V_{50} instead of V_{proof} or alternative methodologies for highly protective EOD PPE

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Abstract. In 2015, AEP-2920 Edition A Version 1 [1] introduced the V_{proof} as a NATO personal armour ballistic test methodology. A given armour panel meets a V_{proof} rating against a specified fragment when at least 22 fragments shot at velocities in a range of V_{proof} to V_{proof} + 20 m/s all get stopped. In the context of Explosive Ordnance Disposal (EOD) Personal Protective Equipment (PPE), the suit areas most likely to be subjected to V_{proof} are those providing the highest level of protection. Historically, the reliance on measurements like V_{proof} for these areas arose from the technical challenge, for many ballistic laboratories, to reach high-enough velocities when firing the 1.1 g Fragment-Simulating Projectile (FSP), which is the most common fragment when testing EOD PPE fragmentation resistance. Prior to the release of the NATO V_{proof} methodology, and still today, some EOD PPE manufacturers and ballistic laboratories have applied unreliable customized test methodologies without statistical significance, to quantify the EOD PPE fragmentation protection performance. Among reasons for not applying the NATO V_{proof}, beyond the potential unawareness of the standard, is the need to fire a large quantity of fragments (22), which implies testing multiple complex and expensive protective panels. In addition, one must define, ahead of the test, a given V_{proof} classification to aim for. An alternative to V_{proof} for highly protective EOD panels, is the V_{50}, but using a heavier fragment. Contrary to V_{proof}, the V_{50}, which is a characteristic a given panel, does not heavily depend on a priori estimations of the performance (the starting velocity only slightly influences the V_{50}). For instance, the NIJ 0117.01 Standard for Public Safety Bomb Suits [2] mandates the use of the 13.4 g FSP for the chest and groin protective areas. Using such a heavy fragment results in lower V_{50} values compared to the 1.1 g case, which eliminates the challenges faced by ballistic laboratories in shooting 1.1 g fragments at very high velocities. In this paper, the statistical implications of selecting a V_{50} test with a heavy fragment as opposed to V_{proof}-like tests with a lighter fragment, are investigated through Monte Carlo simulations based on representative idealized materials. The results support the use of the 13.4 g to quantify the fragmentation protection performance of highly protective area of bomb suits, especially when facing limitations in costs or panels.

1. INTRODUCTION

Explosive Ordnance Disposal (EOD) suits (bomb suits) are not normally designed nor rated to stop bullets. As such, no backface deformation requirements are applicable to bomb suits. On the other hand, a bomb suit ensemble must stop explosively driven fragments originating from the explosive device itself, or those propelled by the force of the blast. As actual explosive devices vary greatly in size, components, construction and as the environment surrounding the explosive is also highly variable, fragmentation protection performance is characterized through standardized laboratory experiments. Such experiments involve the firing of identical and standardized representative fragments.

An ideal material would stop all fragments of a given type below and up to some characteristic velocity. Above that characteristic velocity, all fragments would completely penetrate the material (Figure 1). However, such "ideal" materials do not exist. Instead, in the real-world, there is a "zone of mixed results", where either complete stops or complete penetrations can be observed, when a specific fragment is fired (Figure 2).

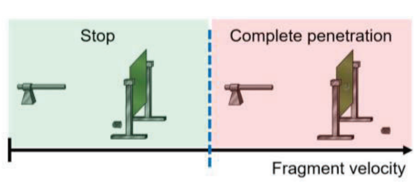

Figure 1. Idealized material

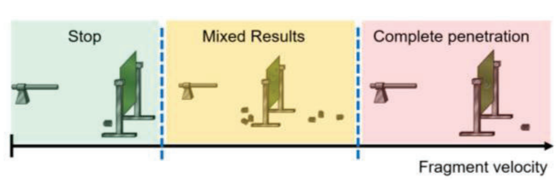

Figure 2. Real-world material, exhibiting a "zone of mixed results"

Binary logistic regression can be performed to illustrate this probabilistic characteristic of real-life materials, with the fragment velocity being used as the continuous explanatory variable and the penetration outcome being used as the categorical variable (Figure 3). At each velocity level, the resulting logistic regression curve from Figure 3, hereon referred to as the "S-curve", provides the probability of a complete penetration, for a specified fragment type. The S-curve is extensively used to completely

https://doi.org/10.52202/080042-0030

define the fragmentation protection characteristic of a material [3]. Unfortunately, accurately determining this curve requires extremely extensive testing. Such testing is generally not practical, other than in the limited context of scientific experiments. Instead, when it comes to characterizing materials, the emphasis is generally put on determining only one or a few points on the S-curve.

The V_{50} is the most widely studied point on the S-curve (Figure 3) and is considered by Cunniff [4] as being "among the most elegant performance metrics for armour systems". There exist well-defined methodologies for the determination of the V_{50} (e.g. MIL-STD-662 [5] and NATO STANAG 2920 [6]). These methodologies involve firing an equal number of fragments that completely penetrate a material, and fragments that get stopped, within a limited range of firing velocities. The V_{50} rating is then defined as the average of all velocities within the range. Many standardized fragments exist (Figure 4). But for evaluating bomb suit materials, the 1.1 g standardized fragment is the most widely used.

For the bomb suit areas requiring the highest levels of protection (red area in Figure 5), the V_{50} ratings with the 1.1 g fragment are typically of the order of 1800 m/s. Unfortunately, many ballistic laboratories experience difficulties in reliably and reproducibly firing 1.1 g fragments at such high velocities. As such, bomb suit manufacturers have often relied instead on means other than the V_{50} to quantify the level of fragmentation protection provided by the most protective area of their suits, against the 1.1 g fragment.

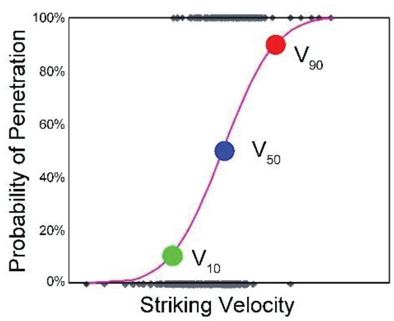

Figure 3. Generic logistic regression curve (S-curve) with three characteristic points highlighted

Figure 4. Fragment Simulating Projectiles (FSPs) used by NIJ [2]

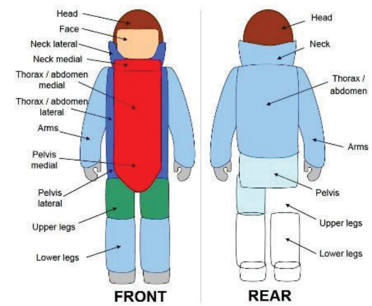

Figure 5: Bomb Suit protective areas as per NIJ [2]. Highly protective areas in red

An alternative to the V_{50}, when reaching the desired firing velocities becomes challenging, is to aim for another point in a lower range of the S-curve, such as the V_0. The V_0 represents the highest velocity at which no complete penetration is expected. The outdated NATO STANAG 2920 Ed. 2 [6] document provided a standardized method to estimate the V_0. This method implied firing fragments at velocities up to 1.5 times higher than the V_0 of a material (Figure 6). The V_0 was then estimated by extrapolating to zero the residual velocities arising from complete penetrations. This requirement to fire fragments at such high velocities made it even more difficult for test laboratories to characterize the protection performance of bomb suits with the 1.1 g fragment. As a workaround, some bomb suit manufacturers conduct customized tests involving a limited number of complete stops, close to the expected V_0. The V_0 is then estimated as the maximum value from these firing tests (Figure 7). However, such made up methodology is not based on a sound statistical approach and overestimates the protection performance. For the purpose of this paper, this custom methodology will be defined as $V_{0\text{-claimed}}$.

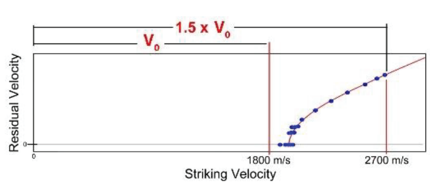

Figure 6. V_0 as per STANAG 2920 Ed. 2

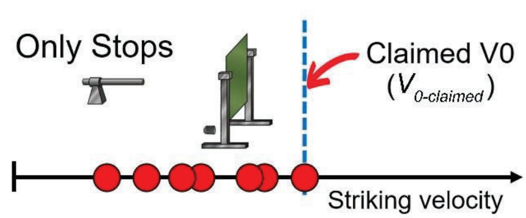

Figure 7. Customized methodology ($V_{0\text{-claimed}}$)

In 2015, NATO released a document entitled AEP-2920 Procedures for the Evaluation and Classification of Personal Armour, Edition A Version 1 [1]. This document includes a standardized approach to estimate a material performance rating similar in concept to the V_0 (velocity below which no penetration is expected), referred to as the $V_{proof.}$ The V_{proof} involves testing in a lower range of the S-curve, compared to the V_0 from STANAG-2920 [6]. AEP-2920 defines the V_{proof} as a validation against

https://doi.org/10.52202/080042-0030

a specified projectile based on a statistical approach, where a defined number of projectiles are fired with a defined velocity at soft armour and/or hard armour, personal armour items, components or material samples. The classification is achieved when the said component has defeated the defined number of projectiles at the defined velocity. Bolduc et al. [7] provided a good overview of AEP-2920.

In this study, three test methodologies will be considered to characterize the fragmentation protection performance of materials: the V_{50}, the V_{proof}, as well as the made-up methodology referred to earlier as the $V_{0\text{-claimed}}$. Monte Carlo statistical simulations will be performed to characterize the performance of simulated materials (no laboratory experiments). Monte Carlo simulations of V_{50} tests have been conducted by Andres et al. [3], Cunniff [4], Eridon et al. [8] and Cheng et al. [9], among others. The approach adopted here will not deviate substantially from these previous studies. However, the focus here will be on the characterization of highly protective bomb suit areas. More specifically, the advantages, caveats, and biases of all three methods listed above will be presented, when applied to quantifying the protection performance of these highly protective armour panels.

2. METHODOLOGY

This study is based on statistical (Monte Carlo) computer simulations. No actual laboratory experiments were considered. Probabilities were used to estimate the firing velocity of any fragment given a target velocity, and to determine whether a complete penetration or a stop (partial penetration) was obtained as the fragment impacted the target material. For the firing velocity, a normal distribution centered around the target velocity was applied. A standard deviation equivalent to 2% of the target velocity was arbitrarily assigned, representative of deviations typically observed in ballistic laboratories (Figure 8). Andres et al. [3] also used a normal distribution with a similar standard deviation for the target velocity.

The S-curve of a material was determined assuming a normal distribution. A Weibull distribution, already discussed in the context of fragmentation testing [9, 10] or other distributions might have provided more realistic probabilities, especially in the low range of the S-curve. Indeed, a normal distribution provides for instance a non-zero probability of complete penetration even for negative firing velocities. Nevertheless, a normal distribution was selected to minimize the number of parameters (only the mean and the standard deviation are required). Andres et al [3] and Eridon et al. [8] have also assumed a normal (Gaussian) distribution when defining the S-curve of their idealized materials.

Two different idealized materials (Material A and Material B) were considered in this study. Both materials share the same V_{50} value but exhibit two different standard deviations. Specifically, a single V_{50} value of 1000 m/s was selected, while standard deviations of 20 m/s (Material A) and 100 m/s (Material B) were selected. Large enough differences in standard deviations were assigned to properly characterize the influence of S-curve steepness. The S-curves for Materials A and B (Figure 9) were used to determine the probability of complete penetration for any given firing velocity.

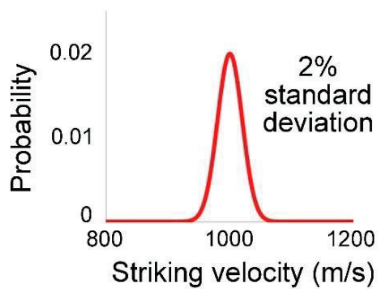

Figure 8. Distribution of striking velocities for a 1000 m/s targeted value, based on a 2% standard deviation

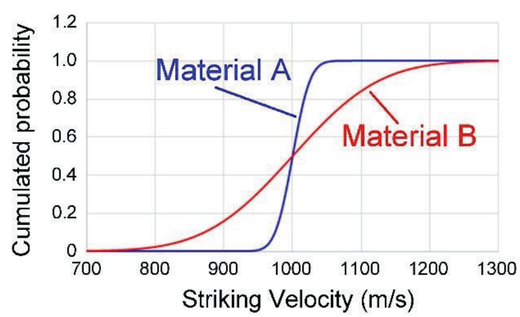

Figure 9. The S-curves for Materials A and B (same V_{50} of 1000 m/s, but standard deviations of 20 and 100 m/s respectively)

To determine the V_{50} of a material, the "up and down" procedure from STANAG-2920 was applied. According to this procedure, a first shot is fired at or near the expected V_{50} value. The following striking velocities are determined according to the decision algorithm illustrated in Figure 10. The procedure ends when either one of the four conditions listed in Table 1 is achieved. Figure 11 illustrates a representative test scenario, having led in that case to the determination of a V_{50} value based on the "3x3" condition from Table 1.

Table 1. STANAG 2920 V_{50} procedure – End conditions

Condition	Number of shots needed	Velocity range	V_{50} calculation
3x3	3 stops and 3 complete penetrations	within a range of 40 m/s	Average of the 6 velocities
4x4	4 stops and 4 complete penetrations	within a range of 60 m/s	Average of the 8 velocities
5x5	5 stops and 5 complete penetrations	within a range of 80 m/s	Average of the 10 velocities
Inconclusive	When none of three above conditions can be met. No V_{50} value can be determined		

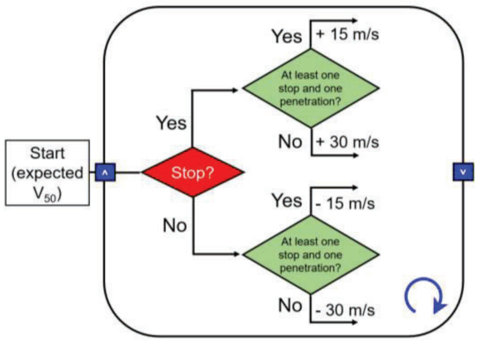

Figure 10. Up and down V_{50} procedure as per STANAG-2920. The suggested velocity changes are approximate

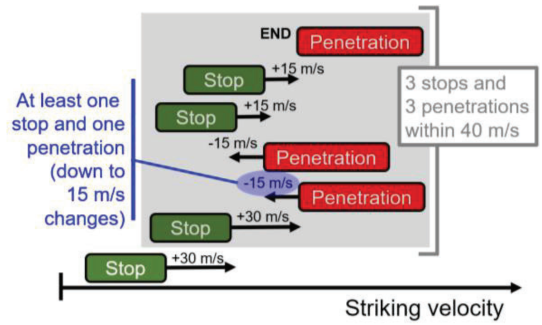

Figure 11. Example of a V_{50} scenario using the up and down procedure (from bottom to top)

To determine a V_{proof} value, AEP-2920 requires a total of 22 stops, fired within a range of the targeted V_{proof} value to 20 m/s above this target (Eridon et al. [8] provides the history and rationale behind this value of 22). Any single complete penetration within this range (or lower) results in a failed V_{proof} test. AEP-2920 does not mandate an actual procedure to determine the velocity at which fragments must be fired. But for the purpose of the current simulations, the target velocity was always in the middle of the sought range, i.e. the target V_{proof} plus 10 m/s. Variations in the actual firing velocity then resulted, from the assumed normal distribution illustrated in Figure 8. The procedure was interrupted either after 22 eligible consecutive stops were obtained, or as soon as a complete penetration was observed, within the desired velocity range. Figure 12 illustrates two representative V_{proof} test scenarios, having led to the two possible outcomes (pass or fail).

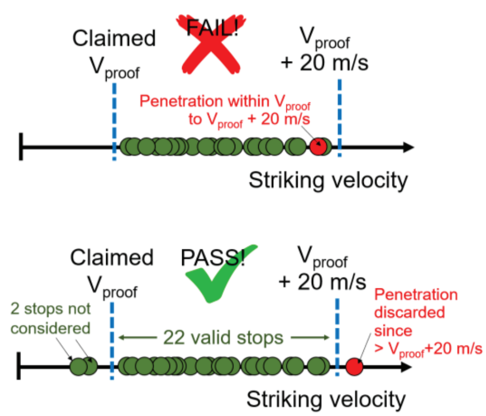

Figure 12. Two representative V_{proof} scenarios

As discussed earlier, some bomb suit manufacturers have sometimes relied on a customized methodology, not recognized by any standard, to quantify a performance characteristic meant to be similar in concept to a V_0 or V_{proof}. As this procedure overestimates the performance (as will be demonstrated), it was labelled as $V_{0\text{-claimed}}$ in the current study. Simulations were conducted whereby all shots were fired at approximately the targeted $V_{0\text{-claimed}}$ velocity. The actual firing velocity then varied according to the normal distribution illustrated in Figure 8. When a velocity exceeded the targeted $V_{0\text{-claimed}}$, the shot was excluded from the analysis, unless it corresponded to a stop. All other shots were considered. The procedure was repeated until a total of 8 accepted shots were fired. Any complete penetration within these 8 data points yielded a failed result. This number of shots (8) was selected based on anecdotal evidence collected over the years, obtained from open bid/tender processes for bomb suits.

https://doi.org/10.52202/080042-0030

3. RESULTS

When performing Monte Carlo statistical analyses, the number of individual simulations conducted must be large enough to obtain consistent average results. A sensitivity analysis was therefore first conducted to determine an acceptable number of simulations to conduct. To this end, V_{50} values were calculated for both materials, with the same starting point corresponding to the V_{50}. The average V_{50} and standard deviation values are plotted in Figures 13 and 14 respectively, as a function of the number of simulations. Variations in both parameters are minimal across all cases, and beyond 20,000 repetitions, the curves get fairly stable. Hence, for the remainder of this work, a total of 20,000 simulations were conducted for each experiment. This number far exceeds the number of Monte Carlo simulations conducted by Andres et al. [3] and Eridon et al. [8] (1000 simulations), but not as high as for Cheng et al. [9] (100,000).

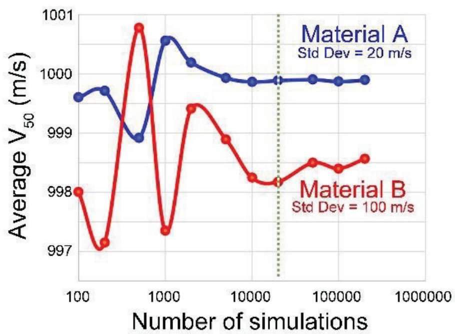

Figure 13. Average V_{50} as a function of the number of simulations

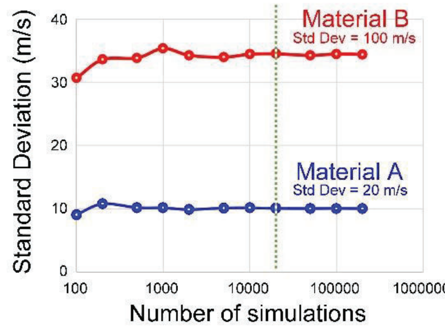

Figure 14. Average standard deviation as a function of the number of simulations

3.1 Effect of starting velocity on the V_{50}

While the STANAG-2920 V_{50} procedure is well defined, the start velocity is rather arbitrary. Indeed, the expected V_{50} is generally not known in advance. Andres et al. [3] and Cheng et al. [9] had already determined that the start velocity introduces a bias in the results (lower V_{50} with a lower start velocity, and higher V_{50} with a higher start velocity). To validate the model against these previous findings, simulations were conducted to investigate the effect of the start velocity on the V_{50} (Figure 15) and on the standard deviation (Figure 16) for both materials. The results indeed confirm the positive correlation between the start velocity and the simulated V_{50} value. The effect is much more pronounced for Material B, characterized by a wider zone of mixed results (less steep S-curve), compared to Material A.

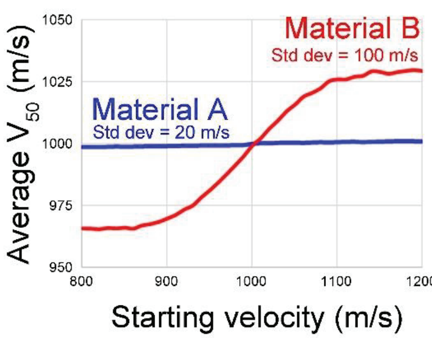

Figure 15. Average V_{50} as a function of the starting velocity

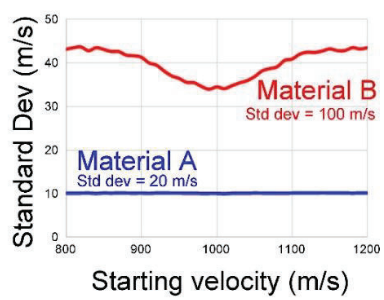

Figure 16. Average standard deviation as a function of the starting velocity

3.2 V_{50} determination in the NIJ 0117.01 standard for public safety bomb suits

The US National Institute of Justice NIJ 0117.01 standard for public safety bomb suits [2] includes V_{50} requirements for multiple protective areas against three specific fragment simulated projectiles. For every combination of area and fragment, a set of *three* V_{50} tests is required. A test panel is deemed to pass if: 1) the average of the three values exceeds the stated requirement, 2) no more than one single V_{50} test lies below the requirement and 3) if a test is below the minimum, it cannot be lower by more than 25 m/s. Table 2 summarizes the possible outcomes from a set of three individual NIJ V_{50} tests.

Table 2. NIJ 0117.01 V_{50} procedure – Possible outcomes

Average of 3 V_{50}s	# of results above the requirement	# of results >25 m/s below requirement	Result
> requirement	3	n/a	PASS
> requirement	2	0	PASS
> requirement	2	1	FAIL
> requirement	1	irrelevant	FAIL
< requirement	irrelevant	irrelevant	FAIL

The NIJ standard refers to the MIL-STD-662 test methodology, which is very similar to STANAG-2920. A similar requirement applies for the start velocity, which is near the expected V_{50} value. In the present study, the start velocity for the first of the three V_{50} tests was varied for investigation purposes. However, the start velocity for the second test was selected as the V_{50} obtained in the first test. And the start value for the third test was taken as the average of the first two V_{50} values. When tests were inconclusive, additional tests were performed to arrive at a set of three valid V_{50} values.

Figure 17 compares the V_{50} histograms obtained for Material A with a start velocity corresponding to the V_{50}, for the two cases of interest: a single V_{50} test (orange), and the NIJ scenario (green) involving the average of three tests. A tighter distribution is obtained in the NIJ case. Figure 18 then compares the V_{50} values obtained as a function of the start velocity for the first test when following the NIJ procedure (three tests) vs. the case with a single test, for Material B. Figure 18 demonstrates that the influence of the start velocity has been reduced in the NIJ scenario involving three tests instead of a single one.

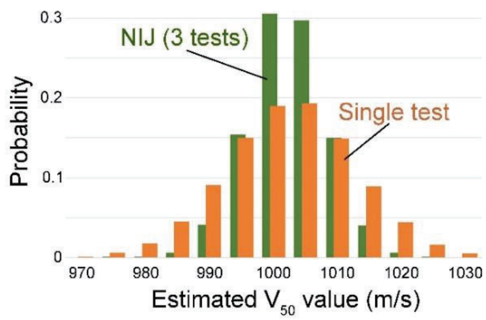

Figure 17. Reduction in V_{50} variability when using three tests as per the NIJ standard [2] (green) vs. a single test (orange) (Material A)

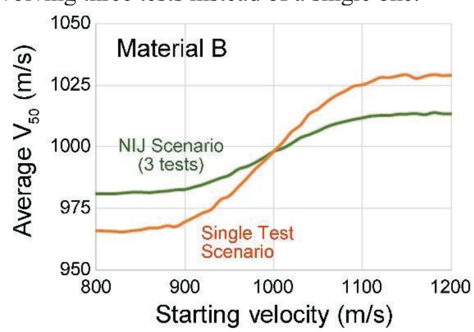

Figure 18. Reduction in V_{50} variability when using three tests as per the NIJ standard [2] (Material B)

Figure 19 investigates the probability of Materials A and B to meet different standard target velocities when tested according to the NIJ methodology. The horizontal axis displays the target NIJ velocity, while the vertical axis displays the probability of passing each of these target values. For both materials, the probability of meeting the true V_{50} of 1000 m/s (as per the S-curve) through an NIJ test is below 40%, which stresses the need to always include a buffer when making V_{50} claims. Specifically, when targeting a specific V_{50} requirement, a material with a higher "true" V_{50} (as per the S-curve) must be selected. Figure 20 complements Figure 19 by displaying the proportion of all 6 possible outcomes from Table 2, for the determination of the V_{50} as a function of the target NIJ value, for Material B.

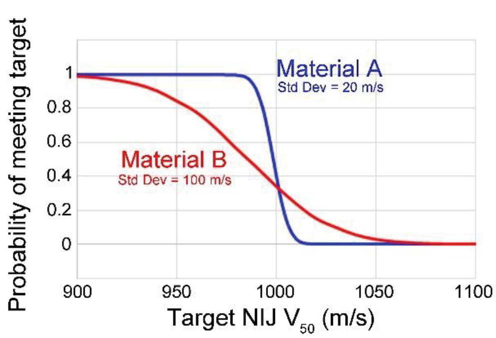

Figure 19. Probabilities for Materials A and B to meet NIJ target V_{50} ratings

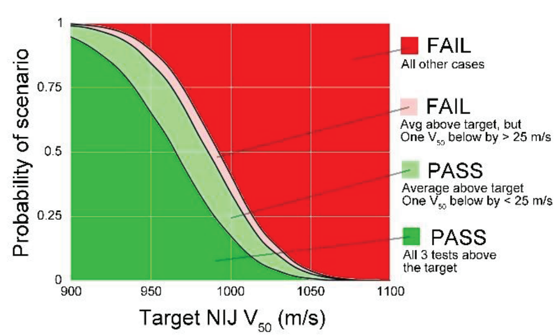

Figure 20. Proportion of all possible NIJ V_{50} outcomes for Material B

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3.3 V_{proof} determination from AEP-2920

Monte Carlo simulations were conducted to estimate the probability of meeting a range of V_{proof} target values for a given confidence level (probability that the observed confidence interval contains the true V_{proof} value). Figure 21 provides these probabilities, highlighting the scenarios with a confidence level of 90% (940 m/s for Material A, 735 m/s for Material B). As a comparison, the V1 for these two materials are 954 m/s and 872 m/s respectively. The 90% confidence V_{proof} values therefore provide conservative assessments of the stopping capability of materials, below the expected V1 performance. A V_0, given the use of a normal distribution for the S-curves, could not be achieved through these simulations. Figure 22 shows the average number of shots required before a first complete penetration, as a function of V_{proof} target level, for both materials. For the 90% confidence level V_{proof} levels, the average required number of shots is 214 for Material A, and 202 for Material B, values much higher than the required number of stops for a V_{proof} (22). This being said, there is nevertheless a 10% chance of failing the V_{proof} test when testing at the 90% confidence level, meaning, 10% chance of a penetration within the first 22 shots.

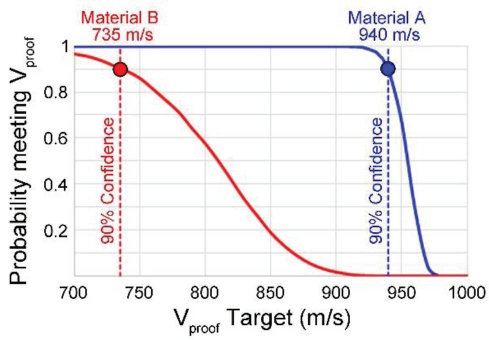

Figure 21. Probabilities for Materials A and B to meet V_{proof} target ratings, highlighting the 90% confidence case

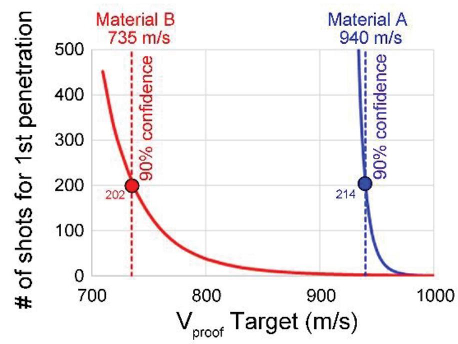

Figure 22. Average number of shots required for a first penetration, for Materials A and B. The 90% confidence level case is highlighted

3.4 $V_{0\text{-claimed}}$ determination (customized methodology)

Figure 23 shows the probability of meeting $V_{0\text{-claimed}}$ target values for Materials A and B. As highlighted before, the $V_{0\text{-claimed}}$ is a customized methodology not based on valid statistical grounds, that was used by some bomb suit manufacturers to *estimate* V_0 ratings. A $V_{0\text{-claimed}}$ experiment consists here of 8 stops (no complete penetration), with the highest stop being considered as the obtained $V_{0\text{-claimed}}$ rating. Figure 23 highlights the fact that for a $V_{0\text{-claimed}}$ target corresponding to the V_{50} of the material (1000 m/s here), there is a non-negligible chance (~20%) of meeting this target for Material A. This corresponds to estimating a V_0 exceeding the V_{50}, which does not make sense. Figure 24 further highlights the issue with the $V_{0\text{-claimed}}$ concept to estimate a V_0. In this figure, the $V_{0\text{-claimed}}$ and V_{proof} ratings for Material A are plotted with respect to the confidence level. The $V_{0\text{-claimed}}$ rating exceeds the V_{proof} rating by approximately 30 m/s across the entire range of confidence levels, which clearly indicates that the $V_{0\text{-claimed}}$, as its nickname suggests it, overestimates the protective capability of materials.

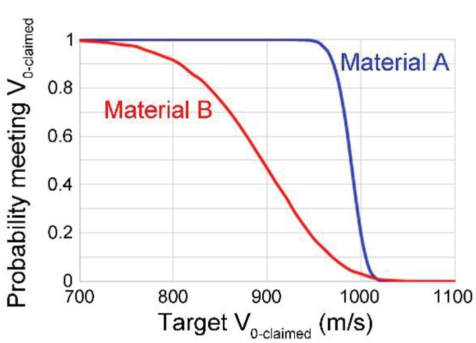

Figure 23. Probabilities for Materials A and B to meet $V_{0\text{-claimed}}$ target ratings

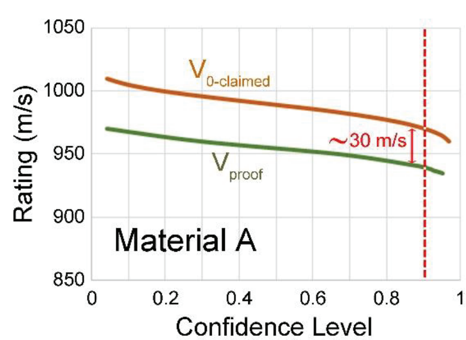

Figure 24. Comparison of the $V_{0\text{-claimed}}$ and V_{proof} ratings for Material A as a function of confidence level, highlighting the 90% confidence level case

4. DISCUSSION

As highlighted in this paper, the V_{50} methodology is effective at characterizing the protective capability of a material, using a standardized test method requiring only a limited number of strikes (typically between 10 to 15). The results are repeatable, as suggested in Figure 16 which shows relatively low standard deviations, relative to a V_{50} of 1000 m/s. The only arbitrary parameter in the V_{50} "up and down" methodology is the start velocity, as the expected V_{50} rating is often unknown. But the variations due to the start velocity can be minimized by applying the NIJ 0117.01 V_{50} test procedure (Figure 18), which requires three tests to be conducted on any given material/fragment combination. The start velocities for the second and third V_{50} tests can then be based on the previous results.

In general, the disadvantage of relying solely on the V_{50} to characterize a material is that only a single point on the S-curve is being quantified. But when applying the NIJ procedure, the requirement to have all three individual values exceeding the requirement (or only two, if the third one is no more than 25 m/s below the target) forces manufacturers to take into account the inherent variability of the materials. Indeed, as shown in Figure 19, Material B, which has the same V_{50} as Material A, needs an additional buffer when it comes to claiming NIJ ratings. For instance, the V_{50} for Material A that can be claimed with 90% confidence using the NIJ 0117.01 procedure is 992 m/s. For Material B, one can only claim 940 m/s. Conversely, to claim a specified V_{50} rating, one must select a material with a V_{50} as per the S-curve exceeding that rating, with a buffer increasing with the standard deviation (variability) of the material. It can therefore be inferred that the NIJ procedure takes the S-curve of the material into account.

It can thus be concluded that the V_{50} is a proper *characteristic* of a material, which can readily be determined without any prior knowledge about the material and based on a limited number of strikes and material samples.

The V_{proof} on the other hand, is *not* a characteristic of a material, unless it is associated with a specific confidence level (e.g., 90%), as also pointed out by Eridon et al. [8]. As an example, a material that meets a V_{proof} of 1800 m/s with 90% confidence can possibly meet a higher V_{proof} with a lower confidence level. It can also meet a lower V_{proof} of 1750 m/s. As such, if no prior knowledge on this material exists prior to testing for V_{proof}, and a test at 1750 m/s indicates a pass, there is no way to know whether the material could qualify for an even higher V_{proof} rating. An additional test conducted at 1750 m/s could even yield a fail, given the probabilistic nature of such tests. Finding the 90% confidence level V_{proof} experimentally for a given material can therefore be a daunting task, requiring an extremely large number of strikes (22 shots multiplied by the number of required iterations, which is much higher than the three times 10 to 15 shots required for the NIJ V_{50} scenario). Moreover, if a V_{proof} close to the 90% confidence value is claimed, it must be kept in mind that there is still a 10% chance that a single V_{proof} test at that velocity would yield a failed result. As such, the V_{proof} is not a *proper* characteristic of a material, the same way the V_{50} is.

In the case highlighted in the introduction, where the V_{50} of a given material against a specific fragment is too high for laboratories to consistently shoot at the required velocities, a heavier fragment should be selected to conduct a V_{50}, rather than relying on a V_{proof} test. This is exactly the approach adopted in the NIJ 0117.01 standard for public safety bomb suits. For the highly protective bomb suit chest and groin areas (red area in Figure 5), the NIJ standard mandates the use of the heavier 2.9 g and 13.4 g FSPs, as opposed to the 1.1 g, recognizing the difficulty in obtaining a proper V_{50} with such a light fragment, for these highly protective areas.

Moreover, the NIJ 0117.01 certification process mandates testing to be conducted at NIJ approved laboratories. This ensures that no liberty can be taken by bomb suit manufacturers in selecting the most favourable tests or picking a start velocity higher than necessary, hoping for a positive influence on the results. The conduct of V_{proof} tests on the other hand, is not governed nor controlled by NIJ, which could allow bomb suit manufacturers to "cherry pick" the best results (testing at various laboratories and selecting the most favourable results) or testing at velocities higher than the 90% confidence level, hoping for luck to be on their side. In addition, relying on a single test sample ($n=1$), which is typically the case when only a few shots are considered such as in the $V_{0\text{-claimed}}$ case, does not result in an acceptable statistical significance.

5. CONCLUSION

As also emphasized by Andres et al [3] and Eridon et al. [4], test cost and panel costs are always a limiting factor when it comes to characterizing the fragmentation protection performance of armour panels. The best fragmentation protection characteristic of a given material to aim for, when cost limitations are present, is the V_{50}. The V_{50} is a proper characteristic of a material, which can be obtained following a

https://doi.org/10.52202/080042-0030

limited number of strikes, even without prior knowledge of the material's performance. If obtaining a proper V_{50} becomes difficult, given the high velocities involved, a heavier fragment should be used. The NIJ 0117.01 standard for public safety bomb suits indeed mandates the heavier 2.9 g and 13.4 g FSPs to be used, as opposed to the lighter 1.1 g, for the highly protective chest and groin areas of a bomb suit. But unfortunately, a lot of requirements still specify the 1.1 g FSP for high velocity V_{50} and V_{proof} ratings. This situation highlights the need for procurement agencies, in addition to manufacturers and test laboratories, to be made aware of the issues highlighted in this paper.

Ideally, the fragmentation protective performance of a bomb suit should be evaluated in the context of the NIJ 0117.01 certification program, which requires testing at NIJ approved laboratories, imposes three V_{50} tests per combination of fragment and panel, and ensures that proper procedures are followed. Following such a certification process is much more desirable than adopting customized methodologies such as the $V_{0\text{-claimed}}$ introduced in this paper, which can inappropriately boost the apparent performance of protective panels.

Of significant importance is that manufacturers and test laboratories should not rely on customized test methodologies, such as the one referred to in this paper as the "$V_{0\text{-claimed}}$", involving a relatively low number of stops, and claiming the highest of the stops as an estimate for a V_0. Such a methodology, in addition to substantially overestimating the protective ratings (as seen on Figure 24) is not based on any statistical ground. Or, if a customized methodology is used, test reports should state it explicitly and avoid misleading references to other test methods like the STANAG 2920 V0, when clearly not followed.

A V_{proof} is only of relevance when stated as a *requirement* to meet specific threats, as opposed to defining a characteristic of a material. V_{proof} tests should only be conducted in conjunction with V_{50} tests or other more extensive tests, for the proper characterization of armour panels.

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