DERMAL ABSORPTION OF TOXIC GASSES BY FIREMEN WEARING PROTECTIVE SUITS

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Abstracts
Victims of toxic releases in buildings in some cases need to be rescued as quickly as possible (grab rescue). Fire fighters may than rescue them. However, the firefighters themselves might get exposed to the toxic gasses as well, either oral (breathing) or dermal (through the skin). Until now, there is hardly any knowledge about the dermal absorption of toxic gasses by firemen wearing protective clothing during a grab rescue.

To develop such knowledge, we firstly mathematically transposed a method for inhalator absorption into a method for dermal absorption. To this end we used well-know intervention values for gasses (mg/m^3) in the open air and a model that calculates the dermal penetration of a toxic gas in milligrams (in case we know the skin surface, exposure time and gas concentration). This enabled us to predict the critical dose for a toxic gas. Secondly, we conducted a series of real life tests (total inward leakage (TIL) 5 movements) involving 6 respondents in a gas filled laboratory area. The respondents (in real life firemen) wore protective clothing and a breathing apparatus. Under these clothes, they were equipped with gas monitoring sensors. During 1) staying, 2) walking, 3) stretching, 4) squats and 5) twisting, we measured the gasses inside the protective clothing. Subsequently, we translated these values into the protection factor (the amount the toxic concentration in the air is reduced before it reaches the skin) of the firemen's clothes. To this end, we combined the critical dose and the measured concentration inside the protective clothing.

Standard firemen clothing hardly protects against toxic gasses penetrating the skin (protection factor in the range from 2-20). Wearing a chemical suit realizes very high protection levels (protection factor of more than 5000).

Finally, for grab rescues inside buildings we deduced several threshold intervention values depending the firemen particular protective clothing.

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1. Introduction

Hazardous substances are integral part of societies. Companies use hazardous substances as part of their products or as a substance to stimulate chemical process, or even produce such hazardous materials themselves. Not only on chemical sites or production facilities, hazardous substances are apparent. Such substances are transported as well.

In laboratory, production and transportation activities something might go wrong: a leakage or an accident may require fire fighters to operate. To this end, specialized hazardous material teams come into action wearing some kind of personal protection equipment. The type of suits may vary from ordinary fire fighter suits, to chemical suits to gas protection suits. The ‘problem’ of the latter is that it takes about half an hour to be operational in such a suit. This might be a too long period in situations were humans need to be rescued, in particular in contained areas such as laboratories and hall for stocking chemicals. As an alternative, less protective, but faster to operate suits may be used such as the ordinary fire suit or chemical suits.

Such suits mainly protect fire fighter against inhaling substances or against direct skin contact due to solid or fluid substances. However, the extent the ordinary suit and chemical suit protects the fire fighter against *dermal* absorption of hazardous gasses is less known.
This paper presents the results of some experiments we conducted to find out the protection factors of various fire fighter suits. In section 2, we present various fire fighter suits that are in use in The Netherlands. In section 3, we describe the experimental design that we used to measure the amount of part that entered the suits and subsequently could be absorbed in the human body via the skin. In section 4, we present the results. In section 5, we draw the conclusions and formulate recommendations. We end this paper with some reflections on our research (section 6).

2. Types of protection suits in The Netherlands

Specialized hazardous material teams come into action wearing some kind of personal protection equipment. The type of suits may vary from ordinary fire fighter suits, to chemical suits to gas protection suits. These suits vary in the way they protect fire fighters and in the response time they can be operational. Table 1 qualitatively assess the three types of suits. The questions marks in table 1 indicate a knowledge gap which is the core of this paper.

Table 1: Three types of fire suits and their protection and speediness

	Ordinary suit	*Chemical suit*	*Gas protection suit*
Protection	??	??	Very good
Time to be operational	Takes scarce time, about 1 minute	Takes scarce time, about 5 minutes	Takes long, about 30 minutes

The gas protection suits are not involved in this research. We are interested high time pressure rescue situations (scoop and run) and the opportunities of quick to operate suits. Because of the safety of the fire fighters, it is important to have a clue to what extent the ordinary suits and chemical suits protect them against hazardous gasses.

The ordinary fire fighter suits are made of permeable layers. In between these layers, several ‘breathing’ membranes are apparent. This construction ensures that body heat and sweat can be drained of from the inside to the outside, but in the same substances can not penetrate form the outside to the inside (impermeable). Some suits are made of one single part, others consist of two parts. The connection between the suit and the mask (near the neck) is sealed using Velcro.

There are several positions in the suits where the hazardous gasses may enter the suit: wrist, neck and foot joint. Because of the various compartments in the suits, only about 1/3 of the total body surface can be exposed (Jongeneelen, 1996).

In addition to the ordinary suits, chemical suits may be used for scoop and run rescue operations. In these experiments and based upon an inventory of chemical suits in the Netherlands, the following suits are tested (Van Beek and Sabel, 2008).

1) Ordinary fire fighter suit without sealed gaps
2) Ordinary fire fighter suit and sealed gaps
3) Ordinary fire fighter suit, without sealed gaps and Splash-1000 hood
4) Ordinary fire fighter suit, sealed gaps and Splash-1000 hood
5) Tychem F chemical suit
6) Splash-2000 chemical suit

The three pictures below show the various types of fire fighter suits. Most left is the ordinary suit where gaps have been sealed with duc tape. The middle picture shows the additional Splash hood of the Splash 1000 chemical suit that is worn over the ordinary suit. The most-right picture is the Tychem F chemical suit.

Figure 1: types of protective fire suits.

Suits have a protection factor. The protection factor is defined as reduction factor of the suit and can be determined by comparing the gaseous concentration inside the suit to the gaseous concentration in the direct environment (e.g. gaseous concentration outside the suit = 60 and inside the suit is 20, than the protection factor of the suit is 3: 60/20).

These suits do have a protection factor for direct skin contact with solids and fluids. However, this protection factor is not applicable to dermal absorption of hazardous gasses. Our goal is to determine the protection factor of each suit for dermal absorption of hazardous gasses. This protection factor is determined for certain movements during a scoop and run rescue operation of fire man in an indoor environment in which a hazardous gas is apparent.

In literature, protection factors for fire suits in above-described typical circumstances do not exist. Therefore we need to develop a model to determine the protection factor. The Skinperm-model (Ten Berge, 2008) is able to calculate the dermal penetration through the skin, expressed in a dose (mg). To this end, the model uses:

- Gaseous concentration (mg/cm^3)
- The exposed skin surface (cm^2)
- Exposure time (minutes)

To determine the risk of this dose, the dose needs to be compared with a critical dose. Critical doses for dermal absorption do not exist yet. Related critical doses exist, such as the US emergency response planning guidelines (ERPG) and the Dutch similar alarm threshold criterion (AGW). The ERPG-II and AGW are defined as the threshold concentrations (mg/m^3) for various hazardous materials being (AIHA, 2008)

"the maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action".

which a person can be exposed to for 60 minutes and as a results get injured and is not able to rescue him/herself anymore. For example, the ERPG-II and AGW of acrylonitrile is about 50 to 75 parts per million (ppm). The lower the AGW, the more toxic the hazardous material is. We use the ERPG-II (based upon a 60 minutes exposure time) to determine the critical doses for dermal absorption as follows:

Critical dose ≈ ERPG-II *x* breathing minute volume *x* exposure time *x* fraction inhaled toxic gas

The exposure time is 60 minutes. The inhaled fraction is about 0,5. The breathing minute volume for a person executing a moderate work is 0,035

Critical dose (mg)	≈	ERPG-II *x* 0,035 *x* 60 *x* 0,5	≈	ERPG-II

The relative risk due to skin or dermal absorption can be determined using the Skinperm calculated dose and the critical dose:

Relative risk dermal absorption = Skinperm calculate absorption dose / critical dose

In case the relative risk dermal absorption number is smaller than 1, this means that no specific skin protection are necessary. In case the number equals of exceeds 1, additional protection equipment is needed, such as gloves or protective suits. The extent to which additional protections reduces the risks can be calculated as follows:

Risk reduction due to protection = Relative risk dermal absorption / protection factor suit

The protection factors of suits are available and can be used to determine the risk reduction due to particular suit for skin absorption of hazardous gases.

3. The experiments

Before conducting the experiments, we need to know what movements are made by fire fighters involved in hazardous material rescue situations. To this end, we observed 4 fire fighter hazardous materials trainings in 3 different fire regions in The Netherlands. We selected those movements that could affect the extent of protection of the fire fighter suits, and that are part of the Total Inwards Leakage (TIL) test EN943 (NEN-EN 943):

a) Staying: just staying on the location
b) Walking: moving 1,5-2 m/s
c) Stretching: moving arms up and down
d) Squats: bending the knees and touching the floor with the arms

e) Twisting: circulating the hips and the arms pressed against the body

The TIL-test is a European norm and is meant to approve or disapprove a protective suit.
In the TIL test, all these movements have to be done during 3 minutes. At least 2 persons should be included in the TIL test, which is sufficient to assess the protection factor of the suits. Inside the suit, we positioned a small hose on the skin from the chest, via the arm to the equipment to measure. For the same person, we ensured enough time to rest between the various tests. A test is a movement during 3 minutes as described above, wearing a particular type of suit. The tests were conducted by 7 real life fire men in the TNO test room, from November 2007-february 2008.
Not each fire man did the same test because of the (dis)availability of a certain type of suit. The table below shows which test was done by each fire fighter.

Table 2: Tests per fire man

	Test					
	1)	2)	3)	4)	5)	6)
Fire man	1,3,4,5,6	1,3	2,3,4,5,6	1,4,5	2,3	2,3,7

4. Test results

Below, we present per test the results in a single table (van Beek and Sabel, 2008). In each table, we present the protection factor for the particular suit per test movement (a), b), …e)) per fire man. Remember that we defined the protection factor as reduction factor of the suit and can be determined by dividing the gaseous concentration in the direct environment by the gaseous concentration inside the suit.

Table 3: test with ordinary fire fighter suit without sealed gaps

	Fire man				
Movement	1	3	4	5	6
Staying	2,7	3,4	4,1	8,9	3,2
Walking	4,0	4,3	16,4	21,2	9,1
Stretching	3,4	2,9	16,2	11,2	5,3
Squats	2,8	2,9	8,5	9,6	2,6
Twisting	2,9	2,5	10,6	9,8	4,1

From table 3, we conclude that ordinary fire fighter suits have a very low protection factor (in the range from 2-20). This means that an ordinary fire suit hardly protects against dermal absorption of hazardous gasses.

Table 4: Ordinary fire fighter suit and sealed gaps

	Fire man	
Movement	1	3
Staying	2,2	6,5
Walking	3,0	6,5
Stretching	2,7	8,2
Squats	1,9	7,7
Twisting	3,4	6,5

In addition to the conclusion from table 3, and based upon table 4, we conclude that sealing the gaps in ordinary fire suits hardly improves the protection factor, and hence the protection factor is low.

Table 5: Ordinary fire fighter suit, without sealed gaps and Splash-1000 hood

	Fire man				
Movement	2	3	4	5	6
Staying	775	40	-	1595	20
Walking	120	45	45	-	25
Stretching	105	30	25	35	50
Squats	80	20	20	120	25
Twisting	205	25	20	195	-

- means not measured

Using the hood, already improves the protection factor substantially.

Table 6: Ordinary fire fighter suit, sealed gaps and Splash-1000 hood

	Fire man		
movement	1	4	5
Staying	105	35	90
Walking	80	560	-
stretching	50	150	300
Squats	20	25	130
Twisting	45	35	605

Sealing the gaps, for the more critical movements such as squats and twisting hardly improves the protection factor (compare table 5 and 6 for fire man 4 and 5)

Table 7: Tychem F chemical suit

	Fire man	
movement	2	3
Staying	5,7	25
Walking	5,4	15
stretching	6,0	6,3
Squats	4,0	10
Twisting	4,7	10

Tychem F chemical suit, like the ordinary fire suits (see table 3) hardly protects against dermal absorption of hazardous gasses.

Table 8: Splash-2000 chemical suit

	Fire man		
movement	2	3	7
Staying	17975	95	930
Walking	-	3620	44600
stretching	11440	2020	105000
Squats	21880	3550	180000
Twisting	29600	-	427000

The Splash-2000 chemical suit realizes a large protection factor. The picture on the right shows a fire man doing squats wearing the Splash-2000 chemical suit.

5. Conclusions en recommendations

In case of a rescue situation involving hazardous gasses, fire fighters have to decide in split seconds which kind of protection to wear to rescue the victim. The rescue operation may often take no longer than 5 minutes. This decision which suit to wear depends mainly upon the gas concentration of the particular gas, the available suit and according protection factor and time pressure.

- Ordinary fire suits have a protection factor in the range from 2-20, which is very low
- Sealing gaps in the suits hardly improves this protection factor
- Ordinary fire suits in combination with a hood improve the protection factor to 30.
- The Splash 2000 chemical suit has a good protection factor, being the rage of 2000-400000.

We conclude that for a rescue operation in a building and under hazardous gasses atmosphere the type of suit is determined by the alarm threshold value (AGW) of a hazardous material:

- AGW is 1-20mg/m^3: always wear Splash-2000 chemical suit
- AGW is 20-150mg/m^3: wear a chemical suit over the ordinary fire suit and breathing apparatus
- AGW exceeds 150mg/m^3: wear at least a ordinary fire suit and independed breathing apparatus

We recommend implementing these rules of thumb for gas concentration (AGW) in combinations with the type suit in fire fighter source documents and education. In addition, they could be part of the standard operating procedures.

6. Reflections

We did the best to ensure valid measurements, however, there are still some aspects that should be bared in mind dealing with the results.
First, we had various fire man involved in the tests, causing variations in the way they execute the movements such as the squats and twisting.
Second, the fire man used their own ordinary suits which had some gaps. We sealed the gaps, using duc tape. However, the quality of the sealing may vary just the suit it self.
Third, each fire man only once executed a single test (suits). More tests per fire man with the same suit would have resulted in a better base for the determined ranges of the protection factors for that type of suit.

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