

## Executive Summary

On November 17, 2003, Attorney General John Ashcroft announced the U.S. Department of Justice's Body Armor Safety Initiative in response to concerns from the law enforcement community regarding the effectiveness of body armor in use. These concerns followed the failure of a relatively new Zylon<sup>®</sup>-based<sup>1</sup> body armor vest worn by a Forest Hills, Pennsylvania, police officer. The Attorney General directed the National Institute of Justice (NIJ) to initiate an examination of Zylon<sup>®</sup>-based bullet-resistant armor (both new and used), to analyze upgrade kits provided by manufacturers to retrofit Zylon<sup>®</sup>-based bullet-resistant armors, and to review the existing program by which bullet-resistant armor is tested to determine if the process needs modification.

As part of the Body Armor Safety Initiative, NIJ has issued two status reports to the Attorney General containing results from the body armor studies.<sup>2</sup> The first two status reports highlighted the following findings:

- Ballistic-resistant material, including Zylon<sup>®</sup>, can degrade due to environmental factors, thus reducing the ballistic resistance safety margin that manufacturers build into their armor designs.
- The ultimate tensile strength<sup>3</sup> of single yarns removed from the rear panel of the Forest Hills armor was up to 30-percent lower than that of yarns from "new" armor supplied by the manufacturer. Artificially-aged armor of the same type that failed in the Forest Hills incident was ballistically tested, but no bullet penetrations occurred.<sup>4</sup>
- The upgrade kits tested did not appear to bring used armor up to the level of performance of new armor. However, used armors with upgrade kits performed better than the used armors alone.

NIJ has now completed ballistic and mechanical properties testing on 103 used Zylon<sup>®</sup>-containing body armors provided by law enforcement agencies across the United States. Sixty of these used armors (58%) were penetrated by at least one round during a six-shot test series. Of the armors that were not penetrated, 91% had backface deformations in excess of that allowed by

---

<sup>1</sup> Zylon<sup>®</sup> (PBO fiber – poly-*p*-phenylene benzobisoxazole) is a high-strength organic fiber produced by Toyobo Co., Ltd. Zylon<sup>®</sup> is a registered trademark of Toyobo Co., Ltd.

<sup>2</sup> "Status Report to the Attorney General on Body Armor Safety Initiative Testing and Activities," March 11, 2004, and "Supplement I: Status Report to the Attorney General on Body Armor Safety Initiative Testing and Activities," December 27, 2004.

<sup>3</sup> Ultimate tensile strength is the maximum stress (force per unit area) that a material, in this case a Zylon<sup>®</sup> yarn, can withstand prior to failure. All Zylon<sup>®</sup> yarns were nominally 500 denier; *i.e.*, the yarns did not vary in linear density or effective cross-sectional area.

<sup>4</sup> NIJ continues to study the Forest Hills body armor penetration, to resolve the cause of that failure.

the NIJ standard for new armor. Only four of the used Zylon<sup>®</sup>-containing armors met all performance criteria expected under the NIJ standard for new body armor compliance.

Although these results do not conclusively prove that all Zylon<sup>®</sup>-containing body armor models have performance problems, the results clearly show that **used Zylon<sup>®</sup>-containing body armor may not provide the intended level of ballistic resistance**. In addition, the results imply that a visual inspection of body armor and its ballistic panels does not indicate whether a particular piece of Zylon<sup>®</sup>-containing body armor has maintained its ballistic performance.

Part of the Body Armor Safety Initiative entailed an applied research component that examined material properties of Zylon<sup>®</sup> in order to understand the causes of the ballistic failures. Zylon<sup>®</sup> fibers show a systematic loss in tensile strength, tensile strain, and ballistic performance correlated with the breakage of specific bonds in the chemical structure of the material.

Preliminary findings from the applied research effort indicate that:

- It is likely that the ballistic performance degradation in Zylon<sup>®</sup>-containing armors is closely related to the chemical changes in poly-*p*-phenylene benzobisoxazole (PBO), the chemical basis of Zylon<sup>®</sup> fiber. The breakage of one particular part of the PBO molecule, known as the oxazole ring, correlates with degradation of the mechanical properties of Zylon<sup>®</sup> fibers. The breakage in the oxazole ring can be monitored using an analysis technique known as Fourier transform infrared (FTIR) spectroscopy.
- Preliminary investigations into Zylon<sup>®</sup> degradation mechanisms have suggested that oxazole-ring breakage occurs as a result of exposure to both moisture and light.
- When there was no potential for external moisture to contact Zylon<sup>®</sup> yarns, there was no significant change in the tensile strength of these yarns. External moisture may be necessary to facilitate the degradation of Zylon<sup>®</sup> fibers.

Based on the direction from the Attorney General and recommendations from the law enforcement community, NIJ has examined its body armor compliance testing program. The current NIJ testing program is based on the ballistic resistance of new armor and does not take into account performance degradation in used armor. NIJ is concerned that Zylon<sup>®</sup> and other materials may be incorporated into body armor, with minimal understanding of performance degradation that may result from environmental exposures. NIJ's research indicates that its testing program should take into account the possibility of ballistic performance degradation over time.

NIJ intends to adopt interim changes to its body armor compliance testing program, to aid in ensuring that officers are protected by body armor that maintains its ballistic performance during its entire warranty period. These actions are set forth in detail in Section VI of this report. Under the NIJ 2005 Interim Requirements for Bullet-Resistant Body Armor, armor models containing PBO (the chemical basis of Zylon<sup>®</sup>) will not be compliant, unless their manufacturers provide satisfactory evidence to NIJ that the models will maintain their ballistic performance over their declared warranty period.

All manufacturers will be required to submit information concerning materials used in the construction of any armor submitted for testing.

NIJ will recommend that those who purchase new bullet-resistant body armor select body armor models that comply with the NIJ 2005 Interim Requirements for Bullet-Resistant Body Armor. A list of models that comply with the requirements will be made available at <http://www.justnet.org>.

NIJ will also encourage manufacturers to adopt a quality-management system to ensure the consistent construction and performance of NIJ-compliant armor over its warranty period. In the future, NIJ will issue advisories to the field regarding materials used in the construction of body armor that appear to create a risk of death or serious injury as a result of degraded ballistic performance. Any body armor model that contains any material listed in such an advisory will be deemed no longer NIJ-compliant unless and until the manufacturer satisfies NIJ that the model will maintain its ballistic performance over its declared warranty period. NIJ will continue its research and evaluation program to determine what additional modifications to the requirements of NIJ's compliance testing program may be appropriate, to understand better the degradation mechanisms affecting existing or new ballistic materials, and to develop test methods for the ongoing performance of body armor.

**NIJ continues to encourage public safety officers to wear their Zylon<sup>®</sup> - containing armor until it is replaced. Even armor that may have degraded ballistic performance is better than no armor.**