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CANADIAN POLICE RESEARCH CENTRE — CENTRE CANADIEN DE RECHERCHES POLICIÈRES

TR-02-95
Deenside Protective Equipment

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Biokinetics and Associates Ltd.

TECHNICAL REPORT

September, 1994

NOTE: Further information
about this report can be
obtained by calling the
CPRC information number
(613) 996-6342

EXECUTIVE SUMMARY

Protective equipment manufactured by Deenside Ltd. was evaluated on the basis of hazards and conditions likely to be encountered by riot police. Two vests were tested. Vest 1 was constructed of 1/2" polyethylene foam and provides upper thoracic protection. Vest 2 is a combination of 1/4" polyethylene foam within a 1/8" polyethylene shell. It too provides upper thoracic protection but has additional arm and leg protection available.

The equipment offers reasonable energy absorption at low energy levels but poor penetration protection. The materials were resistant to low and high velocity impacts with virtually no observable or lasting traces.

The vests offer good range of motion but this is at the expense of coverage. Heat retention may contribute to discomfort, but this may not be a great concern.

Vest 1 appears to offer poor impact protection from blunt or sharp objects. Vest 2 offers improved protection from small diameter impacts at low velocities, but not from high speed and high energy impacts.

Deenside Ltd. was kind enough to provide the equipment to the Canadian Police Research Centre for testing purposes.

For further information on this equipment, write or call:

Deenside Ltd.
Manufacturers of Protective Equipment
Meadows Leather Workds
Henry Street
Northampton NN1 4JE
England
Telephone: 0604 33260
Fax: 0604 604398

Résumé

On a évalué deux gilets fabriques par Deenside Ltd., en fonction des risques et des situations se presentant aux escouades anti-emeute. Le premier gilet, compose de mousse de polyethylene d'une épaisseur de 1/2 po, protege la partie supérieure du thorax. Le deuxième gilet est compose de mousse de polyethylene d'une Bpaisseur de 1/4 po, à l'intérieur d'une enveloppe de 1/8 po de la même matière. II protege également le haut du thorax et peut proteger en plus les bras et les jambes.

Ce materiel offre une absorption raisonnable 8 de faibles niveaux d'energie, mais une faible resistance 8 la pen&ration. Les materiaux résistent aux tirs à faible et à haute vitesse, et ces derniers n'y laissent presque aucune trace visible.

Les gilets permettent une bonne amplitude de mouvement, mais au detriment de la protection. La retention de chaleur peut être inconfortable, mais cela ne pose pas un problème majeur.

Le gilet n° 1 semble peu protéger contre les impacts d'objets émoussés ou pointus. Le gilet n° 2 offre une protection accrue contre les projectiles de petit diamètre à basses vitesses, mais protege peu contre les projectiles à haute vitesse et à hauts niveaux d'energie.

Deenside Ltd. a eu l'amabilité de fournir le materiel au Centre canadien de recherches policières aux fins de l'évaluation. Pour obtenir des précisions, veuillez écrire 8 l'adresse suivante :

Deenside Ltd.
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EVALUATION OF PROTECTIVE EQUIPMENT MANUFACTURED BY DEENSIDE LTD.

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1.0 INTRODUCTION

Protective equipment manufactured by Deenside Ltd. Security Equipment was evaluated on the basis of hazards and conditions likely to be encountered by riot police. Two vests were tested. Vest 1 is constructed of ½" polyethelene foam and provides upper thoracic protection. Vest 2 is a combination of ¼" polyethelene foam within a ⅛" polyethylene shell. It too provides upper thoracic protection but has additional arm and leg protection available.

Protective qualities which are important to consider in injury prevention include: the ability to distribute a load, absorb energy and resist penetration. Comfort qualities which may directly or indirectly contribute to an officer's safety and which can be measured in a laboratory setting, include: material stiffness , coverage and heat transfer. Qualities which contribute to the durability of the protective equipment include: resistance to repeated impacts, dimensional stability and temperature sensitivity. Only empirical tests, reproducible within a laboratory setting were conducted for this evaluation.

2.0 *PROTECTIVE QUALITIES*

2.1 LOW VELOCITY CRUSH

2.1.1 **Apparatus**

Steel Ball (Mass: 0.2545kg, Diameter: 39.72mm)
Tape Measure
Hybrid III Anthropometric Test Dummy (ATD)

2.1.2 **Set-Up and Procedure**

An anthropometric test dummy (ATD) was used as support to simulate a human form. The vest was fastened to the ATD which lay flat on the floor. A 0.2545kg ball bearing was dropped from heights of 1m and 2m, three times at each height, being careful not to impact the same site twice. This created an impact velocity of 4.43m/s (15.94km/h) for the 1m drop and 6.26m/s (22.54km/h) for the 2m drop. If an impact left a mark, the diameter of the mark was recorded.

2.1.3 **Results**

IMPACT SITE	1m DROP	OBSERVATION	2m DROP	OBSERVATION
Vest: 1	No measurable indentation	Momentary compression of the material	No measurable indentation	Momentary compression of the material
Vest: 2	No Mark		No Mark	

Table 1: Observation of impact sites for 1m and 2m drops of a ball bearing

2.2 HIGH VELOCITY CRUSH TEST

2.2.1 Apparatus

Slingshot (“Robert’s Rocket,” wrist supported, folding slingshot)
4.002kg mass
Ruler
C-Clamp
Standard Golf Ball (Titleist "DT" 6) (4.258 cm diameter, 0.0452kg mass)
Stool
Hybrid III Anthropometric Test Dummy (seated in chair)

2.2.2 Set-up and Procedure

The slingshot was calibrated by fixing it to the lab bench such that its spring was hanging freely over the table’s edge. The 4.002kg mass was then hung from the slingshot and its displacement measured to determine the spring constant. The ATD, fitted with the vest, was positioned in a chair and the slingshot was placed on a stool such that when the spring was extended back horizontally, but not stretched, its distance from the ATD's lower chest and upper abdomen was 1m. A standard golf ball was used as the projectile. The slingshot and ball were drawn back 0.25m and released the ball with a velocity of 23.2m/s (83.4 km/h). Three impacts were made to the vest in different locations.

2.2.3 Calculations

m = Mass of ball
v = Velocity of ball
k = Elasticity Constant of the spring
KE = Kinetic energy
x = The distance the spring is stretched

Sample *Calculation*

KE of the spring = KE of the ball

$0.5\ k\ x^2 = 0.5\ m\ v^2$

$v^2 = \frac{(388.3)(0.0625)}{0.0452}$

v = 23.2 m/s (83.4 km/h)

2.2.4 Results

IMPACT SITE	OBSERVATION
Left Clavicle	No Apparent Damage
Left Cardiac	No Apparent Damage
Lower Sternum	No Apparent Damage

Table 2a: Observation of impact sites of golf ball propelled by a slingshot, Vest 1.

IMPACT SITE	OBSERVATION
Left Clavicle	No Apparent Damage
Left Cardiac	No Apparent Damage
Lower Sternum	No Apparent Damage

Table 2b: Observation of impact sites of golf ball propelled by a slingshot, Vest 2

2.3 LOW VELOCITY PENETRATION TEST

2.3.1 Apparatus

Playing Dart
Tape Measure
Hybrid III Anthropometric Test Dummy (ATD)
Vernier Calipers

2.3.2 Set-Up and Procedure

An ATD was used as a support resembling the human form. A playing dart of mass 0.0201kg was dropped onto the vest, fitted to the ATD, from heights of 1m and 2m. The dart was dropped three times from each height to obtain an average. No site was impacted more than once. The depth of penetration was measured if the dart remained embedded in the vest or glove. Penetration was measured using the Vernier Calipers.

2.3.3 Results

Impact Number	Damage from lm Drop	Observation	Damage from 2m Drop	Observation
Vest 1	Penetration 2-3 mm	Stayed in the jacket	Penetration 6-11 mm	Stayed in the jacket
Vest 2	Small indentation	None	Small indentation	None

Table 3: Observation of impact sites for 1m and 2m drops of a playing dart on both vests.

2.4 HIGH ENERGY PENETRATION TEST

2.4.1 Apparatus

Drop tower: free fall system guided by stainless steel rods
Base: MEP pad protected with a block of foam
Conical penetrator anvil (drop mass = 2.708kg)
Velocity gate: VS200.

2.4.2 Set-Up and Procedure

Two areas of the vest not previously impacted were selected. The vest was positioned on the impacting surface and impacted at Site 1 from a height of 0.5m and at Site 2 from a height of 1.0m. The impacted velocity was recorded and the vest inspected for signs of penetration.

2.4.3 Results

Drop Height m	Impact Velocity *m/s*	Impact Energy *J*	Observation
Vest 1			
0.5	**3.07**	**13.52**	penetrated
1.0	**4.44**	**28.27**	transpierced
Vest 2			
0.5	**3.07**	**13.52**	penetrated
1.0	**4.44**	**28.27**	transpierced

Table 4: Observation of penetration test.

2.5 ENERGY ABSORPTION

2.5.1 Apparatus

Drop tower	
MEP pad	
Cylindrical anvil	
Accelerometer:	Endevco Model 7702A-50
Charge Amp:	Endevco Model 101
Velocity gate:	VS200
Data Acquisition and Storage:	Sample rate 10 khz
	Full scale range ±10.00v
	Quantization 1.1 mv
Absolute Accuracy ± 0.03%	(Drop mass: 2.868kg

2.5.2 Set-Up and Procedure

The cylindrical anvil was dropped on to the bare MEP pad from 0.45m and from 1 m to determine baseline energy and acceleration levels. Impact sites were no closer than 7cm are illustrated in Figures la & lb.

Figure la: Location of selected sites for impact tests for Vest 1.

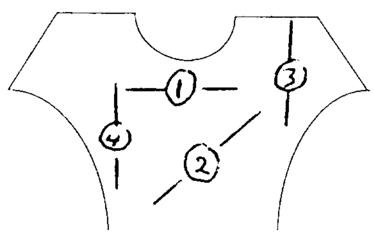

Figure lb: Location of selected sites for impact tests for Vest 2.

2.5.3 **Calculations**

Normalized value: $\frac{\text{Baseline - Test}}{\text{Baseline}}$

Sample calculation:

$$\left[230.94-\frac{(112.79+125.0)}{2}\right] / 230.94=0.49$$

2.5.4 Results

Test #	Drop Height m	Impact Velocity *m/s*	Impact Energy J	Peak Acceleration G
Baseline	0.45	2.95	12.48	230.94
Baseline	1.0	4.42	28.02	379.88
1	0.45	2.88	11.89	104.98
2	1.0	4.42	28.02	240.73
3	.45	2.89	11.98	107.92
4	1.0	4.44	28.27	250.49

Table 5a: Peak acceleration readings as a function of drop height and impact energy.

TEST #	DROP HEIGHT m	IMPACT VELOCITY *m/s*	IMPACT ENERGY J	PEAK ACCELERATION G
Baseline	0.45	2.95	12.48	**230.94**
Baseline	1.0	4.42	28.02	**379.88**
1	0.45	2.86	11.73	**112.79**
2	1.0	4.44	28.27	251.49
3	.45	2.88	11.89	125.0
4	1.0	4.39	27.64	268.56

Table 5b: Peak acceleration readings as a function of drop height and impact energy.

Average Energy J	Normalized Peak Acceleration Values		
	Bonowi	**Deenside 1**	**Deenside 2**
12.02	**.58**	**.54**	**.49**
28.31	**.53**	**.36**	**.32**

Table 5c: Normalized peak acceleration values with respect to baseline values for each.

In order to compare the energy absorbing characteristics of protective equipment submitted for testing, peak acceleration values were normalized. This approach removes the influence of baseline acceleration results. When compared to the previously tested Bonowi® equipment, the Deenside Vests are less effective at absorbing energy, particularly at the higher impact level.

ℐ.0 COMFORT

3.1 STIFFNESS

3.1.1 Apparatus

2.048 kg mass
Ruler
Clamps
Electronic Balance (Scale)

3.1.2 Setup and Procedure

The vest was fastened to the lab bench using clamps such that there was an overhang of greater than 16 cm as shown in Figure 2. A 2.048 kg mass was then suspended from that point and the resulting displacement was measured. The procedure was repeated three times at each point to obtain an average. The points were chosen as shown in Figure 3 for Vest 2 only. Vest 1 could not be evaluated due to the high flexibility of the foam. The experiment was conducted at room temperature and average humidity.

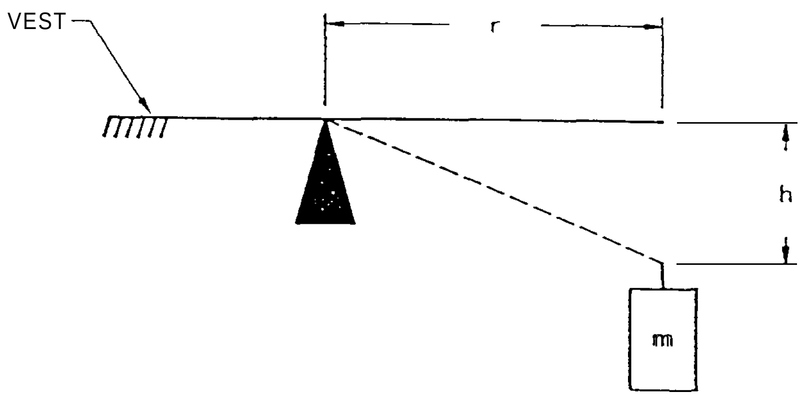

Figure 2: Test set-up

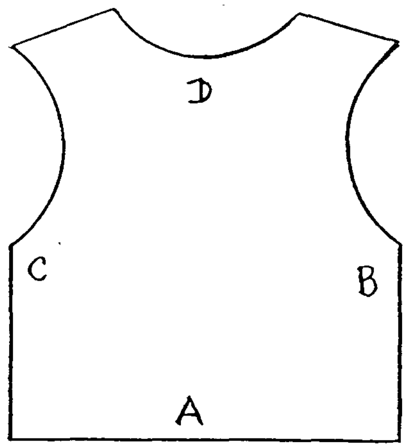

Figure 3: Location of selected sites for torsional stiffness test.

3.1.3 Calculations

F = Force
m = Mass
a = Acceleration
τ = Torque
h = Average Displacement
r = Distance of mass from fulcrum

Sample calculation at point 1:

F = ma
F = (2. 048kg)(9.80 m/s^2)
F = 20.09 N

τ = rF
τ = 0.16m(20.09N)
τ = 3.208 N m

Force required to cause deflection at a distance of 16mm
= τ/h
= 3.208Nm / 0.03m
= 106.93N

A.4 Results

POINT	FORCE n	TORQUE Nm	CHANGE IN HEIGHT m	STIFFNESS N
A	**20.09**	**3.208**	**0.030**	**106.93**
B	**20.09**	**2.411**	**0.030**	**80.36**
C	**20.09**	**5.022**	**0.121**	**41.51**
D	**20.09**	**5.03 1**	**0.122**	**41.23**

Table 6: Summary of material stiffness for Vest 2.

3.2 COVERAGE

3.2.1 Procedure

The vest with arm protection attached was fitted to a large male subject. Coverage was evaluated with respect to the protection of vital organs including; cardiac region, liver, spleen, kidneys, In addition, protection of the spine, and major skeletal structures was examined.

Vital Organs	Complete Coverage	Partial Coverage	No Coverage Range
Heart	✔		
Liver			✔
Spleen			✔
Kidney			✔
Skeletal Structures			
Spine		✔	
Sternum		✔	
Clavicle		✔	
Ribs: Frontal Posterior Lateral		✔ ✔ ✔	

Table 7a: Body regions protected by Vest **1.**

Vital Organs	Complete Coverage	Partial Coverage	No Coverage Range
Heart	✔		
Liver			✔
Spleen			✔
Kidney			✔
Skeletal Structures			
Spine		✔	
Sternum		✔	
Clavicle		✔	
Ribs: Frontal		✔	
Posterior		✔	
Lateral			✔

Table 7b: Body regions protected by Vest 2.

3.3 HEAT TRANSFER

3.3.1 Apparatus

1000 Watt hot plate (14cm diameter element)
Yellow Springs Co. Incorporated Model 44T Thermocouple
Retort Stand and Clamp
Timer

3.3.2 Set-up and Procedure

The vest was held over the heat source by the retort stand and clamp. Temperatures of the element, heated air, the internal surface of the vest, its external surface, and room temperature were recorded every three minutes for the duration of the 30 minute experiment. The heated air temperature was adjusted such that it was between 35 and 40 degrees Celsius.

3.3.3 Calculations

T_2 = internal surface temperature c°
T_e = external surface temperature c°
T_a = air temperature

$$\text{Heat Retained} = \frac{T_2 - T_e}{T_2 - T_a}$$

Sample Calculation

$$\%\ \text{Heat Retained} = \frac{38 - 25}{38 - 18}$$

Heat Retained = 65%

3.3.4 Results

VEST HEATED	OBSERVATIONS
Vest 1	**65 % of heat was retained**
Vest 2	**71% of heat was retained**

Table 8: Observation of two vests exposed to radiant heat

4.0 DURABILITY

4.1 RESISTANCE TO REPEATED IMPACTS

4.1.1 Test Procedure

One site was selected for repeated 1m impacts during the energy absorption test. Peak accelerations were recorded and compared.

4.1.2 Results

Vest 1	IMPACT VELOCITY m/s	IMPACT ENERGY J	PEAK ACCELERATION G
Baseline	4.42	28.02	379.88
Test #1	4.42	28.02	246.09
Test #2	4.41	27.89	270.53

Table 9a: Comparison of Peak G values for repeated impacts for Vest 1.

Vest 2	IMPACT VELOCITY m/s	IMPACT ENERGY J	PEAK ACCELERATION G
Baseline	4.42	28.02	379.88
Test #1	4.42	28.02	246.09
Test #2	4.42	28.02	264.16

Table 9b: Comparison of Peak G values for repeated impacts for Vest 2.

4.2 DIMENSIONAL STABILITY

4.2.1 Test Procedure

A section of the vest was placed beneath a 5kg and 10kg mass for a four hour period.

4.2.2 Results

No permanent dimensional changes were observed.

4.3 TEMPERATURE SENSITIVITY

4.3.1 Procedure

The protective gear was subjected to temperatures of -10°C and +40°C.

4.3.2 Results

The Vest 1 material was slightly more rigid at -10°C.
No dimensional changes were observed for Vest 2.

3.0 SUMMARY AND CONCLUSIONS

Testing of the Deenside Ltd. Vests demonstrated that the equipment offers reasonable energy absorption at low energy levels but poor penetration protection. The materials were resistant to low and high velocity impacts with virtually no observable or lasting traces. Penetration protection is poor as demonstrated by the degree of penetration resulting from the 1 meter drop of the conical impactor. From this result it is expected that if the vests were struck with a small diameter penetrator, such as an ice pick or knife, penetration would occur.

The equipment offers reasonable energy absorbtion. When impacting the vests at energy levels of approximately 12 J, which is equivalent to the energy produced by a golf ball flung at 83.4 km/h, peak acceleration levels ranged from 105 to 108 G's for Vest 1 and 112.8 to 125.5 for Vest 2. These demonstrate acceleration reductions of .54 and .49 for Vest 1 and Vest 2, respectively. Impacting the Vests with 28 J resulted in peak accelerations in the 260 G range representing an approximate .30 reduction in peak G's. The energy absorbing characteristics of the material diminish at higher impact levels. In contrast, the Bonowi® equipment did not exhibit such an important drop in energy absorbing capacity when the energy level was increased.

The vests offer good range of motion but this is at the expense of coverage. For both vests, frontal and rear coverage of the chest includes partial coverage of the clavicle and ribs. There is no lateral rib coverage, nor is there coverage of the liver, spleen and kidneys. Vest 2 offers additional arm protection to the lateral and posterior aspects of the humerus and ulna, leaving the anterior aspect exposed. The olecranon or elbow joint is protected.

Heat retention may contribute to discomfort with this equipment. Heat retention for both vests ranged between 65% and 71%. This may not prove to be a great concern, given the limited body area which is affected.

The compliant nature of Vest 1 makes it susceptible to deformation during storage. However, this could prove to be more of a nuisance than an actual threat to protective qualities. The outer shell of Vest 2 makes it more resistant to distortion during storage. The materials of both are unaffected by cold or warm conditions.

In summary, it appears that the Vest 1 would offer poor impact protection from blunt or sharp objects. Vest 2 would offer improved protection from small diameter impacts at low velocities, but not from high speed and high energy impacts.