Fire suits protecting fire men against dermal absorption of toxic gasses

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TNO | Knowledge for business

Contents

Background

- Toxic releases in laboratories and Haz. Mat. Warehouses
- Toxic gasses releases or vapours: Fire fighters wear gas protective suits
- Takes about 30 minutes to put on
- Victim already wounded/dead
- Necessary: a suit that is quicker to put on but still safe

Background

Fire suit

chemical suit

gas suit

Background

	Ordinary fire suit	Chemical suit	Gas protection suit
Protection factor	??	??	Very good (protection factor >4000)
Time to be operational	Takes scarce time, about 1 minute	Takes scarce time, about 5 minutes	Takes long, about 30 minutes

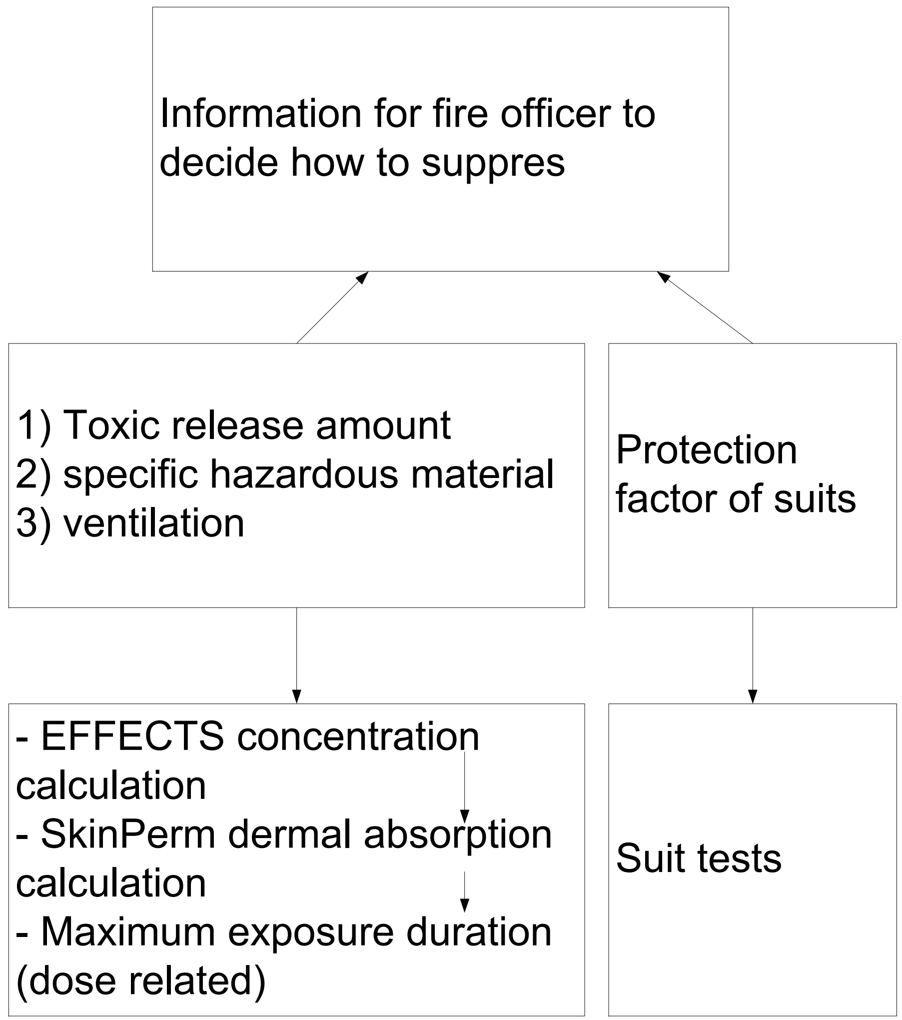
Research framework: goals

- ***Incident commander needs to make a quick and on-scene decision on which suit to wear: fire fighter risk versus speed***

- Research goal:
  a) *develop a method to express personnel safety of non-conventional gas protective suits and*
  b) *apply the method for various movements and suits to reveal a range for the protection factor of these suits*

- How:
  - *By studying theory and conducting experiments*

Research framework



Research framework: focus on …

- Hazardous material releases
- Gasses or liquids: gasses/vapours
- Inhalation or dermal absorption: dermal absorption
- Inside a building or in the open air: inside
- life rescue or damage control: life rescue
- grab rescue or stabilization: grab rescue

Theory: fire suits

- Suit: permeable layers
- Gasses enter the suit: wrist, neck and foot joint
- Suits have compartments: about 1/3 of the total body surface can be exposed

Theory: protection factor

- Suits protection factor =
  gas concentration outside/ gas concentration inside [1]

- Protection factors for ordinary suits due to direct *dermal* absorption do not exist

- Hence, we need a critical dose (via *inhalation*):
  - US emergency response planning guidelines (ERPG II)
  - Dutch similar alarm threshold criterion (AGW)

- ERPG II $\approx$ AGW

Theory: ERPG II

- ERPG II = maximum concentration in the air below which it is believed nearly all individuals could be exposed to 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 (American Industrial Hygiene Association)
- In mg/m3

Theory: Critical dose

- Critical dose ≈ (ERPG-II) *x* (breathing minute volume) *x* (exposure time) *x* (fraction inhaled toxic gas) [2]

- The ERPG 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 ≈AGW

Theory: risk reduction

- Relative risk dermal absorption =

  SkinPerm calculated absorption dose / critical dose [3]

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

- Risk reduction due to protection =

  Relative risk dermal absorption / protection factor suit [4]

Calculations: Concentration

Verdampende Stof uitgestroomd over vloer	Kook-punt	Max. Damp-Spanning (bij 20°C)	Tijd na Vrijkomen	2 tot 50 kg in Labora-torium					200 tot 1000 kg in Loods			
	[°C]	[mbar]	[Min]	V=2	V=4	V=6	V=8		V=0,6	V=1,5	V=3	V=5
Aceton	56	240	15	0,4-9%	0,3-7%	0,3-6%	0,2-5%		2-10%	2-9%	2-7%	1-6%
			30	0,6–14%	0,4-10%	0,3-7%	0,2-6%		4-18%	3-14%	2-11%	2-8%
			60	0,9-19%	0,5-11%	0,3-8%	0,2-6%		7-31%	4-21%	3-13%	2-8%
Ethanol	78	59	15	0,6-15%	0,5-12%	0,4-10%	0,3-8%		3-14%	3-13%	2-11%	2-9%
			30	1-24%	0,7-17%	0,5-12%	0,4-9%		6-26%	5-21%	3-16%	2-11%
			60	1-33%	0,8-19%	0,5-13%	0,4-10%		10-45%	7-31%	4-19%	3-12%
Acrylonitril	77	124	15	0,3-12%	0,3-10%	0,2-8%	0,2-7%		3-13%	2-11%	2-10%	2-8%
			30	0,5–19%	0,4-13%	0,3-10%	0,2-8%		5-23%	4-19%	3-14%	2-10%
			60	0,7-27%	0,4-15%	0,3-10%	0,2-8%		9-40%	6-28%	4-17%	2-11%
Methyl-methacrylaat	100	39	15	0,4-10%	0,3-8%	0,3-7%	0,2-6%		3-14%	2-12%	2-10%	2-8%
			30	0,7-17%	0,5-11%	0,3-8%	0,3-7%		5-25%	4-21%	3-15%	2-11%
			60	0,9-23%	0,5-13%	0,4-9%	0,3-7%		8-44%	6-31%	4-19%	2-12%
Hydrazine	114	21	15	0,4-11%	0,4-9%	0,3-7%	0,2-6%		3-14%	2-13%	2-11%	2-9%
			30	0,7-17%	0,5-12%	0,4-9%	0,3-7%		5-26%	4-21%	3-16%	2-11%
			60	1-24%	0,6-13%	0,4-9%	0,3-7%		9-45%	6-31%	4-19%	2-12%
Nitrobenzeen	211	0,2	15	0,7-16%	0,5-13%	0,5-11%	0,4-9%		4-18%	4-16%	3-14%	3-11%
			30	1-26%	0,8-18%	0,6-13%	0,4-10%		8-33%	6-27%	5-20%	3-14%
			60	2-36%	0,9-21%	0,6-14%	0,4-10%		13-58%	9-40%	6-25%	4-15%

V = ventilatievoud [per uur]

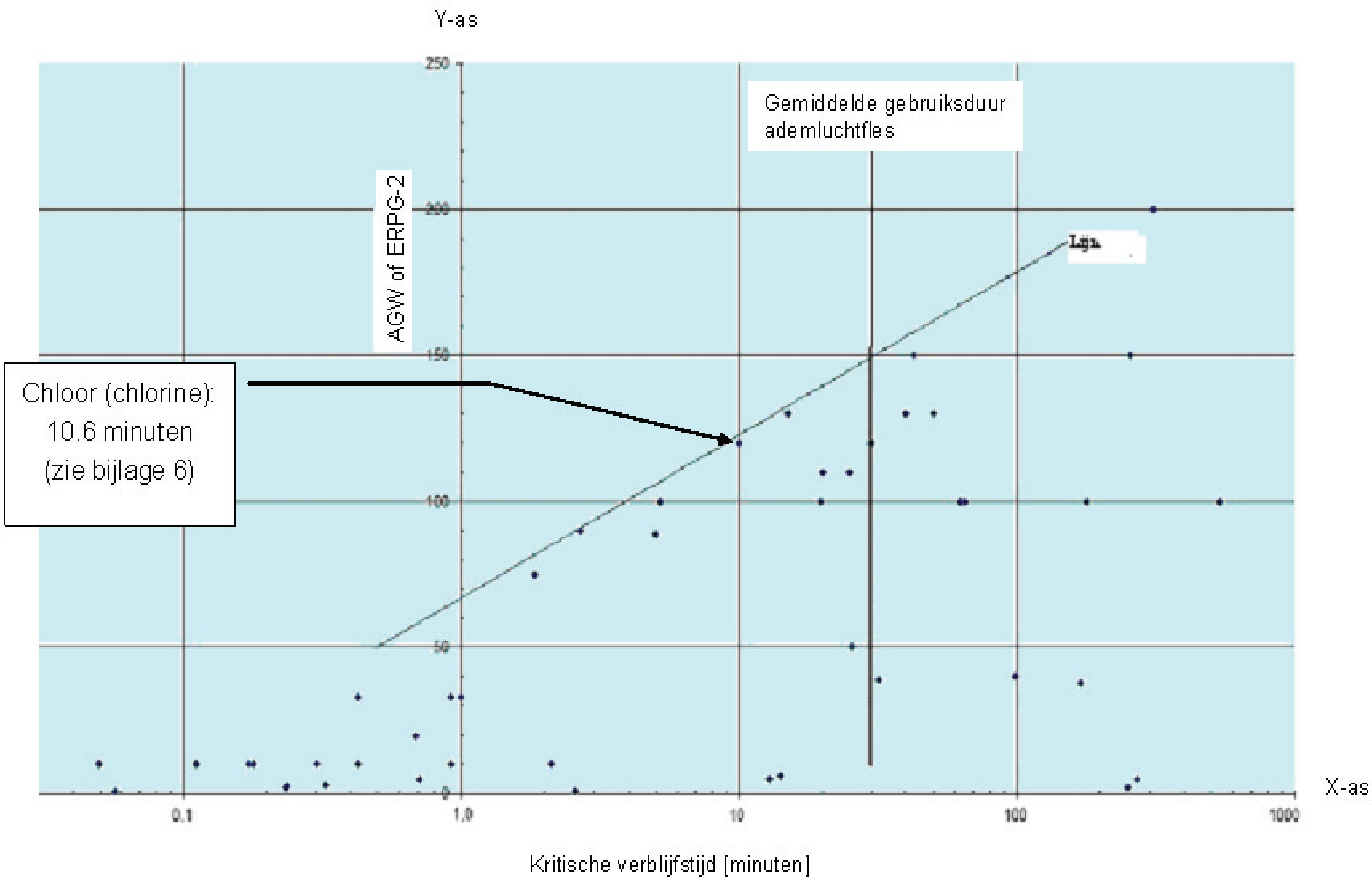
Calculations: Critical exposure times

STOFNAAM	KRITISCHE VERBLIJFTIJD IN LOODS				
	PF=3	PF=10 (alle waarden in minuten)	PF=100	PF=1000	PF=10000
Acroleine	0.0	0.0	0.4	3.8	38.1
Acrylonitril	19.2	63.9	> 120	> 120	> 120
Acrylonitrile	19.2	63.9	> 120	> 120	> 120
Adipinezuur	> 120	> 120	> 120	> 120	> 120
Allyl alcohol	0.2	0.8	7.5	75.4	> 120
Ammonia	14.8	49.3	> 120	> 120	> 120
Benzeen	> 120	> 120	> 120	> 120	> 120
Blauwzuur	0.1	0.4	4.4	44.4	> 120
Butyldiglycol	> 120	> 120	> 120	> 120	> 120
Carbon disulphide	> 120	> 120	> 120	> 120	> 120
Carbon monoxide	> 120	> 120	> 120	> 120	> 120
Chlorine	10.6	35.4	> 120	> 120	> 120
Choroform	> 120	> 120	> 120	> 120	> 120
Dichloortolueen	0.2	0.6	5.9	59.0	> 120
Dicyclopentadieen	74.1	> 120	> 120	> 120	> 120
Ethyleenglycol	48.6	> 120	> 120	> 120	> 120
Ethyleenoxide	2.0	6.7	67.2	> 120	> 120
Formaline (37%)	1.6	5.3	52.9	> 120	> 120
Fosfine	0.2	0.6	5.8	58.1	> 120
Fosforzuur	9.6	32.1	> 120	> 120	> 120
Furfural	23.8	79.4	> 120	> 120	> 120
Hydrazine	0.5	1.8	17.8	> 120	> 120
Hydrogen chloride (36% sol)	0.3	1.1	10.7	106.5	> 120
Hydrogen fluoride	0.5	1.7	17.0	> 120	> 120
Hydrogen sulfide	> 120	> 120	> 120	> 120	> 120
Methylmethacrylaat	> 120	> 120	> 120	> 120	> 120
N-butylalcohol	31.9	106.5	> 120	> 120	> 120
Nitric acid (>70%)	0.1	0.3	2.8	27.8	> 120
Nitrobenzeen	> 120	> 120	> 120	> 120	> 120
Parathion	> 120	> 120	> 120	> 120	> 120
Phenol	3.8	12.6	> 120	> 120	> 120
Phosgene	0.0	0.1	1.4	14.2	> 120
Phosphorus trichloride	0.7	2.3	22.9	> 120	> 120
Phosphoryl trichloride	0.2	0.8	8.1	81.3	> 120
Piperidine	0.1	0.4	4.3	42.9	> 120
Pyridine	1.4	4.6	46.1	> 120	> 120
SO3	0.3	1.1	10.7	106.9	> 120
Sulfuric acid (+)	> 120	> 120	> 120	> 120	> 120
Teer	> 120	> 120	> 120	> 120	> 120
Teerzuur	47.0	> 120	> 120	> 120	> 120
Tetraethyllood	1.9	6.4	64.4	> 120	> 120
Vinylacetaat	> 120	> 120	> 120	> 120	> 120

STOFNAAM	KRITISCHE VERBLIJFTIJD IN LABORATORIUM				
	PF=3	PF=10 (alle waarden in minuten)	PF=100	PF=1000	PF=10000
Acroleine	0.2	0.8	7.6	76.2	> 120
Acrylonitril	> 120	> 120	> 120	> 120	> 120
Acrylonitrile	> 120	> 120	> 120	> 120	> 120
Adipinezuur	> 120	> 120	> 120	> 120	> 120
Allyl alcohol	4.5	15.1	> 120	> 120	> 120
Ammonia	> 120	> 120	> 120	> 120	> 120
Benzeen	> 120	> 120	> 120	> 120	> 120
Blauwzuur-liquified	2.7	8.9	88.8	> 120	> 120
Butyldiglycol	> 120	> 120	> 120	> 120	> 120
Carbon disulphide	> 120	> 120	> 120	> 120	> 120
Carbon monoxide	> 120	> 120	> 120	> 120	> 120
Chlorine	> 120	> 120	> 120	> 120	> 120
Choroform	> 120	> 120	> 120	> 120	> 120
Dichloortolueen	3.5	11.8	118.1	> 120	> 120
Dicyclopentadieen	> 120	> 120	> 120	> 120	> 120
Ethyleenglycol	> 120	> 120	> 120	> 120	> 120
Ethyleenoxide	40.3	> 120	> 120	> 120	> 120
Formaline (37%)	31.8	105.9	> 120	> 120	> 120
Fosfine	3.5	11.6	116.2	> 120	> 120
Fosforzuur	> 120	> 120	> 120	> 120	> 120
Furfural	> 120	> 120	> 120	> 120	> 120
Hydrazine	10.7	35.6	> 120	> 120	> 120
Hydrogen chloride	6.4	21.3	> 120	> 120	> 120
Hydrogen fluoride	10.2	34.0	> 120	> 120	> 120
Hydrogen sulfide	> 120	> 120	> 120	> 120	> 120
Methylmethacrylaat	> 120	> 120	> 120	> 120	> 120
N-butylalcohol	> 120	> 120	> 120	> 120	> 120
Nitric acid (>70%)	1.7	5.6	55.6	> 120	> 120
Nitrobenzeen	> 120	> 120	> 120	> 120	> 120
Oleum-SO3	6.4	21.4	> 120	> 120	> 120
Parathion	> 120	> 120	> 120	> 120	> 120
Phenol	75.4	> 120	> 120	> 120	> 120
Phosgene	0.9	2.8	28.5	> 120	> 120
Phosphorus trichloride	13.8	45.9	> 120	> 120	> 120
Phosphoryl trichloride	4.9	16.3	> 120	> 120	> 120
Piperidine	2.6	8.6	85.9	> 120	> 120
Pyridine	27.6	92.1	> 120	> 120	> 120
Sulfuric acid (+)	> 120	> 120	> 120	> 120	> 120
Teer	> 120	> 120	> 120	> 120	> 120
Teerzuur	> 120	> 120	> 120	> 120	> 120
Tetraethyllood	38.7	> 120	> 120	> 120	> 120
Vinylacetaat	> 120	> 120	> 120	> 120	> 120

Warehouse (1000 litres) and Laboratory (50 litres)

Calculations: ERPG II versus exposure time



Experiments

- Observation of 4 haz.mat training for typical movements, how often and how long:

- Goal: find movements that negatively affect protection factor of suit, i.e. Belly effect

- Schrinking
- Bending knees (squats)
- Stretching

- Grab rescue: max 5 minutes, about 20 movements

Experiments

Experiments

Total Inwards Leakage (TIL) test EN943 (NEN-EN 943):

- •2 tests per suit, (dis)approve suite
- •Aimed to get a feeling of the range of possible protection factors

3 minutes test

•Staying: just staying on the location

•Walking: moving 1,5-2 m/s

•Stretching: moving arms up and down

•Squats: bending the knees and touching the floor with the arms

•Twisting: circulating the hips and the arms pressed against the body

Experiments

Six different suits

- *Ordinary suit without sealed gaps*
- *Ordinary suit and sealed gaps*
- *Ordinary suit, without sealed gaps and Splash-1000 hood*
- *Ordinary fire fighter suit, sealed gaps and Splash-1000 hood*
- *Tychem F chemical suit*
- *Splash-2000 chemical suit*

6 fire fighters,
various test,
harmless gas (sea air),
equipment inside suit

Results

To classify the results:

Protection factor	*Type of suit*	*Protection*
3	Ordinary suit	Very poor
10	Chemical suit	Poor
100	Chemical suit	Moderate
1000	Gas suit, small leakage	Good
>10000	Gas suit	Hardly any leakage

Results

test with *ordinary fire fighter suit* without sealed gaps,

In table, the protection factor (Conc. Outside / Conc. inside)

	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

protection factor: very poor

Results

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

sealing the gaps in ordinary fire suits hardly improves the protection factor: very poor

Results

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	-

Using the hood, already improves the protection factor substantially: poor to moderate

Results

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 hardly improves: poor to moderate

Results

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

hardly protects against dermal absorption of hazardous gasses: poor

Results

Splash-2000 chemical suit

	Fire man	
movement	*2*	*3*
Staying	17975	95
Walking	-	3620
stretching	11440	2020
Squats	21880	3550
Twisting	29600	-

realizes a large protection factor: good to hardly any leakage

Conclusions

1. Ordinary fire suits have a protection factor in the range from 2-20, which is very low, gas suits > 4000

2. Sealing gaps in the suits hardly improves this protection factor

3. Ordinary fire suits in combination with a hood improve the protection factor to 30.

4. The Splash 2000 chemical suit has a good protection factor, > 2000.

Conclusions

Rescue operations in a building and under hazardous gasses atmosphere the type of suit to ware should be determined by the ERPG II value of a hazardous material:

•ERPG II is 1-20mg/m^3: always wear Splash-2000 chemical suit

•ERPG II is 20-150mg/m^3: wear a chemical suit over the ordinary fire suit and breathing apparatus

•ERPG II exceeds 150mg/m^3: wear at least an ordinary fire suit and independent breathing apparatus