United States Environmental Protection Agency
Research and Development

*Risk Reduction* Engineering Laboratory
Cincinnati, OH 45268

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EPA

# Project Summary

# Limited-Use Chemical Protective Clothing for EPA Superfund Activities

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**Because contractor field personnel complained about the poor durability and fit of limited-use chemical protective clothing (CPC) most commonly used at hazardous waste site operations, the U.S. Environmental Protection Agency (EPA) initiated a study to**

- **characterize use of CPC**
- **determine problems encountered**
- **develop solutions to problems**
- **communicate results in publications and procurement guidelines**

**Personnel at two Superfund hazardous waste sites were surveyed about CPC problems. Poor fit of coveralls and lack of fabric durability resulted in garment failures, especially in the seat, crotch, and underarms. Some fabrics were identified that provided improved performance.**

**The commercial market was surveyed, and commercial fabrics for limited-use CPC were identified and obtained. In addition, two experimental fabrics were obtained. All available fabrics were tested for breaking strength and flexibility. Based on these tests and the field survey, acceptable minimum values for breaking strengths of coated and uncoated fabrics and acceptable maximum values for stiffness were determined. One of the experimental fabrics, DuPont Tyvek® 1445* coated with polyethylene, was found to be especially promising when compared with these values.**

**Available standards and specifications describing size and fit parameters for limited-use CPC were identified and reviewed relative to EPA Superfund CPC needs. None of the standards were found to be fully acceptable. American National Standards Institute (ANSI) Standard 101-1985, however, provided a satisfactory baseline for further standards development. Problems with CPC were analyzed and suggested changes to ANSI 101 were developed as a proposed procurement guideline. This information was presented to the Industrial Safety Equipment Association, which developed the ANSI standard.**

***This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

EPA has responsibility for hazardous substances/hazardous waste (HS/HW) in the United States. To address risks to personnel from HS/HW, the Occupational Safety and Health Administration (OSHA) promulgated 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response, in 1988. This regulation requires personal protective equipment (PPE) to be provided for HS/HW activities. PPE for hazardous waste operations and hazardous substance emer-

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

gency response is divided into four levels, A, B, C, and D, with Level A encompassing the most protection, Level D the least, and Level C being the most commonly used level. Health and safety personnel select CPC based on several factors, including the chemical composition and physical form of the HS/HW. Most of the CPC used by EPA and its contractors is discarded after each use. Since coveralls typically cost between $10 and $20 apiece, the total yearly cost for all CPC is estimated at over $5,000,000. To assist field personnel in cost-effectively complying with 29 CFR 1910.120, the EPA sponsored this study to identify and help solve problems that have been observed during the use of limited-use CPC.

## Field Investigation

When EPA contractor personnel were surveyed and interviewed about limited-use CPC, the problems they most commonly voiced concerned durability/tearing and fit.

In general, only one or two sizes were available in the field, and the exceptionally large and the small person had the most problems. The coveralls bound in the hood, chest, back, seat, armholes, and thighs, especially when worn with winter clothing. The survey suggested that the current sizing in the industry was inadequate.

The coveralls tore, both those of uncoated Tyvek® 1422 and those coated with polyethylene or laminated to Saranex 23-P®. The coated and laminated fabrics were more durable but still inadequate. Duct tape was used not only to seal the garments but also to tailor them.

Kleenguard®, another brand of nonwoven fabric, provided better durability than uncoated Tyvek 1422, but it is not available in coated forms. The newer and more expensive fabrics such as Barricade®, Responder®, and Chemrel Max® were found to be tougher but much stiffer and thus required more sizes to fit the personnel. Sijal Chemtex®, a coated woven fabric, was found to be tougher but uncomfortable because of its weight. The stiffer or heavier fabrics are not readily tailored with duct tape.

The Chemtex suits cost about $40 and are usually cleaned and reused rather than being discarded. There appears to be a cost point between $20 and $40 where disposal after one use is prohibitive and, in practice, discouraged.

## Laboratory Investigations

### *Fabric Evaluation*

#### Tests and Results

Physical properties of fabrics are related to both durability and comfort. Available commercial and experimental fabrics were tested for weight, breaking strength, and flexibility using American Society for Testing and Materials (ASTM) standard test methods (Table 1).

Results are presented in Table 2. The fabric most commonly found to fail in the field, Tyvek 1422, showed the lowest breaking strength of any fabric tested, 5.2 x 7.5 lb. (Test specimens were cut from the garments at a 90° angle to one another. The results for each direction are reported using the format A x B.) Kleenguard, which was reputed to have better durability, tested higher, at 9.8 x 12.2 lb. The most commonly used coated fabric, Tyvek 1422/PE, demonstrated a breaking strength of 11.7 x 12.5 lb., and the more durable Tyvek 1422/Saranex 23-P measured higher, at 13.6 x 13.6 lb.

The breaking strengths of two experimental fabrics, Tyvek 1443/PE and Tyvek1445/PE, were greater (12.7 x 13.9 and 14.2 x 15.6 lb., respectively) than that of standard Tyvek 1422/PE.

The uncoated fabrics exhibited the best flexibility, with bending lengths ranging from 1.15 x 1.3 to 1.7 x 2.15 in. (higher bending lengths indicate greater stiffness). The coated nonwoven fabrics showed a much wider range of flexibility, with bending lengths ranging from 1.65 x 1.80 in. to over 10.0 x 3.0 in.

The coated woven fabrics, Chemtex, Chemgard®, and Neonyl®, were the strongest fabrics and were relatively flexible; but they were also the heaviest.

### *Discussion*

The fabrics tested can be divided into two distinct stiffness categories: bending lengths less than or greater than 2.5 in. One could infer that for garments to be accepted in the field, bending length should be less than 2.5 in. This is supported by comments from the field that Tyvek 1422/Saranex 23-P garments are the stiffest fabrics considered acceptable.

There is a similar well-defined gap in fabric breaking strength; fabrics testing less than 9 lb. were not acceptable in the field. Fabrics in the second grouping (> 9 lb.) provided greater durability than those in the first but typically at the expense of reduced flexibility. This supports the comments that, for durability in the field, Tyvek 1422/Saranex 23-P is considered to be the minimum acceptable coated fabric, and Kleenguard is considered the minimum acceptable uncoated fabric.

A promising fabric, the experimental Tyvek 1445/PE, was compared with standard Tyvek 1422/PE. The comparison demonstrated that approximately 30% greater strength can be achieved with an increase of less than 10% in weight and stiffness. This suggests that fabric engineering can increase strength while minimizing increases in stiffness and weight.

### *Evaluation of Fit and Sizing*

#### Procedure

Many limited-use garments are designed to meet the requirements of ANSI Standard 101-1985, Men's Limited-Use and Disposable Protective Coveralls-Size and Labeling Requirements. This voluntary consensus standard was developed by the Industrial Safety Equipment Association (ISEA). ANSI 101 defines five sizes: small through extra-extra-large, and lists measures for seven dimensions, as summarized in Table 3.

***Table 1.*** *Standard Test Methods for Evaluating Chemical Protective Clothing Fabrics*

| *Test Number* | *Test* |
|---|---|
| *ASTM* D 1682* | *Breaking Load and Elongation of Textile Fibers* |
| *ASTM D 1388* | *Stiffness of Textile Fabrics* |
| *ASTM D 3776* | *Mass per Unit Area of Textile Fabrics* |

**American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.*

**Table 2.** *Physical Characteristics of Limited-Use Chemical Protective Clothing Fabrics*

| Fabric | Weight* (SD ++) | Breaking Strength** (SD, SD) | Bending Length + (SD, SD) |
|---|---|---|---|
| **Uncoated Nonwovens** | | | |
| Enhance | 1.88 | 9.5 x 9.8 | 1.7 x 2.15 |
| | (0.2) | (0.9, 0.9) | (0.15, 0.1) |
| Kleenguard | 1.85 | 9.8 x 12.2 | 1.65 x 1.6 |
| | (0.1) | (0.7, 1.2) | (0.05, 0.05) |
| Kleenguard LU | | Sample Not Received | |
| Tyvek 1422 | 1.24 | 5.2 x 7.5 | 1.15 x 1.3 |
| | (0.15) | (0.2, 0.6) | (0.05, 0.05) |
| **Coated/Laminated Nonwovens** | | | |
| Barricade | 6.39 | 24.9 x 31.4 | 5.95 x 4.2 |
| | (0.45) | (6.1, 4.0) | (0.35, 0.2) |
| Blue Max | | Received insufficient sample for testing | |
| Chemrel | 4.08 | 27.6 x 15.0 | 5.2 x 3.3 |
| | (0.45) | (1.1, 1.0) | (0.6, 0.2) |
| Chemrel Max | 5.19 | 44.9 x 33.1 | >10.0 † x 3.0 ‡ |
| | (0.6) | (3.1, 5.5) | (NA, 1.0) |
| Chemtuff | 3.60 | 41.6 x 51.2 | 5.2 x 4.5 |
| | (0.35) | (2.9, 4.7) | (1.35, 1.4) |
| Encase II | 2.33 | 11.1 x 13.8 | 1.1 x 1.65 |
| | (0.3) | (2.0, 2.4) | (0.2, 0.15) |
| Greenguard | | Sample Not Received | |
| PP/Saranex 23-P | 3.53 | 16.0 x 10.1 | 1.85 x 1.85 |
| | (0.25) | (1.7, 1.9) | (0.1, 0.15) |
| Responder | 8.23 | 40.3 x 34.8 | 4.5 x 4.35 |
| | (0.9) | (4.9, 4.4) | (0.4, 0.35) |
| Tyvek/Saranex 23-P | 3.60 | 13.6 x 13.6 | 1.85 x 2.2 |
| | (0.2) | (1.5, 1.4) | (0.2, 0.25) |
| Tyvek 1422/PE | 2.14 | 11.7 x 12.5 | 1.65 x 1.80 |
| | (0.15) | (1.8, 1.1) | (0.25, 0.25) |
| Tyvek 1443/PE | 2.18 | 12.7 x 13.9 | 1.75 x 1.90 |
| | (0.2) | (1.2, 1.1) | (0.15, 0.3) |
| Tyvek 1445/PE | 2.23 | 14.2 x 15.6 | 1.85 x 2.1 |
| | (0.25) | (1.2, 2.2) | (0.45, 0.3) |
| **Coated Wovens** | | | |
| Chemgard | 10.40 | 115.8 x 91.7 | 1.85 x 1.5 |
| | (1.1) | (9.5, 5.9) | (0.1, 0.15) |
| Chemtex | 9.52 | 61.2 x 70.0 | 1.9 x 1.0 |
| | (1.2) | (2.8, 9.3) | (0.1, 0.05) |
| Neonyl | 15.19 | 130.4 x 104.13 | 1.62 x 1.53 |
| | (0.6) | (12.7, 9.0) | (0.2, 0.1) |

* *ASTM D 3776, option C; ounces/square yard.*
** *ASTM D 1682, rate of extension, 5 inch/minute; pounds, direction A x direction B, where direction A is 90° to direction B.*
\+ *ASTM D 1388, option A; inches, direction A x direction B, where direction A is 90° to direction B.*
\++ *Standard deviation, n=5.*
† *Samples curled upward through full range of apparatus.*
‡ *Samples curled downward without flexing.*

A small sample of commercial CPC coveralls was measured and compared against the standard. Full compliance with ANSI 101 was found in only one case. The variations, however, were not considered great enough to cause the garment failures seen in the field. This suggests that the standard itself, rather than poor compliance, is the problem.

A military specification and a General Services Administration (GSA) schedule for limited-use coveralls were identified. Two pairs of coveralls, one conforming to each, were measured and examined. Neither coverall appeared likely to provide better durability or fit than commercial garments meeting ANSI 101.

The National Fire Protection Association (NFPA) is currently preparing a specification on certain limited-use coveralls. The present version of this specification, however, does not incorporate a sizing requirement.

Because of the problems noted in the field and the lack of acceptable limited-use coverall specifications or standards, garment design was investigated to develop a better sizing system than that currently used in ANSI 101. The following was determined:

- The current range of five sizes should be expanded to six to provide a better fit range, especially for women and large males.
- The field data suggest that present coverall designs do not include sufficient back body length. Tearing under the arm may be related to inadequate back width and armhole width. Additional back length and ease for the armhole is required to fit over winter clothing.
- Additional sleeve outseam and leg inseam length will increase the range of fit for tall workers.
- A range of sleeve openings will keep excess bulk from hindering smaller sizes and allow easier donning and doffing for larger males.
- An increase in leg opening size will provide a wider range of fit, especially when donned over safety shoes.
- An increase in the difference between front and back width will increase range of motion, especially for the arms when reaching.
- An increase in the range of front opening lengths will ease donning for larger males.
- ANSI 101 does not currently include hood dimensions; however, hoods are considered desirable for EPA activities and must fit when worn over hard hats. Hood

*Table 3. ANSI* 101-1985 Minimum Requirements*

| *Size*** | *Chest* | *Leg Inseam* | *Sleeve Outseam* | *Body Length* | *Sleeve Opening* | *Leg Opening* | *Front Opening Length* |
|---|---|---|---|---|---|---|---|
| *Small* | *21 1/2* | *27 1/2* | *31 1/2* | *35* | *6 1/2* | *9 1/2* | *29 1/2* |
| *Medium* | *23 1/2* | *28* | *32 1/2* | *36* | *7* | *10* | *29 1/2* |
| *Large* | *25 1/2* | *29* | *33 1/2* | *37* | *7* | *10* | *30* |
| *X-Large* | *27 1/2* | *29 1/2* | *35* | *38 1/2* | *7* | *10* | *30 1/2* |
| *XX-Large* | *29 1/2* | *30* | *36 1/2* | *39* | *7* | *10* | *31* |

* *American National Standards Institute, 1430 Broadway, New York, NY 10018.*
** *All dimensions in inches.*

opening length and hood depth specifications are required.

- Neckline length requirements are needed to ensure fit when worn over winter clothing.

Proposed measurement procedures for measuring coveralls are summarized in Table 4.

Minimum requirements for the Table 4 dimensions were developed for six sizes of limited-use coveralls, and are summarized in Table 5.

## Discussion

In the proposed sizing system, extra-small and small have been optimized for smaller persons, while extra-large and extra-extra-large are optimized for upper-percentile large persons. Size extra-extra-large should fit a 95th percentile worker wearing temperate climate winter clothing.

## Conclusions

Improvements described for both fabrics and coverall sizing are considered a starting point for continuing efforts to provide improved protective clothing for EPA hazardous waste workers. This study has identified a promising, experimental, coated, limited-use CPC fabric, DuPont Tyvek 1445. It is hoped that further development will continue.

Fabric and garment performance and sizing information have been formatted for use as a Procurement Guideline for EPA personnel. This information has also been presented to the ISEA for use in updating ANSI 101.

The study identified several questions that should be investigated further. One was the role of seams, closures, and uncoated fabrics in providing effective protection from liquids. Another was the realization that many waste sites contain solvents and petroleum products that are flammable or combustible, yet flame resistance test methods appropriate for operations at the sites have not yet been identified. Finally, field personnel suggested that better CPC training programs and a PPE "hot line" should be developed.

The full report was submitted in partial fulfillment of Contract No. 68-03-3293 by Arthur D. Little, Inc., under the sponsorship of the U.S. Environmental Protection Agency.

*Table 4. Proposed Limited-Use Coverall Measurement Procedures*

A. ***Back Body Length.*** *Measure from the top of the neckline at the center back collar seam to the crotch seam.*
B. ***Front Body Length.*** *Measured from the top of the neckline at the center back point to the crotch seam with the coveralls flat and front side up.*
C. ***Armhole Width.*** *Establish a line from the base of the armhole that is parallel to the center front. Measure up from the armhole base to the top of the sleeve with the coveralls stretched flat.*
D. ***Sleeve Outseam.*** *Measure from the center back point to the top of the sleeve at the wrist edge.*
E. ***Sleeve Opening.*** *Flatten sleeve at wrist end, completely stretching elastic if present. Measure from one folded edge to the other.*
F. ***Front At Chest.*** *Measure from the base of the armhole across the front chest to the base of the other armhole. If there is no underarm seam on either sleeve or body of coverall, lay the sleeve and body of coverall at an angle where both are flat and establish an underarm point at the juncture of the sleeve and torso.*
G. ***Back At Chest.*** *Measure from the base of the armhole across the back to the base of the other armhole, including all of the fullness that lies between these two points. If there is no underarm seam on either sleeve or body of coverall, lay the sleeve and body of coverall at an angle where both are flat and establish an underarm point at the juncture of the sleeve and torso.*
H. ***Leg Inseam.*** *Measure from the crotch seam down the leg inseam to the bottom edge.*
I. ***Leg Opening.*** *Flatten the leg at the ankle end, completely stretching elastic if present. Measure from one folded edge to the other folded edge.*
J. ***Front Opening Length.*** *Measure from the center back collar base to the bottom of the front opening with the coverall flat and front side up.*
K. ***Hood Opening Length.*** *Flatten the hood along the center seam so that the sides are superimposed. Measure on a flat vertical line that extends upward from the neckline seam to the highest point on the top of the hood.*
L. ***Hood Depth.*** *Flatten the hood along the center seam so that the left and right sides are superimposed. Measure on a horizontal line from the center front (face) edge to the back of the hood at the point of greatest depth.*
M. ***Neckline Length.*** *With front of coverall facing up, stretch neckline seam flat. Measure from one end of seam to the other.*

**Table 5.** *Minimum Finished Dimensions*

| Dimension* | Size | | | | | |
|---|---|---|---|---|---|---|
| | XS | S | M | L | XL | XXL |
| A. Back Body Length | 38 | 39 | 40 | 41 | 42 | 43 |
| B. Front Body Length | 33 | 34 | 35 | 36 | 38 | 40 |
| C. Armhole Length | 12 | 13 | 13 | 14 | 14 | 15 |
| D. Sleeve Outseam | 31 | 32 | 33 | 34 | 35 | 37 |
| E. Sleeve Opening | 6 | 6 | 7 | 7 | 8 | 8 |
| F. Front Chest | 22 | 23 | 24 | 26 | 28 | 30 |
| G. Back Chest | 23 | 24 | 26 | 29 | 32 | 34 |
| H. Leg Inseam | 28 | 29 | 30 | 31 | 32 | 33 |
| I. Leg Opening | 13 | 13 | 14 | 14 | 15 | 15 |
| J. Front Opening Length | 29 | 30 | 30 | 30 | 31 | 32 |
| K. Hood Length | 16 | 16 | 17 | 17 | 18 | 18 |
| L. Hood Depth | 11 | 12 | 12 | 13 | 13 | 14 |
| M. Neckline Length | 16 | 16 | 18 | 19 | 20 | 20 |

* All measurements in inches.



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***Michael Gruenfeld** is the EPA Project Officer (see below).*
*The complete report, entitled "Limited -Use Chemical Protective Clothing for EPA Superfund Activities," (Order No. PB92-143 494AS; Cost: $17.00, subject to change) will be available only from:*
*National Technical Information Service*
*5285 Port Royal Road*
*Springfield, VA 22161*
*Telephone: 703-487-4650*
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