Defence Research and Development Canada | Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Aged Armour Testing Study

Report on Results of 150 Samples

Christopher Withnall

Prepared By:

Biokinetics and Associates Ltd.
2470 Don Reid Drive
Ottawa, Ontario, K1H 1E1

Biokinetics Report No.: R09-28 (rev 2)
Project Leader: Christopher Withnall (613) 736-0384
DRDC Contract Number: W7701-061933/001/QCL
Task Authorization No.12 (PO 84402NG)
Contract Scientific Authority: Daniel Bourget (418) 844-4000 Ext.: 4228

Defence R&D Canada – Valcartier
Contract Report
DRDC Valcartier CR 2010-117
May 2010

Canada

Aged Armour Testing Study

Report on Results of 150 Samples

Christopher Withnall
Biokinetics and Associates Ltd.
2470 Don Reid Drive
Ottawa, Ontario, K1H 1E1

Biokinetics Report No.: R09-28 (rev 2)
Project Leader: Christopher Withnall (613) 736-0384
Contract No.: W7701-061933/001/QCL
Task Authorization No.12 (PO 84402NG)
Scientific Authority: Daniel Bourget (418) 844-4000

DEFENCE R&D DÉFENSE

Defence R&D Canada - Valcartier

DRDC Valcartier CR 2010-117

May 2010

Aged Armour Testing Study

Report on Results of 150 Samples

Christopher Withnall

Biokinetics and Associates Ltd.

2470 Don Reid Drive

Ottawa, Ontario, K1H 1E1

Biokinetics Report No.: R09-28

Project Leader: Christopher Withnall (613) 736-0384

Contract No.: W7701-061933/001/QCL

Task Authorization No.: Task 12 (PO 84402NG)

Scientific Authority: Daniel Bourget (418) 844-4000

Defence R&D Canada - Valcartier

DRDC Valcartier CR 2010-117

May 2010

This report constitutes the final deliverable for Public Works and Government Services, Contract No. W7701-061933/001/QCL, Task No. 12 (PO 84402NG). The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of Defence Research and Development Canada Valcartier.

Authors

Christopher Withnall, P.Eng.
Biokinetics and Associates Ltd.

Laurin Garland, P.Eng.
Vernac Ltd.

Publication approved by

First Last, Title
Defence Research and Development Canada - Valcartier

Abstract

Ballistic testing has been carried out on 150 samples of used soft body armour ranging from 2-17 years old submitted from twenty different Canadian police forces. The aim of this program is to investigate the performance of aged body armour to provide a scientific basis for an Aged Armour Replacement Protocol. Currently the replacement policies for body armour in various police forces range from five years to indefinite service.

Ballistic tests were carried out according to an abbreviated version of the National Institute of Justice standard to which a bullet resistant panel was originally certified. Eighteeen panels allowed bullet perforation (12%) under the NIJ certification protocol of which three panels (2%) failed below the absolute minimum speed as indicated on the stitched label. However, if these results are considered in terms of the most recent NIJ 0101.06 standard where a degradation margin is allowed, they remain acceptable.

Products displaying good performance at 13-17 years and others failing at 3 years suggests that the initial design and construction of body armour might play a greater role in bullet resistance than simple ageing.

Résumé

Des tests balistiques ont été effectués sur 150 gilets pare-balles usagés soumis par 20 différents corps policier canadiens. Le nombre d’année de service des vestes pare-balles fournies variait entre 2 et 17 ans. Le but de ce programme d’essai était d’étudier la performance des gilets pare-balles usagés afin de fournir une base scientifique pour un futur Protocole de Remplacement de Gilets Pare-Balles Usagés. Actuellement les politiques de remplacement de gilets pare-balles des différents corps policier varient de 5 ans à un nombre indéfini d’années de service.

Les tests balistiques ont été effectués selon une version abrégée du standard défini par l’Institut Nationale de Justice (NIJ) américain selon lequel les gilets pare-balles étaient originalement certifiés. Des balles ont pénétré complètement dix-huit vestes (12%) tel que défini par le protocole de certification NIJ. De ce nombre, trois (2%) ont échoué à une vitesse d’impact inférieur au minimum absolue indiquée sur le label d'origine de la veste. Toutefois, si ces résultats sont considérés en fonction du récent standard NIJ

0101.06 où une certaine de dégradation est permise, ils demeurent acceptables.

De bonnes performances offertes par des gilets pare-balles ayant de 13 à 17 années de service contre des échecs pour des produits âgés de seulement 3 ans suggèrent que la conception initiale et la construction des gilets pare-balles peuvent jouer un plus grand rôle dans la résistance à la pénétration que le simple vieillissement.

Executive Summary

Ballistic soft body armour is worn by all Canadian police officers, however its continued bullet resistance as it ages over time is not well understood. Under sponsorship of the Canadian Police Research Centre and with the support of the Canadian Association of Chiefs of Police and the Ontario Association of Chiefs of Police an investigation into the performance of aged body armour has been undertaken. Samples of decommissioned body armour were solicited from Canadian police forces and tested according to an abbreviated version of the National Institute of Justice protocol to which they were originally certified. Twenty two forces supplied 159 sets of NIJ level-II body armour, of which 150 were subjected to laboratory ballistic tests at the Biokinetics and Associates facility. Several key pieces of information relating to service history and usage were also requested in an effort to correlate environmental factors with ballistic performance, but unfortunately such information was mostly unavailable.

NIJ level-II protocol stipulates the firing of both .357 magnum JSP and 9 mm FMJ within specific speed ranges called “fair”. A product must stop the round within this fair speed range to be certified, and the garment typically specifies its minimum protection level on the label as the low end of this fair range. Perforations at fair speed or lower with .357 rounds occurred in 18 panels (12%), three of which (2%) were at speeds below the minimum allowable. However, if these results are considered in terms of the most recent NIJ 0101.06 standard where a degradation margin is allowed, they remain acceptable. There were no perforations with 9 mm rounds at fair speed or lower. Elevated speed testing was also conducted to investigate the early stages of degradation but the results suggested this was not a feasible approach.

Our tested panels ranged from 2 to 17 years old. Results suggested that the age of a panel was less of a factor in its aged performance than was its initial design and construction. Panels 13-17 years old performed well. The highest failure rate was among 6-7 year old panels. Perforations occurred on panels as young as 3-years. In the limited data set thus far, age did not appear to correlate with ballistic performance. However, these results are preliminary and the samples upon which these observations were made are not necessarily representative of current in-service armour.

Police forces continue to submit decommissioned products to be included in a following series of testing. In further tests of aged body it is recommended focusing the target speeds at the low end of the fair speed range in an effort to detect truly non-conforming products.

Table of Contents

List of Tables

List of Figures

1. Introduction

A question exists regarding the "safe" life expectancy of ballistic body armour worn by Canadian police officers. There is currently no accepted practice to determine the proper replacement interval for this essential item. Replacement policies range from five years (to coincide with the typical manufacturer's workmanship warranty) to indefinite service life, replacing a vest only after obvious physical damage, a sizing change requirement, or an officer's departure from service. It is considered that some form of sample selection and proper laboratory testing of in-use armour will ultimately be necessary to indicate when body armour has reached the end of its service life. However, the ballistic capability of aged armour is not well understood, so a testing program has been engaged to study the performance of retired armour from Canadian police forces.

This report details this testing program. The samples were supplied by police services across Canada from their stock of units retired from active service. This testing was carried out to support an initiative sponsored by the Canadian Police Research Centre (CPRC) to develop an Aged Armour Replacement Protocol

The development of the protocol was in response to a request to the CPRC from the Canadian Association of Chiefs of Police (CACP) "to investigate the issue of life expectancy of soft body armour with respect to issues including the manufacturer's warranty period and replacement time". A detailed report on the protocol development program will be prepared and submitted to CPRC in the near future.

In addition to the foregoing, the Ontario Association of Chiefs of Police (OACP) requested CPRC become involved in a research project to investigate "the degradation of ballistic armour material over time" by carrying out a three year program which would "test body armour in a consistent scientific manner". The OACP volunteered to assist where possible in arranging for the supply of aged armour from Ontario police services to use as test samples. This test program grew out of these two initiatives.

Biokinetics and Associates Ltd was contracted through DRDC Valcartier on behalf of the CPRC to secure and test 150 samples of aged soft body armour which had been retired from active duty with police services across Canada and to carry out appropriate ballistic tests to determine whether the performance of the armour had deteriorated with age. A subcontract was issued to Vernac Ltd to familiarize the police forces with this programme as well as to secure aged armour for testing and participate in the analysis of test data. Biokinetics and Vernac are herein referred to as the project team.

All ballistic testing was conducted at Biokinetics' facility in Ottawa, ON.

2. Armour Samples

2.1 Contact with Police Services

Contact was made with police services in a number of ways. CPRC had booths at the annual CACP Conference in Montreal (Aug 08) and the OnScene First Responders Conference in Regina (Sep 08). The project team made contact with many representatives from police services from across Canada by attending at the CPRC booths at these two shows. A briefer on the project was prepared and handed out to participants and contact information was obtained for those forces who agreed the initiative was worth supporting. The team received positive support for the initiative at these venues. The initial contacts were followed up in person and the supply of test samples was arranged where possible.

In addition, the Ontario Ministry of Community Safety and Correctional Services (MCSCS), in cooperation with the OACP and the Ontario Policing Standards Advisory Committee Body Armour Working Group, prepared an All Chiefs Bulletin asking for support for the program. This bulletin was distributed to all police chiefs in Ontario (Jan 09) and resulted in contact with numerous forces which had not been represented at the conferences and thus widened the pool for potential test samples. Again, all initial contacts were followed up in person by the project team.

Finally, contact had been made with a number of police services during the Phase I portion of the Aged Armour Protocol Development (CPRC Technical Report TR-06-2008). These services were contacted again to determine whether they had any armour which they could contribute to the test program.

Our interest was not in the armour carriers but only in the ballistic panels or shot packs which are inserted into pockets in the carriers both front and rear. By the end of testing, the team had received 159 samples of aged soft body armour with both front and rear ballistic panels for each from twenty two police services from across Canada.[1] They represented some of the largest police services in the country as well as some of the smallest. The project team

---

[1] Armour continued to arrive as testing progressed, with some armour deferred until the next phase of testing. At the time of this writing, armour continues to arrive from supporting police forces toward this next round effort.

wishes to thank these police services for donating this armour and taking the effort to retrieve, box and ship the armour samples. The response indicated a true interest in assisting the program.

The contributing police forces are listed in Table 1:

Table 1: Contributing police forces.

Province	**City/Region**
Alberta	Calgary
Nova Scotia	Halifax
Ontario	Brantford
	Brockville
	Chatham
	Cornwall Community
	Durham Regional
	Guelph
	Kingston
	London
	Niagara Regional
	Ontario Provincial
	Peel Regional
	Pembroke
	Perth
	St. Thomas
	Sudbury
	Toronto
	Waterloo Regional
	York Regional
Saskatchewan	Prince Albert
	Regina

Many other forces were supportive of the program but for various reasons had no armour available to contribute. However, they provided useful data on armour procurement and retirement practices and informed the development of the test protocol in that manner, for which we are very appreciative.[2]

2.2 Service Data on the Supplied Aged Armour

Originally it was felt that data on each supplied sample should be collected to allow possible correlation between any observed deterioration in armour performance during testing and some environmental factor such as type of service seen (foot patrol, bicycle patrol, marine duty, patrol car and so on). This was in consultation with the Office of Law Enforcement Standards (OLES, Gaithersburg MD) who has studied issues of heat, humidity and wear related to body armour service type and geographical region in the United States. To this end, the OACP created and had printed standardized labels for inclusion with test samples submitted by Ontario forces. It became evident, however, that this information would not be available since most of the armour samples had been with a service member through various types of operational service and could even have been re-issued to a different member or moved to a different force in some cases. For many of the samples the front and rear panels from an officer had come from different manufacturing batches and it was not possible to determine whether they had been together through their entire service period. This type of data is not regularly recorded and maintained by the contributing forces.

In the end, the relevant data available for all test samples included manufacturer, model, size, date of manufacture and manufacturing lot number, which are included on the manufacturer's labels affixed to the armour inserts.

Since date of retirement from service was not available in all cases, age for our purposes was defined as the time span from date of manufacture to date at testing. By this definition, the age of samples tested ranged from two to seventeen years.

2.3 Supplied Armour Ballistic Ratings

Manufacturer's labels on the samples indicated compliance to standards NIJ-0101.01, NIJ-0101.03, NIJ-0101.04 and the NIJ 2005 Interim Standard[3], with

---

[2] Some armour was received from additional police forces after the first 150 samples were tested, but before the writing of this report. Their contributions will be noted in future test reporting.

a number of samples indicating compliance to "NIJ-0101.03 (To Canadian Testing Procedures)"[4].

The few NIJ-0101.01 vests were NIJ Type I, and represented the oldest samples dating to the early 1990's. Unfortunately they required .22 and .38 spl projectiles of a particular grain that were not readily available at the time of testing, so they were set aside for possible future testing.

Otherwise, all samples were NIJ Type II, meant to protect against 9mm FMJ 124 gr and .357 magnum JSP 158 gr handgun rounds. Minimum speeds for the 9 mm were the same in both .03 and .04 compliant samples, at 358 m/s. The minimum requirements for the .357 magnum rounds differed slightly at 425 m/s for 0101.03 and 427 m/s for 0101.04 and NIJ 2005 compliant panels. These speeds were indicated on the manufacturer's labels affixed to the armour panels.

More discussion on these ballistic ratings will follow in Section 4.2.

2.4 Samples Inventory and Database

A database was created to inventory the pertinent information associated with each aged armour sample that was submitted.

Armour has been received from Canadian police forces typically as a pair of shot packs, without the carrier. In most cases, these are matched pairs as evidenced by size, manufacturer and manufacturing date. But occasionally, the front and back panels have been matched by size only and may be from different lots. The reasons behind this are not clear.

Nevertheless, for each pair of panels received, the front panel was logged in to the inventory database, identified by a sequential number, or ID tag. All information about the panel, including eventual test data, is referenced to the ID tag. The matching, or associated rear panel, was tagged with the same ID as the front, but followed by the letter B. Both front and rear panels have been

---

[3] Note that NIJ 2005 adopts the same test procedures and failure criteria as the 0101.04 standard.

[4] NIJ-0101.03 (To Canadian Testing Procedures) was explained by one manufacturer who we contacted to allow for the smoothing of the garment on the clay-backed ballistic testing surface between shots. Otherwise the garment might become puckered and disheveled after several shots, thus unduly influencing the test outcomes. Later versions of the standard specifically addressed this issue.

photographed, but only the front panel's information is logged in the database, since that is the only panel we tested at this time. Our philosophy is that the rear panel, being in most cases the same as the front in terms of age and usage history, will not offer a unique test data set. This philosophy may change in the future, and the rear panels may be tested as part of a future program.

As a cooperative effort with the OLES, it was originally intended that the rear panels might be sent to their labs for their ballistic tests and scientific materials testing. However, in the end this was not necessary, and only a sample coupon was sent from each tested panel. More discussion on this can be found in Section 3.6.

The information logged into the database for each front panel included the manufacturer, model, size and dimensions, the date and lot of manufacture, the performance standard and ballistic level, the police department, service history and where available the decommission date.

Later test data included the fired projectile, velocity, location, back face signature (BFS) and perforation (yes or no).

Photographs were taken front and back of each panel.

3. Test Procedure

3.1 Abbreviated NIJ Procedure

Standardized NIJ ballistic test procedures include a host of criteria related to size, shape, workmanship, labelling and ballistics. Ballistic tests include both Perforation – Backface Signature (P-BFS) and Ballistic Limit (BL) or V-50. V-50 is a statistical process whereby the speed at which a projectile is likely to perforate 50% of the time is discovered. This is generally found by an iterative convergence of speeds that do and do not perforate. A P-BFS, or V-proof test, checks that the panel can defeat a projectile at a given speed. This testing is repeated at oblique angles and after subjecting the garment to a water spray. V-proof is always a lower speed than V-50 for a given panel.

Of interest to this program were only V-proof tests. Although V-50 tests might have been interesting to observe degradation, we did not have access to the V-50 data when the armour was brand new for comparison. Therefore only V-proof testing was done to establish whether or not the armour continued to meet the designated standard for perforation resistance. Furthermore, the back face signature (BFS) was measured, which is the indent left in the flat clay backing block upon which NIJ ballistic tests are done. The limit is 44 mm for any projectile.

Only ambient testing was conducted, and all shots were straight on[5].

Another abbreviated process was the calibration of the clay backing material. NIJ mandates a check to ensure that the clay is of proper consistency. This is done by dropping a 1043g, 63.5mm diameter steel ball from a height of 2m. The resulting clay indentation must be 19 ± 2mm. The softness of the clay is adjusted by its temperature and clay blocks are typically soaked in a warming chamber prior to use. NIJ specifies a 5 position drop check, but for this testing we did an abbreviated one drop check in the centre of the block[6].

---

[5] No oblique shots were carried out. In our experience oblique shots pose a much lesser likelihood of perforation than straight on shots.

[6] Based on our experience with the ballistic clay backing material, a drop check at the block centre indicates proper clay consistency throughout as long as proper care has been taken in preparation of the material.

3.2 Firing Sequence

NIJ defines a primary and secondary projectile for level II panels. Three shots of the primary projectile form the NIJ "triangle" pattern on the panel, shown in Figure 1. A fourth primary projectile is shot between 1 and 2. A secondary projectile (shot 5) is fired on the line between shots 1 and 3, and again within the triangle (shot 6). The outer shots must not be closer than 75 mm to the outer edge, nor closer than 50 mm to each other. Additional shots may be necessary in the case of speeds that were not within the tolerance range, as long as the spacing criteria are met.

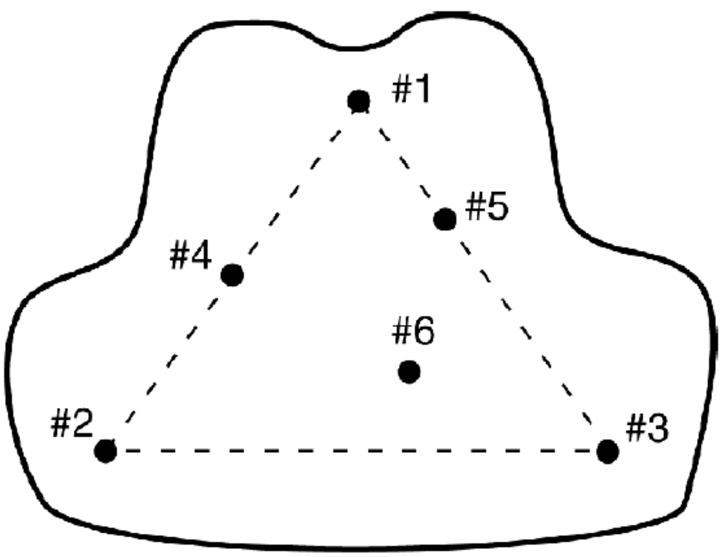

Figure 1: NIJ triangle.

For NIJ-0101.03 the primary projectile is the .357 and the secondary is the 9mm. However for the .04 version, these are reversed. After a few intial panels were tested of each, we confirmed by way of pentrations and back face signatures that the .357 was a more prominent threat, so for all further testing, .03 or .04 versions, we made the .357 the primary projectile.

3.3 Target Speeds and "Fair Velocity"

All testing in this series was of Type II soft body armour meant to meet either the NIJ-0101.03 or .04 standards. Because it is not possible to fire a bullet at a precise speed, the two versions of the standard allow an acceptable test speed range deemed "fair"[7]. A "fair hit" is one where the bullet was traveling within this acceptable speed range. Above the fair speed, a panel might still stop a bullet, but any perforation is not deemed a failure and a retest is done. When testing according to the standard a bullet moving within fair speed range and below must not perforate.

NIJ-0101.03 references a Minimum Required Bullet Velocity[8] of 425 m/s, and defines a fair hit as "an impact velocity no more than 50 ft (15 m) per second greater than the minimum required test velocity"[9]. This gives a .357 range of 425 to 440 m/s, but the defining velocity is the minimum 425m/s, not some higher reference number.

NIJ-0101.04 on the other hand defines a reference velocity plus or minus a tolerance. For .357 this is 436 ± 9.1 m/s or in other words from 427 to 445 m/s[10].

A similar distinction in the definition of fair speeds for 9 mm projectiles exists between the standards.

A summary of fair testing speeds is provided below in Table 2.

3.4 Overspeed Tests

Additionally, we introduced the concept of the 'overspeed' test. The idea was that if armour was indeed degrading over time, a failing V-proof test would only tell you that it had degraded to an unacceptable level. However, testing above the V-proof speed could act as an 'early warning' indicator.

We first set an overspeed of 10% for both rounds, but found that every .357 at this overspeed would perforate, but not any 9mm's. Consultation with the OLES revealed that this was not unexpected, and it was recommended to reduce the .357 overspeed to 5%, and increase the 9mm overspeed to 15%.

The test sequence and projectile speeds are provided below in Table 2.

---

[7] Note that rounds used in standardized testing are hand loaded according to precise recipes. Bullet speeds are carefully verified prior to testing to ensure that the desired speeds are achieved. Yet despite this, there remains some variability in the final projectile speed.

[8] Reference NIJ 0101.03 Table 1.

[9] Reference NIJ 0101.03 section 3.5.

[10] Reference NIJ 0101.04 Table 1.

Table 2: Standard and overspeed tests.

STANDARD	LEVEL	CARTRIDGE	PROJECTILE	SPEED RANGE (m/s)		SHOT NO.	*	ANGLE OF INCIDENCE	SHOT SPACING
NIJ 0101.03 (1987)	II	357 MAG	158 gr JSP	fair	425 - 440	1, 2, 3	BFS	0 degrees	75mm from edge
				+ 5%	446 - 462	4	P		
		9 mm	124 gr FMJ	fair	358 - 373	5	P		
				+ 15%	412 - 429	6	P		
NIJ 0101.04 (2000)		357 MAG	158 gr JSP	fair	427 - 445	1, 2, 3	BFS		50mm from previous shot
				+ 5%	448 - 467	4	P		
		9 mm	124 gr FMJ	fair	358 - 376	5	P		
				+ 15%	412 - 432	6	P		

*data recorded:
BFS = back face signature (44mm max)
P = penetration (yes or no)

3.5 Back Face Signature

Back face signature (BFS) refers to the depth of the depression in the clay backing material upon which the panel is positioned when fired upon. The clay is smoothed and planed level with the outer box frame before testing, and it is against this initial flat surface that the depth is referenced. In standard testing, 44 mm is the maximum allowable depth of indentation, even in cases where the projectile does not perforate. We measured BFS for the standard speed .357 projectiles, but not for the standard speed 9 mm. The 9 mm's were excluded because having lesser mass and speed they always created a lesser indentation than the .357's.

While the BFS bears some relation to injury risk in humans, it is projectile perforation that is of primary interest to this study. Although BFS is a requirement for new armour, it is generally accepted that aged armour will have "softened up" over time with repeated flexing in use and that an increased BFS measurement may not be cause for alarm[11].

3.6 Coupons Sent to OLES

The OLES has an interest in this test series in keeping with its research objectives of understanding the ageing behaviour of body armour materials. As part of a parallel Biokinetics project sponsored by the CPRC, a protocol to determine a suitable replacement interval for body armour is being developed, also being of interest to the OLES. In keeping with the spirit of cooperation for the greater good of policing in both Canada and the United States, and with the agreement of the CPRC, key scientists at the OLES made

[11] This is reflected in the details of NIJ's newest 0101.06 standard.

themselves available for consultation. Similarly, we have made available to the OLES samples of the ballistic fabrics from the tested panels.

The OLES plans to conduct analysis of the fibre properties from the aged armour panels, and use our ballistic test results data in reference to their findings. To this end, we sliced the bottom 50 mm from each front panel tested, labelled and bagged them and shipped them to the OLES for their analysis.

At the time of this writing their materials analysis was ongoing and is not reported in this document.

4. Results and Discussion

4.1 Summary of Test Results

Testing was done according to the projectile speeds defined in the test standard to which a particular panel was designed.

A summary is provided in the Table 3 below for the 150 front panels tested. With the .357 at standard speed, we experienced 24 perforations among 18 panels and 175 cases of BFS > 44mm among 105 panels. At .357 over-speed, there were 66 perforations among 63 panels. There were no 9mm failures at standard speed and only 4 at over-speed. Back face signature was not measured for 9mm rounds.

Because 9 mm failures were non-existent at standard speed, 9mm performance will not be discussed further in this report.

Table 3: Summary test results for 150 panels

Standard	Qty. Panels	Round	Panels Perforated			BFS>44mm
			slow	fair	over-speed	***
NIJ 0101.03*	136	.357	1	12	57	95
		9 mm	0	0	3	n/ a
NIJ 0101.04**	14	.357	2	3	6	10
		9 mm	0	0	1	n/ a

* includes "To Canadian Testing Procedures"

** includes NIJ 0101.05 which is functionally identical

*** fair speeds only

4.2 Fair Velocity Perforation vs. Minimum Protection Level

We must be cautious in distinguishing between a failure at fair velocity and failure of the panel to perform to the minimum speed indicated on the label.

Note that the claimed performance printed on the labels of NIJ-0101.03 panels indicates the minimum end of the allowable fair test velocity range, namely 425m/s for the .357 round. In only one case did we experience a .357 failure below the claimed minimum, which was a perforation failure at 417m/s. Note, however, since we tried to achieve bullet speeds within the fair range, we seldom experienced bullet speeds that were too slow.

NIJ-0101.04 panels do not specify a minimum projectile speed, only that the panel is certified to the standard. Only two NIJ-0101.04 panels experienced

.357 perforations at speeds below the minimum fair hit speed of 427m/s (which were at 419 m/s and 425 m/s).

For either .03 or .04 panels, we cannot say what number might have perforated at sub-standard speeds, because we did not direct our efforts there.

4.3 Perforation Risk vs. Projectile Velocity

The overall data set of .357 shots is illustrated below in Figure 2. It shows that there were shots in the fair range that both did perforate and did not perforate. Perforations are illustrated as dots at the 100% line, and stops are illustrated as dots on the 0% line. Similarly there were shots at elevated speeds that sometimes perforated and sometimes were stopped. Data points from shots that were inadvertently too slow or too fast are included here also.

Dichotomous data (either perforation or stop) with a general overlap as seen here can be generalized using binomial logistic regression. This generates a probablility function to relate the risk of perforation to the .357 projectile's speed. The equation takes the form of

$$p(x) = (1+exp(-B_0-B_1x))^{-1}$$

and using the SPSS® data analysis software for this dataset the step factor B_0 = 0.108 and the constant B_1 = -49.399. These factors are used to generate the logist risk curve in Figure 2.

The resulting logist risk curve suggests that the risk of perforation is approximately 3% at the low end of the fair velocity range, which the reader is reminded corresponds to the minimum performance indicated on the armour's stitched label.

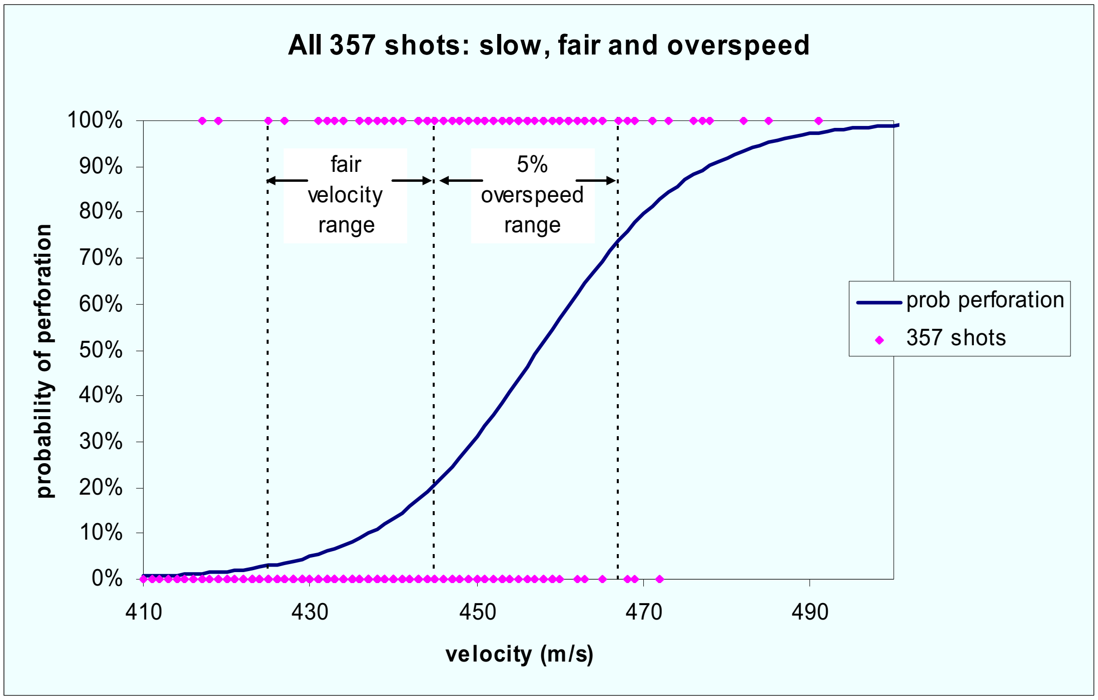

Figure 2: Probability of perforation versus velocity for .357 projectile.

4.4 Perforation Risk vs. Age of Armour

The armour tested in this series ranged from 2 to 17 years old. The age was calculated from the date of manufacture to the date of testing. The age number is presented similar to a person's age, not rounded up or down to the nearest whole number[12]. Perforations of .357 rounds at fair speed or lower were experienced in armour as young as 3 years and as old as 12 years.

The age distribution of the armour tested in this series is presented below in Figure 3. Also presented in this figure are the numbers of .357 perforations experienced among the age ranges. The highest failure rates were among the 6-year old (25%) and 7-year old (27%) armours. However, because this particular group of samples does not necessarily relate to makes and models of current in-service armour, these failure rates are not necessarily indicative of products in the field.

In this case a logist calculation relating perforation risk to age was not mathematially feasible due to the non-overlapping nature of the data

[12] For example armour that is 5 yrs - 11 mos old is classified as 5 years.

distribution. This suggests strongly that there was no clear correlation relating the age of the tested armour to its performance.

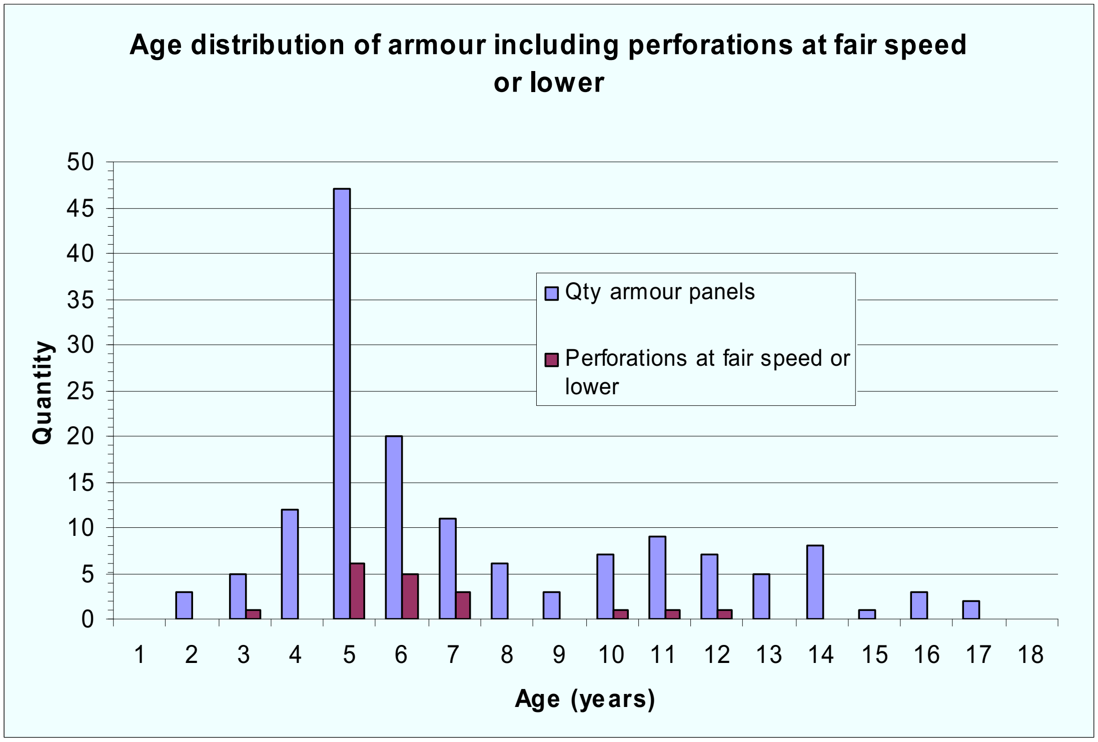

Figure 3: Age distribution of tested armour as well as the fair velocity (or lower) perforations.

4.5 Early Warning Overspeed Indicator

Of the 18 samples that allowed .357 perforations, 11 samples had corresponding .357 overspeed perforations (61%). However, 7 samples allowed .357 perforations at fair velocity and lower but *defeated* the overspeed rounds (39%). This implies that the result of an overspeed test is not a reliable indicator of fair speed performance. It furthur implies that the overspeed test is not effective as an "early warning indicator" of body armour degradation.

4.6 Ballistic Materials

Of the 18 samples that allowed .357 perforations at fair velocity or below, 11 comprised 22 layers of Kevlar fabric, 6 comprised 24 layers of Kevlar fabric and one comprised 27 layers of a hybrid Twaron-Kevlar composite.

4.7 Influence of Armour Size on Perforation

Not all sizes of armour must be submitted for certification. For example in 0101.03 only one size was required to pass testing as long as all further sizes were made of the same materials and layer count. Small sized armour would typically not be tested because the shot spacing would be closer making it more difficult to pass a 6-shot test sequence. While this is not necessarily a cause for alarm, given the low likelihood of a vest in service sustaining multiple shots, it did seem worth checking on the size range of the armours that sustained perforations.

Perforations at fair velocity or below occurred in front panels sized from 34 to 52 inches with a mean of 44.06 inches and standard deviation of 3.67 inches. There was no apparent correlation of perforation with size.

4.8 Initial Assumptions about Soft Body Armour

At the outset of this program, two key assumptions were made. The first was that all armour when new would exceed the minimum requirements of the test standard. The second was that armour's projectile resistance would deteriorate over time until at some point its performance was no longer acceptable.

While this second assumption is undoubtedly true for some point in time, the extent of degradation due to time and use alone remains poorly understood. We experienced 17 year old armour that performed fine and 3 year old armour that did not. There was insufficient information about an armour's service history, and none about its initial performance to arrive at any conclusion regarding degradation.

It is evident that not all armour is created equal, despite claiming compliance with a test standard. Soft body armour is not a precise product, meaning that equally built products might demonstrate slight differences in performance. It is encumbent upon a manufacturer to appreciate this and add some margin of safety to ensure that the band of variation remains above the minimum allowable performance.

However, this margin of safety in ballistic armour would typically be done by adding extra layers of fabric. This increases cost, increases weight and decreases wearer comfort. In a highly competive marketplace where products are often compared by price and specifications (the purchaser typically presuming of course that all perform equally well to the standard), there is little benefit to be gained in adding a substantial safety margin.

This in turn challenges our first assumption. Given a projectile velocity range for a fair shot, one would hope that a product would withstand the highest of that range. But it is readily conceivable that a product may never have actually proven itself at the high end of the fair velocity range, but rather the mid or low end. Given the inherent variability of a bullet's interaction with the armour, and the benefit of chance, an armour may have just barely passed its certification test. Thus production would begin of similar products that also might or might not pass another certification test.

In addition, without an adequate and continued Quality Control program, it is possible that an armour design which performed well during compliance testing would not perform equally well after a number of years of production.

In the aged armour testing in this program, we observed in many cases that armour which stopped a round sustained tearing of the last layers of fiber, indicating that it was at the cusp of failure. Even a modest 5% increase in .357 bullet speed was sufficient to cause perforation in 63 of 150 panels (42%).

Of course this does not necessarily mean that the product is safe or unsafe, just that it might not always be "certifiable" at any stage in its life. In only three cases did we experience perforations below the stated minimum speed stitched on the panel.

Future testing of aged armour will benefit more from exploring performance at this minimum speed rather than fully within the fair range and beyond.

4.9 Test Results Dissemination

At the outset of this program, it was agreed that individual police forces who supplied armour for testing would have access to their test results. To this end, summary test data from each contributing force has been tabulated and delivered to the CPRC for distribution back to that force. Specific test results from other forces have not been disclosed.

Similarly, the makes and models of tested garments have not been reported in this document. The overall intention is not to single out particular designs or manufacturers but rather to learn about aged armour from the field in general. However, this information remains available to the CPRC for future dissemination at its discretion.

4.10 Results Compared to NIJ-0101.06

To put the test results into context, this brief review of armour ballistic standards is offered. All of the armour tested was produced to meet standards developed by the Office of Law Enforcement Standards and issued by the National Institute of Justice (NIJ). Both of these organizations are based in the United States. The standard which governs ballistic performance of body armour is NIJ-0101. Various versions of this standard have been issued over the years, beginning with NIJ-0101.00 in 1972 and progressing through to the current version NIJ-0101.06 which was issued in July 2008. All of the armour tested was in compliance with the .03 and .04 versions of the standard.

At each revision of the standard a number of changes were made to reflect the additional knowledge which was gained in the subject area in the intervening years. One of the most notable additions to the .06 version was the concept of differing performance requirements for "new" and "conditioned" armour. The latter samples are conditioned by being tumbled for ten days in a controlled heat and humidity environment, as the standard says "…to subject test armors to conditions that are intended to provide some indication of the armor's ability to maintain ballistic performance after being exposed to conditions of heat, moisture, and mechanical wear." New armour is tested with bullet speeds which are elevated above expected street speeds. Armour which has been through the conditioning protocol is tested with reduced bullet speeds – less than the new armour but still greater than expected street speeds[13,14]. No previous version of the standard included such a performance requirement for conditioned armour.

During the testing of the first 150 armour samples, which was carried out in accordance with the .03 and .04 standards, we experienced some .357 shots which perforated the armour at bullet speeds below that which should have been stopped by the armour when new. However, the speeds were beyond expected performance for the "conditioned" armour in the .06 version of the standard and thus also above expected street speeds for the particular threat, the .357 magnum 10.2 g JSP.

Since there was no change for the new armour test speed for this threat from the .04 to the .06 version of the standard, we feel it is reasonable to review the test results on aged .03 and .04 compliant armour in comparison to the

---

[13] For conditioned armour NIJ 0101.06 defines a .357 fair velocity range of 399-417 m/s.

[14] Using Federal commercial ammunition, a street velocity for a .357 JSP bullet is reported to be 376 m/s in "Office of Technology Assessment, Police Body Armor Standards and Testing: Volume I, OTA-ISC-534 (Washington, DC: U.S. Government Printing Office, August 1992)" referencing Appendix A – The Origin of and Rationale for the NIJ Standard.

reduced performance level permitted for conditioned armour incorporated into the .06 standard. If we do this, we find the armour performed acceptably.

5. Conclusions

The following conclusions have been drawn as a result of this initial testing of 150 front panels of aged body armour. It is anticilpated that as more aged armour panels are tested in the future, some of these conclusions may change:

1. Of the 150 panels tested, eighteen (12%) failed in .357 perforation within the fair velocity range of certification testing. Only three panels (2%) failed to defeat a projectile below the stated minimum speed of protection. These armours were certified to the NIJ-0101.03 and .04 standards. But if these results are reviewed within the context of the new NIJ-0101.06 standard which allows a margin for age degradation, overall performance remains within current requirements.
2. Of the 150 panels tested, one hundred and five panels (70%) exceeded the minimum back face signature of 44mm although this is to be expected as armour stiffness is reduced after prolonged wear and should not cause serious concern.
3. Based on the particular makes, models and ages in this test series there is insufficient evidence to suggest that bullet resistance necessarily decreases substantially with age. More likely the aged performance of a particular armour is related to the quality and robustness of its initial design and materials and thus its initial performace when new.
4. The notion that testing at elevated speeds might provide some advance warning of deteriorating armour appears to be unfounded. We experienced many cases of armour panels that resisted over-speed perforation but still allowed standard speed perforation.
5. There is limited information available about the service history of aged armour from Canadian police forces. While it would be highly advantageous to study the environmental life cycle of aged armour in the field to determine the causation of any deteriorating performance, that information is simply not available.
6. Further testing of aged armour should continue with target speed centred on the minimum allowable speed. In this fashion, some shots will be too slow and some within the low end of the fair range. Any perforations in this regime will be a more solid indicator of an armour's

true aged performance as related to officer safety. The increased number of tests will also improve confidence in the observations.

7. The armour samples tested in this report were *not specifically selected* as representave samples of armour in continued use by police forces. This was armour already decommissioned from service and slated for disposal. We have no way of knowing how this tested armour relates to the population of armour currently being worn in active service.

DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address) Biokinetics and Associates 2470 Don reid Drive Ottawa, Ontario K1H 1E1	2. SECURITY CLASSIFICATION (Including special warning terms if applicable) Unclassified

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S, C, R or U)
Aged Armour Testing Study Report on Results of 150 Samples

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)
Withnall Christopher

5. DATE OF PUBLICATION (month and year)	6a. NO. OF PAGES	6b .NO. OF REFERENCES
May 2010	33	0

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)
Contractor Report

8. SPONSORING ACTIVITY (name and address)
Canadian Police Research Centre
Defence R&D Canada
222 Nepean St, Ottawa, On

9a. PROJECT OR GRANT NO. (Please specify whether project or grant)	9b. CONTRACT NO.
32BD01	W7701-8-4402

10a. ORIGINATOR'S DOCUMENT NUMBER	10b. OTHER DOCUMENT NOS
R09-28	N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

- ☒ Unlimited distribution
- ☐ Restricted to contractors in approved countries (specify)
- ☐ Restricted to Canadian contractors (with need-to-know)
- ☐ Restricted to Government (with need-to-know)
- ☐ Restricted to Defense departments
- ☐ Others

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)
Unlimited

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

Ballistic testing has been carried out on 150 samples of used soft body armour ranging from 2-17 years old submitted from twenty different Canadian police forces. The aim of this program is to investigate the performance of aged body armour to provide a scientific basis for an Aged Armour Replacement Protocol. Currently the replacement policies for body armour in various police forces range from five years to indefinite service. Ballistic tests were carried out according to an abbreviated version of the National Institute of Justice standard to which a bullet resistant panel was originally certified. Eighteeen panels allowed bullet perforation (12%) under the NIJ certification protocol of which three panels (2%) failed below the absolute minimum speed as indicated on the stitched label. However, if these results are considered in terms of the most recent NIJ 0101.06 standard where a degradation margin is allowed, they remain acceptable. Products displaying good performance at 13-17 years and others failing at 3 years suggests that the initial design and construction of body armour might play a greater role in bullet resistance than simple ageing.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Body armour, personal armour, aged armour, NIJ standard, Police, ballistic test protocol

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE R&D DÉFENSE

www.drdc-rddc.gc.ca