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**Investigation into the Performance of
Models KCW223 and KCW110 Body Armour Vests
Manufactured by Highmark Manufacturing Company Ltd.**

Report of Digby Dyke and Robert Knight, Lorica Research Ltd.

7th April 2004.

Published 1st September 2007

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This Report was prepared for the Home Office Police Scientific Development Branch (PSDB) and for Police customers of Highmark who had purchased body armour vests models number KCW223 and/or KCW110.

The Report is the work of the authors without editorial control or influence from any party.

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On 1st September 2007 circulation and copying restrictions were lifted by Digby Dyke.

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Foreword 1st September 2007

It is believed that over 50,000 KCW223 and KCW110 vests were manufactured and sold by Highmark Manufacturing Co Ltd. to over 30 Police Service customers in the UK during a three-year period from 2001 to 2004. Nearly all have been replaced, or upgraded with specially developed supplementary material insert packs. Some remain in service to this date, although the numbers that do are very small. Those that remain, as far as it is known, with or without having been upgraded with supplementary material insert packs, provide adequate protection for the level of threat to which the wearers are exposed.

Immediately after the discovery of the problems with these vests in 2003 there followed deep concern and activity at the Police Scientific Development Branch of the Home Office (then PSDB, now HOSDB) and among the Police Service customers of Highmark. The National Crime Squad, a customer of Highmark for the vests, removed 2000 officers from duty for a short while. Some Police Forces considered legal action against Highmark. None took it.

The investigation revealed many weaknesses in the police body armour supply chain beginning with the PSDB Body Armour Standards of the day. The Conclusions and Recommendations of this Report were accepted by the Home Office. Substantial revisions to Home Office Body Armour Standards for UK Police have since been made. *HOSDB Body Armour Standards for UK Police (2007)* is in its final draft and is about to be published.


Highmark Manufacturing Co Ltd. was dissolved in 2006.

In this published version of this Report the name of the former Highmark employee who was the “whistleblower” has been removed. He is referred to simply as, ‘Mr X’.

Other revisions are minor for the purpose of improving clarity of information.

This Report is published to help promote learning about body armour.


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In this Report the following abbreviated names are used for the parties:

‘Highmark’	Highmark Manufacturing Co Ltd 2 Moybrick Road Dromara BT25 2BT Co Down Northern Ireland
‘PSDB’	The Home Office Police Scientific Development Branch Sandridge St Albans HERTS AL4 9HQ
‘RMCS’	Cranfield University Royal Military College of Science Engineering Systems Department Shrivenham Swindon SN6 8LA
‘Verseidag’	Verseidag Indutex GmbH PO Box 2906 D-47729 Krefeld Germany
‘Du Pont’	Du Pont de Nemours International SA 2 chemin du pavilion PO Box 50 CH-1218 Le Grand-Saconnex Geneva
‘Lorica’	Lorica Research Limited PO Box 17 MALVERN WR14 2ZQ United Kingdom

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Foreword 7th April 2004

Key Basic Questions Answered.

This Report is a summary of technical and safety issues relating to an investigation into deficiencies in the performance of certain body armour vests manufactured by Highmark Manufacturing Co. Ltd. It does not deal with issues of a commercial or contractual nature, nor of liability.

A more detailed technical report is available for those who especially need it.

Readers may be anxious to have key basic questions answered before reading and digesting this Report. These questions may include the following:

Is the armour 'safe' to wear?

Yes, it is.

Is the armour deteriorating as time goes by?

No, it is not, beyond normal wear and tear.

In what way has the armour failed?


It has failed to pass a laboratory test but it continues to provide protection, albeit at a lower protection level than when qualified.

In what way has protection been reduced?

The armour continues to provide protection but the level of protection has been reduced. Specifically, protection from bullet perforation, behind-armour blunt trauma and knife-stab perforation has been reduced.

Does the armour continue to provide protection to any protection level of the PSDB Body Armour Standards?

The KCW223 armour, which was qualified to PSDB HG1 + KR2, now provides protection at the lower levels of PSDB HG1A + KR1.

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The KCW110 armour, which was qualified to HG1A + KRI, is now NOT providing protection to any current PSDB ballistic-resistant body armour standard, but continues to provide knife-stab protection to PSDB KRI as before.

Can the armour be corrected to return it to the originally intended protection levels?

Yes, by the insertion of a PSDB approved upgrade insert pack obtainable for self-fitting from Highmark Manufacturing Co Ltd.


Do the approved upgrade packs add weight, and do they affect comfort?

Comfort should not be affected, but the upgrade packs will add about 400 grams per vest and extra bulk of about 3mm.

Is there another option?

Yes, and this in some cases will perhaps be the first and best option - It is to re-visit your Risk Assessment to see whether the reduced levels of protection will be sufficient for your needs – in which case nothing more need be done.

NOTE: For police officers on unarmed general duties in low risk situations the recommended protection level of PSDB and ACPO is PSDB HG1A + KRI.

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Report of Digby Dyke and Robert Knight, Lorica Research Ltd.


7th April 2004.

Body armour vests models number KCW223 and KCW110 manufactured by Highmark containing the phenolic resin coated Kevlar® fabric known as AS299® in tests carried out between December 2003 and March 2004 showed a lower performance for knife-resistance and ballistic-resistance when compared with the performance of vests of the same model numbers qualified by PSDB in the year 2000.

Ballistic- and knife-resistance tests were carried out by Digby Dyke and Robert Knight, at Lorica Research, Malvern and Worcester, and at the PSDB approved test house at RMCS, Shrivenham, on behalf of Highmark, Strathclyde Police, Avon & Somerset Police and Dorset Police. Tests also were carried out by Celia Watson, Ian Harrod and Tricia Grognet at the PSDB approved test laboratory at RMCS on behalf of Highmark, PSDB, Strathclyde Police and Lancashire Police. Brian Kerr, Technical Manager at Highmark, conducted some stab-performance tests at Highmark's factory in Northern Ireland.

Except for minor occasional deviations tests were carried out in strict accordance with PSDB Body Armour Standards procedures.

John Croft of PSDB, Celia Watson of RMCS and Digby Dyke of Lorica Research, held conference at RMCS on 13th February 2004 to examine and compare the original qualified vests and many of the recently tested vests and test data. Celia Watson and John Croft concurred with the authors' observations of the vests examined at that meeting. John Croft gave an immediate instruction that Highmark should cease to supply body

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armour vests of the models in question to UK police forthwith. Digby Dyke immediately conveyed this instruction by telephone to Mr Ken Stamford, MD of Highmark.

How it was discovered that a problem existed.

In October 2003 at a meeting of members of the Police Federation held in Belfast a former employee of Highmark, Mr X, alleged to some delegates that a problem existed with the knife-stab-performance of Highmark's body armour. He followed-up the allegation with a message by email to at least one delegate who forwarded the message to Highmark reproduced here as follows (including the typographical errors in the original):


"It was nice to meet you last week in Belfast, I hope that you enjoyed your visit. I would like to clarify the problem that has been discovered with a certain body armour manufacturers armour which is widely used in Scotland and England. It seems that the antistab element of the armour is not now able to defeat the energy that it has been certified against. This particular armour is level HG1/KR2 and it has been found that not only is it failing KR2 but it is also failing KR1. this is obviously a very serious potential problem. It has been suggested that the laminated coating on the material in question may not be of the same consistency as that of the original used in testing leading to decreased protection. I would strongly advise that each force that use this armour should take a few garments and test them at an appropriate test facility in order to see the magnitude of this problem."

A copy of this message was received at Highmark on 3rd November 2003. The forwarder at the same time informed PSDB of the alleged problem and asked PSDB to look into the matter.


Highmark and PSDB discussed the allegation with me, Digby Dyke, the principal author of this Report, and instructed me to investigate whether the allegation had any basis in truth. Brian Kerr, Technical Manager of Highmark and I conducted initial knife-stab-resistance tests of the Highmark body armour at the Highmark factory using Highmark's own test equipment.

The following is the sequence of first events and observations that led to the beginning of the investigation just completed:

- a) If a problem did exist I doubted it would be as serious as Mr X had indicated; that is, I thought it unlikely that formerly qualified KR2 armour would now not qualify even to KR1, as was alleged. Brian Kerr and I conducted initial knife-stab-resistance tests.

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- b) We observed that there were indeed deeper than permissible *occasional* knife penetrations of the armours in question. However, we attributed this to the batch of test knife blades being used, in that their degree of sharpness seemed inconsistent with what hitherto had been ‘the norm’ in our experience. We and others in the body armour industry had in recent past believed there were variations in sharpness of some batches of PSDB Test Knife blades, and in our own test laboratories poorer knife-stab-performances had been observed in some armours that previously had performed better. This coincided with a change in the manufacturer source of PSDB test knife blades. Supplies had popularly been obtained from Wardson Tools Ltd., but had in recent times been obtained more popularly from High Speed & Carbide Ltd. - including the supplies obtained for use by RMCS, the PSDB approved test laboratory.
- c) We learned that Mr X who had made the allegation had witnessed recent internal Highmark knife-stab-performance tests using knives from the same ‘suspect’ batches, and bearing in mind Mr X’s then relative inexperience in the body armour industry and taking into consideration our observations during the testing that we had just completed, we concluded that the allegation made by the employee had no basis in fact in terms of the severity of it.
- d) Nevertheless, the results of the testing did indicate that there *might* be a small but possibly significant reduction in knife-resistance in the armour; and so we considered we should investigate further.
- e) By this time (November 2003) we learned that one police force, Lancashire Police, had reacted to the allegation made by Mr X and had sent some Highmark vests to the RMCS for knife-resistance testing. We decided we would, therefore, wait to learn results of this before acting further.
- f) In January 2004 we learned the results. Three vests had been sent in November 2003 by Lancashire Police for knife-stab testing to their original threat level of PSDB KR2 and on 11th December 2003 RMCS reported that two had “passed” and one had “failed”. The one that had failed had failed with one single knife-stab that was 3mm deeper than permissible for KR2, but the result had been well within the limits of KR1. RMCS advised Lancashire Police “... *it may be prudent to examine and test further samples ...*”
- g) In January 2004 Lancashire Police sent a further seven vests to RMCS for knife-stab testing, again to threat level KR2, and on 4th February 2004 RMCS reported that four had “passed” and three had “failed” with a total of five stabs

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deeper than permissible. The over-penetration depths were one each of 1mm, 2mm, 3mm and 7mm, and two at 6mm. Again, the failed vests had failed KR2 but were well within the limits of KR1.


- h) In view of the fact that the knife-resistance of the armour was now being questioned and investigated, we advised Highmark and PSDB to anticipate an investigation into the *ballistic*-resistance of the armour also. We were subsequently instructed to carry out ballistic-resistance testing of the armours in question, and on 27th January 2004 at Lorica Research in Malvern three KCW223 vests were tested. 36 shots were fired out of which 19 had back face deformations (so-called ‘traumas’) greater than the allowed 25mm depth for PSDB HG1. However, all were within the permissible depth of 44mm for the lower threat level of PSDB HG1/A.
- i) On the basis of the data gathered it was concluded that the KCW223 armour of Highmark previously performing at protection levels HG1 + KR2 seemed now to be performing at the lower protection levels of HG1A + KR1.
- j) Further testing was deemed to be necessary in order to determine the full extent and the cause of the reduction in protection performance, and on 5th February 2003, on instruction from Highmark, we took nine Highmark KCW223 armour panels to RMCS for ballistic-resistance testing to the PSDB HG1 Body Armour Standard. We were present throughout the testing. Eight of the nine panels were tested. Four panels had back face deformations within the limit for HG1 while four had back face deformations in excess of the limit for HG1 but within the limit for HG1/A. The ninth panel was tested for knife-resistance the following day, but the results were not conclusive.
- k) We reported to PSDB and met with Highmark on 8th February to report the results of the investigation so far; following which we were instructed to continue the investigation and to produce a formal report.

KCW223 vests:

The Model KCW223 vest originally was qualified to PSDB HG1 + KR2.

The model KCW223 vest samples tested for ballistic protection in this investigation were found mostly to conform to the lower protection level of PSDB HG1/A.

The model KCW223 vest samples tested for knife-stab protection in this investigation, in the great majority of cases, were found still to conform to the original protection level of

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PSDB KR2. There were, however, a small number of test results that put some of the vests tested as conforming to the lower protection level of PSDB KR1.

KCW110 vests:

The Model KCW110 vest originally was qualified to PSDB HG1 + KR1.

The KCW110 sample vests tested for ballistic protection in this investigation were all shown to conform below HG1 and, in fact, below the minimum PSDB Standard of HG1A. For ballistic protection the vests tested, therefore, did not conform to any protection level under the PSDB Body Armour Standards.

The KCW110 sample vests tested for knife-stab protection were found all to conform well within the limits of their original protection level of PSDB KR1.

Vest Samples:


In this investigation between the laboratories of Lorica Research and RMCS a total of 45 vests (90 panels) and numerous specially manufactured test samples were tested and over 1000 rounds of ammunition and 250 test knives were used.

Vest samples used for tests were each labelled with a Date of Manufacture between 02/2001 and 03/2004.

Most vest samples used were production standard vests that had been manufactured for sale or for sales samples stock. A small number of vests tested were taken from police in-service use and had been worn. A small number of vests tested were manufactured by Highmark specifically for testing in this investigation.

The investigation included an examination of the construction of the vests. Comparisons were made between the construction of the vests originally certified and vests manufactured for sale and for sales samples stock. This included vests provided by the above mentioned police forces.

The examination included a count of the number of layers of armour materials, a visual identification of the materials, and a check of their orientation and the stitching patterns used to join and assemble them. It also included observations of shape and size of samples and of the types and constructions of their outer covers.

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Shooting Tests:

In the shooting tests the ammunitions and velocities used were as specified by PSDB for the protection levels HG1 and HG1A – namely, 9mm FMJ DM11A1B2 at 360m/s \pm 10m/s and .357Mag R357M3 at 385m/s \pm 10m/s.

NOTE: The same ammunitions and velocities are specified by PSDB for both HG1 and HG1A protection levels. The difference between HG1 and HG1A is the allowable backface deformations.

Knife-Stab Tests:

In the knife-stab tests the blades and drop energies used were as specified by PSDB for the protection levels KR1 and KR2 respectively – namely, the PSDB P1 Test Knife at drop energies of 24 and 36 joules for KR1 and of 33 and 50 joules for KR2.

Some Test Knives used were manufactured by Wardson Tools Ltd and some by High Speed and Carbide Ltd.

NOTE: The question of whether or not differences between manufacturers' blades actually exist is an issue being looked at separately by others.

The same engineered Test Knife pattern is specified by PSDB for all three knife resistant armour protection levels, PSDB KR1, KR2 and KR3.

Observations:

Construction of Vests:


The construction of the production-standard vests was compared prior to testing with the construction of the originally qualified vests.

The production standard vests were similar to the originally qualified vests as follows:

The count of plies of armour materials, their appearance and their orientation from strike face to back face were the same.

The production standard vests differed from the originally qualified vests as follows:

The armour materials of the production standard vests contained extra stitching.

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Some of the plies of armour materials in the production standard vests were reduced in size by a few millimetres, thus thinning (graduating) the edges of the armour pack.

The fabric of the outer covers of the original qualified vests and the majority of production standard vests differed. The original cover fabric was a heavier, tougher, fabric than the majority of outer covers of production standard vests.

Many of the production standard vests differed somewhat in shape and style from the original qualified vests.

Examination of the sample vests after testing showed the following:

After Shooting Tests:

Back-face Deformations (Often referred to as ‘Blunt Traumas’):


Back-face deformations of the armour samples in some instances were greater than the maximum permissible depth of the PSDB Body Armour Standards.

Some back-face deformations were typically relatively shallow, dish-shaped and wide, while others were deeper and occasionally cone shaped with the apex pointing away from the strike face generally in the direction of the trajectory of the bullet. This phenomenon has recently been dubbed ‘*penciling*’. In a few of the latter instances the trajectory and thus the direction of the indentation in the plasticine had deflected a few degrees from the perpendicular.

NOTE: Vest samples for ballistic-resistance testing are mounted on plasticine for shooting. Indentations in the plasticine caused by back-face deformation of the armour due to bullet impact are examined and measured after the armour sample is removed from the plasticine. Indentations, mostly referred to as ‘backface signatures’, give an indication of possible behind armour injury from the impact of the arrested bullets (‘blunt trauma’). The maximum permissible depth of indentation (backface signature) in the plasticine for HG1 is 25mm and for HG1A is 44mm.

Complete Penetrations (Perforations through the armour):

In a very few instances there were complete penetrations (perforations) of the armour by projectiles (bullets). These mostly were one or more of two ‘angle’ shots (shots 4 and 5), which escaped from the side edges of the sample under test.

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In some of these instances it was observed that the first angle shot (shot 4) had caused some of the layers of the armour material at the strike face to be drawn to the side in the direction of the shot thus drawing material away from the point of impact of shot 5. In other cases, shot 4 had caused the front layers of armour material to bunch-up and stand off the surface of the layers behind at the point of impact of shot 5.


In a very few instances there were complete perforations of shot 6. In these instances it was observed that the armour material at the strike face had been disturbed by shots 4 and 5 and had bunched-up off the surface of the layers behind.

NOTE: Complete perforations like these described in the foregoing, while certainly constituting a fail of the test according to strict PSDB Standards rules, are a result of disturbance of the material inside vests after some other test shots have been fired and successfully defeated, often from more than one angle of attack. Complete perforations by bullets during testing in circumstances like these are not necessarily an indication that the armour would be completely perforated in actual 'real world' attacks in the low-risk scenarios for which the armour is intended.

Bullets that escape from the side edges of armour vests under test, as in the examples in the foregoing, usually have low residual velocity. Generally, such escaping bullets will not cause harm, although they can do, and it is not desirable that this should happen. If it does happen during testing the armour is deemed to have failed.

In a single case there was a penetration of shot 1 – the first test shot of the normal sequence of 6 shots. It was observed in this case that, while the shot was 2 inches from the edge of the armour (and was thus at the closest allowable distance to the edge and a 'fair' shot under PSDB Body Armour Standards), some layers of material in this vest sample also were 2 inches from the edge, immediately behind the point of impact of the bullet.

NOTE: While reasons for a specific complete perforation of a bullet during testing of armour in the laboratory can mostly be found, as in the case above, unexplainable complete perforations of bullets even in 'good' armours are known occasionally but rarely to occur. If a sufficient number of shots of test ammunition at test velocities are fired, many 'qualified' armour constructions may in time be completely perforated. The study of "Terminal Ballistics" (the effect the projectile causes when hitting the target as well as the counter-effect produced on the

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projectile itself) is still an “experimental science”. There are so many small variables that it is impossible to predict an outcome with complete certainty.

After Knife-Stab Tests:

In a very small percentage of stabs, test knives penetrated through the back-face of the armour by a greater amount than the maximum permissible amount according to PSDB Standards. Over-penetrations ranged from 1mm to 9mm greater than the amount permissible.

NOTE: Vest samples for stab testing are mounted on a prescribed foam block and weighted test knives are dropped from heights and at velocities calculated to deliver the stab at prescribed energies. Test knives may not penetrate through the back-face of the armour by more than a stipulated amount. This is 7mm or 20mm depending on the drop energy for the protection level, e.g. for PSDB KR1, KR2 or KR3, and the energy level E1 or E2, as the case may be.

Effects of Vest Sample Sizes:


The majority of production standard vest sizes available and used for testing were smaller than the sizes of vests qualified in the year 2000. In many of these cases the vest samples tested were not sufficiently large to fit the 250mm triangle shot pattern of the PSDB Standards. In these cases, fewer than six shots were fired at the samples or else shot spacings were made slightly closer than specified.

It is known that there is a greater possibility for deeper back face deformations and for complete bullet perforations where vests under test are smaller and/or where shot spacings are closer than specified.

Effects of Vest Sample Styles and Shapes:

The majority of production standard vests available and used for testing were of different styles and shapes from the vests qualified in the year 2000. In many cases back panels of the vests tested were rounded (arched) at their top edges whereas the vests qualified in the year 2000 were squarer and ‘T’ shirt shaped. In these cases the top edges of both front and back panels were extended upwards at each side towards the top of the shoulders.

It is known that there is a greater or lesser possibility for deeper back face deformations and complete bullet perforations of armour samples according to size, style and shape.

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NOTE: It should be noted that while this Report references these differences of size, style and shape this is not intended to signify a criticism. It is necessary that some vests made for wear should be smaller for smaller people and of variance in shape and style, depending, for instance, on whether they are to be worn under or over clothing.

Effects of Outer Covers:

The majority of production-standard vests available and used for testing were fitted with outer covers of lighter-weight fabrics than the outer cover fabrics of the vests qualified in the year 2000.

It was observed that there was a greater possibility for slightly deeper test-knife penetrations where the outer covers were of lighter-weight fabrics in the samples tested.


In the samples tested there were no measurably deeper back face deformations in shooting tests where the outer covers were of lighter-weight fabrics.

Effects of Extra Stitching in Armour Materials of Production Standard Vests:

In all production standard vests available and used for testing there was the extra stitching of the armour materials already described in the foregoing.

No adverse effect of the extra stitching was observed in any of the samples tested. In fact, in this case, it was observed that the border stitching added after qualification had a beneficial effect in helping to defeat some angle shots.

NOTE: Stitching of armour materials together is well known generally to have an effect on armour performance – an effect that may either be beneficial or detrimental, depending on how it is done. Stitching, apart from the purpose of joining materials, is often employed to improve resistance to angle shots and to help reduce back face deformation. However, some forms of stitching may in some instances reduce resistance to complete perforations of bullets. Stitching added to armour materials in body armour vests after qualification should always be investigated.

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Effects of Thinning (Graduating) Edges of Armour in Production Standard Vests:

In all production standard vests available and used for testing there was the thinning (graduating) of edges of the armour materials described in the foregoing.

It is known that graduating edges of armour panels in this way (making some of the plies of material slightly smaller than others) has the effect of reducing the effectiveness of the armour close to its edges. As already mentioned in the foregoing, it was observed in a single instance that the point of impact of one bullet perforating the armour, a 'fair shot' according to the PSDB Body Armour Standards being 2 inches from the edge of the armour, was upon the very edge of some plies of the material in the particular armour pack.

NOTE: Graduating armour at the edges is a technique employed by body armour manufacturers to increase comfort. Normally, it would be limited to just a few millimetres inside the armour pack edges.

Summary Conclusion to the Foregoing:


Apart from the single instance of the complete perforation of the shot described in the foregoing due to excessive graduation of the armour in this one case, and apart from a few cases where stronger fabrics were used in outer covers, it was not observed during the testing nor was it concluded from a close study of the test data, that the variations described in the foregoing (sample size, shape, extra stitching, thinning of edges, etc.) had caused any significant change in the performance of the armour tested. Consequently further investigations were deemed to be necessary into the possible cause.

Changes in the Composition and Manufacturing Process of Kevlar® AS299:

Kevlar® AS299 is a textile of Kevlar® fibre which has been coated with a phenolic resin and 'cured' with heat and pressure.

Pursuing our investigation, we learned that there had been a change in the manufacturing process and a change in the composition of the Kevlar®AS299 material since the qualification of the above models of body armour vests. The two changes were:

- An extension of the resin curing time in the manufacturing process, and
- A substitution in the Kevlar® fibre used in the manufacture of AS299.

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Change in the Resin Curing Process:

In February 2001 experiments were commenced by Highmark's suppliers, Verseidag, to extend the resin-coating curing time in the manufacturing process of Kevlar® AS299, in order to reduce odour in the material. There had been complaints by customers about odour from new vests. In March 2001, after the armour had been qualified, supplies to Highmark of 'extra-cured' AS299 commenced and probably soon after this all supplies were 'extra-cured'. It is certain that a change in the hardness and stiffness of the resin resulted, affecting the strength of the AS299 material as a result.

The original supplies of AS299 to Highmark in the year 2000 and in early 2001, when cut in stacks of layers with an electric knife in the Highmark factory, fused at their edges by heat from friction of the knife blade. It is reported to us that this did not happen with supplies of 'extra-cured' AS299 (after the change in curing time). The resin used in the manufacture of AS299 is a thermoset, but seemed to behave in a similar way to a thermoplastic in this respect. This was an indication that the material had changed its state, at least in this form, after the alteration in curing time.


NOTE: Finished, or fully cured, 'thermosets' do not soften and become plastic by the application of heat (as this material did, due to heat from friction of the knife blade, in the case above) while 'thermoplastics' do.

It was observed by us and by others that, different samples of AS299 (some taken from production vests and some from the original certified vests) felt slightly different to the touch. The difference could be described as only just discernable and included differences of stiffness and thickness.

Change in the Fibre:

It was reported to us that in March 2002 the Kevlar® fibre used in the manufacturing of AS299 was changed by Verseidag at the behest of Highmark from one known as 1k1156 (S431) to another known as 1k1042 (S331).

It is known that different Kevlar® fibres have different tensile strengths, and Du Pont, the manufacturer of the fibres, informed us that the substituted fibre had a slightly lower tensile strength than the original fibre used in the manufacture of AS299 used by Highmark in the vests submitted for PSDB qualification.

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Further Tests:

Further series of tests were carried out to determine whether either or both of the changes mentioned in the foregoing had significantly altered the performance of the AS299 material and thus also the body armour vests containing the material.

Test Series 1.

To test the theory that the change in fibre may have caused a significant change in the performance of the AS299 material the performance of AS299 manufactured with the original fibre, 1k1156 (S431), was compared with the performance of AS299 manufactured with the substituted and currently used fibre, 1k1042 (S331):

In shooting tests carried out at Lorica Research in Worcester on 4th March 2004 using Kevlar® AS299 recently manufactured using 1k1156 (S431) fibre specifically for testing in this investigation and supplied by Verseidag, back face deformations were similar to the poorest of those of recently tested production armour samples constructed from AS299 known to be manufactured using 1k1042 (S331). There were no complete perforations of bullets.


Test Series 2.

To test the theory that the change in the phenolic resin coating as applied by Verseidag to the Kevlar® fabric may have caused a significant change in the performance of the AS299 two tests were devised:

Tests 2.1

The performance of Kevlar® AS299 manufactured by another manufacturer (also with the fibre 1k1042 (S331)) was compared with the performance of AS299 manufactured by Verseidag:

In shooting tests carried out at Lorica Research in Worcester on 4th March 2004 of armour manufactured using AS299 supplied by Pro-Systems srl., Italy, the performance was very similar to performance of the original Highmark armour vests certified in the year 2000 which were manufactured using AS299 supplied by Verseidag prior to the change in the resin curing process. Occasional back face deformations, however, were slightly excessive. There were no complete perforations of bullets.

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From an analysis of the test data in this investigation we were able to relate the tactile variances mentioned in the foregoing to variances in performance of the AS299 material.

Tests 2.2

The performance of KCW223 vests manufactured using AS299 supplied by Verseidag prior to the change in the resin curing process was compared with the performance of vests manufactured using AS299 supplied by Verseidag after the change:


In shooting tests carried out at Lorica Research in Worcester on divers dates and carried out and witnessed by us at the RMCS on 23rd March 2004, of vests manufactured by Highmark declared to be constructed using AS299 supplied by Verseidag prior to the change in the resin curing process, the results were as follows:

Of five KCW223 vests tested for ballistic-resistance (five pairs of front and back panels with original covers) three conformed fully to the PSDB HG1 Standard, one failed with one shot with an excessive back face deformation of 28mm and one failed with multiple excessive back face deformations, but all were within the limit of HG1A.

One vest was tested for knife-stab performance and conformed fully to the PSDB KR2 Standard, and, in fact, better than the performance of the originally qualified vests for knife-stab performance.

At this point we ended our testing and closely reviewed all our data to-date. While we observed there were some information gaps in our investigation and wished for more time for more testing, and while we identified closely related areas requiring in-depth study, we felt we were ready and able to draw good conclusions and to make some recommendations which we hoped would be found useful to all parties. These are contained in the following.

Digby Dyke
& Robert Knight
Lorica Research Ltd
7th April 2004

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Conclusions:

The reduction in performance of the KCW223 and KCW110 body armour vests manufactured by Highmark Manufacturing Co. Ltd., the subject of this investigation, appears principally to be attributable to the change in the resin curing process early in 2001 after the vests had been developed by Highmark and qualified by PSDB and had begun to be supplied to customers. It seems likely that this change caused the material to become more brittle with loss of elasticity found in the original AS299 material. As a consequence, shear-strength became reduced.


On 8th March 2001 Verseidag Indutex GmbH sent the following message to Highmark Manufacturing Co. Ltd.:

“We sent to you with the last shipment of AS299 sheets, 50 which had been tempered at 150°C for 3 hours in an endeavour to reduce the “smell”. Whilst this tempering does not degrade the ballistic or anti-stab performance, it does however have the effect of causing a browning of the sheet, this is an optical effect only.”

When we, the authors of this Report, as part of our investigation, asked Verseidag what was the basis for the assertion “...this tempering does not degrade the ballistic or anti-stab performance...” we were told that no ballistic testing of the changed material had in fact taken place and that the assertion was an assumption. Stab testing had, we were told, taken place.

It seems that Highmark accepted “in good faith” the statement that the change did not degrade the material and commenced using it in the production of body armour vests without testing it. Copies of correspondence in files at Highmark show that development of the Kevlar® AS299 material by Verseidag continued for some months after Highmark had started to use it and were selling vests to their customers.

On a number of occasions over three years vests of the same model numbers and same armour constructions but of different styles were submitted to PSDB for qualification. These were qualifications for the addition of zips or of breast cups only and not for the vests as a whole. Such additional tests are limited to two shots or stabs directed into the zip or breast cup. In the case of zips, back face deformations are measured for bullet impacts, but not in the case of breast cups.

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Complete perforations of zips and breast cups by bullets, or greater than permissible test knife penetrations are not allowed.

We found no evidence of *any* batch testing by Highmark of either raw materials or finished vests.

A lesser contributory cause of the reduction in protection levels found in these vests may have been the change in the fibre early in 2002. In our testing, however, we were unable absolutely to distinguish a difference in performance between AS299 manufactured with the original fibre from that manufactured with the 'new'.


However, we did notice that the best performing vests were those known to contain AS299 with both original resin curing and original fibre. Some of the vests tested having poor performance, we suspected, were constructed with AS299 having only either one or other of these changes. The worst performing vests of all, we suspected, were vests incorporating AS299 with both the 'new' resin curing time and the 'new' fibre.

Apart from the single instance of a bullet penetration of 'shot 1' in one test sample, it seems that none of the changes made at the Highmark factory to the vests since PSDB qualification (the addition of border stitching, tack stitching and edge tapering) made any discernable difference to the performance of the vests in this case.

Variances in body armour vest outer covers did affect results of some of the knife-stab testing, but not to such a degree as to alone cause the wide variances in performance seen during this investigation. The differences observed in these cases (of different outer covers) in this investigation were so slight as to be significant only (and we wish to emphasise, only) in respect of taking an armour 'a millimetre or two' over the test limit, and not at all significant in our opinion in terms of practical protection.

Backface signatures ('blunt traumas') of the KCW223 vests when qualified to PSDB Body Armour Standards in 2000 were on the limit of test performance with some backface signatures at 25mm and 24mm, and the KCW110 vest also was close to the limit with back face signatures at 23mm and 22mm. Slight changes in the armour could, and seemingly did, have an adverse effect on this.

During this investigation there arose the question whether changes were continuing in the armour after manufacture. Specifically, whether curing of the

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resin with consequential changing in armour material mechanical strength was taking place due simply to ageing. While there was some evidence of some curing taking place after manufacture in the early batches of the AS299 material manufactured prior to the change in the resin curing process, it appears that this was slight and probably of little effect and significance. We concluded that there is no evidence of any ongoing deterioration of the armour due to ageing.


While the vests in question failed tests in the laboratory they continued to provide protection in the field. The loss in protection was limited to a reduction in protection from ‘blunt trauma’ and a small reduction in protection from knife-stab. In spite of a very small number of complete bullet perforations during laboratory testing there was no real reduction in protection of wearers from complete bullet perforations in practical terms.

The majority of vests tested provided protection well within the limits of PSDB protection levels HG1A and KR1 or KR2 as the case may be. Even in the case of the KCW110 vests, which were below the minimum PSDB Standard of HG1A, the loss of protection was limited to a reduction in protection from ‘blunt trauma’. Protection from bullet perforation in this armour was, effectively, retained.

Finally, we feel confident that, had the quality and performance of the AS299 material as was very originally supplied been maintained throughout, it is likely that all production vests would have performed the same as the original qualified vests. We would add, however, that as the armour was on the limit of test performance, it would have been wise to have added extra armour material to provide a margin in performance.

Recommendations and comments are in the following pages.

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& Robert Knight
Lorica Research Ltd
7th April 2004

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Recommendations:

Body armour manufacturers would find it helpful if a list were provided by PSDB of changes to armour that constitute *new armour requiring fresh compliance qualification*. Changes need not be limited to those listed.

Manufacturers of proprietary body armour raw materials and manufacturers of body armour vests should strengthen procedures for quality control to ensure new materials and materials that have changed are not used without them first being thoroughly developed, tested and approved.

Customers, whether for body armour raw materials or for body armour vests, should impose contractual requirements on their suppliers not to make changes to body armour products without notification and agreement.

Customers for body armour vests should impose contractual requirements on suppliers to carry out periodic raw materials and body armour batch-testing and re-qualification during the life of a supply contract.


Customers for body armour vests should select armour that has a good margin of tolerance in test performance rather than armour that is bordering on the test limit.

The PSDB should consider introducing a rating system for body armour vests related to performance only and discontinue completely the present star-rating system relating solely to weight.

The PSDB should introduce a system for describing qualified armour by degree of performance rather than by a binary pass/fail test alone; such as can be provided by a V50 measurement; similarly, by degree of back face deformation (blunt trauma) attenuation.

The PSDB should stipulate specific dimensions and shapes of vests for qualification rather than simply as those capable of accepting the 250mm triangular shot-spacing pattern.

The PSDB should stipulate a material as a standard for body armour vest outer covers for qualification purposes, and they should consider rules controlling supplies to police of vests in covers of a material other than the standard material.

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Supplementary Note – 22nd June 2004

Since the release of this Report we have often been asked to whom we attribute blame, or most blame, for the failure of the Highmark KCW223 and KCW110 vests. We don't want to give an opinion about this, but we believe that our Report provides sufficient reporting and information for the reader to form his/her own opinion. However, we offer the following comment:

- 1 The race for the lightest body armour led to the weakest, and this was encouraged by what in our opinion was a very ill-advised five-star weight-rating system devised by PSDB. It forced body armour manufacturers to put weight at the top of their design criteria rather than protection, and it encouraged customers to select weight before performance.
- 2 The customers of Highmark apparently did not take into account the performance data in the PSDB compliance test certificates which clearly showed that the armour was on the very limit of performance - on the very edge of failing the qualification test.
- 3 Highmark performed no tests for quality and reliability of performance of the armour over the entire three year period the armour was sold with the exception of the small amount of stab testing in latter months which revealed some deficiency in performance leading its former employee, Mr X, to 'blow the whistle'.
- 4 Verseidag implied in a letter to Highmark that certain quality assurance tests of the AS299 material had been carried out; but they had not been.
- 5 Highmark altered the construction of the armour after it had been qualified without submitting it for re-qualification.
- 6 Customers who contracted to buy the armour did so without requiring Highmark to provide *any* quality assurance during the life of the contracts.

All of the parties share the blame. Any one party acting properly could have prevented the problem arising. But, in our opinion, the *responsibility* for the problem lay with PSDB as the Authority. PSDB, in our opinion, did not at the time have either the capability and experience or the foresight necessary to prevent it.

End of Report.