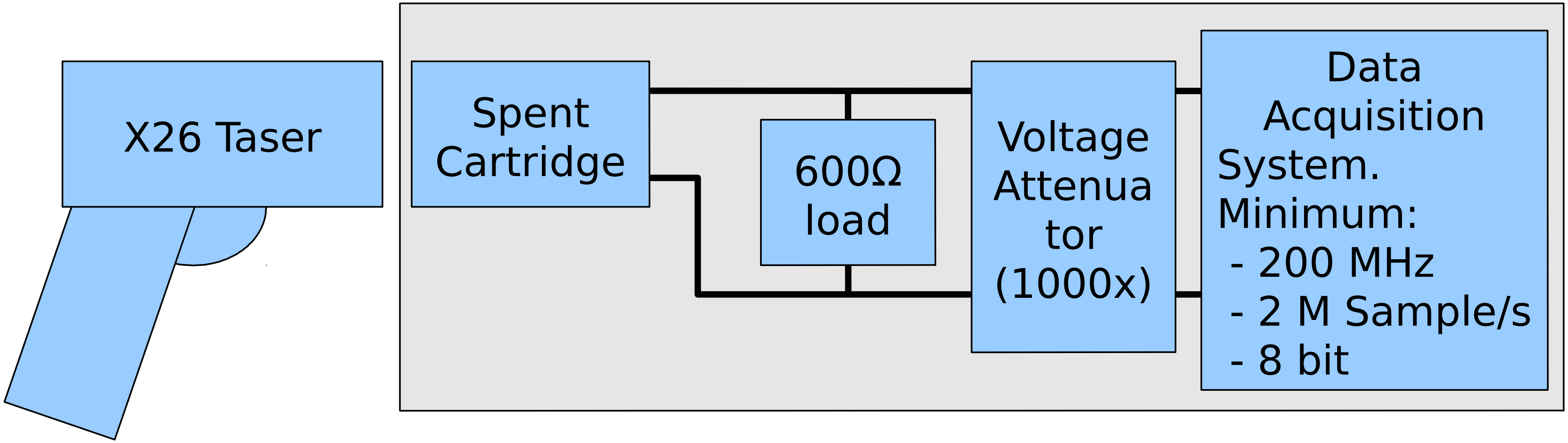


How to measure

A: Test Protocol

- Weapon Serial / model number recorded.
- Visual inspection of the weapon
- Download and recording of usage data from weapon
- Weapon is connected to test system
- Weapon is fired three times and electrical output recorded
- End of test: Weapon is disconnected

B: Test system



- Weapon connects to spent cartridge
- Wires to 600Ω non-inductive load
- Voltage data is recorded

Test system: Spent Cartridge

- Spent Cartridge will stabilize the weapon during firing
- Nominal 1mm air gap between electrodes on weapon and cartridge
- Wires should be of appropriate gauge and voltage rating. Use wiring best practices

Test system: Load

- A 600Ω load was chosen as representative of the electrical resistance of a subject.
- The load should be non-inductive below 1MHz
- The load should be rated for a minimum power dissipation of 10W
- Calibration of the exact resistance of the load is required. Repeated calibrations should be performed as required. Calibration via 4-wire measurement with calibrated ohmmeter

Why 600Ω?

- The value of 600Ω was chosen by Taser Int.
  - Other values (ie. 250Ω) have been used.
- Clearly, 600Ω should be used for the testing against the Taser specs
- We could specify a different load for other tests.
- However, the choice of 600Ω is reasonable
  - Good average body conductivity estimate
  - Taser charge is relatively independent of load
- We need to explain this choice well

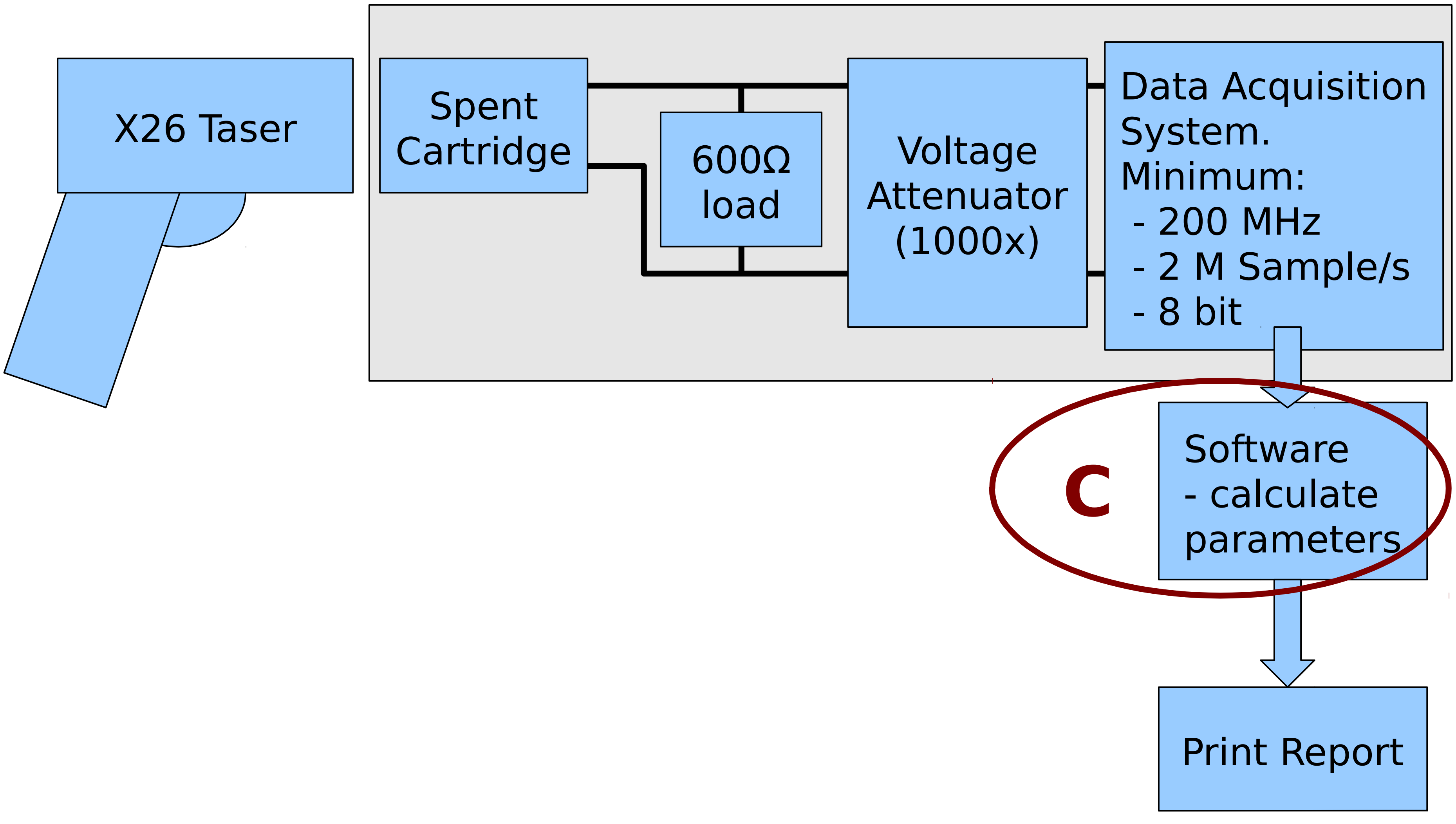
Test system: Data Acquisition

- Normally, a calibrated voltage attenuator or current probe.
  - *Comment:* Most systems have used a 1000x
- Data from all pulses must be recorded
  - *Comment:* It is acceptable to either: 1) record continuously throughout the pulse time, 2) record each pulse with a minimum pre-trigger of 4µs
  - *Comment:* It is not necessary to independently record current. Current may be derived from the voltage measurements

Test system: Data Acquisition (con't)

- The minimum specifications for the data acquisition system are:
  - Bandwidth: 200 MHz
  - Sample rate: 10 Msample/s
  - Minimum data resolution: 8 bit
  - Minimum voltage resolution: 25 V
  - Signal must not be clipped (voltage out of range). Recorded trace must be tested for clipped values (equal to maximum converter value)
- Data acquisition system choices are justified by a accuracy goal of 1%. Thus, each component has better accuracy than high voltage probes

C: Data Analysis

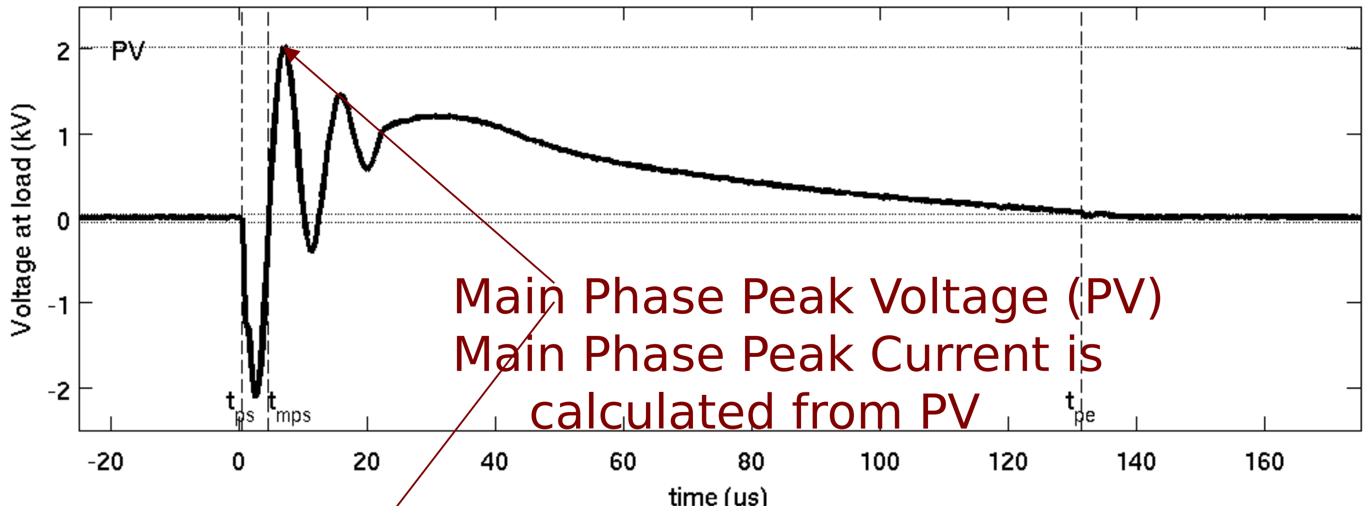


C: Data Analysis

- Parameters for each pulse calculated,
  - Main Phase Peak Voltage — Not in TI spec [1]
  - Main Phase Peak Current
  - Total Charge ✔
  - Monophasic Charge ✔
  - Main Phase Net Charge
  - Pulse Duration ✔
  - Pulse Repetition Rate
- Summary data calculated
  - Max, min, average, std and avg8 (avg of last 8) calculated
  - Pulse Repetition Freq (PRF)
  - Total Burst Length ✔

X26 Taser: Pulse parameters

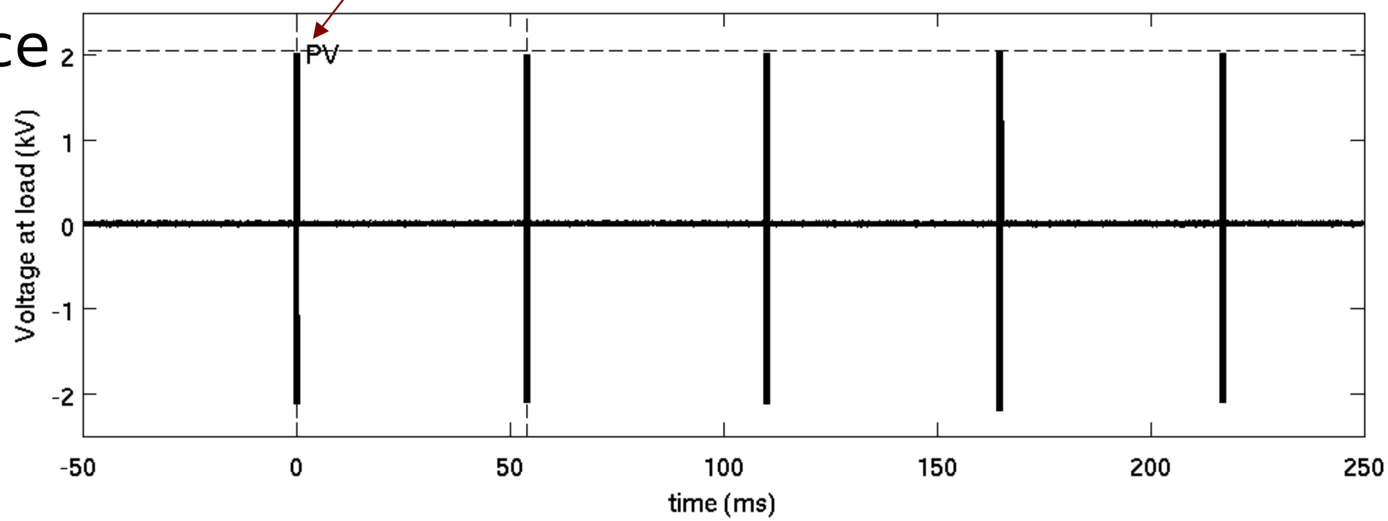
Single Pulse



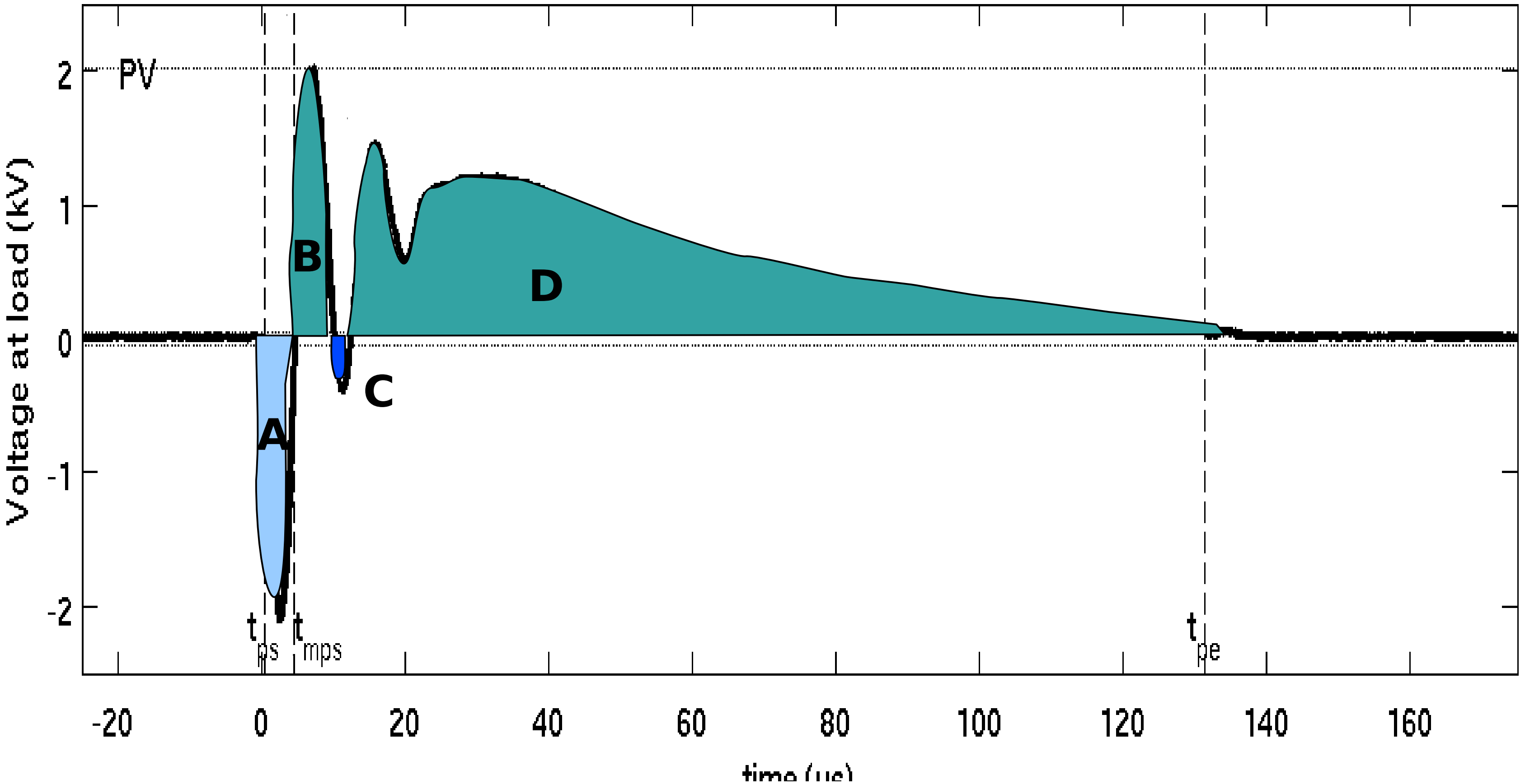
Main Phase Peak Voltage (PV)
Main Phase Peak Current is calculated from PV

Also, Pulse length, interpulse time

Pulse Sequence

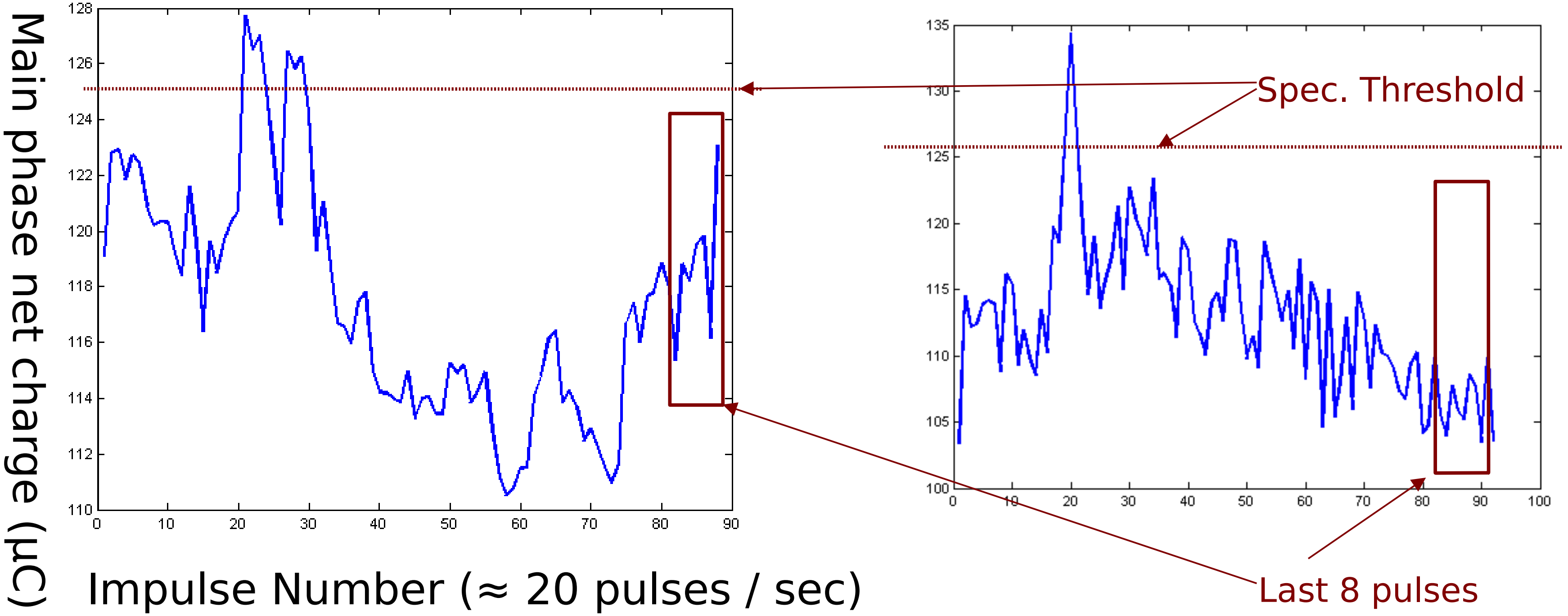


X26 Taser: Pulse parameters



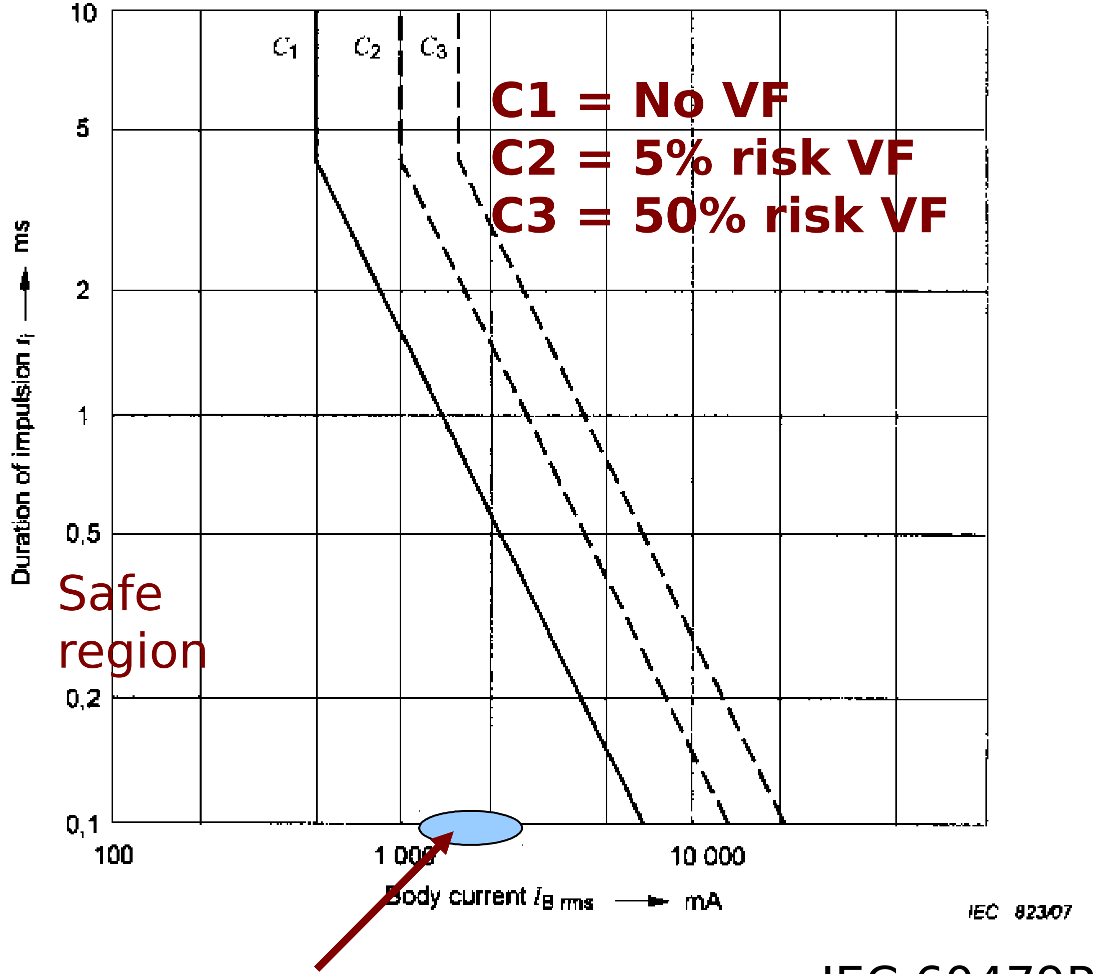
Total Charge = A + B + C + D
Monophasic Charge = max(B + D, A + C)
Main Phase Net Charge = B – C + D

Variability of pulses



- Both weapons are within TI spec [1]
- We propose a spec on the maximum pulse

IEC Safety standards



IEC 60479P2 figure 20

X26 Taser is approximately here
- analysis by P Savard (2008) and by DP Dawson *et al* (2010)

How to interpret IEC 60479

- Suggests Taser Int. limits more stringent than IEC.
- However,
  - IEC uses on total charge, not net charge
  - IEC uses on maximum pulse, not average
  - IEC suggests you should scale for body mass
    - Anecdotal evidence: taser less effective on large subjects
  - IEC threshold is much (up to10x) lower for some cases (Heart arrythmia events)
  - Ventricular fibrillation (VF) isn't the only concern
  - IEC is based on old (50's and 70's) data

Recommendation

- We base our calculation on the "C1 curve" which is defined as "no risk of fibrillation". For a 0.1 ms pulse, this is equivalent to a 710 µC.
- To account for differences in body size and placement of stimulation electrodes, we recommend an additional safety factor of four
- CEWs with Monophasic Charge for any individual pulse in excess of the value listed in the corresponding appendix should be declared Out of Tolerance = 180 µC

Comment: Total charge / Net Charge

- Nomenclature issues:
  - Many different “full” and “net” charges have been defined. MPB uses “total charge” and “main phase net charge”
  - DECISION: *Use terms in MPB “tests concepts documents”*
- Scientific issues:
  - Some literature uses total charge (sum of abs. value of pulses)
  - Some literature uses charge in largest phase
  - DECISION: *Store both.*
- General standard (not X26 specific)
  - Definition of Net Charge (B-C+D) is only for X26
  - DECISION: *Standard will need editing for other CEWs*

C: Data Analysis: *summary data*

Summary data example (for each firing):

Summary	MAX	MIN	AVG	AVG-8	STD
Total Charge (μC)	123	108	115	113	8.3
Main Phase Net Charge (μC)	119	105	111	109	11
Pulse Duration (us)	131	116	128	126	3.5
Interpulse Time (ms)	62.0	49.2	54.3	55.9	5.7
Peak Voltage (V)	2094	1861	1938	1923	80.3
Peak Current (A)	3.52	3.13	3.26	3.23	0.15

How many significant figures: based on hardware accuracy, but at least 3 figures given 0.5% accuracy minimum (ie. 8 bit) specs

Values in the Feb 4, 2009 Spec from Taser Int.

Carleton Software and Report

- Available under a free license (GPL)
- As DRDC report with detailed “business rules”

code for CEW_analyse.m

```
%%This code is designed to analyse CEW X26 weapons according to the test
%%procedure found online at:
%%http://curve.carleton.ca/papers/2010/CEW-Test-Procedure-2010-ver1.1.pdf
%%(c) A. ADLER and O. MARSH, 2009-2011
%%This code may be copied under the GPL licence version 2 or 3 found at:
%%http://www.gnu.org/licenses/gpl.html

%%Main function of CEW_analyse reads data from the file in f_name and places
%%it in data and ss, checks for the presence of energy in the file,
%%finds V at all sample points, plots all voltage values and repeats for the
%%files entered in to the function then calls print_outputs
function CEW_analyse(f_name, options);
```

Reporting

Conducted Energy Weapon Test Report	Date:
Weapon: (mftr and model)	Serial Number:
Police Service:	Police Officer:
Test Service:	Tester:

Visual Inspection	Case ☐ Battery ☐ Electrodes ☐

New Specs

Taser Int. Specs [1]

Firing No	1	2	3	1	2	3	1	2	3	1	2	3
Peak Voltage (V)												
Peak Current (A)												
Net Charge (μC)												
Pulse Duration (μs)												
Pulse Rep Rate (P/s)												
Monophasic Charge (μC)												
Total Charge (μC)												
Burst Length (s)												

#1 #2 #3

Data for Firings

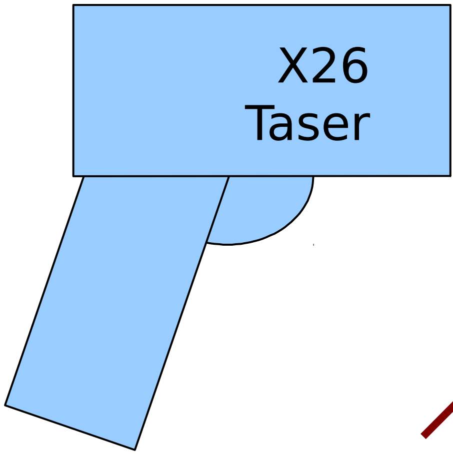
Characterization Data

- Performance data on all weapons tested should be kept in order to facilitate analysis to determine
- Weapon lifecycle
- Prediction of malfunction
- Determine any vulnerable serial number sequences
- Forensic examination (post incident)

How to manage uncertainty?

- *Future-proofing*
- Make sure we record all the parameters which are likely to be relevant to safety tests
- Specifically, max + min (not only not average)
- Parameters for
  - Safety
    - based on electrical safety specs and research
  - Operational
    - indications of poor device functioning device

Summary



Measurement System

Agreement on Hardware
Agreement on Software

Agreement on Contents

Print Report

Police Service:	Police Officer:
Test Service:	Tester: Engineer:

Visual Inspection:	Case □ Battery □ Electrodes □ etc...	
Comments:	*Example: changed battery, couldn't see display*	
Software Version:	Battery Charge:	Data download performed □

Pulse Parameters	Max	Min	Avg	Avg-8	Std
F.P. Total Charge (μC)					
M.P. Net Charge (μC)					
Pulse Duration (μs)					
Interpulse Time (ms)					
M.P. Peak Voltage (V)					
M.P. Peak Current (A)					
Pulse Rep. Freq. (Hz)					
Total Burst Length (s)					

Within Specifications: Yes □ / No □

1. Decision

In spec. / out of spec.
(USE / Don't USE)

2. Data storage

Enable analysis for:
- Weapon lifecycle
- Predict malfunction
- Problem serial number
- Post-incident

Agreement:
- Use TI [1] + new safety and operational specs
- Add new specs based on research output

Agreement on data format
Data repository to be defined

Comments on Certification

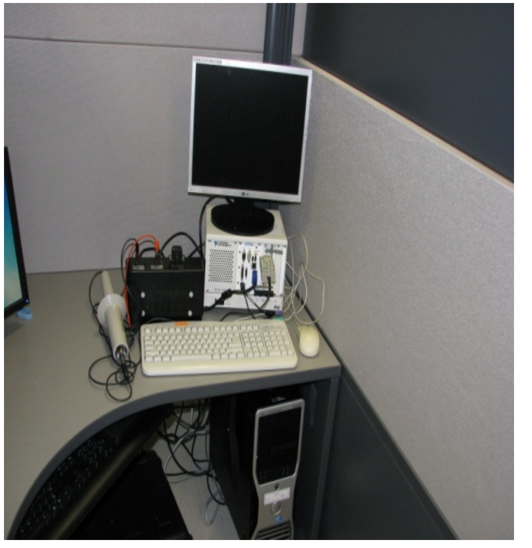
- What we want:
  - Given this protocol, several companies can offer Taser test services to police organizations
- Advantage:
  - Competition will help improve prices and service
- Challenge:
  - To ensure conformance to test protocol
- Possibilities:
  - Standards association certification
  - Individual certification by professional engineers

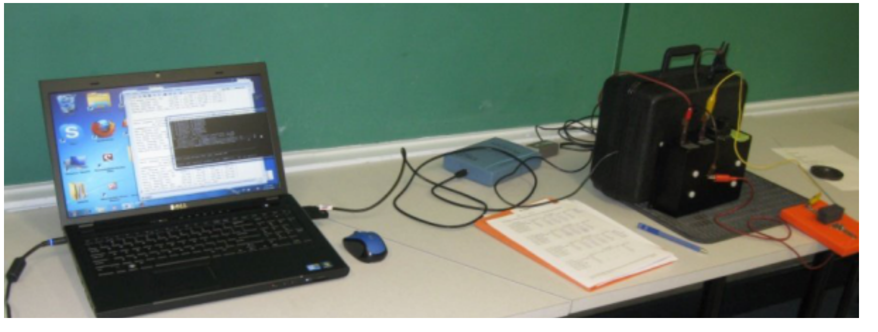
Our tests

- 2 test systems
- Over 4 years, we’ve tested
  - 300+ Taser X26’s
  - 1200+ Firings
  - Weapons from 4 Canadian provinces
  - Several other CEWs
  - Taser XRep

Test systems

- Initial System based on National Instruments PXI platform
- Current system based on Picoscope 4224 and Laptop





Lab systems shown in “research mode”

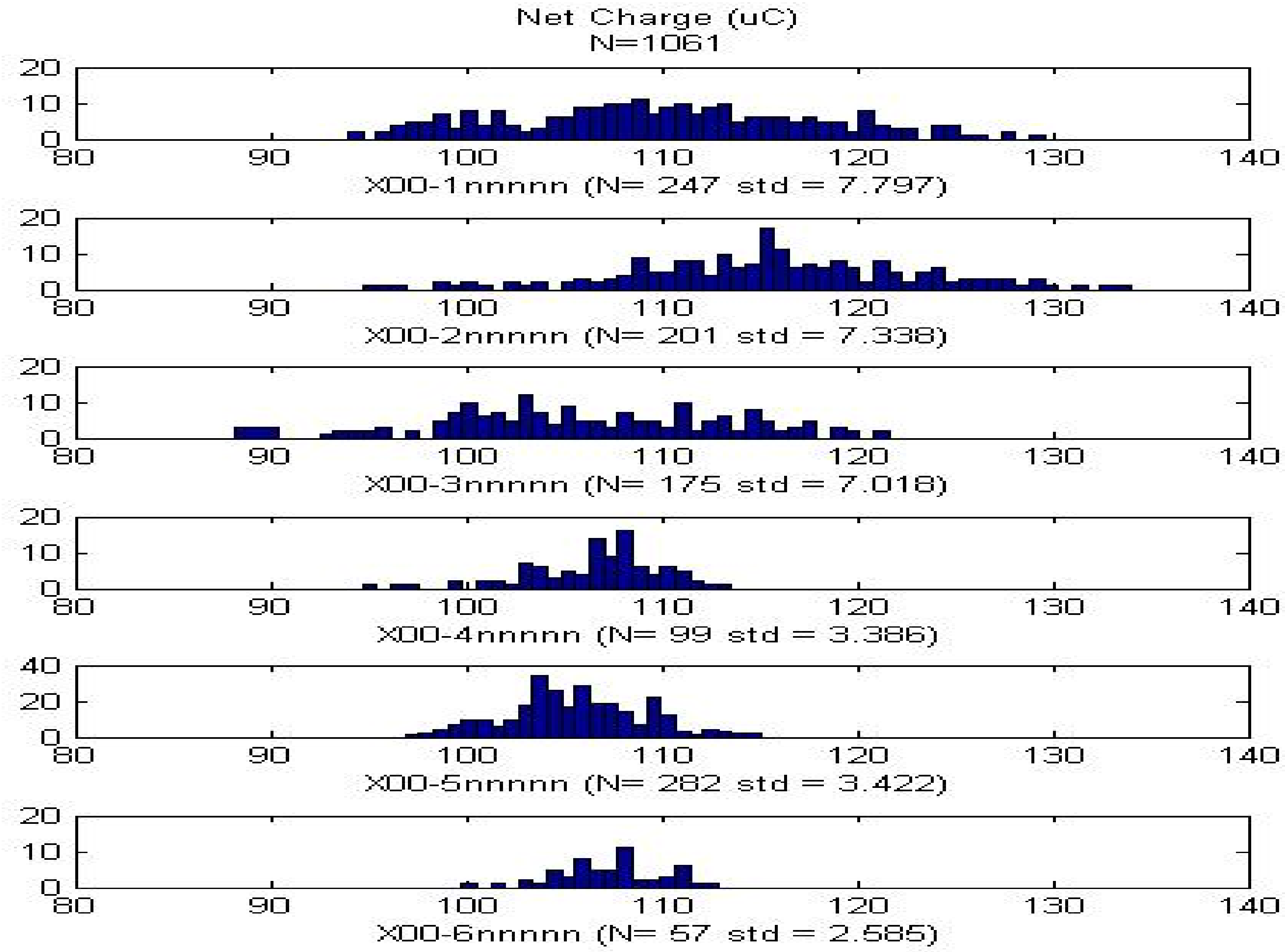
Test Systems: Comments

- Many subtleties to get it right
- Big problem is the ESD from the weapon being picked up in the test system
- Need for a validation / calibration system

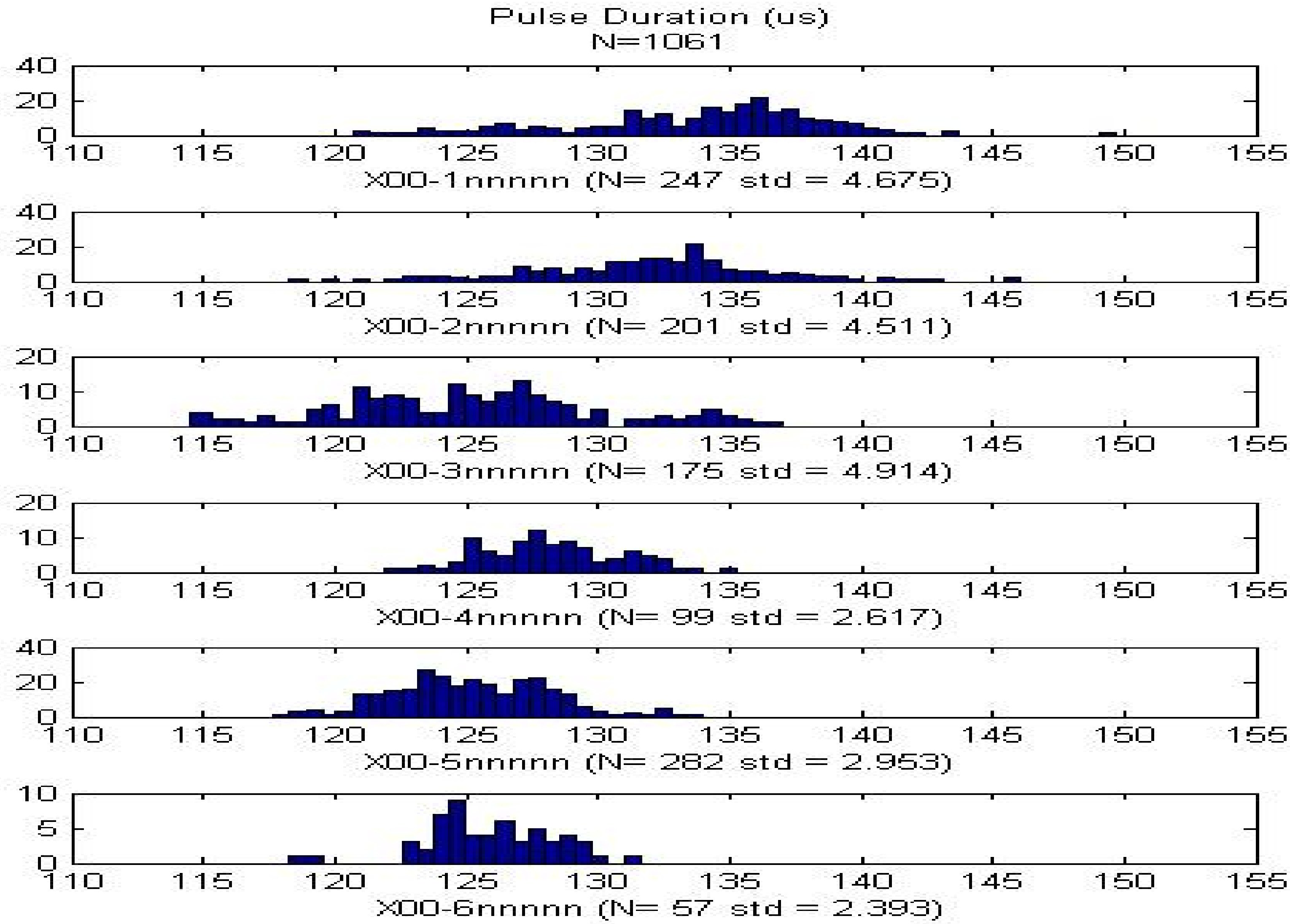
Questions: Variability of weapons

- How do weapons vary from each other?
- How does a single weapon vary over time?
  - What is the shelf life
- How does a single weapon vary over a 5 sec burst?

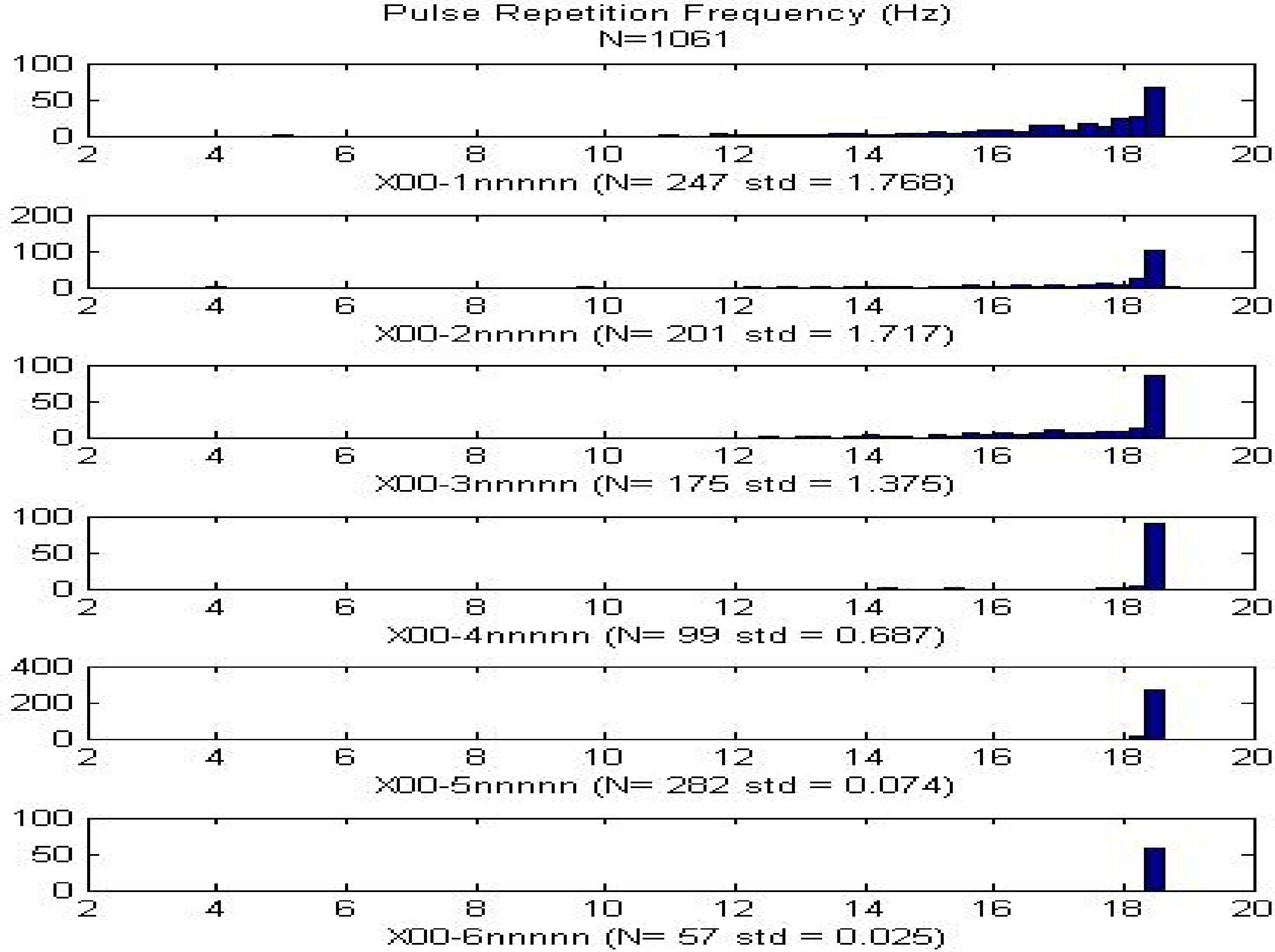
X26 Variation



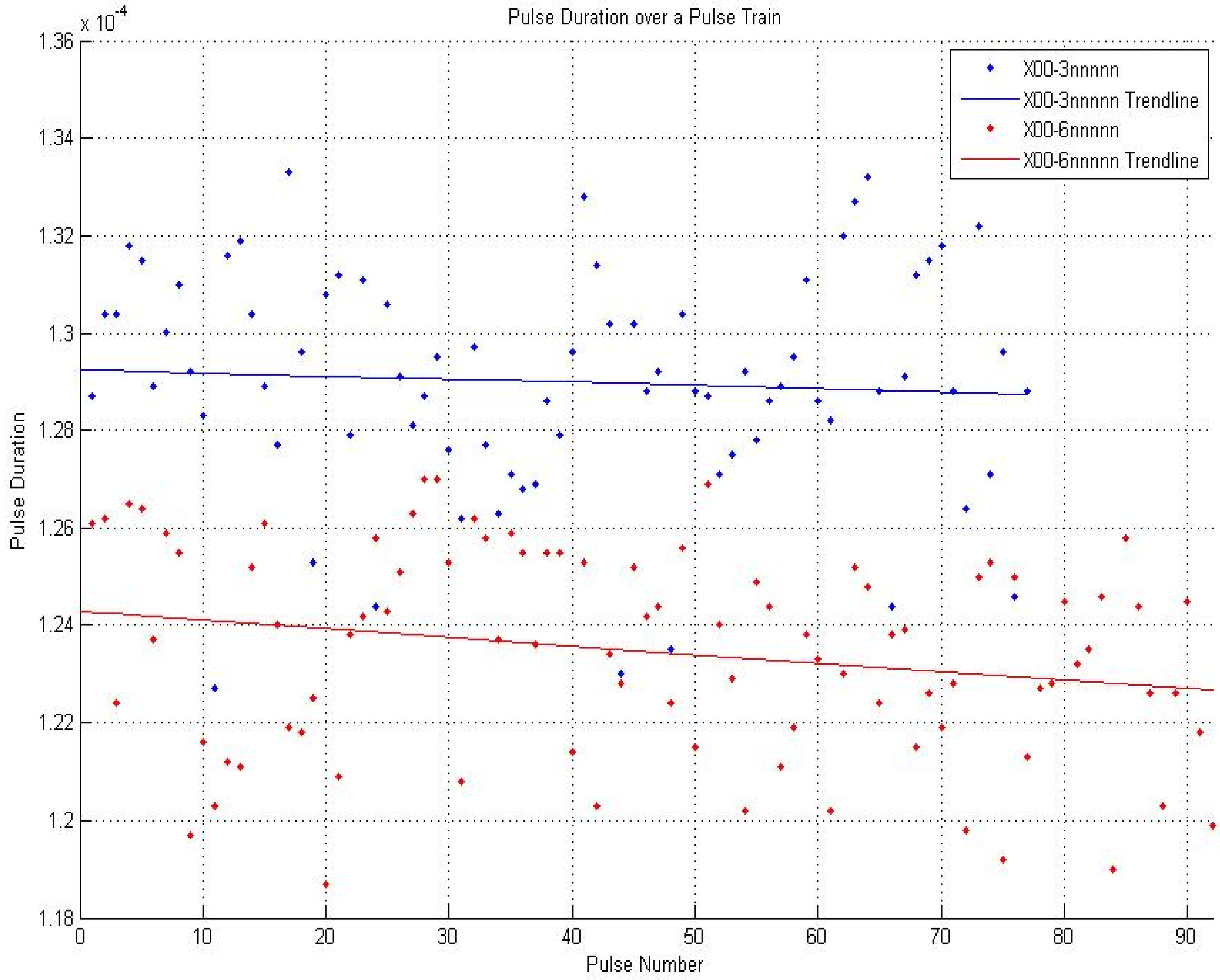
X26 Variation



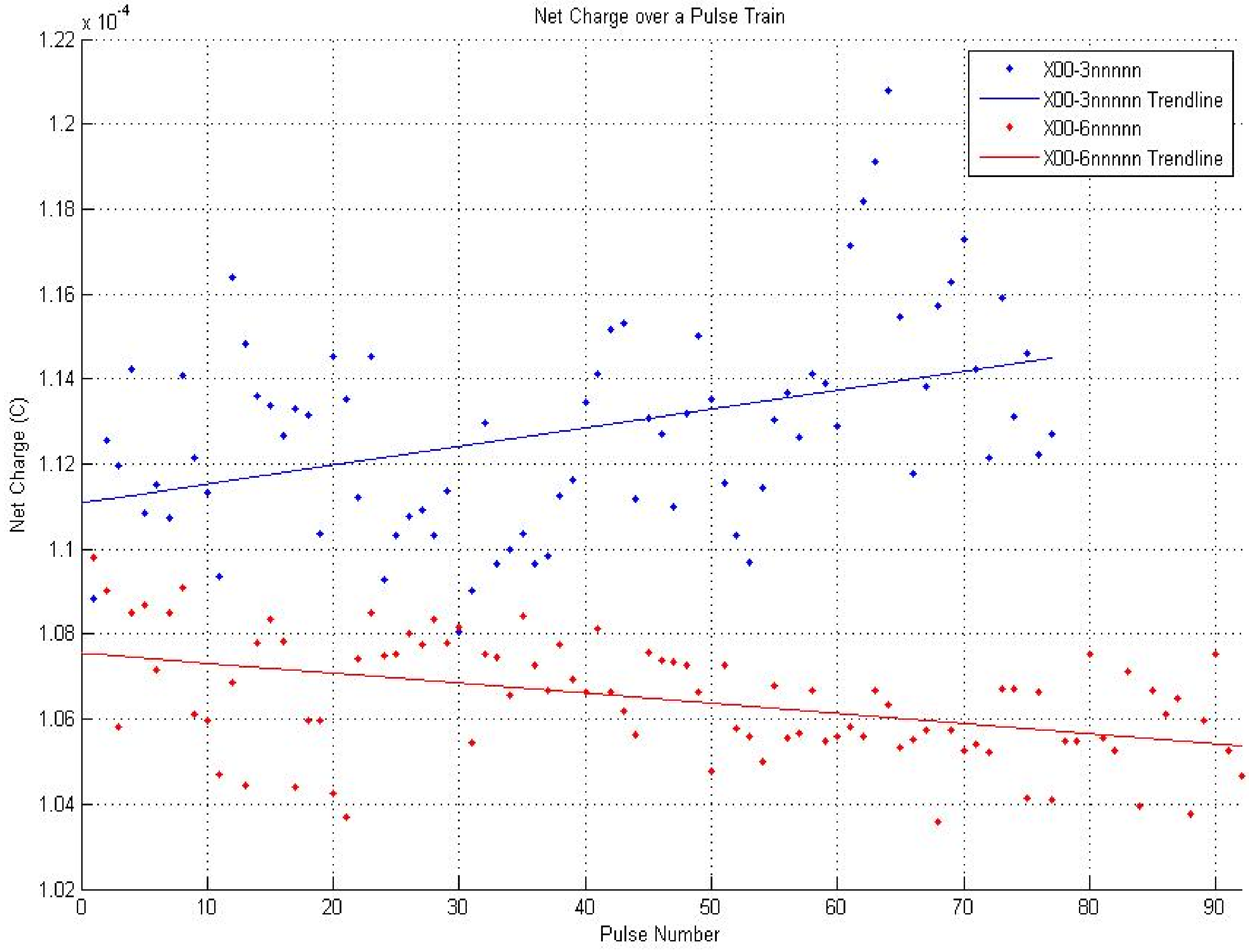
X26 Variation



Pulse duration over the pulse train

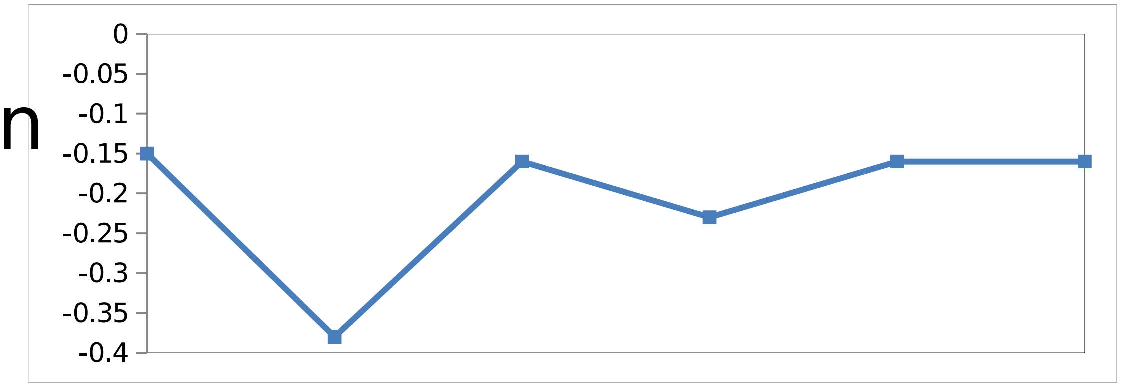


Net charge over the pulse train

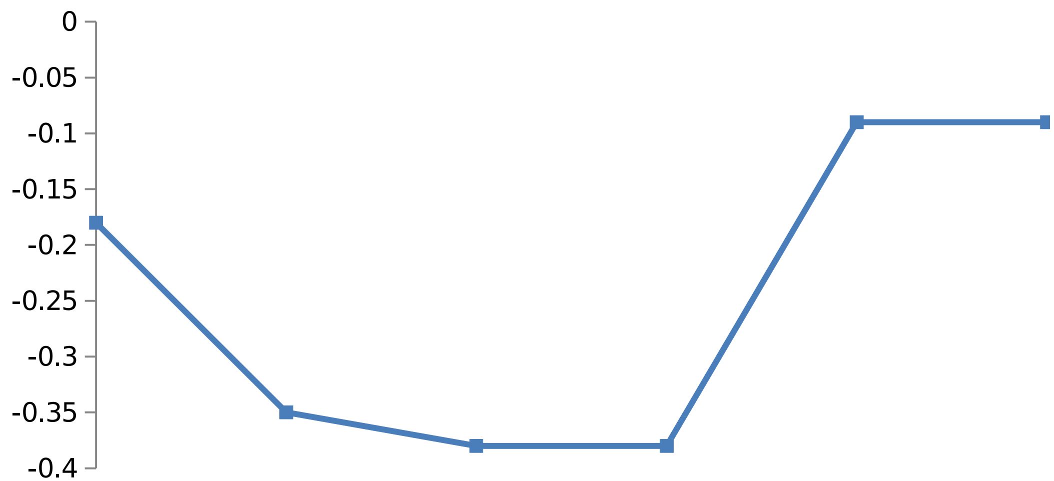


Do the last 8 pulses accurately represent the whole pulse train?

Pulse Duration
(% change: average of last-8 – overall average)



Net Charge
(% change: average of last-8 – overall average)

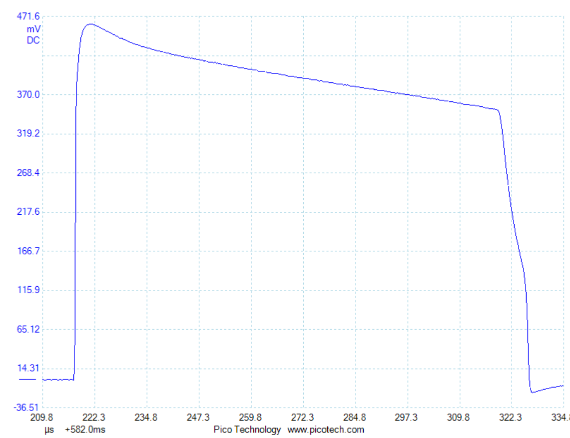


Series X00-?nnnn 1 2 3 4 5 6

Opinions: NIST standard

Opinions: Testing of other ESW

- Yes! We need test methodologies and guidelines
- One issue is “street shockers”. In Canada these are restricted weapons



Opinions: Routine testing of ESWs

- Yes! We need routine testing
- Testing can't be done by manufacturer
  - At least in Canada, this will be seen as the "fox guarding the hen house"
- Manufacturer has an interest to support independent test companies
  - Provide public specs

Why is regular testing so important?

- Many audiences = different concerns
  - Police services
  - General public
  - Media
  - Design & manufacturing
  - Scientific & research
- Lifecycle management
  - Performance
  - Budgeting

What needs to be improved?

- Regular benchmark and performance testing
  - Uniform procedures and protocols
  - “Just perfect” is the enemy of “good enough”
  - User-friendly

- Independent regimes such as UL, CSA, ASTM International, ITL Inc.
  - TI sets performance standards
  - User / testing organization verifies & validates
- Storage of test results

Regulations or ... ?

- Regulations if necessary but not necessarily regulations
  – Regulations reflect and follow reality
  – Regulations are brittle and differ from o jurisdiction to another

- Technical standards
  – Must be guided by good engineering practice
  – Must be agile enough to follow developments in technology.

What needs to be improved?...

- Priori publication of
  - performance standards
  - Manufacturer’s testing procedure
  - Some explanation of design changes
    - Example (180 µC –> 100 µC -> 63 µC)
- Our goals
  - Establish a uniform test procedure
  - Establish a testing database across jurisdictions
  - Get ahead of the curve on testing X-2

Opinions: Lessons for the next non-lethal weapon

- Fact: new weapons/technology is coming
- Fact: policing can’t be risk-free

- Recommendations:
  - Conscious risk choices
    - No claims of “non-lethal”
  - Engage with academics
  - Develop usage policy along with technology

Opinions: Physiological tests needed

- Overall, risks are low to healthy subjects from short duration pulses of the standard stimulation strength of in-use devices.
  - Either stronger or significantly longer electrical stimulation, or simulation close to the heart was required to induce clinically significant effects to cardiac or respiratory function or blood chemistry.
- Case reports:
  - injury profile of CEWs is similar or favourable vs. physical restraint or pepper spray.
- Specific risks
  - *Ventricular fibrillation (VF)*: CEWs stimulate the heart, but did not cause VF unless multiple or stronger stimulations, placement very close to the heart or chemical stimulants were given. One case report shows VF in a healthy subject.
  - *Systemic physiological interactions:* For longer or multiple stimulations, CEWs were shown to have physiological effects on cardiac, respiratory and blood chemical function, which lead to death in some animals. Such effects could interact with events during an arrest (stress, intoxicants, restraint, blood loss).
  - *Specific subject groups:* Groups such as the elderly, children, pregnant women, and cardiac device users may have higher risks. *CEW injuries*: Case reports indicate risks to due the electrode barbs to vulnerable organs (such as the head) and due to falls consequent to incapacitation.

Opinions: Physiological tests needed

- Limitations in the literation
  - Healthy subjects. research has focused on healthy (and largely unstressed) pigs and human volunteers, while deaths proximal to CEW use are most likely in unhealthy, intoxicated, and highly stressed subjects, including those with excited delerium.
  - Several hundred healthy subjects have been reported in experiments; however, CEW-associated deaths have occurred in less than one in a thousand weapon usages, and computer models estimate similarly low risk levels. To reliably investigate such rare events, much larger studies are required.

Thanks

Traffic Jam outside Carleton University

Weapon variability is reduced

Parameter	X00-1nnnnn		X00-2nnnnn		X00-3nnnnn		X00-4nnnnn		X00-5nnnnn		X00-6nnnnn	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Peak Voltage	1938	174	1951	143	1796	224	1668	116	1854	178	2080	93
Peak Current	3.26	0.29	3.28	0.24	3.02	0.38	2.80	0.19	3.12	0.30	3.50	0.16
Pulse Repetition Frequency	17.07	1.77	17.57	1.74	17.53	1.37	18.39	0.69	18.45	0.07	18.54	0.02
Pulse Duration	133.8	4.7	132.1	4.5	125.3	4.9	128.2	2.6	125.2	3.0	125.9	2.4
Net Charge	110.0	7.8	115.6	7.4	106.5	7.0	106.6	3.4	105.5	3.4	107.3	2.6

What needs to be improved?...

X-26 Performance Specifications and Ranges

	Lower Limit	mid-range	Upper Limit
V (volts)	1450	1985	2250
I (amps)	2.3	3.25	4.2
Q (uC)	80	102.5	125
PRF (pps)	16.5	18.3	20
Pulse Duration (us)	105	130	155

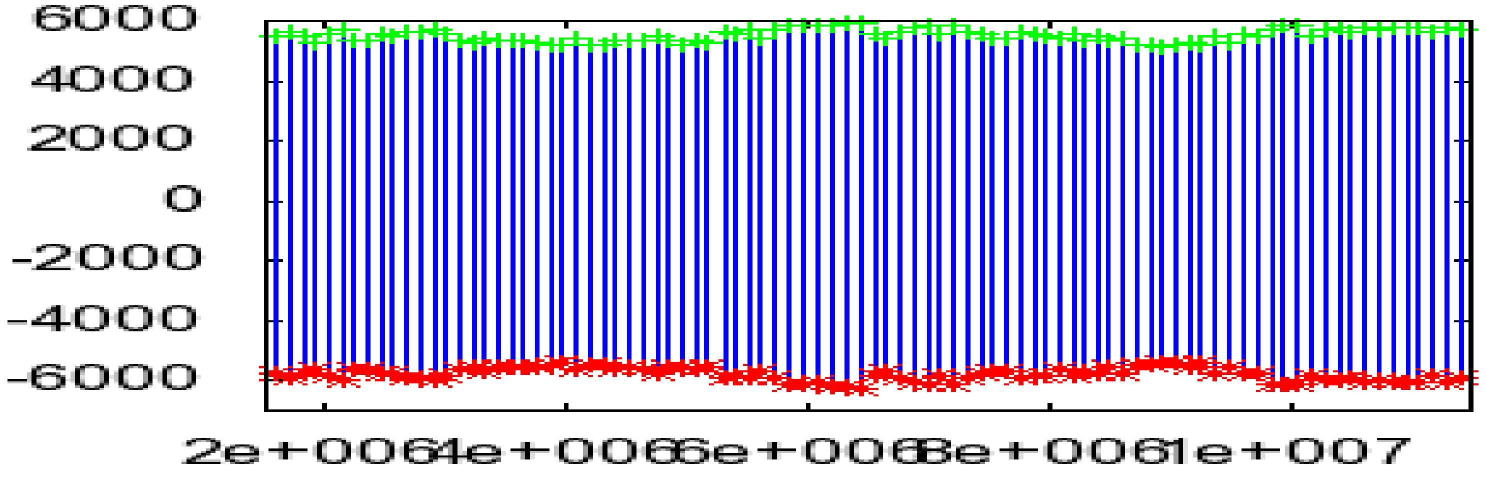
Ver. 1.1 Issues and Challenges...

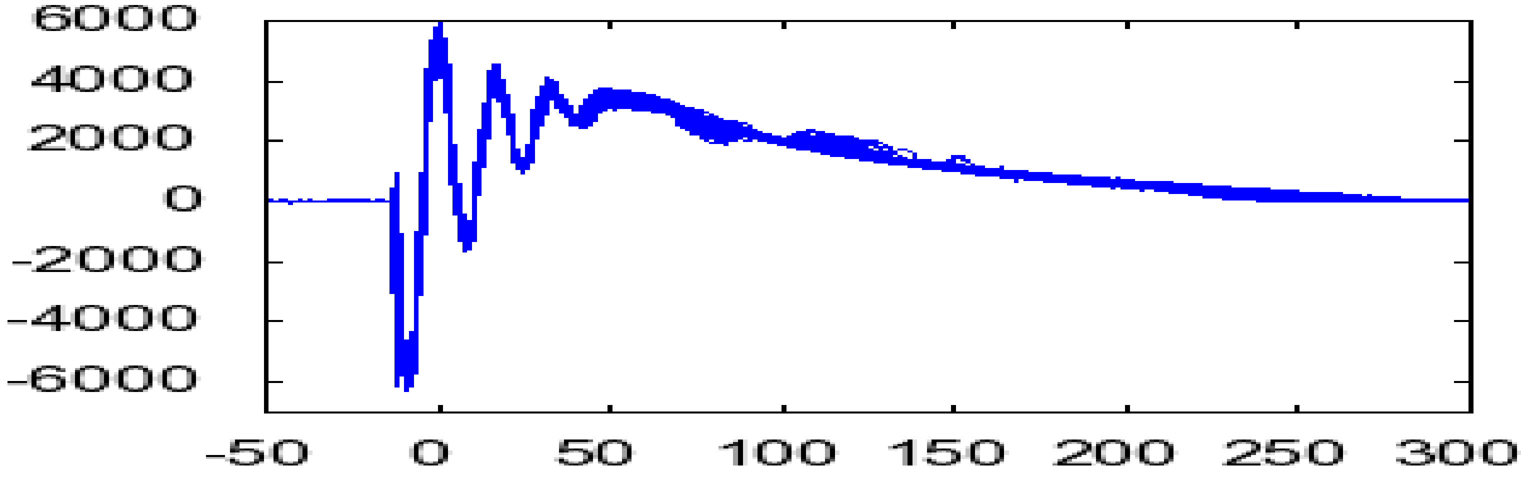
- Concern over inclusion of a safety limit
  - Must start somewhere
  - Based on best information available
  - Concern was rational
- Cost was 3 months of member’s time
- No direct financial cost to government or users

How we first presented testing results.

- 92 pulses in 4.94 s. Pulse Rep Freq = 18.40 p/s
- SUMMARY======== MAX | MIN | AVG | AVG-8 |
- Net Charge (uC) 104.18 | 97.07 | 100.09| 99.11 |
- Full Charge (uC) 105.35 | 98.13 | 101.19| 100.23 |
- Pulse Duration (us) 132.00 | 119.00 | 125.02| 122.69 |
- Interpulse Time (ms) 57.305 | 50.276 | 54.333| 54.302 |
- Pls Peak Voltage (V) 1421.6 | 1384.0 | 1404.3| 1406.9 |
- Pls Peak Current (A) 2.389 | 2.326 | 2.360 | 2.364 |

Pictures are often preferred...





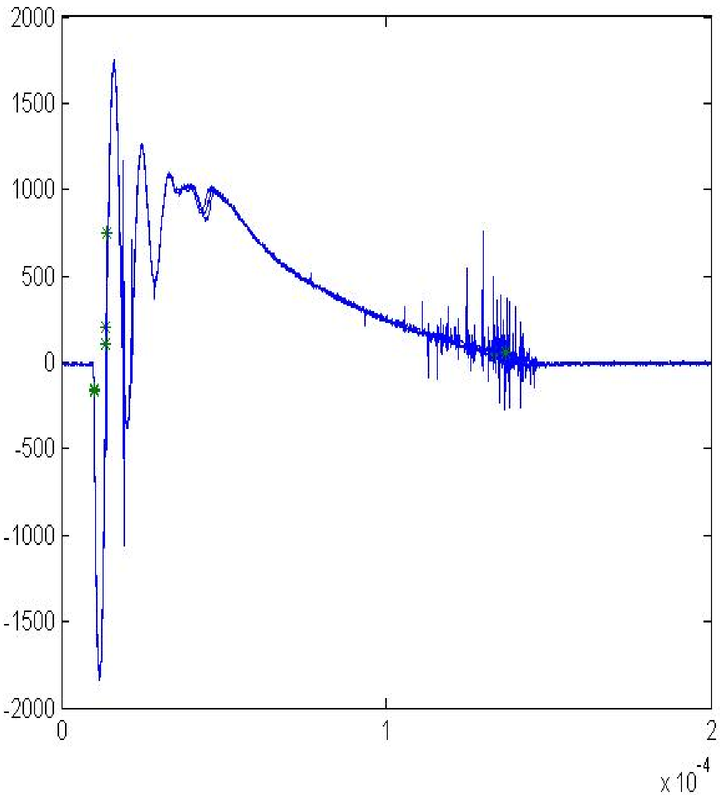
Publications

- http://www.sce.carleton.ca/faculty/adler/
- http://curve.carleton.ca/papers/2010/CEW-Test-Procedure-2010-ver1.1.pdf
- http://www.sce.carleton.ca/faculty/adler/publications/2011/rahma
- http://www.sce.carleton.ca/faculty/adler/publications/2011/dawso
- http://pubs.drdc-rddc.gc.ca/inbasket/mmgreene.111024_1044.DF

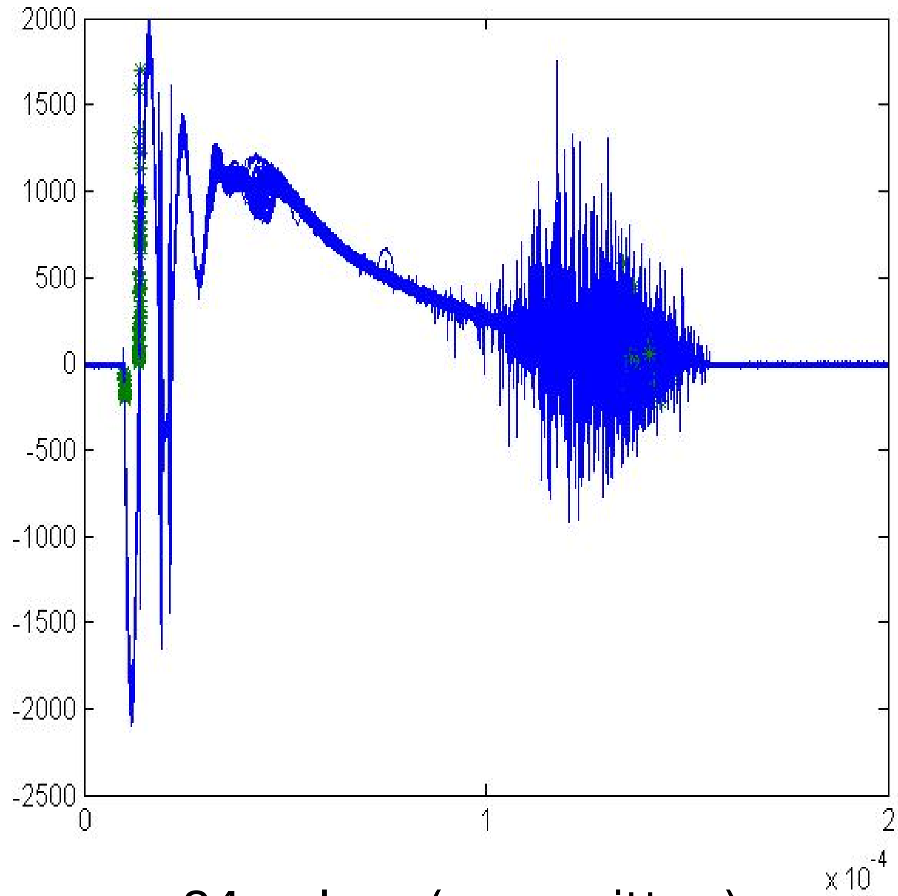
References

- Taser-x26.jpg - http://en.wikipedia.org/wiki/File:Taser-x26.jpg
- Stun Gun - http://www.juststunguns.com/image_manager/attributes/image/i
- Calendar - http://www.worldnewsinn.com/wp-content/uploads/2011/06/caler
- Map of Canada - http://wwp.greenwichmeantime.com/time-zone/north-america/ca
- Justice Braidwood - http://2.bp.blogspot.com/_o8vd6YjZSiM/SrmAhdFdvNI/AAAAAAA
- Octopus http://t2.gstatic.com/images?q=tbn:ANd9GcTXF2k2-SUdYHiCdS

What happens over 5 seconds?...



One pulse



84 pulses (overwritten)