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DECONTAMINATION OF NBC-PROTECTIVE GARMENTS - Part 3: Laundering of NM143 suits and effect of storage conditions

RØEN Bent Tore, ENDREGARD Monica

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The NM143 NBC-protective suit used by the Norwegian armed forces has been examined with respect to the feasibility of decontamination by laundering, effect of storage conditions and lifetime. Protective properties were established by penetration analyses using liquid sulphur mustard (HD) corresponding to a contamination level of 10 g /m². The laundering experiments showed that the suits can be laundered at 40 or 60 °C, but the suit does not stand more than one laundering. The suits can not be laundered at 90°C. It is concluded that the suits can be decontaminated once by laundering at 60 °C with a selected detergent. For cleaning dirty suits a washing temperature of 40 °C is sufficient. The effect of storage conditions was examined on four different suits over a period of 17 months. All suits showed a significant variation in protective properties which could be correlated to variations in relative humidity (RH) due to seasonal changes. Further tests have to be performed under controlled conditions in order to validate this theory. Examinations of the protective properties of 12 suits after 10-13 years of storage show that the suits still meet the protection requirement against chemical warfare agents. As compared to an investigation in 1997 the protective properties have decreased. Hence, it is important to continue to do regular tests of the protective properties of NM143 garments.

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APPENDIX

DECONTAMINATION OF NBC-PROTECTIVE GARMENTS - Part 3: Laundering of NM143 suits and effect of storage conditions

1 INTRODUCTION

The main objective of this study is to examine the effects of laundering on NBC-protective suits used by the Norwegian Army (NM143) with respect to tear and wear and protective properties against chemical warfare agents (CWA). These suits are permeable and contain activated carbon for adsorption of CWA. The fabric is made of activated carbon powder impregnated on polyurethane foam with a liquid-repellent outer layer. The present work is part of an investigation to identify a possible decontamination procedure for NM143 garments. Small-scale laundering experiments have previously shown that laundering could be a means of decontaminating this type of NBC-protective garment after exposure to sulphur mustard (HD) (1-4). However, before a decontamination procedure can be recommended, full-scale laundering experiments are necessary to ensure endurance of the garments protective properties and the structural integrity of the suits after laundering.

Full-scale laundering tests of NM143 suits were performed using a conventional washing machine and commercially available detergents. The protective properties before and after each laundering cycle were measured by penetration analyses using HD. Experiments were performed on both unused and used, dirty suits.

The NM143 suits were produced in the period 1988 to 1991. The lifetime of the suits was investigated in 1997 (5). It was concluded that the lifetime could be prolonged to 15 years under the condition that samples were investigated regularly to ensure sustainable protective properties against CWA. Hence, lifetime investigations of NM143 are reported.

In the course of the experiments it was observed that the protective properties for one of the suits changed after storage in the laboratory. In order to achieve reliable results for laundering experiments, this possible new parameter had to be examined on several suits.

In summary, the objectives of this study are to answer the following:

- The feasibility of decontaminating NM143 suits by laundering
- The possibility of cleaning dirty NM143 suits by laundering
- The effect of storage conditions on NM143 suits
- The lifetime of NM143 suits

2 BACKGROUND

2.1 Decontamination and laundering

A subject in the project "Chemical weapons- protection and verification", has been to investigate the possibility of laundering NBC-protective suits either for decontamination or simply for cleaning dirty suits.

In small-scale laundering tests on the NM143 material the possibility of decontaminating this material by laundering has been examined (1-4). The samples were contaminated with liquid HD corresponding to 10 g/m². Different laundering temperatures, types of commercially available detergents, and amounts of detergent were tested. Penetration analyses were performed after decontamination to assess the protective properties. The results showed that NM143 fabric can be decontaminated and the protective properties re-established by laundering at temperatures ranging from 60 – 90 °C with selected detergents. A temperature of 40 °C did not give the required recovery of protective properties.

In the full-scale experiments the suits are not contaminated before laundering. The principal question is if the suits maintain their protective properties after laundering using the established parameters from the small-scale tests. As a consequence of the physical strain during laundering the polyurethane foam will lose some of the activated carbon and the adsorption capacity of the material will be reduced. The laundering may also damage the impregnation on the surface of the outer material, thereby reducing the liquid repellence. This will change the penetration course when the material is challenged with liquid drops of chemical warfare agents.

2.2 Effect of storage conditions

In March 2000 some recently opened suits were analysed in preparation for the laundering tests. When one of these suits was tested again in July 2000, the protective properties had become significantly better. During this period the suit had been stored in the laboratory on a clothes hanger. To get reliable results from the laundering tests, it was important that the examinations were performed on suits with stabile protective properties over a period of time. Therefore the effects of change in storage conditions and aeration of the suits after opening were examined more closely on several suits before initiating laundering tests.

2.3 Lifetime

From the manufacturers, the guaranteed lifetime of the NBC-suits was 5 years from production date. However, the stipulated durability for this type of suit is at least 10 years, if stored under appropriate conditions. In an investigation in 1997 the condition of the suits was examined after 6 - 8 years of storage, including the protective properties against liquid chemical warfare agents. Penetration analyses were performed on several suits, both unused and suits that had been used in a field exercise. As a conclusion from this study the latest type of NM143 suits, which were produced from 1988 to 1991, was given a prolonged lifetime of 15 years. This is under the prerequisite that regular analyses are performed on selected suits to ensure

sustainable protective properties. As part of the present study the protective properties against CWA are evaluated after 10 – 13 years of storage.

3 EXPERIMENTAL SECTION

3.1 Specifications for NM143 NBC-protective suits

The NBC-protective suits used by the Norwegian Army (NM143) are permeable and contain activated carbon for adsorption of CWA. The fabric is made of activated carbon powder impregnated on polyurethane foam with a liquid-repellent outer layer.

The latest models of NM143 were produced in the period from 1988 to 1991. They were delivered from two different manufacturers; "K Stormark AS" in Norway and "Paul Boyè" in France. The suit consists of a jacket with hood and a pair of trousers. After production the suits were wrapped in a sealed packaging for storage until use. The technical specifications are:

Outer material:

Type of material	Polyester/cotton, impregnated liquid repellent
Colour	Brown-grey
Thickness	0.6 ± 0.1 mm
Weight	250 ± 10 g/m²

Inner material:

Type of material	Polyurethane foam impregnated with activated carbon powder, laminated to a thin knitted layer
Thickness	2.0 ± 0.5 mm
Weight	275 ± 20 g/m²

Required protective properties against liquid chemical warfare agents:

Maximum penetration of 4 µg/cm² within 24 hours after exposure, corresponding to a contamination level of 10 g/m²

3.2 Laundering experiments

A conventional washing machine of the type "Ariston AL 1456 TX", with a barrel volume of 42 litres was used. All washing cycles were performed using washing programme 2 (duration ca 2 hours), with temperatures 40, 60 or 90 °C. At this programme 6.5 litres of wash water is used, and there are two rinse cycles with 6.5 litres of rinse water each, and a last one of 18.5 litres of rinse water. The temperature gradient for a washing cycle has been measured with a waterproof logger of type "Optic StowAway Temp". Figure 3.1 gives a graphical view of the temperature in a cycle with wash programme 2 at 60 °C.

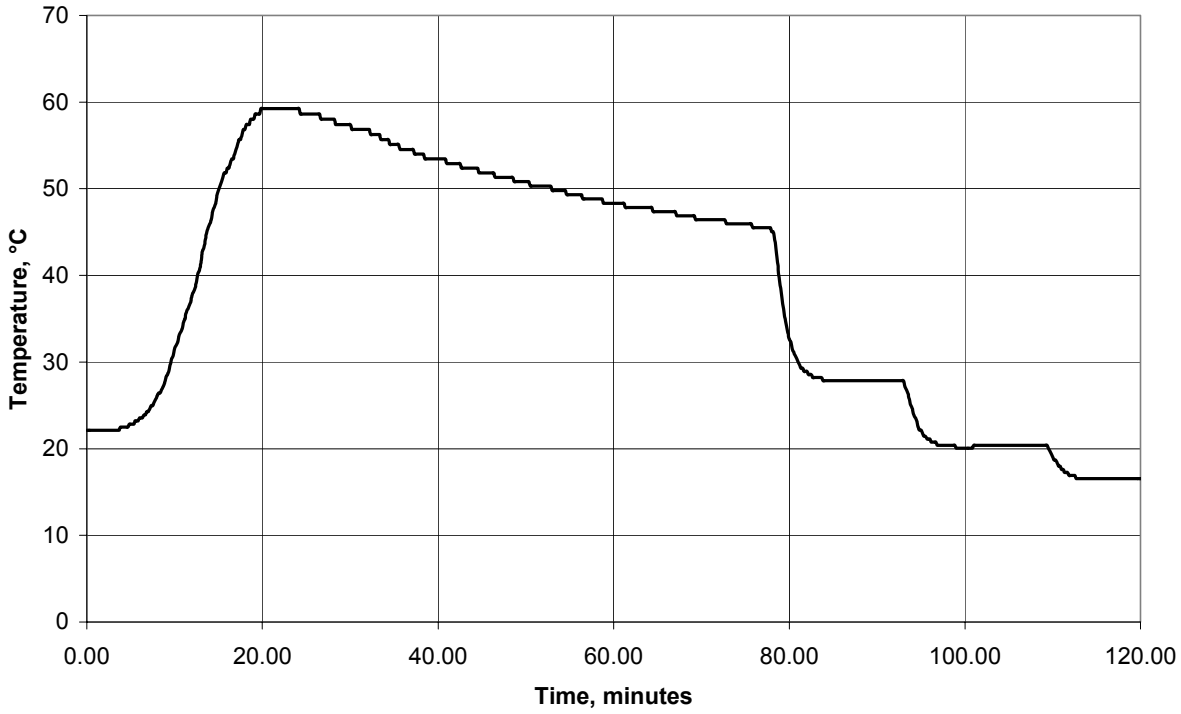


Figure 3.1 Temperature gradient with wash programme 2 at 60 °C

The clothes are being heat-treated for 60 minutes. As shown from the temperature curve there is no after heating of the water during the wash cycle. Consequently, the temperature decreases to 45 °C at the end of the cycle. Note that this constitutes a difference from small-scale laundering, where the samples were kept at constant temperature for 45 minutes.

3.3 Penetration analyses

The penetration analyses were performed on a system that measures the vapour penetration through a material when it is challenged with a liquid chemical. The system consists of 16 independent penetration cells, and Figure 3.2 shows the cross section of such a cell.

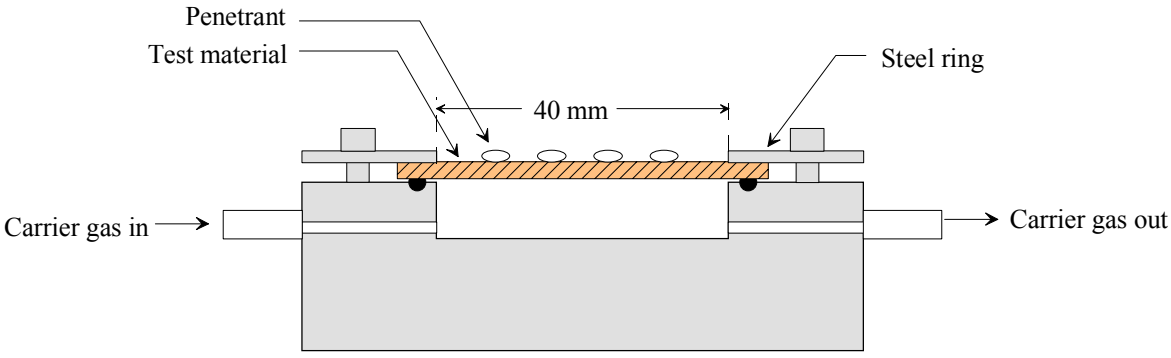


Figure 3.2 Cross section of a penetration cell

A circular swatch of the test material is attached to the cell with a steel ring, with inner diameter of 40 mm, which gives a test area of 12.5 cm². A thin film of polyethylene (12 µm) is placed under the test specimen to prevent the carrier gas to flow out through the sample. This film has a negligible absorbency of the chemical. The liquid chemical, in this case HD, is placed on the test material with a syringe in small drops of 1 µl each. The penetrated vapour is

carried with the gas under the material (nitrogen) to a gas chromatograph (GC). In the GC a Flame Ionisation Detector (FID) measures the vapour concentration of the penetrating agent. The penetrated vapour is measured at a regular time interval between each cell of 1.5 minutes. When all test cells are in use, the time interval between measurements for each of the cells is 18 minutes. For each measurement the penetration rate (ng/(cm²*min)) and the accumulated penetrated amount (µg/cm²) are calculated. The system is described in detail in a previous FFI report (6).

Experimental parameters:

Penetrating agent	Liquid HD, 10x1 µl, corresponding to a contamination level of 10 g/m²
Temperature	21 – 23 °C, room temperature
Horizontal wind speed	ca 0.1 m/s
Time	24 hours

The relative humidity (RH) is not controlled but varies according to the local conditions in the laboratory. During the analyses in connection with the laundering experiments the RH varied between 24 and 45 %.

The contamination level of 10 g/m² is in accordance with the NATO NBC-protective cloth triptych AEP-38.

3.4 Detergents

The detergent that gave the best results in the small-scale laundering experiments was "Blenda Sensitive", manufactured by "Lilleborg fabrikker" in Norway. This detergent contains no bleaches, phosphates, perfumes or dyes.

Density:	ca 0.85 g/ml
Contents:	
15 – 30 %	Anionic tenside, zeolite, percarbonate
5 – 15 %	Nonionic tenside
> 5 %	Soap, polycarboksylate, phosphonate

Two other commercial detergents were also tested in initial full-scale experiments: Omo Ultra and Smili Micro. Omo Ultra contains soap, surfactants, zeolite, polycarboxylate, phosphonate, enzymes and perfume. It does not contain optical bleaches. Smili Micro contains soap, surfactants, zeolite and perborate. It does not contain phosphate. Detergent components in general are described in more detail elsewhere (4).

The amount of detergent used in the experiments was 20 g/kg clothes for each wash. The jacket and trousers were washed separately. The typical weight of a jacket is 1.4 – 1.5 kg and for a pair of trousers 1.2 – 1.3 kg. With an amount of wash water of 6.5 litres this means an amount of detergent of 4.3 – 4.6 g/l and 3.7 – 4.0 g/l, respectively.

4 LAUNDERING TESTS

4.1 Comparison of detergents

Small-scale laundering experiments showed that the detergent Blenda Sensitive gave less weight loss than the other detergents at all three temperatures (40, 60 and 90 °C). Full-scale laundering experiments were performed using the same three detergents. Garments were laundered at 60 °C and dried by hanging in room temperature as described in Chapter 3.2. The garments had been used in a field exercise of 24 hours continuous use in 1997, and had been exposed to heavy rain and mud. The suits had no visible damages from tear and wear. All three garments passed the protection criterion prior to laundering. After laundering three samples from each suit were subject to penetration analyses. The results are summarised in Table 4.1.

Detergent	**P_{24h} (µg/cm^2) 1st wash**	**P_{24h} (µg/cm^2) 2nd wash**	**P_{24h} (µg/cm^2) 3rd wash**
Blenda Sensitive	1.3 (1.0)	4.3 (0.7)	3.4 (2.4)
Omo Ultra	2.6 (1.7)	5.9 (2.4)	7.3 (4.4)
Smili Micro	7.0 (2.9)	6.6 (2.0)	7.2 (5.3)

*Table 4.1 Accumulated penetrated amount of HD (**P_{24h}**) after laundering at 60 °C for NM143 garments. Results are based on three parallel samples, standard deviation in parenthesis*

Visible signs of wear and tear of the garments were observed as white areas on the inside of the garments. The three parallels were chosen from areas with different degree of whitening, and in most cases the whitening could be correlated with higher HD penetration, possibly due to a higher loss of active carbon from the inner layer of the garment.

These preliminary results show that these garments maintain a sufficient degree of protection against HD after one wash either with Blenda Sensitive or Omo Ultra. Laundering with Smili Micro did not give satisfactory results. The second and third washes with Blenda Sensitive also gave good results. It should be noted that these results are based on only one garment for each detergent, hence repetitive experiments are necessary before conclusions can be drawn.

The observed difference between the detergents gives support to findings from small-scale laundering experiments reported previously (4). Since Blenda Sensitive gave the best results both in small-scale laundering experiments and these initial full-scale experiments, it was decided to use this detergent in the following experiments. The results indicate that Omo Ultra can also be used.

4.2 Suits being tested

8 suits have been used in the laundering tests, and these are listed in Table 4.2.

Suit no	Produced	Manufacturer
1	10.91	Paul Boye
2	10.91	Paul Boye
3	10.91	Paul Boye
4	10.91	Paul Boye
5	10.91	Paul Boye
6	10.91	K Stormark
7	11.91	K Stormark
8	11.91	K Stormark

Table 4.2 Overview of the suits used in the laundering tests

Suits number 1-5 have been stored in original packaging since production date and were opened 4 – 5 months before analyses. Suits number 6-8 were used in field practice in connection with lifetime studies of NM143 NBC-protective suits in 1997, and have been stored at FFI in an outdoor container since then.

4.3 Analyses

The laundering tests were performed at three different washing temperatures, 40, 60 and 90 °C. Circular pieces were stamped out for penetration analyses before and after each wash. The suits were weighed before and after wash to measure the loss in weight. After each wash the suits hang for a minimum of 24 hours before weighing. Before penetration analyses the suits hang for at least 4 days to reach equilibrium with the local humidity conditions.

4.4 Visual wear and tear after laundering

During the laundering cycle the degree of wear and tear varied on different parts of the suits. Figure 4.1 illustrates the effect of laundering on the inner side of the garments. The upper picture is of an unused jacket, not laundered. The middle is from a jacket laundered once at 40 °C and the bottom picture shows a jacket laundered three times at 40 °C.

Some sections of the inner material seemed very worn with white fields on the surface. This side of the inner material has a thin knitted layer on which the foam is laminated, and the white fields appear when the threads in the layer lose the activated carbon. This does not necessarily mean that the foam, which is the main carrier of the activated carbon, has lost activated carbon in equal quantities on the same places. On the other hand, the visual whitening of the knitted layer is an indicator of the physical strain this part of the suit has been exposed to. Therefore, when stamping out the swatches for penetration analyses after each wash, samples were taken from places with a representative variation of visible wear and tear.

Figure 4.1 Jackets from NM143 suits not laundered (top), laundered once at 40 °C (middle), and laundered three times at 40 °C (bottom)

4.5 Changes in penetration after laundering

When applying the liquid HD on the samples before wash, the droplets keep their spherical form on the liquid repellent outer material. After one wash the outer material had lost much of its liquid repellent quality, and the droplets spread on the material after some minutes. After two and three washes the droplets spread immediately after application. Figure 4.2 shows how this influences the penetration course through the material. The figure gives the results for suit number 7, washed three times at 60 °C with detergent (20 g/kg). The curves show the penetration rate in the period from 0 to 24 hours after exposure. Each curve represents the average of four replicates taken from the suit after each wash.

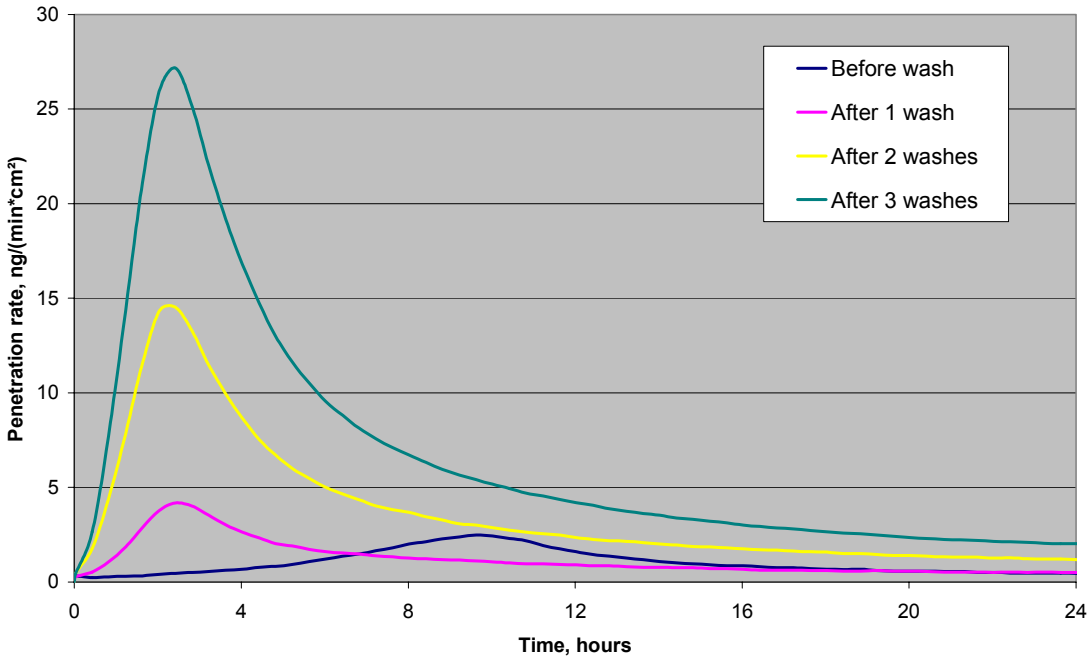


Figure 4.2 Penetration rate for suit no 7 presented as the average of four parallels before and after each wash at 60 °C

The penetration rate before laundering is low the first hours and reaches its maximum after ca 10 hours. After the suit has been washed, the outer material loses the liquid repellent quality and the droplets are spread on the material. This results in a quicker breakthrough and a higher penetration rate the first hours. However, since the droplets are spread on the material, they also have a higher evaporation rate to the environment. After 2 – 3 hours all liquid HD has evaporated from the surface of the outer material and the penetration rate decreases. As a result of the physical strain during laundering the inner material loses some activated carbon. Therefore the penetration rate, and thereby the total penetrated amount, increases after each wash. Figure 4.3 shows the results from the penetration analyses on suit number 7 as total penetrated amount of HD. The vertical lines represent ± 1 standard error of the four parallels.

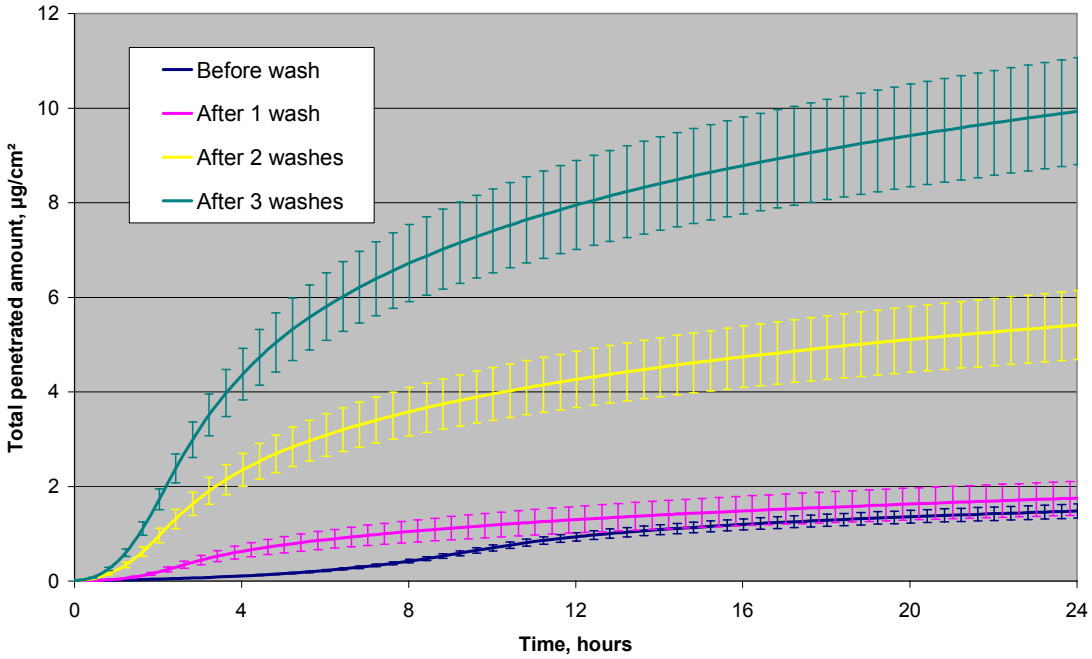


Figure 4.3 Results from penetration analyses on suit no 7 presented as total penetrated amount of HD before and after each wash, given as the average of four parallels, vertical lines indicate ± 1 standard error

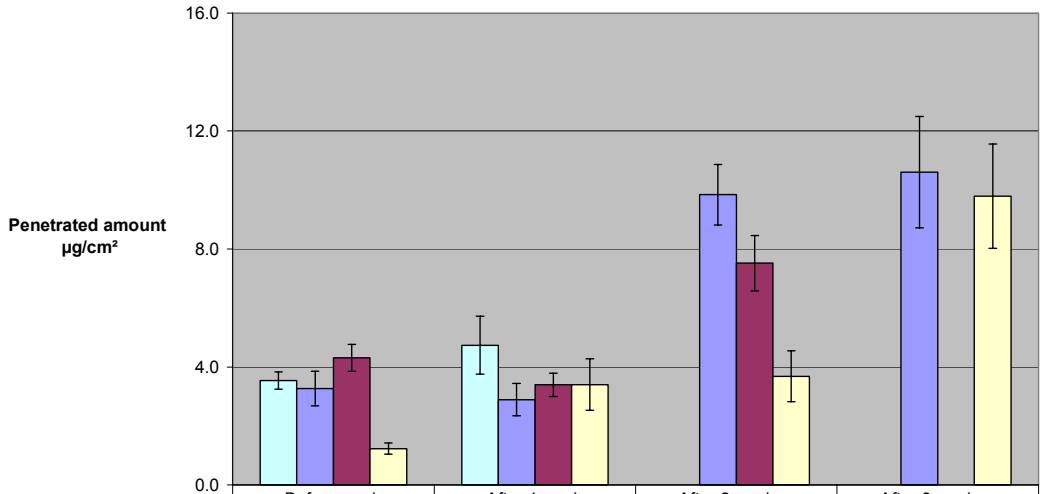
After one wash the material still meets the requirement of maximum penetrated amount of 4 µg/cm² after 24 hours. Even though the penetration rate is higher during the first hours, there is no significant increase in the total penetrated amount after 24 hours. After two and three washes the adsorption capacity of the material has decreased significantly and the suit does not meet the protection criterion.

4.6 Results from the laundering tests

4.6.1 Washing temperature 40 °C

Four suits were laundered at 40 °C. Suit number 1 was washed without detergent for comparison, while for the others the detergent Blenda Sensitive (20 g/kg) was added. Figure 4.4 shows the results as the average total penetrated amount of HD after 24 hours ± 1 standard error of the parallels, before and after each laundering cycle. In appendix A the results for all parallels from each test are reported as total penetrated amount of HD 12 and 24 hours after exposure.

For suits number 1 and 2 the results represent an average of the samples taken from both the jacket and the trousers. For suits number 5 and 6 the test was performed only on the trousers and the jacket, respectively. Suit number 1 was washed without detergent, and as the figure shows this suit offers a slightly poorer protection factor after one wash. Suits number 2 and 5 give slightly better results after one wash, while suit no 6 has significant poorer result, but still satisfy the requirement of a maximum penetration of 4 µg/cm² 24 hours after exposure. After two washes the results vary more, and two of three suits have average results above the requirement.



	Before wash	After 1 wash	After 2 washes	After 3 washes
Nr 1	3.54	4.74		
Nr 2	3.27	2.89	9.84	10.60
Nr 5, trousers	4.31	3.40	7.52	
Nr 6, jacket	1.23	3.40	3.69	9.79

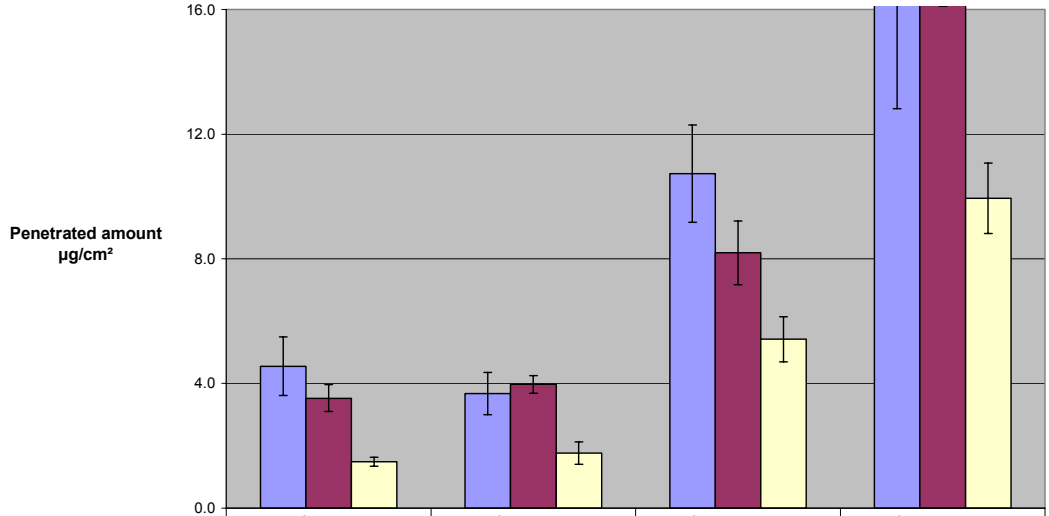
Figure 4.4 Results from laundering at 40 °C, presented as total penetrated amount of HD after 24 hours ± 1 standard error of the parallels

From these results two conclusions can be drawn:

- The use of detergent does not seem to deteriorate the protective properties of the suit, as compared to being washed in pure water
- The suits meet the requirements for protective properties after one wash at 40 °C, but do not seem to stand further washes at this temperature

4.6.2 Washing temperature 60 °C

Three suits have been washed at 60 °C, all with detergent added. The results from the penetration analyses before and after each laundering cycle are presented in Figure 4.5.



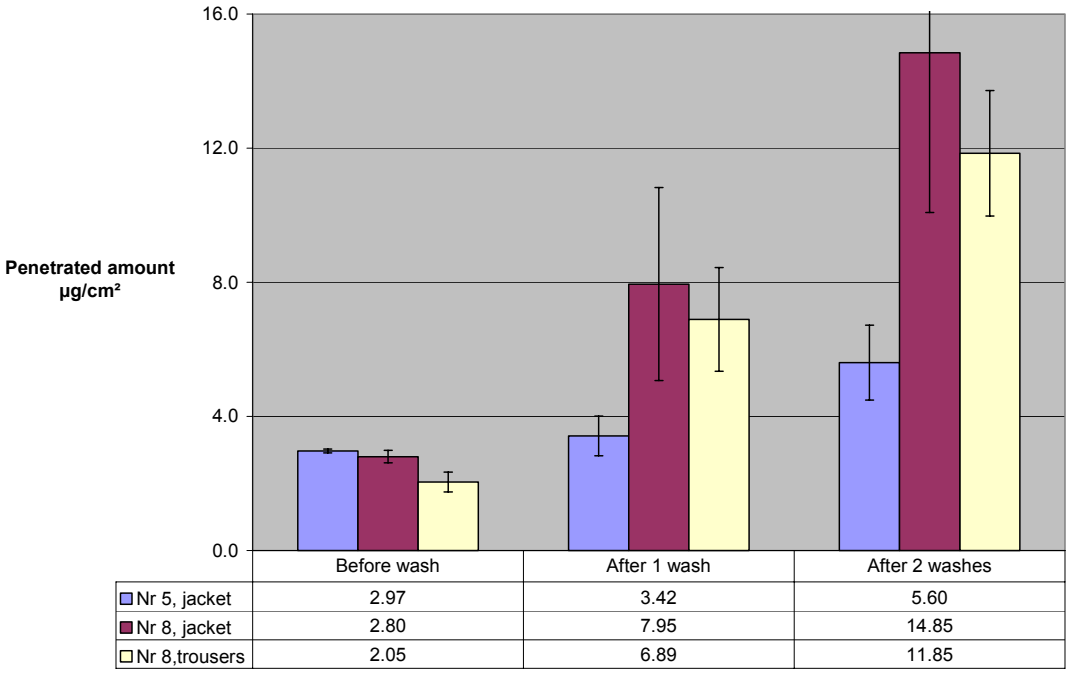
	Before wash	After 1 wash	After 2 washes	After 3 washes
Nr 3	4.55	3.67	10.73	17.63
Nr 4, jacket	3.52	3.97	8.19	17.32
Nr 7	1.48	1.76	5.42	9.94

Figure 4.5 Results from laundering at 60 °C presented as total penetrated amount of HD after 24 hours ± 1 standard error

For all three suits the average results meet the requirement of the protective properties after one wash. After two washes the penetrated amount becomes considerably higher and the protection requirement is exceeded for all suits.

4.6.3 Washing temperature 90 °C

Two suits were tested with washing temperature 90 °C. For suit number 8 the results for the jacket and trousers are presented separately, since they were washed and analysed on different days. Figure 4.6 gives the results from the analyses.



	Before wash	After 1 wash	After 2 washes
Nr 5, jacket	2.97	3.42	5.60
Nr 8, jacket	2.80	7.95	14.85
Nr 8,trousers	2.05	6.89	11.85

Figure 4.6 Results from laundering at 90 °C presented as total penetrated amount of HD after 24 hours ± 1 standard error

In two of three cases the suits do not satisfy the requirement after one wash at this temperature. At this high washing temperature the effect of the liquid repellent layer is totally destroyed after one wash, which was seen on the liquid drops of HD that was spread immediately after application. The relative high standard error also shows that the protective properties varied a lot between samples taken from different locations on the suit.

4.7 Loss in weight

Table 4.3 shows the loss in weight after each laundering cycle for all suits. The results vary, and the number of parallels is too low to state if there are any significant differences in loss in weight between the three washing temperatures. However, even if there are no significance in the numbers there seems to be a tendency of higher loss in weight at washing temperature 60 °C than at 40 °C. There is also a tendency that the loss in weight decreases after each laundering at all three temperatures.

Washing temperature	Suit no	Loss in weight (%) 1 wash	2 washes	3 washes
	1, jacket	1.5		
	1, trousers	1.3		
40 °C	2, jacket	1.3	0.9	1.3
	2, trousers	1.9		
	5, trousers	1.1	1.1	
	6, jacket	1.1	1.1	0.3
	Average	1.3	1.0	0.8
	3, jacket	2.0	2.3	1.2
	3, trousers	1.5	1.6	
60 °C	4, jacket	2.4	2.1	1.0
	4, trousers	2.2		
	7, jacket	1.6	0.7	1.3
	7, trousers	1.9	0.6	0.6
	Average	1.9	1.5	1.0
	5, jacket	1.4	1.6	
90 °C	8, jacket	1.0	1.5	
	8, trousers	2.4	0.8	
	Average	1.6	1.3	

Table 4.3 The loss in weight after laundering

4.8 Discussion of laundering results

The required level of protection for the suits is maximum 4 µg/cm² total penetrated amount 24 hours after exposure. With washing temperature 40 and 60 °C the suits meet this requirement after one wash. There was no significant difference between the results at these two washing temperatures. After two or more launderings at 40 and 60 °C the physical strain on the garment caused a reduction of the protective properties below the required level for most of the suits. After washing at 90 °C the suits did not meet the requirement even after one wash.

From the small-scale experiments of decontamination by laundering a washing temperature of 60 °C was recommended, because 40 °C gave incomplete decontamination of the garment. Hence, to decontaminate by laundering the washing temperature should be 60 °C with the selected detergent. For cleaning dirty suits a washing temperature of 40 °C is sufficient. At both temperatures the suits can only be washed once.

5 EFFECT OF STORAGE CONDITIONS

5.1 Effect of storage after opening the packaging

A NM143 suit was analysed for the first time in March 2000, just after opening of the sealed packaging, and then again in July 2000, after storage in the laboratory on a clothes hanger. The results showed that during these months the protective properties had improved significantly. This initiated an investigation on several suits in order to identify whether the observed effect is a general trend for the NM143 suits, and if so, to understand the cause for

this effect. Three additional suits were investigated in the period from September 2000 to August 2001. The suits have been stored in their original sealed packaging from production date. The protective properties were assessed by penetration analyses immediately after opening, and then analysed repeatedly throughout the time period. After opening the suits were stored in a laboratory at a temperature of 21-23 °C, without exposure to chemicals. Due to seasonal changes the relative humidity (RH) in the laboratory varied. Table 5.1 shows all results from the penetration analyses performed during the period.

Suit no	Produced	Opened	Date of analysis	Number of parallels	Penetrated HD (µg/cm²)	Standard error (STE)
A	03.1990 (K Stormark)	28.03.00	29.03.00	4	3.49	0.458
			06.04.00	4	3.40	0.225
			11.07.00	5	1.72	0.172
			17.07.00	6	1.82	0.238
			13.08.01	6	1.38	0.167
B	03.1990 (K Stormark)	12.09.00	12.09.00	12	3.96	0.238
			19.09.00	12	3.63	0.165
			26.09.00	11	3.83	0.233
			10.10.00	12	1.56	0.130
			24.10.00	12	1.85	0.131
			21.11.00	8	1.86	0.158
			08.03.01	6	3.09	0.252
			12.06.01	6	2.69	0.061
			15.08.01	6	1.59	0.130
C	10.1988 (K Stormark)	13.09.00	13.09.00	12	2.84	0.171
			20.09.00	12	3.31	0.225
			28.09.00	12	4.01	0.228
			11.10.00	11	2.26	0.200
			25.10.00	12	2.45	0.153
			24.11.00	5	2.55	0.158
			08.03.01	6	2.96	0.345
			12.06.01	6	2.18	0.145
			15.08.01	5	1.45	0.165
D	01.1990 (Paul Boyè)	20.11.00	20.11.00	8	3.65	0.498
			06.01.01	6	4.02	0.387
			02.03.01	12	4.38	0.303
			13.08.01	6	1.74	0.285

Table 5.1 Protective properties for four NM143 NBC-protective suits analysed repeatedly in the period from March 2000 to August 2001 presented as the accumulated amount of penetrated HD 24 hours after exposure (10 g/m^2)

Suit A is the suit for which the variation in protective properties over time was discovered. Two other suits (B and C) were opened in September 2000 and analysed weekly the first time, thereafter less frequently. Suit D was opened in November 2000. The variation in protective properties by time is illustrated in Figure 5.1, where the results from Table 5.1 are plotted against date of analyses. In addition, the measured RH in the laboratory is plotted. The figure also includes results for NM143 yard goods in the same period. This material has been stored at K Stormark since the production of NBC-suits ended in 1991 and was received at FFI in February 2000. The analyses of this fabric were performed in connection with other

examinations, and the results are included here for comparison. The fabric was stored in the same laboratory as the suits during this period.

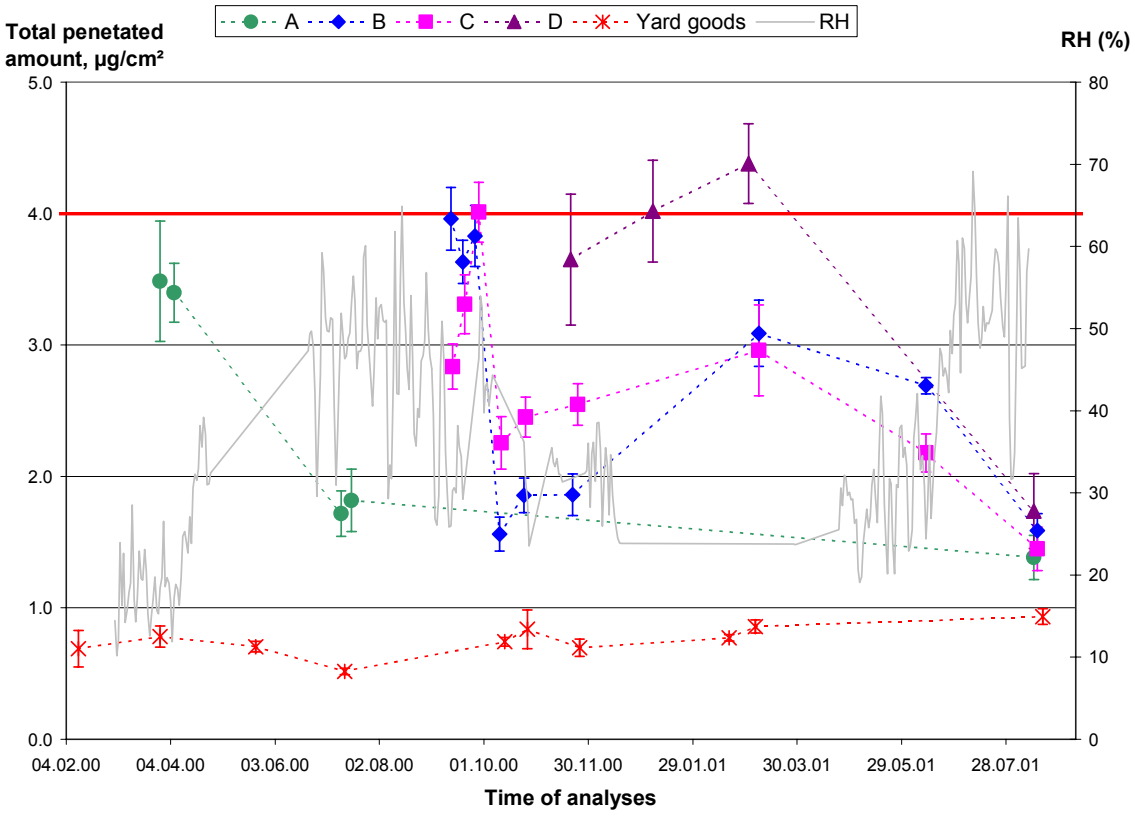


Figure 5.1 *Penetration analyses for four different NM143 suits and yard goods from the same material. The total penetrated amount of HD 24 hours after exposure is plotted against the date of analysis. A red line indicates the protection criterion of a maximum penetration of 4 µg/cm²*

RH was not measured continuously the whole period, hence values for some periods are not included. Even though the RH can vary a lot within short periods of time, the tendency associated with seasonal changes is evident.

Suits B and C were opened and analysed two subsequent days. The first two weeks after opening the results were stable for suit B, and increasing for suit C. After that the protective properties of the two suits show a distinct co-variation. After 4 weeks a significant decrease in the results is observed for both suits, and thereafter a slight increase up to the analyses in March 2001. From March to June and August the results again decreased. To examine if the sudden change in results from 2 to 4 weeks after opening was related to any experimental or instrumental conditions, additional analyses were performed with yard goods together with samples from both suits. The results for the suits were confirmed while there was no difference in the results for the yard goods as compared to earlier analyses.

Suit D which was opened in November 2000, had no decrease in protective properties during the first 3 months after opening. There was a slight increase in the results the first 3 months, and thereafter a significant decrease when the suit was analysed again in August.

The results from analyses on the yard goods are considerably lower than for the suits. This can be due to different quality from production of the material, or may also be caused by different storage conditions. The results vary between 0.5 and 1.0 µg/cm² during the period but this variation is not as dramatic and seems more random than for the suits.

5.2 Discussion

The results can be summarised as follows:

- All suits gave relatively high results immediately after opening of the packaging, close to and sometimes above the protection criterion defined for these suits.
- All four suits showed a significant variation and an eventual improvement in protective properties over the period of this investigation.
- The results tend to be high in the periods where the humidity was low and significantly lower in the periods with higher humidity.
- The exception from the former statement is the behaviour of suit B and C the first four weeks after opening, where a significant decrease in penetration of HD was observed while no dramatically change in RH was measured.
- The variation in the results of the yard goods can not be correlated to the variation in the humidity. However, this fabric has generally much better protective properties than the suits. Consequently, the influence of the RH on the results may not be noticeable to the same extent.

It can be concluded that the protective properties for a NM143 NBC-protective suit actually varies from when it is unpacked and over a longer period after that. The present results indicate that the humidity of the storage area affects the measured protective properties.

To validate that the variations in protective properties are correlated to the humidity further investigations have to be performed. It is necessary to compare storage conditions with varying humidity at the same time. Samples from the same suit should be stored under both stable and varying RH for a longer time and thereafter compared by penetration analyses. To do a proper comparison the analysis conditions above the penetration cells also have to be controlled with respect to RH.

6 LIFETIME STUDIES

6.1 Lifetime studies in 1997

In 1997 the condition of NM143 NBC-protective suits was examined after 6-8 years of storage, including the protective properties against liquid chemical warfare agents. The suits were used in a field practise, thereby exposed to rain, mud and 24 hours of wear and tear. After the field practice penetration analyses were performed with two parallels from each suit. The results are presented in Table 6.1 as total penetrated amount of HD after 24 hours. The table also includes results from two other suits from the investigation in 1997, which were not used in the field exercises. These were analysed with 7 parallels.

Suit no	Produced	Manufacturer	Total penetrated amount		
			No of parallels	µg/cm²	Std.error
6	10.91	K Stormark	2	<0.01 and 0.03	-
7	11.91	K Stormark	2	<0.01 and 0.03	-
8	11.91	K Stormark	2	<0.01 and 0.01	-
-	91	K Stormark	7	1.33	0.711
-	90	Paul Boye	7	1.25	1.028

Table 6.1 Results from penetration analyses from lifetime studies in 1997 as total penetrated amount of HD (µg/cm²) after 24 hours

As the results show, the suits that were used in the field exercises had better results than the two unused suits. Even though suits 6-8 had very good results, not all the suits from the field practice gave similar low results, but all had results below the requirement of 4 µg/cm².

The conclusion from this investigation was that the latest type of NM143 suits from both manufacturers could be given a prolonged lifetime temporarily up to 15 years. This was under the prerequisite that regular tests are performed to ensure that the suits maintain their protective properties.

6.2 Lifetime studies in 2001

The relevant results from the penetration analyses in chapter 4 and 5 are summarised in Table 6.2. For suits number 1 – 8 the results are from penetration analyses before laundering, and for suits A – D from the analyses immediately after opening of the packaging.

Suit no	Produced	Manufacturer	Total penetrated amount		
			No of parallels	µg/cm²	Std.error
1	10.91	Paul Boye	6	3.54	0.293
2	10.91	Paul Boye	6	3.27	0.585
3	10.91	Paul Boye	4	4.55	0.941
4	10.91	Paul Boye	4	3.52	0.430
5	10.91	Paul Boye	3	2.97	0.058
6	10.91	K Stormark	4	1.23	0.189
7	11.91	K Stormark	4	1.48	0.148
8	11.91	K Stormark	10	2.35	0.220
A	03.90	K Stormark	4	3.49	0.458
B	03.90	K Stormark	12	3.96	0.238
C	10.88	K Stormark	12	2.84	0.171
D	01.90	Paul Boye	8	3.65	0.498

Table 6.2 Summary of results from penetration analyses on NM143 suits as total penetrated amount of HD (µg/cm²) after 24 hours

The most important result is that of a total of 12 suits, 11 of them still offer a protection below the criterion of 4 µg/cm². The three suits that have been stored opened since 1997 (6 - 8) actually have the best results of all these suits. However, the mean values of penetrated amount of HD are considerably higher than the results from analyses in 1997.

The results from the penetration analyses depend to some extent on the analysis conditions above the sample cells. Temperature and horizontal wind speed above the sample influence the evaporation rate of the liquid HD drop. The higher the temperature and the wind speed are,

the higher is the evaporation rate, and the less is the challenge for the adsorption layer. The effect and the importance of the RH is less understood. The penetration cells are placed inside a fume hood, and these parameters are not controlled but follow the environment in the fume hood. The temperature is relatively stable, between 21 and 23 °C, and the wind speed above the cells is 0.1 ± 0.05 m/s. The RH shows variations as shown in chapter 5.1.

Before 1999 the analysis apparatus was placed in another laboratory, also here inside a fume hood. However, both the temperature and the air stream in the fume hood varied a lot more in the old laboratory than in the new facility. Therefore, comparison of results achieved before and after 1999 should be performed with caution.

It should be noted that the test criteria in the NATO NBC protective clothing triptych AEP-38 recommends an analysis temperature of 30 °C and a wind speed over the sample of 0.5 m/s. With these conditions the evaporation rate will be higher, and consequently the penetrated amount of HD will be lower.

6.3 Discussion

It can be concluded that the protective properties of the NM143 NBC-protective suits have decreased as compared to the analysis in 1997. The degree of deterioration is difficult to state since the former analyses were performed at the earlier facility, with less stable test conditions. The requirement for protective properties against liquid chemical warfare agents is ≤ 4 µg/cm² total penetrated amount in 24 hours. 6 of 12 tested suits had total penetrated amount between 3 and 4 µg/cm², and one suit had a result higher than 4 µg/cm². In the discussion of these results it must be taken into consideration that the analysis conditions used at FFI are stricter than the recommended test criteria in NATO triptych AEP-38. It can be concluded that the NM143 suits still give sufficient protection. However, it is important to continue to do regular tests to follow the development of the protective properties of the suits in the coming years.

It is recommended to upgrade the analysis apparatus so that the temperature, wind speed above the samples and the relative humidity can be controlled. This would make it possible to do penetration analysis in accordance with the recommended test criteria in the NATO triptych. In addition it would be possible to investigate the significance of these factors with respect to penetration through garments.

7 CONCLUSIONS

In summary, the objectives of this study was to answer the following:

- The feasibility of decontaminating NM143suits by laundering
- The possibility of cleaning dirty NM143 suits by laundering
- The effect of storage conditions on NM143 suits
- The lifetime of NM143 suits

7.1 Decontamination and laundering

Full-scale laundering experiments have been performed on the NM143 NBC-protective suits. The work is a continuation of the small-scale decontamination experiments on the NM143 garment. The present experiments have been performed in a conventional washing machine with "Blenda sensitive" as detergent, and washing temperatures 40, 60 and 90 °C. The protective requirement for the suits against liquid chemical warfare agents is maximum 4 µg/cm² penetrated amount in 24 hours with a contamination load corresponding to 10 g/m². With washing temperatures 40 and 60 °C the suits still meet this requirement after one wash. There was no significant difference between the results after laundering at 40 and 60 °C. After two or more launderings at these temperatures the protective properties were reduced and a penetration above the criterion was measured. With washing temperature 90 °C the suits did not meet the requirement of protective properties even after one laundering cycle.

From the small-scale experiment of decontamination by laundering a washing temperature of 60 °C was recommended, because 40 °C gave incomplete decontamination of the garment. Hence, the conclusion from this work is that the NM143 NBC-protective suits can be decontaminated by laundering with washing temperature 60 °C with the selected detergent. A washing temperature of 40 °C can be used for cleaning dirty suits. The suits can only be washed once.

7.2 Effect of storage conditions

Four different suits were analysed immediately after opening of the packaging, and thereafter repeatedly in the period from March 2000 to August 2001. Through this period the suits were stored in a laboratory with stable temperature and varying relative humidity (RH) due to seasonal changes. All suits showed varying protective properties during the period. The change in protective properties could be correlated to the variation in RH, with better protection in periods with high RH.

However, to confirm that the variations in protective properties are caused by variations in RH, it is necessary to do further investigations. Samples of garment from the same suit should be stored under different RH for the same period, and analysed with the same RH as under the storage. To do this, an upgrading of the analysis system to control the RH above the penetration cells is necessary.

7.3 Lifetime studies

Twelve NM143 suits have been examined regarding the protective properties against liquid chemical warfare agents. Three of the suits were investigated in lifetime studies in 1997, and have been stored at FFI since then. The others have been stored in their original packaging until analysis.

Penetration analyses were performed using liquid sulphur mustard (HD) with a contamination level of 10 g/m². The required protection is maximum 4 µg/cm² total penetrated amount after 24 hours. Due to instrumental limitations at FFI, the test conditions for the penetration analyses are stricter than the recommended criteria in the NATO triptych for protective clothing AEP-38.

Eleven of the suits met the protection requirement while one had a result slightly above the requirement. It can be concluded that the suits still meet the protective requirements. However, compared to the examination in 1997 the protective properties have decreased. Therefore, it is important to continue to do regular tests to follow the development of the protective properties of the suits in the coming years.

APPENDIX

A RESULTS FROM PENETRATION ANALYSES FOR LAUNDERING EXPERIMENTS

Washing temp. (°C)	Suit nr	Total penetrated amount after 12 and 24 hours, µg/cm²							
		Before wash		After 1 wash		After 2 washes		After 3 washes	
		12 h	24 h	12 h	24 h	12 h	24 h	12 h	24 h
40	1, jacket	2.185	3.160	1.602	2.133				
		1.706	2.412	2.787	3.521				
		2.879	3.996	5.430	6.659				
	1, trousers	2.480	3.327	6.228	7.100				
		2.816	3.985	5.723	6.874				
		3.239	4.378	1.610	2.124				
	2, jacket	1.331	1.831	3.472	4.592	8.162	10.520	11.149	14.152
		4.026	5.513	3.326	4.264	9.700	12.431	4.278	5.634
		3.284	4.470	2.426	3.031	6.168	7.997	9.967	12.821
						6.619	8.412	7.617	9.811
	2, trousers	2.199	3.010	0.839	1.134				
		1.600	2.113	1.578	2.093				
		1.936	2.699	1.719	2.251				
	5, trousers	4.506	6.042	3.083	3.941	6.016	7.857		
		3.163	4.232	2.176	2.752	3.902	5.001		
		3.095	4.169	1.404	1.796	9.156	11.624		
		3.665	4.937	3.649	4.501	4.335	5.765		
		2.798	3.793	2.882	3.695	5.858	7.649		
		2.022	2.716	2.918	3.688	5.775	7.221		
	6, jacket	0.936	1.392	3.040	3.833	1.507	1.997	5.623	7.073
		1.038	1.563	2.532	3.263	1.850	2.409	10.091	12.525
		0.807	1.276	4.058	5.379	3.963	5.091	5.092	6.412
		0.443	0.693	0.818	1.134	4.172	5.249	10.449	13.165
60	3, jacket	2.288	3.244	1.387	1.891	5.548	7.121	13.323	16.840
		1.867	2.623	2.538	3.383	11.881	14.541	7.228	9.260
								10.238	13.104
								25.212	31.298
	3, trousers	4.435	6.187	3.733	4.949	7.444	9.691		
		4.574	6.137	3.349	4.465	8.848	11.565		
	4, jacket	2.914	4.050	3.754	4.788	8.541	10.735	12.224	15.647
		2.392	3.380	3.024	3.899	6.744	8.615	11.902	14.955
		1.736	2.373	2.718	3.517	5.902	7.589	14.537	18.547
		3.221	4.294	2.812	3.664	4.501	5.822	16.195	20.121
	7, jacket	0.955	1.524	0.761	1.058	4.083	5.232	7.082	8.902
		1.048	1.629	1.510	2.020	5.998	7.526	6.727	8.462
								11.341	13.963
	7, trousers	1.070	1.728	0.965	1.321	3.539	4.512	10.372	12.873
		0.688	1.058	2.012	2.647	3.450	4.396	6.467	8.158
								5.743	7.272

Table A.7.1 Total penetrated amount of HD (µg/cm^2) before and after laundering at 40 and 60 °C for NM143 protective suits

Washing temp. (°C)	Suit nr	Total penetrated amount after 12 and 24 hours, µg/cm²							
		Before wash		After 1 wash		After 2 washes		After 3 washes	
		12 h	24 h	12 h	24 h	12 h	24 h	12 h	24 h
90	5, jacket	2.177	3.053	2.737	3.592	5.214	6.728		
		2.100	2.997	1.816	2.467	2.138	2.856		
		2.004	2.859	3.968	5.019	6.093	7.971		
				1.938	2.589	3.681	4.855		
	8, jacket	2.235	2.939	5.234	6.319	24.480	28.496		
		2.388	3.224	2.851	3.496	9.577	11.562		
		1.970	2.694	4.639	5.594	10.924	12.992		
		1.741	2.347	13.797	16.381	5.117	6.351		
	8, trousers	1.410	1.986	6.339	7.814	15.992	19.387		
		2.305	3.316	4.052	4.945	9.053	11.143		
		1.161	1.609	11.003	13.297	8.805	10.975		
		0.874	1.215	6.978	8.332	9.343	11.432		
		1.703	2.298	3.380	4.214	10.656	13.019		
		1.325	1.859	2.178	2.757	4.045	5.123		

Table A.7.2 Total penetrated amount of HD (µg/cm^2) before and after laundering at 90 °C for NM143 protective suits

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