Taser 10 Technical Testing Results

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PA Consulting was asked by the Home Office to produce an independent technical report on the Axon Taser 10 (T10) conducted energy device (CED). This report provides a technical analysis of the testing, which was conducted by specialists Ribbands Explosives at their licensed site in Norfolk, based on Home Office guidance. These results are one of several reports that will inform the Home Office's assessment of the suitability of the T10, including its relative performance to previous models of Tasers.

Contents

Executive summary

PA Consulting was asked by the Home Office to produce an independent technical report on the Axon Taser 10 (T10) conducted energy device (CED). This report presents the results of testing on the Axon Taser 10 (T10) conducted energy device (CED) for the Home Office. The results are one of several inputs to the Home Office's assessment of the suitability of the T10 including its relative performance to previous models of Tasers (particularly the X2). The scope of this testing spanned the kinetic behaviour of the T10 probes (accuracy, maximum range, inter-magazine and intra-magazine variation, key ballistic parameters), how it penetrates different targets (skin simulants, clothing and skull models), its robustness to drop damage, the amount of sound and laser power it produces, and the electrical output through the probes.

Direct comparisons between the T10 and X2 were carried out for skin penetration, skull penetration/fracture and sound level testing.

The T10 produced significantly more repeatable penetration of a skin simulant target than the X2 which had a high proportion of probes bounce out of the target (93% of T10 probes were retained in the target, compared to 57% for X2 probes) with a slightly deeper penetration depth.

In skull penetration testing, both devices scored identically on a Dstl fracture scale classification system and produced comparable quantitative data, although the dart of one T10 probe fully perforated the bone and was not possible to remove by hand, while another T10 dart fractured with a dart fragment breaking off into the bone. The T10 probes therefore may pose a slightly higher risk of skull penetration than the X2, although no instances of skull penetration by the probe body or impact absorber were observed.

Sound levels measured for the T10 and X2 when firing were measured; the sound of a cartridge being fired was on average 2dBA (~60%) higher for the T10. All sound levels were measured in laboratory-style conditions, and end-users should test sound levels in their respective typical environments.

T10-only testing provided insights into performance and produced data for comparison with existing X2 data

The point of impact (POI) and point of aim (POA – set by the laser sight, which is not adjustable) at different ranges was measured for duty and training cartridges. This data can be analysed in future work against existing X2 data to compare accuracy. In the current testing, there was no evidence for significant variation between different magazines, different bays, or between clamped and hand-fired devices. Both duty and training cartridges showed a tendency to impact the target below the POA. Noticeably, the 'zeroing' range (the range at which the POA should match the POI) is understood to be 10.1m, but at this range the mean POI relative to the POA varied for four different T10 handles between 59.8mm and 91.7mm for duty probes (85.3mm for training probes based on one handle).

Comparison of duty and training cartridge ballistics showed no significant differences, indicating the training cartridges behave suitably similarly to duty cartridges for training purposes.

Measurements of the mass, velocity, momentum and kinetic energy of the T10 probes were made at different ranges to facilitate future analysis. A small decrease in average velocity was observed for hand-fired devices compared to clamped devices.

Testing assessed a realistic absolute maximum range (the limit beyond which the probe repeatedly detached from the wire) to be 15m, with all shots at 15.35m range detaching from the device. The probes therefore remained attached to the wires consistently beyond the Axon recommended 13.7m maximum range. Note that it is up to other groups to determine the maximum range for UK operational situations.

The T10 showed highly effective clothing penetration for denim, cotton t-shirts and hoodies – 99.4% of probes successfully penetrated the clothing, including 100% success at 15m range. More challenging clothing (a multi-layer combination including a thick padded jacket) produced a success rate of 88% (across different ranges) – there are therefore reasonable combinations of clothing that may prevent individual probe firings from penetrating.

Robustness was assessed by drop testing and concluded that severe drops onto an unforgiving surface can cause parts to separate, the laser sight to change alignment, and the magazine and/or battery to eject up to 1-2m away. When dropped while in the 'armed' state, no deployments of probes were observed, although when dropped while in the 'safe' state, the device was sometimes observed to become armed (with no deployment of probes observed). In general, however, all these effects rely on specific drop orientations and, even after the most significant drop impacts, the device still functioned as designed (after reinsertion of the battery and/or magazine) and retained accuracy comparable to the shot-to-shot variation recorded in accuracy testing. It is recommended that any T10 which has suffered a severe drop, particularly if onto a hard surface, should be withdrawn from operational service as a precaution.

Electrical output levels were broadly within manufacturer specifications, although not all behaviour is fully understood. Key performance characteristics were identified: only a single probe pair was seen to be energised on each pulse delivered during a discharge cycle; the pulse frequency is limited to 45±1Hz; and the average pulse charge is around 75μC (for 602Ω loads), rising to around 85μC for larger loads (~1500-3000Ω), with 88.5% of all measured pulse charges being between the manufacturer specified limits of 52-95μC. Mechanisms for outlier charge generation (including consistently lower charge observed in some discharges into high resistive loads) have been identified, with root causes likely primarily the result of the testing methodology, although the precise causes have not been fully identified.

Laser power levels were within the manufacturer specifications.

Handling issues were documented during testing; all appear to have limited impact.

A range of issues were observed during testing of the T10s, but none appear to pose major risks provided that devices are maintained regularly and usage is tracked, although it is up to other groups to determine suitable maintenance and usage of the devices. Cartridge deployment failures occurred at a rate of 0.6%, and one complete handle failure was observed after over 530 shots, which highlights that devices have a limited but relatively long lifetime. The trigger feel was also observed to change after ~380 shots, but not in a way that prevents operation of the device.

Note, however, that even if operational use is unlikely to be significantly impacted by these issues in isolation, there is a risk that users noticing these issues (either during operational deployment or training) could contribute to negative impressions about the build quality, and hence performance, of the devices.

This testing produced no immediate major concerns as a part of the T10 assessment process, noting limitations with the testing that are important to consider.

Overall, the T10 broadly performed similarly to the X2 where direct comparisons were available, and no immediate major concerns were identified during testing. This testing was conducted based on Home Office guidance, and provides a useful assessment of aspects of the T10, although was not intended to be comprehensive in all areas and has limitations that are highlighted throughout the report when interpreting the results. In particular: skin penetration testing highlighted that the skin simulant may not be entirely suitable for CED testing; electrical output testing used resistors to simulate real targets; and a total of 9 T10 handles and ~1080 shots (~1040 T10 and 40 X2) were used in this testing – using a significantly higher number of shots and/or handles would provide more statistical confidence and may highlight subtler trends. The slightly higher risk of skull penetration compared to the X2 observed here should also be considered in the further assessment of the T10.

1 Introduction

The purpose of this report is to present the results of testing on the Taser 10 (T10) conducted energy device (CED), which were performed in accordance with Technical Test Plans[1] [2] [3] [4] developed based on Home Office guidance. The results are intended to be a key input into the Home Office's assessment of the suitability of the T10, including its performance relative to previous models of Tasers (particularly the X2).

During the process of conducting this testing, approaches to improve future testing have been identified. These are noted in this report where relevant and are captured more comprehensively in the accompanying T10 Testing Improvements report.[5]

The testing was conducted by Ribbands Explosives at their licensed firearms and explosives site in Norfolk.

1.1 Document structure

A range of different tests were conducted as part of the T10 testing, and these are reported in turn in the main body of the report with a brief methodology, presentation of key data, and analysis of the conclusions. This is supported by more details of the methodology and equipment in appendices that correspond to each chapter in the main body of the report, and the raw testing data is provided in Appendix A.

This report is structured as follows (with chapters containing direct comparisons between T10 and X2 devices denoted by *):

- **Chapter 1: Introduction**
  A summary of the purpose of the report.
- **Chapter 2: Kinetics: Accuracy**
  Assessment of the accuracy and consistency of the T10, including variation between different bays and different magazines, and whether it is able to achieve reliable probe placement at different ranges (for both duty and HALT cartridges).
- **Chapter 3: Kinetics: Accuracy – Clamped vs hand-fired**
  Further assessment of the accuracy of the T10 to determine whether a perceived discrepancy with the mean point of impact at the 'zeroing' range (10.1m) was due to handle zeroing inconsistency or to weapon recoil when hand-fired.
- **Chapter 4: Kinetics: Training probe behaviour**
  Assessment of how similar the ballistic behaviour of the training (HALT) probes is to the duty probes.
- **Chapter 5: Kinetics: Absolute maximum range**
  Assessment of the absolute maximum range at which the T10 probe wires reach their maximum length and to determine whether the probes detach.
- **Chapter 6: Kinetics: Mass, velocity, momentum & kinetic energy**
  Measurement of the kinetic properties of the duty probes at different ranges and, in the event that the probes break free from the wire following a miss, to allow a comparison with previous CED models.
- **Chapter 7: Skin penetration***
  Assessment of the risk of skin penetration of T10 cartridges using a skin simulant target.

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[1] Document *MIQ-24-0007-D - Technical Test Plan*
[2] Document *MIQ-25-0018-D - Technical Test Plan - Additional Testing*
[3] Document *Simultaneous Probe Energisation Test Plan v3* (subsequently superseded by 4)
[4] Document *MIQ-25-0021-D_F - Technical Test Plan - Further Synchronisation Testing*
[5] Report *MIQ-24-0016-D - Taser 10 Testing Improvements*

- **Chapter 8: Clothing penetration**
  Assessment of the effectiveness of the T10 against different clothing combinations, including the ability of the probe to penetrate clothing and be retained in the skin.
- **Chapter 9: Skull fracture/penetration***
  Assessment of the risk of skull fracture and penetration by T10 cartridges using a skull fracture model target.
- **Chapter 10: Robustness**
  Assessment of the robustness of the T10 through drop testing.
- **Chapter 11: Sound levels***
  Measurement of the noise from the T10 device and the possible impact on users, based on a comparison between the T10 and the X2 in the same environment.
- **Chapter 12: Laser power**
  Measurement of the output power of the laser sighting system.
- **Chapter 13: Electrical output: Initial high-level measurements**
  High-level measurements of the typical electrical output of T10 devices and comparison with the stated specification, primarily based on Axon's specified test procedure. Supplemented by further electrical output testing in Chapter 14.
- **Chapter 14: Electrical output: Simultaneous probe measurements**
  Detailed measurements of the electrical output of the T10 device, including simultaneous measurement of all deployed probes.
- **Chapter 15: Issues**
  Summary of other issues, failure modes and observations identified during testing.
- **Appendices**
  Additional detail on the testing including:
  - **Raw testing data** (Appendix A).
  - **Extended methodologies, equipment lists and results**, sorted by the type of testing (Appendix B to Appendix L).
  - **Detailed list of issues observed during testing** (Appendix M).
  - **Mapping of the contents of this report against the original technical test plan** (Appendix N).

Note that testing was performed over three periods of time. The majority of testing occurred from September to December 2024 following an original test plan[6], then two sets of additional testing was performed based on the findings of the initial testing. The first set of additional testing took place across February and March 2025 following a new test plan[7] and comprising: the clamped vs hand-fired accuracy testing (see Chapter 3); and clothing penetration of 'challenge' clothing (in addition to the 'basic' clothing penetration testing performed in the initial round of testing). The second set of additional testing focused on understanding simultaneous probe energisation, and took place across March and May 2025, again following new test plans.[8]

1.2 Definitions

For reference throughout this report, the key constituent parts of a Taser CED are defined as:

[6] Document *MIQ-24-0007-D - Technical Test Plan*
[7] Document *MIQ-25-0018-D - Technical Test Plan - Additional Testing*
[8] Documents *Simultaneous Probe Energisation Test Plan v3* and *MIQ-25-0021-D_F - Technical Test Plan - Further Synchronisation Testing*

- **Handle / Body / Weapon** – the bulk of the Taser system into which the magazine and battery pack are inserted.
- **Battery pack** – inserted into the handle and charged in the battery dock.
- **Magazine** – inserted into the handle of the T10, containing cartridge bays (the X2 does not have a magazine; individual twin-probe cartridges are inserted directly into the weapon).
- **Bay / Cartridge bay** – contained in the magazine; house cartridges (referred to as ‘barrels’ in the original Home Office guidance).
- **Cartridge / Ammunition** – inserted into a bay in the T10 magazine, or directly into the X2. The two main types of cartridges are ‘duty’ (also referred to as ‘live’ or ‘operational’) and ‘HALT’ (short for hook-and-loop training), used for operational use and training use respectively.
- **Probe / Projectile** – contained within each cartridge; travels towards the target while either spooling out wire behind it (T10), or drawing wire from the fixed cartridge (X2). More details on the constituent parts of the T10 and X2 Duty probes are provided in Section 7.2.
- **Wire** – enables a electrical pathway between the energy-generating circuit in the weapon, and the probe; deployed as the probe travels forward.
- **Central information display (CID)** – the display on the rear of the handle that provides information to the operator about the status of the device (inc. the number of loaded bays).
- **Connection** – as defined by Axon, a connection specifically refers to a valid electrical pathway between two probes.

2 Kinetics: Accuracy

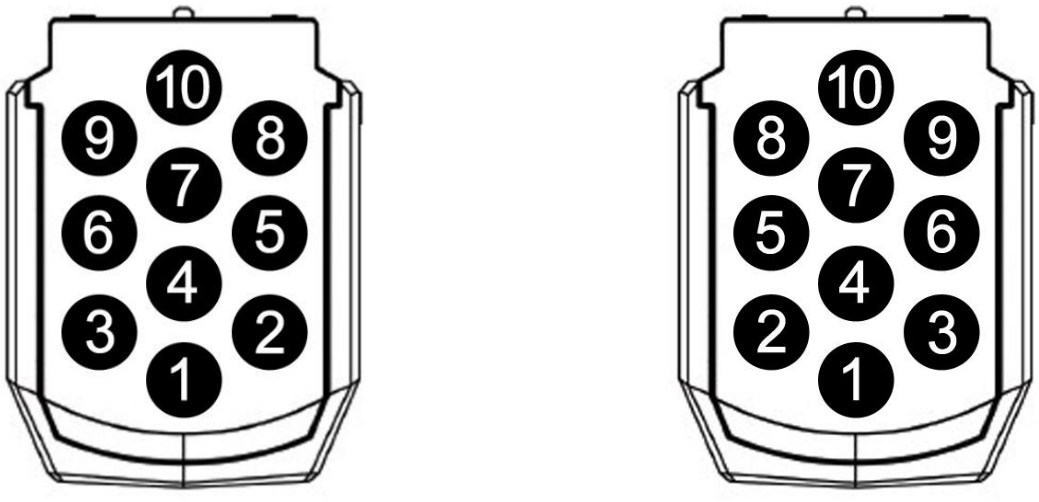
2.1 Purpose

The purpose of this test was to assess the accuracy and consistency of the T10 when fired from a fixed firing rig, including variation between different bays and different magazines, and whether it is able to achieve reliable probe placement at different ranges for duty and HALT cartridges.

2.2 Methodology

A fixed firing rig was used to securely hold the device, which was fired at a flat Axon-provided target. Graph paper was placed over the target to allow both the point of aim (POA – where the laser sight was on the target) and the point of impact (POI – where the probe hit the target) to be measured to an accuracy of 1mm in the horizontal (x) and vertical (y) directions.

A total of 300 duty cartridges were fired at different ranges, primarily from a single magazine (denoted as magazine ID S1) in order to generate statistics on variation between bays, as well as some use of other magazines to assess inter-magazine variability. The same handle was used throughout. Bays in the magazine are numbered as shown in Figure 1 (in accordance with the TASER 10 User Manual[9]). Note that the bay numbers do not correspond to the order that they are deployed – the order of bay deployment is variable and controlled by the T10 handle to attempt to keep an even level of usage (and hence degradation) across all bays.



View from rear of CED **View from front of CED**

Figure 1: The numbering scheme of bays in T10 magazines. ***Left:*** *the bays shown from the rear of the device (i.e. the position of the active user);* ***right:*** *the bays shown from the front of the device (i.e. from the position of a target).*

Testing was first conducted at a range 10.1m with a high number of shots (100) to generate inter-magazine and intra-magazine statistics. This allowed the bays with the highest and lowest dispersion (where dispersion is defined as the mean radial distance of the POI relative to the POA – i.e. a general measure of accuracy) to be identified. Subsequent testing used a single magazine at different ranges with fewer shots (including just using the lowest and highest dispersion barrels at some ranges) to build up statistics for accuracy at different ranges.

[9] *TASER 10 Energy Weapon: User Manual (MMU0083 Rev B, August 2024)*

The same methodology was used to assess HALT accuracy, with fewer overall shots (170).

Note that 10.1m is stated as the ‘zeroing range’ (the range at which it is understood that the POI should align with the POA from the laser sight) by Axon and 4.6m is considered a typical operational distance. These distances were therefore prioritised for higher numbers of shots to build up statistical confidence in the results.

More details on the methodology are provided in Appendix B. Note also that other testing was performed in parallel with the accuracy testing (including measurements of mass, velocity and sound levels, and using the accuracy data to compare the behaviour of duty and HALT cartridges) – the methodologies for those tests are reported separately in their respective sections.

2.3 Results

The results of the accuracy testing are divided into five sections in the following:

- **Inter-magazine variation of duty cartridges** – how the accuracy varied between six different duty magazines tested (labelled S1 to S6 for convenience in the following), evaluated at 4.6m and 10.1m.
- **Intra-magazine variation of duty cartridges** – how the accuracy varied between the 10 bays in one particular duty magazine (magazine S1), evaluated at 4.6m and 10.1m
- **Inter-magazine variation of HALT cartridges** – how the accuracy varied between six different HALT magazines tested (labelled H1 to H6 for convenience), evaluated at 10.1m.
- **Intra-magazine variation of HALT cartridges** – how the accuracy varied between the 10 bays in one particular HALT magazine (magazine H1), evaluated at 10.1m.
- **Accuracy at different ranges** – how the accuracy of duty and HALT magazines (S1 and H1, respectively) varied over different ranges from 1.5m to 13.7m.

2.3.1 Inter-magazine variation (duty cartridges)

Figure 2 shows the dispersion of six different duty magazines at two different ranges; 10.1 m and 4.6m. Confidence ellipses are used to indicate the dispersion, and statistical measurements of the mean POI and spread of POI are shown in Table 2 and Table 3 for 10.1m and 4.6m ranges respectively.

Note that there was an outlier for S1 at 10.1m (denoted with a red x in Figure 2). This was a shot for which the wire failed to deploy due to breaking at the bay end. The probe bounced after impact on the target, leaving a longitudinal depression on the target paper. It is suspected that the probe was made to be ballistically unstable by the wire failure, causing it yaw and/or tumble in flight, resulting in the unusual longitudinal impact and bounce out. Footage recorded at 25 frames per second supported this hypothesis, although no high-speed video was available to provide confirmation. The outlier was excluded from the analysis (the statistics of Table 1, and the confidence ellipses of Figure 2).

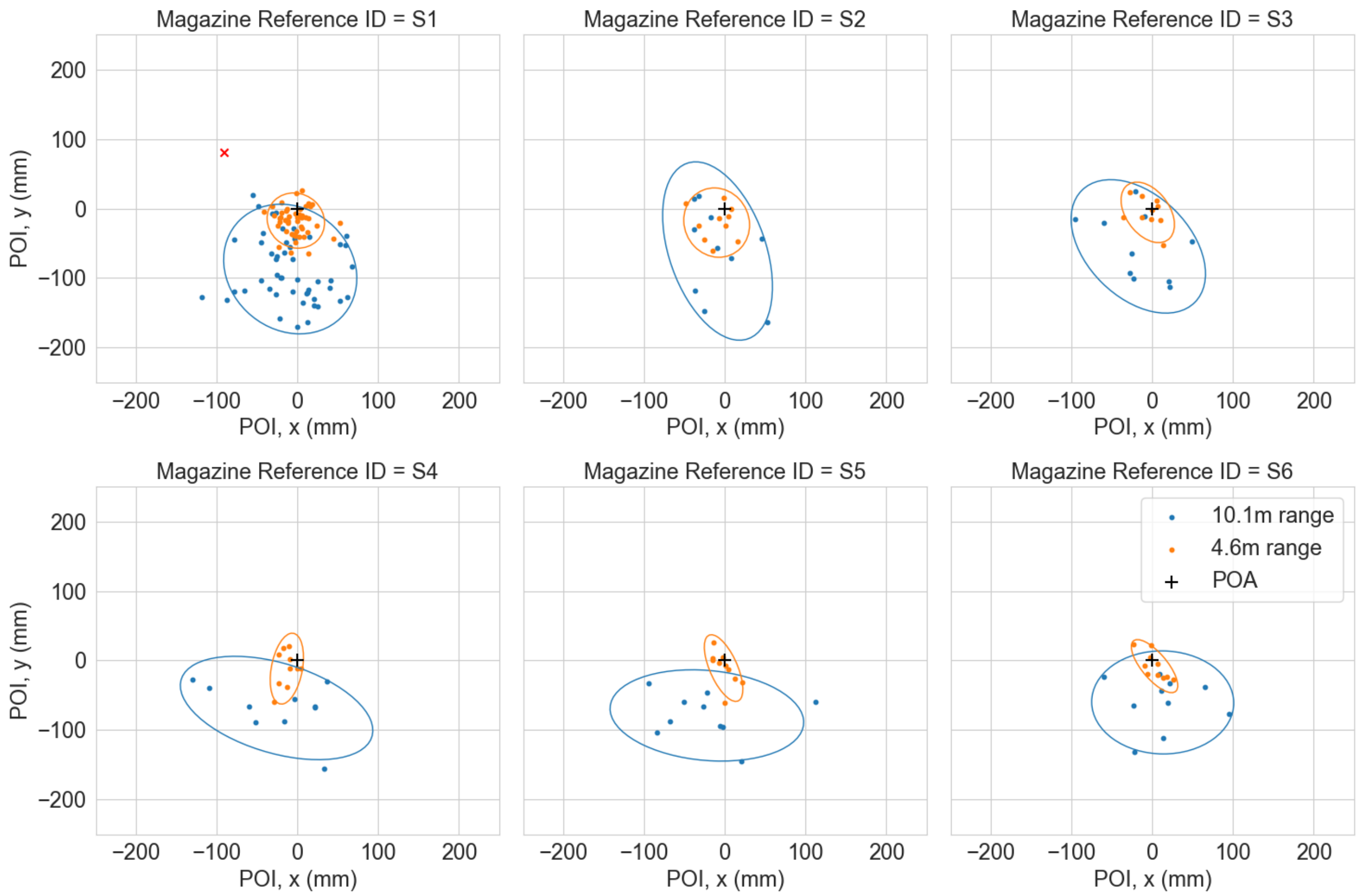


Figure 2: Plots of POI data by magazine for duty cartridges at a range of 10.1m (blue) and 4.6m (orange). The points are the raw POI, the ellipses are the confidence ellipses that correspond to containing 95% of the data for each range, the black cross indicates the POA, and the red x is an outlier at 10.1m which was excluded from the analysis (more details are in the text above).

Magazine Reference ID	Measurement Count	POI, x (mm)		POI, y (mm)		POI, r (mm)		POI, r* (mm)
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Standard deviation
S1	49	-9.0	41.2	-87.0	46.6	98.9	41.1	25.9
S2	10	-9.1	34.0	-61.1	64.1	78.5	51.6	33.9
S3	10	-17.3	41.6	-54.4	48.0	76.7	33.5	21.8
S4	10	-25.9	59.6	-68.3	37.2	93.1	35.1	33.4
S5	10	-22.3	60.0	-79.0	32.8	100.8	29.5	37.6
S6	10	12.9	44.0	-60.3	37.0	74.6	36.8	27.3
All	99	-10.7	45.1	-75.7	46.6	91.7	40.0	28.9

Table 1: Statistics for inter-magazine variation of duty magazines at a range of 10.1m. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively. r is the distance from the POI to the mean POI (for which the mean r* would be 0).*

Magazine Reference ID	Measurement Count	POI, x (mm)		POI, y (mm)		POI, r (mm)		POI, r* (mm)
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Standard deviation
S1	50	-2.1	17.8	-17.2	19.9	27.7	15.3	12.8
S2	10	-10.2	20.4	-20.2	24.9	33.0	19.8	13.2
S3	10	-5.6	16.5	-5.5	21.8	22.6	15.8	13.7
S4	10	-13.2	10.3	-11.7	25.5	26.8	17.5	12.7
S5	10	-1.6	11.9	-10.9	24.0	22.2	17.4	14.8
S6	10	2.8	14.4	-8.1	19.1	22.0	10.8	10.6
All	100	-3.8	16.7	-14.3	21.5	26.5	15.8	13.5

Table 2: Statistics for inter-magazine variation of duty magazines at a range of 4.6m. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively. r is the distance from the POI to the mean POI (for which the mean r* would be 0).*

No significant accuracy variation between duty magazines was observed in this testing. At 4.6m all magazines had a mean radial POI (relative to the POA) between 22mm and 33mm, with the mean x and y position within 1.5 standard deviations of the POA (see Figure 2) – i.e. the distribution of shots was relatively centred on the POA. At 10.1m, the distribution of shots was wider in both x and y directions, due to the longer range (see also Section 2.3.5), and remained reasonably centred horizontally (the mean x position of all magazines was between 9mm and 26mm) but drifted downwards vertically so that the mean y position was between 54mm and 87mm below the POA (about 2 standard deviations away from the POA). S2 was an exception to this (the mean y position was just under one standard deviation from the POA), but note that the relatively limited amount of POI data for non-S1 duty magazines produces confidence ellipses that are less circular due to relative outliers that significantly impact the statistics. This is in contrast to S1 for which there was 5 times as much data (50 shots) and resulted in broadly circular confidence ellipses.

Larger amounts of POI could show that some duty magazines produce more elliptical POI patterns than others, or patterns with statistically significant differences in mean POI, but based on the data acquired in this testing, no significant inter-magazine variation of duty magazines was observed.

2.3.2 Intra-magazine variation (duty cartridges)

Figure 3 shows POI data for each bay in duty magazine S1 at a range of 10.6m and 4.6m, and summary statistics are provided in Table 3 and Table 4 for 10.6m and 4.1m respectively..

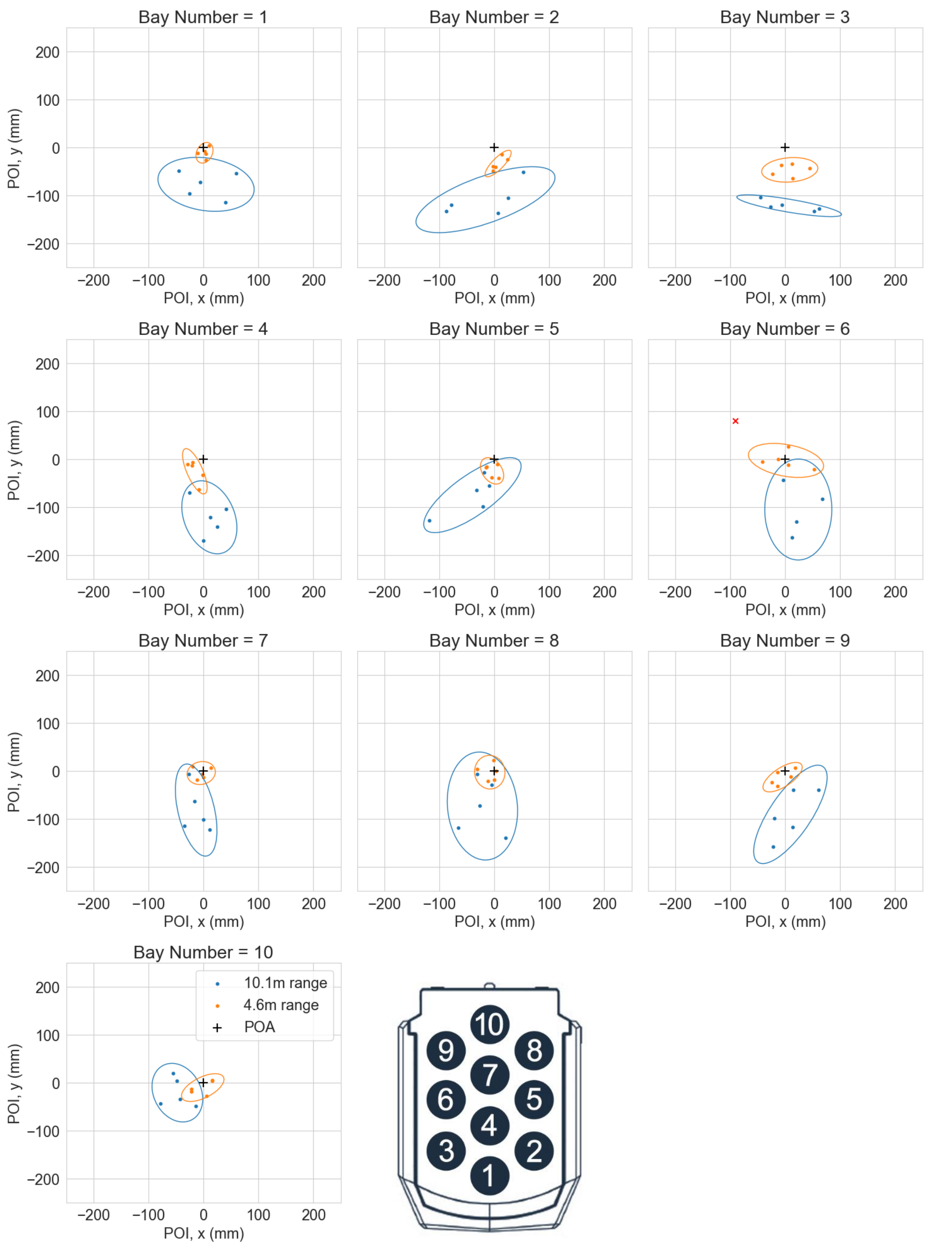


Figure 3: Plots of POI data by bay for duty cartridges in magazine S1 at a range of 10.1m (blue) and 4.6m (orange). The black cross indicates the POA, the points are the raw POIs, the red cross is an outlier point at 10.1m excluded from the analysis (the same as in Figure 2), and the ellipses are confidence ellipses that correspond to containing 95% of the data. A diagram of the bays (from the rear of the device – i.e. the position of an operator) is provided for reference.

Bay Number	Measurement Count	x (mm)		y (mm)		r (mm)		r* (mm)
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Standard deviation
1	5	4.6	43.8	-76.6	28.2	87.5	22.5	19.9
2	5	-16.2	63.2	-108.6	34.4	123.7	33.5	22.8
3	5	7.2	47.6	-121.2	11.4	128.5	13.4	17.6
4	5	10.6	25.1	-121.0	38.1	124.0	36.1	23.7
5	5	-40.0	44.3	-74.8	39.1	87.3	54.4	30.7
6	4	23.8	30.5	-104.8	52.7	111.2	51.0	18.3
7	5	-13.4	18.9	-81.6	48.0	87.5	40.6	22.9
8	5	-21.8	32.0	-73.2	56.3	82.9	53.7	28.4
9	5	9.4	33.4	-90.6	51.3	98.5	44.6	22.4
10	5	-47.6	23.1	-21.0	30.6	60.5	16.7	12.2

Table 3: Statistics for the intra-magazine variation data of Figure 3 for 10.1m range. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively. r is the distance from the POI to the mean POI (for which the mean r* would be 0).*

Bay Number	Measurement Count	x (mm)		y (mm)		r (mm)		r* (mm)
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Standard deviation
1	5	1.8	7.8	-10.8	10.8	14.9	7.0	6.8
2	5	6.8	11.9	-33.2	13.8	36.4	10.6	5.1
3	5	8.2	25.5	-46.4	12.8	52.0	14.4	10.3
4	5	-15.8	11.2	-25.0	23.7	34.6	16.9	10.0
5	5	-4.2	10.6	-24.2	13.8	26.8	12.5	3.1
6	5	1.4	34.2	-2.4	17.7	30.2	18.9	18.6
7	5	-4.2	12.9	-4.4	12.0	16.0	6.0	7.9
8	5	-8.4	13.8	-2.6	17.5	19.7	10.5	5.4
9	5	-4.8	17.9	-13.0	15.4	23.6	10.1	6.5
10	5	-1.4	19.3	-10.4	14.5	23.4	6.3	1.8

Table 4: Statistics for the intra-magazine variation data of Figure 3 for 4.6m range. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively. r is the distance from the POI to the mean POI (for which the mean r* would be 0).*

Defining the dispersion as the mean distance between the POI and POA (i.e. the parameter r in the table above), the bay with highest dispersion was Bay 3 and the bay with the lowest dispersion was Bay 10. After being identified, these bays were used for accuracy testing at some ranges to provide a likely best and worst case for bay accuracy (more details in Appendix B).

Broadly, all the bays in the duty magazine displayed similar behaviour to the duty magazines of Section 2.3.1. At 4.6m the shot distribution is relatively centred on the POA, while at 10.1m the distribution broadens and drifts vertically down (see Figure 3). The limited amount of data (5 shots per bay, compared to 10 to 50 shots per magazine in the section above) prevents drawing more detailed insights on the performance of different bays.

2.3.3 Inter-magazine variation (HALT cartridges)

Figure 4 shows the dispersion of six different HALT magazines at a distance of 10.1m. Confidence ellipses are used to indicate the dispersion, and statistical measurements of the mean POI and spread of POI are shown in Table 5.

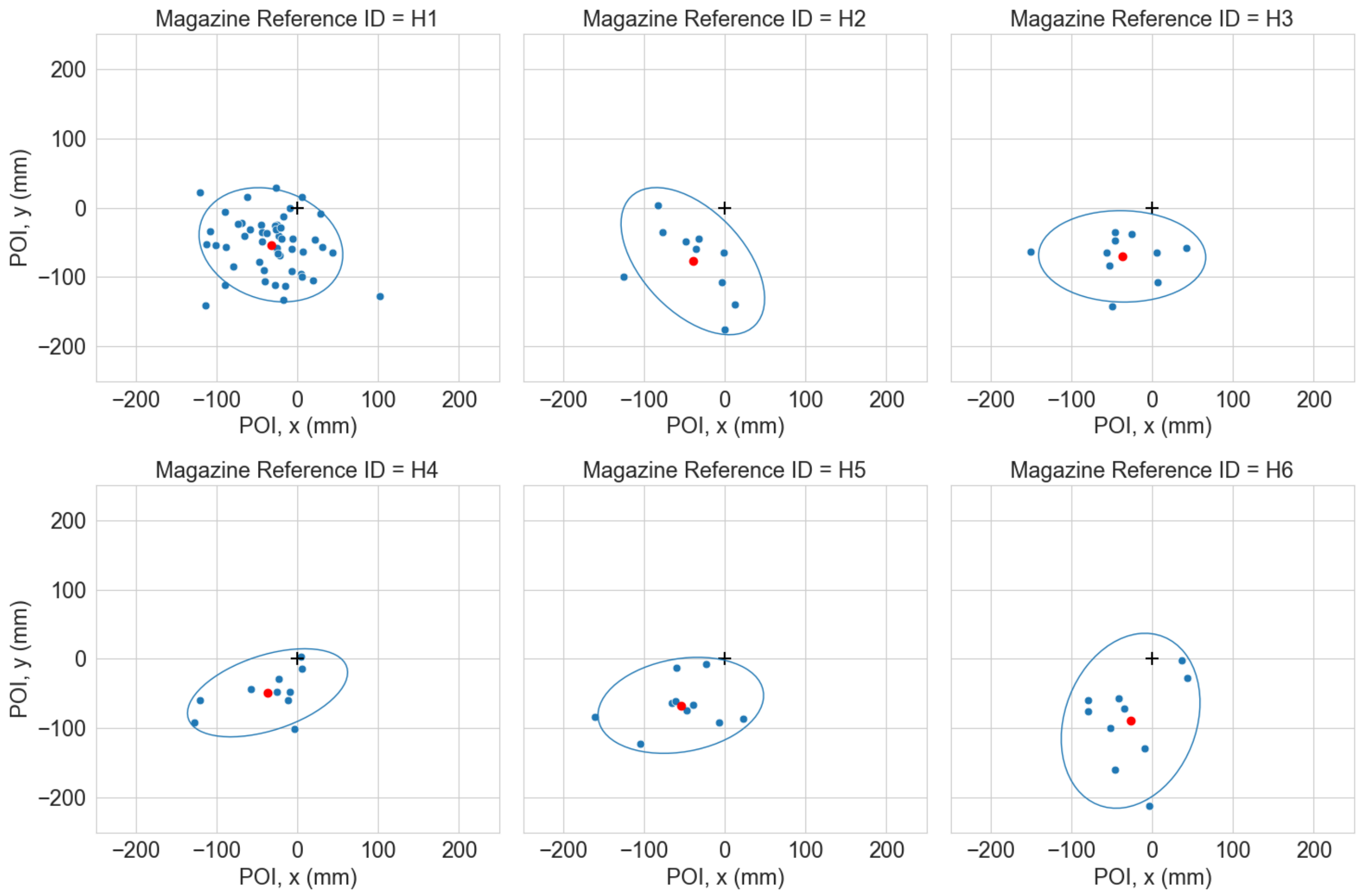


Figure 4: Plots of POI data by magazine for HALT cartridges at a range of 10.1m. The black cross indicates the POA, the blue points are the raw POIs, the red point is the calculated mean POI, and the blue ellipse is the confidence ellipse that corresponds to containing 95% of the data.

Magazine Reference ID	Measurement Count	x (mm)		y (mm)		r (mm)		r* (mm)
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Standard deviation
H1	50	-32.9	44.5	-53.4	41.1	78.2	37.9	30.4
H2	10	-39.7	44.5	-77.0	53.0	100.8	42.8	30.5
H3	10	-37.3	51.7	-70.1	32.9	91.0	39.5	30.8
H4	10	-37.1	49.6	-48.8	31.7	68.5	49.3	29.9
H5	10	-54.6	51.3	-66.9	34.6	95.2	45.2	35.0
H6	10	-26.8	42.9	-89.1	63.0	106.6	53.0	35.4
All	100	-36.0	45.6	-61.9	43.7	85.3	42.7	32.5

Table 5: Statistics for inter-magazine variation of HALT magazines. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively. r is the distance from the POI to the mean POI (for which the mean r* would be 0).*

Similar to the inter-magazine behaviour of duty cartridges, the six HALT magazines (which were only compared at one distance of 10.1m) produced broadly similar POI distributions (see Figure 4) – if overlayed there would be substantial overlap of the confidence ellipses for all magazines. The mean POI of each magazine was below and to the left of the POA, similarly to the duty magazines (more analysis provided in Section 3). The mean radial distance from the POI to the POA varied from 68mm to 107mm between magazines, with an overall average of 85.3mm.

2.3.4 Intra-magazine variation (HALT cartridges)

Figure 5 shows POI data for each bay in HALT magazine H1 at a range of 10.6m and 4.6m, and summary statistics are provided in Table 6.

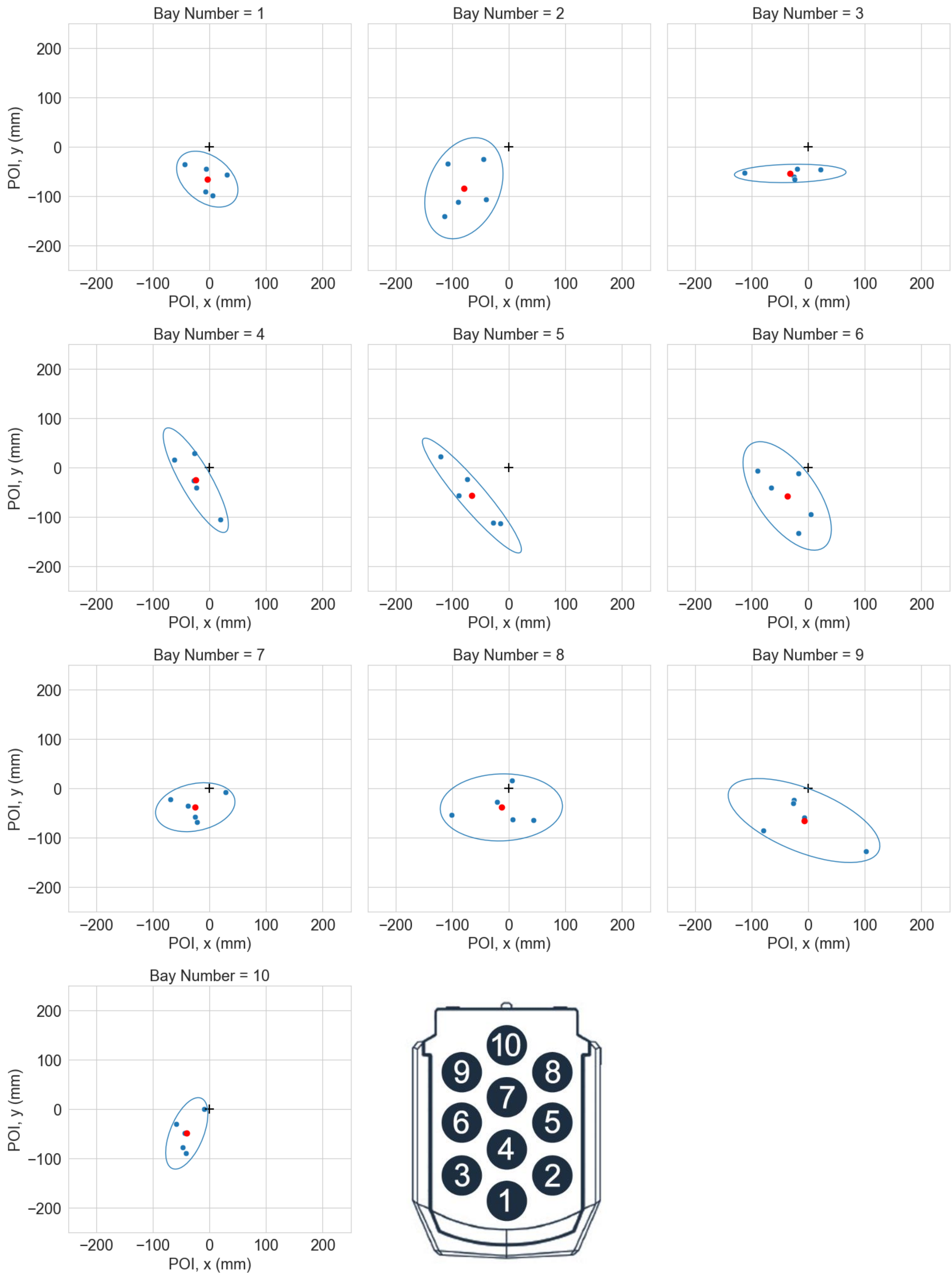


Figure 5: Plots of POI data by bay for HALT cartridges in magazine H1 at a range of 10.1m. The black cross indicates the POA, the blue points are the raw POIs, the red point is the calculated mean POI, and the blue ellipse is the confidence ellipse that corresponds to containing 95% of the data. A diagram of the bays (from the rear of the device – i.e. the position of an operator) is provided for reference.

Bay Number	Measurement Count	x (mm)		y (mm)		r (mm)		r* (mm)
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Standard deviation
1	5	-4.0	27.1	-65.2	28.3	71.2	23.1	11.4
2	5	-79.6	34.6	-83.6	51.2	120.7	47.7	16.0
3	5	-32.0	49.3	-53.6	9.3	71.8	30.8	31.4
4	5	-24.2	28.8	-25.4	53.0	59.1	28.5	34.8
5	5	-65.4	43.8	-56.6	58.2	107.1	17.7	29.9
6	5	-37.4	39.0	-57.4	55.0	83.6	41.0	18.3
7	5	-25.2	35.1	-38.4	24.8	57.7	17.9	19.8
8	5	-13.4	54.0	-38.8	34.0	61.5	38.0	29.2
9	5	-7.6	67.0	-65.4	42.5	83.3	55.3	45.0
10	5	-40.2	18.6	-49.6	36.2	66.4	35.3	20.1

Table 6: Statistics for the intra-magazine variation data of Figure 5. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively. r is the distance from the POI to the mean POI (for which the mean r* would be 0).*

Defining the dispersion as the mean distance between the POI and POA (i.e. the parameter r in the table above), the bay with highest dispersion was Bay 2 and the bay with the lowest dispersion was Bay 7. After being identified, these bays were used for accuracy testing at some ranges to provide a likely best and worst case for bay accuracy (more details in Appendix B).

Again, intra-magazine variation between the bays in the tested HALT magazine (denoted H1) was limited, within the limits of analysis that the testing data allows. All bays showed a tendency for POIs that were below and to the left of the POA, with a range of shapes of the confidence ellipses arising from the relatively small number of shots recorded for this test (see Figure 5). The mean radial distance from the POI to the POA varied from 57mm to 120mm between bays.

2.3.5 Accuracy vs range

Figure 6 shows the POI data at different ranges for a single duty magazine and a single HALT magazine. Note that the data at 1.5m, 3.0m, 6.1m and 7.1m used just the lowest and highest dispersion bays for both duty and HALT shots. At 4.6m, all bays were used equally for duty data, while just the lowest and highest dispersion bays were used for HALT data. All other ranges used all bays equally for both shot types. See also Section 3 for additional comparison of duty and HALT data.

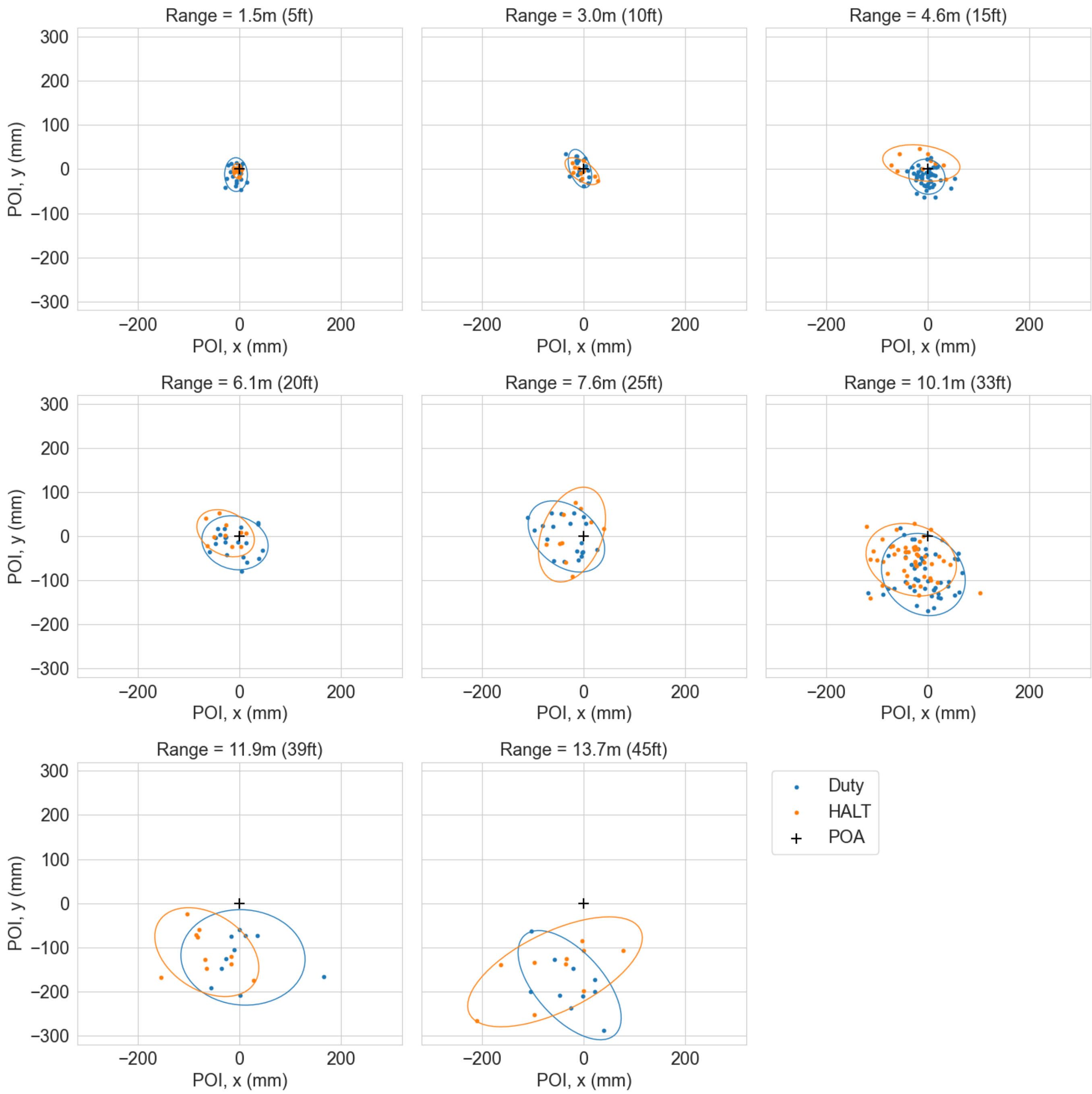


Figure 6: Plots of POI data at different ranges for duty and HALT cartridges. The black cross indicates the POA, the blue and orange points are the raw POIs for the duty and HALT shots respectively, and ellipses are the confidence ellipses that correspond to containing 95% of the data for duty and HALT respectively.

Figure 7 and Figure 8 plot the variation in the horizontal, vertical and radial POI, for duty and HALT cartridges respectively. The corresponding statistics are summarised in Table 7 and Table 8.

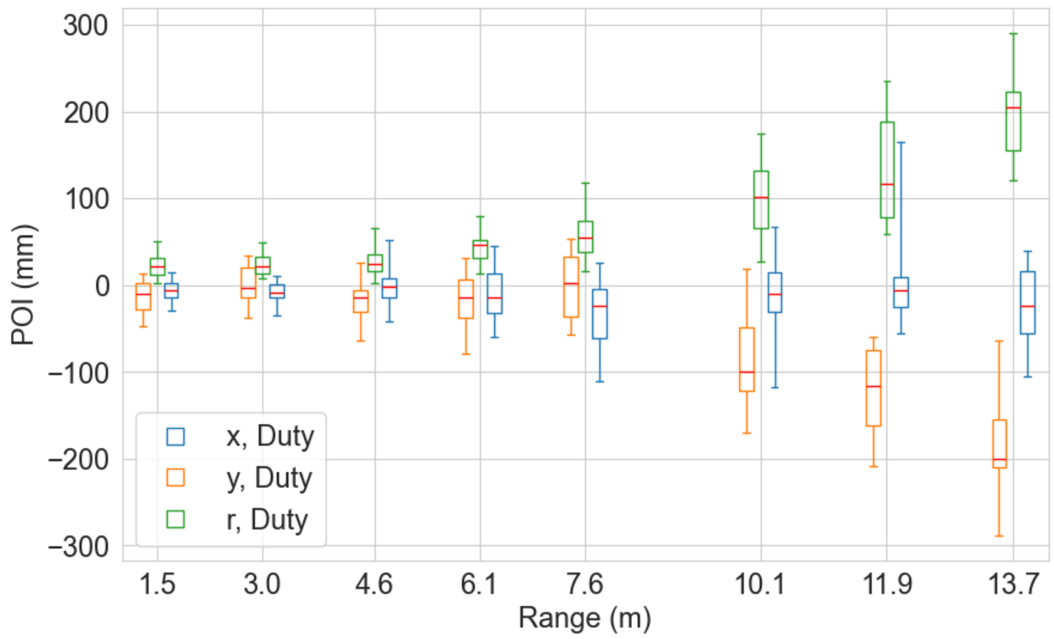


Figure 7: Box plots of POI data at different ranges for duty cartridges using a single magazine. The POI data is separated by the x (horizontal), y (vertical) and r (radial) distance from the POA. The boxes for a given range are slightly offset along the range axis to avoid overlap. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

Range (m)	Measurement Count	x (mm)		y (mm)		r (mm)	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1.5	20	-7.0	11.2	-12.4	19.1	22.3	13.6
3.0	20	-7.5	11.6	1.1	21.8	22.8	11.0
4.6	50	-2.1	17.8	-17.2	19.9	27.7	15.3
6.1	20	-9.0	32.6	-15.0	30.6	43.9	17.2
7.6	20	-34.1	37.6	-0.7	40.3	58.6	25.7
10.1	49	-9.0	41.2	-87.0	46.6	98.9	41.1
11.9	10	6.7	61.1	-122.8	54.1	132.2	63.6
13.7	10	-27.8	50.7	-185.7	61.9	196.6	51.2

Table 7: A summary of the dispersion of shots from a single duty magazine at different ranges. x, y and r are the distance between the POA and the POI in the horizontal, vertical and radial directions, respectively.

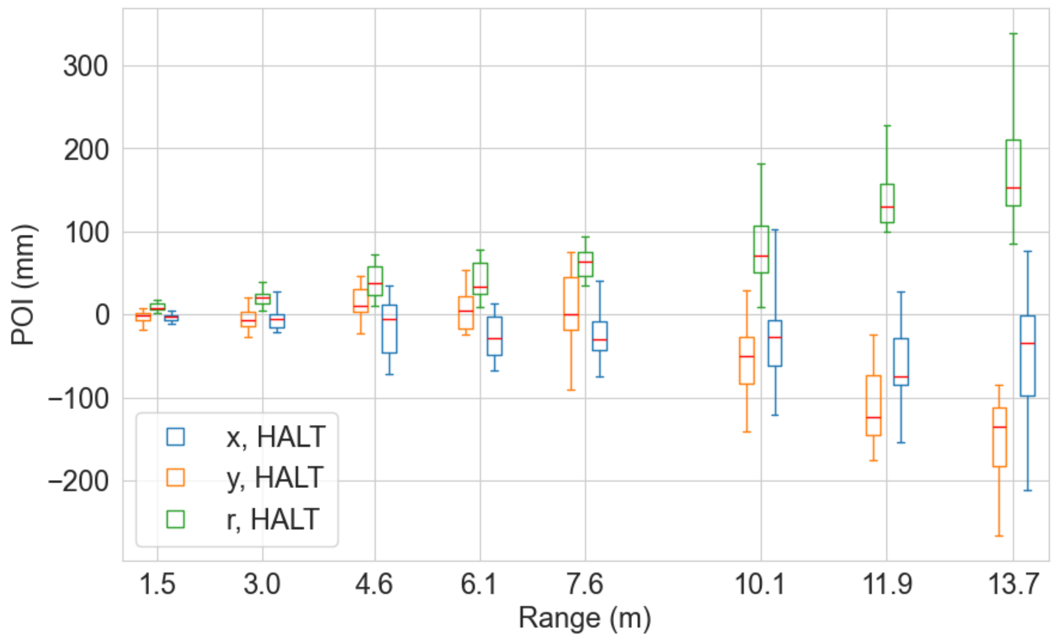


Figure 8: Box plots of POI data at different ranges for HALT cartridges using a single magazine. The POI data is separated by the x (horizontal), y (vertical) and r (radial) distance from the POA. The boxes for a given range are slightly offset along the range axis to avoid overlap. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

Range (m)	Measurement Count	x (mm)		y (mm)		r (mm)	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1.5	10	-4.1	4.9	-4.1	8.5	9.6	5.4
3.0	10	-3.3	16.8	-4.6	15.3	20.3	9.6
4.6	10	-13.0	38.0	13.9	20.7	40.4	21.3
6.1	10	-27.5	28.3	6.7	26.7	40.5	24.1
7.6	10	-23.2	33.0	3.6	53.7	61.9	18.2
10.1	50	-32.9	44.5	-53.4	41.1	78.2	37.9
11.9	10	-64.5	51.2	-110.8	50.4	140.2	39.8
13.7	10	-56.6	85.9	-155.5	62.3	178.7	78.7

Table 8: A summary of the dispersion of shots from a single HALT magazine at different ranges. x, y and r are the distance between the POA and the POI in the horizontal, vertical and radial directions, respectively.

For the duty magazine, the accuracy reduced with range, with a pronounced tendency to impact below and slightly to the left of the POA (see Figure 7). In the horizontal direction, the mean POI was less than 10mm from the POA up to a range of 6.1m, then varied non-linearly between 34.1mm to the left (for 7.6m) to 6.7mm to the right (for 11.9m) at longer range. In the vertical direction, the mean POI was within 17.2mm of the POA up to 7.6m range, then increased to 185.7mm below the POA at 13.7m range (the Axon-recommended maximum range). The noticeable vertical drop at increased range is due to gravity and the relatively slow speed of T10 probes compared to conventional ballistics. The spread of POI in the x and y directions was similar, with a standard deviation of less than 20mm within 3.0m range, rising to over 60mm at 13.7mm.

The HALT magazine showed similar behaviour, with increased spread and reduced accuracy at longer range (see Figure 8). A comparison of duty and HALT behaviour is provided in Section 3.

2.4 Conclusions

Based on the POI data collected in this testing, for duty magazines there was no evidence for significant variation between different magazines or between different bays. Similarly, there was no evidence for significant variation between different HALT magazines or HALT bays. Further testing with substantially higher numbers of shots may bring to light statistically significant differences between different bays or magazines. Note that a comparison of duty and HALT accuracy is considered in Section 3.

The accuracy of both duty and HALT cartridges was measured at various ranges and showed a tendency to impact the target below and slightly to the left of the POA. This was less pronounced at short distances, with the mean POI within 15mm of the POA at 4.6m, but increased at range. Noticeably, the ‘zeroing’ range (the range at which the POA should match the POI) is understood to be 10.1m, but at this range the mean POI was 91.7mm from the POA for duty cartridges (and 85.3mm for HALT cartridges). The POA is defined by the laser sight which is not adjustable by the operator, and all accuracy testing used a single handle, so it was not clear from this testing whether this tendency is common to all T10 handles, or if the laser sight direction varies significantly between handles. Additional testing was subsequently conducted to assess whether this varied between different handles, and whether hand-firing the devices changes the accuracy – this is reported in Section 3.

An assessment of how the measured accuracy of the T10 correlates with operational usefulness is outside the scope of this report.

3 Kinetics: Accuracy – Clamped vs hand-fired

3.1 Purpose

The purpose of the tests was to determine whether a perceived discrepancy with the mean point of impact at 10.1 m from the T10 handle used in the original technical testing (see Section 2.3.5) and the results from the (10 m) College of Policing user handling trial was due to handle zeroing inconsistency or to weapon recoil when hand-fired.

3.2 Methodology

The same experimental setup and procedure was used as for the previous accuracy testing (see Section 2.2), with the following changes:

- Half of the shots were deployed with the device hand-fired, and half were deployed from the device clamped in the same firing rig as the previous testing.
    - Specifically, 3 different T10 handles were used at a range of 10.1m, for both hand-fired and clamped states, with 3 full duty magazines per handheld per state (a total of 180 shots).
    - Three different magazines were used to enable any intra-magazine dependence of the accuracy to be highlighted. These three different magazines were used for each handle in each state (clamped or hand-fired) in order to eliminate unnecessary variability.
    - When a device was hand-fired, the two-handed grip taught by the College of Policing to the testing team was used. More details on the adapted procedure are available in Appendix A.
- The projectile velocity was measured at one point only (1m from the muzzle) using a dual gate optical chronograph, for each shot. The aim of this was to help identify erroneous shots (by abnormal velocity measurements).

More details on the methodology are provided in Appendix C.

Note that the handle used for the previous accuracy testing (all of which used a clamped device) was no longer functional (as detailed in Section 15.2.4) so could not be used for hand-fired testing here, but the clamped data for that handle is included in the following for comparison.

3.3 Results

Figure 9 shows the dispersion of the three tested handles, alongside the handle previously used for clamped accuracy testing (serial number T19E24561) for comparison. Confidence ellipses are used to indicate the dispersion, and statistical measurements of the mean POI and spread of POI are shown in Table 9. The data is also presented as boxplots in Figure 10.

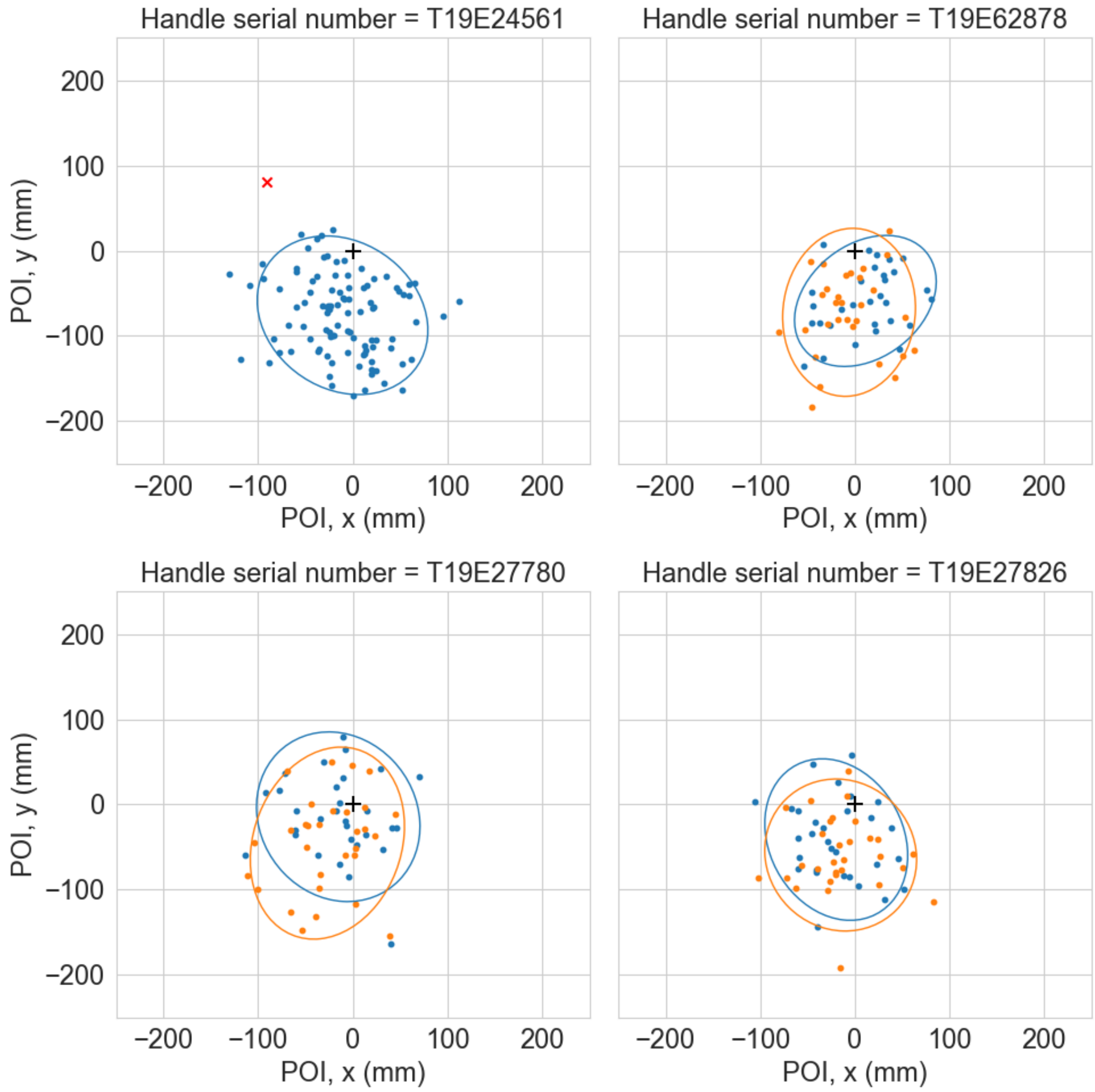


Figure 9: Plots of POI data by handle for duty cartridges at a range of 10.1m for both clamped (blue) and hand-fired (orange) states. Top left is the handle used for previous accuracy testing (all clamped data), and the other plots are the three handles tested in both clamped and hand-fired states. The points are the raw POI, the ellipses are the confidence ellipses that correspond to containing 95% of the data for each range, and the black cross indicates the POA.

Handle serial number	State	Measurement count	POI, x (mm)		POI, y (mm)		POI, r (mm)	
			Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
T19E24561	**Clamped**	99	-10.7	45.1	-75.7	46.6	91.7	40.0
T19E62878	**Clamped**	30	11.0	37.4	-58.9	38.5	72.8	33.4
	Hand-fired	30	-6.2	35.1	-72.3	49.3	82.5	45.3
T19E27780	**Clamped**	30	-15.2	43.2	-14.4	49.8	59.8	33.1
	Hand-fired	30	-26.7	40.7	-45.4	56.3	74.4	44.4
T19E27826	**Clamped**	30	-19.8	37.7	-41.2	47.4	68.2	31.9
	Hand-fired	30	-15.1	40.1	-59.3	44.6	75.9	38.9

Table 9: Statistics for the dispersion of handles at a range of 10.1m when clamped and hand-fired. All measurements are in mm. x, y and r and the distances of the POI from the POA in the x, y and radial directions respectively.

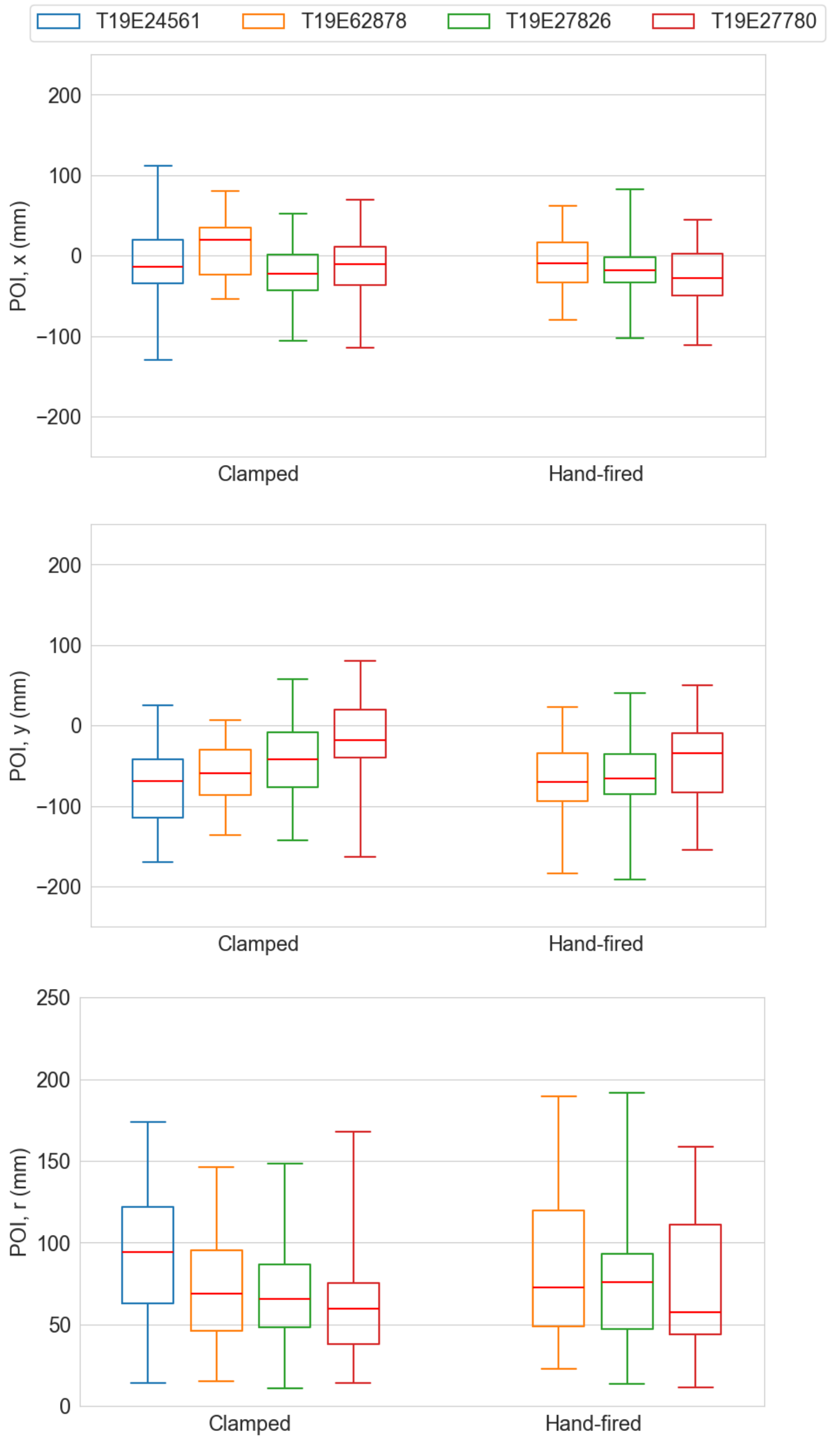


Figure 10: Box plots of POI data at 10.1m for clamped and hand-fired devices. The plots show the distance from the POI to the POA for the x (horizontal), y (vertical) and r (radial) directions in the top, middle and bottom plots, respectively. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

Appendix C contains additional plots comparing the effect of different magazines – no significant variation was observed.

Appendix C also contains analysis of the velocity data measured in this testing. A small reduction and increased spread in the measured velocities when hand-fired compared to when clamped was identified, but this did not correlate with lower accuracy.

3.4 Conclusions

No significant accuracy variation between clamped and hand-fired states was observed, as indicated by the high degree of overlap between the respective confidence ellipses in Figure 9. The mean POI was between 13.6mm and 31.0mm lower when the device was hand-fired, but these differences are relatively small compared to the standard deviations of the POI data (typically about 3.5 to 5cm). Horizontally, the mean POI varied from being 17.2mm further left to 4.7mm further right when hand-fired rather than clamped, depending on the handle. Figure 10 highlights that the variability between different handles was more significant than the variability between clamped and hand-fired states.

Regarding the ‘zeroing distance’ being 10.1m, all three handles tested here were more accurate to the POA in both the radial and vertical directions than the original handle used in the previous testing (see Section 2.3.5), although those handles still showed a tendency to impact lower than the POA. The mean radial POI was 91.7mm for the original handle, while the three newly tested handles had mean radial POIs of between 59.8mm and 82.5mm in their clamped and hand-fired states. All handles had a mean vertical POI between 41.2mm and 75.7mm below the POA, except for handle T19E27780 when clamped, which produced the most accurate spread of probes on the target (mean POI of 15.2mm left of the POA and just 14.4mm below the POA).

Overall, it appears that there is significant variability between handles in accuracy relative to the POA, and although some handles may be reasonably centred on the POI for some sets of shots, it seems likely from the data gathered that the zeroing of the handles is only accurate for a 10.1m range to within around 5cm vertically (this is for the zeroing, i.e. the average POI; the spread of POIs is broader, with around ±5cm spread horizontally and vertically around the mean POI). It is beyond the scope of this report to speculate on any operational implications of this inter-handle variability in the zeroing point and it is for others to determine whether or not it is relevant.

Note also that a small decrease and increased spread of measured velocity was observed for hand-fired probes compared to for clamped devices – the mean velocity was 2.5% lower, the standard deviation was twice as high, and while the maximum measured velocity was the same (to within 1%) the minimum velocity was 14.2% lower. This is understood to be due to the hand-fired devices being less securely fixed in place than a clamped device, introducing greater shot-to-shot variability and potential for energy loss. A lower velocity corresponds to a lower momentum, lower kinetic energy, and reduced ability to penetrate a target – a hand-fired device will therefore have on average a slightly lower ability to penetrate a target than a clamped device. Two consequences for the testing done throughout this report are:

- The testing done with clamped devices represents a worst-case scenario when considering the injury-causing potential of devices.
- The clothing penetration testing (which used clamped devices) may slightly overestimate the penetration achievable from the devices.

In both cases the impact is likely to be small given the small decrease in mean velocity for hand-fired devices compared to clamped devices, and the high amount of overlap in the velocity distributions for each state.

4 Kinetics: Training probe behaviour

4.1 Purpose

This test is to assess how similar the ballistic behaviour of the training (HALT) probes is to the duty probes.

4.2 Methodology

The data from the accuracy testing of the duty and HALT probes was used; see Section 2.2 for the methodology, with more details in Appendix B. Only the data from the S1 and H1 magazines were used to avoid any variability from different magazines – these were the only magazines used at all ranges, whereas the other magazines were only used at 10.1m (and 4.6m for the duty magazines).

4.3 Results

A comparison of the POI data for duty and HALT data is shown in Figure 11, Figure 12 and Figure 13 for the horizontal, vertical and radial directions, respectively. This is the same data as in Figure 7 and Figure 8 in Section 2.3.5, but separated here by direction to allow duty and HALT data for each direction to be compared on the same graph.

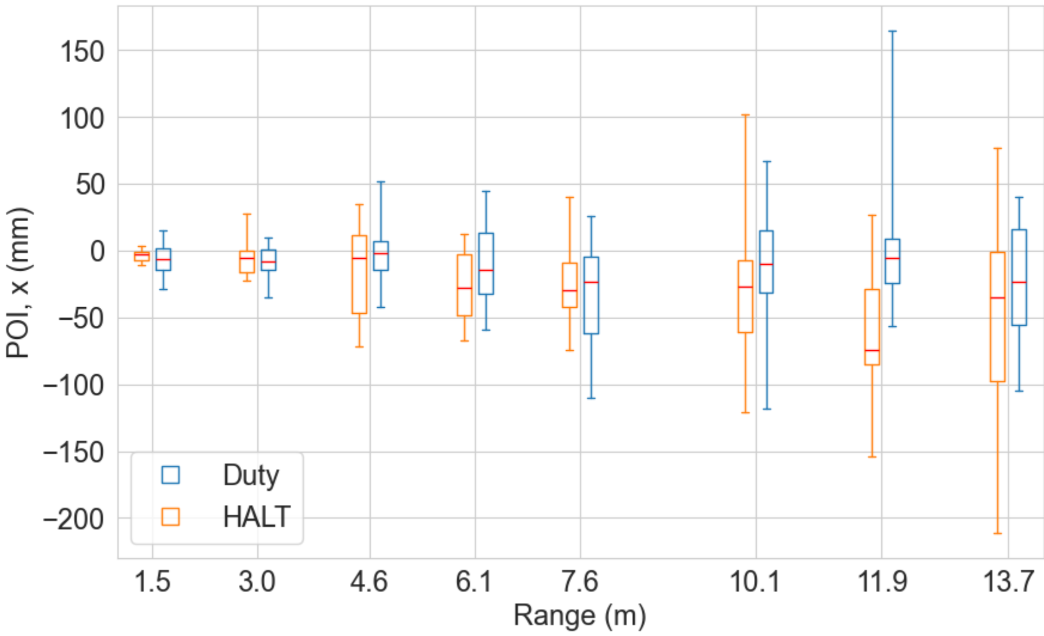


Figure 11: Box plots of POI data in the x (horizontal) direction at different ranges for duty and HALT cartridges. The boxes for duty and HALT data are slightly offset along the range axis to avoid overlap but were captured at the same ranges. Note that a negative x POI means an impact to the left of the POA from the perspective of the T10 user. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

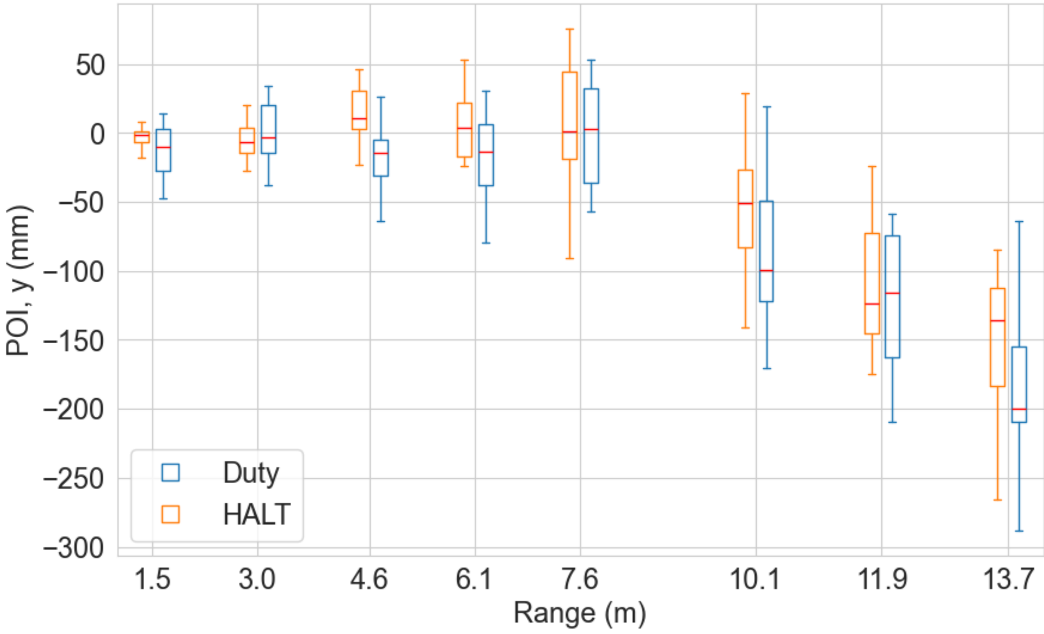


Figure 12: Box plots of POI data in the y (vertical) direction at different ranges for duty and HALT cartridges. The boxes for duty and HALT data are slightly offset along the range axis to avoid overlap but were captured at the same ranges. Note that a negative y POI means an impact to the left of the POA from the perspective of the T10 user. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

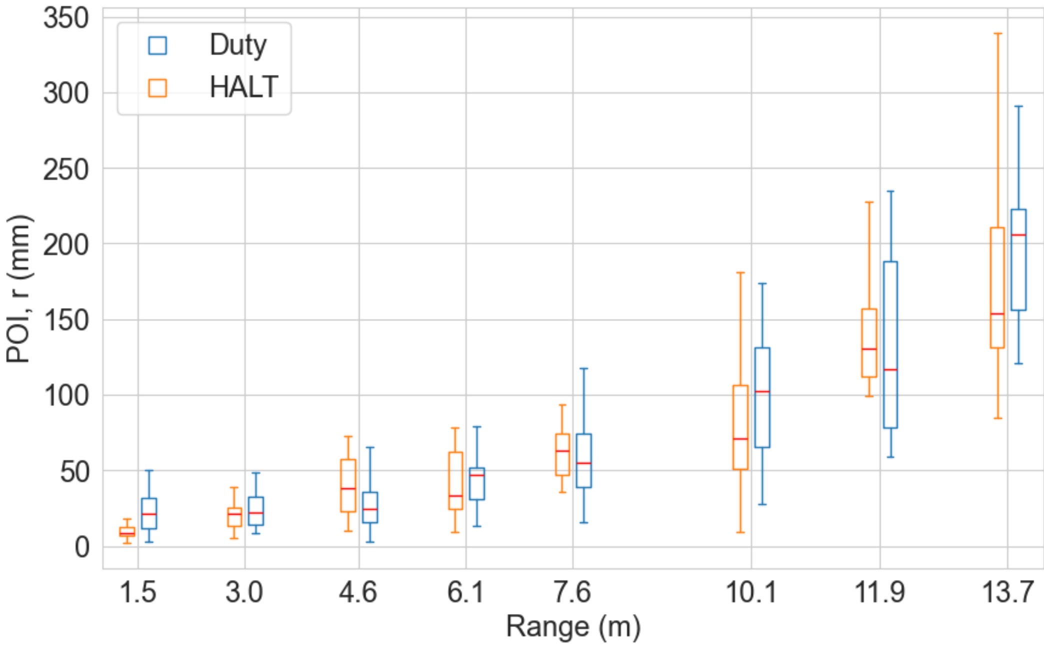


Figure 13: Box plots of POI data in the r (radial) direction at different ranges for duty and HALT cartridges. The boxes for duty and HALT data are slightly offset along the range axis to avoid overlap, but were captured at the same ranges. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

See also Table 7 and Table 8 for summary statistics of x, y and r POI at different ranges for duty and HALT cartridges respectively.

4.4 Conclusions

Duty and HALT probes were observed to show generally similar ballistic behaviour over different ranges. Both types of probes showed a tendency to impact below and slightly to the left of the POA (from the perspective of the CED user). Comparing the dispersion at different ranges, the HALT or duty probes may appear to be slightly more or less accurate but not in a statistically significant way, given the amount of data. 10.1m was the range at which the largest amount of data was collected at, and at that range the standard deviations in the x, y and r POI were all within the range of 37.9mm to 46.6mm, indicating similar levels of spread (vertically, horizontally and radially). The mean POI at 10.1m was more accurate horizontally for duty probes (mean x POI of -9.0mm compared to -32.9mm for HALT probes), while HALT probes were more accurate vertically (mean y POI of -53.4mm compared to -87.0mm for duty probes) and radially (mean r POI of 78.2mm compared to 98.9mm for duty probes), but at other ranges the reverse is true – e.g. at 7.6m where the duty probes were more accurate in r and y, but the HALT probes were more accurate in x. This appears to be an artifact of the limited amount of data combined with the similar behaviour of duty and HALT probes.

In summary, no significant differences in HALT and duty behaviour were observed in this testing.

5 Kinetics: Absolute maximum range

5.1 Purpose

The purpose of this test was to ascertain the absolute maximum range at which the T10 probe wires reach their maximum length and to determine whether the probes detach. Note that this is the absolute maximum range, not the maximum range for operational use, which would include additional factors and is the responsibility of other groups to decide.

5.2 Methodology

Duty cartridges were fired from the same mounting rig used for the accuracy testing, but with no target or other objects within 20m range. The range was varied to identify at what distance the probe detached from the wire, with repeat measurements to estimate the probability of detachment. Note that Axon state that the maximum range of the T10 is 13.7m, and earlier tests (see Section 2) verified that the probes travelled the 13.7 m range without detaching from the wires.

5.3 Results

The results of the testing are summarised in Table 10.

Range	No. of shots fired	No. of shots detached	No. of shots not detached	% shots detached
17 m	2	2	0	100%
15.35 m	10	10	0	100%
15.2 m	4	2	2	50%
15.1 m	2	1	1	50%
15 m	7	2	5	29%
15m*	*40*	*7*	*33*	*18%*

*Table 10: Absolute maximum range data considering whether probes detach or not at different ranges. * relevant data from clothing penetration testing performed at 15m range (see Section 8.3) is also included to complement the absolute maximum range testing data.*

5.4 Conclusions

At 15.35m, all 10 shots resulted in detachment, whereas at 15.1m and 15.2m only half of shots resulted in detachment. The assessment of absolute maximum range is therefore that beyond 15.3m detachment should be expected, with 15m being a realistic absolute maximum range under testing conditions. Note also that T10 testing at 15m range for clothing penetration testing (see Section 8.3) found that 33 of 40 shots did not result in detachment (an 83% success rate). The 15m range absolute maximum range exceeds the Axon-specified maximum range of 13.7m, indicating probe detachment from the wires is not expected at the specified maximum range.

In practice, using a T10 at a target 15m away in an operational context may be impractical because movement of the target or the operator is likely to increase the distance between target and CED to beyond the detachment distance soon after impact. The Axon recommended 13.7m maximum range therefore appears sensible, although it is beyond the scope of this report and up to other groups to determine the maximum range for UK operational situations.

6 Kinetics: Mass, velocity, momentum & kinetic energy

6.1 Purpose

This test was to measure the kinetic properties of the duty probes at different ranges and, in the event that the probes break free from the wire following a miss, to allow a comparison with previous CED models.

6.2 Methodology

Measurements of mass and velocity were taken in the course of performing accuracy testing (see Section 2). Mass measurements of probes were conducted by cutting the wire at the base of the probe and using a weighing scale to measure the mass to a precision of less than 1mg. Velocity measurements were taken using a chronograph. From the mass and velocity measurements, the corresponding momentum and kinetic energy was calculated.

6.3 Results

In the following, the mass and velocity measurement data are presented, then those results used to calculate the momentum and kinetic energy at different ranges. More detailed data is available in Appendix B.

6.3.1 Probe mass

The probe mass data is shown in Figure 14 with summary statistics in Table 11. The mass shows a linear reduction with distance, as expected for the wire unspooling behind the probe as it travels. A simple linear fit gives a mass reduction of 63mg per metre travelled.

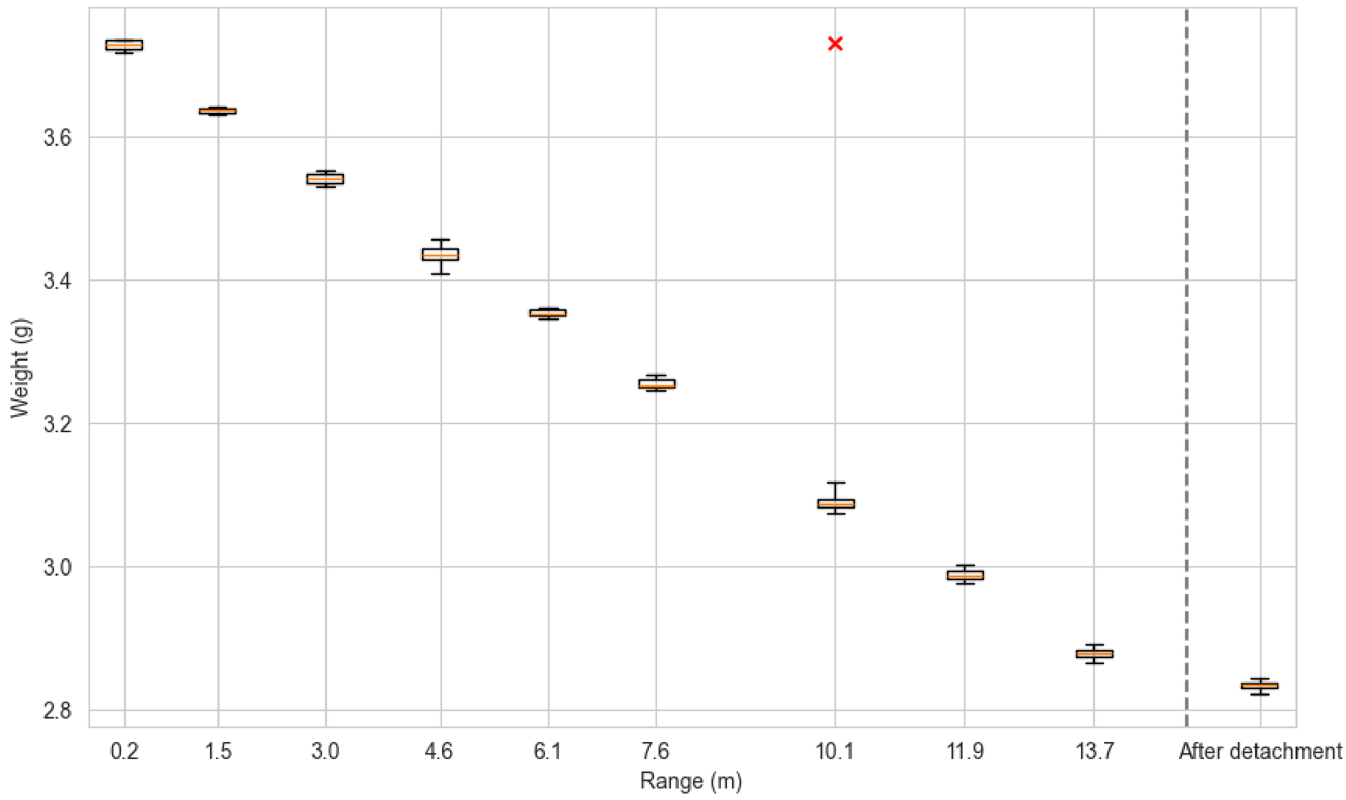


Figure 14: Plots of the probe mass at different ranges. A range of 0.2m was the minimum practically measurable range in testing. The red x is an outlier shot where the wire detached in the bay; all the wire remained inside the probe and travelled with it. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value. The vertical dotted line indicates the point beyond which detachment regularly occurred (15m – see Section 5).

Range (m)	Measurement Count	Probe mass (g)				
		Mean	Maximum	Minimum	Standard deviation	Standard error
0.2	5	3.728	3.736	3.718	0.008	0.003
1.5	10	3.637	3.643	3.630	0.004	0.001
3.0	10	3.541	3.552	3.530	0.008	0.002
4.6	20	3.435	3.458	3.409	0.013	0.003
6.1	10	3.354	3.362	3.346	0.006	0.002
7.6	10	3.255	3.268	3.246	0.008	0.003
10.1	49	3.089	3.118	3.073	0.009	0.001
11.9	10	2.988	3.002	2.976	0.009	0.003
13.7	10	2.878	2.892	2.865	0.008	0.002
Beyond detachment	10	2.834	2.844	2.822	0.006	0.002

Table 11: Statistics for the mass of duty probes at different ranges, including beyond the absolute maximum range where the probe has detached from the handle due to the wire breaking.

6.3.2 Probe velocity

The probe velocity data is shown in Figure 15 with summary statistics in Table 12. Shot-to-shot variation is significantly higher for velocity than for mass – the range of velocities measured at a given distance is of order 10-20% of the mean, compared to of order 1% for mass measurement variation (see Table 11). At point blank range, typical velocities are 60-65m/s, dropping approximately linearly with distance to around 50m/s at the manufacturer's maximum range. For shots that detach from the wire, the velocity (measured at 15.35m) drops significantly to 30-40m/s.

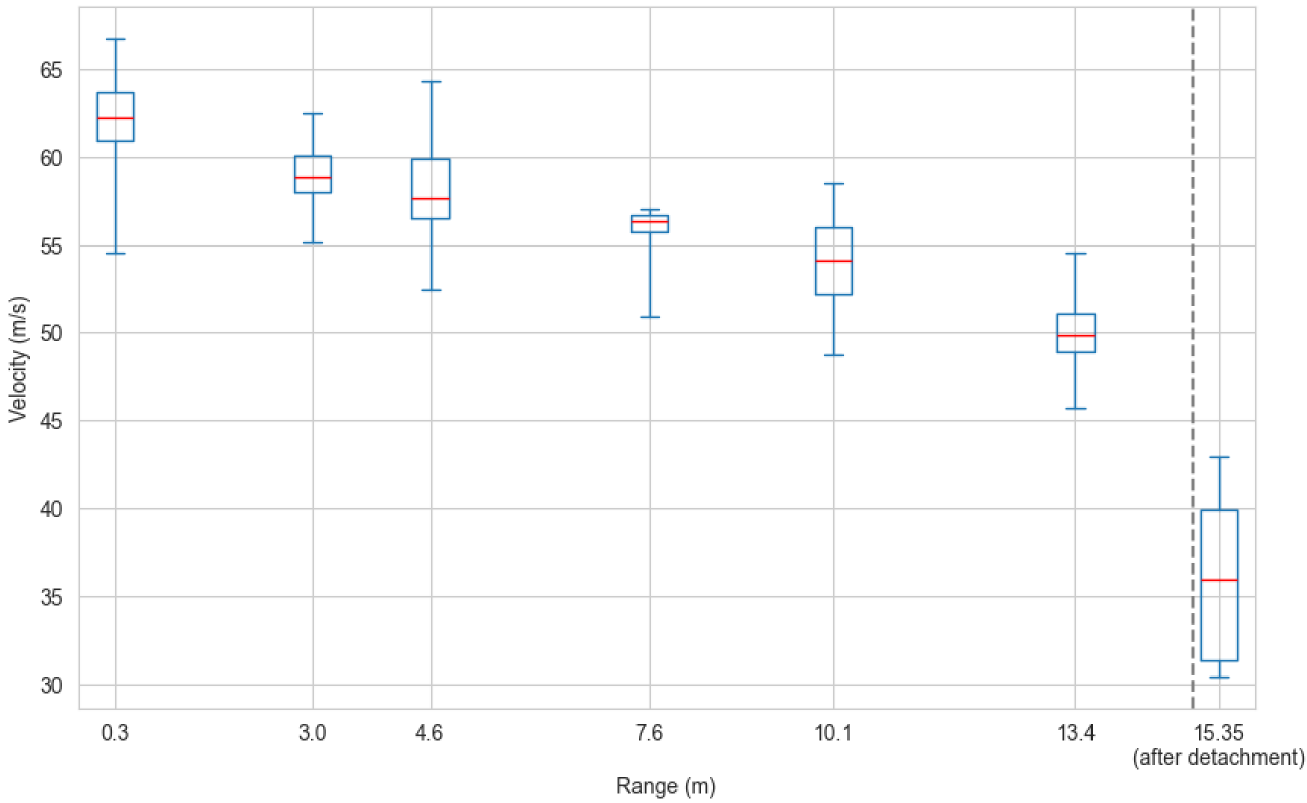


Figure 15: Plots of the probe velocity at different ranges, including after detachment. A range of 0.2m was the minimum practically measurable range in testing. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value. The vertical dotted line indicates the point beyond which detachment regularly occurred (15m – see Section 5).

Range (m)	Measurement Count	Probe velocity (m/s)				
		Mean	Maximum	Minimum	Standard deviation	Standard error
0.3	70	62.24	66.75	54.56	2.35	0.28
3.0	20	58.93	62.48	55.17	2.02	0.45
4.6	15	58.42	64.31	52.43	3.26	0.84
7.6	7	55.60	57.00	50.90	2.13	0.81
10.1	10	53.92	58.52	48.77	3.03	0.96
13.4	10	49.74	54.56	45.72	2.52	0.80
15.35m (after detachment)	5	36.15	42.98	30.48	5.38	2.41

Table 12: Statistics for the velocity of duty probes at different ranges, including beyond the absolute maximum range where the probe has detached from the handle due to the wire breaking.

6.3.3 Probe momentum & kinetic energy

Table 13 summarises the momentum and kinetic energy calculated at different ranges from the corresponding mass and velocity data. The variability in velocity (relative to the mean velocity) is significantly higher than for the mass; the uncertainty in velocity is therefore the main source of error in calculating the momentum and kinetic energy.

		Range						
		0.3m*	3m	4.6m	7.6m	10.1m	13.7m*	After detachment
Velocity (m/s)	Mean	62.24	58.93	58.42	55.60	53.92	49.74	36.15
	Standard deviation	2.35	2.02	3.26	2.13	3.03	2.52	5.38
	Standard error	0.28	0.45	0.84	0.81	0.96	0.80	2.41
Mass (g)	Mean	3.711	3.541	3.435	3.255	3.089	2.887	2.834
	Standard deviation	0.008	0.008	0.013	0.008	0.009	0.008	0.006
	Standard error	0.003	0.002	0.003	0.003	0.001	0.002	0.002
Momentum (g m /s)	Mean	231.0	208.7	200.7	181.0	166.6	143.6	102.4
	Standard deviation	8.7	7.2	11.2	6.9	9.4	7.3	15.2
	Standard error	1.1	1.6	2.9	2.6	3.0	2.3	6.8
Kinetic energy (J)	Mean	7.19	6.15	5.86	5.03	4.49	3.57	1.85
	Standard deviation	0.54	0.42	0.65	0.39	0.50	0.36	0.55
	Standard error	0.06	0.09	0.17	0.15	0.16	0.11	0.25

*Table 13: Summary statistics for the velocity and mass of duty probes at different ranges, with the corresponding calculated momentum and kinetic energy. * the probe mass was adjusted using a linear extrapolation for some ranges to match the ranges for which velocity measurements were taken.*

At most ranges, both mass and velocity data were available, although for 0.3m and 13.7m only velocity data was available, so mass measurement data from slightly different distances (0.2m and 13.4m respectively) were used with a small adjustment to the mean probe mass (based on the 63mg per metre mass loss described above). This adjustment amounted to a less than 0.5% change in the probe mass used for the calculations.

6.4 Conclusions

The highly linear reduction in probe mass with distance is indicative of good standardisation of wire length and thickness within the probe. The higher variability in velocity with distance is likely due to slightly different shot-to-shot orientations of the probe in the air, and yawing motion during its flight, which causes variation in the amount of air resistance experienced.

At 13.7m (the recommended maximum range), the kinetic energy is 50% of the initial kinetic energy, while the momentum is reduced by 38%, the velocity is reduced by 20%, and the mass is reduced by 22%. After the probe has detached from the wire, the mass is essentially unchanged (since at 13.7m almost all the wire has already been deployed), while the kinetic energy drops another 50%, arising from the energy required to break the wire.

Note that the data in this chapter used clamped devices, and it has been subsequently identified that hand-fired devices appear to exhibit a small (2.5%) decrease in average velocity and an increase in the velocity spread, compared to clamped devices (see Chapter 3). The results in this chapter may therefore be a slight overestimate of the velocity, momentum and kinetic energy of probes that are hand-fired, although any overestimate is likely to be small given the small decrease in mean velocity for hand-fired devices compared to clamped devices, and the high amount of overlap in the velocity distributions for each state (including near-identical maximum measured velocities).

7 Skin penetration

7.1 Purpose

This test assessed the risk of skin penetration by the probe body from ‘contact range’ (meaning as close as is reasonably practical for testing).

7.2 Methodology

The target was a TP5 skin simulant pack (provided by Dstl) designed to simulate particularly vulnerable areas of human skin. The skin simulant was mounted vertically and a probe was fired at the target from a range of 50cm, then visual inspection of the target was performed to assess the extent of skin penetration, with one or more photographs taken to document the penetration. The target was moved before the next shot was fired. This was repeated 15 times for both a T10 and a X2 (note that each shot of the X2 consists of 2 probes).

The result of each shot was noted based on:

1. If any penetration of the probe observed (note that this was challenging to definitively identify when a probe bounced off the target).
2. If so, how much of the probe penetrated the target, with the probe divided up into the dart, the probe body, and (in the case of the T10), the rubber impact absorber.
    - We define here the term ‘*perforation*’ as referring to any breakage of the outer layer of the skin simulant by part of the probe other than the dart (for the purposes of the skin penetration testing). This distinguishes the scenario of severe lateral movement/tearing of the outer skin layer(s) from the more common scenario of penetration of the thin dart into the skin causing minimal lateral movement/tearing of the skin.
3. If the probe remained in the target.

For reference, a typical T10 and X2 probe are shown in both Figure 16 and Figure 17. A T10 probe consists of:

- a 11mm dart (a shaft protruding from the probe body, with a barb)
- a 13mm impact absorber (comprised of two rubber elements, coloured white and black)
- a 37mm probe body, with a brass ring on one end of the body that connects to the impact absorber

The total length of a T10 probe is 61mm. A X2 probe consists of just a dart (11mm long, again with a barb) and a probe body (25mm long), with a total length of 36mm. Note that the barbs on the T10 and X2 darts are different – see Figure 17.

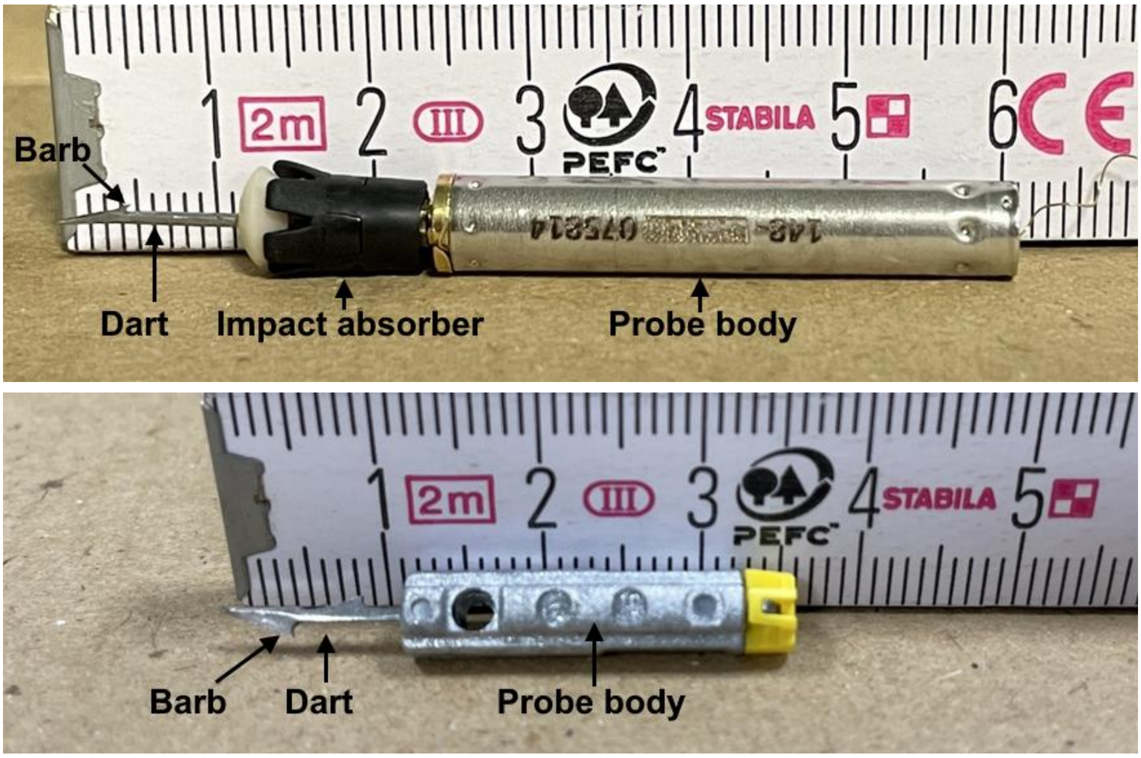


Figure 16: A T10 (top) and X2 (bottom) probe shown with a ruler for reference.

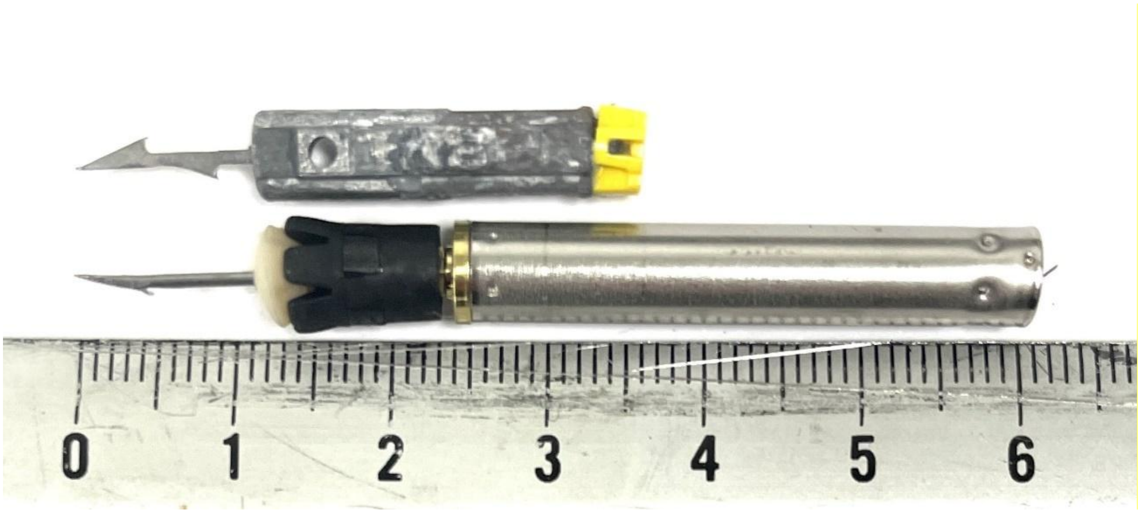


Figure 17: Close-ups of the X2 (top) and T10 (bottom) darts, to compare lengths and to highlight the different barbs.

7.3 Results

Table 14 contains the results for the T10 skin penetration testing, and Table 15 contains the X2 results. Note that when a probe bounced off the target, it was very challenging to determine whether penetration had occurred due to penetration of the dart only forming a very small and difficult to detect hole in the rubber of the skin simulant target. In some cases rubber was observed on the barb, so penetration was evident, whereas in others (the large number of bounce-outs for the X2) it was not possible to be certain about whether penetration had occurred.

Shot ID	Device	Observations	Dart penetration	Perforation: Impact absorber penetration	Perforation: Probe body penetration	Probe remained in the target	Remaining exposed length (mm)	Penetrated length (mm)
486	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	35	26
487	T10	Remaining length 42mm.	y	y		y	42	19
488	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	34	27
489	T10	Probe bounced out. Rubber observed on the probe barb, so penetration evidenced.	y				-	-
490	T10	Very slight penetration of impact absorber.	y	y		y	45	16
491	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	35	26
492	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	33	28
493	T10	Very slight penetration of impact absorber.	y	y		y	43	18
494	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	31	30
495	T10	Penetration of entire impact absorber. Partial penetration of brass ring.	y	y	y	y	36	25
496	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	35	26
497	T10	Entire impact absorber and part of probe body penetrated.	y	y	y	y	36	25
498	T10	Very slight penetration of impact absorber.	y	y		y	43	18
499	T10	Ceased just before brass ring at the top of penetration site, with part of impact absorber visible at the bottom.	y	y		y	36	25
500	T10	Very slight penetration of impact absorber.	y	y		y	43	18

Table 14: Skin penetration results for T10 probes. For each shot, the occurrence of various effects (dart penetration, impact absorber penetration, probe body penetration, and the probe remaining in the target) are denoted by the dark shaded areas. The remaining exposed length of the probe is recorded, and the penetrated length inferred from the exposed length and the known total length of the probe (61mm).

			Upper Probe					Lower Probe				
Shot ID	Device	Observations	Dart penetration	Perforation: Probe body	Probe remained in the target	Remaining exposed length (mm)	Penetrated length (mm)	Dart penetration	Perforation: Probe body	Probe remained in the target	Remaining exposed length (mm)	Penetrated length (mm)
501	X2	Both probes bounced out. No visible penetration.	?			-	-	?			-	-
502	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	16	20	?			-	-
503	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	15	21	?			-	-
504	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	16	20	?			-	-
505	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	13	23	?			-	-
506	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	17	19	?			-	-
507	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	11	25	?			-	-
508	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	14	22	?			-	-
509	X2	Both probes penetrated and embedded.	y	y	y	15	21	y	y	y	19	17
510	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	10	26	?			-	-
511	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	17	19	?			-	-
512	X2	Both probes penetrated and embedded.	y	y	y	16	20	y	y	y	18	18
513	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	11	25	?			-	-
514	X2	Upper probe body penetrated epidermis. Lower probe bounced and not embedded.	y	y	y	17	19	?			-	-
515	X2	Both probes penetrated and embedded. Lower probe – probe only penetrated; probe body not penetrated.	y	y	y	18	18	y		y	-	-

Table 15: Skin penetration results for X2 probes. For both probes for each shot, the occurrence of various effects (dart penetration, impact absorber penetration, probe body penetration, and the probe remaining in the target) are denoted by the dark shaded areas. The remaining exposed length of the probe is recorded, and the penetrated length inferred from the exposed length and the known total length of the probe (36mm).

For the T10, the dart penetrated the skin for all shots. For 14 of the 15 (93%) shots, the probe remained embedded in the target, and for all of those shots at least the impact absorber also penetrated the skin (along with the dart), therefore causing skin perforation. The probe body penetrated the skin for 8 shots. Penetration often occurred at a slight angle, but it was not clear whether the probe entered the skin at an angle, or whether the probe became angled after striking and penetrating the skin simulant target.

For the X2, the upper probe penetrated and remained in the skin simulant for 14 of the 15 (93%) shots, with the probe body also penetrating the skin in all of those instances, causing perforation. The lower probe, in contrast, bounced out of the target for all but 3 of the 15 shots (20%), with it being unclear whether penetration of the dart occurred prior to bounce out –

overall 17 of 30 (57%) X2 probes remained in the target. Of the 3 lower probes that did penetrate and remain in the target, 2 had the probe body also perforate the skin.

7.3.1 Impact absorber compression

During testing it was noted that compression of the rubber impact absorber would mean that the length of dart able to enter the skin would be longer than the 11mm that is exposed when the impact absorber is uncompressed (see Figure 16). To measure an estimate of the length of dart that could be exposed after compression (i.e. the length the tip of the dart could penetrate into a target, such as skin, if the impact absorber is compressed), a T10 duty probe was hand pushed into the jaws of a vice that was opened such that only the dart could pass between the jaws. This allowed the impact absorber to be manually compressed against the side of the jaws.

The length of the T10 dart after compression of the impact absorber was approximately 15mm (see Figure 18). This is only an estimate of what would happen when a dart impacts a target – the details of how the impact absorber compresses and decompresses would require additional testing to capture.

Figure 18: Compression testing of the impact absorber of a T10 probe, showing an exposed dart length of approximately 15mm after compression (compared to 11mm without compression).

7.3.2 Kinetic energy density

An interesting additional parameter to compare between the T10 and X2 in the context of skin penetration is the kinetic energy density, where the kinetic energy of the probe is compared to the surface area of the probe body. This parameter, when compared for different probes (e.g. X2 probes), could provide a useful indicator of relative perforation likelihood, since perforation requires kinetic energy of the probe to be used to break bonds in the skin surface corresponding to the size of the probe body in order for it to penetrate the outer skin layer and cause perforation.

For the T10, the probe body diameter was measured to be 6.0mm (to within 0.1mm), and the average kinetic energy of the probe was measured to vary from 7.19±0.54J at 0.3m range to

1.85±0.55J after detachment (see Section 6.3.3). The corresponding kinetic energy densities are therefore 0.254±0.021 J/mm^2 and 0.065±0.02 J/mm^2.

This could be compared with X2 probes (or other CED probes) to indicate relative perforation likelihood. X2 probe velocity was not measured in this testing, so the kinetic energy is not known, but previous test data could be used to evaluate the kinetic energy density for a comparison. Note that the X2 probe has a smaller diameter (approximately 5.1mm, although the probe does not have a cylindrical profile, but instead has slots cut into it along its length) than the T10, so will have a higher kinetic energy density for a given kinetic energy. This may explain why the X2 and T10 produce comparable skin penetration results here, given that the T10 is understood to produce significantly higher kinetic energy probes than the X2 – the increased surface area of the T10 offsets some of the increased kinetic energy when considering the probability and extent of perforation.

Note that the presence of the T10 impact absorber complicates the interpretation of the kinetic energy density as a direct measurement of the likelihood of skin perforation – the impact absorber is both designed to absorb energy (reducing the probe kinetic energy), as well as presenting a slightly larger surface area for impact (reducing the kinetic energy density), both of which will reduce the likelihood of perforation. The X2, in contrast, has no impact absorber.

7.4 Conclusions

Comparing the T10 and X2 skin penetration results, both showed repeated perforation of the skin simulant target (i.e. penetration by more of the probe than just the dart). For the X2, only 1 of 17 shots that remained in the target did not have the probe body perforating the skin; for the T10, all shots that remained in the target had perforation – at least the impact absorber penetrating the skin, and over half (8 out of 14; 57%) also having the probe body penetrating the skin.

The length of probe penetration into the skin was similar but typically slightly higher for the T10 (between 16mm and 30mm across all shots) than the X2 (between 18mm and 25mm across all shots). Comparing the deepest probe penetrations as a basic estimate for a worst case, the T10 (30mm) achieves 20% higher penetration depth than the X2 (25mm). For the average penetration, the T10 penetration was 10% deeper than the X2 (23.4mm compared to 21.3mm). Note that it is understood that the skin pack used is designed to simulate the vulnerability of different skin layers and not to give an accurate simulation of penetration depth, so interpretation of penetration depth data should be performed with additional understanding of the details of the skin pack behaviour not available to the authors. Note also that the dart lengths are the same for both types of probes (11mm), although compression of the T10 impact absorber upon the probe hitting a target was estimated to expose a dart length of order 15mm.

In terms of the repeatability of penetration, only 1 of 15 T10 probes (7%) did not remain in the target, whereas 13 of the 30 X2 probes (43%; mainly the bottom probe, presumably due to a less preferable entry angle) bounced from the target and were not retained in the target. The T10 was therefore more consistent at penetrating and remaining in the target than the X2 during testing.

Note that the testing here focused on a skin simulant target intended to mimic the properties of particularly vulnerable human skin – the results are not indicative of the behaviour of typical human skin. Therefore, the high level of perforation that was observed should not be used to infer that perforation is likely for all relevant skin targets, or for all ranges (note the short range of 0.5m in this testing). The primary focus of this test was a comparison of the skin penetration of X2 and T10 probes, and an assessment of the likelihood of skin perforation from T10 probes would require additional investigation using different skin targets to represent different types of skin targets, and at different ranges. In particular, it is understood (by comparison of the T10 ballistics data in this report with existing X2 data not available to the authors) that the relative kinetic energy between a T10 and X2 probe increases with distance – i.e. a X2 probe loses kinetic energy at a faster rate than a T10 probe. This is likely to mean that if skin penetration behaviour at short range is similar between the T10 and X2 probes, as observed here, the differences in behaviour may become more apparent at longer ranges. Note also that no skin perforation was observed in the clothing penetration testing (see Section 8) despite the use of a similar skin simulant target (albeit with a conductive layer inserted beneath the outer skin layer) and the inclusion of some thin clothing (e.g. a single t-shirt layer).

In summary, the T10 was observed to penetrate skin and be retained in the skin more repeatably than the X2, with a similar but slightly higher average penetration depth. The testing here used simulants of particularly vulnerable skin, so the frequency and extent of perforation observed may not be typical of typical human skin.

Note also that the data in this chapter used clamped devices, and it has been subsequently identified that hand-fired devices appear to exhibit a small (2.5%) decrease in average velocity and an increase in the velocity spread, compared to clamped devices (see Section 3). The results in this chapter therefore represent a worst-case scenario when considering the injury-causing potential of devices.

In both cases the impact is likely to be small given the small decrease in mean velocity for hand-fired devices compared to clamped devices, and the high amount of overlap in the velocity distributions for each state.

8 Clothing penetration

8.1 Purpose

This test was to assess the effectiveness of the T10 against different clothing combinations, including the ability of the probe to penetrate clothing and be retained in the skin.

8.2 Methodology

A T10 was fired at a target covered with a skin surrogate and different combinations of clothing:

- **'Basic' clothing**
    1. A single layer cotton T-shirt
    2. A hoody
    3. A single layer denim jeans material
    4. A hoody over a cotton T-shirt
- **'Challenge' clothing**
    5. A thick padded jacket over a hoody over a cotton T-shirt

This was repeated 15 times for each clothing combination, at a range of both 8m (a typical operational distance) and 2m (to explore whether any flight instability of the probes at short range may change the clothing penetration due to variability in the incident angle). The range was subsequently varied to establish the maximum range of successful penetration.

The target was a TP5 skin pack (as used in the skin penetration testing – see Section 7) with a thin conductive layer inserted below the outermost skin layer. This was in order to allow the electrical conductivity between the probe and the target to be measured and assessed for each shot. Probes were left in place with the shot placement varied to allow inter-probe conductivity measurements to be measured (between the two most recent shots), as well as probe-to-target resistances. These measurements were performed by measuring the resistance between the inside of the fired cartridge (which is electrically connected to the wire and probe) and a copper wire (of 1.0mm diameter) connected to the wire wool pack. Conductivity was considered to be achieved if a resistance below 100Ω was achieved.

More details on the methodology are provided in Appendix E.

8.3 Results

Table 24 summarises the results of the clothing penetration testing, with a breakdown of the data provided in Appendix E. The analysis is split in the following between 'basic' clothing (types 1 to 4 – single or double layers), and 'challenge' clothing (type 5). This reflects the order of testing – types 1 to 4 were initially tested, with type 5 introduced subsequently to assess a particularly challenging type of clothing as identified by end users.

Range	Clothing combination	Number of Shots	Shots with connectivity achieved	Success rate
2m	T-shirt	15	15	100%
	Hoody	15	15	100%
	Denim	15	15	100%
	Hoody + T-shirt	15	15	100%
	Padded Jacket + Hoody + T-shirt (Back)	15	15	100%
8m	T-shirt	15	15	100%
	Hoody	15	15	100%
	Denim	15	15	100%
	Hoody + T-shirt	15	14	93%
	Padded Jacket + Hoody + T-shirt (Front)	15	10	67%
	Padded Jacket + Hoody + T-shirt (Back)	15	12	80%
13.4m	Padded Jacket + Hoody + T-shirt (Back)	10	10	100%
15m	T-shirt	10	10	100%
	Hoody	10	10	100%
	Denim	10	10	100%
	Hoody + T-shirt	10	10	100%
	Padded Jacket + Hoody + T-shirt (Front)	10	9	90%
	Padded Jacket + Hoody + T-shirt (Back)	10	10	100%
Overall ('basic' clothing)		**160**	**159**	**99.4%**
Overall ('challenge' clothing)		**75**	**66**	**88%**
Overall (all clothing types)		**235**	**225**	**95.7%**

Table 16: Results of the T10 clothing penetration testing for different ranges and clothing combinations.

8.3.1 'Basic' clothing

Of the 160 shots used on basic clothing (types 1 to 4 as described above), only one was unsuccessful in producing an electrical pathway between the probe and the target – this was for a hoody over a cotton t-shirt at a range of 8m, for which the probe impacted in a fold of the hoody and no penetration occurred (see Figure 19). Representative photographs are shown in Table 17.

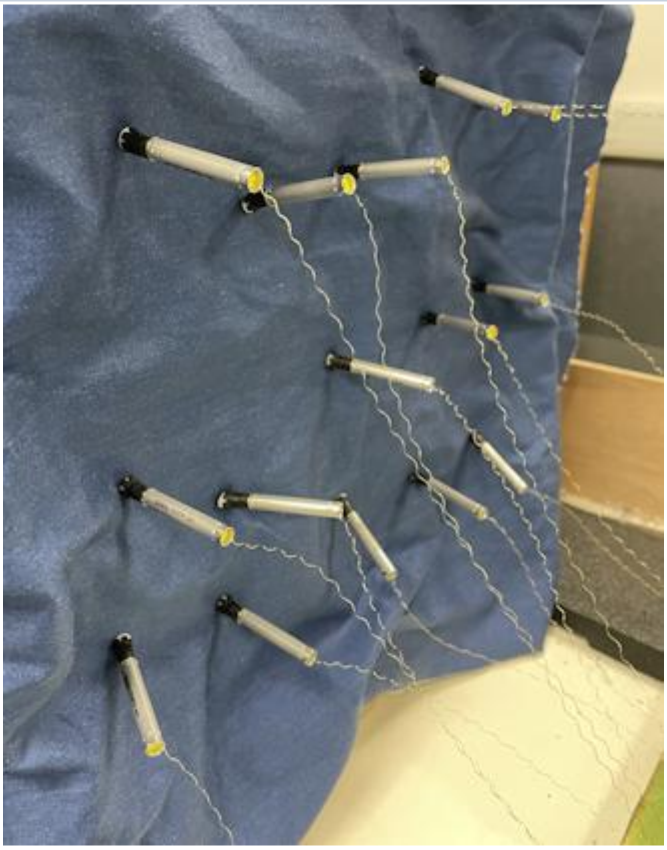
Clothing penetration representative images	
	
Cotton t-shirt at 2m range	Hoody over cotton t-shirt at 15m range
	
Denim at 2m range	Hoody over cotton t-shirt at 2m range

Table 17: Representative photographs of clothing penetration testing of different 'basic' clothing combinations at different ranges.

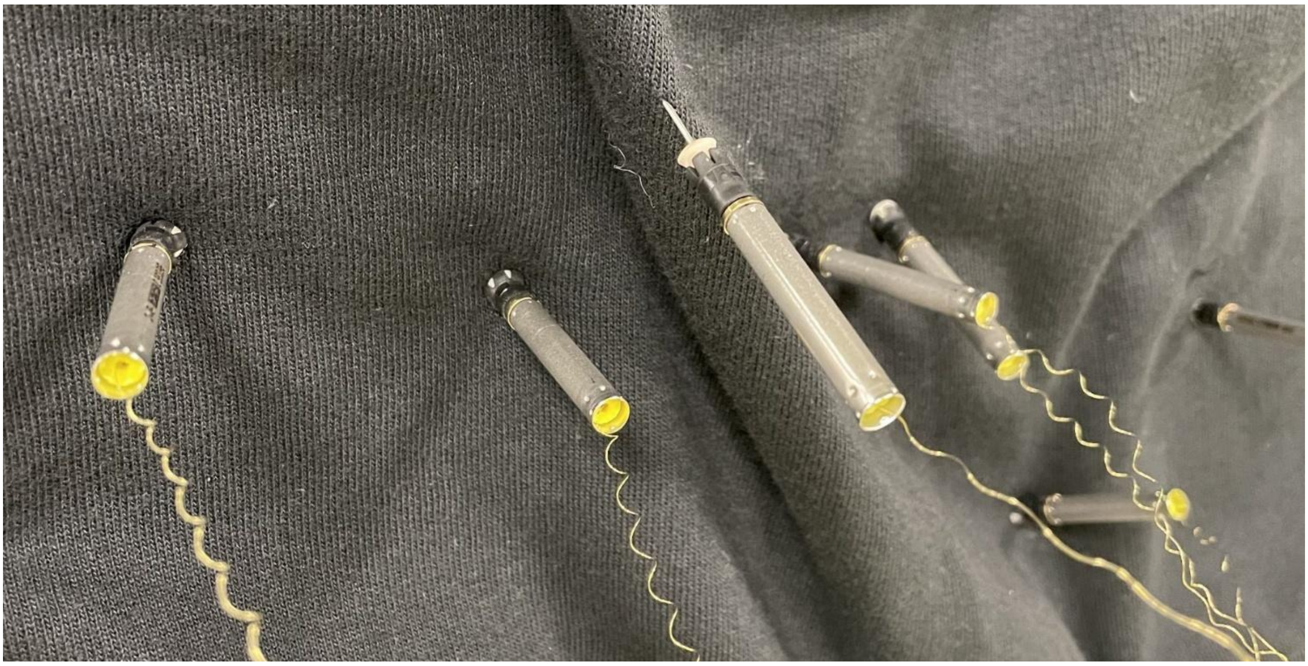


Figure 19: Photograph of the only shot during 'basic' clothing penetration testing that did not successfully penetrate the target; the top middle probe was caught in a fold of the hoodie.

Given the high rate of success, when investigating the maximum range that clothing penetration occurred at, testing began at 15m as the longest practical range available (given that 15.35m had been previously determined to be the nominal probe detachment point – see Section 5.3). All 40 shots (10 for each clothing type) were successful at this range.

The wire in 7 of the 40 shots at 15.0m snapped. In such cases of wire break, the probe-to-target and probe-to-probe resistances were still obtained, either by de-insulating the wire and reading from the wire at the CED end, or by reading directly from the probe body then adding the missing wire resistance (known from previous measurements). Close inspection of the snapped wires revealed that these were not significantly shorter wires (indicating a tight length tolerance on T10 wires).

It is hypothesised that in these cases, violent yawing of the probe body on impact may have flicked the wire into an arc, causing it to fail in tension at one of either end. This hypothesis also explains why the free-flight probes in Test 1 Serial 9 always disconnected at the probe end, as there was no target impact and therefore no consequent flicking of the wire.

The conductivity measurements were highly consistent throughout – probe to target resistance was between 43Ω and 48Ω for all measurements (the resistance is non-zero due to the resistance of the wire between the bay and the probe), and probe-to-probe resistance was between 86Ω and 94Ω (i.e. equal to the sum of two separate probe-to-target resistances).

Note that no skin perforation was observed in any clothing penetration tests.

8.3.2 'Challenge' clothing

Testing of the challenge clothing (a thick padded jacket over a hoodie over a t-shirt) initially began at 8m with the front of the padded jacket facing the device. 10 out of 15 shots (67%) successfully achieved a pathway, with plastic zips and seams contributing to some of the 5 failed shots: one shot was deflected by a seam and bounced out of the clothing; one shot penetrated a double layer of hood plus jacket but did not remain in contact with the conductive target; one impacted near a zip and did not penetrate the conductive target; and two shots bounced out of the clothing without a clear cause. Another shot successfully penetrated through a zip and achieved an electrical pathway to the target. Representative photographs are shown in Table 18.

'Challenge' clothing penetration representative images

Padded Jacket (front) + Hoody + T-shirt at 8m range

Padded Jacket (back) + Hoody + T-shirt at 8m range

Padded Jacket (back) + Hoody + T-shirt at 2m range

Padded Jacket (front) + Hoody + T-shirt at 15m range

Table 18: Representative photographs of clothing penetration testing of the 'challenge' clothing type at different ranges.

The testing at 8m was then repeated with the back of the jacket facing the device (thereby presenting a more uniform target), to reduce the variability caused by zips. The underlying hoody and t-shirt were also reversed so the backs of all items of clothing were facing the device (thereby ensuring there were no zips between the device and the conductive target). 12 of 15 (80%) shots successfully achieved an electrical pathway, with the three unsuccessful shots all remaining lodged in the clothing.

Subsequent testing at 2m achieved a 100% success rate over 15 shots for the back of the jacket. The same results (15 out of 15 successes) were achieved at 13.4m (chosen as a previously-used distance which approaches the maximum useable engagement distance, but at which there remains no possibility of wire snap). Finally, at 15m range, 10 out of 10 (100%) shots were successful when using the back of the jacket, and testing was also performed using the front of the jacket (to allow comparison with the data at 8m range) which observed 9 out of 10 (90%) shots being successful – the one unsuccessful shot was due to the probe hitting a zip. Note that at 15m, 50% of the shots resulted in the wire snapping (as described above in the 'basic' clothing results).

As was observed for the 'basic' clothing testing, the conductivity measurements were highly consistent throughout and no skin perforation was observed for any shots.

8.4 Conclusions

Clothing penetration was consistently observed for all tested clothing combinations at 2m and 15m. This indicates that there are no significant issues with probe flight instabilities at short range (2m) that prevent penetration of the tested clothing. The consistent penetration at 15m highlights the effectiveness of the probes towards the limit of their range. Note this is beyond any practicable operational range, as even though accuracy may remain adequate for a stationary target, the wire will be fully unwound, meaning that any operator or target movement would likely result in wire snap and immediate disconnection (see also Section 5).

Clothing penetration at 8m was, counterintuitively, less consistent than at 2m and 15m. For the 'challenge' clothing, successful penetration was achieved for 22 out of 30 shots (73% success) and was strongly influenced by the presence of features such as zips – when using the back of the jacket (to minimise the number of such features) the success rate was 80%, compared to 67% for the front of the jacket. For 'basic' clothing, in contrast, there was only one failure out of 160 shots (99.4% overall success), which was for a hoody over a t-shirt and caused by a fold in the fabric (see Figure 19). The key finding is therefore that there are 'reasonable' levels of clothing that may prevent individual probe firings from penetrating. Two additional findings are: the presence of small features (including zips and folds as observed here, and likely including buttons, fasteners, etc.) can prevent penetration; and there appears to be a noticeable drop in the ability to penetrate more challenging clothing at intermediate range compared to at close range and long range. One hypothesis might be that projectile stability changes mid-flight (possibly due to how the wire is deployed behind the probe), leading to non-normal impact and a greater likelihood of failure when striking challenging clothing combination at mid ranges. The data collected in this testing was, however, not able to test this hypothesis. It is possible that Axon may already be aware of such an effect, and approaching them for advice may be instructive.

When considering the impact on operational use of different penetration success rates, it is important to distinguish between the success rate for single probe penetration (which has been the focus of the analysis above) and the success rate for two probes to penetrate (which is required for successful energisation of the device against a target) given a certain number of shots. If, for example, the individual probe success rate is 80%, the likelihood of achieving two successful penetrations from two shots is only 64%, but rises to 90% after three shots are deployed and 97% after 4 shots (see Table 19). This highlights how the effect of a (relatively) low single probe penetration success rate changes significantly with the number of shots. Note that Table 19 represents a best-case scenario – the penetration ability of hand-fired devices may be reduced compared to clamped devices (see Section 2.4), and to achieve a desired effect on a target depends on the probe placement and separation, not just achieving an electrical connection.

Probability of achieving a successful connection between at least two probes						
		Number of on-target shots				
		1	**2**	**3**	**4**	**5**
Probability of successful penetration for a single probe	**100%**	N/A	100%	100%	100%	100%
	90%	N/A	81%	97%	100%	100%
	80%	N/A	64%	90%	97%	99%
	70%	N/A	49%	78%	92%	97%
	60%	N/A	36%	65%	82%	91%
	50%	N/A	25%	50%	69%	81%

Table 19: The probability of achieving a successful electrical connection between at least two probes as a function of the probability of successful penetration (i.e. probability of a single probe making an electrical pathway with the target) and the number of shots (assuming that all shots are accurate and impact the target).

Note also that the data in this chapter used clamped devices, and it has been subsequently identified that hand-fired devices appear to exhibit a small (2.5%) decrease in average velocity and an increase in the velocity spread, compared to clamped devices (see Section 3). The results in this chapter may therefore be an overestimate of the ability of probes to penetrate a target when hand-fired rather than clamped, although any overestimate is likely to be small given the small decrease in mean velocity for hand-fired devices compared to clamped devices, and the high amount of overlap in the velocity distributions for each state.

It is interesting to note that for all shots in this testing, penetration of the skin packs was only by the darts – there was no penetration by the probe body or the impact absorber. The interaction of the clothing with the skin and probe appears to consistently prevent the deeper penetration observed in the skin penetration testing (see Section 7).

9 Skull fracture/penetration

9.1 Purpose

This test was to assess the risk of skull fracture or penetration using a skull fracture model target.

9.2 Methodology

A T10 and X2 were fired at short range (50cm – the practical limit for testing, and for consistency with other tests) into bone surrogate models provided by Dstl. One T10 and one X2 shot were used on each of twenty models repeated 20 times with a T10, with a single T10 probe shot at 20 different bone surrogate models.

The model was visually inspected by the operator after the shots (note that initially this was performed after each shot, but latterly after both the T10 and X2 shots once there was sufficient confidence that the two impact sites would not interfere). This inspection documented any fractures and penetration (including quantifying the extent to which penetration occurred – i.e. just the dart, or the dart and the probe body). Photographs were taken to document the effect on the model (and, as per other testing, videos recorded of each shot). Damage was assessed using a fracture scale provided by Dstl which is believed to be consistent with other trials using these skull models:

1. No visible fracture of scapula
2. Linear fracture
3. Depressed intact fracture
4. Depressed detached fracture
5. Total fracture

Where the dart penetrated and stayed in, the remaining probe length was measured. The structure of a T10 and X2 probe are detailed in Section 7.2; for reference they are 61mm and 36mm in length respectively, each with an 11mm dart.

Appendix F provides further information regarding the test models and methodology for this testing.

9.3 Results

Table 20 contains the results for the T10 skull fracture/penetration testing, and Table 21 contains the X2 results.

CED type	Shot ID	Observations	Fracture scale	Remaining exposed length (mm)	Penetrated length (mm)	Skin penetration	Remained in the target	Mark on bone	Bone penetration
T10	726	Bounced. Distorted dart. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
T10	727	Penetrated and stayed in. Distorted dart. Mark on skin. No visible mark on bone.	1	40	21	y	y		
T10	728	Penetrated and stayed in. Pin prick on bone.	1	44	17	y	y	y	
T10	729	Penetrated and stayed in. Distorted dart. No visible mark on bone.	1	32	29	y	y		
T10	730	Penetrated and stayed in. Distorted dart. Pin prick on bone.	1	42	19	y	y	y	
T10	731	Penetrated and stayed in. Distorted dart. Pin prick on bone.	1	44	17	y	y	y	
T10	732	Penetrated and stayed in. Distorted dart. Small mark on bone.	1	42	19	y	y	y	
T10	733	Bounced. Distorted dart. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
T10	734	Bounced. Bent dart. Pin prick on bone.	1	-	-	y		y	
T10	735	Penetrated and stayed in. Distorted dart. Pin brick on bone.	1	44	17	y	y	y	
T10	736	Penetrated and stayed in. Distorted dart. Pin prick on bone. Small bit of dart broken off and retained in bone.	1	45	16	y	y	y	
T10	737	Penetrated and stayed in. Bent dart. Two pin prick marks on bone.	1	41	20	y	y	y	
T10	738	Penetrated and stayed in. Distorted dart. Pin prick on bone.	1	40	21	y	y	y	
T10	739	Bounced. Distorted dart. Small mark on skin. No visible mark on bone.	1	-	-	y			
T10	740	Penetrated and stayed in. Perforated to the back of the bone and hooked back. Unable to remove dart by hand. (Note that compared to 741, bone was not significantly thinner at point of impact.) Bone thickness at impact site = 3.6mm.	1	35	26	y	y	y	y
T10	741	Bounced. Dart slightly bent at tip. No visible mark on bone. For reference: bone thickness at impact site = 3.7mm, so similar thickness to 740 but different results.	1	-	-	y			
T10	742	Bounced. Distorted dart. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
T10	743	Bounced. Distorted dart. Mark on skin. No visible mark on bone.	1	-	-	y			
T10	744	Penetrated and stayed in. Distorted dart. Very slight insertion of probe body. Mark on skin. Pin prick on bone.	1	36	25	y	y	y	
T10	745	Penetrated and stayed in. Distorted dart. No visible mark on bone.	1	45	16	y	y		

Table 20: Skull penetration results for T10 probes. For each shot, the occurrence of various effects (penetration of the skin layer, damage/penetration of the bone, and the probe remaining in the target) are denoted by the dark shaded areas. Where the probe remained in the target, the remaining exposed length of the probe was recorded, and the penetrated length inferred from the exposed length and the known total length of the probe (61mm).

CED type	Shot ID	Observations	Fracture scale	Remaining exposed length (mm)	Penetrated length (mm)	Skin penetration	Remained in the target	Mark on bone	Bone penetration
X2 (top probe)	746	Penetrated and stayed in. Bent dart. No visible mark on bone. (Note: gouge mark present from butcher, not from impact.)	1	26	10	y	y		
X2 (top probe)	747	Bounced. Bent dart. Very small mark on skin. No visible mark on bone.	1	-	-	y			
X2 (top probe)	748	Bounced. Bent dart. Small mark on skin. Small mark on bone. (Note: Air pocket behind impact point. Bottom dart penetrated.)	1	-	-	y		y	
X2 (top probe)	749	Bounced. Both darts bent. Small mark on skin. No damage on bone.	1	-	-	y			
X2 (top probe)	750	Bounced. Bent dart. Small mark on skin. No damage to bone.	1	-	-	y			
X2 (top probe)	751	Bounced. Bent dart. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
X2 (top probe)	752	Bounced. Bent dart. Small mark on skin. Small nick on bone.	1	-	-	y		y	
X2 (top probe)	753	Bounced. No deformation on dart. Small mark on skin. No mark on bone. (Note: bottom dart penetrated.)	1	-	-	y			
X2 (top probe)	754	Penetrated and stayed in. Dart very slightly bent. Pin prick on bone.	1	27	9	y	y	y	
X2 (top probe)	755	Penetrated and stayed in. Bent dart. Didn't get through gelatine layer. No mark on bone.	1	25	11	y	y		
X2 (top probe)	756	Penetrated and stayed in. Dart bent at tip. Pin prick on bone.	1	32	4	y	y	y	
X2 (top probe)	757	Bounced. Bent dart. Didn't get through gelatine layer. Small mark on skin. No mark on bone.	1	-	-	y			
X2 (top probe)	758	Bounced. Bent dart. Mark on skin. Pin prick on bone.	1	-	-	y		y	
X2 (top probe)	759	Penetrated and stayed in. Dart slightly bent. Pin prick on bone.	1	25	11	y	y	y	
X2 (top probe)	760	Penetrated and stayed in. Bent dart. Pin prick on bone.	1	27	9	y	y	y	
X2 (top probe)	761	Bounced. No deformation on dart. Slight mark on skin. No visible mark on bone.	1	-	-	y			
X2 (top probe)	762	Bounced. No deformation on dart. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
X2 (top probe)	763	Bounced. Bent dart. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
X2 (top probe)	764	Bounced. Dart very slightly bent. Small mark on skin. Pin prick on bone.	1	-	-	y		y	
X2 (top probe)	765	Penetrated and stayed in. Slight bend in dart. Pin prick on bone.	1	25	11	y	y	y	

Table 21: Skull penetration results for X2 probes. For each shot, the occurrence of various effects (penetration of the skin layer, damage/penetration of the bone, and the probe remaining in the target) are denoted by the dark shaded areas. Where the probe remained in the target, the remaining exposed length of the probe was recorded, and the penetrated length inferred from the exposed length and the known total length of the probe (36mm).

There were two notable results from T10 shots worth detailing. In shot 736, the end of the dart snapped and was retained in the bone (in addition to considerable dart deformation, which was observed regularly in T10 shots); Figure 20 shows the deformation and fragment of the dart. In shot 740, the dart penetrated fully through the bone and became embedded such that it was not possible to remove the dart by hand.

Figure 20: Photos of the T10 dart after shot 736, in which a fragment of the dart remained in the model. ***Left:*** *The T10 probe; note the missing end of the dart.* ***Left:*** *Snapped piece of dart removed from bone.*

Note that, in subsequent examination, variation in bone thickness was observed across models, though for shot 740 the bone thickness at the impact site was not notably different to other shots which did not have the same effect (3.6 mm compared to 3.7 mm in shot 741 which did not have the same result). There was also considerable variation in gel thickness (above the bone) such that, for some shots, it is believed that the dart would have impacted the bone before the impact absorber impacted the skin (and vice versa for other shots). This applies equally to X2 and T10 shots, so comparative results remain valid.

9.4 Conclusions

All shots for both T10 and X2 probes scored a 1 on the fracture scale provided by Dstl; this was regardless of whether there was no bone damage or if there was a pin-prick perforation or small chip to the bone as the schema does not account differently for these. According to this scoring, the two devices are equivalent.

This scoring system, however, does not highlight the slight variation in actual damage between the devices. The most common result for both devices was a pin-prick or small mark to the bone – 13 of 20 (65%) for T10 shots; 12 of 20 (60%) for X2 shots. There were slightly more instances of no mark to the bone for the X2 (8 of 20 – 40%) compared to the T10 (6 of 20 – 30%) though this is not significant given the number of tests conducted.

Notably, there were two exceptional results for the T10 (which still score 1 according to the fracture scale) and none for the X2. One shot for the T10 resulted in a dart fragment breaking off into the bone, and another in a probe for which the dart (but not the probe body or impact assembly) fully perforated the bone and was not possible to remove by hand.

The T10 does, therefore, appear to present a slightly higher risk of skull penetration by the dart than the X2, while still scoring identically on the fracture scale and producing comparable quantitative data (within the statistical confidence of the amount of data collected). No instances of skull penetration by the probe body or impact absorber were observed.

Note also that the data in this chapter used clamped devices, and it has been subsequently identified that hand-fired devices appear to exhibit a small (2.5%) decrease in average velocity and an increase in the velocity spread, compared to clamped devices (see Section 3). The results in this chapter therefore represent a worst-case scenario when considering the injury-causing potential of devices.

10 Robustness

10.1 Purpose

This test was to assess the robustness of the T10 through drop testing and supplements the data from Axon available to the Home Office.

10.2 Methodology

A T10 was loaded with 10 duty cartridges, placed into the ARMED state (controlled by the position of the selector switch), and dropped from a height of 2m using an electromagnetic drop release mechanism (to ensure consistent drop speed) onto a 12mm thick metal plate placed on a concrete floor. The T10 was dropped such that the impact point varied according to the table below:

Drop Position	Impact Point
1	Bottom
2	Front
3	Top
4	Back
5	Right-hand side
6	Left-hand side
7	Front bottom corner
8	Top back corner
9	Back bottom corner
10	Front top corner

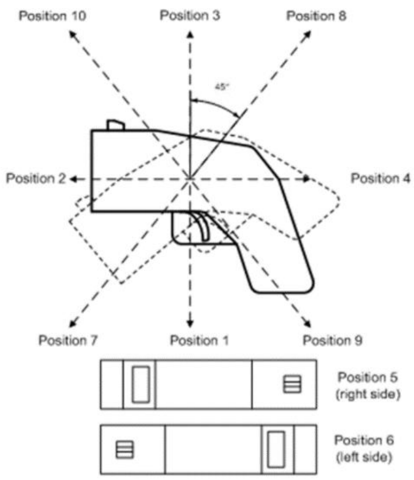


Figure 21: The drop positions used for the robustness testing.

After each drop the device was checked in the following order:

1. Visual check that the magazine and battery were still engaged correctly – i.e. not dislodged.
2. Visual check that the Central Information Display (CID) was operating normally.
3. Visual check that the selector switch remained in the ARMED position.
4. A function check carried out.
5. The device test fired once.
6. The alignment of the laser sights assessed – the device was mounted in the same firing rig used for the other tests and the position of the laser on a target 12m away (the point of aim, POA) was measured. (Prior to the drop tests, the device was inserted and removed from the firing rig 10 times to measure and assess the variability of the POA with remounting.)

The single fired bay was then reloaded before the next drop.

The same handle and magazine were used for all drop tests to understand cumulative effects as well as single-drop impacts.

10.3 Results

A summary of the results of the drop test are provided in Table 22. For measurements of the POA of the laser after the drop test, the x and y measurements were recorded, as well as a high-level assessment of whether the POA fell within the expected range given the variation associated with mounting the device in the firing rig, defined here as within 3 standard deviations of the mean position to provide a ballpark estimate of significant change in the laser direction – more details are in Appendix G. Figure 22 shows a common error observed on the CID after drops. Figure 23 and Figure 24 shown visible separation and displacement of the frame after the two drops that resulted in visible damage.

			State of the device after drop									
Drop order	Drop position	Impact point	Magazine remained engaged	Battery remained engaged	Function test completed w/o errors	Test fired normally	POA, x (mm)	POA, y (mm)	POA within expected variation, x & y	Selector switch remained in ARMED	No physical damage observed	Notes
1	1	Bottom	y	y	y	y	5	0	y		y	No sign of physical damage to any part of weapon. CID showed a blinking red battery icon with an X inside. The battery error on the CID cleared when selector switch moved to ARMED position for function test.
2	2	Front	y	y	y	y	-1	6		y	y	No sign of physical damage to any part of weapon. CID showed a blinking red battery icon with an X inside. The battery error on the CID cleared after function test.
3	3	Top	y	y	y	y	0	-40		y	y	No sign of physical damage to any part of weapon.
4	4	Back	y	y	y	y	15	-18		y	y	No sign of physical damage to any part of weapon.
5	7	Front bottom corner	y	y	y	y	-8	-10		y	y	No sign of physical damage to any part of weapon.
6	8	Top back corner	y	y	y	y	15	-2	y	y	y	No sign of physical damage to any part of weapon.
7	9	Back bottom corner	y	y	y	y	2	-4		y	y	When device was picked up from the ground, the CID went blank with gun appearing dead. On further movement, the device returned to LIVE state. CID showed a blinking red battery icon with an X inside. Note that the battery percentage reported by the function test dropped from 65% after the previous shot to 0%. No sign of physical damage to any part of weapon.
8	10	Front top corner		y	y	y	2	-117		y		Slight separation of frame at rear and front of device observed, and a small gap formed between front body and top of magazine (see Figure 23). Video recording failed so drop was repeated.
9	10	Front top corner		y	y	y	-2	-23		y	y	No sign of physical damage to any part of weapon.
10	5	Right-hand side	y		y	y	-18	76		y	y	No sign of physical damage to any part of weapon.
11	6	Left-hand side	y		y	y	-	-	-	y		The frame of the device separated at the grip. (See Figure 24) Laser accuracy test not possible as the displaced frame would not fit the mount. Device fired manually instead.

Table 22: Summary of drop test results. POA measurements are recorded, as well as an assessment of whether the POA is within the expected range.

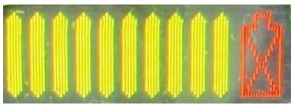


Figure 22: View of the CID when it showed a blinking red battery icon with an X inside, as occurred several times after drops. According to the Axon manual, this indicates that the device did not recognise the battery correctly. Each time the error disappeared after completing a function test.

Figure 23: Slight separation/displacement of the frame after drop onto the front top corner of the device (position 10). The magazine was ejected on this drop and was replaced manually in the right-hand picture to show the frame displacement.

Figure 24: Separation/displacement of the frame after drop onto the left-hand side (position 6). The battery was ejected on this drop.

Following the drop tests above, additional drop tests were conducted to further investigate magazine ejection and battery ejection. These results are summarised below in the Conclusions, with more detail in Appendix G.

10.4 Conclusions

10.4.1 Laser accuracy

The measured laser position on the target after drops showed that, aside from the first drop, the laser had moved more than would be expected just from variation due to remounting the handle in the firing rig. Extreme deviation first occurred (-117mm change in the y position at a range of 12m) after a drop from position 10 onto the front top corner (this drop also resulted in ejection of the magazine). Note that the impact point was very close to where the laser is mounted in the handle. As only one drop per position was required in this testing, it is not possible to generate statistically significant conclusions regarding the robustness of the laser mountings, and therefore how the device's zero may be affected by drops. It is, however, clear from this testing that it is possible to disturb the device's zero by dropping the device. The variation of the zero did remain within the general measured accuracy of the weapon as maximum useable ranges are approached (see Section 2), so there was not a clear reduction in useability.

10.4.2 Magazine ejection

Magazine ejection was only observed for drop position 10 (front top corner) in the initial drop tests. Further informal investigation was conducted using a previously undropped handle which was manually dropped 4 times in each of drop positions 7, 2 and 10 (12 total drops). The magazine detached in drop position 10 every time, but never in the other positions. With 'practice' of getting the correct impact position, it was possible to make the magazine eject every time, even from lower drops (~1m) and with an unloaded, therefore light, magazine in place. The behaviour is clearly real, and readily repeatable.

It appears that when the device is dropped such that the upper body directly forward of the foresight strikes the ground first (with no direct floor strike by the magazine itself) this results in an ejection. This motion emulates the normal magazine unloading kinetics for the T10, which by design has no magazine release catch. Whilst potentially inconvenient to a user in the event of an accidental drop, it appears limited to highly specific drop positions, although when magazine ejection did occur, it could be ejected up to 2m from the drop point, which would prevent immediate reloading and use of the device.

10.4.3 Battery ejection

Battery ejection was observed for drop positions 5 (right-hand side) and 6 (left-hand side) in the initial drop tests. To further investigate battery disengagement, 9 drops were completed onto the left and right sides of the device, with 4 of those (44%) resulting in battery ejection. Unlike with magazine ejection, it was difficult to repeatably achieve battery ejection due to air resistance causing the device to tend to not remain side-on during a drop. When ejection did occur, the battery was often ejected across the floor to about 1m distance from the drop point.

It is unclear what the mechanism of the battery ejections were. Whilst side impact may be expected to cause one of the two sideways-operating retention spring clips to release, the opposite clip should not be affected. It is possible that some temporary frame distortion or shockwave reflection effect is occurring, which causes the second clip also to release.

The key result is that battery ejection does appear to occur around half the time for side-on drop impacts, while non-side-on impacts did not result in ejection, albeit this is all with a limited sample set.

10.4.4 Auto-arming

An additional observation is that during some of the additional battery ejection drops with the devices in the SAFE mode, the selection lever moved on impact from SAFE to ARMED. Note that this effect could not be observed during the main drop tests, as the devices were always dropped armed to observe any dangerous occurrences of accidental discharge on impact (no such incidents occurred). The self-arming effect was seen only when the device was dropped from Position 3 (i.e. top down) and fell without any appreciable deviation with the top of the frame striking the floor reasonably cleanly.

To further investigate self-arming, a further 12 manual top-down drops were carried out (drop position 3). In 6 of the 12 drops (50%), the device armed itself. As with magazine detachment, the operator soon became skilled at causing the effect; precise orientation was key. It was possible to repeat the effect on a thinly carpeted concrete floor with significantly reduced drop heights (no more than 1m).

10.4.5 Summary

The T10 is formed from robust, well-moulded, but quite thin plastic components with clipped and glued body parts. Severe drops onto an unforgiving surface can cause parts to separate, the laser pointer to change alignment, the magazine and/or battery to eject up to 1-2m away, and the device to auto-arm. In general, however, these effects rely on specific drop orientations. At no point did the test operators observe damage which rendered the device inoperable – even after the most significant drop impacts, the device still functioned as designed (after reinsertion of the battery and/or magazine), and retained accuracy comparable to the shot-to-shot variation recorded in accuracy testing (see Section 2). To use the device after a drop in an operational scenario, a user would have to pick up the handle, find and replace any ejected battery or magazine, re-initialise the device, aim and fire.

On the basis of the testing performed (noting the relatively small number of measurements prevent statistically significant assessments of the robustness being made for different orientations), it is recommended that any T10 which has suffered a severe drop, particularly if onto a hard surface, should initially be withdrawn from service.

11 Sound levels

11.1 Purpose

This test is to measure the noise from the device and the possible impact on users, based on a comparison between the new T10 and the in-service X2 in the same environment (which is not intended to be a typical operational environment).

11.2 Methodology

The sound level was measured at a distance of 50cm from the devices, to reflect a typical distance from the device to the ear of an operator. This was performed for three scenarios:

1. **The device being fired (for T10 and X2 devices)**

   This was performed outside to ensure the sound of the probes' impact on a target did not influence the measurement.

   The device emitting the warning alert (for T10 devices) – this is produced by the T10 when either: a) the device has not deployed a cartridge and the selector switch is briefly moved to the press up position to activate a warning alert, consisting of a loud noise and a flashing light (strobing); b) cartridges have been deployed, and the selector switch is moved to the press up position to reenergize the cartridges, and there is not a connection (the flashlight lights as normal – no strobing). This was measured indoors.
2. **The device emitting its connection alert (for T10 devices)** – this is a continuous tone that means an electrical connection with a target has been achieved and electricity is being delivered. This was measured indoors.

The measurement was taken at 45° to the front right of the muzzle, as seen from behind the device – this position was chosen on the basis that the sound pressure level is highest towards the front of the device (due to the sound propagating primarily forward out of the bays, and the forward facing position of the speaker), and is therefore a worst-case scenario. In practice, this would be the experience of a person having a taser deployed from behind them, and a lone operator would likely experience a lower sound pressure level due to being positioned at the rear of the device.

More details are provided in Appendix H.

11.3 Results

The results are shown in Figure 25 and Table 23, separated by the CED type and the scenario in which the sound level was measured. More details are provided in Appendix H.

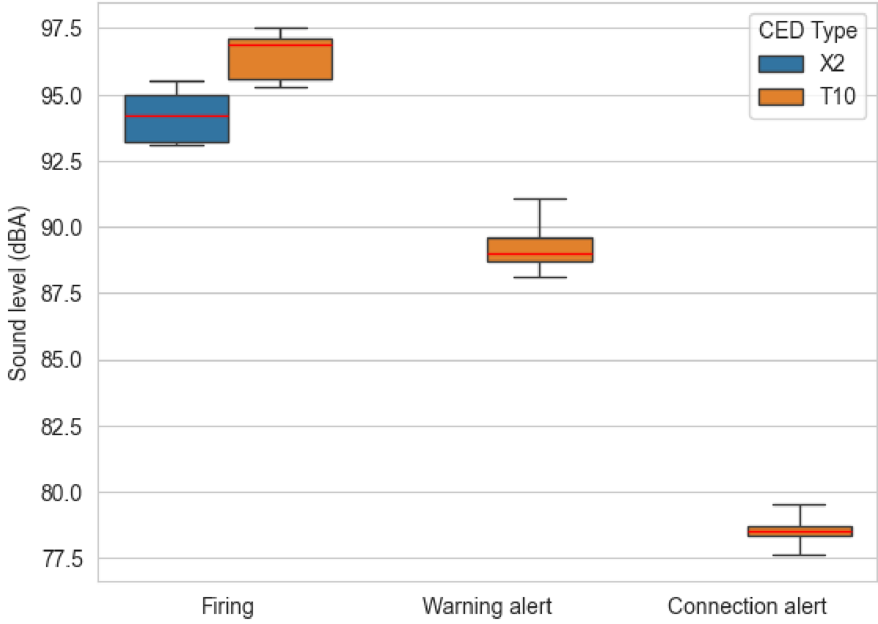


Figure 25: Box plots of sound levels measured for the T10 and X2 devices in different scenarios. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

Scenario	CED Type	Measurement count	Sound level statistics (in dBA)				
			Mean	Maximum	Minimum	Standard deviation	Standard error
Firing	T10	5	96.48	97.5	95.3	0.97	0.43
	X2	5	94.20	95.5	93.1	1.07	0.48
Connection alert	T10	10	78.51	79.5	77.6	0.51	0.16
Warning alert	T10	5	89.30	91.1	88.1	1.14	0.51

Table 23: Statistics for the sound levels measured from T10 and X2 devices in different scenarios.

11.4 Conclusions

The sound levels produced by the T10 and X2 when firing were broadly comparable; the T10 produces a sound pressure level by approximately 2dBA, corresponding to 60% higher. The warning alert of the T10 is quieter than either the X2 or T10 when being fired, but louder than the connection alert of the T10 (as expected, since the warning alert is intended for persons the operator is engaging with, rather than the operator themselves, for whom the connection alert is for). Overall, the T10 was not observed to be significantly louder than the X2 in testing, although end users should test the sound levels in their own operational environments in order to ensure that cumulative sound levels do not surpass safety limits.

Note that the measurement of the sound level for the T10 being fired was originally performed with the device aimed at a target board (as used in the accuracy testing), but the sound of the probe impacting on the target board was loud enough to influence the measurements. Sound levels were instead recorded while firing the T10 at a range that would guarantee detachment. This means that the highest sound levels observed by an T10 operator could be from the probe impact rather than the discharge of the CED – this would be situation and target dependent.

All the sound levels measured here were measured in laboratory-type conditions to perform a comparison between the T10 and X2; they are unlikely to be representative of the absolute sound levels that end users would be exposed to due to operational environments differing from the testing environment. For example, training environments may be highly reverberant, which would impact the sound levels that users would be exposed to. It is important that all end users perform their own testing to ensure that sound levels do not exceed the relevant limits, both for the peak exposure and cumulative exposures.

12 Laser power

12.1 Purpose

The output power of the laser sighting system was measured to confirm that the device is labelled correctly.

12.2 Methodology

The laser power was be measured by a Coherent ‘Laser Check’ portable laser power meter (set to detect 510nm light) at a 1m distance from the laser emitter. The measurement was repeated 10 times for 6 different T10 handles (60 total measurements). More details are available in Appendix I.

12.3 Results

The results are shown in Figure 26 and Table 24 for each of the six T10 handles tested. More details are provided in Appendix I.

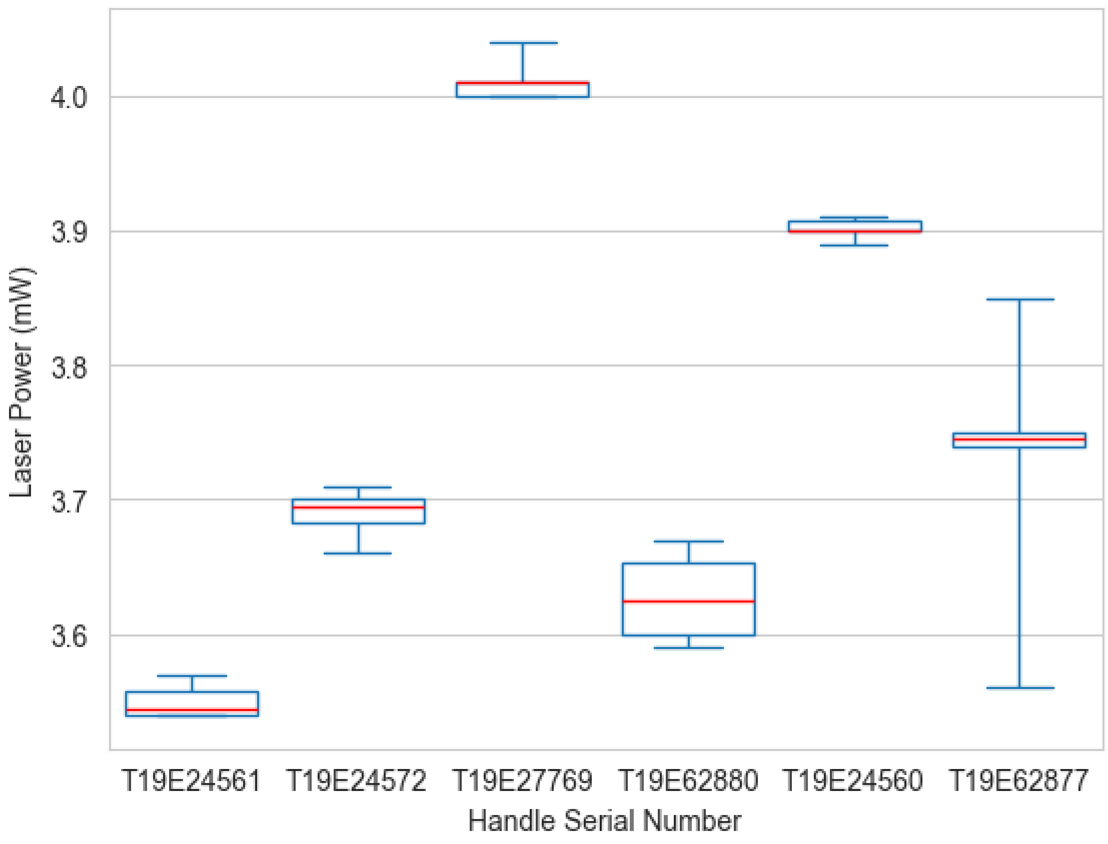


Figure 26: Plots of laser power levels measured for 6 different T10 handles. The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line is the median value.

Handle Serial Number	Measurement Count	Laser power (mW)				
		Mean	Maximum	Minimum	Standard deviation	Standard error
T19E24560	10	3.90	3.91	3.89	0.007	0.002
T19E24561	10	3.55	3.57	3.54	0.012	0.004
T19E24572	10	3.69	3.71	3.66	0.016	0.005
T19E27769	10	4.01	4.04	4.00	0.012	0.004
T19E62877	10	3.74	3.85	3.56	0.071	0.022
T19E62880	10	3.63	3.67	3.59	0.029	0.009
Total	**60**	**3.75**	**4.04**	**3.54**	**0.162**	**0.021**

Table 24: Statistics for the laser power levels measured from different T10 handles.

12.4 Conclusions

The laser power variation was larger between handles than measurement-to-measurement for individual handles, with a maximum laser power of 4.04mW, and all measurements falling in a 0.5mW range – all measurements were within 12.4% of the maximum measured power. The laser power of the tested handles was therefore broadly consistent.

Figure 27 shows the labelling which was attached to the versions of the T10 handles tested. The measured output powers above are less than the specified maximum output on the label (5mW). 5mW is also the maximum output of this laser to meet the Class 3R classification according to both the IEC 60825 and ANSI Z136 standards, and since the maximum measured laser power was below this threshold, it is correctly labelled as a Class 3R laser.

Figure 27: The labelling attached to a T10 handle.

13 Electrical output: Initial high-level measurements

13.1 Purpose

The aim of this test was to measure the typical electrical output of T10 devices to provide assurance that they meet the stated specification.

Note that more detailed testing was subsequently carried out with a different methodology, as detailed in Chapter 14, which supplements the results reported in this Chapter.

13.2 Methodology

Electrical testing was carried out via two methods. The first was the Axon-prescribed method detailed in the document *Axon Certified Test Procedure for Testing to TASER 10 Specifications* (release date 24 June 2024). This approach uses non-standard cartridges and magazines, provided by Axon, to allow current probes to measure the electrical output across a standardised (nominal) 600Ω resistive load (which was measured to be 598.6 Ω). It is understood to be intended as a quality assurance test that is designed to check that the output is within limits when the device leaves the factory and is therefore deliberately highly prescribed. The second approach, performed as an additional test, was a high-level assessment of the electrical output under more representative conditions (beyond the scope of the original Technical Test Plan) by taking measurements using a different methodology:

1. Firing two duty cartridges, into a conductive target board at about 2m range.
2. Allowing the weapon to discharge normally for five seconds.
3. Removing the probes from the target board.
4. Attaching the probes to the oscilloscope setup of the Axon-specified methodology.
5. Reenergising the weapon ten separate times, recording single pulse analyses using the same parameters as in the standard tests.

This alternative test approach presented the device with a resistive load of 684.0Ω. More details on the methodologies are provided in Appendix J.

13.3 Results

A summary of the statistics for the different measured parameters is shown in Table 25 for the Axon-specified testing, and in Table 26 for the alternative testing approach. Typical waveforms are also shown in Figure 28 and Figure 29.

	Pulse rate (Hz)	Pulse charge (μC)	Peak loaded voltage (V)	Pulse peak current (A)	Pulse duration (μs)
Count	20	20	20	20	20
Mean	22.25	68.80	870.21	1.45	58.29
Standard deviation	0.02	0.54	4.94	0.01	0.52
Standard error	<0.01	0.12	1.10	<0.01	0.12
Axon specification	**22 ± 1**	**52 to 95**	**653 to 883**	**Not specified**	**Not specified**

Table 25: Summary statistics for the electrical output measurements, performed according to the Axon guidance. Axon specifications for parameters are from the Axon testing methodology

document.[10] Statistics are reported to the number of decimal places that the measurements were recorded at (limited by the measurement device precision).

	Pulse charge (µAs)	Peak loaded voltage (V)	Pulse peak current (A)	Pulse duration (µs)
Count	10	10	10	10
Mean	73.36	904.66	1.32	65.31
Standard deviation	0.62	1.03	<0.01	1.25
Standard error	0.20	0.33	<0.01	0.40
Mean, relative to Axon testing	**+6.6%**	**+4.0%**	**-9.0%**	**+12.0%**

Table 26: Summary statistics for the electrical output measurements, performed to recreate more realistic conditions than the Axon guidance. Statistics are reported to the number of decimal places that the measurements were recorded at (limited by the measurement device precision).

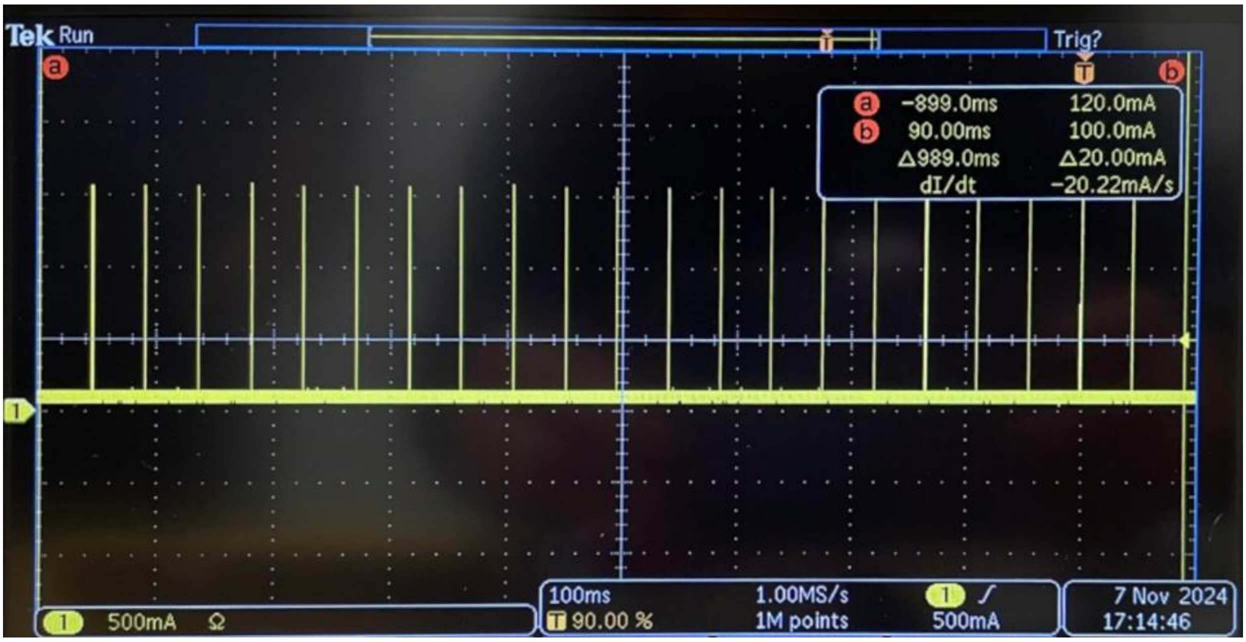


Figure 28: Typical waveform output during Axon-specified testing, showing the train of electrical pulses. The span of the x-axis is 1000ms.

[10] *Axon Certified Test Procedure for Testing to TASER 10 Specifications* (release date 24 June 2024)

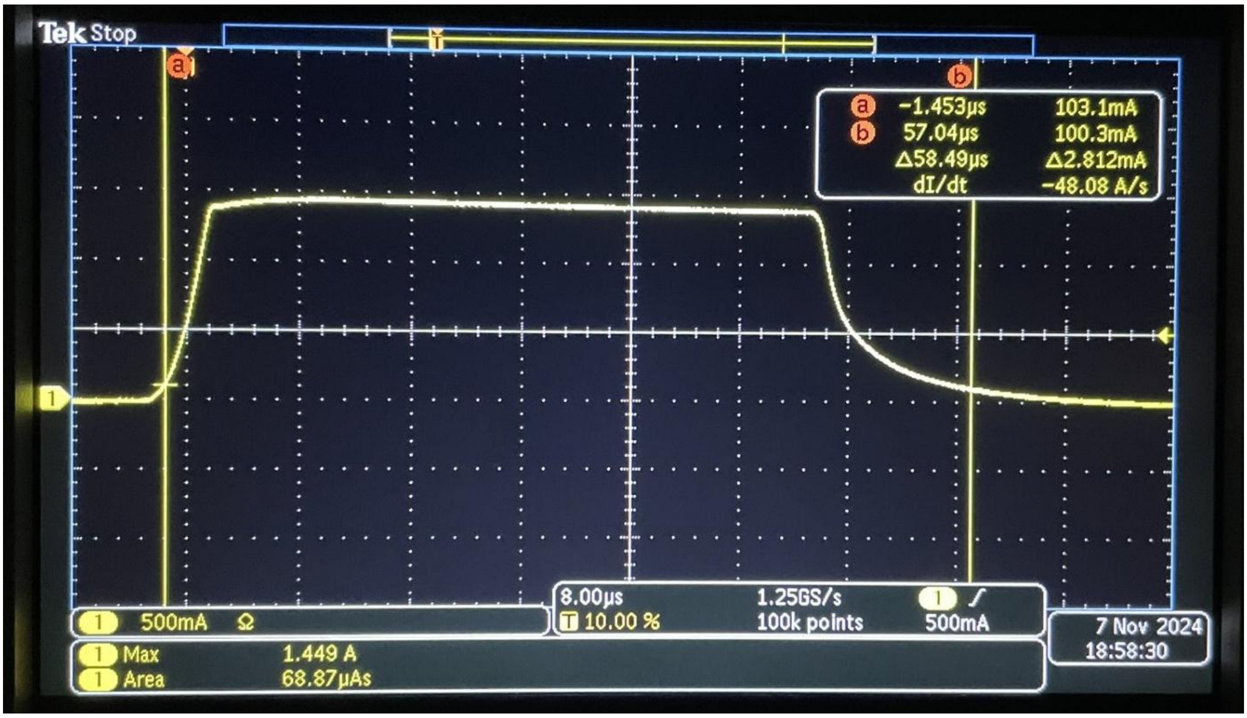


Figure 29: Typical waveform output during Axon-specified testing, showing the profile of a single pulse. The span of the x-axis is 80µs.

13.4 Conclusions

The electrical output measured under Axon-specified conditions met the Axon specifications. Measurement under non-Axon-specified conditions (i.e. deployed duty cartridges) observed a 6.6% higher pulse charge, a 4% higher voltage, a 12% longer pulse, and a 9% reduction in peak current (see Table 26). The energy delivered was still within the Axon specifications, while the voltage was 2.5% above specification (904.66V compared to 883V as the maximum in the Axon specified range).

The changes in measured electrical output for deployed cartridges compared to the Axon guidance is likely primarily due to the different resistive load presented to the device, and the ~10% variation in parameters does not appear especially surprising. The aim of this additional testing was as an initial indicator of whether the electrical output varied significantly in conditions significantly removed from the highly prescribed settings of the Axon methodology; no significant surprises were observed. Further testing was subsequently carried out to better understand the characteristics of the electrical output and under more realistic scenarios – see Chapter 14.

14 Electrical output: Simultaneous probe measurements

14.1 Purpose

The purpose of this test was to understand how probes are energised during a single 5-second discharge by a T10 into a single subject. This included measuring the pulse frequency (understood from the manufacturer to be no greater than 43-45 Hz) and the charge per pulse (specified by the manufacturer, Axon, to be 52-95μC, with a typical value of 70μC when the load 'seen' by each probe pair is 600Ω).[11] The primary driver of this additional electrical testing came from SACMILL, the concern being that there was no independent confirmation of the number of probes energised during each pulse, and therefore of the charge delivered per pulse, in the event that a discharge was delivered to a person who had three or more probes embedded in their skin.

This testing supplements the results from Chapter 13 that used a simpler methodology (including measuring probes one at a time, rather than simultaneously). It also supersedes the testing reported in Appendix L, which used an alternative methodology with limitations that were subsequently addressed with the methodology reported in this Chapter.

14.2 Methodology

14.2.1 Targets

To simulate the engagement of a single subject, while providing full control over the resistive loads between each probe pair, 10 separate targets were used. Note that this experimental setup was designed to facilitate data collection, not to replicate real-world scenarios in which multiple subjects are engaged or when all ten probes are deployed into a single subject, which are not expected to be realistic operational scenarios. Each target comprised:

- A layer of Shieldtex 565
- A ~5mm layer of grade 000 wire wool
- A second layer of Shieldtex 565, sandwiching the wire wool layer
- A non-conductive pinboard panel over a plywood backing

Each target was placed immediately above floor level on a non-conductive base. Flying leads were used to connect the targets together electrically via potential dividers as shown in Figure 30 and Figure 31. Each potential divider was comprised of a small and large load, each of which could be comprised of multiple individual resistors in series (see Section 14.2.2). The voltages across the smaller loads within each potential divider were measured by a HBK Gen3i data recorder (provided by Dstl). This enabled data to be recorded and saved for later analysis, including calculating the charge in the delivered pulses. The resistive loads were comprised of multiple separate non-inductive resistors in series, as detailed below, based on the availability of resistors. The data acquisition system used differential measurements to minimise the effect of 'floating' voltages due to not having access to any ground plane within the handle.

[11] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023.

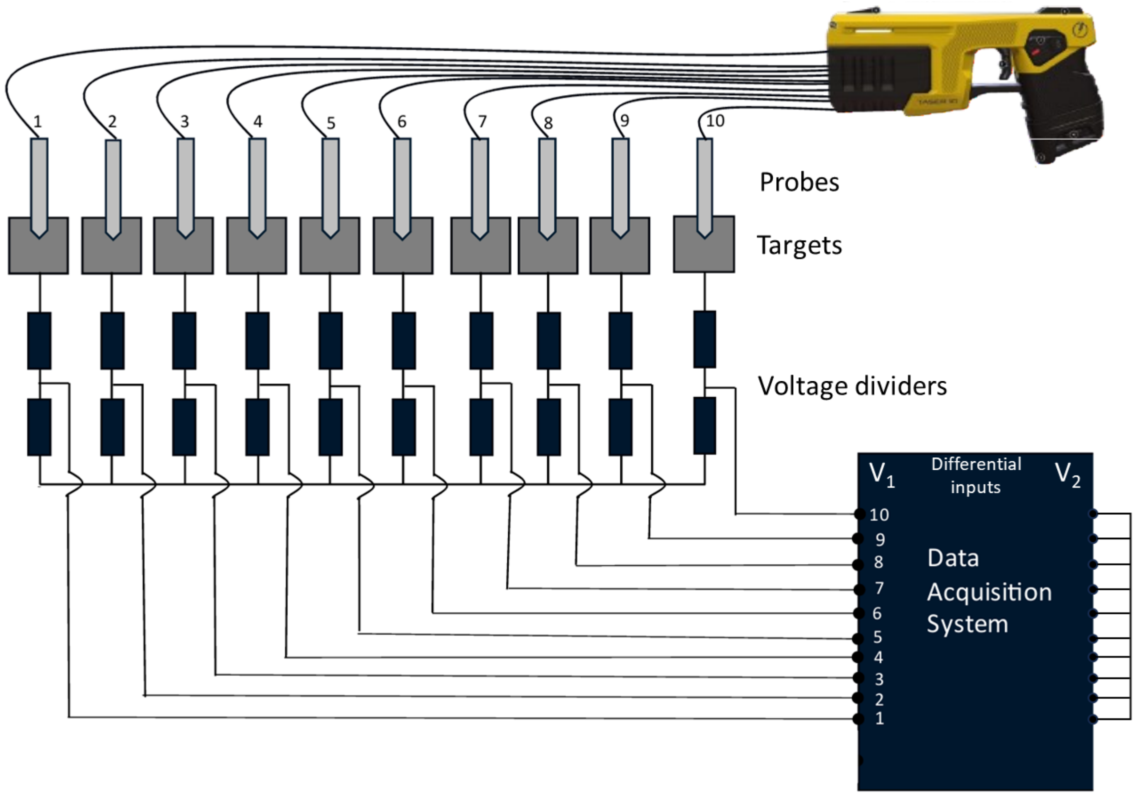


Figure 30: High level experimental setup for simulating the engagement of a single subject and measuring the resultant electrical output.

Figure 31: Photograph of the target setup.

14.2.2 Probe deployment

A single T10 handle was loaded with a full magazine of 10 duty cartridges and fired from a range of 5m at a set of 10 conductive targets. This was to ensure the Taser wires fall neatly to the floor, without excessive tangling or crossing, to enable unambiguous identification for later analysis. Each successive shot was fired at a separate target (the targets were numbered sequentially in the order they were targeted). This procedure was repeated 3 times to check for consistency – each set of 10 cartridges was referred to as a 'Salvo':

- **Salvo 1**

Each potential divider consisted of a 270Ω load (comprised of one 120Ω resistor and one 150Ω in series) and a 32Ω load (comprised of two 16Ω resistors in series), meaning the total resistance seen by each probe would be 302Ω and each connection (between two probes) would be 604Ω. This was chosen to align with the 600Ω used by Axon when specifying electrical performance. To summarise, the resistances were:

Probe Number	Load 1	Load 2 (across which the voltage was measured)	Total Load of Potential Divider
All probes (1 to 10)	**270Ω** (120Ω + 150Ω)	**32Ω** (16Ω + 16Ω)	**302Ω**

Following all 10 shots having been deployed and energisations measured, the device was further energised an additional 5 times and the output recorded – this was to assess repeatability in the absence of any significant physical changes to how the device was connected to the targets.

- **Salvo 2**

  During the first attempt at Salvo 2, it was identified that some resistors had become damaged and no longer exhibited the correct resistance – instead they appeared to be an open circuit. In particular, it was noted that the 150Ω resistors appeared to be 'burning out' after a small number of energisations and only a limited number of spares were available. In order to continue testing, it was decided to attempt to reduce this effect by adding more resistance to each probe's load. Due to the numbers of resistors available, it was not possible to continue to make each probe's potential divider identical. The Salvo was therefore restarted with the following loads:

Probe Number	Load 1	Load 2 (across which the voltage was measured)	Total Load of Potential Divider
Probes 1 to 5	**740Ω** (470Ω + 120Ω + 150Ω)	**32Ω** (16Ω + 16Ω)	**772Ω**
Probes 6 to 10	**1570Ω** (1300Ω + 120Ω + 150Ω)	**32Ω** (16Ω + 16Ω)	**1602Ω**

  These resistances increased the total resistance between pairs of probes, with possible total loads between two probes of 1544Ω (within the 600-2000Ω range used to specify typical pulse charges[12]), 2374Ω (within the 3000Ω limit the handle can energise – see Appendix K), and 3204Ω (beyond the 3000Ω limit).

  Following all 10 shots having been deployed and energisations measured, the device was again further energised an additional 5 times to assess repeatability.

- **Salvo 3**

  The resistances remained the same as for Salvo 2, with Salvo 3 taking place immediately after Salvo 2.

  Following all 10 shots having been deployed and energisations measured, the device was again further energised an additional 5 times and the output recorded. The device was then turned off for 1 minutes, then turned back on and energised repeatedly while cutting wires between energisations to observe the impact in case it gave further insights.

For a small number of shots, the probe bounced out rather than embedding in the target. The probe was subsequently inserted into the intended target by hand and measurement continued.

[12] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023.

14.2.3 Data analysis

The captured data from the data acquisition system was exported in .csv format for subsequent analysis using Python. The primary questions to answer from the analysis were:

- The number of probes that could be energised during each individual discharge pulse
- The total number of probes contributing to the energised probe pairings over the course of the 5 second discharge
- The total number of pulses delivered for each energised probe during a 5 second discharge
- The total number of pulses delivered across all energised probes during a 5 second discharge (from which the frequency can be calculated)
- The direction of current flow for each energised probe
- The charge in each energised probe's pulses (by integrating the area under a pulse and dividing by the 32Ω resistance)
- The total charge delivered across all energised probes during a 5 second discharge

14.2.4 Additional tests

Additional tests were performed as secondary priorities:

- **Multiple subjects**

  Engagement of multiple separated subjects was simulated by connecting the targets in pairs, rather than all being connected together. It was observed that the targets did not appear electrically isolated as intended, which was understood to be due to the 1MΩ path between separate sets of targets provided by the data acquisition system. No solution was found within the limited timescales of the testing, so this testing was not continued.

  Note that the simultaneous energisation of 5 subjects is not expected to be a realistic scenario in any operational use of T10s, but this testing was originally intended to further confirm observed performance with Axon's claimed performance of the device.

- **Single-subject varied resistances**

  As an extension of the single-subject identical-resistance testing described above, adapting the approach to use varied resistances was explored on the basis that using identical resistances between probes is an unrealistic scenario, and having varied resistances may present a more realistic scenario. (Note that this was partially achieved in the above testing by the resistor changes for Salvos 2 and 3). Although data was captured for several Salvos, it was observed to be difficult to interpret and it was agreed to focus analysis on the data from Salvos 1 to 3 (from Section 14.2.3), partly because Salvo 1 in particular better matches Axon's suggested test conditions (a load of 600Ω) and is therefore more straightforward to compare to the claimed performance.

14.3 Results

The results of the testing are presented in the following, starting with a summary table of the key parameters, then more detail on the pulse count/frequency, the pulse charge, the pulse duration, then a discussion of the various complexities with analysing the data. Analysis of the results is provided in Section 14.4

14.3.1 Summary table

A compilation of the analysis results is provided in Table 27. Additional graphs and plots are provided in the appendix and the following sections.

Event No.	Salvo No.	Event Description	Probes Deployed	Probes in Targets	Number of Pulses	Average Frequency (Hz)	Total Charge Delivered (C)	Average Charge Delivered (µC)	Average Pulse Duration (ms)	Maximum Simultaneous Probes Energised	Total Different Probes Energised
1	1	Shot 1	1	1	-	-	-	-	-	-	-
2	1	Shot 2	2	2	110	22.2	0.009	79.2	0.20	2	2
3	1	Shot 3*	3	3	187	37.8	0.014	75.1	0.25	2	3
4	1	Shot 4	4	4	171	34.5	0.013	76.3	0.12	2	4
5	1	Shot 5	5	5	225	45.5	0.017	76.4	0.15	2	4
6	1	Shot 6*	6	6	194	39.2	0.013	65.5	0.15	2	6
7	1	Shot 7	7	7	223	45.1	0.016	71.2	0.15	2	7
8	1	Shot 8*	8	8	211	42.6	0.015	72.4	0.12	2	6
9	1	Shot 9	9	9	221	44.6	0.016	72.6	0.09	2	7
10	1	Shot 10	10	10	219	44.2	0.016	72.2	0.09	2	8
11	1	Re-energised device	10	10	220	44.4	0.016	72.7	0.08	2	5
12	1	Re-energised device	10	10	222	44.8	0.016	70.7	0.08	2	5
13	1	Re-energised device	10	10	219	44.2	0.016	71.1	0.08	2	5
14	1	Re-energised device	10	10	222	44.8	0.016	71.4	0.08	2	5
15	1	Re-energised device	10	10	225	45.5	0.016	71.4	0.08	2	5
16	2	Shot 1	1	1	-	-	-	-	-	-	-
17	2	Shot 2	2	2	111	22.4	0.009	84.9	0.22	2	2
18	2	Shot 3	3	3	112	22.6	0.010	85.4	0.23	2	3
19	2	Shot 4	4	4	182	36.8	0.016	86.0	0.36	2	3
20	2	Shot 5	5	5	225	45.5	0.020	87.0	0.26	2	4
21	2	Shot 6	6	6	226	45.7	0.019	82.9	0.33	2	5
22	2	Shot 7	7	7	226	45.7	0.018	80.1	0.51	2	5
23	2	Shot 8	8	8	226	45.7	0.018	81.0	0.53	2	5
24	2	Shot 9**	9	9	226	45.7	0.011	46.7	0.43	2	6
25	2	Shot 10 (bounced out)**	9	9	169	34.1	0.010	61.2	0.83	2	6
26	2	Re-energised device**	10	10	218	44.0	0.007	30.1	0.33	2	5
27	2	Re-energised device**	10	10	226	45.7	0.006	28.6	0.34	2	5
28	2	Re-energised device**	10	10	226	45.7	0.007	29.2	0.34	2	5
29	2	Re-energised device**	10	10	226	45.7	0.007	29.2	0.35	2	5
30	2	Re-energised device**	10	10	226	45.7	0.007	29.3	0.35	2	5

Event No.	Salvo No.	Event Description	Probes Deployed	Probes in Targets	Number of Pulses	Average Frequency (Hz)	Total Charge Delivered (C)	Average Charge Delivered (µC)	Average Pulse Duration (ms)	Maximum Simultaneous Probes Energised	Total Different Probes Energised
31	3	Shot 1	1	1	-	-	-	-	-	-	-
32	3	Shot 2	2	2	111	22.4	0.009	84.9	0.22	2	2
33	3	Shot 3	3	3	226	45.7	0.019	84.7	0.21	2	3
34	3	Shot 4	4	4	226	45.7	0.019	84.5	0.32	2	4
35	3	Shot 5	5	5	224	45.3	0.019	85.3	0.21	2	5
36	3	Shot 6 (bounced out)	5	5	225	45.5	0.019	85.4	0.24	2	6
37	3	Shot 7 (bounced out)	6	6	225	45.5	0.019	83.9	0.26	2	6
38	3	Shot 8 (bounced out)	7	7	224	45.3	0.018	80.9	0.46	2	6
39	3	Shot 9	9	9	225	45.5	0.019	82.4	0.47	2	5
40	3	Shot 10	10	10	226	45.7	0.019	82.5	0.61	2	6
41	3	Re-energised device	10	10	222	44.8	0.018	80.4	0.47	2	6
42	3	Re-energised device	10	10	223	45.1	0.018	80.3	0.43	2	6
43	3	Re-energised device	10	10	225	45.5	0.018	80.6	0.45	2	6
44	3	Re-energised device	10	10	223	45.1	0.018	80.5	0.45	2	6
45	3	Re-energised device	10	10	226	45.7	0.018	80.5	0.45	2	6
46	3	Re-energised device after switching off	10	10	219	44.2	0.018	80.5	0.44	2	6
47	3	Re-energised device after probe wire #7 cut	9	9	223	45.1	0.018	82.1	0.63	2	4
48	3	No change from previous	9	9	222	44.8	0.018	82.1	0.62	2	4
49	3	Re-energised device after cut lines #3, 4, 5, 6 & 8 – Cut wires left in place and may have caused induction effects	4	4	224	45.3	0.021	92.2	1.25	2	4
50	3	As above, but cut wires removed	4	4	222	44.8	0.018	81.7	0.59	2	4
51	3	Re-energised device after wire #1 cut	3	3	221	44.6	0.017	76.1	0.70	2	3
52	3	Re-energised device after wire #9 cut	2	2	98	19.8	0.008	84.2	0.92	2	2

*Table 27: Summary of the calculated statistics for a 5 second discharge after various Events. Note that the charge here is the summed charge of all peaks from all probes (in the region of interest – either the entire discharge for the Total Charge, or just one pulse for the Average Charge) divided by 2 to avoid double counting (as described in Section 14.3.3). * denotes when the energisation behaviour was observed to be non-stable during the 5 second discharge, which was unusual (see Section 14.3.6 for more details). ** denotes when the energisation behaviour was observed to end up cycling between 'normal' charge levels and unusually low charge levels (see Section 14.3.6.2 for discussion).*

14.3.2 Pulse count & frequency

Figure 32 shows the total number of pulses produced by the handle over each 5 second discharge, and Figure 33 shows the total number of pulses produced by each individual probe in each 5 second discharge. Analysis of the key takeaways is provided in Section 14.4. Both figures show the corresponding pulse frequency at the top of the plots. The frequency was calculated by dividing the number of identified pulses by the discharge duration (5 seconds of data were recorded, but no peaks were observed in the first 50ms, due to the use of a 50ms pre-trigger delay, so a discharge duration of 4.95 seconds was used). Note that, over a 5 second discharge, the overall number of pulses produced by the handle is half the total number of pulses observed across all probes, since a single pulse of charge produced by the handle is registered twice in the measured voltages (once on its way out through one probe into the target/subject, and once on its return back to the handle through a different probe).

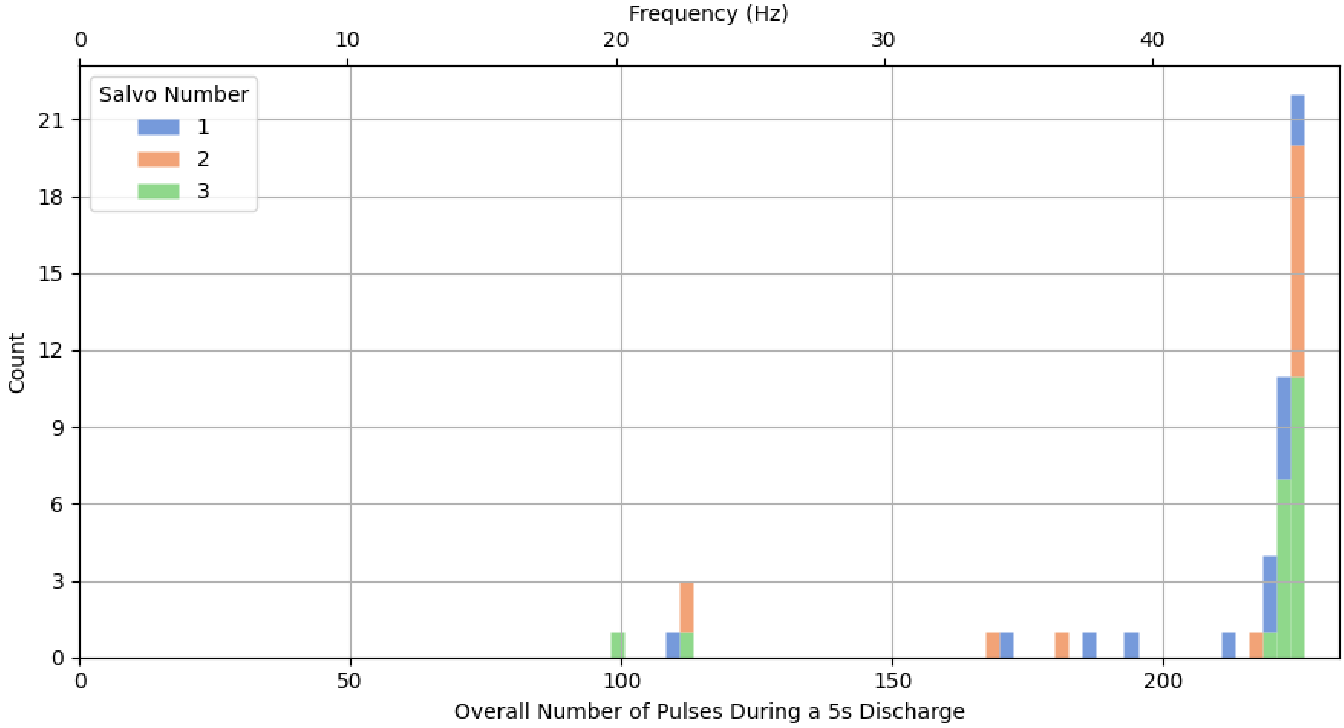


Figure 32: Stacked histogram of the overall number of pulses produced by a handle during a 5 second discharge, with the contribution from each Salvo highlighted and the corresponding frequency shown on the top axis.

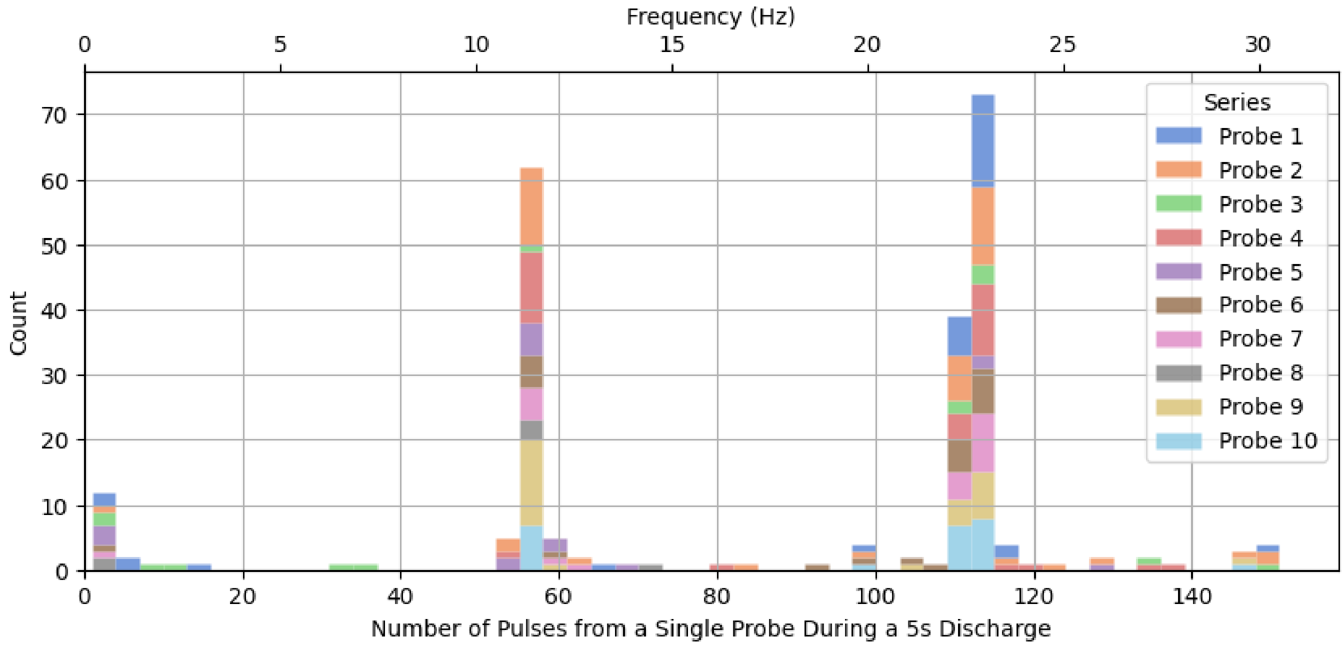


Figure 33: Stacked histogram of the number of pulses from a single probe during a 5 second discharge, with the contribution from each probe number highlighted, and with the corresponding frequency shown on the top axis.

14.3.3 Pulse charge

The charge in each pulse was calculated by using the relation:

$$\text{Charge} = \frac{\int V}{R}$$

where V is the measured voltage, $\int V$ is the measured voltage integrated over the duration of the pulse, and R is the resistance over which the voltage was measured. This process was automated for each identified peak in each probe's measured voltage during the 5 second recorded discharge. The charge deposited through the subject was calculated by summing the calculated charge for all peaks (from different probes) that overlapped in time, and dividing by 2 to avoid double-counting (i.e. a pulse of charge passing along, for example, probe 1 and back out along probe 2 would be registered as a peak on the probe 1 trace and as a peak, with opposite polarity, on the probe 2 trace).

The distribution of individual pulse charges is shown in Figure 34 as overlaid histograms for each Salvo, and in Figure 35 as cumulative distribution functions. A breakdown of the pulse charges by individual Events is also provided in Appendix 0.

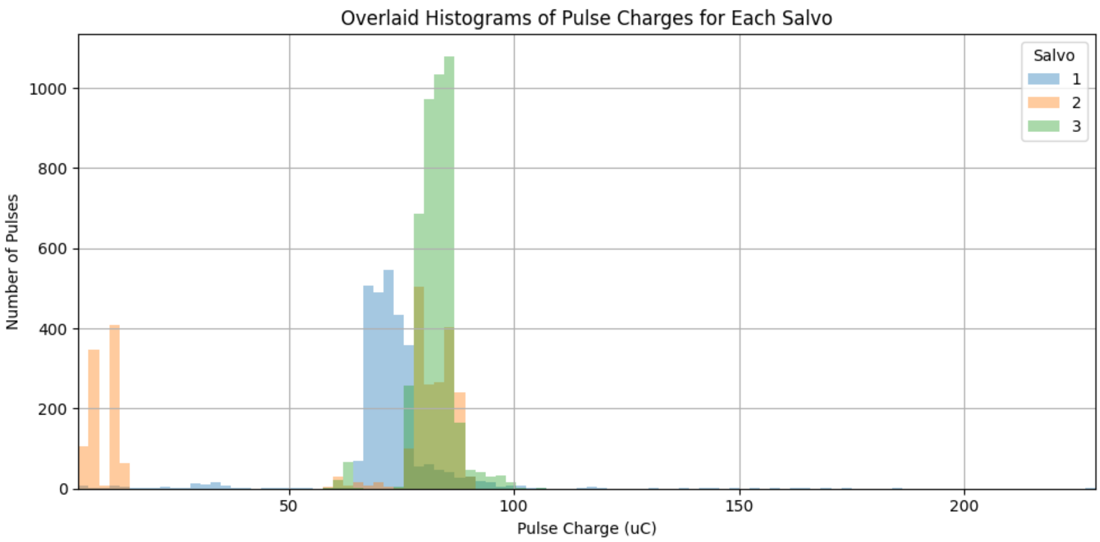


Figure 34: Overlaid histograms of the charge in each pulse, grouped by Salvo.

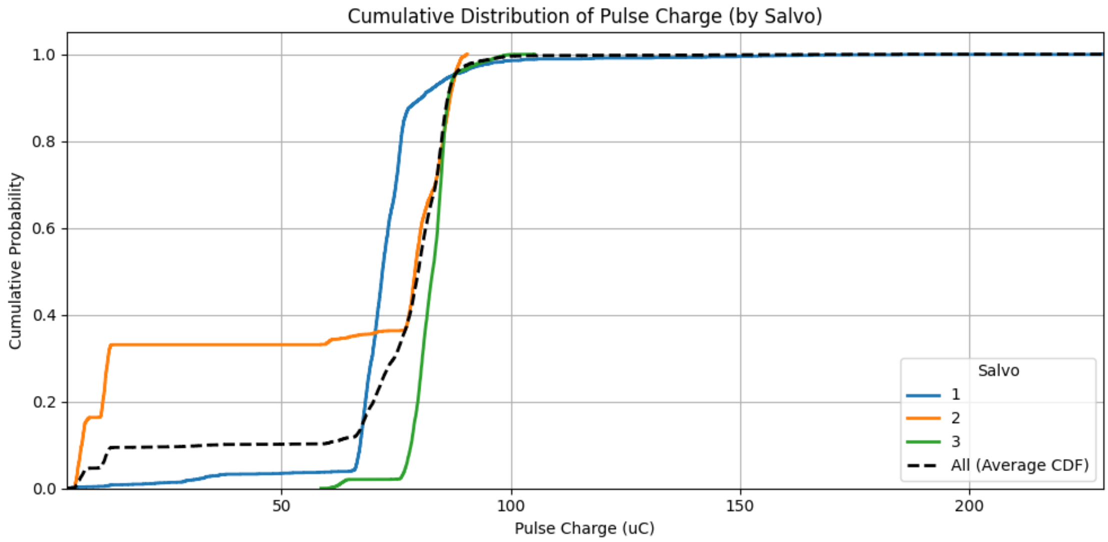


Figure 35: Cumulative distribution function (CDF) plots for the charge in each pulse, grouped by Salvo, with the overall CDF for all Salvos overlaid in black.

Table 28 shows the proportion of pulses for each Salvo for which the charge was below a given value (this is a tabularised version of the CDFs from Figure 35).

Salvo No.	Pulse Charge Threshold					
	< 10 µC	< 52 µC (Axon lower limit)	< 70 µC (Axon typical value)	< 95 µC (Axon upper limit)	< 120 µC	< 240 µC
1	0.4%	3.6%	32.1%	97.7%	99.1%	100.0%
2	16.4%	33.1%	35.8%	100.0%	100.0%	100.0%
3	0.0%	0.0%	2.1%	98.5%	100.0%	100.0%
All	4.7%	10.2%	19.9%	98.7%	99.8%	100.0%

Table 28: The proportion of recorded charge pulses in each Salvo that were below different thresholds.

14.3.3.1 Pulse charge outliers

Axon specify that for a load of 300-2000Ω, the minimum and maximum pulse charges (based on the average of 8 successive pulses) are 52µC and 95µC respectively.[13] For each Event during testing, the average pulse charge was within this range (see Table 27), except for 6 of the last 7 Events in Salvo 2, which are discussed further in Section 14.3.6.2.

Focussing on the outlier pulse charges that are outside the Axon-specified range, Figure 36 shows the outliers for each Salvo. The key takeaways are:

- Salvo 1 showed the largest range of outliers, with a significant number of pulses both below and above the Axon specified limits, including the largest observed pulse charges (of 228-229µC). This behaviour is discussed further in Section 14.3.6.3, where related abnormal behaviour is considered in the analysis.
- Salvo 2 had a significant number of low-charge pulses, which are discussed further in Section 14.3.6.2, including the particularly structured nature of when the low-charge

[13] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023.

pulses were outputted, which differs to the seemingly stochastic nature of the Salvo 1 outliers.

- The only outliers for Salvo 3 were from Event 49, for which 29.4% of the pulses were above 95μC. There are, however, several factors to consider here:
    - Event 49 was identified during testing to possibly have induction effects due to cut wires overlapping the remaining wires, and therefore should be treated with caution with interpreting the results.
    - The outliers were still all within 11% of the 95μC upper limit (indeed, all but one of the outliers were within 7%), and given that the Axon specified upper limit is an average over multiple pulses, it is possible that some pulses over the 95μC limit may be expected.[14]
    - All pulses in Event 49 occurred between two probes with a total load of 2374Ω, which is outside the test conditions of 300-2000Ω specified by Axon, so the device is operating outside of the test conditions applicable to the 95μC upper limit.
    - Considering all the above, it seems reasonable to not treat the Salvo 3 outliers as particularly significant, given the number of caveats around the data, and the fact that all other pulses in the other ~20 Events within Salvo 3 were consistently within the upper and lower Axon limits for the pulse charge.

[14] Axon confirmed that, in human flesh, they would expect to see outliers of as low as 51μC and as high as 120μC, with larger outliers possible for non-flesh testing (see Appendix K). This supports the idea that the stated 95μC limit is not a hard limit, and that some pulses up to 120μC for biological targets are not unexpected by Axon.

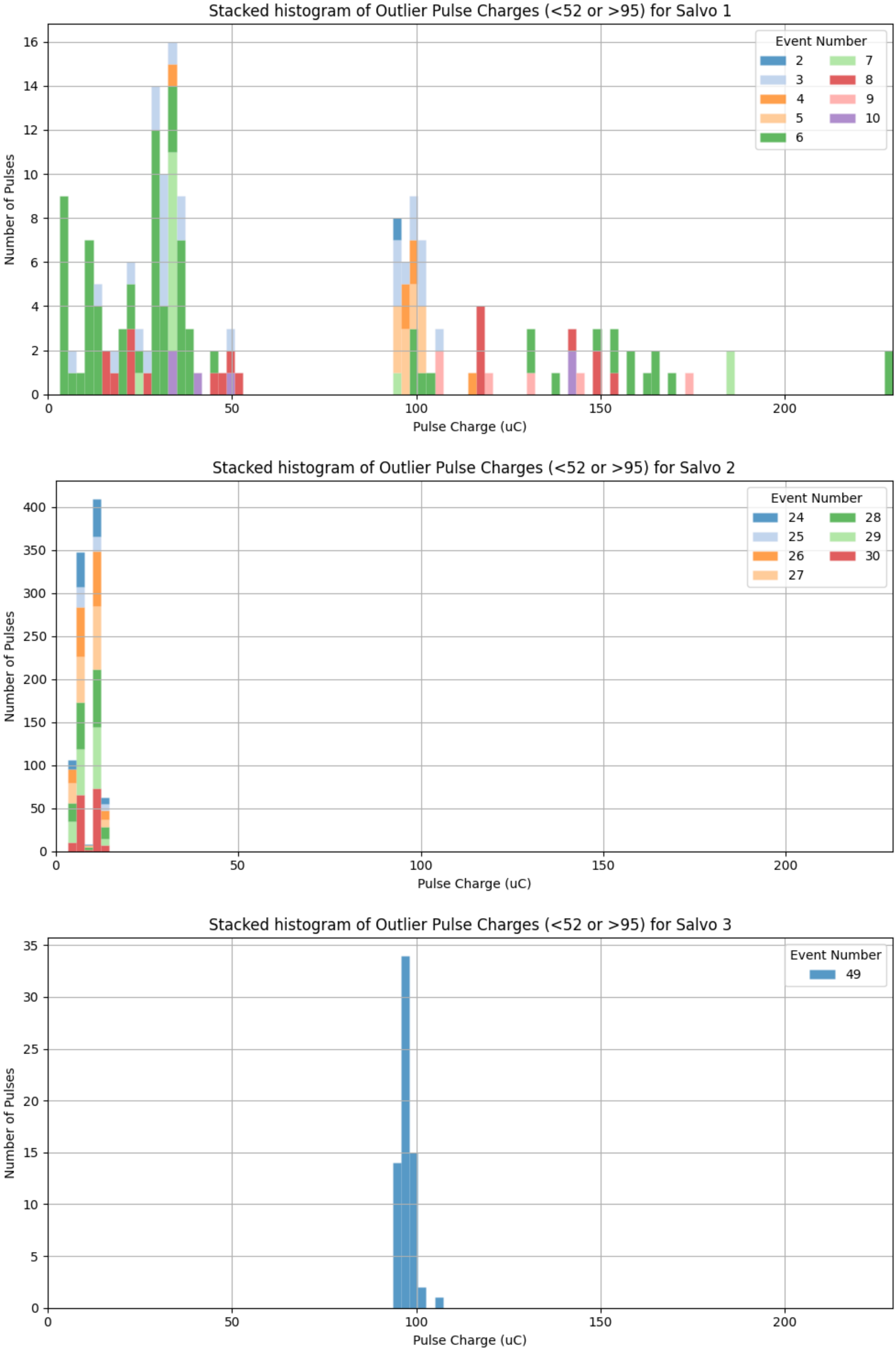


Figure 36: Stacked histograms of outlier pulse charges for each Salvo, with the contribution from each Event indicated. Outliers are based on being outside the Axon specified range of 52 to 95μC.

The largest observed charge was 229µC during Event 6, which also saw the smallest charges (of under 10µC). Event 6 showed some unusual behaviour, as discussed more in Section 14.3.6.3, so these outlier results may be specific to the underlying cause of this behaviour (which is hypothesised to be related to the resistor burn out seen after Salvo 1 – see Section 14.3.7.2 – but this has not been able to be confirmed).

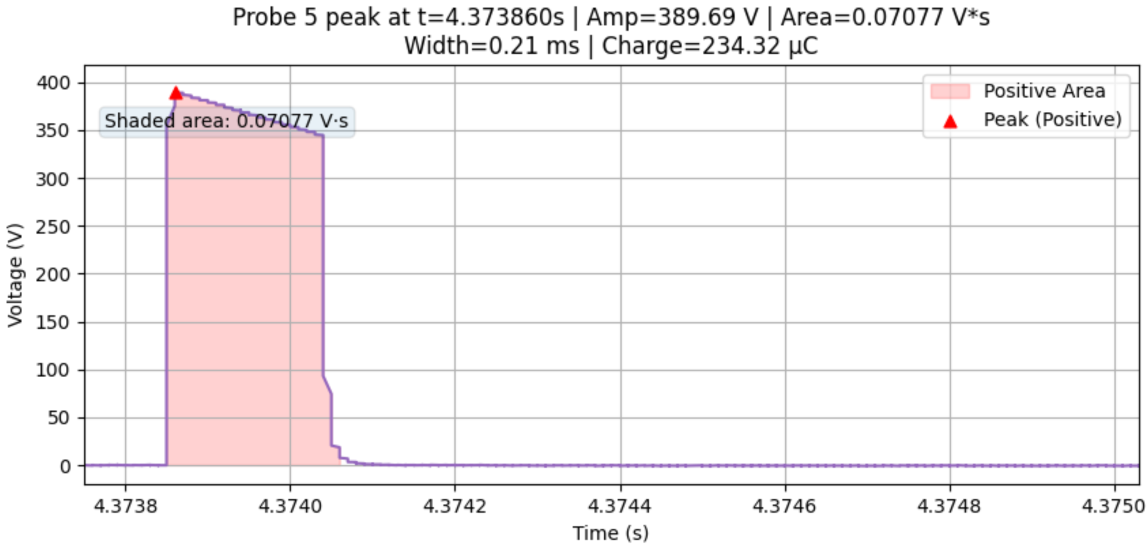


Figure 37: The pulse shape of the largest observed charge (from Event 6 – after the 6th probe had been fired in Salvo 1). Note that although the charge noted here for the positive voltage peak is 234.32µC, the corresponding negative voltage peak had a smaller amplitude, and the average was 229µC, which was the final estimate for the pulse charge).

14.3.4 Total charge delivered

Figure 38 shows the total charge delivered over the 5 second discharge as a stacked histogram. Figure 39 shows the dependency of the total charge on how many probes are deployed into targets at the time of the energisation. Analysis of the key takeaways is provided in Section 14.4.

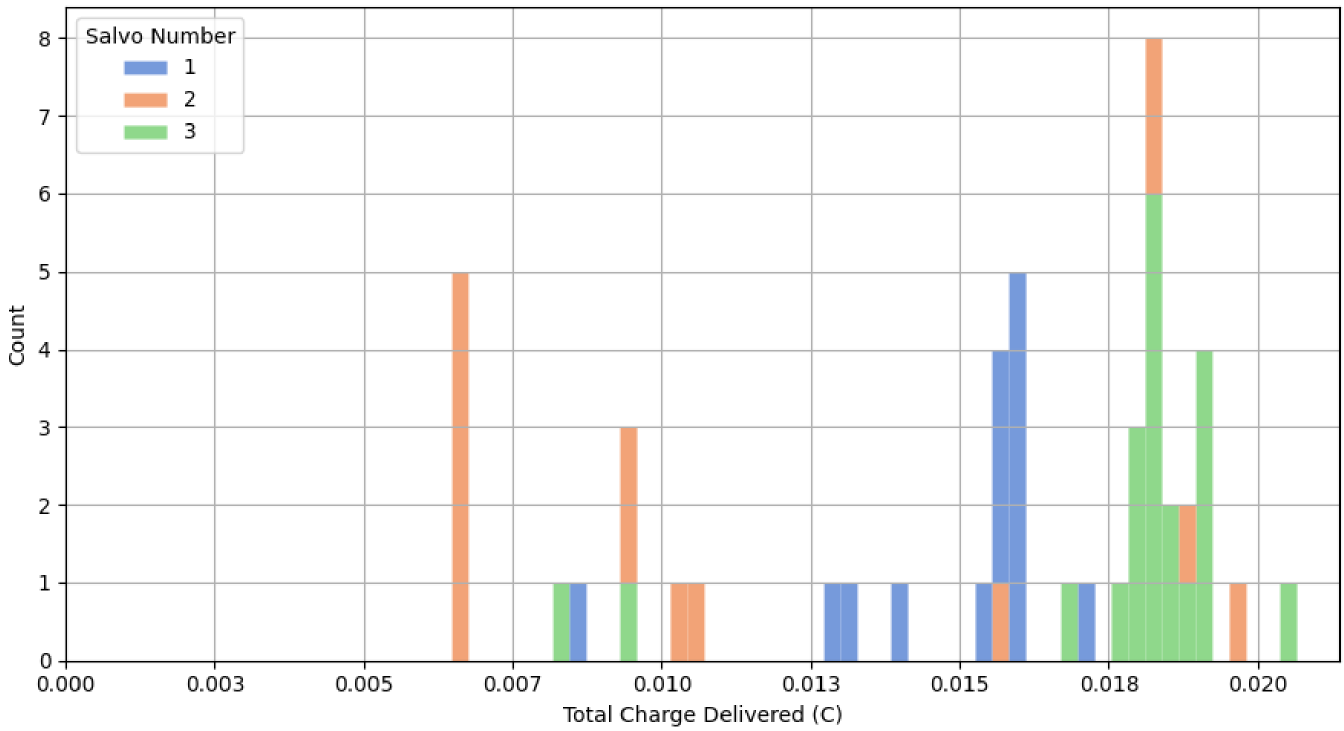


Figure 38: Stacked histograms of the total charge delivered during a 5 second discharge, grouped by Salvo.

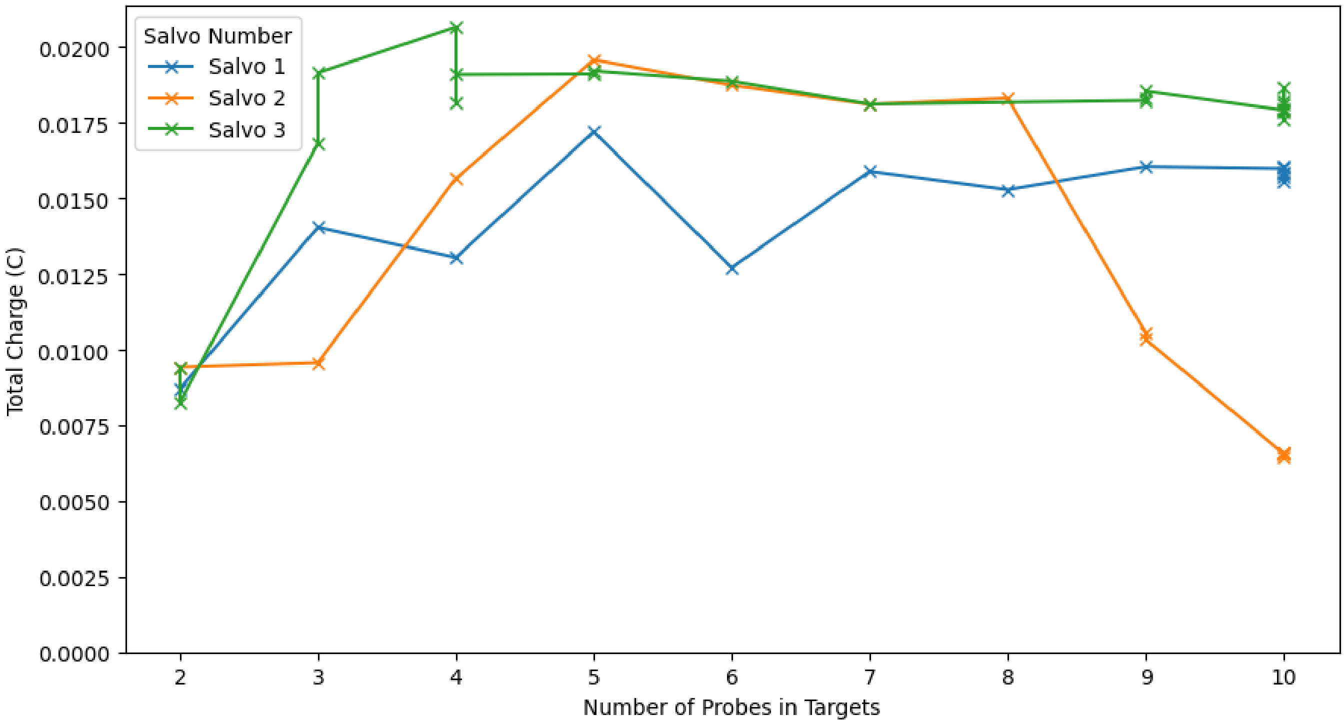


Figure 39: Line plots of the total charge delivered during a 5 second discharge against the number of probes in targets, grouped by Salvo.

14.3.5 Pulse duration

The average pulse duration in the main summary table (Table 27) is based on the entire duration of the pulse, defined by the time before and after the peak of the pulse for which the voltage was near-zero for at least 0.2ms. Many peaks have a long, low-voltage tail (often an exponentially decaying tail), which results in an average pulse duration that is not representative of the time during a pulse that the voltage is relatively high. An alternative metric is the full-width half-maximum (FWHM) pulse duration, which is the time between the pulse reaching 50% of its maximum amplitude on the rising edge of the pulse, then falling back below 50% on the falling edge of the pulse.

Figure 40 shows the total pulse durations compared to the FWHM pulse durations. The FWHM pulse duration is typically 50-100µs for Salvo 1, compared to the total pulse duration being 70-600µs. Similarly, for Salvos 2 and 3 the FWHM pulse duration was typically 150-200µs, while the total pulse duration was 200-1200µs. The difference between Salvos is assumed to be due to the higher resistances for Salvos 2 and 3, requiring a combination of higher voltages and longer pulses to deliver the same charge per pulse.

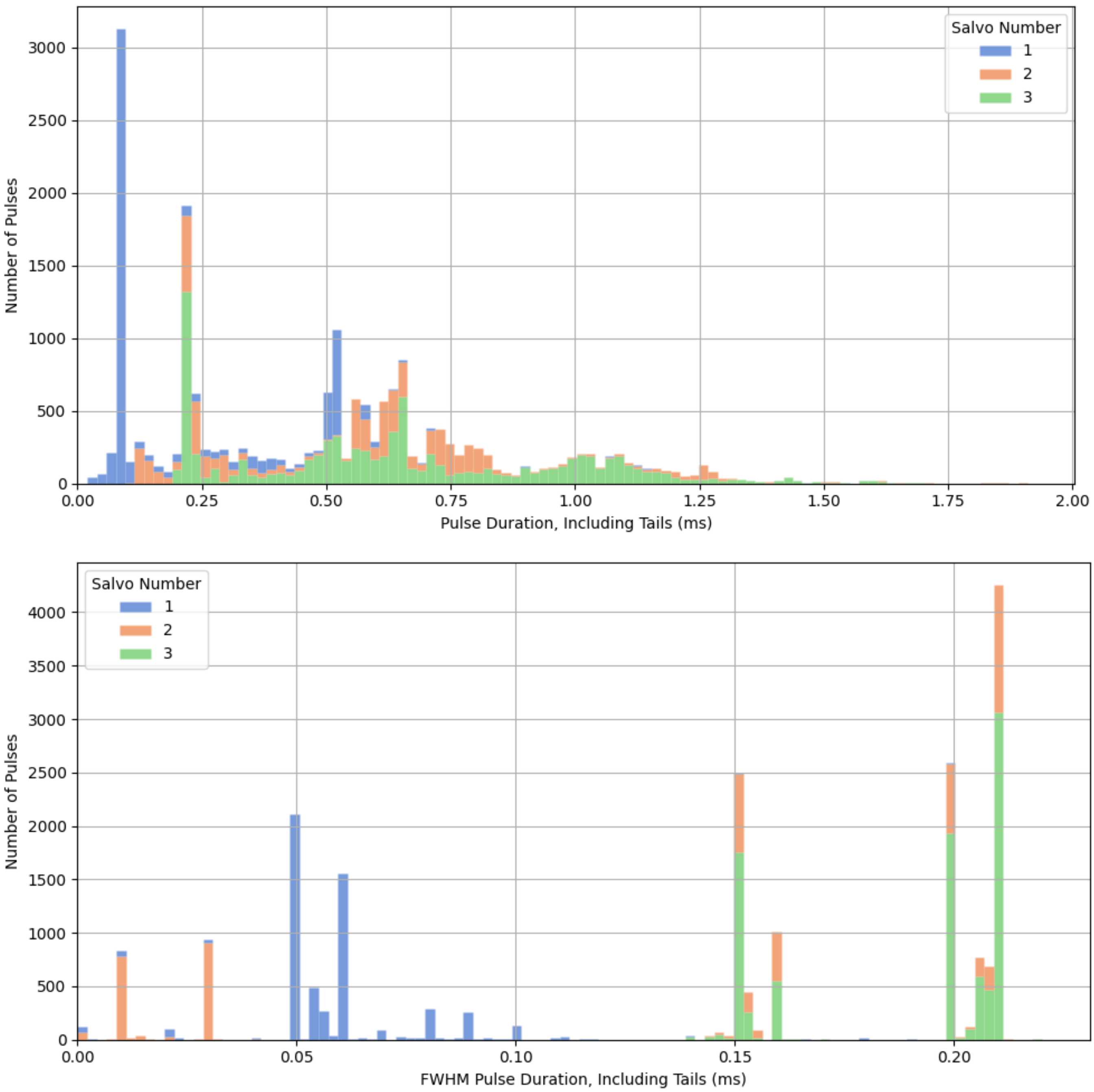


Figure 40: Stacked histograms of the pulse durations, grouped by Salvo. ***Top:*** *total pulse durations (i.e. including tails).* ***Bottom:*** *FWHM pulse durations.*

14.3.6 Salvo variation

There was noticeable variation in energisation behaviour between different Salvos. The following sections first describe what was identified as 'typical' behaviour across most of the Events, then details differences in behaviour for specific Events, separated by Salvo.

14.3.6.1 Typical behaviour

The typical energisation pattern was (assuming more than just two probes deployed into targets) some variation over the first ~0.5 seconds, followed by a consistent frequency and pattern of probes being energised, with similar amounts of charge in each pulse. This behaviour is interpreted to mean that the handle is changing between different connections initially, before settling into a preferred pattern. It is hypothesised that this is due to some small changes in the probes within the first 0.5 seconds, either due to heating effects from the high voltage (which may stabilise after ~0.5 seconds of pulses, resulting in no significant changes to the system that would cause the handle to change the connections it has selected), or mechanical effects (the most recently deployed probe moving/settling in the target before stabilising). Where repeated energisations were recorded without deploying any additional probes, the initial period of varying connections was shorter or non-existent, suggesting the system was stable.

Salvo 3 followed this pattern consistently (note the discussion in Section 14.3.3.1 regarding the only outlier pulses identified in Salvo 3, and the rationale behind not considering them highly significant).

14.3.6.2 Variation in Salvo 2

Salvo 2 mostly followed the typical pattern consistently except for:

- Events 19 and 20 (after the 4th and 5th shots), which showed some instability (changing between different probe combinations).[15] In both cases, the charge in each pulse was highly consistent (to within ~10%). For Event 19, the instability manifested as changes in frequency (equivalent to missing pulses). For Event 20, the pulse frequency remained constant and the instability was only observable in which pulses were being energised.
- Events 24 onwards (after the 9th probe was deployed, through to after 5 repeated energisations with 10 probes deployed), where the handle settled in (after the first ~0.5s of each discharge) to a patten of highly varying charge – for Events 24 and 25 the pattern was two 'normal' charge pulses (~80μC) followed by one 'low' charge pulse (<12μC), which then repeated; for Events 26 to 30 the pattern was one 'normal' charge pulse then three 'low' charge pulses (as seen in Figure 41).

  One result of this behaviour was a reduction in the overall charge delivered to the subject, from ~0.018C before Event 24, to 0.010C for Events 24 and 25, to ~0.006C for Events 26 to 30.

  Figure 42 shows typical examples of the 'normal' and 'low' charge peaks in these Events for comparison. The 'low' charge pulses occurred exclusively when both probes had the highest 1602Ω load (i.e. probes 6 to 10), so the total load was 3204Ω, well beyond the

[15] Note that instability is not a fundamentally problematic observation – the handle is intended to change the connections energised in response to changes in the measured impedances. Where instability is observed in the absence of other unexpected behaviour (e.g. pulse charge outliers), it can be inferred that the device is operating as expected in response to some (likely small) changes in the impedance.

2000Ω limit given by Axon in their specifications.[16] [17] This anomalous behaviour is therefore likely to be due to operating the device outside its intended parameters. It is unclear why the handle in Salvo 2 chose to energise pairs of the high-load probes, seemingly resulting in the low charge pulses, whereas in Salvo 3 the handle almost never chose to energise these pairs (instead it preferred to energise a high-load probe and a lower-load probe). The only exception in Salvo 3 was Event 51, for which 7 wires had been cut, leaving probes 2, 9 and 10. The handle periodically energised probes 9 and 10, outputting 61-65μC, which was ~20% below the other charges in the discharge (78-86μC). It is unclear why this energisation of a pair of high-load resistors in Salvo 3 did not result in the same very low charges seen in Salvo 2.

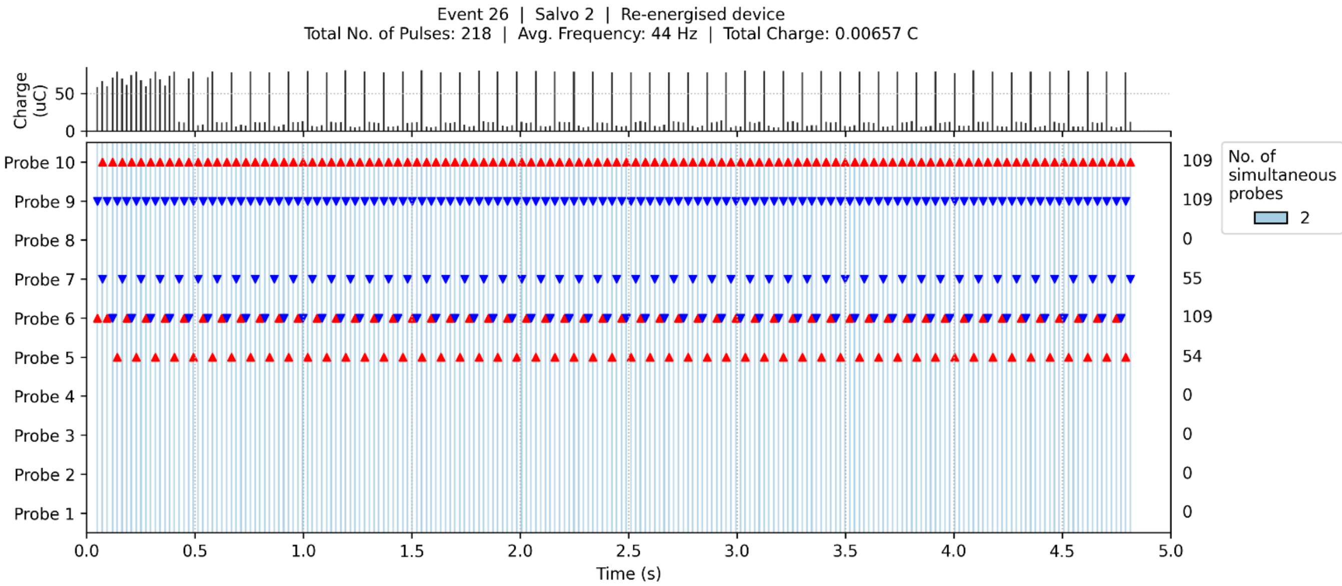


Figure 41: An example event plot for an energisation (Event 26) near the end of Salvo 2 that showed the handle settling into an energisation pattern of one 'normal' charge pulse then 3 'low' charge pulses (shown in the plot of charges for each pulse at the top of the figure).

[16] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023.
[17] Note that 3204Ω is also above the nominal 3000Ω threshold above which the device will not attempt to energise a connection (see Appendix K). This is discussed further in Section 14.4.

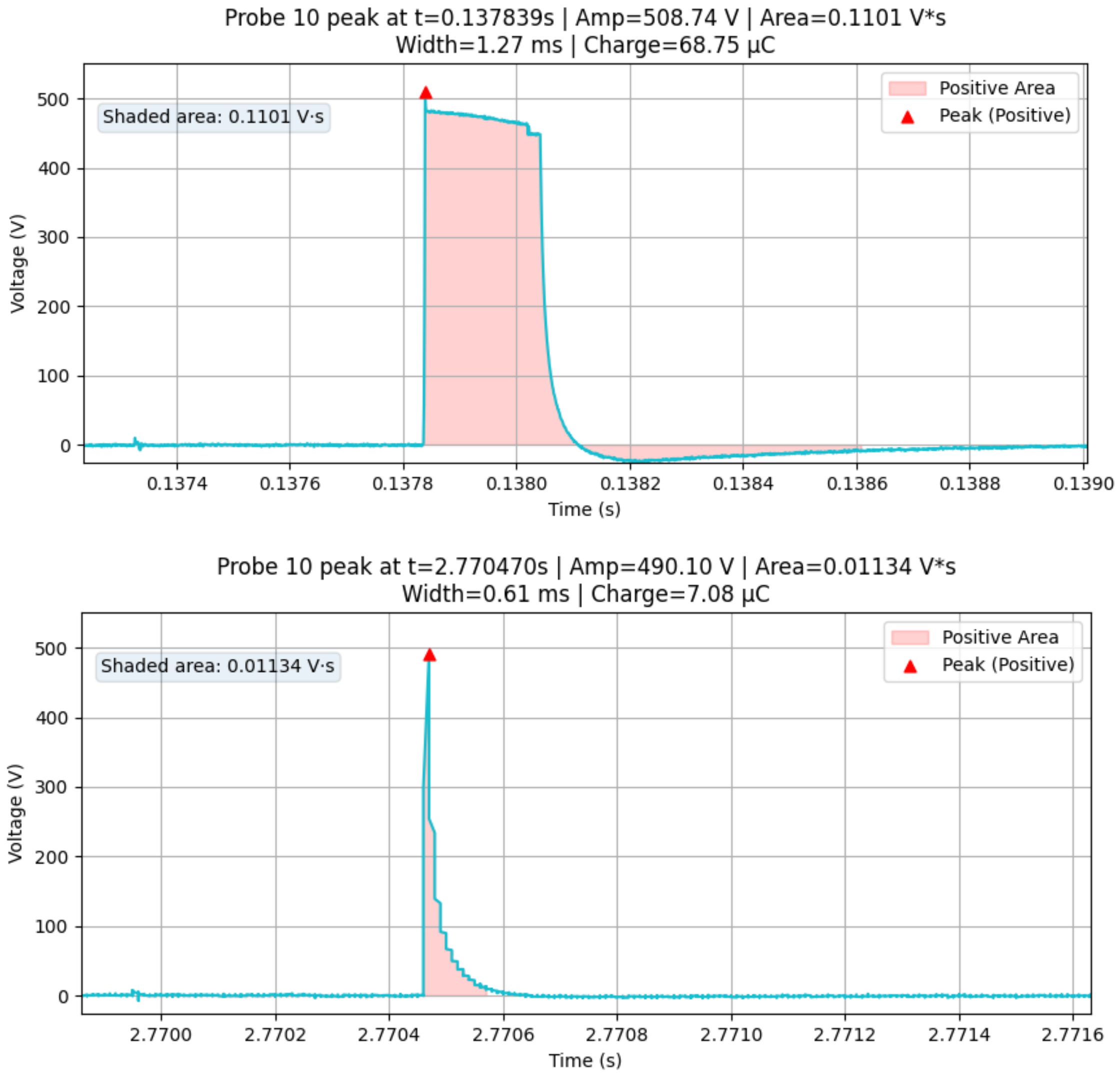


Figure 42: Typical examples of the 'normal charge' and 'low charge' peaks observed repeatedly towards the end of Salvo 2 (Events 24 through to 30). The peaks have similar height but very different durations (the combination of which results in the calculated charge being correspondingly different).

Note that Salvo 3 was conducted immediately after Salvo 2,[18] with no changes to the experimental setup. The only identified differences were that: the targets and resistors were more used for Salvo 3 (having been used for Salvo 2); and the battery had lower charge (both Salvos used the same battery, serial number X44983449, which had 92% charge at the start of Salvo 2 and had reduced to 71% at the start of Salvo 3). The testing was conducted indoors in a room without temperature or humidity stabilisation, so variations are possible (with of order a few degrees centigrade typical over the course of a day) but were not continuously recorded.

14.3.6.3 Variation in Salvo 1

Salvo 1 mostly followed the typical pattern consistently except for:

- Events 3, 6 and 8 (after the 3rd, 6th and 8th shots), which showed some instability (changing between different probe combinations). In all cases (as shown in Figure 43), there was significant variation in the output pulse charge (see Figure 36), as well as in

[18] Specifically, the 10 shots for Salvo 2 were deployed between 14:35 and 14:38, and the 10 shots for Salvo 3 were deployed between 15:02 and 15:08, while the 10 shots for Salvo 1 were deployed between 11:10 and 11:16, all on the same day.

the frequency and the pattern of probes being energised (see Figure 43). This instability is therefore notably different to the instability in the two Events from Salvo 2 which saw frequency and probe variation but steady charge (as mentioned above). It is also notably different to the low charge pulse production observed in Salvo 2 because that production had a clearly repetitive nature (1/2 'normal' charge pulses, followed by 3/2 'low' charge pulses), whereas the variability in pulse charge from Events 3, 6 and 8 appears stochastic. Note also that the resistance between any two probes in Salvo 1 was identical (604Ω), unlike in Salvo 2 where probes 6 to 10 had higher resistances and resulted in some loads that exceeded the Axon specified test conditions of 300-2000Ω.

Understanding the cause of this instability is important because these 3 Events contribute a significant number of outliers to the measured pulse charges, particularly Event 6 which contained the largest observed pulse charges (two were 228-229μC, both for energisations between the 5th and 6th probes). Even ignoring Events 3, 6 and 8 based on the clear instability would still leave significant pulse charge outliers in the Salvo 1 data: there are 28 outliers above 95μC across Events 2, 4, 5, 7, 9 and 10, including 7 pulses between 131-186μC across Events 7, 9 and 10; and there are 13 pulses with 25-34μC across Events 4, 7 and 10.

The argument for ignoring the Salvo 1 data from the analysis (particularly of peak charge) is that it is known that some of the resistors used in Salvo 1 were observed to be broken when first attempting Salvo 2 (see Section 14.3.7.2 for more details on the resistor burn out observed, and the applied electrical powers compared to their specified powers). It is therefore possible that the instability and atypical results observed in Salvo 1 are a result of the resistors being pushed beyond their intended operating conditions (possibly due to the high peak powers applied, or due to low quality resistors from manufacturing variation), and the lack of similar instability in Salvos 2 and 3 are due to the changes in resistors used.

The argument to not ignore the Salvo 1 data is that even though resistors were observed to have burnt out, this was not seen until Salvo 2 was started several hours after Salvo 1 was completed, and the symptom of burn out was no voltage data being recorded, which was not seen at any point during Salvo 1. Ignoring the Salvo 1 data assumes that the burn out is the final result of prolonged performance degradation occurring throughout Salvo 1, but the observed instability is intermittent between Events – Events 2 and 11 to 15 showed no outlier pulse charges and no instability, and Events 2, 4, 5, 7, 9 and 10 showed highly stable output with no or minimal charge outliers after settling into a repeated pattern (which took ~0.5-1s). If resistors were corrupting the data, it would seem likely that all Events were affected similarly, or later Events were affected worse (if the resistors were degrading over time). Also, resistor burn out would be expected to be triggered by overheating from the high peak powers, but no excessively warm resistor cases were observed by the testing team (noting that the testing team were not specifically looking for temperature changes, so they could feasibly have been missed) – the heating could have been internal and highly localised, but this relies on significant assumptions.

Overall, Salvo 1 showed significantly higher instability than Salvos 2 and 3, including particularly high pulse charges beyond the Axon specified limits, and there is some evidence that the resistors may not have been suitable for the testing, but this evidence is not conclusive and it was recommended to explore the findings with Axon. This was achieved through the questions and responses of Appendix K, discussion of which is in Section 14.4.

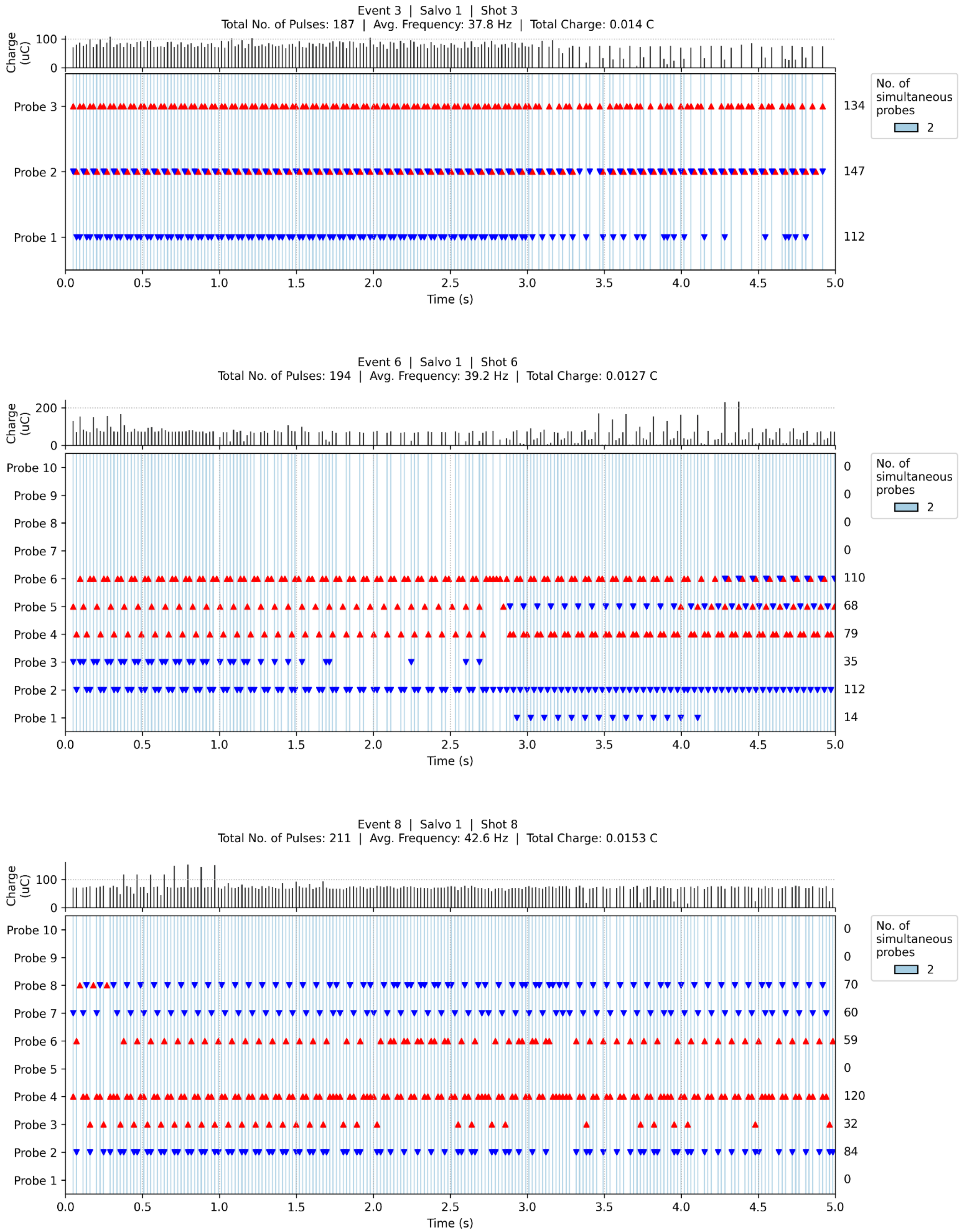


Figure 43: The three main examples of instability in Salvo 1, shown as Event plots with charge plots above. ***Top:*** *Event 3.* ***Middle:*** *Event 6.* ***Bottom:*** *Event 8.*

14.3.7 Data analysis complexity

A range of complicating factors were encountered when analysing the data that should be kept in mind when interpreting the results, as discussed in the following sections.

14.3.7.1 Artefacts

The use of differential voltage measurements was chosen to avoid the risk of floating voltages (due to not being able to access any internal ground plane in the handle), and this generated some measurement artefacts in the form of pulses that coincided temporally with 'real' pulses but at lower amplitude and often in targets that did not have a probe deployed into it. The source of these artefacts is due to all the targets being electrically connected together, and when a pulse is applied between two probes, it can raise the voltage of the common rail connecting all the potential dividers. In this way, even though the handle is only driving current through 2 potential dividers, and not through the other 8, the measured voltage between those 8 potential dividers and the common rail is observed to change, because the voltage of the common rail has changed.

The crosstalk between measurement channels requires analysis of the data to distinguish between real peaks and artefacts. This was achieved by setting a threshold voltage below which peaks would be ignored if they did not surpass the threshold. The threshold was set based on the typical height of artefacts observed in voltage traces for unconnected targets. In Salvo 1, artefacts were up to 50V, so a threshold of 75V was used, while in Salvos 2 and 3, the higher load resistances resulted in larger artefacts, with over 200V artefacts observed in unconnected channels – a threshold of 250V was used and was generally suitable. For Events 25 and 49, however, a higher threshold of 300V was used due to some artefacts surpassing 250V – it was confirmed that the artefacts being ignored followed the same pattern of typical artefacts (for a given pulse, all artefact peaks shared the same polarity, were lower voltage than the 'real' peaks, and had the same amplitude as other artefact peaks from measurements over the same resistance – larger resistances increased the size of the artefacts). It was noted that the height of the artefact peaks increased as more probes were deployed into targets.

It is believed that all artefacts have been accurately removed from analysis by the thresholding approach, and the phenomena of artefacts is only required to be understood when observing and interpreting the raw data (e.g. in Appendix A).

14.3.7.2 Resistor burnout

As outlined in Section 14.2.2, during the first attempt at Salvo 2, it was observed that no voltage peaks were being recorded during initial discharges, which was identified as being due to some resistors acting as an open circuit. In particular, some 150Ω resistors appeared to have 'burnt out' and the resistors were replaced (with different resistances, as described in Section 14.2.2) before restarting the Salvo. Chronologically, Salvo 1 was conducted in the morning, with no burn out observed, then Salvo 2 was conducted in the afternoon (i.e. after a moderate break), followed immediately by Salvo 3. No resistor burnout was identified during Salvo 2 or Salvo 3.

The resistors used were Arcol AP101 resistors,[19] rated for 3.5W of continuous electrical power (or 100W when mounted to a heat sink at 25°C; no heat sinks were used in this testing). The average power outputted during an electrical discharge can be estimated as the instantaneous power during a pulse ($P = V^2/R$) multiplied by the duty cycle (the product of the pulse width and the pulse frequency):

[19] Arcol datasheet for AP101 100W TO-247 High Power Resistors.

- For Salvo 1, this gives an instantaneous power of ~264W through a 150Ω resistor (based on a 400V pulse amplitude across the 302Ω single-probe load[20]), a duty cycle of 0.45% (conservatively assuming a 100μs FWHM pulse width and the resistor being energised in every pulse of a 45Hz discharge), and an average power of 1.18W.
- For Salvo 2 and 3, the instantaneous power was ~182W through the 1300Ω resistor (assuming a 600V pulse across 1602Ω[21]) and a duty cycle of 0.99% (assuming a 220μs FWHM pulse width, and 45Hz), resulting in an average power of 1.80W.

These conservative calculations are in agreement with Axon's specifications of 0.70-1.95W when outputting at 22Hz into 600Ω.[22] In summary then, the average outputted power should have been within the resistors' specified acceptable power level with a ~100% margin (which was the rationale for choosing these resistors), although the instantaneous power of the discharge pulses would have exceeded the continuous power specification for the resistors.

It is conceivable that the high instantaneous power may have been sufficient to cause the damage to the resistors by making them operate outside their operating range. Figure 44 is the resistors' derating curve which shows how the rated power decreases with the temperature of the case – a 50-67% reduction (which would bring the rated power down to approximately the highest average output powers calculated for individual resistors above) would occur for a case temperature of 100-130°C (assuming the derating curve applies when the case is not heat-sinked, which is not known). During testing, there were no observations of any significant temperature increases for the resistors, including when the resistors were identified to have burnt out and were promptly inspected and replaced. It may be that the internal temperature of the resistors was briefly raised (by the pulsed nature of the electrical output) in a way that damaged them without noticeable external temperature variation. It is also possible that some of the resistors belonged to a defective batch that made them more likely to burn out. Note also that stickers were placed on the resistors to identify their resistances (see Figure 45), with the reverse side of the resistors near or touching a textile surface, which both would likely have reduced the ability of the resistors to dissipate heat, potentially reducing the power they could handle, although whether by a significant amount or not is not clear.

[20] ~400V is the highest amplitude voltage measured in Salvo 1 across the 302Ω loads, which corresponds to 199V across just the 150Ω resistor, which is subject to the highest power of all 4 resistors in the potential dividers (compared to 28W for each 16Ω resistor, and 210W for the 120Ω resistor).

[21] 600V across the 1602Ω load means 487V across the 1300Ω which corresponds to 182W; the 16Ω, 120Ω and 150Ω resistors are subjected to peak powers of 2W, 17W and 21W respectively.

[22] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023.

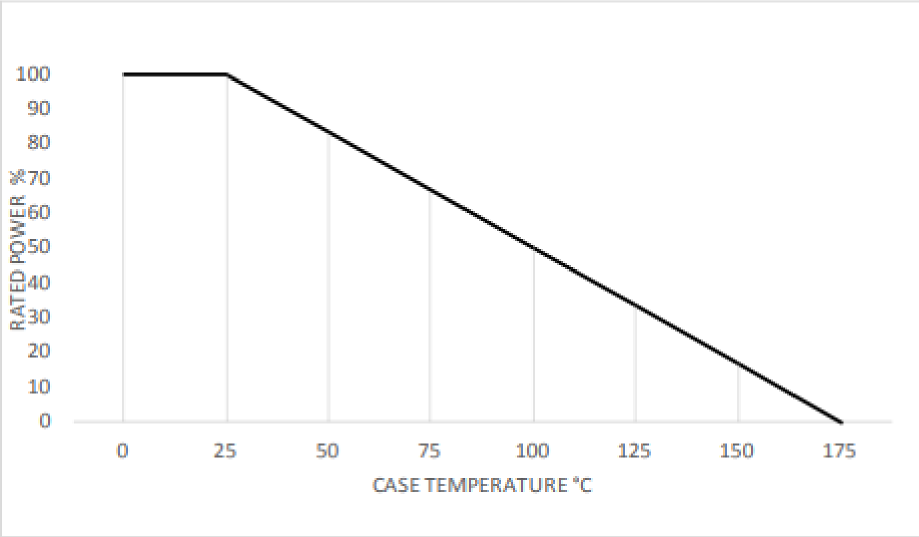


Figure 44: The derating curve of the resistors used in testing, indicating how the performance reduces with the temperature of the resistor's case.[23]

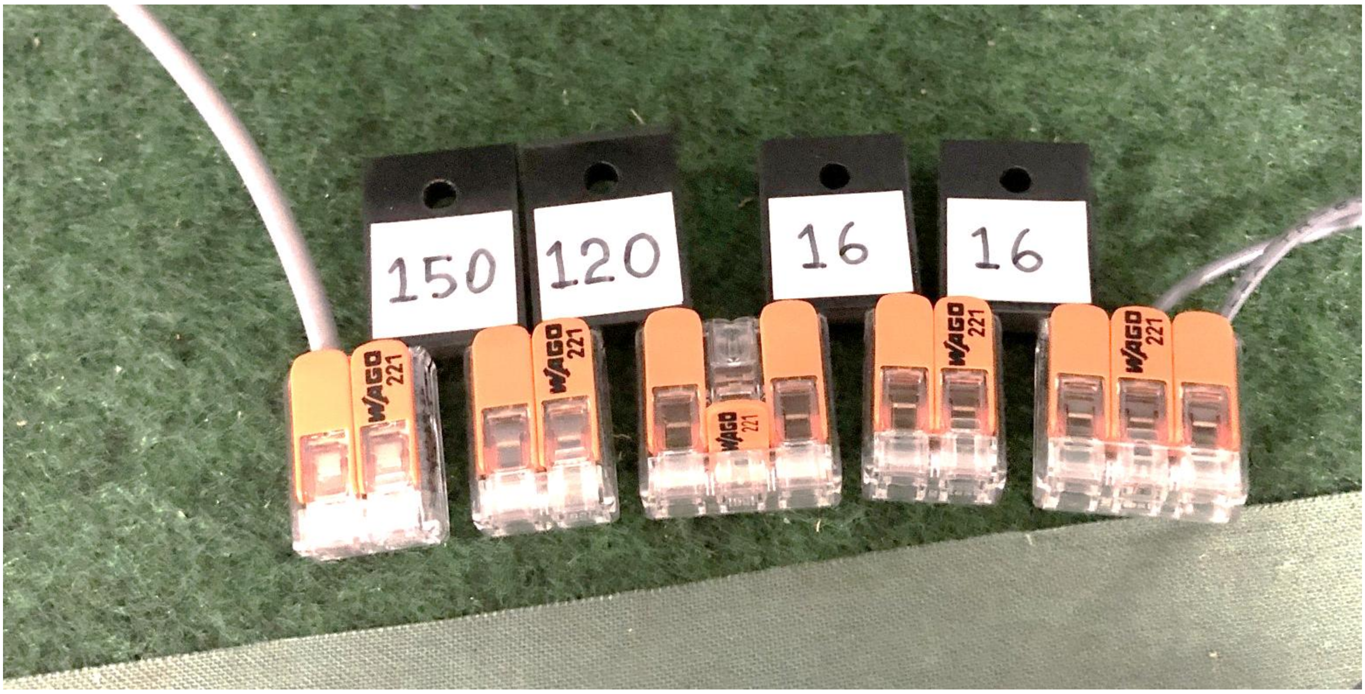


Figure 45: The resistor setup for one potential divider during Salvo 1.

The key question concerning the resistors is whether their burnout at the start of the aborted Salvo 2 indicates that they may have been subject to performance degradation during Salvo 1. If so, this may explain the instability and significant outliers observed in Salvo 1 but generally not in Salvos 2 or 3 (see Section 14.3.6.3). It is understood that when AP101-type resistors are subjected to high powers, it most likely causes an increase in resistance as the ink traces thin, eventually leading to the resistor going open circuit. This could be a plausible mechanism to explain how the open circuits observed at the start of Salvo 2 originated from damage in Salvo 1, since increasing resistance causes the voltage across the resistor to increase, and hence increases the power. Note though that the way Salvo 1 varied between 'abnormal' and 'normal' discharges did not give a clear picture of accumulating damage, which complicates directly attributing this damage mechanism. Also, it is understood that for single pulses of the <50μs

[23] https://ohmite.com/acl-ap101/

duration seen in this testing, the maximum peak power the resistors can handle may be orders of magnitude higher than the maximum continuous power, but repeated pulses will cause heating that lowers the threshold power, further complicating the assessment of how close to a damage threshold the resistors were being operated. Given that the only evidence is that the resistors burnt out at the start of Salvo 2, and the precise damage mechanism is unclear (but hypothesised to be due to the high instantaneous power pushing the resistors beyond their operating range), it is not possible to confidently attribute the Salvo 1 behaviour to resistor degradation, but it is a plausible explanation.

14.3.7.3 Other limitations

It is important to note that the methodology deployed here was novel, having been developed specifically for this testing and constrained by available time and resources. Only one handle was tested (in order to maintain consistency and comparability between different Salvos/measurements) and testing a larger range of handles may produce different results. The setup was designed to simulate the engagement of a single subject using resistive loads typical of Axon's specified resistances (which are understood to be based on biological/anatomical data), although replacing biological matter with resistors will always have limitations.[24]

14.4 Conclusions

14.4.1 Answers to key questions

The results above allow all the key questions to be answered:

- **The number of probes that could be energised during each discharge pulse**
    - After removing artefacts (as described in Section 14.3.7.1), only 2 probes were observed to be simultaneously energised during each individual discharge pulse.
- **The total number of probes contributing to the energised probe pairings over the course of the 5 second discharge**
    - Up to 8 of the 10 probes were energised over the course of the 5 second discharge. This was observed once across all three Salvos (in Event 10), while 7 probes being energised during a 5 second discharge was observed twice (in Events 7 and 9). It is hypothesised that small changes in the resistances caused the handle to change what connections it preferred. It is understood that the maximum number of probes that could be energised in 10, given that up to 4 connections can be energised by the device (spanning up to 8 different probes) as it cycles between different connections,[25] and that which 4 connections can change during a 5 second discharge if impedance changes are observed, in which case all 10 probes could be energised at some point during the full discharge.
    - Note that, as highlighted in the previous bullet point, irrespective of the total number of probes energised during a discharge cycle, only two probes were energised simultaneously to deliver each individual pulse.
- **The total number of pulses delivered for each energised probe during a 5 second discharge (from which an estimated frequency can be calculated*)**

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[24] This is highlighted by Axon's responses (see Appendix K), which noted that, in the context of pulse charge outliers, human flesh is understood to them to provide a particular range of outliers (51-120μC), but other testing scenarios not using human flesh (e.g. using resistors) can create larger outliers.

[25] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023. "Although as many as 10 probes could be connected to the subject at once, the weapon will only energize up to four connections at one time."

- The number of pulses from a single probe varied between different discharges. A probe that was energised in a repeated fashion throughout a 5 second discharge typically outputted either 110-115 or 55-58 pulses, corresponding to 22-23Hz and 11-11.5Hz respectively (out of a single probe). Figure 33 shows that these represent the majority of cases, with a wide range of other pulse counts also observed, generally due to instability in the output (e.g. a probe only being energised a small number of times initially before the handle settles on other probes to energise, or the handle changing probes mid-way through the 5 second discharge). Stable output of 147-151 pulses from a single probe were observed (corresponding to 29.7-30.5Hz), which occurred during Events 3, 33 and 51, all of which had 3 probes deployed in targets – this appears to be the scenario that results in the largest number of pulses from a single probe, but the total number of probes was still ~225, corresponding to ~45Hz, so is not an indicator of the device outputting more charge into a subject for that scenario.

- **The total number of pulses delivered across all energised probes during a 5 second discharge (from which the frequency can be calculated)**
  - This was consistently in the range 218-226 pulses over the 5 second discharge, corresponding to a frequency of 44.0-45.7Hz (see Figure 32) for the full distribution. Lower pulse numbers (and hence frequencies) were consistently observed when only a small number of probes had been deployed – typically for just two deployed probes the frequency was 19.8-23Hz, rising to 44-45Hz after 3 probes for Salvo 3, 5 probes for Salvo 2 and 7 probes for Salvo 1 (noting the challenges with some of the Salvo 1 data).
- **The direction of current flow for each energised probe**
  - This is visualised in the Event plots (and voltage traces) in the appendices. The direction of current flow can vary for a single probe over the 5 second discharge, which is in line with the expected behaviour of the T10.
- **The charge in each energised probe's pulses (by integrating the area under a pulse and dividing by the 32Ω resistance)**
  - **Salvo 1**

    The average charge per pulse for each Event (i.e. each 5 second discharge cycle) in Salvo 1 (using 604Ω loads to match Axon's typical testing conditions) was 65.5μC to 79.2μC, which is within the specified 52-95μC range.

    The individual pulse charges were more varied, with 94.1% within the specified range but outliers <10μC and up to 229μC observed. It is possible that these outliers may be erroneous due to difficulties with the resistors, but the evidence is not conclusive.

    Axon highlighted in their responses (see Appendix K) that pulse charge outliers can be caused by differences between the measured impedance (which is measured pre-pulse) and the actual impedance (encountered when the pulse is delivered). One cause of this discrepancy that Axon identified is changes in the impedance between the point at which the handle makes its measurement and when the handle outputs the pulse as being one cause. Another cause could be an incorrect impedance measurement by the handle. The fact that high-charge pulses occurred intermittently rather than sequentially suggest that changes to the impedance after the handle's measurement and before the pulse may be the most likely cause, since if this was the case the handle would adjust for the next pulse after re-measuring the impedance, avoiding multiple high-charge pulses in a row, which indeed is what was observed. Fully understanding this behaviour may require understanding how the device measures impedance (in case there are mechanisms that this could be made inaccurate by resistors operating outside their operating range), although this information is proprietary to Axon.

Given this identified (and plausible) mechanism by which outlier pulse charges can be generated, the key question is what the underlying cause was in Salvo 1. The prime candidate is unusual resistor behaviour, likely triggered by operating near or beyond the operating range of the resistors, with evidence as detailed in Section 14.3.7.2, albeit largely based on observations of subsequent resistor failures after Salvo 1 was completed. An alternative cause could be that the electrical connection between probes and the targets were highly sensitive (e.g. to vibrations, or to thermal expansion due to the high voltage pulses), although this is considered less likely given this was not observed in later Salvos (noting that different loads were used in Salvos 2 and 3 so the situations were not identical). Overall, the most likely cause is unusual resistor behaviour, but the evidence is not conclusive, and for either identified cause, the charge outliers appear to be primarily due to the testing methodology rather than a cause clearly applicable to real-life operational use on human flesh.

- **Salvos 2 & 3**

  Salvos 2 and 3 used larger resistances than Salvo 1, and displayed generally less instability.

  The average pulse charge for each Event was in the range 76-92µC with no significant outliers for Salvo 3.

  For Salvo 2 the average pulse charge for each Event was in the range 28-87µC, comprised of consistent 80-87µC Events until the 9th shot was deployed, after which there were a high proportion of low charge pulses (<12µC) outputted in a periodic pattern, which lowered the average outputted charge for each Event until it was consistently 28-30µC for 5 successive reenergisations. The low charge pulses always occurred when the energised probes had a 3204Ω load between them, which is beyond the 2000Ω in Axon's specified test conditions and beyond the 3000Ω limit that Axon identified in their responses as the threshold beyond which the device will not attempt to energise a connection (see Appendix K). It is hypothesised that the handle measured the 3204Ω paths as being under 3000Ω and therefore considered them suitable to energise, but lacked sufficient output to energise them effectively, resulting in a 'dropped' or 'failed' pulse. Understanding this further would require knowledge of the device's impedance measurement approach, which is proprietary information Axon are not currently able to share.

  Under seemingly identical conditions in Salvo 3, the device selected the lower resistance probe connections and did not present any low charge behaviour. It is therefore unclear what caused the behaviour in Salvo 2, and whether it would have any impact on operational use – the high loads involved make it most likely to be an edge case of the device's operation outside its expected operating conditions. Note also that it only occurred for Events with at least 9 probes deployed, which is understood to not be a realistic use-case.

- **Summary**

  Overall, the average charge is broadly in line with the Axon stated spread of pulse charges, but with significant outliers in Salvos 1 and 2 that may in part be due to resistor behaviour and selection causing edge cases not representative of real-world behaviour, but it has not been possible to confirm the source of the behaviour. Axon have highlighted a mechanism by which outlier pulse charges can be created by sudden changes in impedance, and have noted that larger outliers are possible for resistor-based setups (such as the one deployed in this testing) but that they do not expect to see pulse charges beyond the range 51-120µC for human flesh.

- **The total charge delivered across all energised probes during a 5 second discharge**
  - With two probes deployed, the total charge delivered was 0.008-0.009C across all salvos.
  - With more than 2 probes deployed, for Salvo 1 (with 604Ω loads between any two probes), the total charge was 0.013-0.016C. For Salvo 3 (with between 1544Ω and 3204Ω loads), the total charge delivered was larger at 0.017-0.019C (with one exception of 0.021C, highlighted below) – a ~25% increase compared to Salvo 1 with the lower loads.
  - For Salvo 2, with nominally identical loads to Salvo 3, the total charge delivered was 0.016-0.020C from shot 4 to shot 8, after which it decreased to 0.011C for shot 9, 0.010C for shot 10, and 0.006-0.007C for the remaining 5 discharges. The reduced charge was observed in the voltage data as the handle cycling between outputting ‘normal’ and ‘low’ charge pulses, which (as described above) is suspected to be an edge case caused by the high resistive loads. Note that although the total charge delivered dropped by over 50%, it remained above the total charge delivered with 2 probes; the impact on achieving NMI in a single subject is therefore unclear and beyond the scope of this report, particularly given that it would require greater knowledge of the mechanisms behind NMI than is available to this report’s authors.
  - The highest total charge delivered was 0.021C and occurred for Event 46 which was a reenergisation of 10 deployed probes after switching the handle off and on. Resetting the handle in this way may be directly responsible for the higher charge delivered, although this was only tested once so would need further investigation to confirm.

14.4.2 Summary

Overall, there are some interesting features of how the device behaves that are not fully understood and could allow a clearer understanding of precisely how the device operates, but the key performance characteristics of the device have been identified. In particular: only a single probe pair was seen to be energised on each pulse delivered during a discharge cycle; the pulse frequency is limited to 45±1Hz; and the average pulse charge is around 75μC (for 602Ω loads), rising to around 85μC for larger loads (~1500-3000Ω), with 88.5% of all measured pulse charges being between the Axon specified limits of 52-95μC. A range of outlier pulse charges were also observed (both above and below the specified limits), with identified mechanisms by which they may have been generated, which are primarily the result of the testing methodology rather than effects believed to be applicable to real-life operational scenarios with human flesh, although the precise causes have not been fully identified (for a majority of the low charge outliers, the cause appears to be around measurement of very high loads understood to be beyond the loads seen for human flesh; and for the highest charge outliers, the most likely cause is considered to be resistor burn out impacting the results).

In addition, some unexpected behaviour was observed with the total charge delivered, with Salvo 2 showing a significant drop (up to 50%) in total charge delivered after the 9th shot was deployed. The cause is believed to be due to using higher resistive loads than the device expects (and which are understood to be unrealistic loads for real-life operational scenarios), although the device chose to attempt to energise those high load pathways even though lower load pathways were available for the device to use, and Salvo 3 did not show the same behaviour despite nominally identical setups. Note that even with the 50% decrease, all discharges in Salvo 2 were above the charge delivered by all instances with 2 probes deployed (0.008-0.009C).

The testing conducted has identified typical performance of the T10 across a range of metrics, based on testing of a single handle, although not all observed behaviour is yet fully understood, noting that the testing setup simulates engagement of a single target using resistors rather than human flesh, which is likely to introduce more edge cases and unrealistic scenarios than would be applicable to operational use.

15 Issues

A range of issues were observed and noted during testing that are not reported as part of the tests above. These issues are summarised in Table 29 with full details in Table 48 of Appendix M. The issues could be broadly classified into minor quality assurance issues, deployment failure issues, and expected degradation.

Failure type	Specific issue	Brief description	Occurrence rate
Minor quality assurance	**Multiple ID bands**	The presence of two ID bands on cartridges prevented them being loaded into magazines without manually removing one band.	2 out of ~170 (1.2%) HALT cartridges used. 0 out of ~620 (0%) duty cartridges used. 2 out of ~790 (0.3%) cartridges (both types) used.
	Laser sight vertical stripe	The laser sight produces a vertical stripe as well as a dot at the target.	1 out of 6 (17%) tested handles
Deployment failure	**Wire failure**	The wire failed to deploy from the cartridge, preventing any electrical pathway to a target.	0 out of ~170 (0%) HALT cartridges used. 1 out of ~620 (0.2%) duty cartridges used. 1 out of ~790 (0.1%) cartridges (both types) used.
	Cartridge deployment failure	The cartridge failed to deploy from the bay. Often this was accompanied by an error on the CID. Of the 5 times this occurred, reseating the cartridge enabled it to be subsequently deployed 2 times, while 3 times the cartridge could not be deployed.	1 out of ~170 (0.6%) HALT cartridges used. 4 out of ~620 (0.6%) duty cartridges used. 5 out of ~790 (0.6%) cartridges (both types) used.
	Trigger sensitivity	The trigger subtly changed feel and behaviour with use, presumably due to wear and tear. It required a heavier trigger pull to repeatably deploy a cartridge, with occasional double pulls required.	First occurred after ~380 shots with one handle, then double pulls required for two shots of the following ~460 shots. No such occurrence after ~250 shots with a second handle.
	Complete handle failure	The handle stopped being capable of detecting or deploying cartridges.	Occurred after ~530 shots with one handle. No such occurrence after ~250 shots with second handle.
Expected degradation	**Interposer bucket**	The interposer bucket became dirtied and contaminated with use, eventually causing pins to malfunction, and possibly contributing to poor electrical connections related to cartridge deployment failures. Wear of the interposer bucket is anticipated by Axon, with a recommended replacement after 150 cartridge deployments.	1 interposer bucket required replacing after ~310 shots.

Table 29: A summary of issues encountered with the T10 hardware and software during testing.

Note that these observations and statistics are based on the first set of testing (conducted from September to December 2024). Later testing (between February and May 2025, which involved the deployment of an additional 358 duty cartridges across 4 new handles) did not focus on documenting issues so are not included, but did not observe any significant issues with the hardware that affected the testing.

15.1 Minor quality assurance issues

Two issues were identified as minor quality assurance issues.

The first was that a small number (2 out of ~170; 1.2%) of HALT cartridges had two blue ID rings on rather than one (see Figure 46), which prevented them being loaded into a magazine. Assuming operators are provided with pre-loaded magazines and/or are not loading cartridges into magazines in operational scenarios, this does not pose a significant issue.

Figure 46: A HALT cartridge with two blue ID bands, preventing it being loaded into a magazine bay.

The second issue was that 1 out of 6 (17%) handles produced a vertical stripe from the laser sight as well as a dot at the target (see Figure 47). The device is, however, fully useable as the intensity of the dot remains adequate for aiming (the dot was brighter than the stripe).

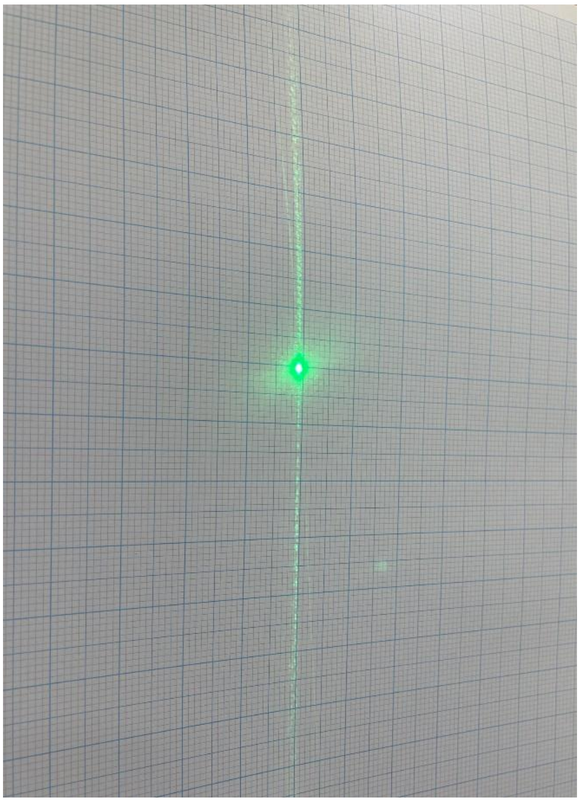


Figure 47: One of the six T10 handles used for the laser power tests produced a vertical line as well as a dot – shown here on the graph paper on the target used for POI measurements.

Neither of these issues are considered of significance for use of T10s.

15.2 Deployment failure

Several modes of failure which prevented successful deployment of a cartridge at a target were observed.

15.2.1 Wire failure

One instance was observed of the wire failing to be deployed by the cartridge due to the wire breaking off in the bay. This represents a failure rate throughout testing of ~0.1%. The cartridge was retained to allow further analysis to be conducted, if required.

15.2.2 Cartridge deployment failure

Five instances of a cartridge failing to be deployed from a loaded bay (ignoring issues with trigger sensitivity which are discussed below) were observed, representing a failure rate throughout testing of ~0.6%. The causes appeared to be mainly due to temperamental physical contact between the handle and the cartridge (likely in part due to the interposer bucket – see Section 15.3), with software issues potentially a factor although this was not possible to confirm. Some cartridges were able to be deployed after reseating them in the bay, while others were not able to be deployed at all – those have been retained for future analysis.

15.2.3 Trigger sensitivity

The trigger was initially deployed with a very light trigger pull, in order to minimise any input from the operator to the direction and accuracy of the device. After over 380 shots, it was noticed that such a light trigger pull did not consistently cause the device to trigger. This was assumed to be due to internal wear and tear. The methodology changed to use a firmer trigger pull, which worked reliably except for two shots (after the handle had been used for over 460 shots) that required two pulls of the trigger.

To attempt to quantify the change, force measurements were made for three different handles (see Appendix M for details). Within the measurement-to-measurement variation, all the handles appeared similar with no significant trends. An experienced operator, however, reported that, despite this, there is a notable difference to how the trigger feels – specifically, how progressive it is up to the point of discharge. So although the measurable force was not noticeably changed, there was a noticeable difference for an operator. An operator trained to use a firm trigger pull therefore appears unlikely to encounter any significant issues, particularly if deploying a lightly used T10 handle. Operators employing a very light trigger pull may notice a change, depending on the force used, which would require further work with users to determine the likelihood of such light trigger pulls being preferred.

15.2.4 Complete handle failure

After about 530 shots, one handle stopped registering any loaded cartridges and was unable to be used. No other handles were used for more than ~250 shots. Based on this limited sample size, a T10 handle appears to have a lifetime of several hundred shots, and it is not clear whether the complete handle failure observed here would be repairable by the manufacturer or by specialists. It may serve as a useful indication for what could correspond as an approximate limit a 'heavily used' device, and inform the lifetime that devices may be expected to have even in training environments (where heavy use is expected and minor issues may be more acceptable than in operational scenarios, but full handle failure would prevent further use of the device without repair).

15.3 Expected degradation

The interposer bucket is a consumable part that acts as the physical and electrical interface between the handle and the end of the cartridges when inserted into the magazine bays. It contains several pogo pins to make the electrical contacts. Axon state[26] that the “interposer bucket is designed to be replaceable since it takes the brunt of the impact from the cartridge’s recoil” and they “recommend that a T10’s interposer bucket should be replaced after 150 cartridge deployments, if the handle has stuck pogo pins, or if the pogo pins are darkened/tarnished and cannot be cleaned”.

In the course of testing, one failure of an interposer bucket was observed, which occurred in the form of a stuck pogo pin after ~310 shots from a single handle with the same interposer bucket throughout. When this failure occurred, the interposer bucket was inspected and found to be heavily contaminated with combustion products, with evidence of possible corrosion of the metallic elements. Attempting to clean it with isopropyl alcohol was ineffective. Figure 48 shows the interposer bucket with the depressed pogo pin, and Figure 49 shows a comparison of the interposer bucket with an unused one, with clear visual evidence of contamination of the electrical connections on the heavily used one. Figure 50 shows the same comparison but with the interposer buckets removed from the respective handles. Close inspection found some evidence that the connections below the interposer bucket were also contaminated and/or slightly corroded; there appeared to be slight voids between the metallic and plastic elements of the interposer bucket, allowing corrosive gases to permeate behind the components.

Figure 48: An interposer bucket with a permanently depressed pogo pin that could not be fixed (red circle).

[26] https://my.axon.com/buy/s/product/axon-taser-10-replacement-interposer-bucket/01tDo000000HXsJIAW

Figure 49: A comparison of a heavily used interposer bucket (left; over 310 shots, and the same interposer bucket as in Figure 48) and an unused interposer bucket (right).

Figure 50: A comparison of a heavily used handle with the interposer bucket removed (left; over 310 shots, and the same handle as in Figure 48) and an unused handle (right), again with the interposer bucket removed.

Given that the interposer bucket was used beyond the 150-shot lifetime that Axon recommends, this degradation of the interposer bucket appears to be expected by Axon, and, as such, replacement of the interposer bucket in line with the recommended lifetime appears sensible. Given that, in this testing, the only interposer bucket failure occurred after more than double the recommended number of shots, and only one pin failed at once, it appears likely that the effect of a previously operational interposer bucket failure on a user would be small – the operator would be able to move on to deploying a different cartridge (assuming more cartridges are available), rather than all bays failing simultaneously. Note though that a full assessment of the lifetime and failure modes of interposer buckets would require additional testing (likely involving thousands of shots across multiple interposer buckets).

Overall, it would appear advantageous to monitor the usage levels of different handles, with heavily used ones primarily reserved for training scenarios, where minor failures may be of less importance.

15.4 Other

In addition to the above failure modes, it was noted during testing that the CID display made it difficult to easily assess the number of loaded bays. Figure 51 shows the CID when there are 9 cartridges loaded, both for the normal display (top) and after a function test (bottom). For the function test result screen in particular it is difficult to distinguish between loaded and empty bays, particularly for an operator glancing briefly at the screen in an operational scenario, and the normal CID display is better but still difficult to accurately know the number of loaded cartridges at a glance.

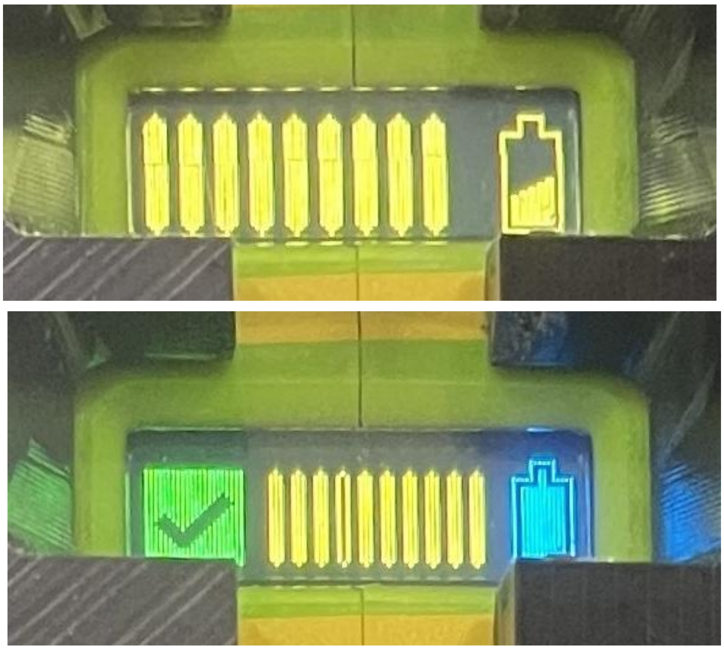


Figure 51: The CID display for 9 loaded bays for (top) default output and (bottom) after function test. It was observed that it can be difficult to easily interpret the number of cartridges at a glance, particularly on the post-function test display.

An improvement for future versions of the software controlling the CID may be to show the number of loaded cartridges numerically, although the current display does allow easy highlighting in red of bays with issues. It would require consultation with users to ascertain what is preferable for the CID to display in operational scenarios.

15.5 Summary

Overall, a range of issues were observed during testing of the T10s, but none appear to pose major risks provided that devices are maintained regularly and usage is tracked, although it is up to other groups to determine suitable maintenance and usage (e.g. what level of usage is suitable for operational deployment compared to training use) of the devices. Some cartridge deployment failures appear to be expected, but at a rate of order 0.6%, and complete handle failure was observed which highlights that devices appear to have a limited lifetime, but only after 530 shots in this single case.

Note, however, that even if operational use is unlikely to be significantly impacted by these issues in isolation, there is a risk that users noticing these issues (either during operational deployment or training) could contribute to negative impressions about the build quality of the devices beyond what is reasonable based on the data, but in a way that could make widespread deployment of the devices more challenging. Planning how to communicate to new users about the types of likely issues, and their likelihood and impact, would aid preventing unnecessary negative sentiment to rise.

Note also that the testing conducted here involved approximately 790 T10 cartridges (both duty and HALT) spread over predominantly two different handles, and it is possible that other issues may arise when a larger sample size is used (either in further testing, or in the process of rolling out T10 devices to end users), or the likelihood of different issues could vary. In particular, the observation here that one handle failed after ~530 shots should not be taken to infer that 530 shots is a likely upper or lower limit on the number of shots achievable from one handle, given that handle-to-handle variation is currently unknown.

Appendices

Appendix A Raw testing data

Appendix A consists of the raw testing data (including all equipment numbers), which is provided alongside this report as a spreadsheet: *MIQ-24-0015-D - Taser 10 Technical Testing Data*.

Appendix B Kinetics: Accuracy

Equipment

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Velocity measurements were performed with a Pro Chrono DLX chronograph with infrared LED light kit. Mass measurements used a Adam Equipment digital analytical balance PW124 with inbuilt self-calibration (precise to 0.0001g).

Methodology

The methodology is outlined in Section 2.2, with more details provided in the following.

The T10 devices were mounted in a firing rig, consisting of an Axon-provided machined metal holder securely mounted to a mounting platform (Ransom Master Series Combo Rest, with built-in windage adjustment) typically used for firearms testing, therefore minimising any effects of recoil from the devices. A hinged rectangular shield was in front of the firing rig, which when rotated into the 'up' position blocked the device from firing down the range as a safety precaution between shots. The mount allowed the CID screen to be visible, and allowed the magazine to be removed and reinserted without removing the handle. The firing rig is shown in Figure 52.

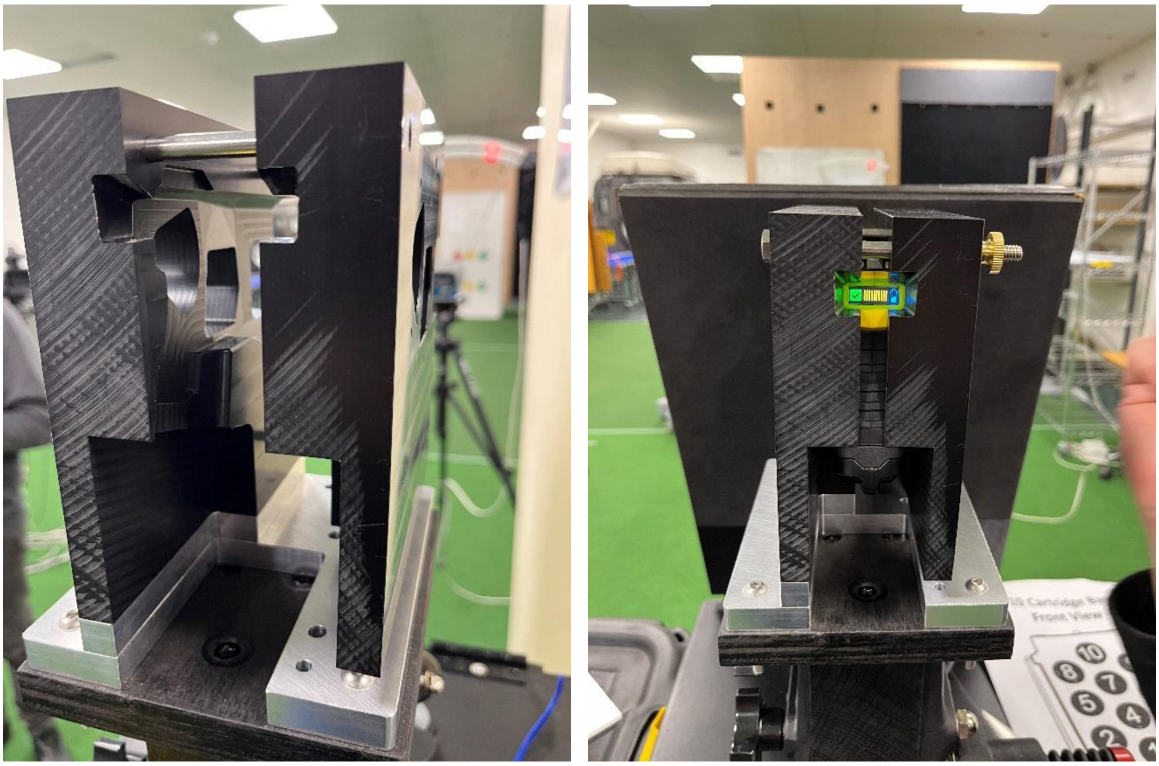


*Figure 52: The firing rig used to hold the T10 handle during firing. **Left**: the empty mount. **Right**: with a T10 mounted and secured in place, with the CID visible and the rectangular shield in the 'up' position, shielding the range from the device.*

The target was an Axon-provided target consisting of multiple high-density foam layers with a conductive layer included, which was mounted to a plywood backing with spacers to allow the Axon target to flex when the probes impacted. It was found that mounting the Axon target directly to the plywood resulted in a high likelihood of the probes bouncing back from the target – believed to be due to the probe compressing the Axon target such that it impacted against the plywood with enough energy to rebound out of the Axon target. The plywood backing was mounted to a lightweight tube frame on wheels to allow the target to be moved, while preventing any significant movement of the target upon impact of probes. For measuring POI and POA data, 2mm lined graph paper was placed over the target using drawing pins. The target is shown in Figure 53.

Figure 53: The target used for kinetic testing – an Axon-provided flat layered target mounted to a plywood backing for support. ***Left****: The target with graph paper overlayed for POI measurements.* ***Right****: A close-up of the side of the target.*

The step-by-step process for taking measurements was:

1. Perform a function test.
2. Confirm the test number, serial number and shot number.
3. Load the weapon while recording each cartridge serial number and corresponding bay number.
4. Shield moved to the 'up' position to prevent probes entering the forward range area in the case of an accidental discharge.
5. Arm the device, to turn on the laser sight and allow the POA to be noted on the target (using the graph paper).
6. Shield lowered to the 'down' position.
7. Trigger pulled using a very light pressure to minimise any motion being transmitted to the device and impacting the measurement.
8. Wire (from the deployed cartridge) cut at the magazine end, and the shield moved back to the 'up' position.
9. Target inspected with measurements (POI, velocity, mass, etc.) and notes (any unusual behaviour) recorded as required.
10. Probe removed from the target (if it remained in the target), to avoid it possibly being hit by a subsequent probe and invalidating the measurement.
11. Repeat for any additional shots. Graph paper was replaced as required.
12. Perform another function test at the end of the series of shots.

Velocity measurements were performed using a chronograph with a gate separation of 300mm, at varying ranges as reported in Appendix A and Section 6.3.2). The velocity recorded is therefore the average velocity of the probe as it passes between the two gates of the chronograph. This also limited how near to the muzzle the velocity could be measured.

Mass measurements were conducted by weighing a probe using the weighing scales after cutting the wire at the rear of the probe.

Note also:

- The ambient temperature was recorded at regular intervals throughout the day.
- The original Technical Test Plan called for function tests to be carried out at the start and end of each serial (see the Technical Test Plan for details on different serials). It was, however, decided that for longer serials (e.g. Test 1, Serials 1 & 4), a function test would be performed every 10 shots with the results recorded (see Appendix A). This included recording the precise battery percentage, which is not shown on the CID during operational use, in order to facilitate identification of specific shots and serials in the data logs for the CEDs (which are expected to be collected after the conclusion of this testing).

Data

Key plots and statistics are in Section 2.3, with all raw data provided in Appendix A. In addition, data for the maximum range testing (whereby the range was varied to assess at what range the probe would detach from the wire) is provided below for reference.

Absolute maximum range data

Data on the absolute maximum range of the probes was recorded as part of Test 1 Serial 9. A summary is provided in Table 30, with a more detailed breakdown provided in Table 31. Note that all shots impacted the Axon target board, whether detached or not.

Range	No. of shots fired	No. of shots detached	No. of shots not detached
17 m	2	2	0
15.35 m	10	10	0
15.2 m	4	2	2
15.1 m	2	1	1
15 m	7	2	5

Table 30: A summary of the absolute maximum range data considering whether probes detach or not at different ranges.

Shot ID	Range	Notes	Mass of wire
471	17 m	Detached at probe	-
472	17 m	Detached at probe	-
473	15.35 m	Detached at probe	0.8835g
474	15.35 m	Wire detached at handle end and still attached to probe	0.9110g
475	15.35 m	Detached at probe	0.8868g
476	15.35 m	Detached at probe	0.8878g
477	15 m	Detached at probe	0.9086g
478	15 m	Wire fully deployed but not detached	0.9072g
479	15 m	Wire fully deployed but not detached	0.9077g
480	15 m	Detached at probe	0.9018g
801	15 m	Not detached	-
802	15 m	Wire fully deployed but not detached	-
803	15 m	Wire fully deployed but not detached	-
804	15 m	Detached at probe	-
805	15.1 m	Not detached	-
806	15.1 m	Not detached	-
807	15.2 m	Wire detached at handle end and still attached to probe	-
808	15.2 m	Wire fully deployed but not detached	-
809	15.2 m	Wire detached at handle end and still attached to probe	-
810	15.2 m	Detached at probe	-
811	15.35 m	Detached at probe	-
812	15.35 m	Wire detached at handle end and still attached to probe	-
813	15.35 m	Wire detached at handle end and still attached to probe	-
814	15.35 m	Detached at probe	-
815	15.35 m	Wire detached at handle end and still attached to probe	-

Table 31: A breakdown of the absolute maximum range data considering whether probes detach or not at different ranges, also available in Appendix A. The mass of wire was measured for a subset of the shots as supplementary data.

Appendix C Kinetics: Accuracy – Clamped vs Hand-Fired

Equipment

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Velocity measurements were performed with a Pro Chrono DLX chronograph with infrared LED light kit.

Methodology

The methodology closely followed the methodology of the previous accuracy testing (see Appendix B), along with the changes detailed in Section 3.2.

To accommodate the change to including hand-fired measurements, the process for taking measurements was revised to:

1. Perform a function test.
2. Confirm the test number, serial numbers and shot number.
3. Load the device while recording each cartridge serial number and corresponding bay number.
4. Fire the device. For a clamped measurement this involved:
    - Move the shield to the 'up' position to prevent probes entering the forward range area in the case of an accidental discharge.
    - Arm the device, to turn on the laser sight and allow the POA to be noted on the target (using the graph paper).
    - Lower the shield to the 'down' position.
    - Pull the trigger using a very light pressure to minimise any motion being transmitted to the device and impacting the measurement.
5. For a hand-fired measurement, this involved:
    - Mark an aim point on the target (using the graph paper), at a height to match the height of the device when held in a firing position by the operator (who was right-handed throughout).
    - Arm the device, to turn on the laser sight and the operator directs the POA to match the marked aim point on the target. Aim the device using the two-handed grip and stance as per the College of Policing training.
    - Pull the trigger to fire the device. Fire the device (still using a two-handed grip and regular stance) as per the College of Policing training. Note the handedness of the operator.
    -
6. Cut the wire (from the deployed cartridge) at the magazine end, and make the device safe.
    - For a clamped measurement, the device was made safe by moving the shield back to the 'up' position.
    - For a hand-fired measurement, the device was made safe by switching the device to SAFE mode and manually lowered to the table with the muzzle pointed downwards against an impact pad. The operator then calls "Safe", after which personnel could approach the target to report the impact data.
7. Inspect the target to measure the POI relative to the POA and note any unusual behaviour.

- For point of impact (POI) and point of aim (POA) data, measurements were conducted by visual observation of the impact point, using the millimetric graph paper facing of the target to allow recording of the Cartesian coordinates of the POI relative to the original POA. Accuracy was ±5mm or better.

8. Remove the probe from the target (if it remained in the target), to avoid it possibly being hit by a subsequent probe and invalidating the next measurement.
9. Repeat for any additional shots. Replace the graph paper as required.
10. Perform another function test at the end of the series of shots.

The probe velocity was measured at a distance of 1m from the device, primarily to highlight any erroneous shots (e.g. an unusual discharge of the propellant that would alter the velocity and trajectory, and therefore should be retaken).

Results

Section 3.3 contains the main plots and tables used to analyse the data. In addition, data on the inter-magazine variation and the measured velocities is provided here.

Inter-magazine variation

Figure 54 shows how the dispersion varies across both handles and magazines – Figure 54 is the same data as in Figure 9, Table 9 and Figure 10, but divided by handle and magazine, and excluding the clamped-only data from the previous testing (handle serial number T19E24561). This allows the effect of different magazines to be observed.

No significant variation between magazines was observed (noting that the limited number of data points mean that an outlier can have a significant effect on the plotted confidence ellipses without having a statistically significant impact on the overall dispersion pattern), in agreement with the previous assessment of inter-magazine variation (see Section 2).

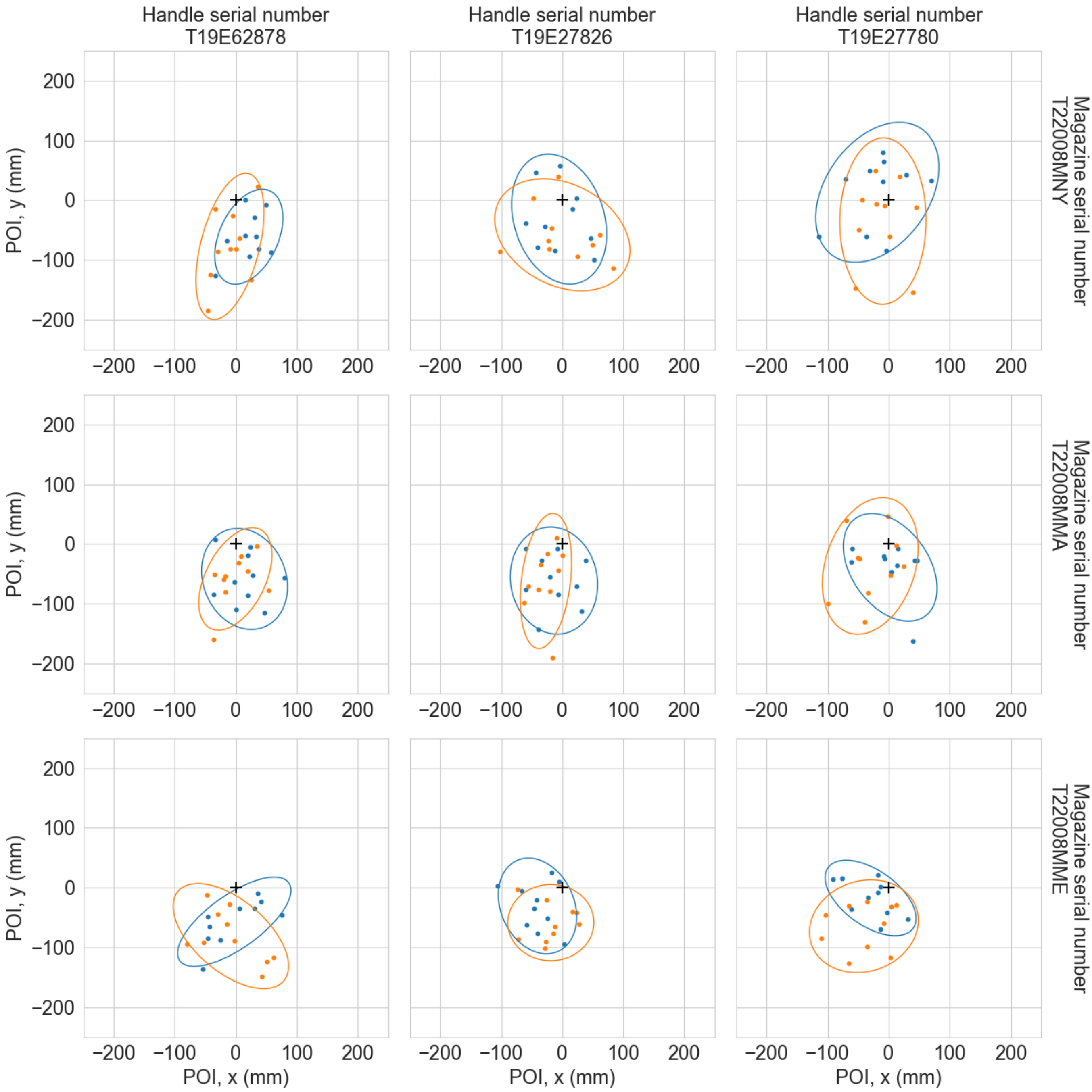


Figure 54: Plots of POI data by handle and by serial number for duty cartridges at a range of 10.1m for both clamped (blue) and hand-fired (orange) states. Each column of plots corresponds to a specific handle (denoted at the top of the column), and each row of plots corresponds to a specific magazine (denoted at the right of the row). The points are the raw POI, the ellipses are the confidence ellipses that correspond to containing 95% of the data for each range, and the black cross indicates the POA.

Velocity data

Figure 55 shows the measured velocity (1m from the device) for the different handles in both clamped and hand-fired states, and Table 32 contains a statistical summary of the data. Overall there is a small reduction and increased spread in the measured velocities when hand-fired compared to when clamped – the mean velocity is 1.54m/s (2.5%) lower, the standard deviation is twice as high, and while the maximum measured velocity is the same (to within 1%) the minimum velocity is 7.93m/s (14.2%) lower. This is reasonable given that the device when hand-fired is less securely held than when clamped, with more shot-to-shot variation.

Importantly, the hand-fired shots with a significantly lower velocity than the typical velocities for clamped shots did not show a reduction in accuracy – i.e. these lower velocities were not indicators of erroneous shots. Figure 56 shows the POI data for each handle with the hand-fired shots highlighted where their measured velocity was lower than the minimum recorded clamped velocity (55.78m/s). While some of these highlighted shots are towards the edge of the distribution of shots, others are particularly close to the POA. Therefore, there appears to be no significant dependence on accuracy (given the limits of the amount of data collected).

Note also that no significant variation in velocity between different magazines or handles was observed.

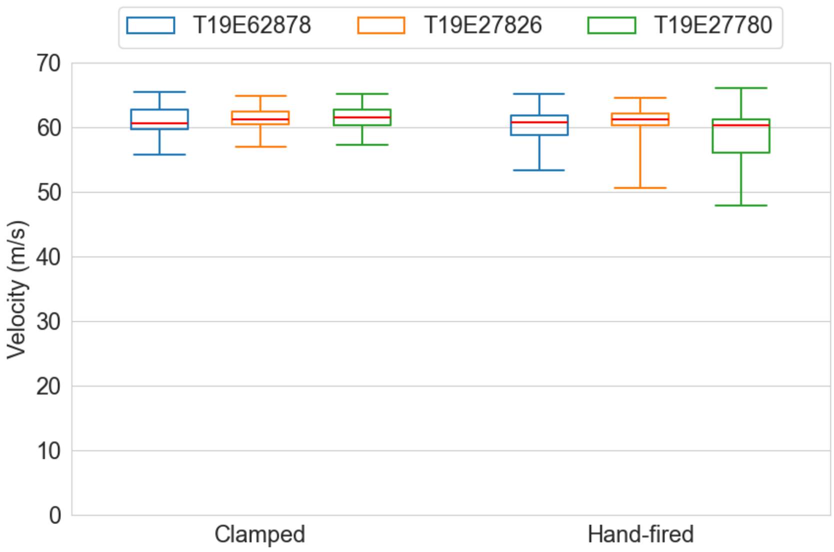


Figure 55: Box plots of the velocity data measured 1m from the device, separated by handle serial number and state (clamped and hand-fired). The boxes show the interquartile range, the whiskers extend to the minimum and maximum values, and the red line for each box is the median value.

Clamped or hand-fired	Handle serial number	Measurement Count	Velocity (m/s)				
			Mean	Maximum	Minimum	Standard deviation	Standard error
Clamped	**T19E27780**	30	61.64	65.23	57.30	1.87	0.34
	T19E27826	30	61.37	64.92	57.00	1.86	0.34
	T19E62878	30	60.91	65.53	55.78	2.04	0.37
	All handles	**90**	**61.31**	**65.53**	**55.78**	**1.93**	**0.20**
Hand-fired	**T19E27780**	30	58.17	66.14	47.85	5.34	0.97
	T19E27826	30	60.73	64.62	50.60	2.82	0.51
	T19E62878	30	60.42	65.23	53.34	2.33	0.43
	All handles	**90**	**59.77**	**66.14**	**47.85**	**3.87**	**0.41**

Table 32: Statistics for the velocity of probes (measured 1m from the device) for handles in both the clamped and hand-fired states.

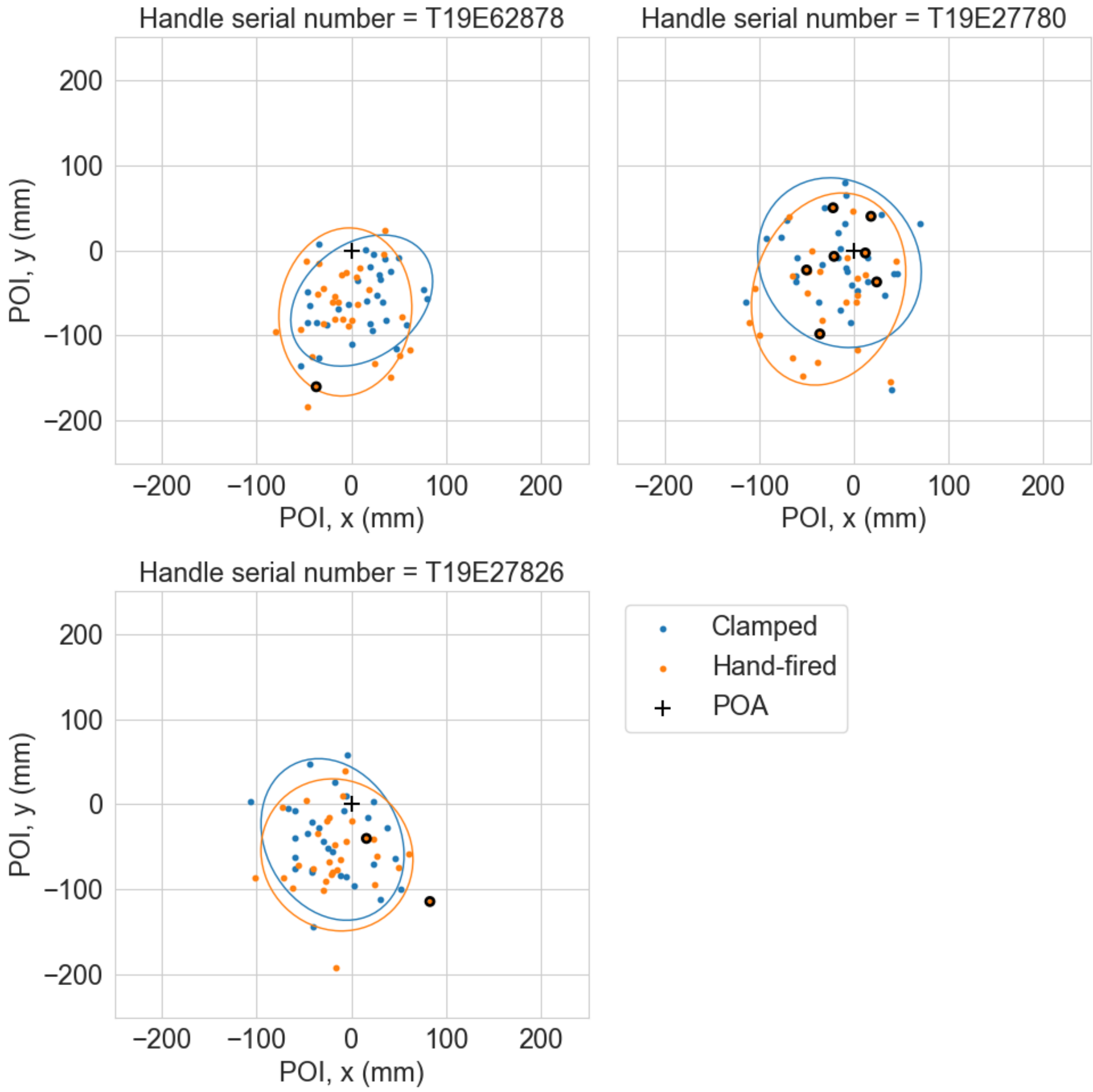


Figure 56: The same plots of POI data as in Figure 9, with hand-fired shots highlighted with black rings where the measured velocity was lower than the lowest recorded velocities for clamped devices (55.78m/s). Note that the plot for handle T19E24561 is not present due to the velocity measurements for that data being at a different range.

Appendix D Skin penetration

Equipment

The skin simulant target was a TP5 Biofidelic Shoot Pack from Biokinetics, provided by Dstl. Each pack measured approximately 15.5”x18” and were composed of multiple layers of rubber of varying hardness to replicate the different layers of skin. The composition of the packs was:

1. An outer layer of 1.6mm SM124 grade SRR, to replicate the dermis layer
    a. Note that the original outer layer is a different material provided by Biokinetics, with an average thickness of 1.3mm, which was replaced for by Dstl.
2. A secondary layer to replicate the epidermis, with a nominal thickness of 6.4±1.0mm.
3. 12 subsequent layers to replicate soft tissue, each layer having a nominal thickness of 6.4±1.0mm.

The minimum assembled thickness of the skin simulant pack was 69.8mm.

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Methodology

A summary of the methodology including the classification system is provided in Section 7.2, with more details below. Note that the classification scheme used in this testing is different to that proposed in the original trial plan due to the need to categorise different levels of penetration beyond just the dart – the original scheme assumed that the main differentiator would be whether anything beyond the dart penetrated, rather than how much beyond the dart penetrated.

The skin simulant pack was mounted in a right-angle plywood support and held in place by two clamp stands. Masking tape was placed around the edges of the pack to keep the layers together. This was all placed on a height-adjustable mount on wheels, to allow the positioning of the target to be moved between shots. The impact of the probes on the target had a negligible impact on the position of the target, with a slight oscillating motion of the tips of the clamp stands noticeable, but no change to the positioning of the skin simulant pack or right-angle mount. The intention was not to ensure a fully rigid mounting, in order to better recreate a realistic and relevant target. Figure 57 shows the setup.

The CED was mounted according to the methodology of Appendix B.

After each shot, a photograph was taken of any penetration, with a sticker denoting the shot ID to enable clear subsequent identification of the photograph. Where penetration occurred, the length of probe protruding from the target was recorded using digital callipers to an accuracy of ±1mm. Where penetration did not occur, a photograph was taken of the probe(s) next to the target.

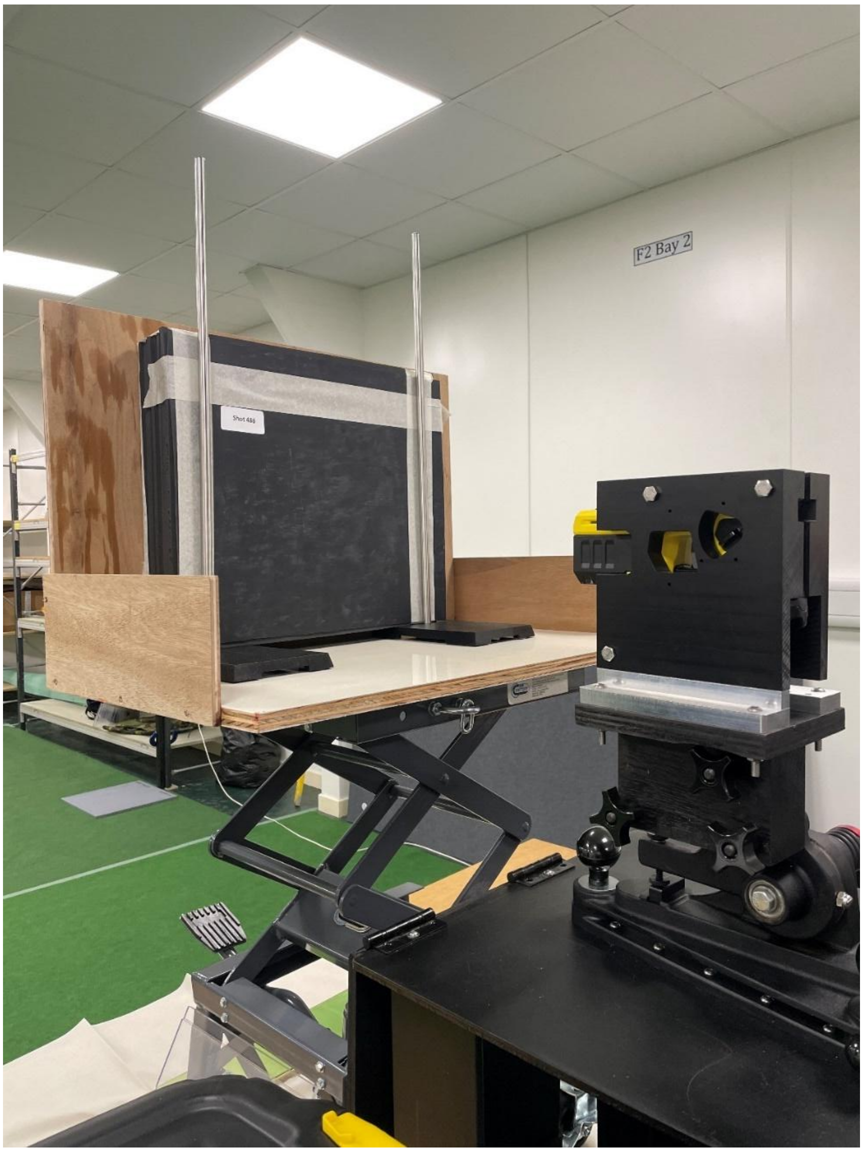
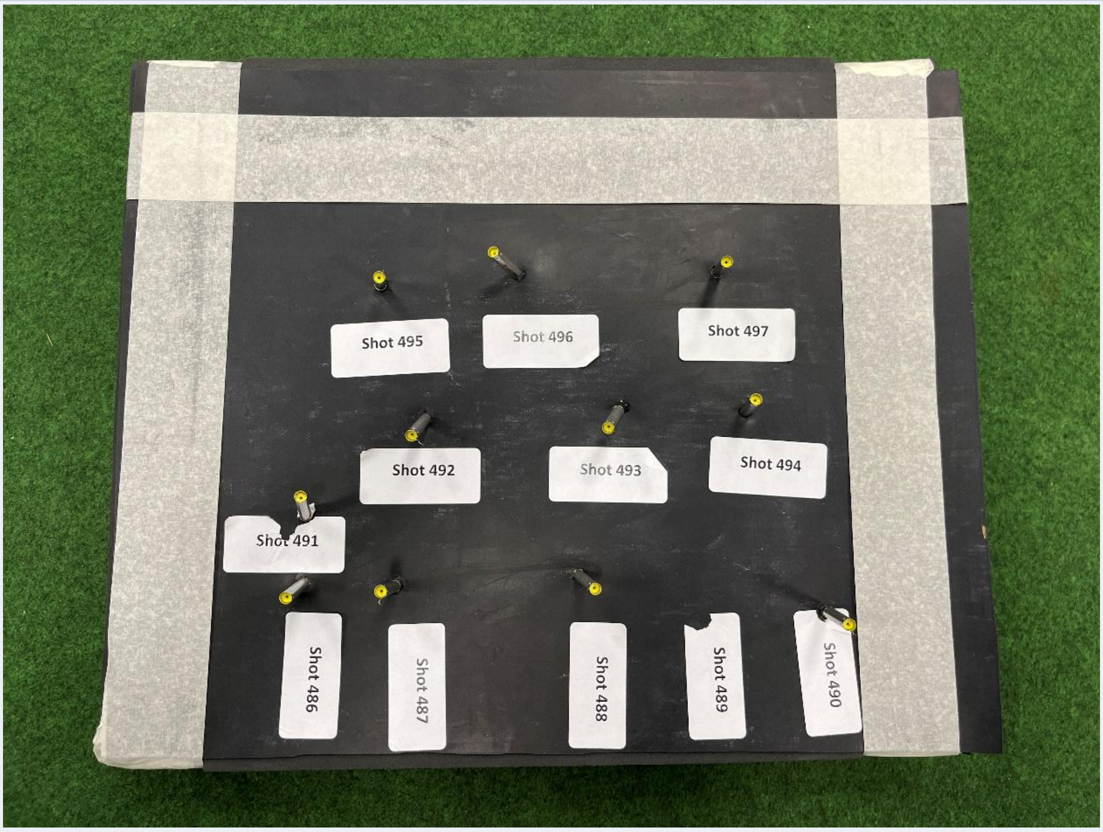
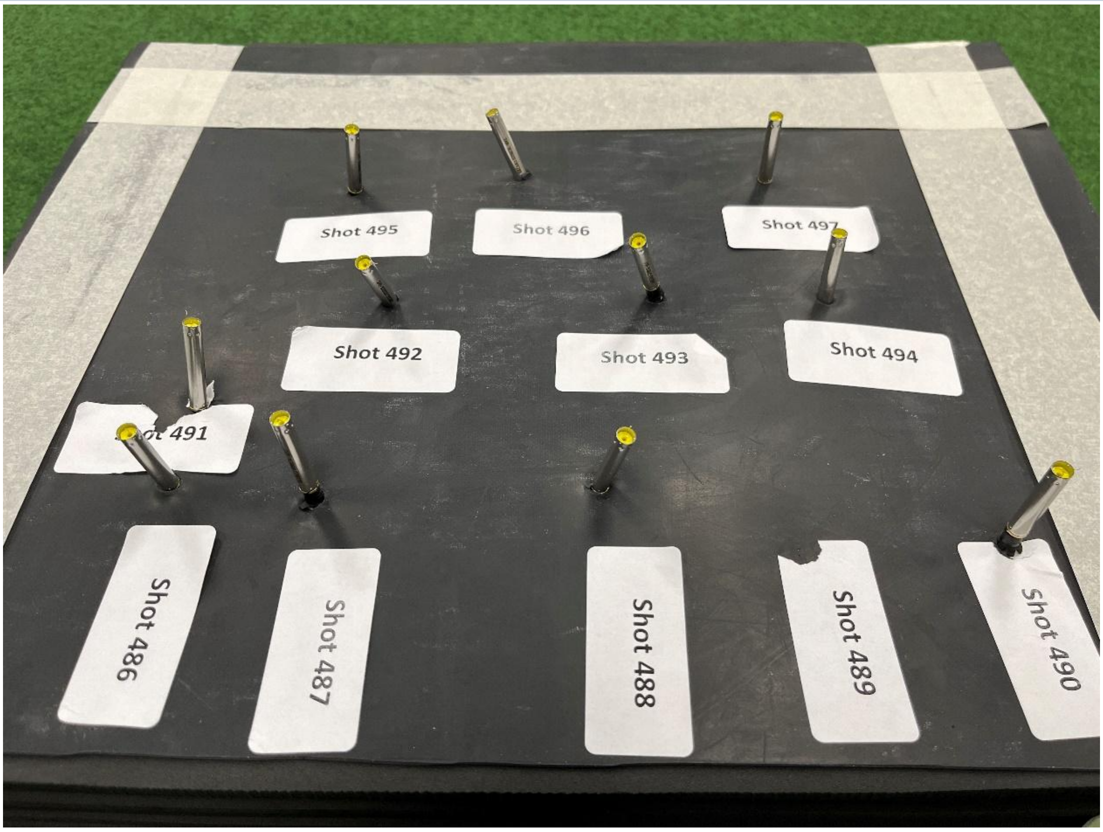


Figure 57: Setup of the skin penetration testing.

Efforts were made to ensure impact points were at least 5cm apart. This was not always successful due to the inherent inaccuracy of the device. Since 14 out of 15 (93%) T10 probes penetrated and remained in the skin pack, and the only one that did not remain was further than 5cm from the other probes, it was concluded that penetration was not affected by the proximity of other probes.

Data

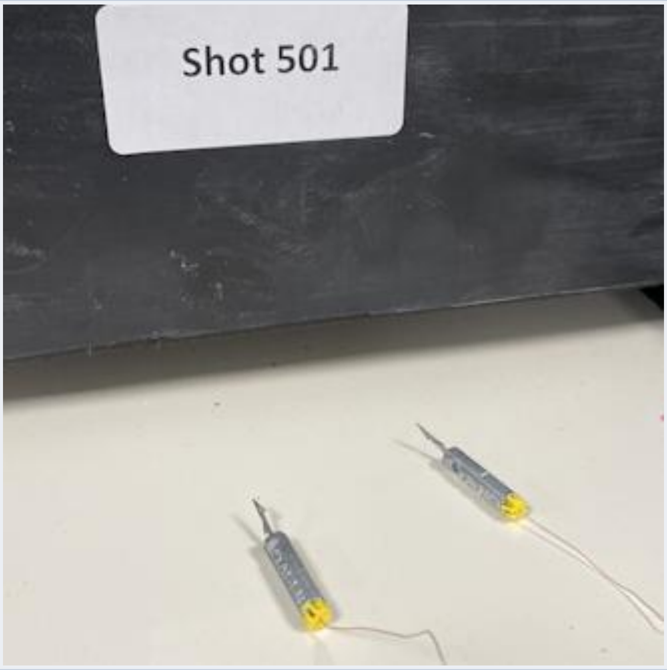
The observations are recorded in Section 7.3, as well as in Appendix A, and pictures of each shot are provided below - Table 33 for T10 testing and Table 34 for X2 testing.

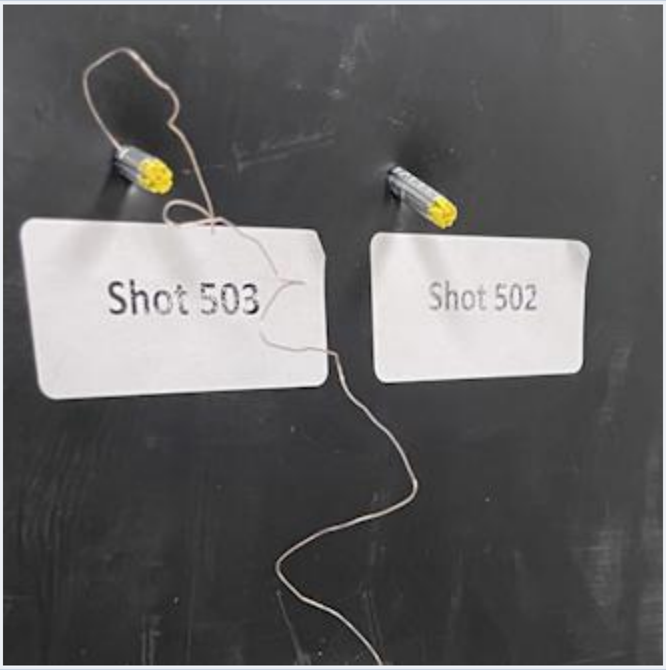
T10 skin penetration images



T10 skin penetration images	
	
	

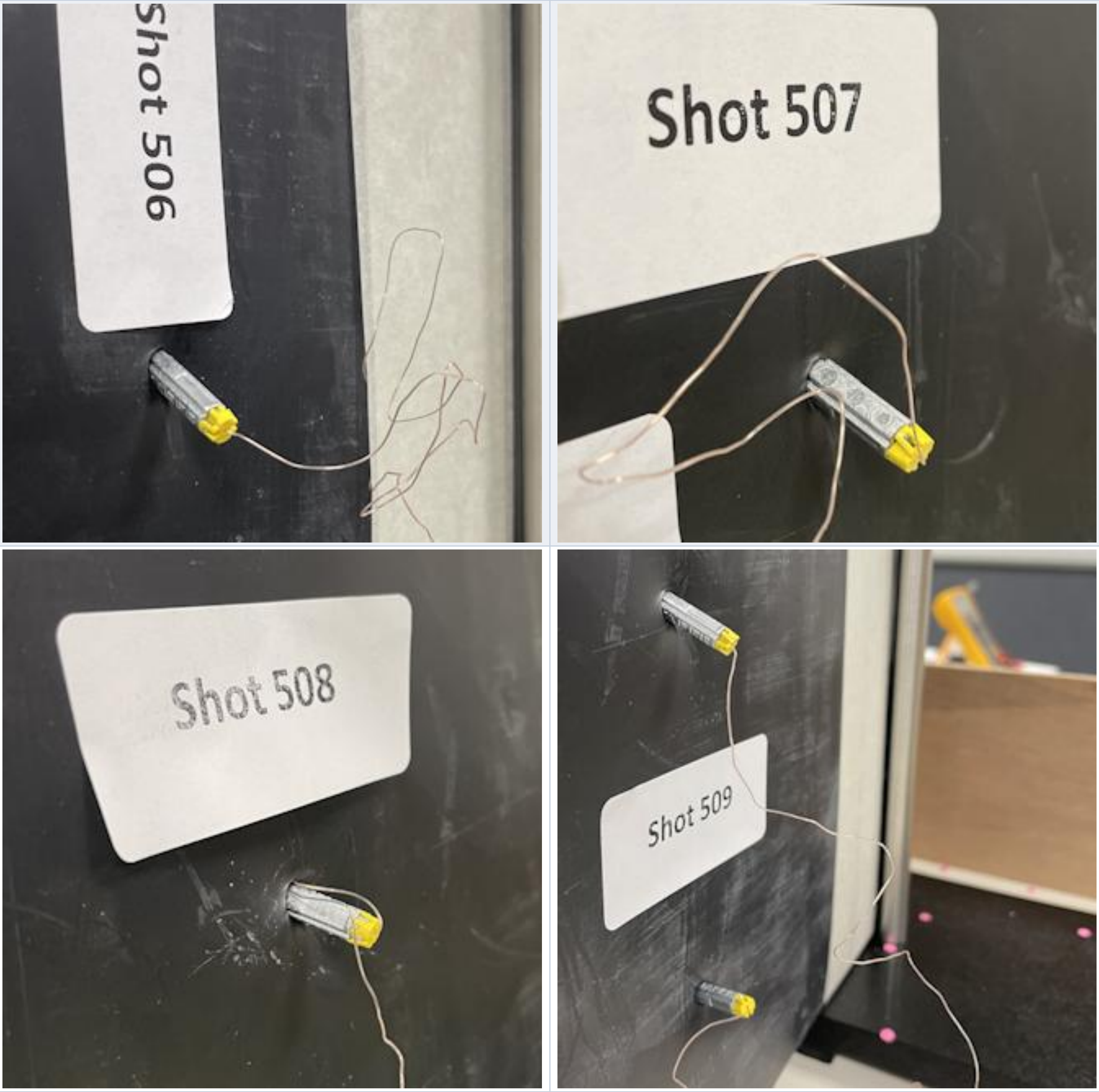
Table 33: Photographs of T10 skin penetration shots.

X2 skin penetration images

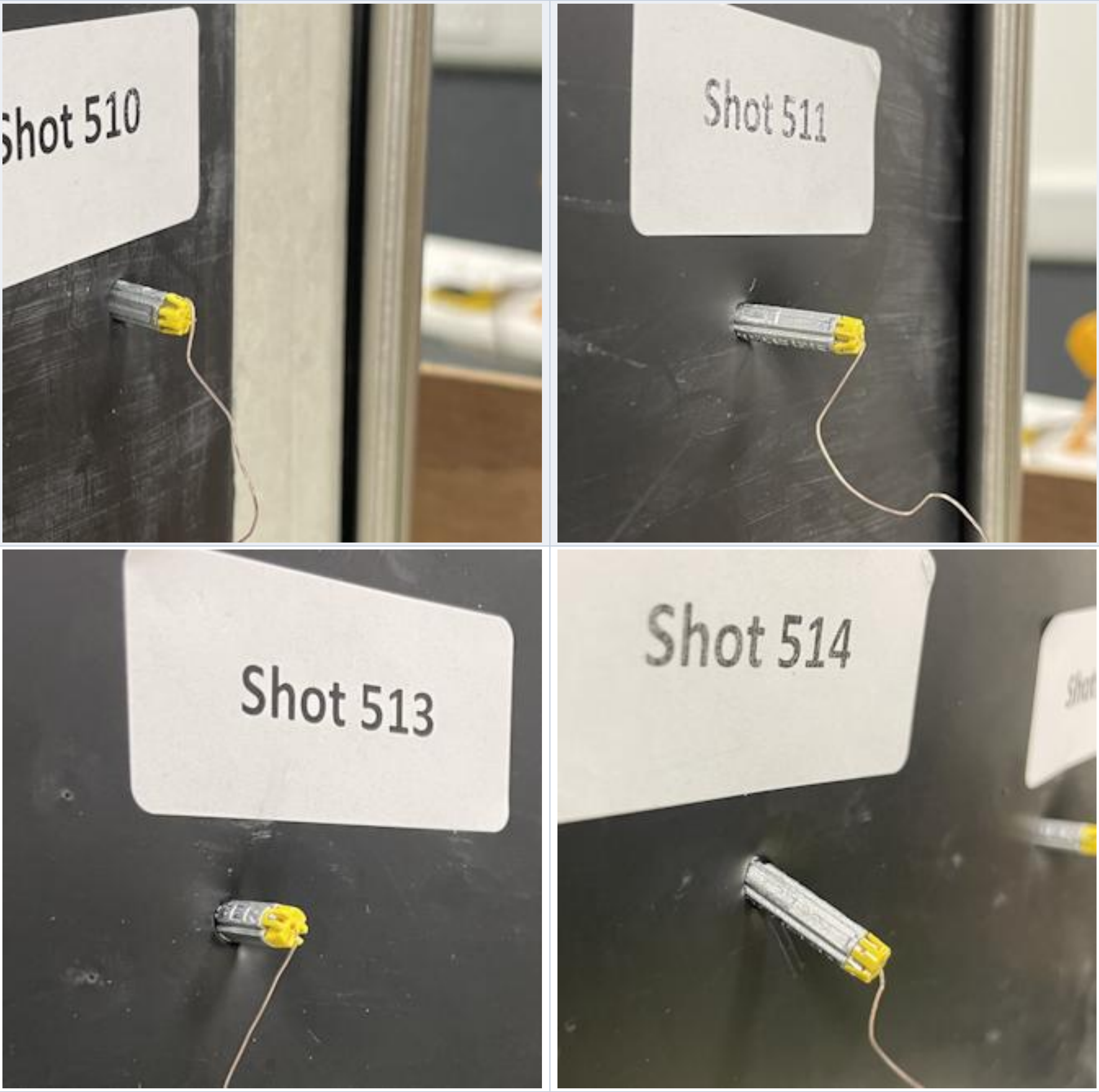




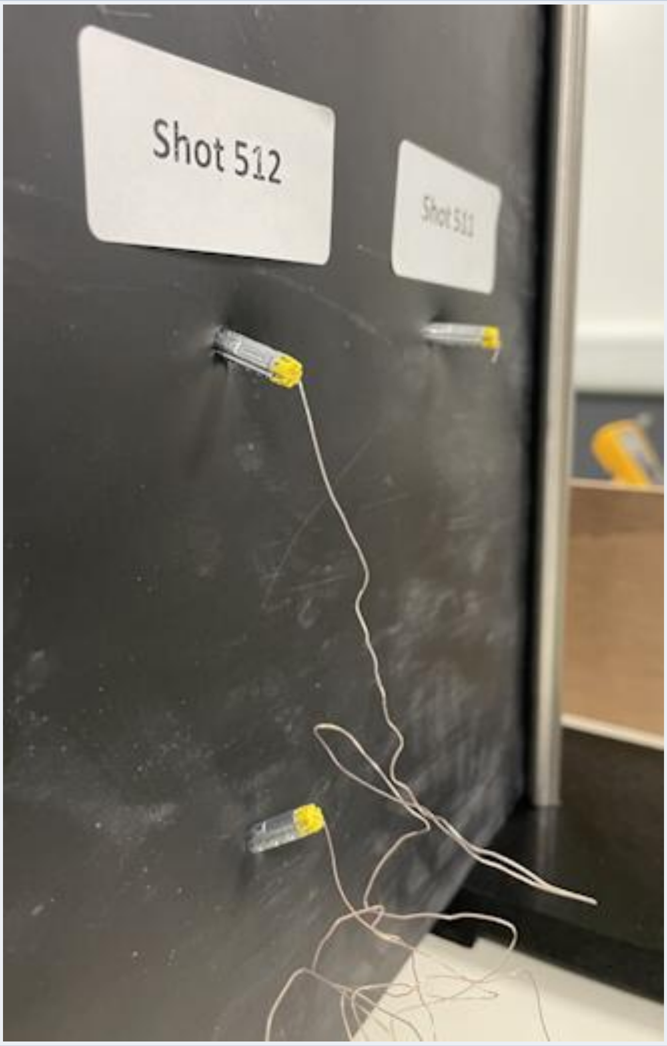
X2 skin penetration images



X2 skin penetration images



X2 skin penetration images



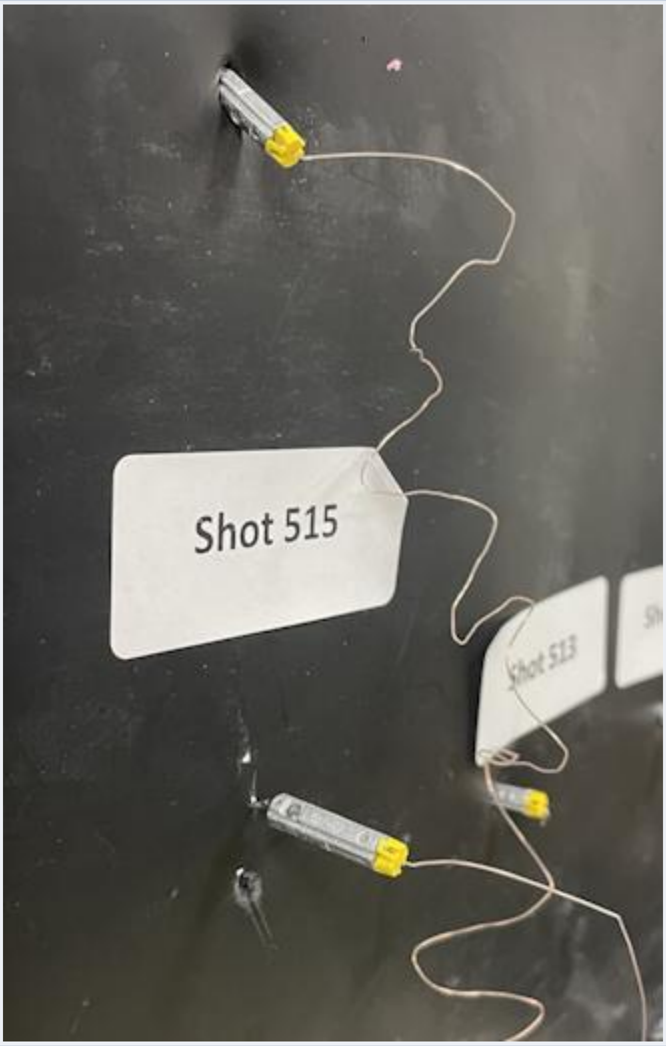


Table 34: Photographs of X2 skin penetration shots.

Appendix E Clothing penetration

Equipment

The target was comprised of a TP5 skin simulant pack (as detailed in Appendix D) with a thin conductive layer inserted below the outer layer (i.e. between the epidermal and dermal simulant layers) to enable conductivity measurements to be taken. The conductive layer was composed of a sandwich of two layers of Shieldtex 565 (an aluminium-faced woven glass cloth weighing 565g/m^2 with a light PU backing, produced by Textile Technologies), separated by a ~5mm layer of Grade 0000 oil-free iron wire wool, thinly teased out and rolled. The whole assembly was held together by light applications of 'Trimfix' fabric adhesive. To summarise, the target was composed of:

1. The clothing type being tested
2. The epidermis simulant from the TP5 skin simulant pack
3. A conductive layer formed of:
    - A layer of Shieldtex 565
    - A ~5mm layer of grade 0000 wire wool
    - A second layer of Shieldtex 565, sandwiching the wire wool layer
4. The dermis simulant from the TP5 skin simulant pack
5. The soft tissue simulant from the TP5 skin simulant pack

Initially a single layer of Shieldtex was tested, but it was found to produce inconsistent conductivity measurements due to the thin aluminium layer tearing as the probe moved. The sandwich approach provided consistent conductivity measurements while providing minimal physical resistance to the passage of the probe. Note that this approach would not be suitable for X2 testing due to the higher voltage of the X2 causing arcing that would set fire to the wool layer.

Conductivity was measured using a Fluke 175 Handheld Digital Multimeter.

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Methodology

The methodology is outlined in Section 8.2. Additional details of the clothing combinations used were:

1. A single layer 100% cotton T-shirt
2. A hoody (50% cotton / 50% polyester)
3. A single layer denim jeans material (11oz, 98% cotton / 2% spandex)
4. A hoody over a cotton T-shirt (composition as above for each piece of clothing)
5. A thick padded jacket over a hoody over a cotton T-shirt
    - Padded jacket: 100% polyamide (Mountain Warehouse Vista Men's Padded Jacket; item number 029851188001), with plastic zipper
    - Hoody: 85% cotton / 15% polyester (Jack & Jones Men's Jjebasic; item number 12181901), with plastic zipper
    - T-shirt: 100% cotton (Urban Classics; item number TB6372)

Clothing was secured over the target with drawing pins to hold it in place while allowing a loose fit over the target.

Note that to perform the conductivity measurements, initially a flame was used to burn off the insulation from a section of wire to expose the inner metal core of the wire. The difficulty with this approach was that moving the wires tended to cause small movements of the probe embedded in the target, which appeared to tear and move the conductive layer, causing the conductivity measurement to vary due to the connection between the probe and the conductive layer. Using the inside of the deployed cartridge (which remained in the bay), as described in Section 8.2, provided a significantly more reliable measurement setup by avoiding moving the wire or probe.

Note that the ‘challenge’ clothing (type 5) was tested in the additional series of testing after the release of the first version of this report. It was chosen due to the understanding that thick padded jackets have presented a particular challenge to deployment of the X2.

Data

A breakdown of the measurements and observations for each shot are provided in Table 35 for the ‘basic’ clothing and Table E for the ‘challenge’ clothing, as well as in Appendix A.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
T-shirt	8m	526	46	-	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	527	45	90	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	528	45	90	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	529	45	91	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	530	44	90	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	531	44	89	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	532	46	91	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	533	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	534	48	92	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	535	46	93	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	536	44	90	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	537	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	538	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	539	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	8m	540	46	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	541	44	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	542	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	543	46	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	544	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	545	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Hoody	8m	547	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	548	44	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	550	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	551	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	552	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	553	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	554	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	555	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	546	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	8m	549	43	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	556	43	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	557	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	558	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	559	45	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	560	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	561	45	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	562	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	563	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	564	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	565	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	566	44	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	567	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	568	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	569	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	8m	570	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	571	45	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	572	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	573	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	574	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Hoody + T-shirt	8m	575	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	576	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	577	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	578	x	x	No	Impacted in fold of hoody. No penetration. No connectivity.
Hoody + T-shirt	8m	579	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	580	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	581	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	582	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	583	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	584	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	8m	585	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	586	44	-	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	587	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	588	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	589	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	590	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	591	46	89	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	592	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	593	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	594	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	595	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	596	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	597	45	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	598	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	599	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	2m	600	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	601	44	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	602	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	603	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Hoody	2m	604	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	605	43	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	606	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	607	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	608	43	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	610	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	611	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	612	43	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	613	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	614	46	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	615	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	2m	609	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	616	44	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	617	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	618	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	619	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	620	43	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	621	44	86	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	622	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	623	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	624	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	625	45	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	626	46	91	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	627	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	628	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	629	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	2m	630	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	631	44	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	632	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Hoody + T-shirt	2m	633	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	634	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	635	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	636	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	637	43	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	638	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	639	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	640	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	641	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	642	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	643	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	644	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	2m	645	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	646	44	-	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.
T-shirt	15m	647	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	648	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	649	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	650	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	651	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	652	45	89	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.
T-shirt	15m	653	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	654	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
T-shirt	15m	655	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	666	47	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	667	43	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	668	45	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	669	43	88	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.
Hoody	15m	670	46	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	671	43	89	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Hoody	15m	672	45	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	673	46	91	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	674	44	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody	15m	675	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	686	44	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	687	46	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	688	44	89	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.
Denim	15m	689	47	91	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	690	45	94	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	692	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	693	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	694	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	695	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Denim	15m	691	45	90	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	706	44	-	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.
Hoody + T-shirt	15m	707	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	708	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	709	44	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	710	44	87	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	711	45	88	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	712	44	88	Yes	Full dart insertion. Impact absorber functioned as designed. Wire snapped.
Hoody + T-shirt	15m	713	45	90	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	714	45	89	Yes	Full dart insertion. Impact absorber functioned as designed.
Hoody + T-shirt	15m	715	43	88	Yes	Full dart insertion. Impact absorber functioned as designed.

Table 35: A breakdown of the T10 clothing penetration testing for the ‘basic’ clothing combinations at different ranges, also available in Appendix A.

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
T-shirt	8m	526	46	-	Yes	Full dart insertion. Impact absorber functioned as designed.
Padded Jacket + Hoody + T-shirt (Front)	8m	1181	42.9		Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1182	44.2	86.6	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1183	42.1	86.0	Yes	Penetrated despite hitting zip of padded jacket.
Padded Jacket + Hoody + T-shirt (Front)	8m	1184	-	-	No	Deflected by seam in hoodie, bounced out from clothing.
Padded Jacket + Hoody + T-shirt (Front)	8m	1185	-	-	No	Bounced out from clothing.
Padded Jacket + Hoody + T-shirt (Front)	8m	1186	44.2	86.0	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1187	43.1	86.7	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1188	42.8	85.8	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1189	43.3	85.9	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1190	-	-	No	Penetrated double layers of pockets (padded jacket & hoodie). Either bounced out from target or did not make contact with target. Remained attached to clothing.
Padded Jacket + Hoody + T-shirt (Front)	8m	1191	-	-	No	Impacted close to zip. Did not penetrate target but remained attached to clothing.
Padded Jacket + Hoody + T-shirt (Front)	8m	1192	54.7	99.2	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1193	-	-	-	Impacted near bottom of clothing and missed target. Repeated as Attempt B.
Padded Jacket + Hoody + T-shirt (Front)	8m	1193	43.3	86.6	Yes	
Padded Jacket + Hoody + T-shirt (Front)	8m	1194	-	-	No	Bounced out from target but retained in clothing.
Padded Jacket + Hoody + T-shirt (Front)	8m	1195	42.0	84.9	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1196	45.2	-	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1197	42.9	87.8	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1198	44.2	86.9	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1199	-	-	No	Failed to penetrate. Lodged in padded jacket.
Padded Jacket + Hoody + T-shirt (Back)	8m	1200	43.3	77.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1201	-	-	No	Failed to penetrate. Lodged in padded jacket. Fell off after Shot 202 made impact.
Padded Jacket + Hoody + T-shirt (Back)	8m	1202	43.2	87.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1203	44.9	87.0	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1204	46.6	91.3	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1205	43.7	90.2	Yes	

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Padded Jacket + Hoody + T-shirt (Back)	8m	1206	44.5	87.4	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1207	43.1	87.5	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1208	43.0	85.3	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1209	43.3	87.4	Yes	
Padded Jacket + Hoody + T-shirt (Back)	8m	1210	-	-	No	Failed to penetrate. Lodged in padded jacket.
Padded Jacket + Hoody + T-shirt (Back)	2m	1211	44.0	-	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1212	42.9	85.9	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1213	43.5	86.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1214	43.9	86.5	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1215	42.6	85.9	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1216	43.5	86.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1217	43.4	86.2	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1218	43.6	86.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1219	44.4	87.6	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1220	43.9	87.7	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1221	43.7	86.9	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1222	43.2	86.4	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1223	45.5	87.9	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1224	43.8	89.5	Yes	
Padded Jacket + Hoody + T-shirt (Back)	2m	1225	43.1	86.5	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1226	48.4	-	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1227	46.5	94.6	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1228	45.6	91.6	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1229	44.1	89.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1230	-	-	N/A	Missed. Hit wooden target frame. Full penetration. Repeated as Attempt B.
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1230	45.9	89.6	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1231	43.8	89.2	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1232	44.1	87.4	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1233	45.1	88.9	Yes	

Clothing combination	Range	Shot ID	Resistance measurements (Ω)			Observations
			Probe-to-target	Probe-to-probe	Connectivity achieved?	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1234	43.2	88.0	Yes	
Padded Jacket + Hoody + T-shirt (Back)	13.4m	1235	46.2	89.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	15m	1236	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Back)	15m	1237	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Back)	15m	1238	43.9	-	Yes	
Padded Jacket + Hoody + T-shirt (Back)	15m	1239	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Back)	15m	1240	44.5	88.1	Yes	
Padded Jacket + Hoody + T-shirt (Back)	15m	1241	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Back)	15m	1242	44.4	88.2	Yes	
Padded Jacket + Hoody + T-shirt (Back)	15m	1243	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Back)	15m	1244	43.3	87.3	Yes	
Padded Jacket + Hoody + T-shirt (Back)	15m	1245	43.4	86.2	Yes	
Padded Jacket + Hoody + T-shirt (Front)	15m	1246	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Front)	15m	1247	43.7	-	Yes	
Padded Jacket + Hoody + T-shirt (Front)	15m	1248	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Front)	15m	1249	x	-	No	Struck very closed to zip. Lodged in clothing. No connection.
Padded Jacket + Hoody + T-shirt (Front)	15m	1250	-	-	N/A	Missed. Hit wooden target frame. Full penetration. Repeated as Attempt B.
Padded Jacket + Hoody + T-shirt (Front)	15m	1250	44.4	88.3	Yes	
Padded Jacket + Hoody + T-shirt (Front)	15m	1251	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Front)	15m	1252	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Front)	15m	1253	44.2	88.3	Yes	
Padded Jacket + Hoody + T-shirt (Front)	15m	1254	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.
Padded Jacket + Hoody + T-shirt (Front)	15m	1255	-	-	Yes	Wire snapped. Full penetration. Bay-to-target < 1Ω.

Table 36: A breakdown of the T10 clothing penetration testing for the ‘challenge’ clothing combination at different ranges, also available in Appendix A.

Appendix F Skull fracture/penetration

Equipment

The Dstl models were comprised of bovine scapulae, to represent the human skull, with the skin and underlying tissue represented with graded chamois and tissue simulant, respectively. Bovine scapula was used because a region of the bovine scapula has been previously shown by Dstl to behave similarly to certain areas of the human calvarium under low velocity impact.

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Methodology

The methodology is summarised in Section 9.2, and additional details are provided here.

For each model, the suitable impact area (i.e. the region in the model with the correct properties) was identified by Dstl staff and marked prior to aiming. Both the T10 and X2 shots were then fired into this marked area, maintaining adequate separation (~10cm+) between the two impact sites. The order of the T10 and X2 firing was also varied (in blocks of 4 to 6) between bone models to account for any environmental effects as the models warmed from fridge temperature to room temperature. For T10 shots, bay 10 was used for every shot since this was identified in the accuracy testing (see Section 2) as the most accurate bay, and using this bay therefore minimised the risk of interference between shots.

The relative positioning of the T10 and X2 sites was varied during testing to mitigate for any systematic variation within the target areas. Note that only the top probe was considered for X2 shots, as this was the probe dispensed into the target area. When the X2 was dispensed above the T10 impact site, a physical screen was used to protect the T10 impact site from the lower X2 probe.

Data

The results of the skull penetration tests are provided in Table 20 and Table 21 in Section 9.3, as well as in Appendix A.

Appendix G Robustness

Equipment

The same handle and magazine were used for all drop tests – handle serial number T19E62877 and magazine serial number T2T22008MTW. Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

A custom in-house drop rig was used to perform repeatable drop tests. It comprised a rotatable MDF disc with 45-degree points marked, and had multiple mounting holes for 12Vdc electromagnets that, on energisation, supported ferrous discs with foam-sheathed polyoxymethylene (POM) fingers which held the device in place. Power was supplied by a Circuit Specialists Model 3005EIII regulated DC bench power supply, and removal of power to the electromagnets initiated the drop. The apparatus is shown in Figure 58.

Figure 58: The drop rig developed in-house for drop testing. Left: the full 2m rig. Top right: a device mounted in the POM fingers controlled by electromagnets. Bottom right: the steel drop plate.

Methodology

The methodology is detailed in Section 10.2.

Data

The results of the main drop tests are provided in Appendix A.

The raw data along with calculated statistics for the variation in laser alignment due to repeatedly mounting the device in the firing rig are given in Table 37.

	Measurement Number										Statistics			
	1	2	3	4	5	6	7	8	9	10	Count	Mean	Standard deviation	Standard error
POA, x (mm)	0	7	-4	8	5	0	-13	-1	0	-5	10	-0.3	6.2	2
POA, y (mm)	0	0	3	2	2	2	4	2	0	1	10	1.6	1.3	0.4

Table 37: Data and statistics for variation in the laser alignment due to repeated mounting in the firing rig used in the robustness testing. The mean and standard deviation give a measure of normal variation due to the mounting system, as opposed to abnormal variation that may arise in the testing due to mechanical damage to the device.

In addition to the main drop tests, repeat drops were undertaken to better understand battery ejection, magazine ejection, and self-arming.

To assess magazine ejection, a previously undropped handle (S/N T19E24561, battery S/N X44983455, magazine S/N T22008MTW) was subjected to 4 drops in each of drop positions 7, 2 and 10 (12 total drops). The magazine detached in drop position 10 every time, but never in the other positions.

For battery ejection, the same handle, battery and magazine were used, and 14 drops onto the left-hand and right-hand sides were performed. The results are shown in Table 38. During several drops the device began to rotate on descent, presumably from air resistance, and the impact was not directly on the side of the device.

Drop order	Drop position	Impact point	Accurate drop	Battery remained engaged	Notes
1	6	Left-hand side	y		Battery disengaged.
2	6	Left-hand side	y	y	Battery remained engaged. Grip displaced (clipped back before next drop).
3	6	Left-hand side		n/a	Inaccurate drop. No data.
4	6	Left-hand side	y		Battery disengaged.
5	6	Left-hand side		n/a	Device struck plate in a non-standard orientation, tilted towards the top of the device. Device armed itself. Battery and magazine remained engaged.
6	6	Left-hand side		n/a	Inaccurate drop. No data.
7	6	Left-hand side	y		Battery disengaged.
8	5	Right-hand side	y	y	Battery remained engaged. Grip displaced (clipped back before next drop).
9	5	Right-hand side	y	y	Battery remained engaged.
10	5	Right-hand side		n/a	Inaccurate drop. No data.
11	5	Right-hand side	y	y	Battery remained engaged.
12	5	Right-hand side		n/a	Device struck plate at incorrect angle. Tilted towards top of device. Device armed itself. Battery and magazine remained engaged.
13	5	Right-hand side	y		Battery disengaged.
14	5	Right-hand side	y	y	Battery remained engaged.

Table 38: Results for additional battery ejection drop tests onto the left and right sides of the device (identified from the initial drop tests as most likely to cause battery ejection), also available in Appendix A.

Finally, to investigate self-arming, a further 12 manual top-down drops were carried out (drop position 3) using the same handle, magazine and battery. In 6 of the 12 drops (50%), the device armed itself.

Appendix H Sound levels

Equipment

Sound levels were measured with a Chauvin Arnoux CA832 sound meter. Sound measurements are in dBA, measured at a position 50cm from muzzle; specifically, the sound meter was placed at 45° to the front right of the muzzle, as seen from behind the device – this position was chosen on the basis that the sound pressure level is highest towards the front of the device (due to the sound propagating primarily forward out of the bays, and the forward facing position of the speaker), and is therefore a worst-case scenario. In practice, this would be the experience of a person having a taser deployed from behind them, and a lone operator would likely experience a lower sound pressure level due to being positioned at the rear of the device.

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Methodology

The methodology is outlined in Section 11.2, with more details provided here. Sound level measurements were performed for three scenarios:

1. **The device being fired (for T10 and X2 devices)**

   Initially, sound levels for the T10 were measured while carrying out Test 1 Serial 4. However, it became evident that the sound of the probe hitting the target board was loud enough to influence the measurements. The sound levels were therefore re-measured for both the X2 and T10 by firing them outside (while hand-held) to provide sufficient range to avoid the sound of their impact effecting the measurement. They were recorded as Shot IDs 851 to 860.

2. **The device emitting the warning alert noise (for T10 devices)**

   This was measured indoors with the device in the firing rig (as detailed in Appendix B).

3. **The device emitting its connection alert (for T10 devices)**

   Two probes were fired against the standard target board provided by the College of Policing. The weapon was then re-energised 10 times, and the connectivity alert was recorded each time, at a distance of 50cm from muzzle. This was measured indoors with the device in the firing rig (as detailed in Appendix B).

Note that testing of the T7 device was out of scope of this project.

Data

The raw data (including all equipment numbers) is provided in Appendix A, and summarised below for reference:

Shot ID	CED Type	Scenario	Sound Level (dBA)
851	T10	The device being fired	95.6
852	T10	The device being fired	97.5
853	T10	The device being fired	95.3
854	T10	The device being fired	96.9
855	T10	The device being fired	97.1
856	T10	The device emitting the warning alert noise	91.1
857	T10	The device emitting the warning alert noise	89
858	T10	The device emitting the warning alert noise	88.7
859	T10	The device emitting the warning alert noise	88.1
860	T10	The device emitting the warning alert noise	89.6
516	X2	The device being fired	95.5
517	X2	The device being fired	93.1
518	X2	The device being fired	95
519	X2	The device being fired	93.2
520	X2	The device being fired	94.2
926 & 927	T10	The device emitting its connection alert	78.3
926 & 927	T10	The device emitting its connection alert	78.4
926 & 927	T10	The device emitting its connection alert	77.6
926 & 927	T10	The device emitting its connection alert	78.6
926 & 927	T10	The device emitting its connection alert	79.5
926 & 927	T10	The device emitting its connection alert	78.7
926 & 927	T10	The device emitting its connection alert	78.9
926 & 927	T10	The device emitting its connection alert	78.4
926 & 927	T10	The device emitting its connection alert	78.0
926 & 927	T10	The device emitting its connection alert	78.7

Table 39: A breakdown of the measured sound level data, also available in Appendix A.

Appendix I Laser power

Equipment

The laser power was be measured by a Coherent Laser Power Meter (part number 1098293). Six different T10 handles were used to assess variability between handles. The details of the handles are recorded in Appendix A; all were hardware revision number D and firmware revision number 1.5.3.

Methodology

Laser powers were measured at a 1m distance from the laser emitter with the power meter set to a detection frequency of 510nm. The power meter was set on a tripod such that the detection window was 1000mm from the muzzle and aligned normal to the laser beam. Each reading was taken over a period of 5 seconds. An empty magazine was inserted into the handle during this test. The measurement was repeated 10 times for each of the 6 different T10 handles (60 total measurements).

Data

The raw data (including all equipment numbers) is provided in Appendix A, and summarised below for convenience:

Handle Serial Number	Laser Power (mW)		Handle Serial Number	Laser Power (mW)		Handle Serial Number	Laser Power (mW)
T19E24561	3.55		**T19E27769**	4.04		**T19E24560**	3.90
	3.54			4.01			3.89
	3.55			4.00			3.90
	3.54			4.00			3.91
	3.54			4.01			3.90
	3.54			4.02			3.89
	3.54			4.01			3.90
	3.57			4.01			3.91
	3.56			4.00			3.91
	3.57			4.00			3.90
T19E24572	3.68		**T19E62880**	3.63		**T19E62877**	3.85
	3.67			3.63			3.56
	3.70			3.62			3.74
	3.69			3.60			3.74
	3.70			3.60			3.74
	3.70			3.59			3.75
	3.70			3.60			3.75
	3.66			3.66			3.75
	3.71			3.66			3.74
	3.69			3.67			3.75

Table 40: A breakdown of the measured T10 laser power level data by handle, also available in Appendix A.

In addition to the plot and summarised statistics in Section 12.3, a histogram of all the measured laser power levels is provided below.

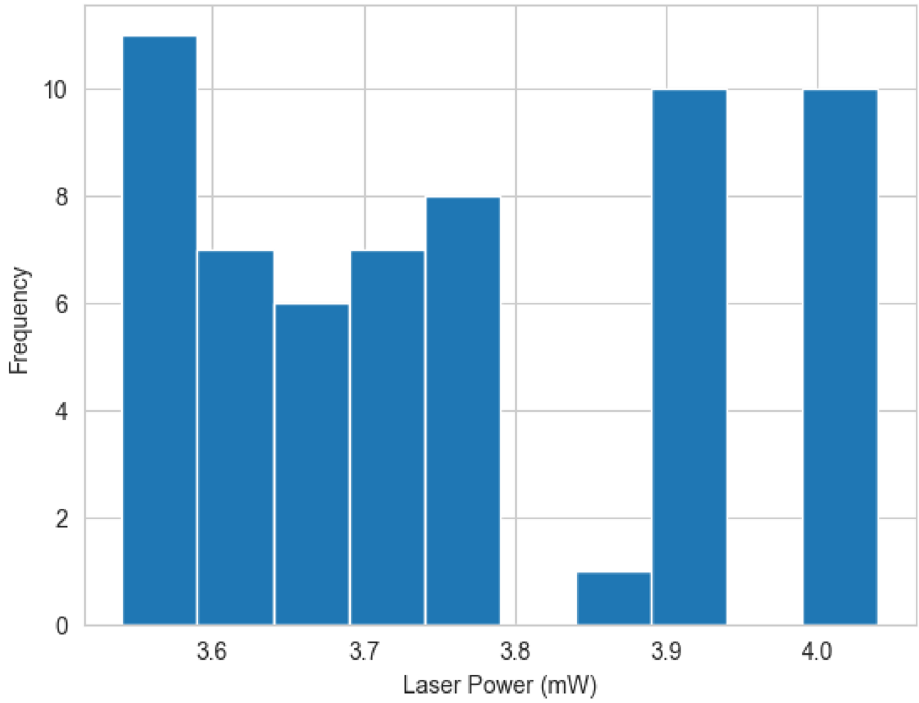


Figure 59: Histogram of measured laser power levels.

Appendix J Electrical output: Initial high-level measurements

Equipment

The equipment used to measure the electrical output of T10 devices was:

- Tektronix MDO3034 oscilloscope, S/N C029899
- Tektronix TCP-202 current probe, S/N B019245
- Tektronix TPA-BNC adapter, S/N C022358
- TASER 10 bench test magazine
- Axon TASER 10 test cartridges
- Fluke multimeter Model 177
- Non-inductive resistor made up of 4 x Ohmite AP101 150Ω 100W TO-247 resistors in series (nominally 600Ω; the measured resistance was 598.6Ω including the connection cables)

Measurements were taken for 4 different T10 handles – details of handles and batteries are provided in Appendix A. All handles had firmware version 1.5.3.

Methodology

The two methodologies used are outlined in Section 13.2 and the Axon guidance.[27] In addition, note that:

- The ambient temperature was 22C ± 2C, with a relative humidity of < 80%.
- The battery level reported by the CED was > 65% for all tests.
- The oscilloscope was warmed up for 45 minutes, then the scope's Signal Path Compensation procedure was carried out before taking measurements.
- For the non-Axon test method, the target was the normal Axon target used for the kinetics testing (see Appendix B).

The testing setup is shown in Figure 60.

[27] *Axon Certified Test Procedure for Testing to TASER 10 Specifications*, release date 24 June 2024

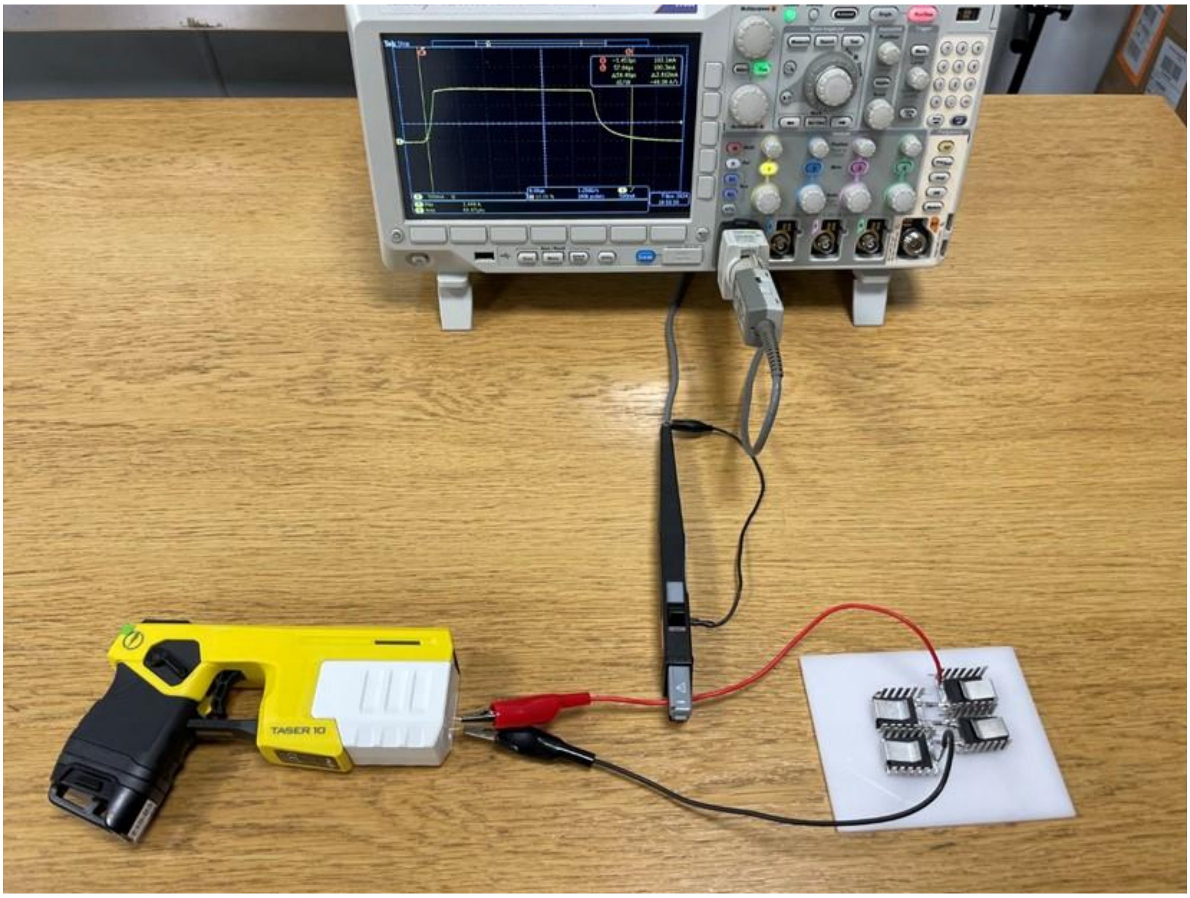


Figure 60: Testing setup for measuring the electrical output.

Note that several departures were made from the Axon-specified guidance out of necessity – the guidance provided appeared to have several mistakes and typos, none of which affected the overall ability to perform the testing, but which are listed here:

- If the oscilloscope is set, in accordance with the Axon guidance, to trigger only on a rising edge waveform, it is important to ensure that the current probe is clamped in the correct current direction, or no trigger event would occur. The Axon guidance (paragraph 2.4) states that if bays 2 and 3 are used, bay 2 is always positive, which is correct, but the photograph in the guidance showing the lead layout (Axon's Fig 5) is incorrect, as the polarity is reversed. Figure 60 shows the correct wiring.
- There is a reference to using bays 1 and 2 (in Additional notes on page 2 of the guidance); this appears to be incorrect and was ignored.
- The Axon guidance calls for the pulse duration to be recorded as that occurring between the point before the current first reaches *negative* 100mA, to the point where the current drops below positive 100mA (paragraph 8.9 in the guidance). These points are set manually by reference to the displayed waveform; the duration is then calculated by the oscilloscope and displayed on-screen as the time delta value. There were, however, no observed negative voltage components to the T10's electrical output, so Axon's reference to an initial *negative* current is believed to be in error, possibly arising from previous CEDs producing different pulse shapes. This instruction was therefore ignored and the oscilloscope was set to calculate duration (and, by extension, pulse charge) between the first and last points closest to positive 100mA. Note that this procedure is important as the energy calculated to have been delivered in each pulse (Pulse Charge in µAs) is proportional – in classical mathematical terms – to the 'area under the graph' so standard specification start and end points are important to ensure reproducibility of results.

Data

The raw measurements are provided in Appendix A, and summary statistics are provided in Section 13.2. In addition, the average noise measured during the 'Current Probe Zero' procedure specified in the Axon guidance was measured to be -20.4nC with a maximum current of 13.1mA. Note that the peak loaded voltage was, in accordance with the Axon guidance, calculated from the peak current multiplied by the load (598.6Ω for the Axon-specified load; 684.0Ω for the non-Axon-specified load).

Appendix K Electrical output: Simultaneous probe measurements

Equipment

Details of the CED hardware and cartridge used for each shot are recorded in Appendix A.

Methodology

The methodology is detailed in Section 14.

The methodology was based on the methodology of previous (and now superseded) simultaneous electrical output testing (see Appendix L), but differed in several significant ways:

- Energisation of probes was measured simultaneously across all active probes, rather than for one probe at a time, as was the case previously
- Resistive loads were present between all probes
- Current flow was recorded by measuring the voltage across ten potential dividers using a multi-channel data acquisition system (recording at 1MHz sampling frequency, with each channel having an input impedance of 1 MΩ)
- More quantitative measurements of frequency and charge were performed

The experimental setup assumed that:

- The incorporation of measurement hardware into the electrical pathway would not alter how the handle behaves (in comparison to the less invasive current probe used in the previous testing)
- The artificial test environment would provide data representative of the electrical behaviour of the T10 in an operational setting

Data

The following provides additional data to that presented in Section 14.3. Specifically, a table summarising the different data files is provided, then voltage traces and event plots are provided for Salvo 1, followed by charge variation plots.

Data file summary

The recorded data was converted to .csv files for analysis. Details of the files are in Table 41.

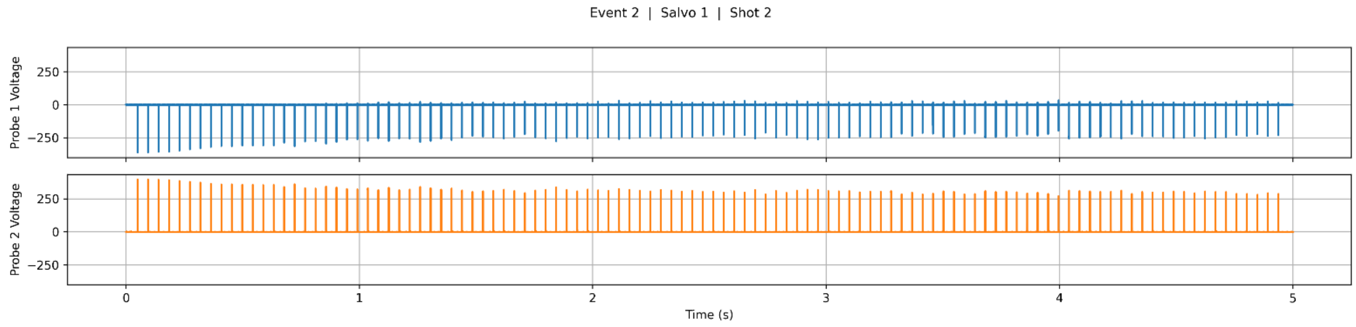
Event Details			Filename	Comment
Order	Salvo	Description		
01	Salvo 1	Shot 1	*[No data collected – only 1 probe]*	
02	Salvo 1	Shot 2	*Phase1-Salvo1-001_Scaled.CSV*	
03	Salvo 1	Shot 3	*Phase1-Salvo1-002_Scaled.CSV*	
04	Salvo 1	Shot 4	*Phase1-Salvo1-003_Scaled.CSV*	
05	Salvo 1	Shot 5	*Phase1-Salvo1-004_Scaled.CSV*	
06	Salvo 1	Shot 6	*Phase1-Salvo1-005_Scaled.CSV*	
07	Salvo 1	Shot 7	*Phase1-Salvo1-006_Scaled.CSV*	
08	Salvo 1	Shot 8	*Phase1-Salvo1-007_Scaled.CSV*	
09	Salvo 1	Shot 9	*Phase1-Salvo1-008_Scaled.CSV*	
10	Salvo 1	Shot 10	*Phase1-Salvo1-009_Scaled.CSV*	
11	Salvo 1	Re-energised device	*Phase1-Salvo1-009b_001_Scaled.CSV*	
12	Salvo 1	Re-energised device	*Phase1-Salvo1-009b_002_Scaled.CSV*	

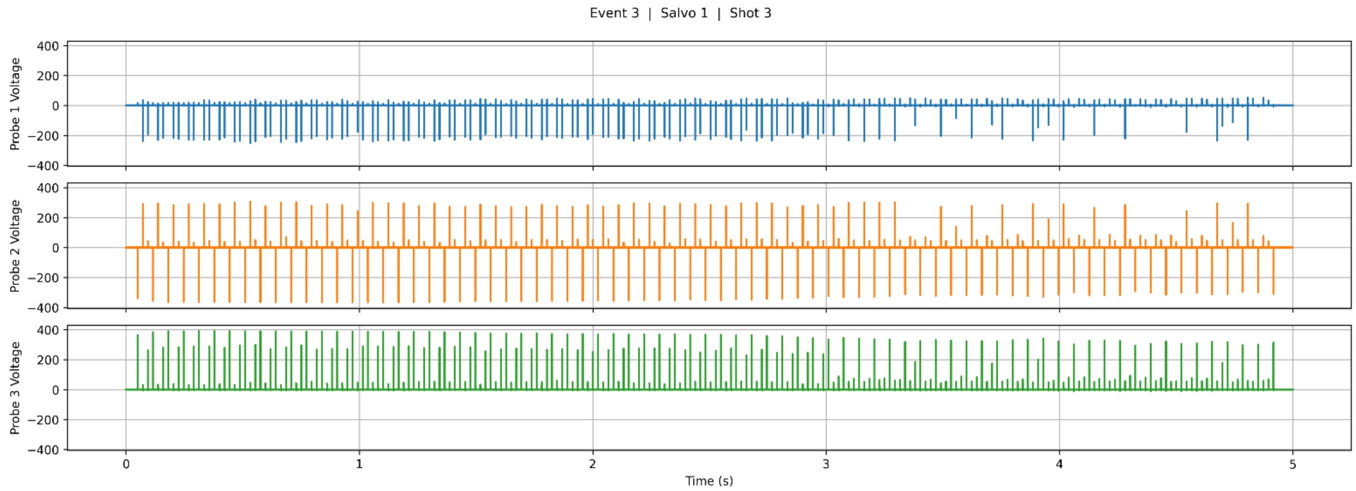
Event Details			Filename	Comment
Order	Salvo	Description		
13	Salvo 1	Re-energised device	*Phase1-Salvo1-009b_003_Scaled.CSV*	
14	Salvo 1	Re-energised device	*Phase1-Salvo1-009b_004_Scaled.CSV*	
15	Salvo 1	Re-energised device	*Phase1-Salvo1-009b_005_Scaled.CSV*	
16	Salvo 2	Shot 1	*[No data collected – only 1 probe]*	
17	Salvo 2	Shot 2	*Phase1-Salvo2-001_Scaled.CSV*	
18	Salvo 2	Shot 3	*Phase1-Salvo2-002_Scaled.CSV*	
19	Salvo 2	Shot 4	*Phase1-Salvo2-003_Scaled.CSV*	
20	Salvo 2	Shot 5	*Phase1-Salvo2-004_Scaled.CSV*	
21	Salvo 2	Shot 6	*Phase1-Salvo2-005_Scaled.CSV*	
22	Salvo 2	Shot 7	*Phase1-Salvo2-006_Scaled.CSV*	
23	Salvo 2	Shot 8	*Phase1-Salvo2-007_Scaled.CSV*	
24	Salvo 2	Shot 9	*Phase1-Salvo2-008_Scaled.CSV*	
25	Salvo 2	Shot 10	*Phase1-Salvo2-009_Scaled.CSV*	Bounced out of target, replaced for next test.
26	Salvo 2	Re-energised device	*Phase1-Salvo2-009b_001_Scaled.CSV*	
27	Salvo 2	Re-energised device	*Phase1-Salvo2-009b_002_Scaled.CSV*	
28	Salvo 2	Re-energised device	*Phase1-Salvo2-009b_003_Scaled.CSV*	
29	Salvo 2	Re-energised device	*Phase1-Salvo2-009b_004_Scaled.CSV*	
30	Salvo 2	Re-energised device	*Phase1-Salvo2-009b_005_Scaled.CSV*	
31	Salvo 3	Shot 1	*[No data collected – only 1 probe]*	
32	Salvo 3	Shot 2	*Phase1-Salvo3-001_Scaled.CSV*	
33	Salvo 3	Shot 3	*Phase1-Salvo3-002_Scaled.CSV*	
34	Salvo 3	Shot 4	*Phase1-Salvo3-003_Scaled.CSV*	
35	Salvo 3	Shot 5	*Phase1-Salvo3-004_Scaled.CSV*	
36	Salvo 3	Shot 6	*Phase1-Salvo3-005_Scaled.CSV*	Bounced out of target, replaced for next test.
37	Salvo 3	Shot 7	*Phase1-Salvo3-006_Scaled.CSV*	Bounced out of target, replaced for next test.
38	Salvo 3	Shot 8	*Phase1-Salvo3-007_Scaled.CSV*	Bounced out of target, replaced for next test.
39	Salvo 3	Shot 9	*Phase1-Salvo3-008_Scaled.CSV*	
40	Salvo 3	Shot 10	*Phase1-Salvo3-009_Scaled.CSV*	
41	Salvo 3	Re-energised device	*Phase1-Salvo3-009b_001_Scaled.CSV*	
42	Salvo 3	Re-energised device	*Phase1-Salvo3-009b_002_Scaled.CSV*	
43	Salvo 3	Re-energised device	*Phase1-Salvo3-009b_003_Scaled.CSV*	
44	Salvo 3	Re-energised device	*Phase1-Salvo3-009b_004_Scaled.CSV*	
45	Salvo 3	Re-energised device	*Phase1-Salvo3-009b_005_Scaled.CSV*	
46	Salvo 3	Re-energised device after switching off	*Phase1-Salvo3-009b_006_Scaled.CSV*	
47	Salvo 3	Re-energised device after probe wire #7 cut	*Phase1-Salvo3-009b_007_Scaled.CSV*	
48	Salvo 3	No change from previous	*Phase1-Salvo3-009b_008_Scaled.CSV*	
49	Salvo 3	Re-energised device after cut lines #3, 4, 5, 6 & 8 – Cut wires left in place and may have caused induction effects	*Phase1-Salvo3-009b_009_Scaled.CSV*	
50	Salvo 3	As above, but cut wires removed	*Phase1-Salvo3-009b_010_Scaled.CSV*	
51	Salvo 3	Re-energised device after wire #1 cut	*Phase1-Salvo3-009b_011_Scaled.CSV*	
52	Salvo 3	Re-energised device after wire #9 cut	*Phase1-Salvo3-009b_012_Scaled.CSV*	

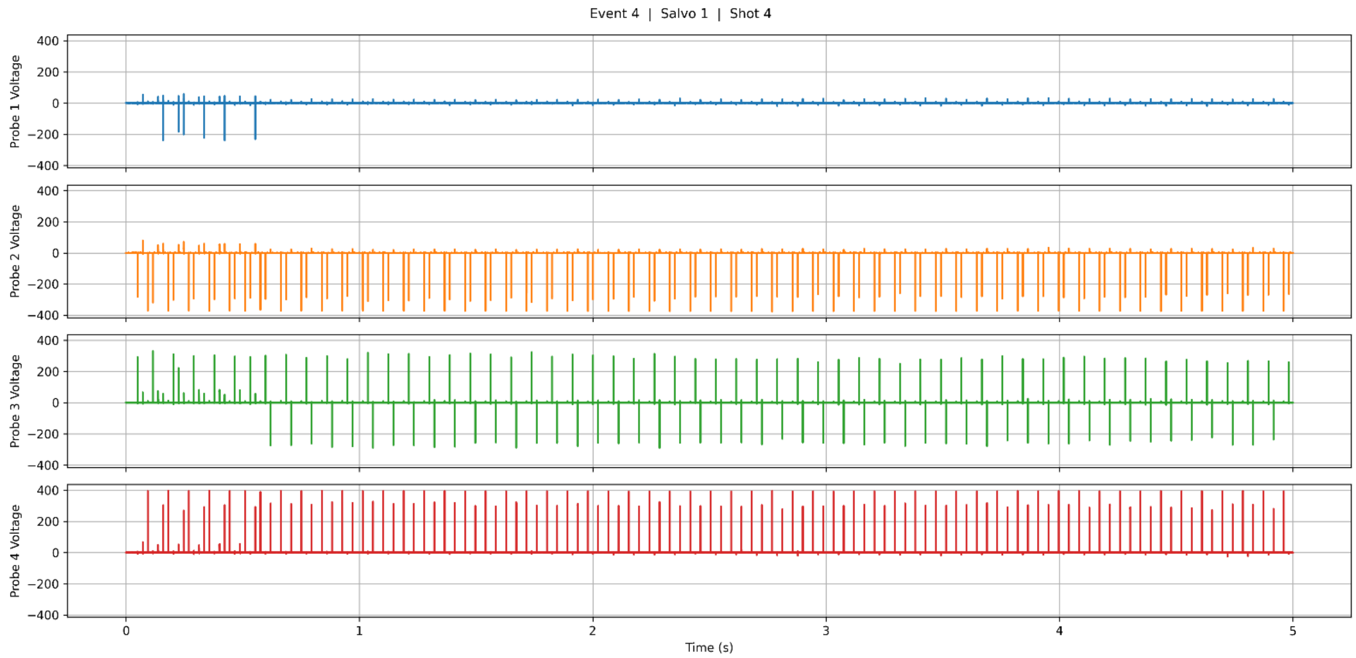
Table 41: Summary of files containing the recorded data.

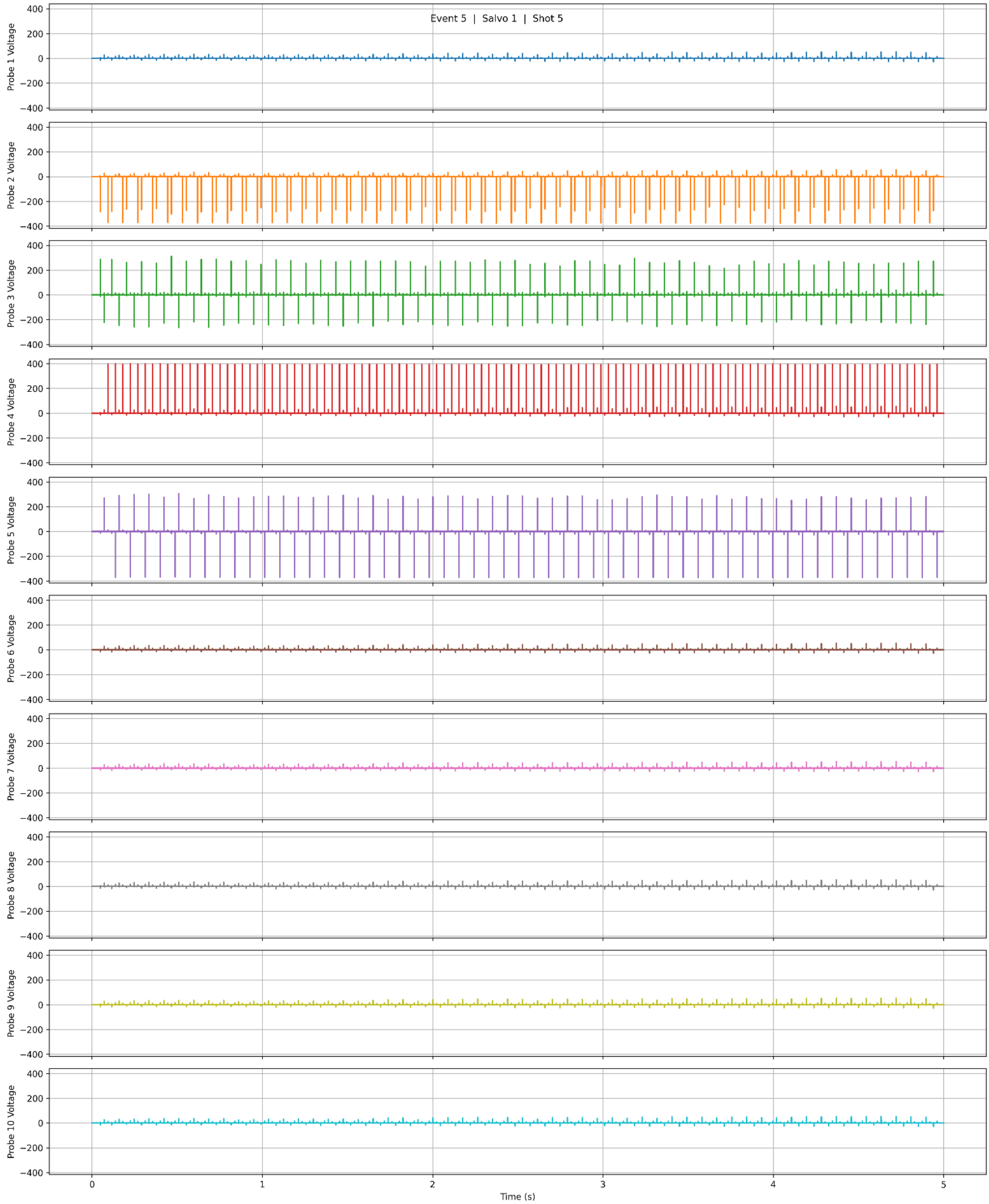
Voltage traces (Salvo 1)

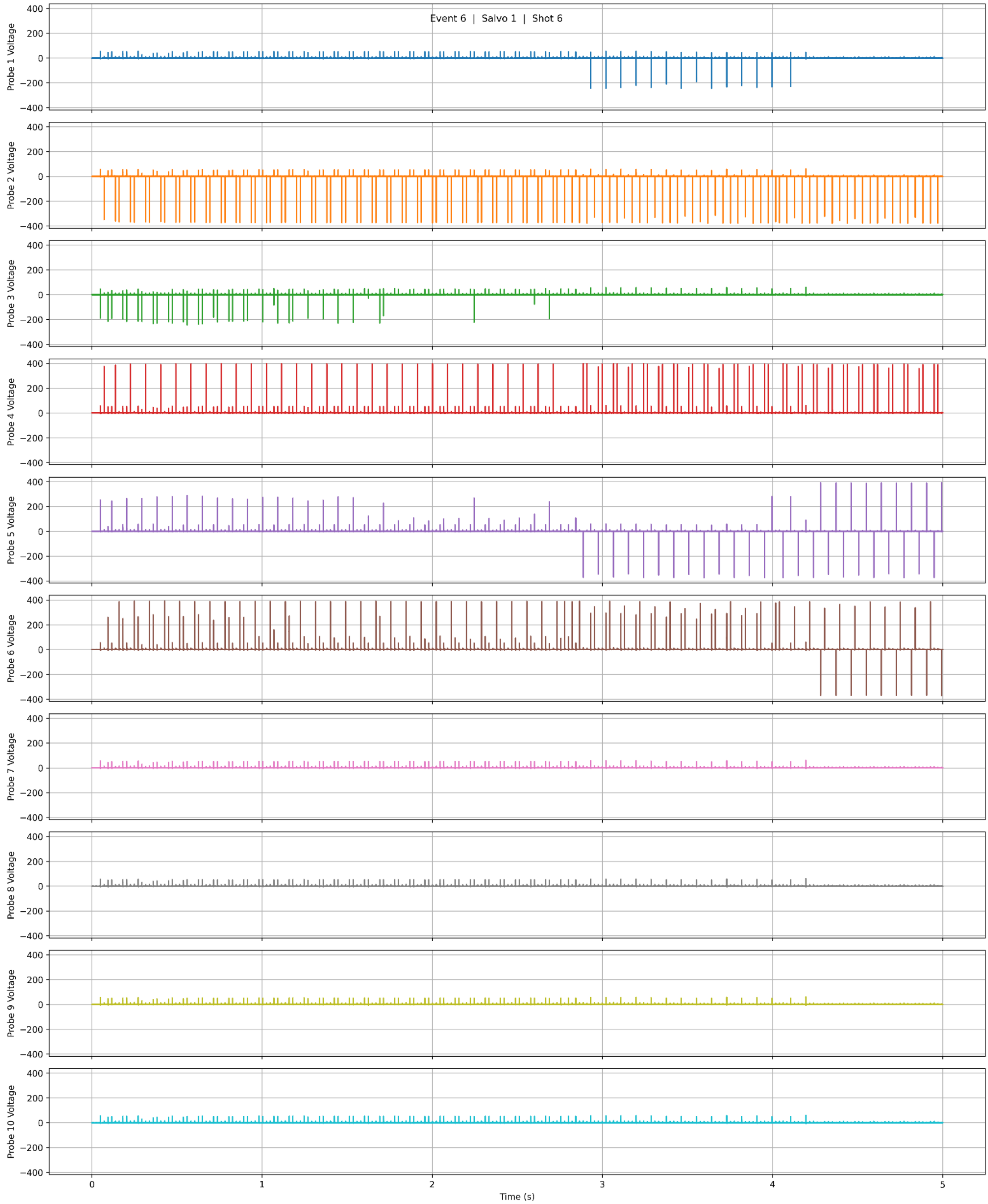
Salvo 1 had identical resistances for all probes, with a total resistance between any two probes of 604Ω (see Section 14.2.2 for more details).

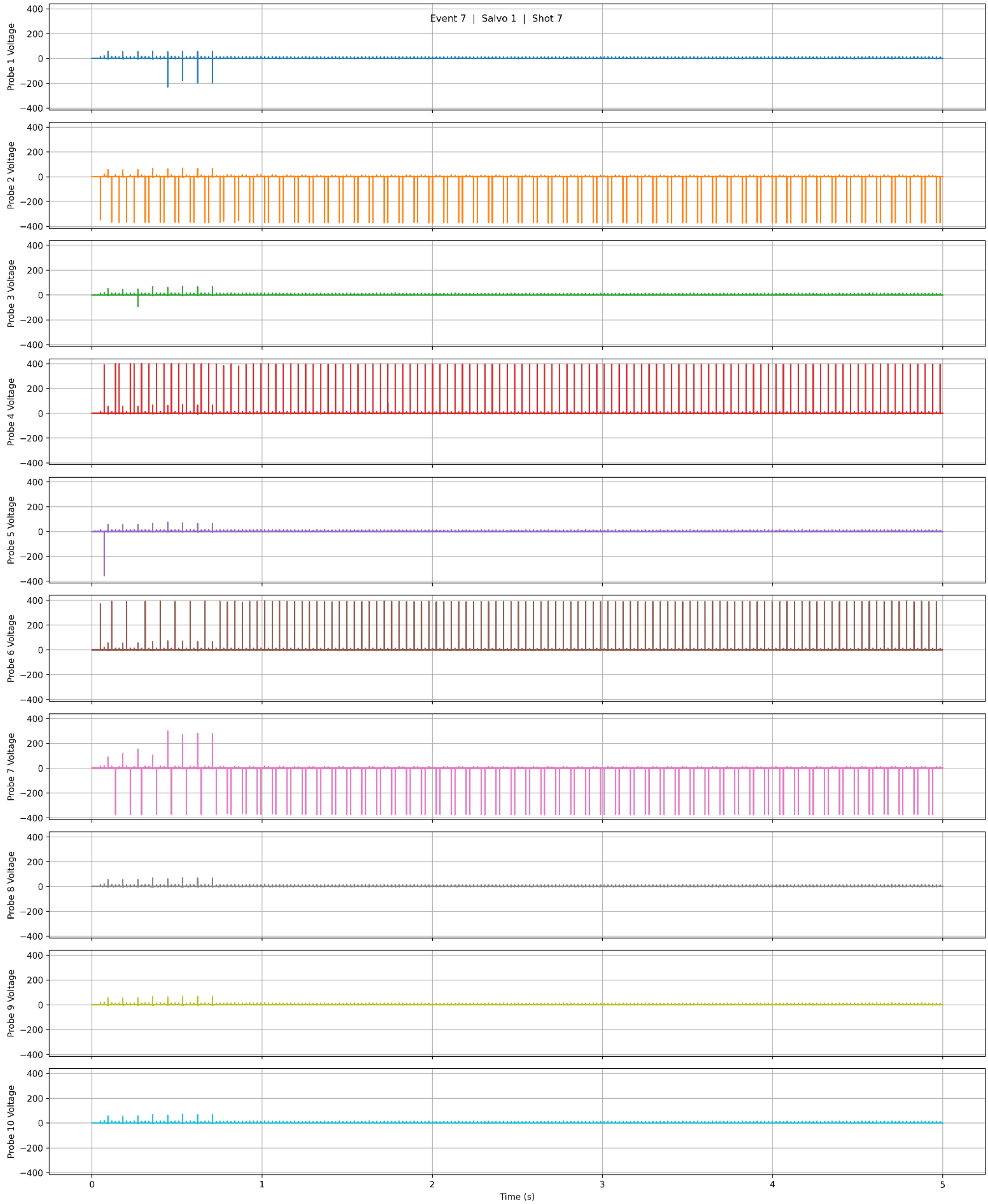


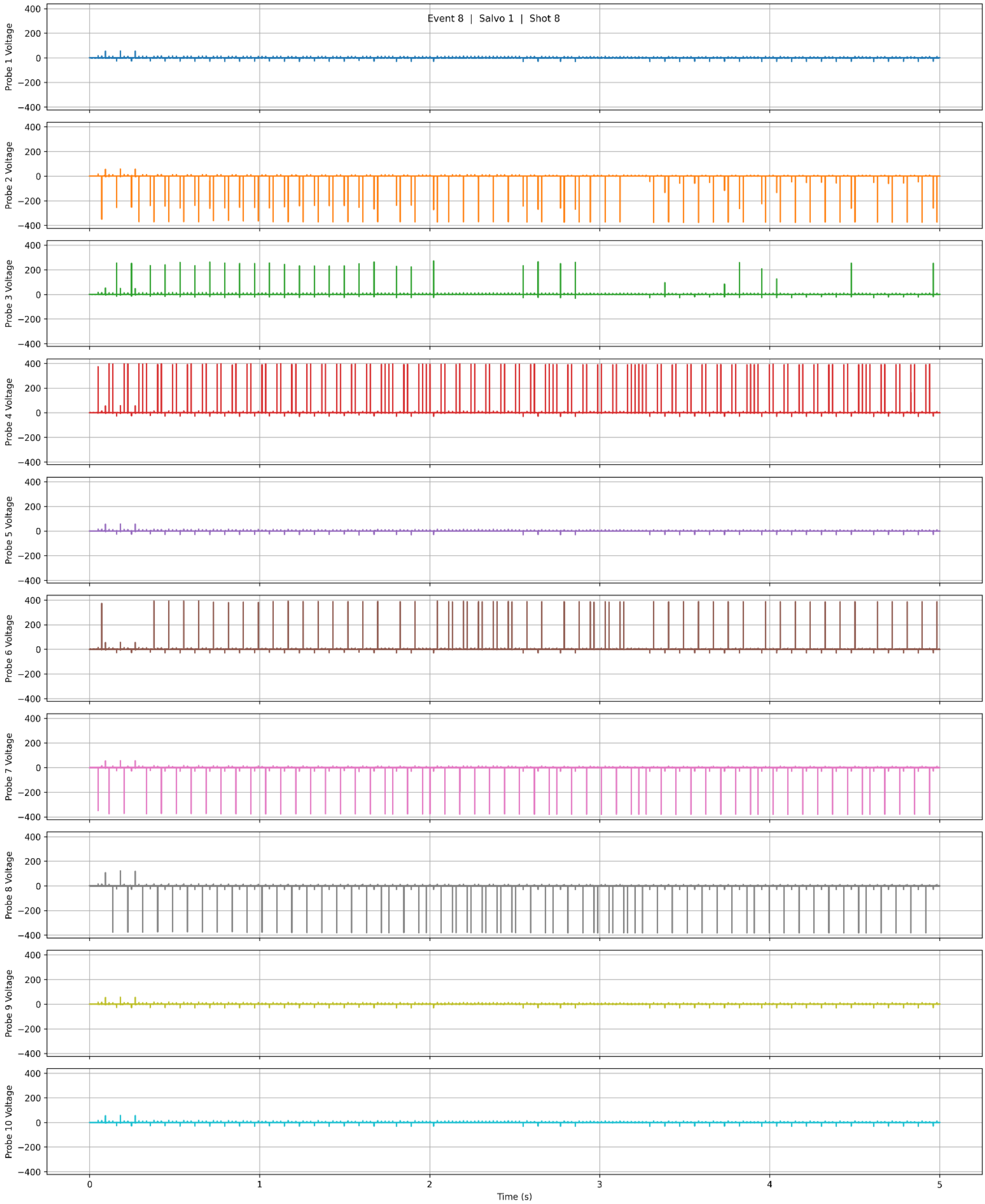


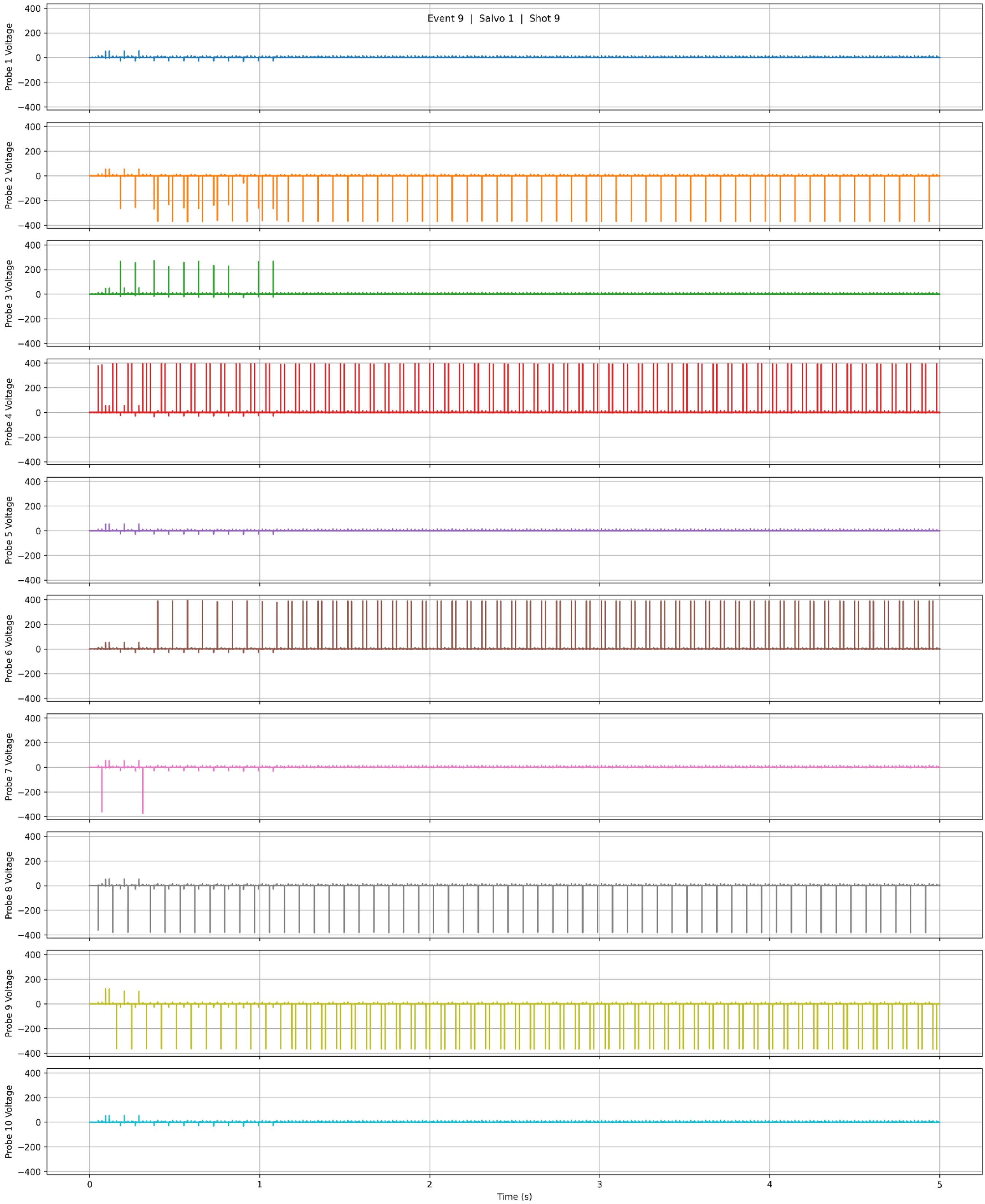


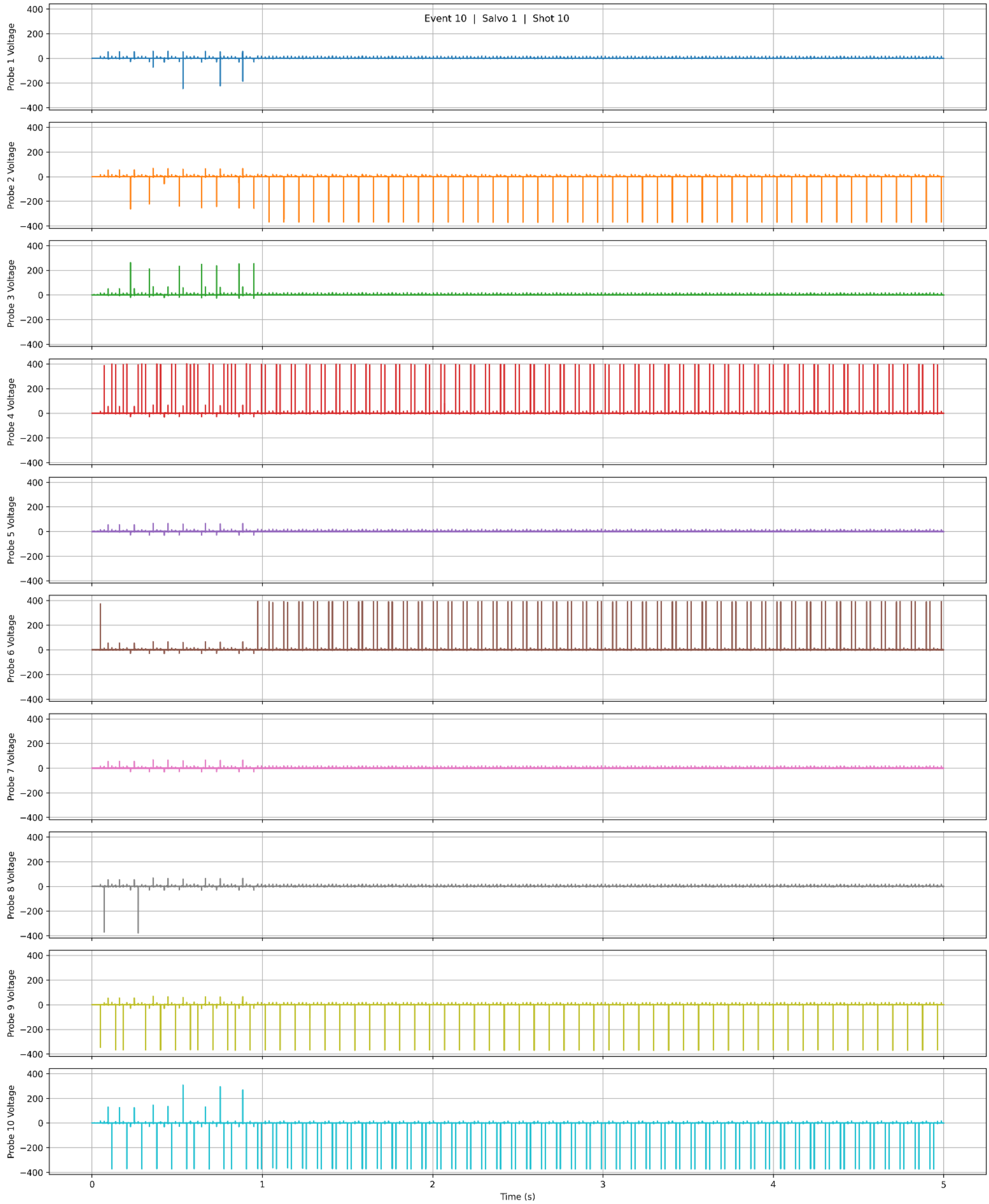

Event 5 | Salvo 1 | Shot 5
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

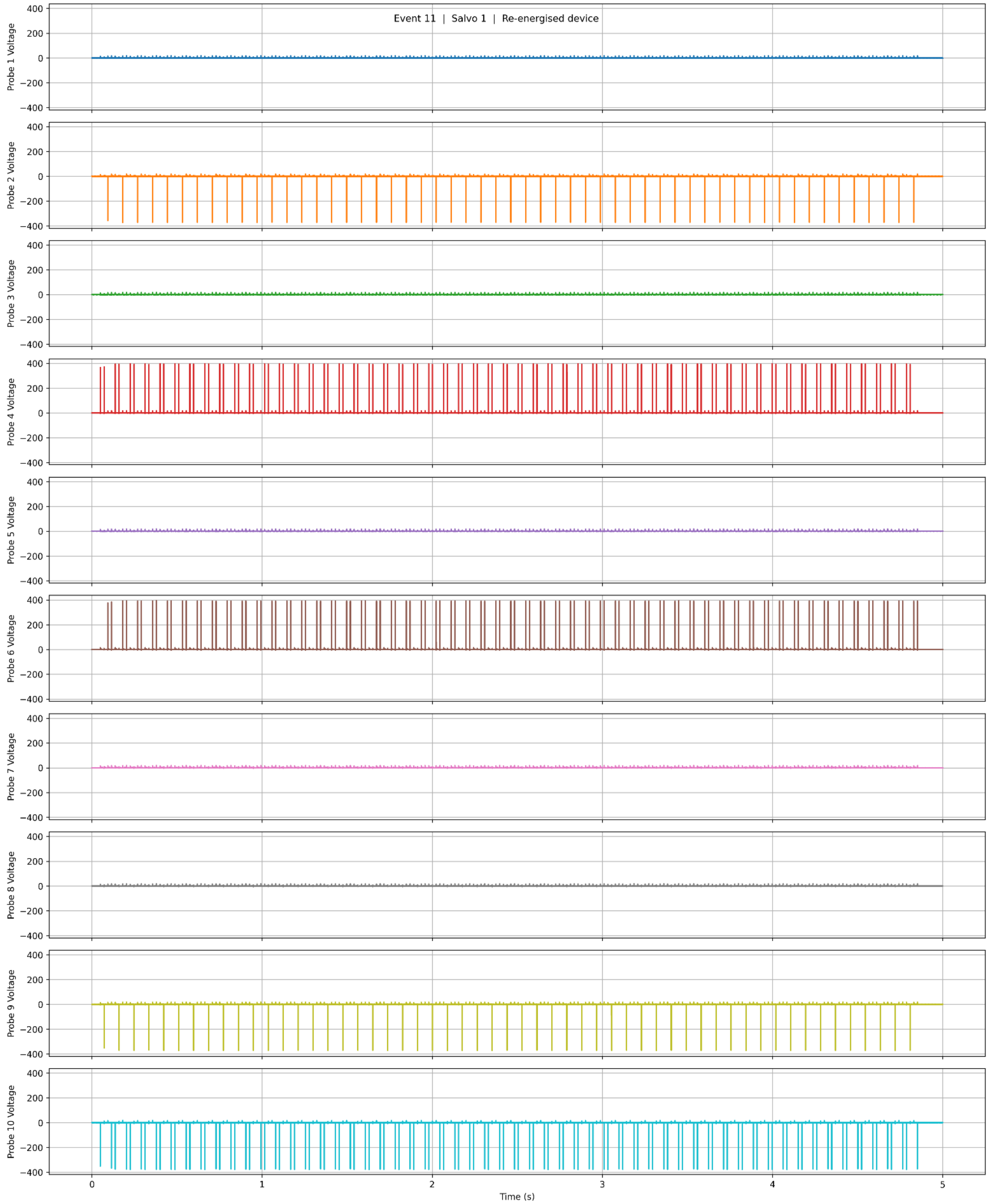

Event 6 | Salvo 1 | Shot 6
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

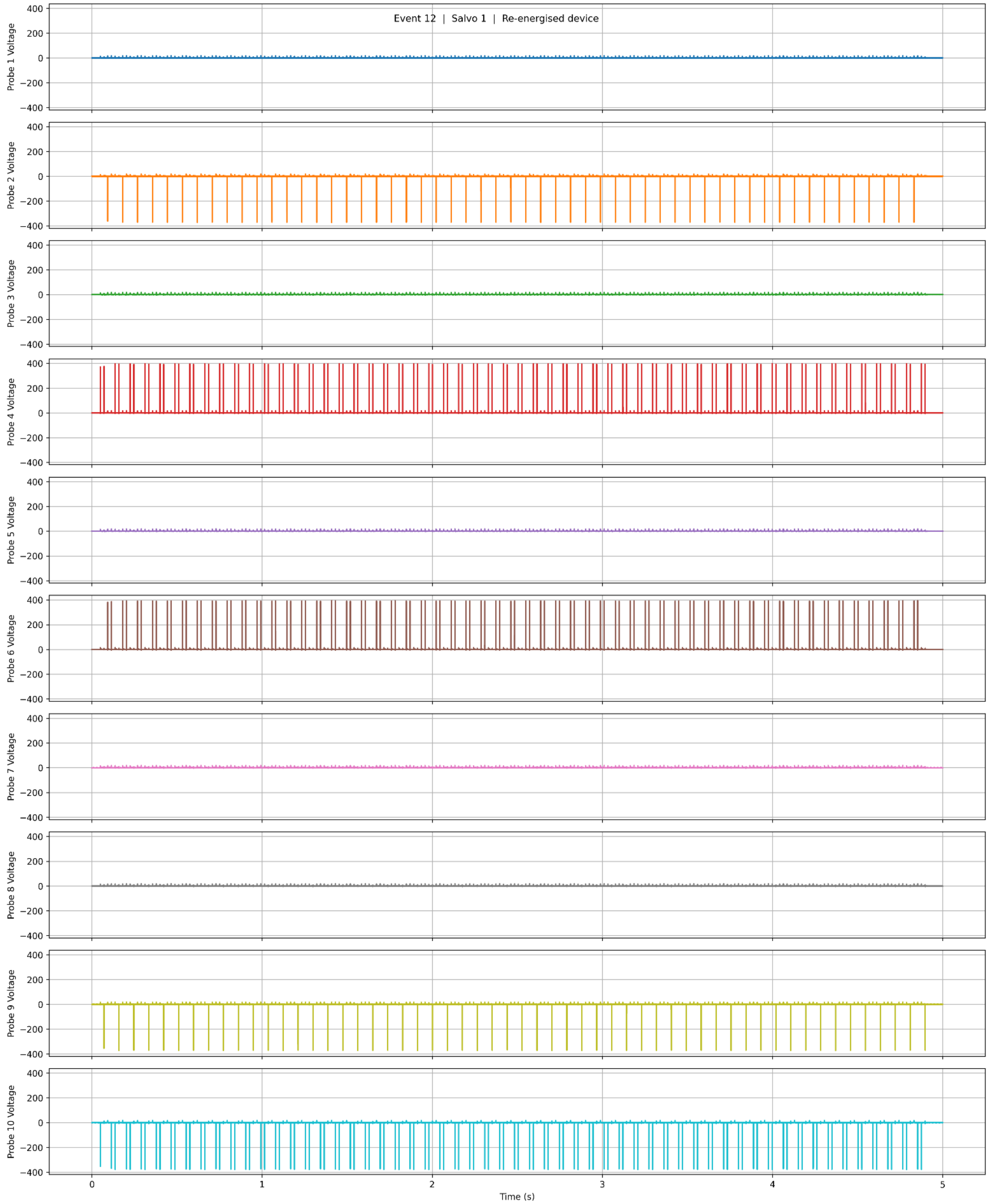

Event 7 | Salvo 1 | Shot 7
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

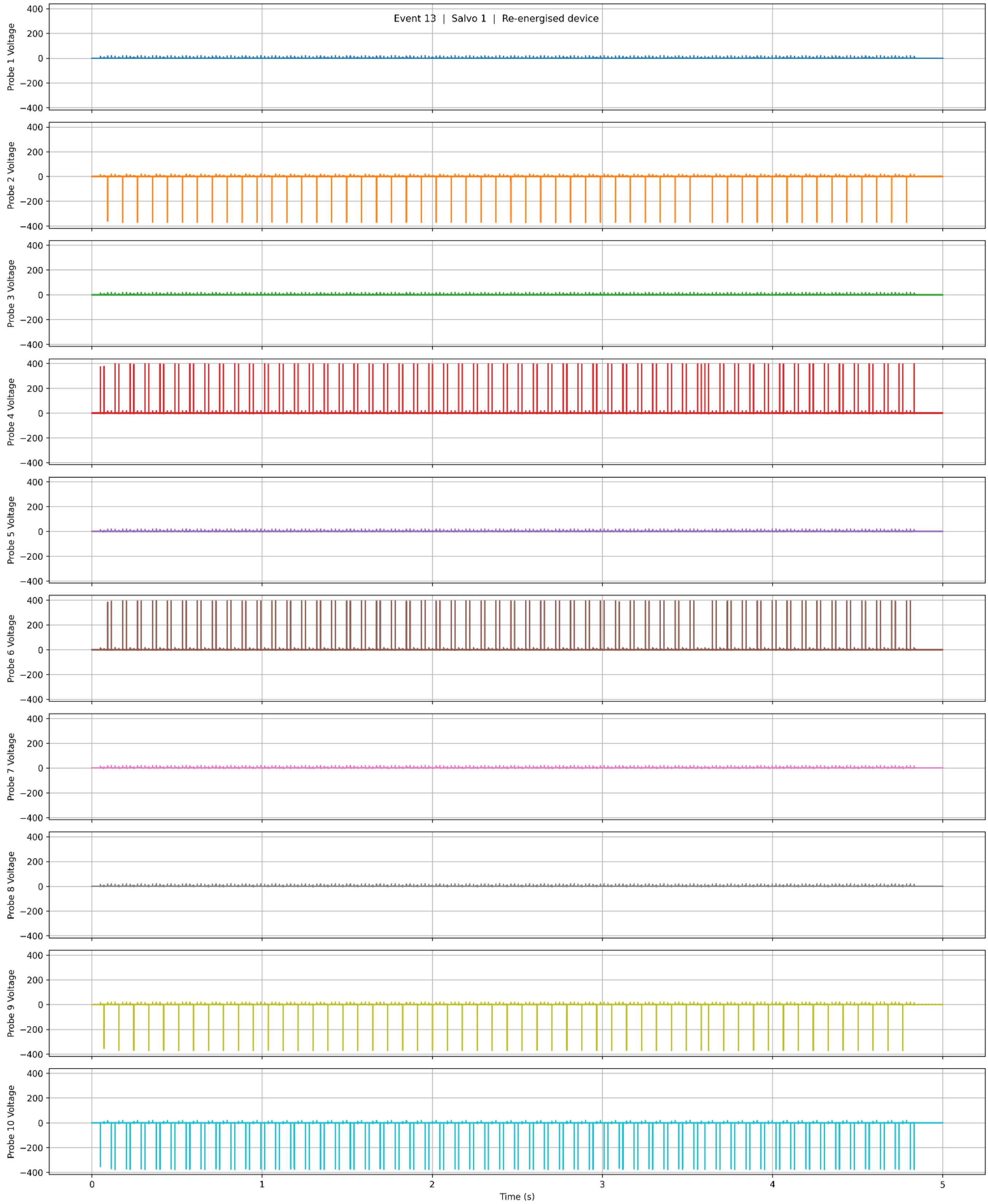

Event 8 | Salvo 1 | Shot 8
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

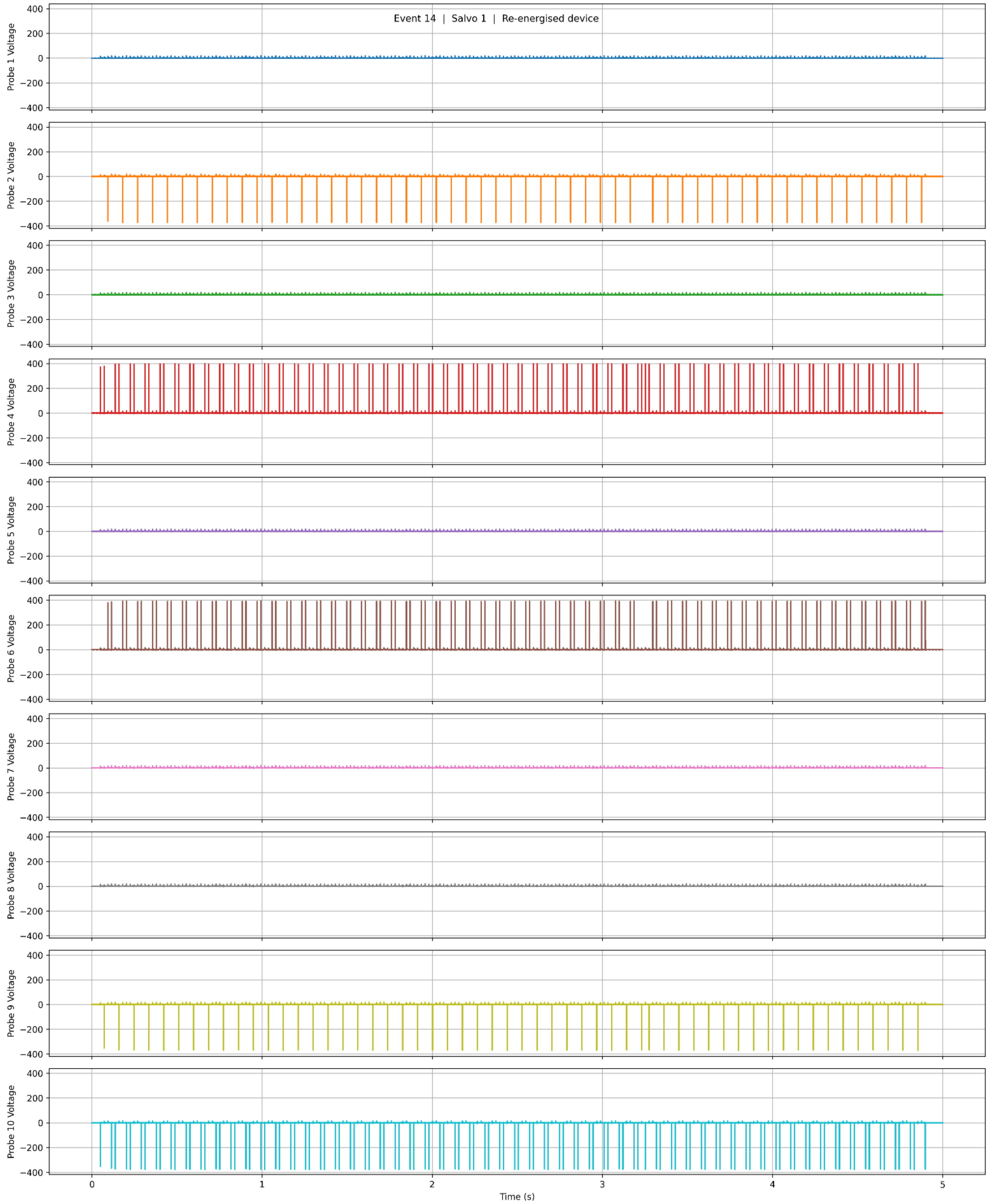

Event 9 | Salvo 1 | Shot 9
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

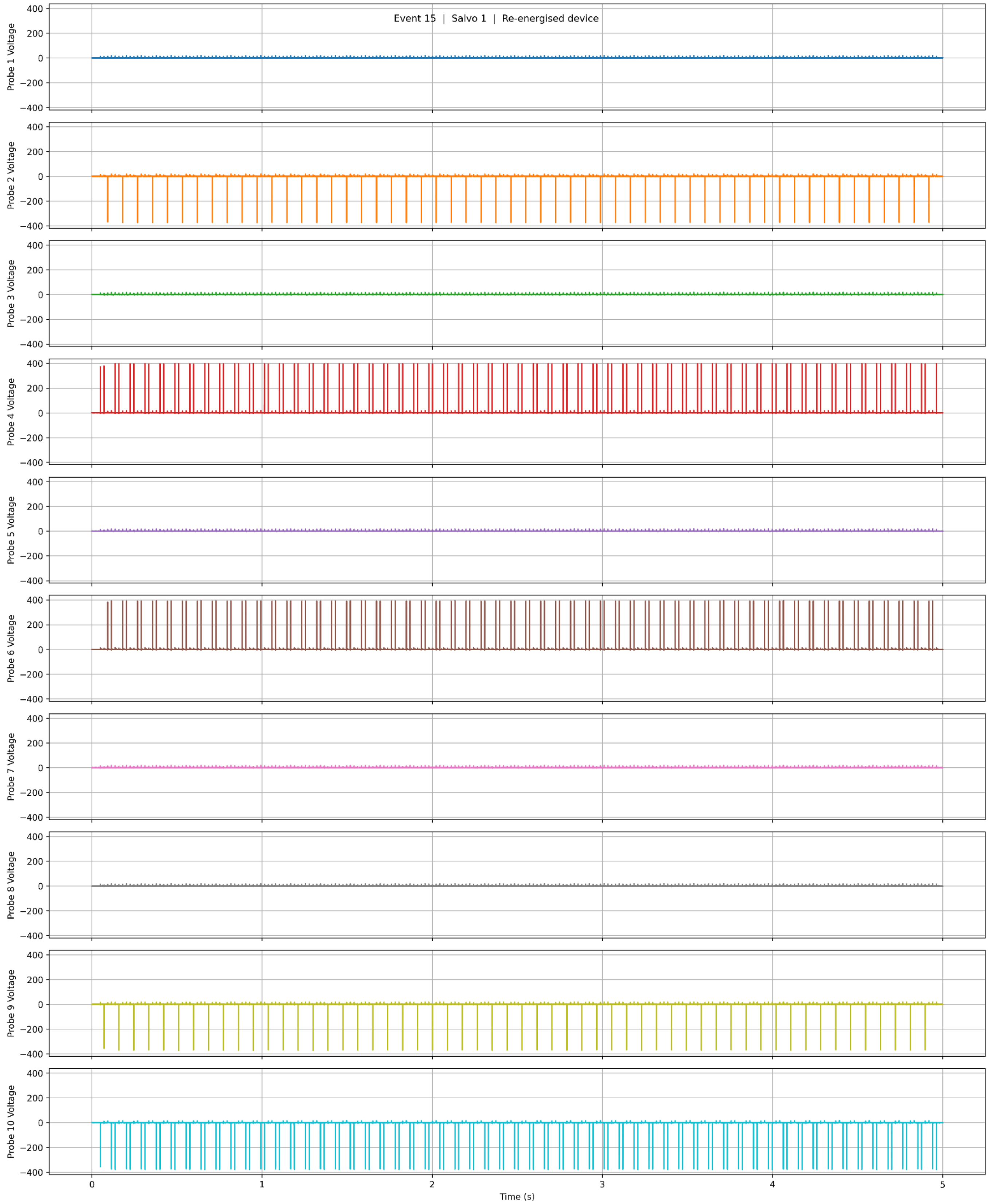

Event 10 | Salvo 1 | Shot 10
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)


Event 11 | Salvo 1 | Re-energised device
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)


Event 12 | Salvo 1 | Re-energised device
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)


Event 13 | Salvo 1 | Re-energised device
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

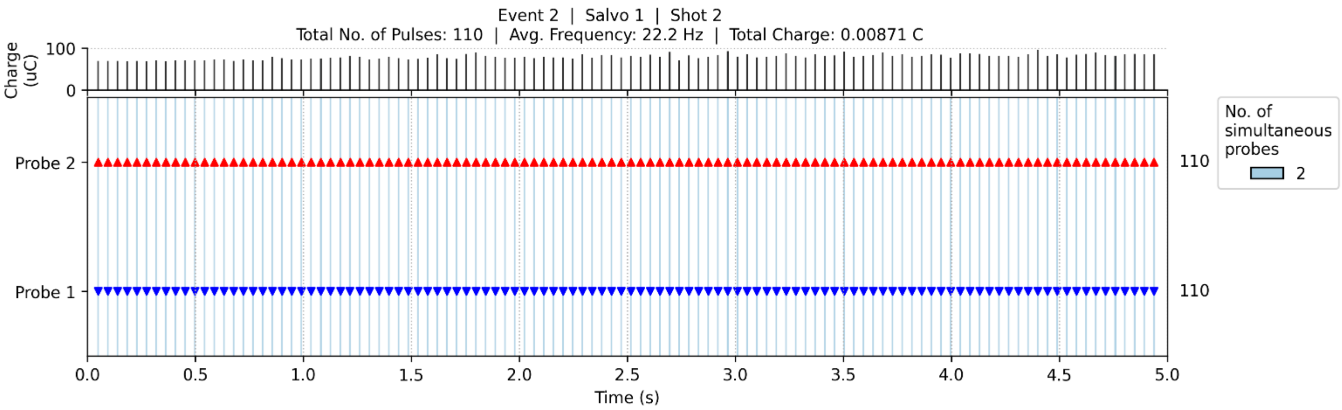

Event 14 | Salvo 1 | Re-energised device
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

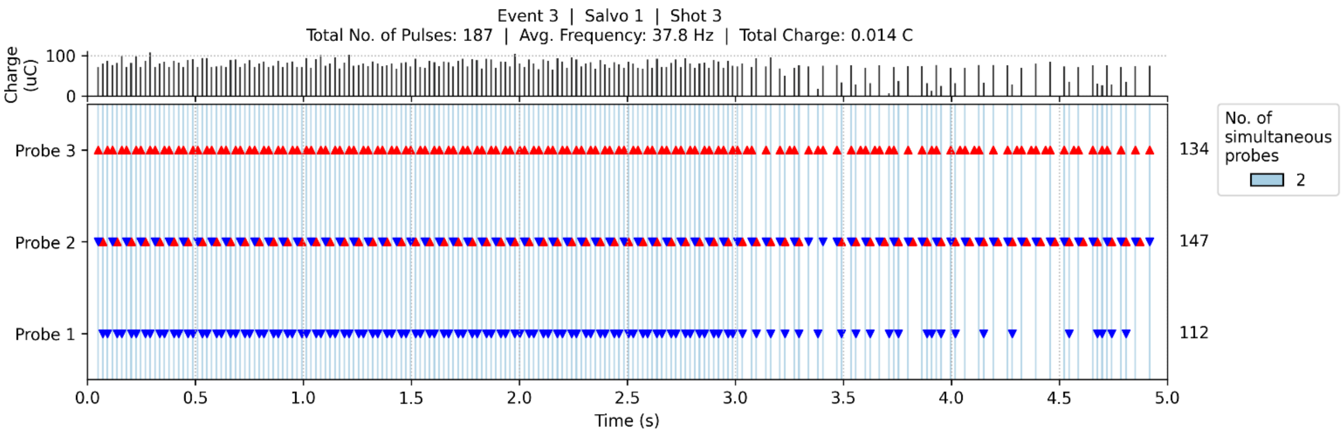


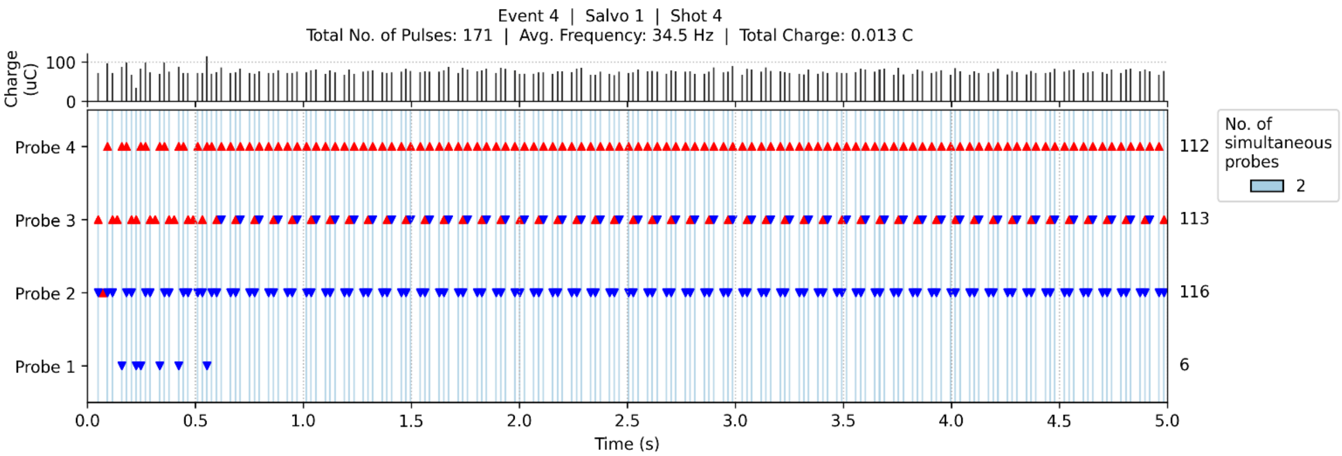
Event 15 | Salvo 1 | Re-energised device
Probe 1 Voltage
Probe 2 Voltage
Probe 3 Voltage
Probe 4 Voltage
Probe 5 Voltage
Probe 6 Voltage
Probe 7 Voltage
Probe 8 Voltage
Probe 9 Voltage
Probe 10 Voltage
400
200
0
−200
−400
0
1
2
3
4
5
Time (s)

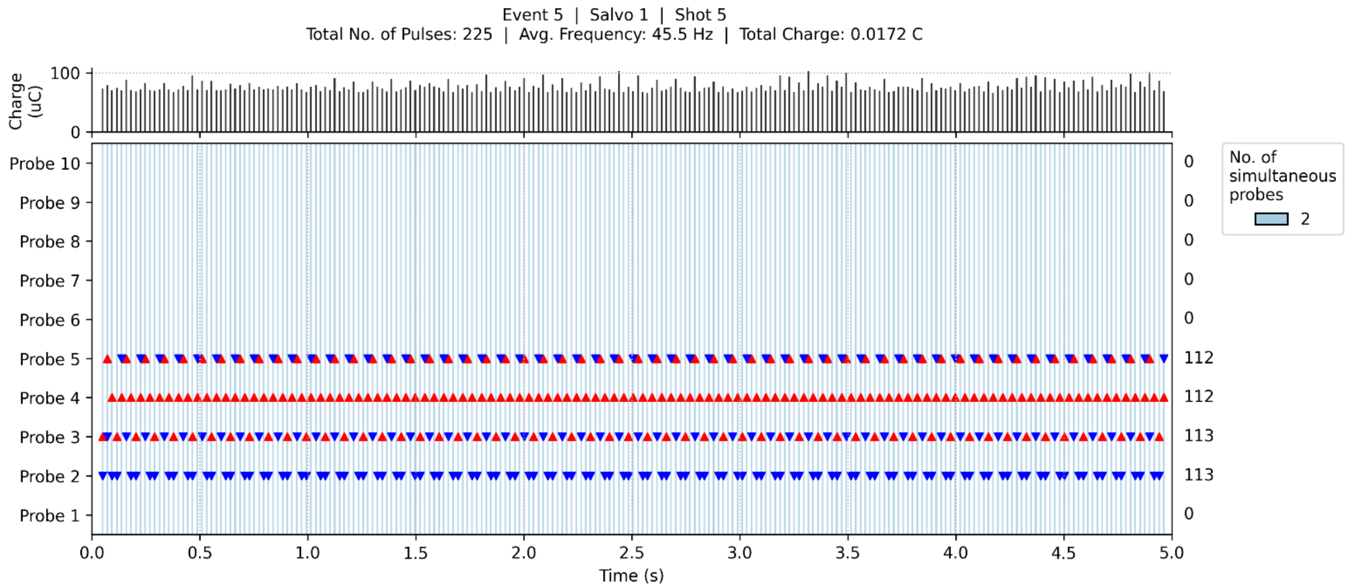
Event plots (Salvo 1)

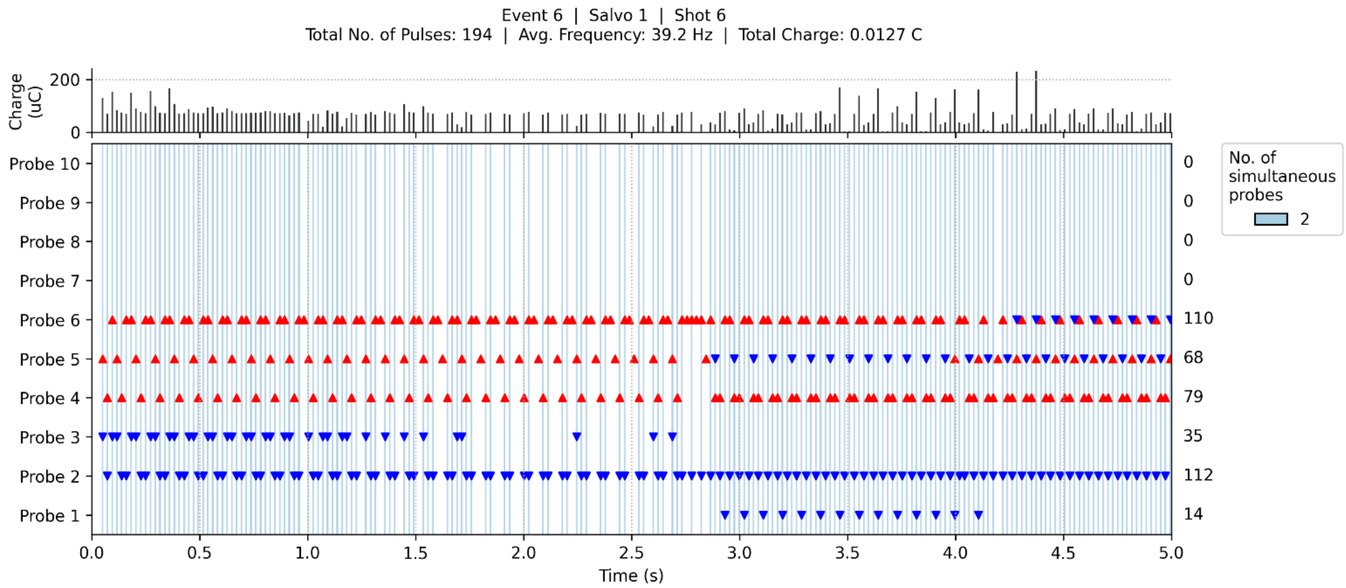
The Event plots here show each peak recorded from each probe during a discharge, with positive and negative peaks denoted by red and blue triangles respectively. Vertical lines indicate a time during which there was at least 1 probe energised ('coincident Events'), and the colour of the lines indicate how many probes were energised simultaneously. Above the Event plots is a plot of the total charge from all energised probes for each coincident Event, to indicate how much the charge was varying. The number of energised peaks observed for each probe is recorded on the right side of the plots. The plot title contains summary information: the total number of coincident Events (i.e. the number of pulses delivered by the handle), the total time of the measurement, the average frequency of the pulses, and the total charge delivered across all pulses.

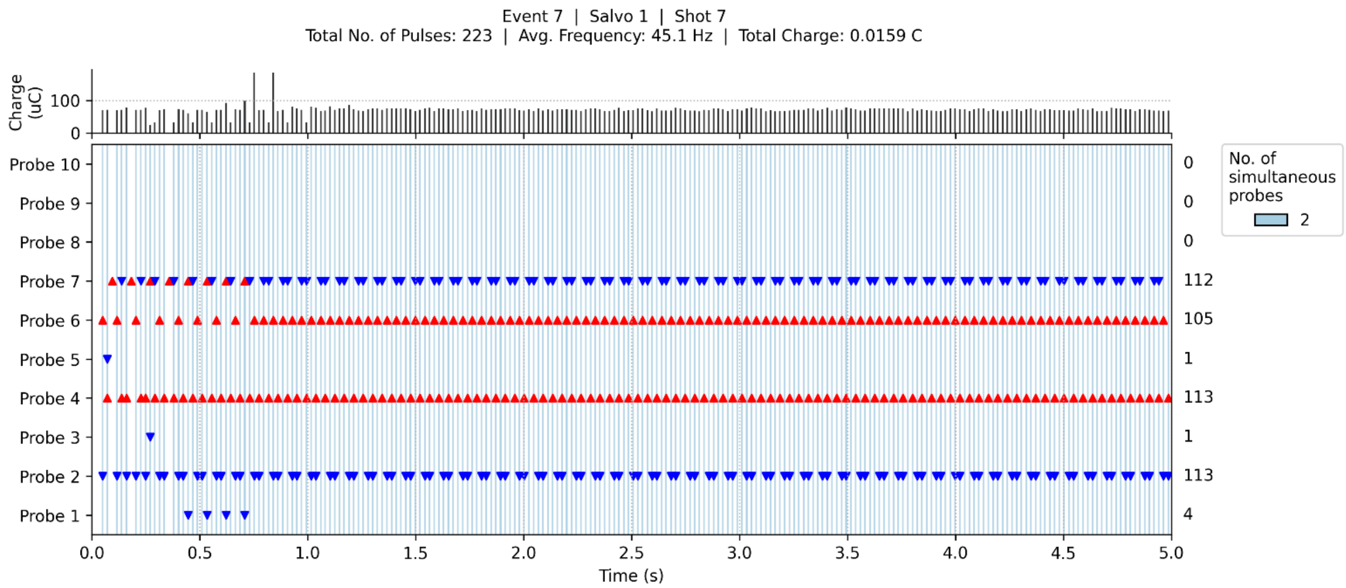


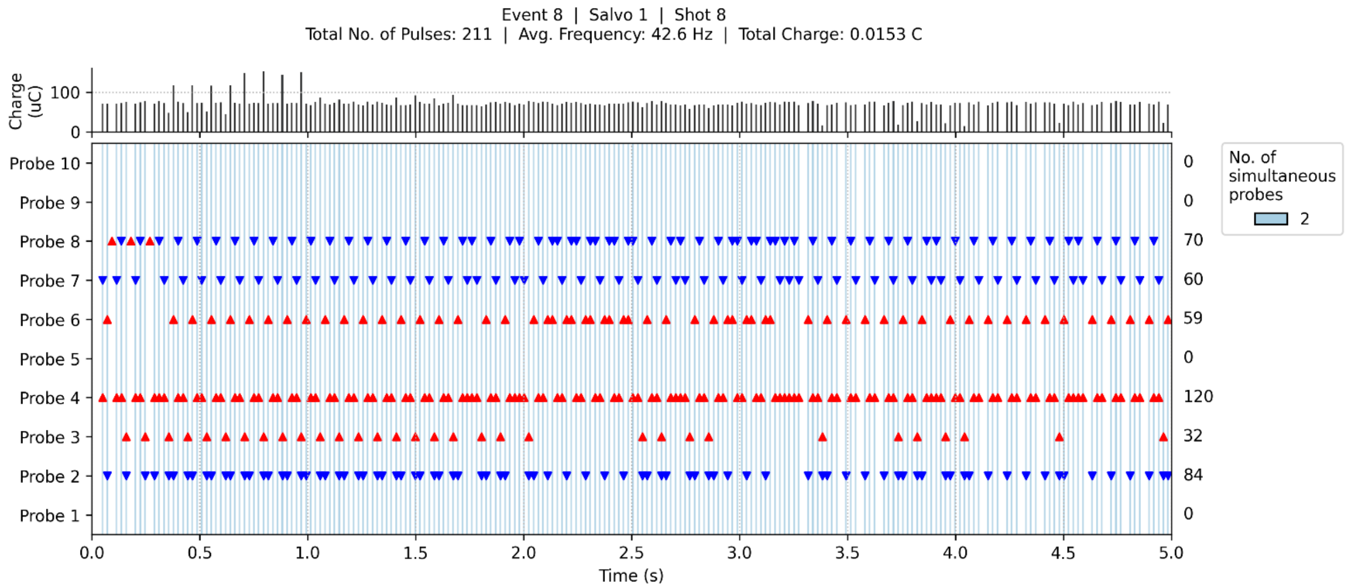


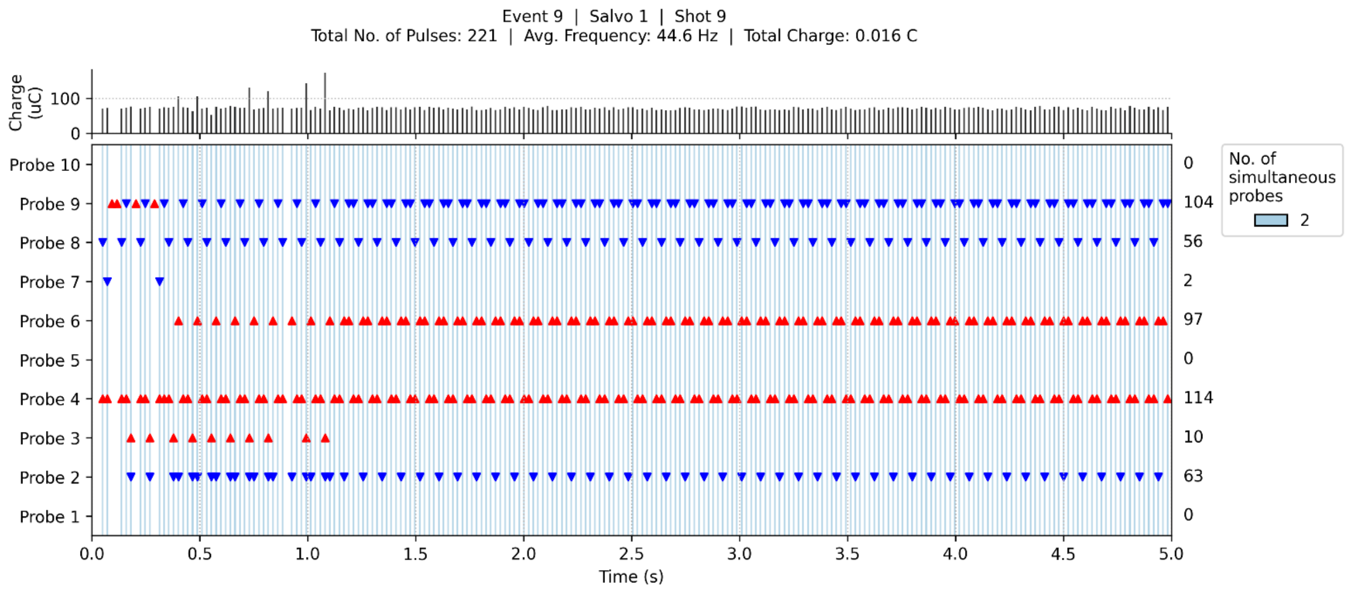


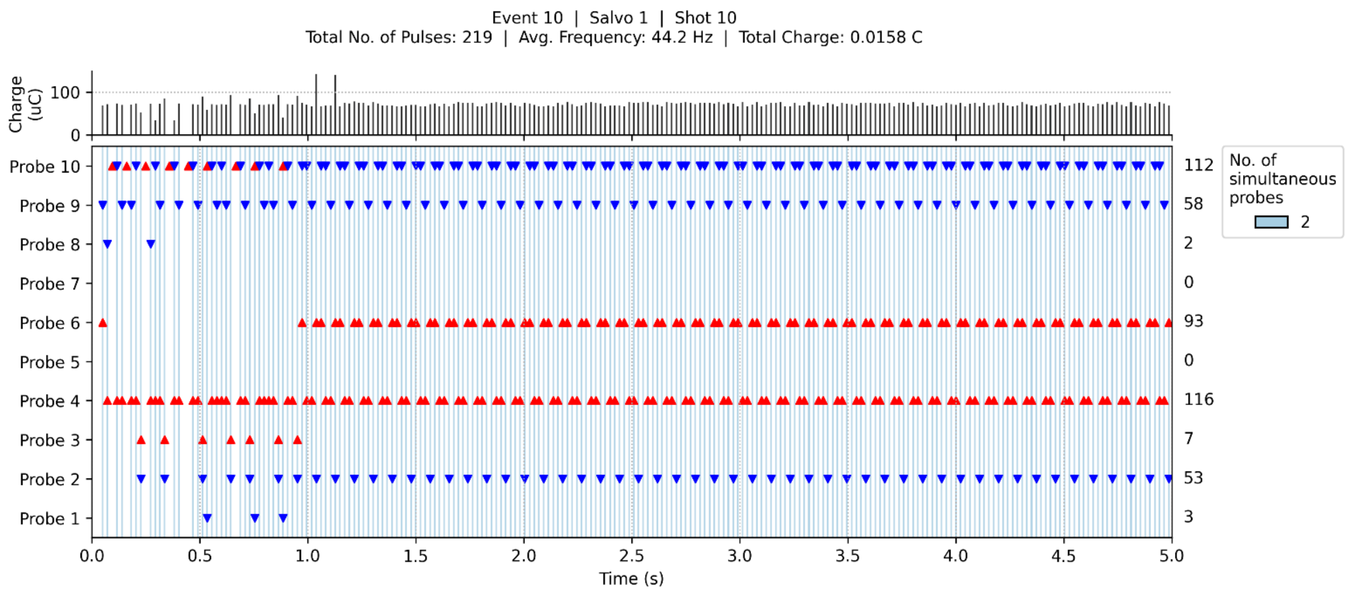

Event 5 | Salvo 1 | Shot 5
Total No. of Pulses: 225 | Avg. Frequency: 45.5 Hz | Total Charge: 0.0172 C
Charge (uC)
100
0
Probe 10 0
Probe 9 0
Probe 8 0
Probe 7 0
Probe 6 0
Probe 5 112
Probe 4 112
Probe 3 113
Probe 2 113
Probe 1 0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
Time (s)
No. of simultaneous probes
2


Event 6 | Salvo 1 | Shot 6
Total No. of Pulses: 194 | Avg. Frequency: 39.2 Hz | Total Charge: 0.0127 C
Charge (uC)
200
0
Probe 10 0
Probe 9 0
Probe 8 0
Probe 7 0
Probe 6 110
Probe 5 68
Probe 4 79
Probe 3 35
Probe 2 112
Probe 1 14
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
Time (s)
No. of simultaneous probes
2

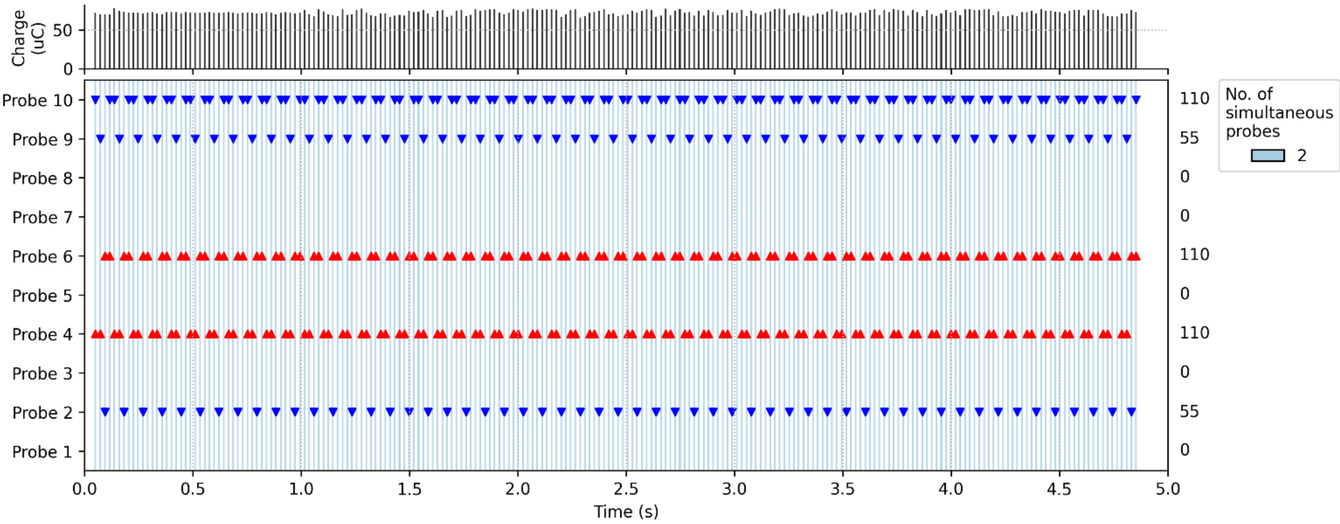

Event 7 | Salvo 1 | Shot 7
Total No. of Pulses: 223 | Avg. Frequency: 45.1 Hz | Total Charge: 0.0159 C
Charge (uC)
100
0
Probe 10 0
Probe 9 0
Probe 8 0
Probe 7 112
Probe 6 105
Probe 5 1
Probe 4 113
Probe 3 1
Probe 2 113
Probe 1 4
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
Time (s)
No. of simultaneous probes
2


Event 8 | Salvo 1 | Shot 8
Total No. of Pulses: 211 | Avg. Frequency: 42.6 Hz | Total Charge: 0.0153 C
Charge (uC)
100
0
Probe 10
Probe 9
Probe 8
Probe 7
Probe 6
Probe 5
Probe 4
Probe 3
Probe 2
Probe 1
0
0
70
60
59
0
120
32
84
0
No. of simultaneous probes
2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time (s)

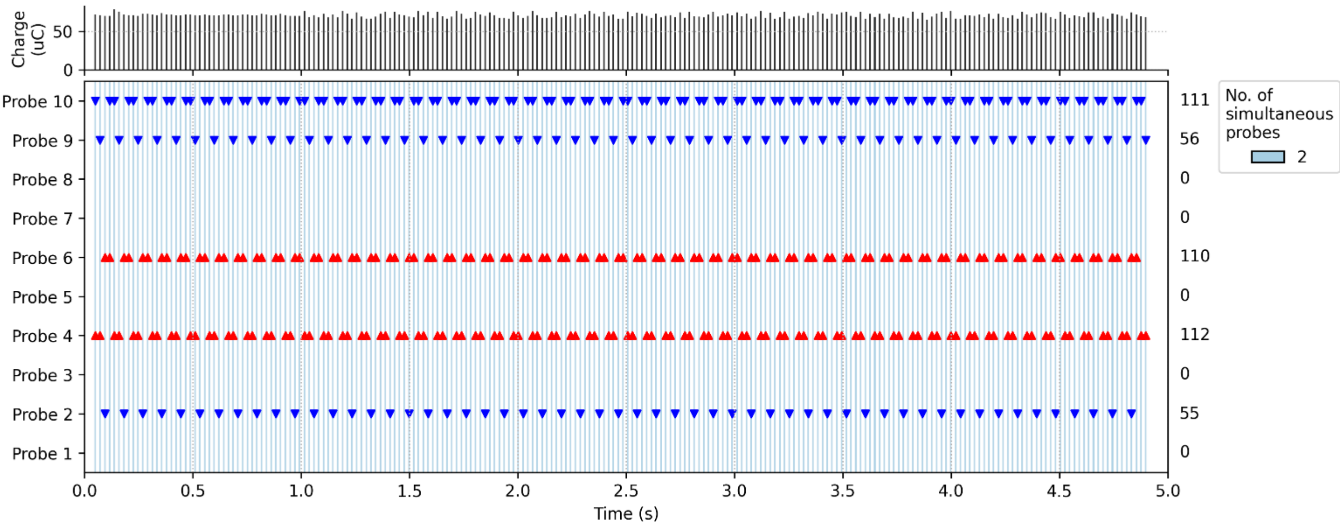

Event 9 | Salvo 1 | Shot 9
Total No. of Pulses: 221 | Avg. Frequency: 44.6 Hz | Total Charge: 0.016 C
Charge (uC)
100
0
Probe 10
Probe 9
Probe 8
Probe 7
Probe 6
Probe 5
Probe 4
Probe 3
Probe 2
Probe 1
0
104
56
2
97
0
114
10
63
0
No. of simultaneous probes
2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time (s)


Event 10 | Salvo 1 | Shot 10
Total No. of Pulses: 219 | Avg. Frequency: 44.2 Hz | Total Charge: 0.0158 C
Charge (uC)
100
0
Probe 10
Probe 9
Probe 8
Probe 7
Probe 6
Probe 5
Probe 4
Probe 3
Probe 2
Probe 1
112
58
2
0
93
0
116
7
53
3
No. of simultaneous probes
2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time (s)

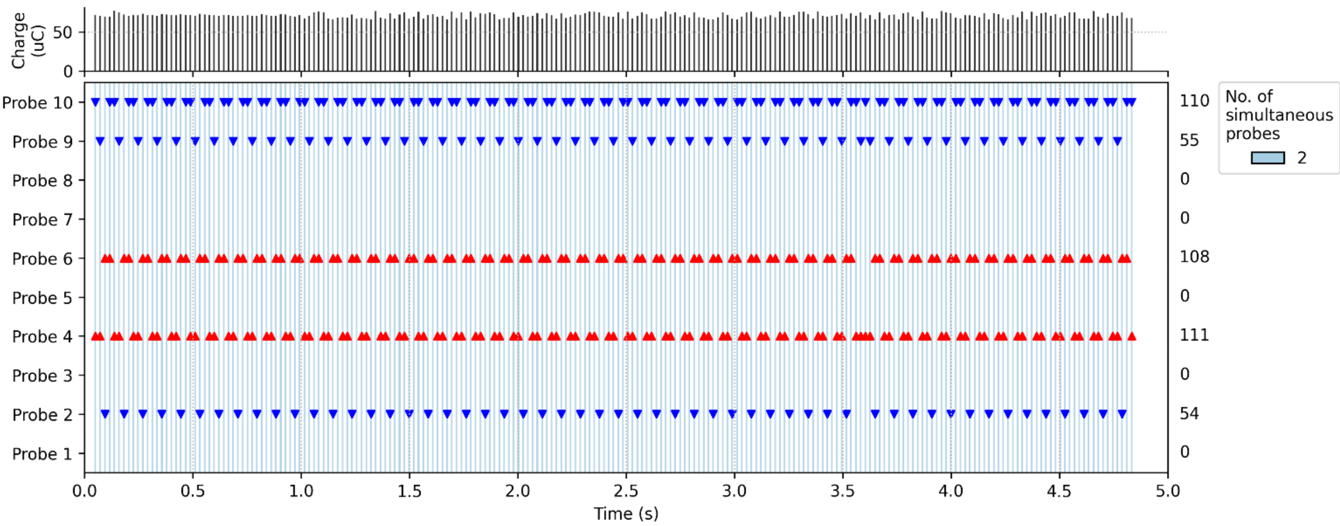
Event 11 | Salvo 1 | Re-energised device
Total No. of Pulses: 220 | Avg. Frequency: 44.4 Hz | Total Charge: 0.016 C

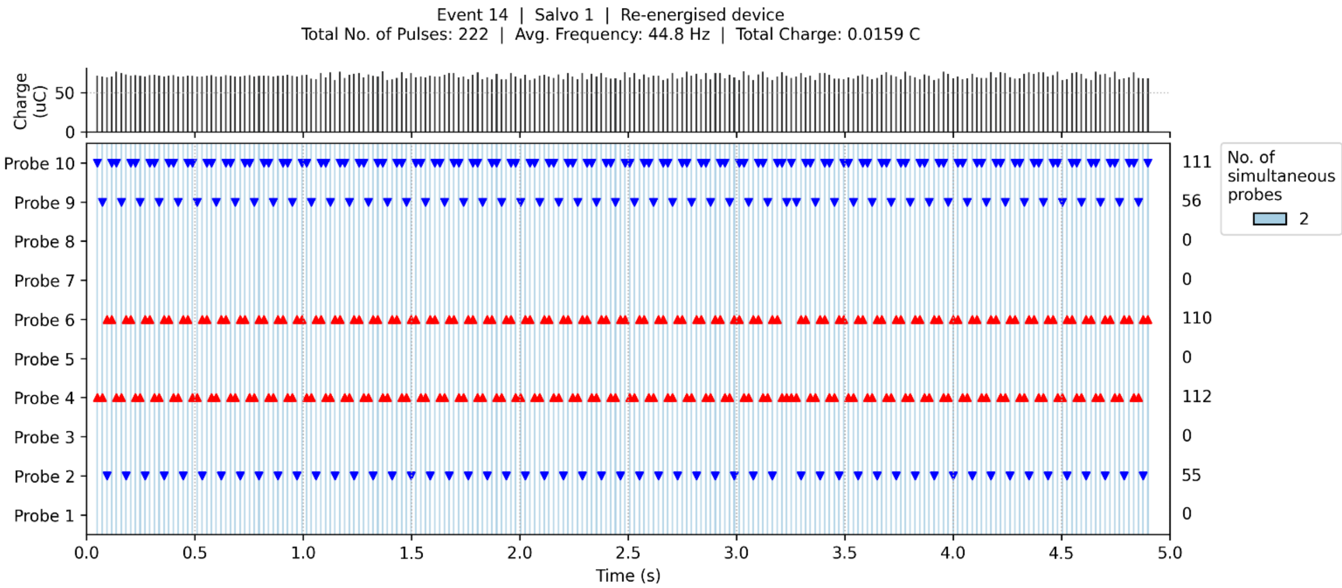


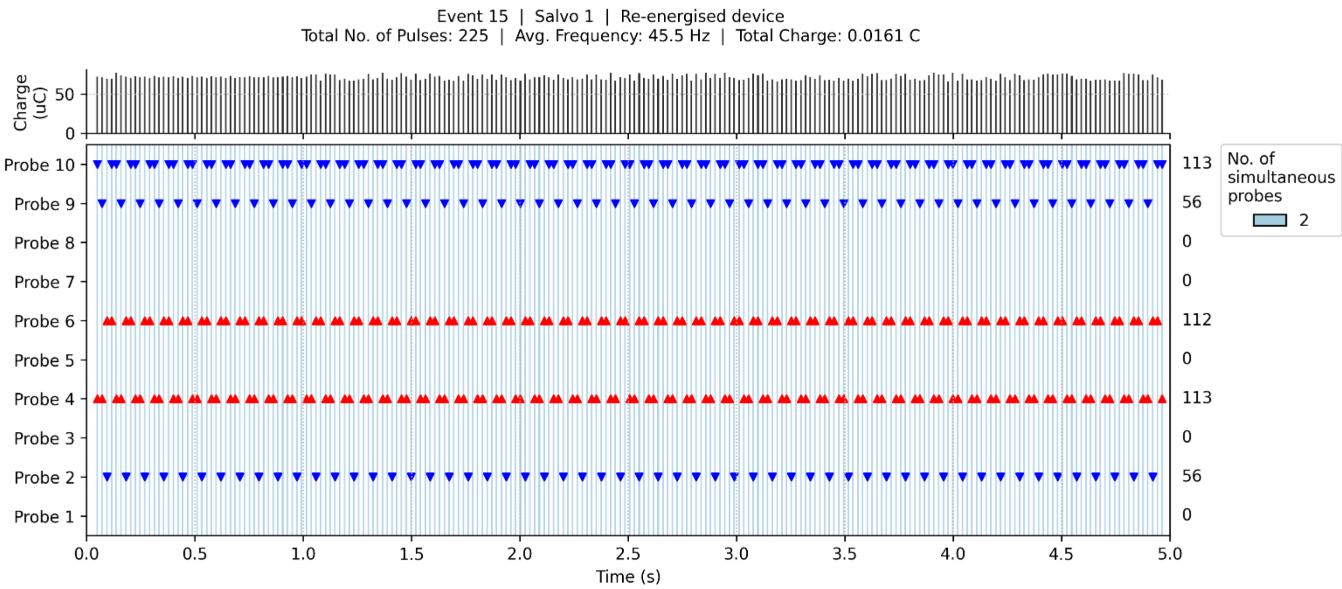
Event 12 | Salvo 1 | Re-energised device
Total No. of Pulses: 222 | Avg. Frequency: 44.8 Hz | Total Charge: 0.0157 C



Event 13 | Salvo 1 | Re-energised device
Total No. of Pulses: 219 | Avg. Frequency: 44.2 Hz | Total Charge: 0.0156 C




Event 14 | Salvo 1 | Re-energised device
Total No. of Pulses: 222 | Avg. Frequency: 44.8 Hz | Total Charge: 0.0159 C
Charge (uC)
Probe 10
Probe 9
Probe 8
Probe 7
Probe 6
Probe 5
Probe 4
Probe 3
Probe 2
Probe 1
111
56
0
0
110
0
112
0
55
0
No. of simultaneous probes
2
Time (s)


Event 15 | Salvo 1 | Re-energised device
Total No. of Pulses: 225 | Avg. Frequency: 45.5 Hz | Total Charge: 0.0161 C
Charge (uC)
Probe 10
Probe 9
Probe 8
Probe 7
Probe 6
Probe 5
Probe 4
Probe 3
Probe 2
Probe 1
113
56
0
0
112
0
113
0
56
0
No. of simultaneous probes
2
Time (s)

Charge variation plots

Below are layered histograms and cumulative density function plots of the charge in each pulse, plotted separately by Salvo and with each Event's data shown separately – these contain the same data as Figure 34 and Figure 35, but without the different Events separated out.

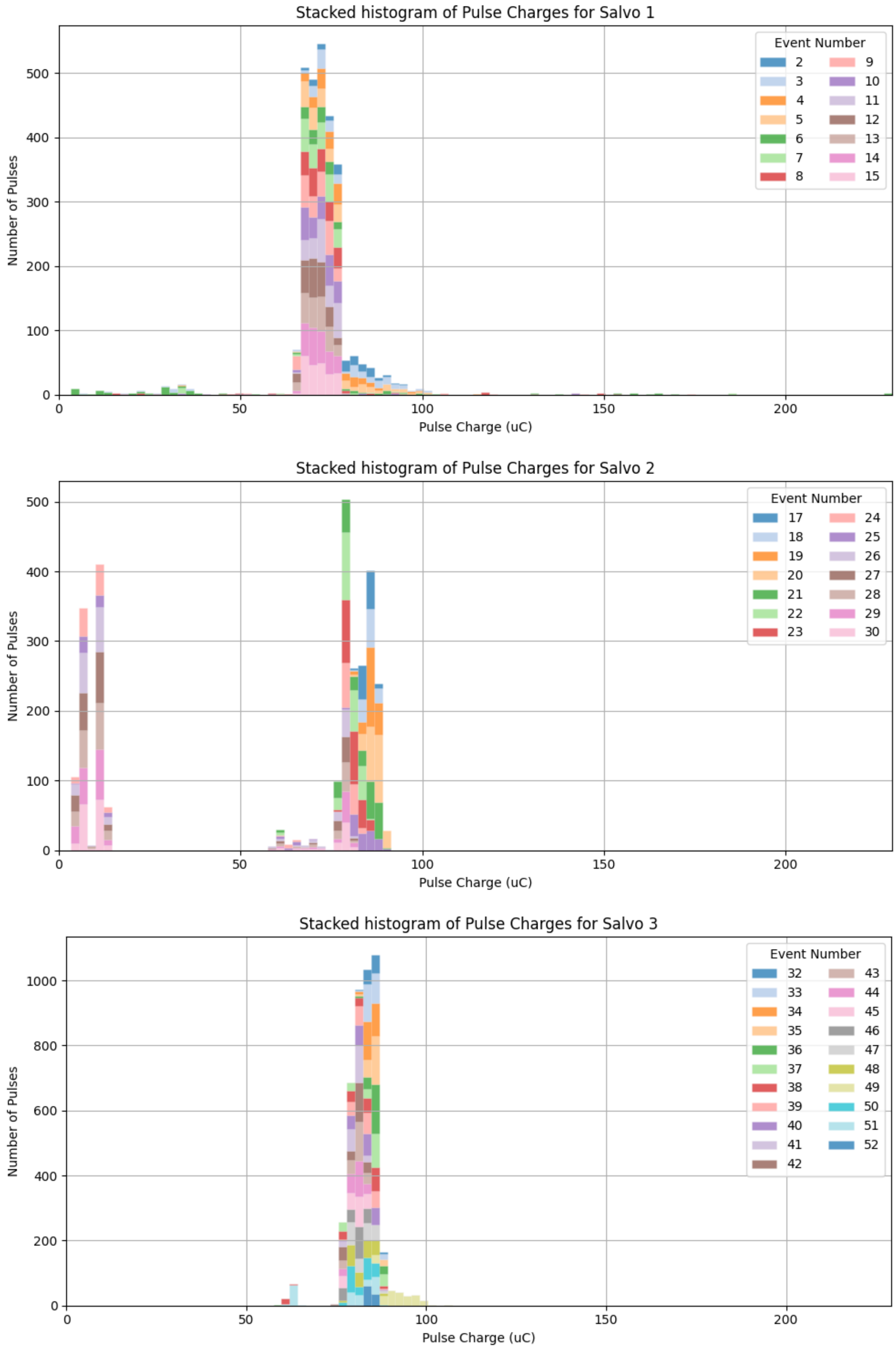


Figure 61: Histograms of the charge in each pulse. Each Salvo is plotted separately, with the histograms for each individual Event overlaid on each other.

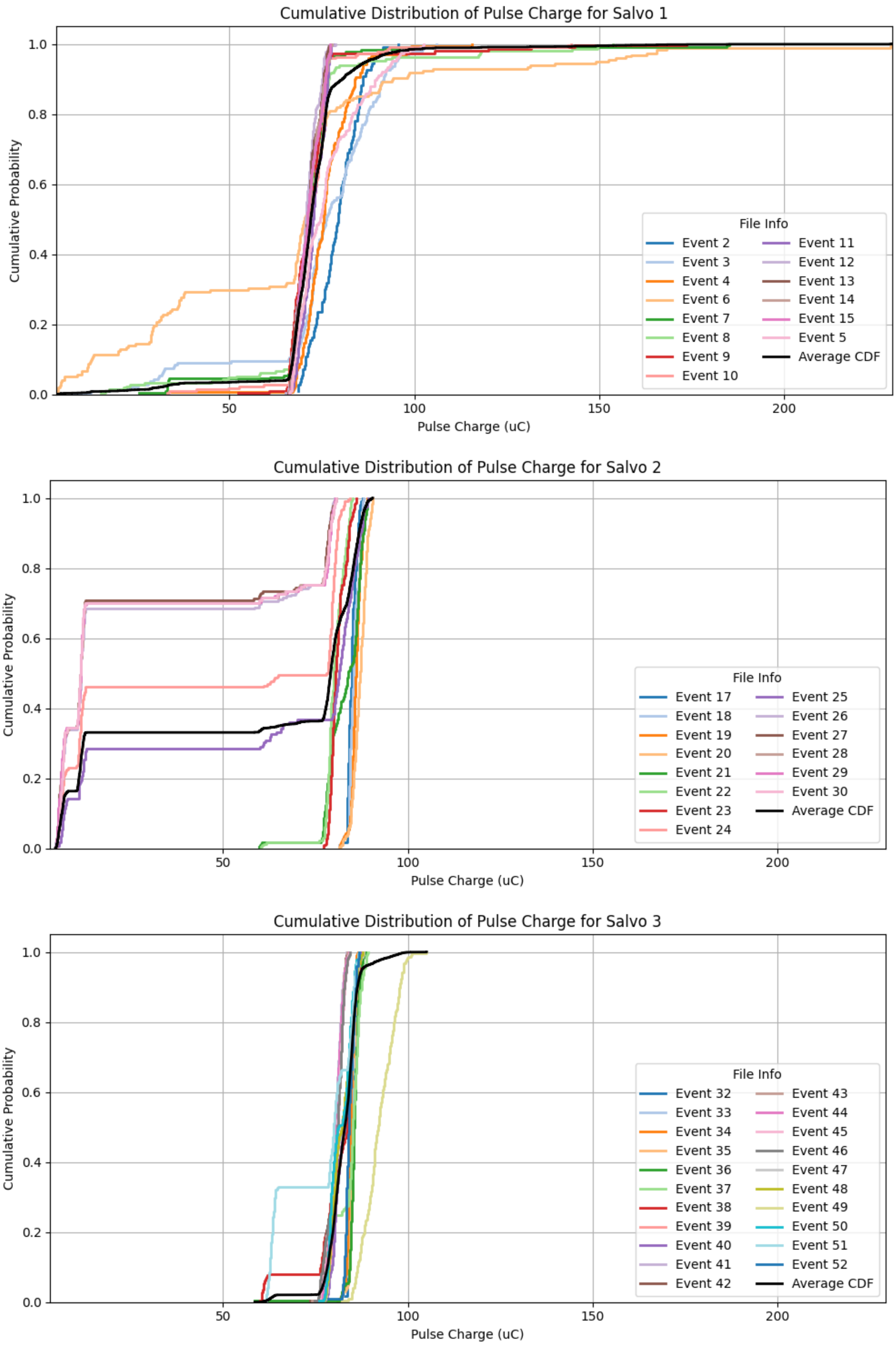


Figure 62: Cumulative distribution function (CDF) plots for the charge in each pulse. Each Salvo is plotted separately, with the CDFs for each individual Event overlaid on each other. An overall CDF for each Salvo is overlaid in black.

Axon responses

Following the analysis of the data from the further probe synchronisation testing, Axon were approached through HO to provide responses for specific questions that arose from the analysis. The questions and responses are documented in Table 42. These responses were provided following discussion of some of the unexpected behaviour observed. Axon were not provided with the testing data. The contents of this report were unchanged by the Axon responses, aside from including them in the discussion of Section 14.4 and adding footnotes in the Results section to highlight relevant information in the responses.

Question	Axon Response
The specified minimum and maximum pulse charge limits (52-95uC) are based on averaging over 8 pulses[28] – what would the range of expected pulse charges be without averaging over 8 pulses? i.e. what would be a typical absolute maximum and minimum pulse charge for normal operation?	In human flesh, we would expect cases of extreme impedance changes between pulses for there to be as little as 51uC and as high as 120 uC. This is dependent on how extreme the impedance change is and the timing in which it occurs, so it can go to even lower or higher extremes in larger impedance shifts, however that is outside of realistic probability.
What could cause anomalously/exceptionally high or low pulse charges?	The measurement and then adjustment of charge occur on separate pulses, so if the impedance is measured at one level on a pulse, but then changes between pulses, the next pulse would get charge that was designed for the previously measured pulse. For example, if the impedance is measured at 1,000 ohms on one pulse, the next pulse is adjusted based on 1,000 ohms, however if the impedance changes between those pulses to 600 ohms, we would expect one pulse of a large amount of charge until the weapon adjusts it down on the next round. The same goes on the low side, if the weapon is discharging into 600 ohms and between pulses it changes to 1500 ohms, we would expect a small pulse generated until the next pulse adjustment.
If the device has a choice of low, medium and high resistance connections to choose from, is there an upper limit on the 'high resistance' that it would choose not to energize (i.e. if it is above the 2000/3000 ohm indicated limit of the device)?	The weapon caps at 3,000 ohms, where will no longer select that path to discharge to.

Table 42: Axon responses to questions relayed via HO following the analysis of the further probe synchronisation testing.

[28] TASER 10 Energy Weapon Specifications. Version 1.0 February 27, 2023.

Appendix L Superseded electrical output testing

After the initial electrical output testing (see Chapter 13), it was identified that more detailed measurements with a different methodology was required to obtain a greater understanding of the device's electrical output. This appendix contains details of a methodology (and associated results) initially developed, but which was subsequently superseded by the methodology of Chapter 14, which offered significantly greater insight into the device performance (primarily by measuring the output of all probes simultaneously, rather than one at a time). The methodology and results of the superseded electrical output testing is reported here for reference and completeness.

Purpose

The purpose of this test was to determine how many T10 probes may be simultaneously energised in different scenarios by simulating the engagement of a single subject and multiple deployments into multiple subjects, including misses.

Methodology

A single T10 handle was loaded with a full magazine of 10 duty shots and fired from a range of 5m at a set of 5 conductive targets. After each shot, it was determined whether current was flowing in any of the deployed wires, and if so, the direction of the flow. One wire was measured at a time. Each measurement required a new energisation of the device. After all wires had been measured, the probes were left in the targets and the next shot was taken, with the measurement process repeating.

The placement and order of the shots, as well as whether the targets were electrically connected to each other, was varied to simulate the engagement of a single subject or multiple subjects. The details of the placements are given in the Results section below, and in summary they were:

- **Engagement 1:** Two shots into each of five electrically separate targets. This simulates the sequential engagement of five separate subjects.
- **Engagement 2:** Two shots into five separate targets as in Engagement 1, but with the targets electrically connected. This simulates the engagement of a single subject with all ten shots.
- **Engagement 3:** Between one and three shots into five electrically separate targets. This simulates the sequential engagement of five separate subjects, with some receiving one shot (effectively a miss), some two, and some three shots.
- **Engagement 4a:** A similar arrangement to Engagement 3 but with a different order and pattern. This again simulates the engagement of five separate subjects but not sequentially – i.e. one target may be hit by the 2nd and 7th shots, rather than consecutive shots as in Engagement 3.
- **Engagement 4b:** Following Engagement 4a, all probes are left in the targets and no changes are made except that the targets are connected electrically. This investigates how the device applies its decision algorithm when inter-probe resistances, and therefore the perceived inter-probe distances, are significantly changed during an existing deployment.

The five targets each comprised:

1. A layer of vinyl matting (to decelerate the projectile)
2. A layer of Shieldtex 565 (an aluminium-faced woven glass cloth weighing 565g/m^2 with a light PU backing, produced by Textile Technologies)
3. A ~5mm layer of Grade 0000 oil-free iron wire wool

4. A second layer of Shieldtex 565, sandwiching the wire wool layer
5. A non-conductive pinboard panel over a plywood backing

These were placed immediately above floor level on a non-conductive base. Flying leads were used to connect the targets together electrically as required.

At various points during the engagements, repeat measurements were taken without any changes to the deployed probes in order to assess whether the probe energisation (e.g. which probes) varied in the absence of any physical changes to the scenario – i.e. whether the device changed which probes it energised spontaneously to, for example, distribute the workload between different bays.

During the testing, it became apparent that the pulse frequency varied between different energised probes. Once this was observed, an approximate relative frequency was recorded (based on the number of pulse peaks observed during a fixed timescale on the measurement oscilloscope) – this served to highlight significant frequencies differences, which aided the analysis.

Note again that this methodology was chosen in order to provide reasonable confidence in assessing the simultaneous probe energisation performance of the device within a very tight time frame. A more comprehensive approach involving measuring all deployed wires simultaneously, and using resistive targets to better simulate a real subject, was subsequently performed and superseded this methodology – the improved methodology and associated results are reported in Chapter 14.

Results

The data collected from the testing are presented in the following tables for each engagement, with the placement of probes and the electrical connections between targets depicted in the corresponding figures. First though, Table 43 provides the key used to colour code the data in the table. This highlights that the current in individual wires was sometimes measured to be directed from the handle to the target (defined as ‘positive’ for convenience), sometimes directed from the target to the handle (defined as ‘negative), and sometimes alternating between positive and negative – the current is, in all cases, delivered as a sequence of pulses by the handle, and in some cases the pulses alternated between positive and negative. This highlights an interesting observation from the testing; it appears that energisation is applied through several different combinations of wires, rather than just pairs of wires (as may be assumed):

- **A pair of wires:** one wire carries current to the target, and one wire carries current back from the target. The pulse frequency is the same for both wires. This is effectively a simple loop circuit.
- **A ‘positive triad’:** three wires combine such that one wire carries a negative current, while two carry a positive current. The negative wire has twice the pulse frequency of the positive wires – the handle alternates between sending a current pulse out along one positive wire and back along the negative wire, then out along the other positive wire and back along the same negative wire.
- **A ‘negative triad’:** as above, except two wires are negative and one is positive.
- **A ‘bi-directional triad’:** three wires combine where one always carries a positive current, one always carries a negative current, and one alternates between carrying a positive current and a negative current. The pulse frequency of the alternating wires is double that of the other two wires – pulses are alternately sent out of the handle along the positive wire and back along the bidirectional wire, then out along the bidirectional wire and back along the negative wire.

This behaviour does not appear to be explicitly mentioned in any Axon document that has been identified in this project. The definitions above for triads have therefore been defined here for convenience, and do not align to any official Axon terminology. It may also be possible that there are more complex combinations of wires (specifically when 4 or more wires are deployed into the same subject) that may occur but which were not identifiable in this work due to the relatively restricted measurements of relative frequency and timing of the pulses in each wire. It is recommended that discussing these findings with Axon would be the quickest way to assess the accuracy of the 'triads' understanding of the T10 energisation process.

	No wire deployed
	Wire deployed, no current
7	Wire deployed, current present (current directed from the handle to the target). Where a pulse count is available as an approximate frequency measure, it is included as text.
5	Wire deployed, current present (current directed from the target to the handle). Where a pulse count is available as an approximate frequency measure, it is included as text.
±	Wire deployed, current present (direction switches)

Table 43: Key for the following tables of simultaneous probe energisation testing results.

As noted in the Table 43 caption, for some measurements a rough estimate of pulse frequency was taken by counting the number of peaks shown on the oscilloscope display (which was set at a fixed time duration throughout the testing), and this number is shown on the corresponding measurement where available.

Note also that although the frequency of the peaks varied, the amplitude of the peak (i.e. the amount of charge transferred) was not observed to change noticeably.

A key assumption in the methodology was that repeatably energising the device to measure one wire each time would produce the same results as measuring all wires simultaneously – i.e. that the device would not change which wires were energised between energisations if there was no change in the physical circumstances of the probes or targets. This was assessed during testing by taking repeat measurements during several of the engagements. As shown in the tables below, in all cases the repeat measurements produced the same results, giving a reasonable confidence that the single-wire measurement approach used here accurately measures the probe energisation (noting again that Chapter 14 provides an improved methodology and associated results that should be considered when interpreting the following).

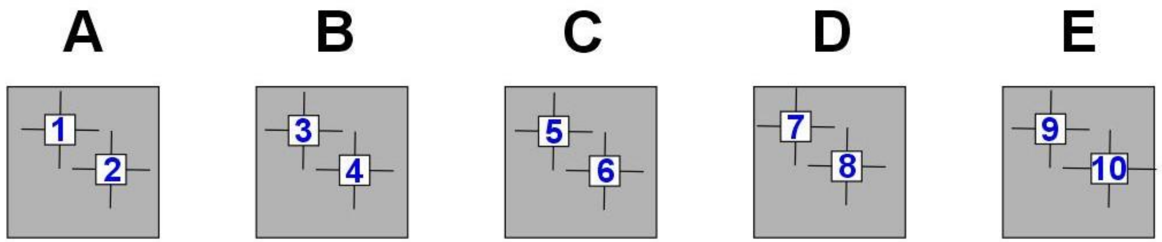


Figure 63: Target setup, and probe placement and numbering, for Engagement 1 – simulating the sequential engagement of five separate subjects.

Measurement Number	Event	Energisation Status (by Wire)										Notes / Interpretation	Total Probes Deployed	Total Probes Energised	Separate Subjects w/ 2+ Probes	Energised Subjects
		1	2	3	4	5	6	7	8	9	10					
1	Shot 1 deployed											No energisation possible	1	0	0	0
2	Shot 2 deployed	7	7									1 pair (normal frequency)	2	2	1	1
3	Shot 3 deployed	7	7									1 pair (normal frequency)	3	2	1	1
4	Shot 4 deployed	7	7	7	7							2 pairs (normal frequency)	4	4	2	2
5	Shot 5 deployed	7	7	7	7							2 pairs (normal frequency)	5	4	2	2
6	Shot 6 deployed	3	3	5	5	3	3					3 pairs (all reduced frequency)	6	6	3	3
7	Shot 7 deployed	3	3	3	3	7	7					3 pairs (1 normal frequency, 1 reduced frequency)	7	6	3	3
8	Shot 8 deployed	3	3	3	3	7	7	7	7			4 pairs (2 normal, 2 reduced frequency)	8	8	4	4
9	Shot 9 deployed			3	3	7	7	3	3			3 pairs (1 normal frequency, 1 reduced frequency)	9	6	4	3
10	Shot 10 deployed					7	7	3	3	3	3	3 pairs (1 normal frequency, 1 reduced frequency)	10	6	5	3
10.1	No change					7	7	3	3	3	3	3 pairs (1 normal frequency, 1 reduced frequency) - stable for repeat measurements	10	6	5	3
10.2	No change					7	7	3	3	3	3	3 pairs (1 normal frequency, 1 reduced frequency) - stable for repeat measurements	10	6	5	3
Separated Targets/Subjects:		Target A		Target B		Target C		Target D		Target E						

Table 44: Probe energisation data for Engagement 1 – simulating the sequential engagement of five separate subjects.

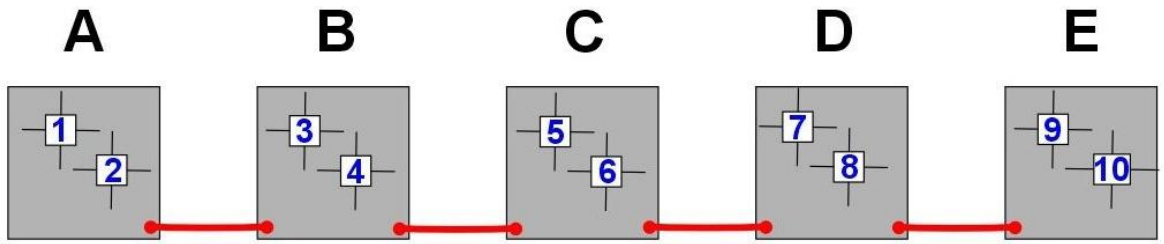


Figure 64: Target setup, and probe placement and numbering, for Engagement 2 – simulates engagement of a single subject with ten shots.

Measurement Number	Event	Energisation Status (by Wire)										Notes / Interpretation	Total Probes Deployed	Total Probes Energised	Separate Subjects w/ 2+ Probes	Energised Subjects
		1	2	3	4	5	6	7	8	9	10					
1	Shot 1 deployed											No energisation possible	1	0	0	0
2	Shot 2 deployed											1 pair	2	2	1	1
3	Shot 3 deployed											1 pair	3	2	1	1
4	Shot 4 deployed											2 pairs	4	4	1	1
5	Shot 5 deployed											1 pair	5	2	1	1
6	Shot 6 deployed						±					1 pair, 1 bidirectional triad	6	5	1	1
7	Shot 7 deployed						±					1 pair, 1 bidirectional triad	7	5	1	1
8	Shot 8 deployed					±						1 pair, 1 bidirectional triad	8	5	1	1
9	Shot 9 deployed									±		1 bidirectional triad, 1 negative triad	9	6	1	1
10	Shot 10 deployed									±	±	2 bidirectional triads	10	6	1	1
10.1	No change									±	±	2 bidirectional triads - stable for repeat measurements	10	6	1	1
10.2	No change									±	±	2 bidirectional triads - stable for repeat measurements	10	6	1	1
10.3	No change									±	±	2 bidirectional triads - stable for repeat measurements	10	6	1	1
10.4	No change									±	±	2 bidirectional triads - stable for repeat measurements	10	6	1	1
11	Lines 5 to 10 cut											2 pairs	4	4	1	1
11.1	No change											2 pairs - stable for repeat measurements	4	4	1	1
11.2	No change											2 pairs - stable for repeat measurements	4	4	1	1
12	Lines 3 to 4 cut											1 pair	2	2	1	1
12.1	No change											1 pair - stable for repeat measurements	2	2	1	1
12.2	No change											1 pair - stable for repeat measurements	2	2	1	1
12.3	No change											1 pair - stable for repeat measurements	2	2	1	1
12.4	No change											1 pair - stable for repeat measurements	2	2	1	1
Separated Targets/Subjects:		All Targets Electrically Connected to Form 1 Subject														

Table 45: Probe energisation data for Engagement 2 – simulates the engagement of a single subject with all ten shots.

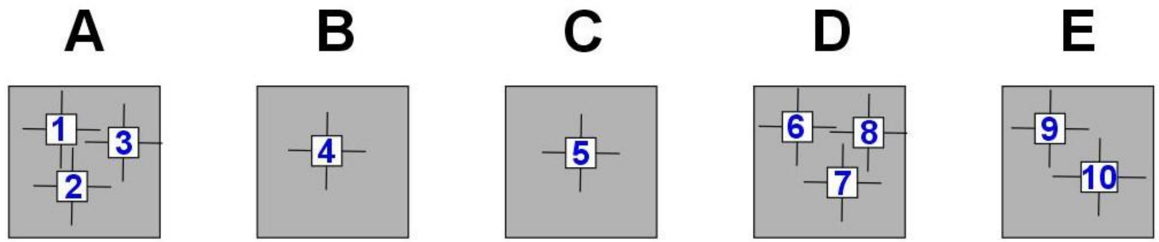


Figure 65: Target setup, and probe placement and numbering, for Engagement 3 – simulates the sequential engagement of five separate subjects, with some receiving one shot (effectively a miss), some two, and some three shots.

Measurement Number	Event	Energisation Status (by Wire)										Notes / Interpretation	Total Probes Deployed	Total Probes Energised	Separate Subjects w/ 2+ Probes	Energised Subjects
		1	2	3	4	5	6	7	8	9	10					
1	Shot 1 deployed											-	1	0	0	0
2	Shot 2 deployed											1 pair	2	2	1	1
3	Shot 3 deployed		±									1 bidirectional triad	3	3	1	1
4	Shot 4 deployed		±									1 bidirectional triad	4	3	1	1
5	Shot 5 deployed		±									1 bidirectional triad	5	3	1	1
6	Shot 6 deployed		±									1 bidirectional triad	6	3	1	1
7	Shot 7 deployed		±									1 bidirectional triad, 1 pair	7	5	2	2
8	Shot 8 deployed		±					±				2 bidirectional triads	8	6	2	2
9	Shot 9 deployed		±					±				2 bidirectional triads	9	6	2	2
10	Shot 10 deployed	6	3	3			6	3	3	7	7	1 positive triad, 1 negative triad, 1 pair (normal frequency)	10	8	3	3
10.1	No change	6	3	3			6	3	3	7	7	1 positive triad, 1 negative triad, 1 pair (normal frequency) - stable for repeat measurements	10	8	3	3
10.2	No change	6	3	3			6	3	3	7	7	1 positive triad, 1 negative triad, 1 pair (normal frequency) - stable for repeat measurements	10	8	3	3
10.3	No change	6	3	3			6	3	3	7	7	1 positive triad, 1 negative triad, 1 pair (normal frequency) - stable for repeat measurements	10	8	3	3
Separated Targets/Subjects:		A			B	C	D			E						

Table 46: Probe energisation data for Engagement 3 – simulates the sequential engagement of five separate subjects, with some receiving one shot (effectively a miss), some two, and some three shots.

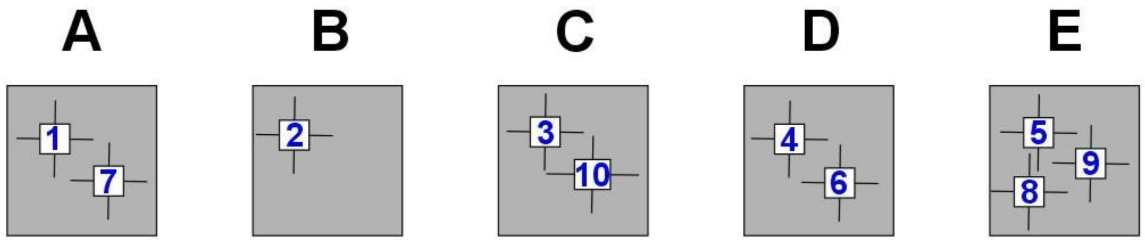


Figure 66: Target setup, and Probe placement and numbering, for Engagement 4a – simulates the sequential engagement of five separate subjects, with some receiving one shot (effectively a miss), some two, and some three shots, with a different ordering and placement than Engagement 3.

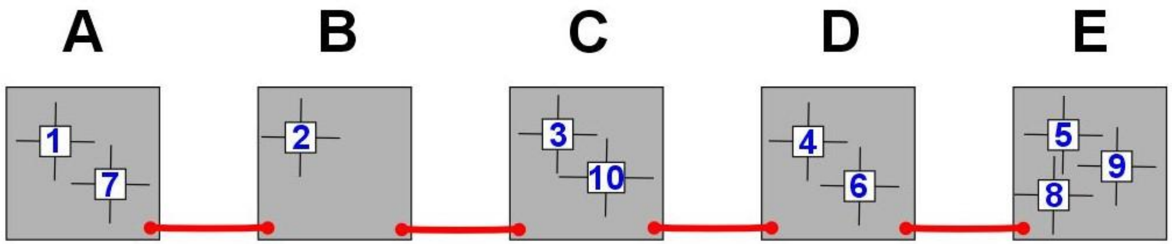


Figure 67: Target setup, and Probe placement and numbering, for Engagement 4b – the same arrangement as Engagement 4a except with the targets electrically connected in order to understand how the device changes its energisation decisions when the inter-probe resistances change significantly during an encounter.

Measurement Number	Event	Energisation Status (by Wire)										Notes / Interpretation	Total Probes Deployed	Total Probes Energised	Separate Subjects w/ 2+ Probes	Energised Subjects
		1	2	3	4	5	6	7	8	9	10					
1	Shot 1 deployed											No connections possible.	1	0	0	0
2	Shot 2 deployed											No connections possible.	2	0	0	0
3	Shot 3 deployed											No connections possible.	3	0	0	0
4	Shot 4 deployed											No connections possible.	4	0	0	0
5	Shot 5 deployed											No connections possible.	5	0	0	0
6	Shot 6 deployed				7		7					1 pair (normal frequency)	6	2	1	1
7	Shot 7 deployed	3			3		3	3				2 pairs (reduced frequency)	7	4	2	2
8	Shot 8 deployed	6			3	5	3	6	5			3 pairs (reduced frequency)	8	6	3	3
9	Shot 9 deployed	3			3	6	3	3	3	3		2 pairs (reduced frequency), one negative triad	9	7	3	3
10	Shot 10 deployed	3		3	3	3	3	3		3	3	4 pairs (reduced frequency)	10	8	4	4
10.1	No change	3		3	3	3	3	3		3	3		10	8	4	4
Separated Targets/Subjects:		A	B	C	D	E	D	A	E	E	C					
11	Targets connected together	3	6		3		3	3		3	3	2 pairs (reduced frequency), 1 positive triad	10	7	1	1
11.1	No change	3	6		3		3	3		3	3	2 pairs (reduced frequency), 1 positive triad - stable for repeat measurements	10	7	1	1
11.2	No change	3	6		3		3	3		3	3	2 pairs (reduced frequency), 1 positive triad - stable for repeat measurements	10	7	1	1
Separated Targets/Subjects:		All Targets Electrically Connected to Form 1 Subject														

Table 47: Probe energisation data for Engagement 4 – simulates the sequential engagement of five separate subjects, with some receiving one shot (effectively a miss), some two, and some three shots, with a different ordering and placement than Engagement 3.

Conclusions

The main aim of this testing was to establish the number of probes that could be simultaneously energised. The testing demonstrated that, for the choice of targets, up to 8 probes may be energised, enabling up to 4 targets to be energised simultaneously. The methodology was, however, limited by measuring probes individually rather than simultaneously, and using targets without resistive loads. An improved methodology was subsequently developed and implemented, as described in Chapter 14, which supersedes the contents of this appendix, which is provided only for reference and completeness.

Appendix M Issues

Table 48 contains a list of the issues observed during testing that are not included in the other tests in this report. Following the table, details on the force measurements of the trigger are provided.

Note that where the number of shots performed by a particular component at the time of an issue occurring is reported, this is a lower estimate based on the number of recorded shots throughout testing – it does not include any shots taken in setup work (up to 30 shots were used to initially identify optimal testing methods and conditions, before testing commenced).

Note also that these observations and statistics are based on the first set of testing (conducted from September to December 2024). Later testing (between February and May 2025, which involved the deployment of an additional 358 duty cartridges across 4 new handles) did not focus on documenting issues so are not included, but did not observe any significant issues with the hardware that affected the testing.

Summary			Issue description			Shot ID
Name	Type of issue	Date	Initial issue	Steps taken	Conclusion	
Wire failure	Deployment failure	03/10/2024	The wire failed to deploy. The probe bounced after impact, leaving a longitudinal depression on the target paper.	The faulty cartridge (serial number: T2504D71K) and probe have been retained for further analysis.	Appeared to be an issue with the wire in the cartridge. It is believed that the non-tethered full-weight probe was ballistically unstable and yawed or tumbled in flight.	019
Cartridge deployment failure	Deployment failure	04/10/2024	After pulling the trigger, no cartridge was deployed, but the weapon pulsed for 5 seconds and the CID showed a cartridge as fired (it showed 3 cartridges having been deployed, but only two had actually deployed).	The weapon was put in SAFE mode, and a function test carried out - results: battery 11%; CID showed a green tick with 3 cartridges fired; no errors showing. Testing continued, and after a further 7 shots, all cartridges except bay 8 had deployed, but the CID indicated no cartridge present. A function test was conducted - results: battery 0%; no errors. A new cartridge (serial number: T2504D6XA) was placed in bay 8 for shot 073/B. The cartridge deployed and the results recorded as normal. A function test was conducted - results: battery 0%; no errors. The faulty cartridge has been retained for further analysis. Note that the battery indication of '0%' is not relevant to this failure. Tests had shown that at an indicated '0%' the device still operates normally.	Appeared to be an issue with the specific cartridge - subsequent cartridges operated as normal.	073
Laser sight vertical stripe	Minor quality assurance	06/10/2024	One of six handles (serial number: T19E6287) used for laser power testing produced a vertical line as well as a dot from the laser sight.	The laser window was cleaned with isopropyl alcohol, which had no effect.	The weapon is fully useable as the intensity of the dot remains adequate. This finding is included only for interest, and as a possible quality control issue.	-
Multiple ID bands	Minor quality assurance	07/10/2024	A HALT cartridge (serial number: T26501R62) had two blue ID bands installed, preventing loading into the magazine.	One band was removed by hand and discarded.	Assessed to be a minor quality control issue.	133
Cartridge deployment failure	Deployment failure	08/10/2024	The HALT cartridge (serial number: T26501R6R) failed to fire upon pulling the trigger. The CID showed the bay 7 indicator flashing red.	The handle was put in SAFE mode then re-armed. The cartridge then fired (recorded as shot 160/B) despite bay 7 still flashing red on CID. A function test showed a green check mark and a red bay 7. When the magazine had been emptied by subsequent shots, it was removed then re-inserted into the handle, and bay 7 no longer showed as red on the CID.	Appeared to be an issue with the physical connection between the cartridge and handle (possibly the interposer bucket).	160

Summary			Issue description			Shot ID
Name	Type of issue	Date	Initial issue	Steps taken	Conclusion	
Cartridge deployment failure	Deployment failure	10/10/2024	A cartridge (serial number: T2504D6W3) loaded into bay 4 was not detected by the handle's software after running a function test - bay 4 showed as empty.	The magazine (serial number: T22008MF2) was removed and re-inserted into the handle; bay 4 still showed as empty. The cartridges in bay 4 was swapped with the cartridge in bay 1 (serial number: T2504D6V4); bay 4 still showed as empty after a function test. The device was put in SAFE mode then re-armed; the CID showed 9 loaded bays. The connection pin spring for bay 4 was checked and observed to be functioning normally. The cartridges in bays 1 and 4 were swapped back, then the bay 4 cartridge was replaced with a new cartridge; all bays then showed as loaded. The original bay 4 cartridge was placed back into bay 4; bay 4 showed as empty again. The cartridge was retained for further investigation.	Appeared to be an issue with the particular cartridge, preventing it being deployed.	261 to 270
Interposer bucket	Expected degradation	11/10/2024	Bay 1 was shown as empty on the CID after a function test, despite a full magazine.	Inspecting the interposer bucket on the handle (serial number: T19E24561) revealed that the centre pogo pin on the bay 1 connector was depressed - attempts to release the pin were unsuccessful.The interposer bucket was replaced with an interposer bucket from an unused handle (serial number: T19E24560), and all bays functioned and fired correctly.	Issue with the interposer bucket having a faulty pin, likely due to expected wear after having been used for over 310 shots (the interposer bucket is a consumable part with an Axon-stated lifetime of 150 shots).	331
Multiple ID bands	Minor quality assurance	17/10/2024	A HALT cartridge (serial number: T26501R8F) had two blue ID bands installed, preventing loading into the magazine.	One band was removed by hand and discarded.	Assessed to be a minor quality control issue.	225
Trigger sensitivity	Deployment failure	17/10/2024	The trigger on a handle (serial number: T19E24561) did not respond consistently to a light trigger pull - this began after over 380 shots.	The method of pulling the trigger was changed from a light pull to a firmer pull to ensure reliable firing. This worked consistently, except for shots 386 and 393 (at which point the handle had been used for over 460 shots), for which a double pull on the trigger was required to fire the cartridges (see below).	Appeared that internal wear and tear after over 380 shots from the same handle caused the second stage trigger feel to change. The handle continued to operate and, in the operator's initial assessment, this slight observed change in characteristics would not affect usability in the field.	238 & 243

Summary			Issue description			Shot ID
Name	Type of issue	Date	Initial issue	Steps taken	Conclusion	
Trigger sensitivity	Deployment failure	20/10/2024	The trigger on a handle (serial number: T19E24561) did not respond to a single trigger pull - this occurred after over 460 shots.	A double trigger pull was used to deploy the cartridges.	This is a continuation of the apparent internal wear and tear that alters the trigger sensitivity.	386 & 393
Cartridge deployment failure	Deployment failure	25/10/2024	The cartridge failed to fire.	The cartridge was retained for further investigation.	Assessed to be a faulty cartridge.	691
Complete handle failure	Deployment failure	28/10/2024	The CID display showed no cartridges loaded, despite the handle (serial number: T19E24561) having been loaded with 10 cartridges and used to successfully fire 4 of them.	A function test was run, with no errors raised, then the CID went blank. A trigger pull did not fire the next shot. The magazine (serial number: T22008MF2) was swapped for another (serial number: T22008N4V), and again the CID showed no cartridges loaded and then went blank. A function test showed no errors, but a trigger pull did not fire the next shot. The original magazine was placed into a different handle (serial number: T19E24572) and operated as normal - the CID displayed all 6 cartridges, and all were fired successfully.	The handle failed and was unable to be used. The cause is presumed to be wear and tear after over 530 shots.	865
Cartridge deployment failure	Deployment failure	31/10/2024	The cartridge was shown as red on the CID and failed to deploy.	The cartridge was removed then re-seated, after which it deployed successfully.	Appeared to be an issue with the physical connection between the cartridge and handle (possibly the interposer bucket).	736

Table 48: A list of issues encountered with the T10 hardware and software during testing. The issues are shown in chronological order, and the Shot ID is included to allow cross-referencing of timings and hardware details from Appendix A. Note that measurements were not taken in the order of Shot ID.

Trigger force measurements

The method used to measure the force required to activate the trigger was to use a force gauge to engage the trigger up to the point that it discharged and record the maximum force required. The setup is shown in Figure 68 below, and measurement results are in Table 49 for three different handles with varying levels of use.

Device & status	Force measurements		
T10 – heavily used (over 530 shots previously fired)	905g	975g	955g
T10 – used (~250 shots previously fired)	>1kg	>1kg	975g
T10 – brand new (no previous shots fired)	975g	975g	915g

Table 49: Trigger force measurement results (1kg was the limit of the force gauge).

Within the measurement-to-measurement variation, all the handles appear similar with no significant trends. An experienced operator, however, reported that, despite this, there is a notable difference to how the trigger feels – specifically, how progressive it is up to the point of discharge. So although the measurable force was not noticeably changed, there was a noticeable difference for an operator.

Figure 68: Testing setup for measuring the force required to pull the trigger for different handles with varying levels of use.

Appendix N Mapping of this report to the Technical Test Plan

The testing that this report documents was based on two Technical Test Plans agreed with the Home Office – one for the majority of testing[29], and a second test plan for the subsequent additional testing.[30] How the contents of this report maps against the tests listed in the Technical Test Plans is shown in Table 50.

Content of this report	Content of the Technical Test Plans	Notes
Chapter 2: Kinetics: Accuracy	Test 1: Serials 1 to 8	
Chapter 3: Kinetics: Accuracy – Clamped vs hand-fired	Test 10	
Chapter 4: Kinetics: Training probe behaviour	Test 3 (based on the data from Test 1)	
Chapter 5: Kinetics: Absolute maximum range	Test 1: Serial 9	
Chapter 6: Kinetics: Mass, velocity, momentum & kinetic energy	Test 1: Serials 10 to 13	Additional velocity data was also taken at 7.6m to allow closer interpolation of results.
Chapter 7: Skin penetration	Test 2	Augmented by testing on the compressibility of the impact absorber.
Chapter 8: Clothing penetration	Test 6 & 10	
Chapter 9: Skull fracture/penetration	Test 7	
Chapter 10: Robustness	Test 8	
Chapter 11: Sound levels	Test 4	The Technical Test Plan incorrectly said to measure the X2 connectivity alarm – this was corrected in testing to be the T10 connection alert.
Chapter 12: Laser power	Test 5	
Chapter 13: Electrical output	Test 9	Augmented by non-Axon prescribed testing methodology.

Table 50: Mapping of the contents of this report against the tests listed in the original Technical Test Plan and additional Technical Testing Plan.

[29] Document *MIQ-24-0007-D - Technical Test Plan*
[30] Document *MIQ-25-0018-D - Technical Test Plan - Additional Testing*

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