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PROTECTIVE PROPERTIES OF LABORATORY GLOVES AGAINST CHEMICAL WARFARE AGENTS

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A b s t r a c t :

We measured the breakthrough times of laboratory gloves that are commonly used in laboratories and are easily accessible on protective equipment market. Standard measuring method of the Army of Czech Republic called MIKROTEST has been used to measure these breakthrough times. To measure breakthrough times this measuring method uses the distilled *sulfur mustard [bis(2-chloroethyl) sulfide]. The breakthrough time has been measured separately for different parts of each type of laboratory gloves (fingers, palm, back and wristband). The thickness of all the different glove parts has also been measured using a quick thickness meter. The measurement results have been statistically processed and minimal breakthrough time values for separate glove parts and for the whole gloves (disregarding the point of measurement) have been determined. Altogether nine types of laboratory gloves have been the subject of breakthrough time measurement.*

1. Introduction

To ensure perfect protection of personnel working with chemical warfare agents is the primary objective. The means of body surface protection are supplied with protective

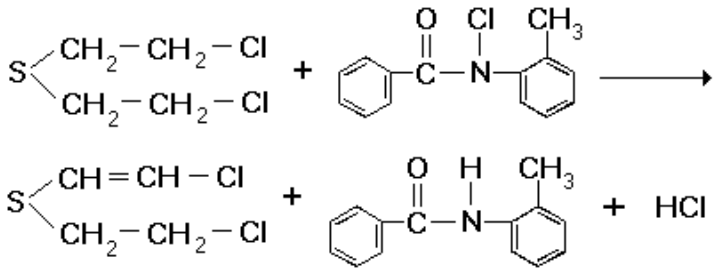
gloves, the purpose of which is to ensure protection against those agents, that these protective gloves are intended for. However protective gloves supplied within the protective suit sets are intended primarily for "rougher" types of work that usually do not require maintaining high hand sensitivity. Different types of gloves than those originally supplied within the means of body surface protection sets are very often used for instruments and laboratory equipment handling or in case of material shortage. The problem that might occur when using different types of gloves is the unfamiliarity with their protective properties against chemical warfare agents. The above is a reason to measure protective properties of laboratory gloves against chemical agents within the area of interest and to provide recommendation of protective equipment for different types of work based upon these measurements.

The actual protective properties of different materials against chemical warfare agents are specified by their so called breakthrough time. *The breakthrough time of a material may be defined as the time since the moment of contact of one side of a tested material with a liquid or gas chemical warfare agent or toxic industrial chemical until the moment, when threshold amount or otherwise defined limit amount of testing agent vapors appear on the opposite side.* The distilled sulfur mustard [bis(2-chloroethyl) sulfide] is used as a testing agent for testing materials designated to protect against chemical warfare agents. Because the breakthrough time depends upon temperature and phase of contaminant, the results have to be presented together with the temperature of measurement and method of contamination. Basic temperature for breakthrough measurements would then be 30 °C.

2. Measurement principle

The standard measuring method for measuring breakthrough times of barrier materials in the army is the MIKROTEST method [1, 2]. As an indicator of sulfur mustard penetration this method uses hygroscopic cellulose paper colored by Congo red (pH-indicator) and after drying out activated by CNITI-8 chloramide [*N*-chloro-*N*-(2-tolyl)benzamide]. The principle of indication is based upon the fact that reaction of CNITI-8 amide with sulfur mustard produces hydrogen chloride, the presence of which is observed as a change of pH factor and thus the originally red indication paper going blue in its color. This reaction may be represented by following formula:

The indication paper is directly in contact with the measured isolation foil (material) and the change of color occurs at the point of chemical warfare agent penetration. The moment of penetration of threshold amount (0.005 $mg.cm^{-2}$) of the chemical warfare agent is signaled by the first perceptible blue spot about 1 mm in diameter. The blue spot appearance is found out subjectively by observation. The change of color represents a change of pH within the range of 4 to 5. This color change is initiated by hydrogen chloride in concentration of about $1 \cdot 10^{-3}$ $mol.dm^{-3}$, which theoretically corresponds the same concentration of sulfur mustard.



An advantage of this method is the quick reaction of sulfur mustard with the indicator that is as Slabotinsky [3] points out almost four times faster than by the previously used method that used kupral (Sodium *N*,*N*-diethyldithiocarbamate) as a reagent.

3 Experimental part

3.1 Used chemicals, solutions and equipment

Congo red (pure), Lachema Brno, Czech Republic; CNITI-8 chloramide [*N*-chloro-*N*-(2-tolyl)benzamide] prepared by benzoylation of *o*-toluidine and subsequent chlorination of the occurring benzoyl-*o*-toluidine by sodium hypochlorite; bis(2-chloroethyl)sulfide (technical grade, content of HD 96,7%) (sulfur mustard, HD Gas) 072 Zemianske Kostolany, Slovakia; chloroform (purris, p.a.), Lachema Brno, Czech Republic.

1.5 % solution of CNITI-8 amide in chloroform, water-alcoholic solution of Congo red in concentration of 1 $g.dm^{-3}$.

Biological thermostat BMT, Brno, Czech Republic; quick thickness meter type 542–401, Mitutoyo, Japan; automatic pipette for CWA dosing; breakthrough time measurement utility consisting of two pieces of 70 by 70 mm underlay glass, 70 by 70 mm rubber mask 3mm thick with an opening 20 mm in diameter in the middle and Mauly 25 clincher for clinching the whole utility together; smooth paper tissues without printing and with neutral leach; polyurethane foam; aluminum foil; laboratory gloves, specifications of which are listed in the following table 1.

Table 1

Protective laboratory gloves characteristics

Type of glove: **Latex Exam Gloves Lightly Powdered** GN03 **Characteristic:** The gloves are intended as disposable examination gloves for medical and veterinary clinics, handling cosmetics and medicaments. They are suitable for groceries handling. **Material:** Natural latex; **Color:** Beige; **Size:** XS – XL **Manufacturer:** HPC Healthline UK Limited Colwood House, 158 Garth Road, Morden, Surrey, England SM4 4LZ
Type of glove: **Camatril® Velours** Art. 730 **Characteristic:** These gloves are recommended for automobile industry, petrochemical industry, printing works, paint shops, chemical industry, building cleaning and industrial cleaning, food industry. **Material:** Nitrile rubber; **Color:** Green; **Size:** 7, 8, 9, 10, 11 **Manufacturer:** Kächele-Cama Latex GmbH, Industriepark Rhön, Am Kreuzacker 9, D-36124 Eichenzell
Type of glove: **Bi-Colour™** Ref. 87-900 **Characteristic:** These gloves are recommended for aircraft industry, chemicals handling, batteries handling and electro technical industry. **Material:** Neoprene/Natural rubber (inner layer); **Color:** Green/yellow (wristband); **Size:** 6.5, 7, 7.5, 8, 8.5 9, 9.5, 10, 10.5, 11; **Manufacturer:** Ansell Healthcare Europe N.V., Riverside Business Park, Spey House, Boulevard International 55, B-1070 Brussels, Belgium.
Type of glove: **SEMPER-VELVET** **Characteristic:** These gloves are suitable for cleaning, food industry, gastronomy, laboratories, medicaments handling, agriculture, industrial works and house works. **Material:** Natural rubber; **Color:** Pink, yellow, blue; **Size:** 7, 8, 9, 10; **Manufacturer:** Semperit Technische Produkte Ges.m.b.H. & Co KG, Modecenterstraße 22, A-1031 Wien, Austria .
Type of glove: **Butoject®** Art. 898 **Characteristic:** Very durable gloves suitable for chemicals handling. They are recommended for printing works, laboratories, paints handling, chemical industry, in processing metals and plastics, wastes handling, cleaning and also for firefighters and armed forces. **Material:** Butyl rubber; **Color:** Black; **Size:** 8, 9, 10, 11; **Manufacturer:** Latex GmbH, Industriepark Rhön, Am Kreuzacker 9, D-36124 Eichenzell.

Table 1 part 2

Type of glove: **Camapren**® Art. 720 **Characteristic:** Durable gloves suitable for chemicals handling. They are recommended for laboratory works, chemical and petrochemical industry, galvanizing works, food industry and machinery manufacturing. **Material:** Chloroprene rubber; **Color:** Black; **Size:** 7, 8, 9, 10, 11; **Manufacturer:** Kächele-Cama Latex GmbH, Industriepark Rhön, Am Kreuzacker 9, D-36124 Eichenzell.
Type of glove: **Textile underlay protective gloves STANDARD** **Characteristic:** All-purpose gloves suitable for all kinds of industrial works and households. Most suitable in wet environment. According to supplied booklet these gloves endure the exposure of petrochemical products and acids. **Material:** Cotton knitwear with barrier layer (info booklet says PVC, PVC-Nitrile, Nitrile rubber); **Color:** Yellow; **Size:** 8, 9, 10 (sizing according to EN 9.5, 10.5, 11.5); **Manufacturer:** KOZAK Tachov, Tovarni No. 1, Czech Republic.
Type of glove: **PVC Rempo No. 151213** **Characteristic:** These cotton inner layer gloves with PVC outer barrier layer are suitable for diluted acids and lye, mineral oils, paints and gas handling. **Material:** Cotton tissue with PVC outer layer; **Color:** Red-brown; **Size:** 10, 11; **Manufacturer:** Gloves purchased in the Rempo Holoubek, a. s. sales network (The manufacturer was not identified).
Type of glove: **Greenfit™ Plus** Ref. 79-300 **Characteristic:** These gloves are recommended for automobile industry, chemicals handling, and constructions. **Material:** Nitrile rubber; **Color:** Green; **Size:** 7, 8, 9, 10; **Manufacturer:** Ansell Healthcare Europe N.V., Riverside Business Park, Spey House, Boulevard International 55, B-1070 Brussels, Belgium.

3.2 Conducted procedures

3.2.1 Indication paper preparation

An amount of 1.5 % solution of CNITI-8 amide in chloroform as needed for activation, the expenditure being presumed 0.05 cm^3 of reagent for 1 cm^2 indication paper, and a solution of Congo red in concentration of 1 $g.dm^{-3}$ has been prepared for the indication paper activation. Straps of paper tissues 50 to 65 mm wide (corresponding the width of samples) have been cut up and laid out upon a filtration paper and then using a disperser these straps have been sprayed with the prepared

Congo red solution. After spraying with this Congo red solution the straps were dried out freely by the laboratory temperature. Once dry the straps have been laid out upon a glass surface or filtration paper and using another disperser they have been sprayed with the CNITI-8 amide solution in such manner that the straps were just dipped. After that the straps have been dried out once again by the laboratory temperature. Once dry these straps have been cut up to separate indication papers 50 by 50 to 65 by 65 mm (depending upon the size of isolation foil samples). A sensitivity test has been conducted upon the indication paper after it was prepared like this. This sensitivity test has been conducted upon randomly picked out indication paper that did not show any evidence of being damaged (a significant change of color from red to blue in comparison with the other indication papers). The sensitivity of indication papers has always been tested whenever a new CNITI-8 chloramide solution was prepared.

3.2.2 Indication paper sensitivity test

The indication paper has been placed upon the 70 by 70 mm underlay glass and on the indication paper the rubber mask with a cut out middle opening has been placed after that. The rubber mask has then been covered by an 70 by 70 mm aluminum foil 0.05 mm thick with an 5 mm middle opening. Another rubber mask has been placed upon this aluminum foil and was subsequently covered by a 70 by 70 mm covering glass. The whole utility was sealed together by metal clinchers, put into a biological incubator and tempered for 10 to 15 minutes by temperature of 30 ± 1 °C. After the above time the utility has been taken out of the incubator and carried into a digester where after removing the covering glass a small polyurethane circlet saturated in sulfur mustard has been put upon the aluminum foil using a pincer. The covering glass has then been put back on; the utility has been sealed back together and put back into the incubator. Since the moment of contamination, that is the moment of placing the polyurethane circlet saturated in sulfur mustard upon the aluminum foil, a stopwatch was initiated and the bottom part of the utility was being observed carefully. At the moment of blue color occurring upon the indication paper the stopwatch was stopped. The indication paper is sensitive enough, if the blue color appears within 120 seconds.

3.2.3 Preparation of the protective glove samples for breakthrough time measurement

Samples of isolation foil have been cut out of predetermined parts of protective gloves – fingers, palm, back and wristband (an extended part of glove protecting the wrist). 50 by 50 to 70 by 70 mm squares have then been cut out the size depending upon the glove part that the isolation foil sample has been cut out of. These separate squares have then been checked and only those that did not show any evidence of being damaged have been used for breakthrough time measurements. The samples were marked by serial numbers and letters according to glove parts they were cut out of.

Using the quick thickness meter Mitutoyo the thickness has been measured in the middle of each sample.

3.2.4 Measuring of the protective glove samples breakthrough time

The indication paper has been placed upon the 70 by 70 mm underlay glass and then covered by a prepared protective laboratory glove sample. The rubber mask has then been placed upon the sample (Picture 1). A 7 mm circlet of filtration paper has been placed into the middle opening of the rubber mask and 20 µl sulfur mustard have been trickled onto this circlet. The rubber mask was after that covered by 70 by 70 mm covering glass and the whole utility was sealed together by metal clinchers. The breakthrough time measuring utility has then immediately placed into a biological incubator tempered to 30 °C temperature in such manner that it allowed the bottom part of measuring utility to be observed in order to spot the expected change of color. The time of sulfur mustard being applied was recorded. The above procedure has been used to prepare all the other samples as well.

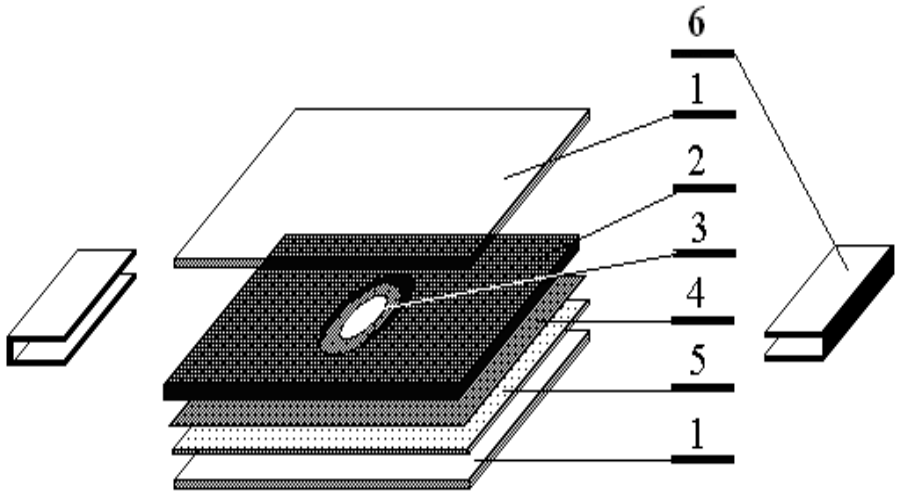


Fig. 1 The breakthrough time measuring utility ready to be put into a thermostat

1- underlay and covering glass, 2 – rubber mask, 3 – filtration paper scrap,
4 – isolation protective foil sample, 5 – indication paper, 6 – clincher

After the breakthrough time expiration, that is since the moment of sulfur mustard application upon the top of the sample until the moment the first blue 1 mm spot appears on the bottom side upon the indication paper, the elapsed time has been recorded and the isolation foil breakthrough time has been determined. After the breakthrough time being measured by all samples, the utilities have been taken out of the biological incubator and maintaining the proper safety precautions taken apart and put into a prepared decontamination solution.

4. Results and explanation

The results of material thickness measurements have proved that there are remarkable differences in thickness not only among different types of gloves but also among separate glove parts within those types. The thickness measured upon the textile underlay protective gloves STANDARD and PVC Rempo No. 151213 did not correspond with the actual protective layer thickness because these two types of gloves have their barrier (protective) layer applied upon an inner cotton fabric layer (see Table 1). This inner fabric layer does not represent any protective capability against the chemical warfare agents. The thickness measurements by the SEMPER -VELVET, Bi-Colour™, Camapren® and Greenfit™ Plus types may have been influenced by their profile (pattern) that covers the gripping parts of palm and fingers. According to the above reasons it is necessary to consider the results of thickness measurements by these types of gloves only as directory information that must not be considered as criteria for estimates or comparison of breakthrough times based upon glove thickness measurements. The construction of Latex Exam Gloves Lightly Powdered GN3 does not allow one to distinguish the palm from the back. That is the reason why the measurement of the back part is not presented in Table 2. The results for this part of glove are the same as for the palm.

The measurements have proven (Table 2) that the weakest part of a glove is usually its wristband (altogether in 6 cases when considering the minimal value of thickness or in 8 cases when considering the mean value of thickness). On the contrary the strongest glove part would generally according to the measurements in 7 cases be the fingers. Considering the fact that the wristband would usually be covered up by the sleeve of a body surface mean of protection, this result does not necessarily influence the protection of a user when handling chemical warfare agents. The lower thickness of a wristband and subsequently the protective properties of protective gloves are important to be taken in consideration when used as a protection against other pollutants by handling of which the protection of the whole body surface is not necessary.

Table 2

Statistical evaluation of the glove thickness [mm] depending upon the point of measurement (for valid number 10)

Statistical parameter	Measured glove part			
	Palm	Back	Wristband	Fingers
Glove type:	**Latex Exam Gloves Lightly Powdered GN3**			
Mean value	0.128	-	0.101	0.141
Median	0.126	-	0.100	0.143
Standard deviation	0.0132	-	0.0081	0.0151
Reliability level (95 %)	0.0095	-	0.0058	0.0108
Min. thickness value	0.119	-	0.095	0.130
Glove type:	**Latex Exam Gloves Lightly Powdered GN3 (2 layers)**			
Mean value	0.256	-	0.201	0.294
Median	0.257	-	0.200	0.294
Standard deviation	0.0251	-	0.0057	0.0131
Reliability level (95 %)	0.0179	-	0.0041	0.0094
Min. thickness value	0.238	-	0.197	0.285
Glove type:	**Camatril® Velours**			
Mean value	0.469	0.478	0.422	0.497
Median	0.472	0.481	0.428	0.501
Standard deviation	0.0336	0.0303	0.0260	0.0238
Reliability level (95 %)	0.0241	0.0217	0.0186	0.0171
Min. thickness value	0.445	0.456	0.403	0.480
Glove type:	**Bi-Colour™**			
Mean value	0.644	0.644	0.542	0.668
Median	0.640	0.646	0.540	0.668
Standard deviation	0.0472	0.0250	0.0125	0.0668
Reliability level (95 %)	0.0338	0.0179	0.0089	0.0478
Min. thickness value	0.610	0.626	0.533	0.620
Glove type:	**SEMPER-VELVET**			
Mean value	0.470	0.431	0.361	0.494
Median	0.473	0.445	0.361	0.479
Standard deviation	0.0995	0.0365	0.0220	0.0718
Reliability level (95 %)	0.0711	0.0261	0.0157	0.0513
Min. thickness value	0.399	0.405	0.345	0.443

Table 2 part 2

Statistical parameter	Measured glove part			
	Palm	**Back**	**Wristband**	**Fingers**
Glove type:			**Butoject®**	
Mean value	0.745	0.657	0.699	0.729
Median	0.730	0.661	0.687	0.741
Standard deviation	0.0419	0.0254	0.0261	0.0746
Reliability level (95 %)	0.0300	0.0182	0.0187	0.0533
Min. thickness value	0.715	0.639	0.680	0.676
Glove type:			**Camapren®**	
Mean value	0.713	0.721	0.687	0.761
Median	0.713	0.718	0.685	0.781
Standard deviation	0.0340	0.0297	0.0146	0.0428
Reliability level (95 %)	0.0243	0.0213	0.0105	0.0306
Min. thickness value	0.689	0.700	0.677	0.730
Glove type:			**Textile underlay protective gloves STANDARD**	
Mean value	1.365	1.346	1.371	1.227
Median	1.371	1.351	1.373	1.233
Standard deviation	0.0561	0.0402	0.0267	0.0607
Reliability level (95 %)	0.0401	0.0288	0.0191	0.0434
Min. thickness value	1.325	1.317	1.352	1.184
Glove type:			**PVC Rempo No. 151213**	
Mean value	1.157	1.208	1.097	1.214
Median	1.157	1.169	1.105	1.195
Standard deviation	0.0618	0.1061	0.0438	0.0593
Reliability level (95 %)	0.0442	0.0759	0.0313	0.0424
Min. thickness value	1.113	1.132	1.066	1.172
Glove type:			**Greenfit™ Plus**	
Mean value	0.502	0.472	0.424	0.489
Median	0.462	0.472	0.425	0.487
Standard deviation	0.0991	0.0154	0.0198	0.0230
Reliability level (95 %)	0.0709	0.0110	0.0141	0.0164
Min. thickness value	0.431	0.461	0.410	0.473

The conducted breakthrough time measurements have proven that the Latex Exam Gloves Lightly Powdered GN3 do have almost none protective capability against chemical warfare agents whatsoever. Practically immediately after applying the sulfur mustard it has penetrated through the foil of the measured glove part samples. As mentioned above the measurement was conducted by 30 °C temperature. Considering the fact that this type of gloves is very thin, it is most probable that the glove warms itself quickly up to the human body temperature. Because the breakthrough time decreases with growing temperature, generally with 10 °C temperature increase it decreases twice to 2.5 times, it is possible that after contamination by liquid chemical warfare agent it could simply break through the glove foil immediately and thus contaminate the user. Two layers of the examination gloves have been measured also after considering the fact that according to the Vsevojsk-2-10 manual [4], article 101 these gloves are predetermined as an optional hand protective gear by adjusting a chemical warfare agents set, purpose of which it is to contaminate vehicles and materiel. Not even the measurements of two layers have shown a remarkable increase of the breakthrough time. The breakthrough time mean value for the palm, as presented in table 3, is 10.2 minutes and for fingers it is 10 minutes. The minimal breakthrough time values acquired by calculation are 8.2 minutes for the palm and 8.4 minutes for fingers. The values measured for the palm are possible to presume also for the back. As it was mentioned before the universal construction of this type of gloves does not allow one to distinguish these two glove parts. Considering the fact that the wristband is the thinnest part of these gloves, the breakthrough time of this glove part has not been measured. Taking also the short breakthrough times by the other glove parts into consideration the breakthrough time of the wristband would have no practical significance.

Table 3

Statistical evaluation of the breakthrough times [min] depending upon the measured glove part (for valid number 10)

Statistical parameter	Measured glove part			
	Palm	Fingers	Palm	Fingers
Glove type:	Latex Exam Gloves Lightly Powdered GN3			
	1 layer		2 layers	
Mean value	2.0	3.1	10.2	10.0
Median	2.0	3.0	10.5	9.5
Standard deviation	0	0.88	2.74	2.31
Reliability level (95 %)	0	0.63	1.96	1.65
Min. breakthrough time value	2.0	2.5	8.2	8.4
Glove type:	**Camatril® Velours**			
Statistical parameter	**Palm**	**Back**	**Wristband**	**Fingers**
Mean value	63.0	59.8	55.6	58.4
Median	62.0	60.5	52.5	57.5
Standard deviation	11.57	3.36	6.08	6.85
Reliability level (95 %)	8.27	2.40	4.35	4.90
Min. breakthrough time value	54.7	57.4	51.3	53.5
Glove type:	**Bi-Colour™**			
Mean value	30.7	34.8	28.9	40.5
Median	30.5	36.0	29.0	40.0
Standard deviation	2.87	4.39	1.52	6.24
Reliability level (95 %)	2.05	3.14	1.09	4.46
Min. breakthrough time value	28.7	31.7	27.8	36.0
Glove type:	**SEMPER-VELVET**			
Mean value	12.3	18.5	12.4	16.1
Median	13.0	19.0	12.0	17.0
Standard deviation	1.25	2.76	0.70	2.38
Reliability level (95 %)	0.90	1.97	0.50	1.70
Min. breakthrough time value	11.4	16.5	11.9	14.4
Glove type:	**Butoject®**			
Mean value	630.8	627.5	602.9	623.6
Median	631.5	637.0	632.5	622.5
Standard deviation	18.39	25.73	71.73	34.60
Reliability level (95 %)	13.16	18.41	51.31	24.75
Min. breakthrough time value	617.6	609.1	551.6	598.9

Table 3 part 2

Statistical parameter	Measured glove part			
	Palm	Back	Wristband	Fingers
Glove type:	**Camapren®**			
Mean value	32.7	51.2	47.4	44.8
Median	32.5	51.0	47.5	44.5
Standard deviation	2.06	2.53	1.78	7.84
Reliability level (95 %)	1.47	1.81	1.27	5.61
Min. breakthrough time value	31.2	49.4	46.1	39.2
Glove type:	**Textile underlay protective gloves STANDARD**			
Mean value	66.6	74.6	65.5	66.0
Median	64.5	72.5	67.5	62.0
Standard deviation	8.67	4.35	5.68	12.37
Reliability level (95 %)	6.20	3.11	4.06	8.85
Min. breakthrough time value	60.4	71.5	61.4	57.2
Glove type:	**PVC Rempo No. 151213**			
Mean value	53.8	53.9	42.6	66.0
Median	53.5	54.0	42.0	68.5
Standard deviation	5.92	4.63	6.13	10.15
Reliability level (95 %)	4.24	3.31	4.39	7.26
Min. breakthrough time value	49.6	50.6	38.2	58.7
Glove type:	**Greenfit™ Plus**			
Mean value	56.0	55.1	41.9	57.7
Median	58.0	55.5	42.0	60.0
Standard deviation	9.53	6.74	8.79	7.48
Reliability level (95 %)	6.82	4.82	6.29	5.35
Min. breakthrough time value	49.2	50.3	35.6	52.4

The definitely best breakthrough time values have been measured by Butoject® gloves, which are also certified for handling chemical warfare agents and are usually supplied within means of body surface protection sets. Breakthrough times of the palm, back and fingers have very similar mean values that vary between 623 and 630 minutes. The breakthrough times of fingers embodied high variance, which is most probably caused by big differences in thickness among individual samples. That might also have been the reason the minimal measured breakthrough time for this glove part was 598 minutes. The above is confirmed by minimal and maximal finger glove part

thicknesses presented in table 2. On the other hand the variance of the palm breakthrough times is considerably lower and that indicates a relatively consistent proportional homogeneity of thickness at this glove part. The worst glove part according to its breakthrough time would be the wristband, the minimal value of which was 551.6 minutes. This glove part embodied a high variance of breakthrough time values. To find a satisfactory explanation of this phenomenon would be difficult, because according to thickness variance this glove part is comparable with the back part, while the breakthrough time variance is almost three times as high.

The breakthrough time measurements of the other glove types proved that wristband is the weakest part according to protection against chemical warfare agents. The wristband was found to be the weakest glove part by Camatril® Velours, Bi-Colour™, PVC Rempo No. 151213 and Greenfit™ Plus gloves. The wristband of SEMPER-VELVET gloves embodied very similar minimal breakthrough time values as the palm, which was found to be the weakest part of this glove type (palm 11.4 minutes, wristband 11.9 minutes).

The measurement results do not allow us to rank the individual glove parts by their protective capability against persistent chemical warfare agents. Among the measured types of gloves, if we leave out the latex examination gloves, the most durable glove part according to the minimal breakthrough time value was in four cases the back, in three cases the fingers and in one case the palm. According to the breakthrough time mean value the most durable glove part was then in three cases the back and the palm and in two cases the fingers. That is why the breakthrough time values have been evaluated regardless of the measured glove part.

As table 4 shows regardless of the measured glove part the worst results have been measured by the latex examination gloves, the breakthrough time of which does not ensure any protection for a user even in case when used in two layers. A short breakthrough time has been measured by the SEMPER-VELVET gloves. The minimal breakthrough time value of 13.8 minutes is definitely insufficient for the protection of a user. As insufficient may also be considered the minimal breakthrough time value of 31.8 minutes that has been a result of measurements by the Bi-Colour™ gloves.

The conducted measurements have proven (Table 4) that by five types of gloves - Camapren®, Greenfit™ Plus, PVC Rempo No 151213, Camatril® Velours and Textile underlay protective gloves STANDARD the minimal breakthrough time value lays within the range of 41.4 to 65.4 minutes. The question is, whether these minimal breakthrough time values are sufficient for the protection of a user. To provide a qualified decision in real conditions basic factors that influence the breakthrough time of polymeric barrier materials would have to be known – temperature, the type of a chemical warfare agent, its concentration in the air or whether the contamination is supposed to be by a liquid or vapors of an agent etc. Therefore it is possible, in order to reach a decision as to whether some type of gloves is or is not suitable for protection, to conduct a qualified estimate.

Table 4

Statistical evaluation of the breakthrough times [min] regardless of the measured glove part

Glove type	Latex Exam Gloves Lightly Povdered GN3	Latex Exam Gloves Lightly Povdered GN3 (2 plies)	Camatril® Velours	Bi-Colour™	SEMPER-VELVET
Statistical parameter					
Mean value	2.6	10.1	59.2	33.7	14.8
Median	2	10	58	32	14
Standard deviation	0.83	2.47	7.75	6.02	3.25
Valid number	20	20	40	40	40
Reliability level (95 %)	0.39	1.16	2.48	1.93	1.04
Min. breakthrough time value	2.2	8.9	56.7	31.8	13.8

Table 4 part 2

Glove type	Butoject®	Camapren®	Textile underlay protective gloves STANDARD	PVC Rempo No. 151213	Greenfit™ Plus
Statistical parameter					
Mean value	621.2	44.0	68.2	54.1	48.7
Median	632.0	47.0	68.5	52.5	49.5
Standard deviation	42.61	8.16	8.87	10.76	10.72
Valid number	40	40	40	40	40
Reliability level (95 %)	13.63	2.61	2.84	3.44	3.43
Min. breakthrough time value	607.4	41.4	65.4	50.7	45.3

Some kind of guidance to this decision might be the presumptive time of work with the means of body surface protection by temperature corresponding with the temperature of conducted glove breakthrough time measurements. The Chem-2-2 manual "Means of individual protection and their employment" presents in table 8, article 424 the boundary employment times of individual protection gear in protective position depending upon the temperature conditions, after which none thermal damage of organism as a result of overheating occurs. These boundary time limits are designated in cases when it is not possible to alternate the working regime and rest for the temperature of 26 to 30 °C and moderate working load to 2 hours, for intermediate working load to 1 hour and for heavy working load to 50 minutes. Assuming that most of the activities will remain in the category of intermediate and heavy working load, the employment of body surface protection gear will be limited by the time of 60 minutes. This time limit also corresponds with the time limit of isolation breathing devices employment time limit or the time a supply of breathing medium would by an intermediate working load suffice considering also the temperature conditions.

Regarding to the time limits and considering the minimal measured breakthrough time values only two of the tested glove types are applicable for user protection. These two types are the Butoject® gloves and the textile underlay protective gloves STANDARD. All the other tested glove types have too short breakthrough time values according to any practical employment and do not ensure reliable user protection without taking other protective measures. The only type of gloves reaching the requirements of a warranted protection against chemical warfare agents are the Butoject® gloves. These gloves should be a standard protective utility when handling such kind of pollutants.

5. Conclusion

Whenever handling highly toxic agents, which also without any doubt contain chemical warfare agents, proper protective gear with known protective properties should be used. That definitely relates to protective gloves. The gloves may get into a direct contact with a pollutant. The breakthrough time measurements of commonly used laboratory gloves have proven that protective properties of these gloves against chemical warfare agents are not sufficient and that it is not possible to use them as a protection against this type of pollutants. Only the Butoject® gloves meet requirements for their employment when working with chemical warfare agents. Considering the protective properties the textile underlay protective gloves STANDARD, the minimum breakthrough time value of which is by 30 °C about 60 minutes might also be used. Absolutely unsatisfactory for protection against chemical warfare agents are the latex examination gloves. Their breakthrough time is so short that the sulfur mustard basically immediately penetrates their foil. It is necessary to mention that the measured breakthrough times correspond with a liquid chemical warfare agent's influence. These liquid agents take effect upon a contaminated material through the whole time of glove breakthrough time measurement. In case of an effect of chemical warfare agent vapors the breakthrough time increases considerably and it would

depend most of all upon temperature, concentration, type of the chemical warfare agent and material used for the particular glove construction. These parameters would influence the time the used gloves would protect for.

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- Protective mask OM-90 and CM-6M;
- Disposable protective suit JP-90;
- Isolating protective suit OPCH-05.