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Hazard evaluation of infrared smoke grenades based on the dispersion and the composition of the smoke

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Summary

Norwegian Institute for Air Research (NILU) was asked by Raufoss Technology (RATEC) to analyse the contents of polycyclic aromatic hydrocarbons (PAH) and dioxins in a visual/infrared screening smoke. The scope of the examination was to quantify the carcinogenic PAH components according to the International Agency for Research of Cancer (IARC) classification and to quantify the dioxin risk.

Based upon a calculation of the amount of combustion products, an analysis of the PAHs and dioxins and a simple dispersion calculation, the hazard exposure has been evaluated. A comparison between the calculated exposure of carcinogenic PAH from one 76 mm smoke shell and from one smoke canister in a 155 mm artillery smoke shell and the exposure of carcinogenic PAH from smoking cigarettes have been made.

Based upon calculations for wind velocities of 3 m/s, the following conclusions can be drawn:

- Downwind concentrations of dioxins are less than 1.7 pg/m^3 at 20 m distance from the 155 mm canister.
- Exposure for the duration of the smoke screen through inhalation is then calculated to be more than a factor 1000 below the guideline (TDI) given by the World Health Organization (WHO) and European health authorities.
- Downwind concentrations of carcinogenic PAHs are less than 15 µg/m^3 at 20 m distance from the 155 mm canister.
- At 100 m from the smoke source of the 155 mm canister, exposure to carcinogenic PAHs through inhalation for the duration of the smoke screen is equivalent to the carcinogenic PAH exposure from smoking less than two cigarettes.
- At 20 m from the smoke source of the 76 mm grenade, exposure to carcinogenic PAHs through inhalation for the duration of the smoke screen is equivalent to the carcinogenic PAH exposure from smoking three cigarettes.

Hazard evaluation of infrared smoke grenades based on the dispersion and the composition of the smoke

1. Introduction

Norwegian Institute for Air Research (NILU) was asked by Raufoss Technology (RATEC) to analyse the contents of polycyclic aromatic hydrocarbons (PAH) and dioxins in screening smoke. Based upon a calculation of the amount of combustion products, an analysis of the PAH and dioxin and a simple dispersion calculation, the hazard exposure has been evaluated. The calculated exposure to carcinogenic compounds in the screening-smoke has been compared to the exposure to the same compounds through smoking cigarettes.

2. Sampling and analysis

2.1 Sampling

The sampling of soot was performed by Norwegian Defence Research Establishment (NDRE). Smoke canisters were ignited and placed in a smoke chamber. The floor of the chamber was covered by an aluminium sheet. The sample of soot was collected from the aluminium sheet after the combustion was finished. The smoke chamber was closed during the combustion, and the sample was collected after the chamber had cooled off to the air temperature. The cooling lasted for approximately 30 minutes. The sample was then transferred to a cleaned polyethylene bottle.

2.2 Analysis

Analysis of PAH was carried out in accordance with the standard NILU clean-up and quantification procedure for PAH (NILU-O-3). A short description of the method is given in Appendix A.

The soot sample was weighed and transferred to an extraction thimble. Internal standards were added, and the sample was soxhlet-extracted with cyclohexane for 24 hours.

Only a part (aliquot) of the extract was taken for the analysis.

For analysis of dioxins (PCDD/PCDF), the standard NILU clean-up and quantification procedure for dioxins (NILU-O-1) was used. This procedure is described shortly in Appendix B. The analysis of the sample was difficult due to a high amount of anthracene. Anthracene has a structure closely related to dioxins. The uncertainty of the results, which is normally below $\pm 25\%$, is slightly higher, but well below 50%.

3. Composition of the smoke

The scope of this examination is to quantify the carcinogenic PAHs components, according to the International Agency for Research of Cancer (IARC) classification.

During the combustion of the smoke charges, the whole spectrum of PAH components is created. Anthracene, which has a purity of 98% in the smoke charges, is detected in the soot with approximately 60% of the quantified PAH components. Approximately 30% of the PAHs are more volatile than anthracene and approximately 10% are less volatile.

So-called semi-volatile PAHs will be found both in the gaseous phase and condensated to particles. The components from naphthalene to benz(a)anthracene are described as semi-volatile. This fraction makes up for 97% of the quantified PAH components. Normally, a significant amount of gaseous-phase PAHs will be present, especially of the bi-cyclic components. In this sampling and analysis, the gaseous-phase is omitted. According to the IARC classification of carcinogenic PAH components, these will be condensated to particles.

The heavier fractions of PAH which are bound to particles, makes up 3% of the total amount of quantified PAHs. This fraction contains the carcinogenic components as classified by IARC. It is these components that have been treated further here in the sections containing dispersion and exposure. Table 3.1 shows the PAHs found in the sample.

The PCDD/PCDF concentration in the sample is very low, 66.2 pg/g soot given as 2,3,7,8-TCDD toxicity equivalent.

Table 3.1: PAH concentrations in the soot sample.

PAH	µg/g
Naphthalene	1405
2-Methylnaphthalene	53.6
1-Methylnaphthalene	25
Biphenyl	575
Acenaphthylene	42.2
Acenaphthene	
Dibenzofuran	598
Fluorene	620
Dibenzothiophene	36.5
Phenanthrene	4482
Anthracene	14786
2-Methylphenanthrene	
2-Methylanthracene	
1-Methylphenanthrene	
Fluoranthene	1912
Pyrene	40.5
Benzo(a)fluorene	7.4
Reten	
Benzo(b)fluorene	
Benzo(ghi)fluoranthene	101
Cyclopenta(cd)pyrene	
Benz(a)anthracene*	65.8
Chrysene/Thriphenylene*	80.0
Benzo(b/j/k)fluoranthenes*	366
Benzo(a)fluoranthene	28.7
Benzo(e)pyrene	32.1
Benzo(a)pyrene*	5.5
Perylene	15.2
Indeno(1,2,3-cd)pyrene*	85.8
Dibenzo(ac/ah)anthracene*	27.3
Benzo(ghi)perylene	17.2
Anthanthrene*	13.6
Coronene	46.6
Totalt carcinogenic PAHs	644

*: Carcinogenic

4. Dispersion of smoke

Dispersion calculations through the use of a gaussian dispersion model have been carried out. The dispersion calculations are based upon assumptions that the smoke will be in near thermal equilibrium with the surrounding air at a distance of 20 m from the release point, and that the smoke screen at this point will be approximately 10 m high and 10 m wide. Field experiments have shown that when the wind velocity is below 3 m/s the smoke screen will rise significantly above ground level. For calculations of ground level concentrations, a windspeed of 3 m/s is used as a critical wind velocity. The expansion of the smoke screen downwind will dilute the emitted soot from the smoke canister.

To describe the dilution process, a gaussian distributed plume equation is used. The growth of the gaussian plume with downwind distance is described by dispersion parameters expressed by the standard deviations in horizontal and vertical direction perpendicular to the wind.

Suitable expression for the dispersion parameters for a small source emitted at ground level are given by Briggs (1974). The expressions used in these calculations reflect dispersion during neutral atmospheric stratification. The crosswind areas covered by the smoke screen at different distances from the source are shown in Table 4.1. The horizontal and vertical standard deviations are also given.

Table 4.1: Crosswind area of the smoke screen at different distances from the release point. The applied dispersion parameters are also shown.

Distance (m)	20	100	150	200	250
Horizontal standard deviation, σ_y (m)	2.5	10.5	14.4	18.3	22.3
Vertical standard deviation, σ_z (m)	2.5	8.1	11.6	13.0	15.3
Plume area ($4\sigma_y \times 4\sigma_z$) ($m^2$)	100	1356	2681	3821	5443

With an anticipated constant combustion products release, the dissemination of soot from one 76 mm smoke canister is calculated to be approximately 4.2 g/s over a period of 30 seconds, and for one 155 mm canister approximately 7 g/s over a period of 100 seconds. Included in this soot are the PAHs and dioxins.

Combination of the plume area from Table 4.1 with the release rate gives the downwind average concentrations of soot. The concentrations are calculated for three different wind velocities and are given in Table 4.2.

Table 4.2: Average concentrations of soot (mg/m^3) within the smoke screen for given distances and wind velocities.

Distance / Grenade type	Concentrations (mg/m^3)					Wind velocity (m/s)
	20 m	100 m	150 m	200 m	250 m	
155 mm	23	1.7	0.87	0.61	0.43	3
76 mm	14	1.0	0.52	0.36	0.26	3
155 mm	12	0.86	0.44	0.31	0.22	6
76 mm	6.9	0.26	0.26	0.18	0.13	6

The average concentration in the smoke screen of the carcinogenic PAHs are shown in Table 4.3 and 4.4 for different distances and for 3 m/s wind velocity.

Table 4.3: Average concentrations in µg/m³ for the most carcinogenic PAHs and average concentration in i-TE pg/m³ for PCDD/PCDF from one 155 mm canister at different distances for wind velocity of 3 m/s.

	Concentrations (µg/m³)				
Distance	20 m	100 m	150 m	200 m	250 m
Benzo(a)pyrene	0,130	0,010	0,003	0,003	0,002
Benz(a)anthracene	1,537	0,113	0,057	0,040	0,030
Chrysene	1,867	0,140	0,070	0,047	0,033
Benzo(b/j/k)fluoranthenes	8,540	0,633	0,317	0,220	0,160
Dibenzo(ac/ah)anthracenes	0,637	0,047	0,023	0,017	0,013
Anthranthrene	0,317	0,023	0,013	0,007	0,007
Indeno(1,2,3-cd)pyrene	2,003	0,150	0,073	0,050	0,037
PCDD/PCDF in i-TE pg/m³	1,543	0,113	0,057	0,040	0,030

Table 4.4: Average concentrations in µg/m³ for the most carcinogenic PAHs and average concentration in i-TE pg/m³ for PCDD/PCDF from one 76 mm canister at different distances for wind velocity of 3 m/s.

	Concentrations (µg/m³)				
Distance	20 m	100 m	150 m	200 m	250 m
Benzo(a)pyrene	0,077	0,007	0,003	0,002	0,001
Benz(a)anthracene	0,253	0,067	0,037	0,023	0,017
Chrysene	1,120	0,083	0,043	0,030	0,020
Benzo/b/j/k)fluoranthenes	5,123	0,377	0,197	0,133	0,093
Dibenzo(ac/ah)anthracene	0,383	0,027	0,013	0,010	0,007
Anthanthrene	0,190	0,013	0,007	0,007	0,003
Indeno(1,2,3-cd)pyrene	1,200	0,090	0,047	0,030	0,023
PCDD/PCDF in i-TE pg/m³	0,923	0,067	0,037	0,023	0,017

Air concentrations of PAH downwind from a 155 mm canister are shown in appendix C.

The average total amount of PAH detected in the samples was 25.5 mg PAH per gram soot. The concentrations of all PAH are shown in Table 4.5 for 3 m/s wind velocity. A graphical presentation of downwind concentrations for the carcinogenic PAHs are shown in Appendix E.

Table 4.5: Average concentrations of total PAH (µg/m³) for different distances from the source. Wind velocity: 3 m/s.

Distance / Grenade type	Concentrations (µg/m³)				
	20 m	100 m	150 m	200 m	250
155 mm	595,0	44,3	22,0	15,3	11,0
76 mm	357,0	26,3	13,7	9,3	6,7

When used in the field, four smoke canisters will be ejected from the projectile up in the air at height of 400-600 m and spread out approximately 50 m between

each canister in the trajectory line. The maximum downwind concentration will occur when the wind direction is along the line of canisters. Downwind from the last canister the concentrations of total PAHs will be as shown in Table 4.6.

Table 4.6: Average concentrations of total and carcinogenic PAH (µg/m³) for different distances downwind from the last of four 155 mm canisters lined up along the wind direction. Wind velocity: 3 m/s.

Distance (m)	20	100	150	200
Total PAH (µg/m³)	753	86	45	22
Carcinogenic PAH (µg/m³)	19	2.2	1.1	0.6

The 76 mm grenades will be fired in a salvo containing up to 8 individual grenades. The salvo will be fired from an armoured fighting vehicle in a semi-circle approximately 20 m from the vehicle, with a distance of 4 m between each individual grenade. At distances beyond 150 m from the fired salvo, the resulting concentration level will be approximately 8 times the concentration level from one individual canister. The total PAH concentrations are shown in Table .4.7.

Table 4.7: Average concentrations of total and carcinogenic PAH (µg/m³) for different distances downwind from a salvo of eight 76 mm canisters. Wind velocity: 3 m/s.

Distance (m)	20	100	150	200
Total PAH (µg/m³)	570	160	95	67
Carcinogenic PAH (µg/m³)	14	4.1	2.4	1.7

5. Exposure

5.1 Exposure to PAH

In order to assess possible health risk from being exposed to the screening smoke, the calculated concentration levels could be compared to air quality guidelines. The air quality guidelines are usually expressed by a long-term concentration level (as a monthly or yearly average concentration) and a short-term concentration level (as an hourly average concentration). Due to their carcinogenic effects, however, no safe level of PAH is recommended by the World Health Organization (WHO). The time of exposure is short, due to the short duration of the smoke screen. Most of the carcinogenic PAHs in the screening smoke are also found in cigarette smoke.

As a measure towards the level of exposure to PAHs within the smoke screen, the inhalation of PAH is compared to smoking. The inhaled air from personel within the smoke screen has been estimated based upon the average figures for inhalation given in Table 5.1.

Table 5.1: Inhaled air volumes for grown-up persons under different physical conditions.

Condition	Inhaled air l/min.
Resting	7- 12
Walking	20- 50
Running	50-120

Based upon the figures in Table 5.1, it is assumed that a soldier in the smoke screen, in stressed physical condition, will inhale 60 l/min. Total inhalation for the duration of the smoke screen is 100 l for the 155 mm screen and 30 l for the 76 mm screen.

The corresponding intake of carcinogenic PAHs during the time that the smoke screen last is shown in Table 5.2.

Table 5.2: Intake of PAHs (ng) at different distances from the source. 155 mm canister.

	Intake (ng)				
Distance	20 m	100 m	150 m	200 m	250 m
Benzo(a)pyrene	13,00	1,00	0,33	0,33	0,23
Benz(a)anthracene	153,67	11,33	5,67	4,00	3,00
Chrysene	186,67	14,00	7,00	4,67	3,33
Benzo(b/j/k)fluoranthenes	854,00	63,33	31,67	22,00	16,00
Dibenzo(ac/ah)anthracene	63,67	4,67	2,33	1,67	1,33
Anthanthrene	31,67	2,33	1,33	0,67	0,67
Indeno(1,2,3-cd)pyrene	200,33	15,00	7,33	5,00	3,67

Table 5.3: Intake of PAHs (ng) at different distances from the source. 76 mm canister.

	Intake (ng)				
Distance	20 m	100 m	150 m	200 m	250 m
Benzo(a)pyrene	2,30	0,20	0,09	0,06	0,04
Benz(a)anthracene	7,60	2,00	1,10	0,70	0,50
Chrysene	33,60	2,50	1,30	0,90	0,60
Benzo(b/j/k)fluoranthenes	153,70	11,30	5,90	4,00	2,80
Dibenzo(ac/ah)anthracene	11,50	0,80	0,40	0,30	0,20
Anthanthrene	5,70	0,40	0,20	0,20	0,10
Indeno(1,2,3-cd)pyrene	36,00	2,70	1,40	0,90	0,70

PAHs in cigarette smoke have been measured by Grimmer et al. (1987). The results are shown in appendix D. This investigation gives values for all of the PAHs in Table 5.2 and 5.3 except anthanthrene and dibenzanthracene. The total amount of PAH in main stream cigarette smoke for the five remaining components in Table 5.2 is 73.4 ng.

A comparison between the inhalation of carcinogenic PAHs from cigarette smoke and the inhalation due to exposure by being within the smoke screen at different distances have been made. The results given as "cigarette equivalents" for different distances, are shown in Table 5.4.

Table 5.4: Exposure to carcinogenic PAHs in the smoke screen expressed as cigarette equivalents.

Distance / Grenade type	Cigarette equivalent of PAH-amount.				
	20 m	100 m	150 m	200 m	250
155 mm	19	1.4	0.7	0.5	0.4
76 mm	3.5	0.3	0.13	0.1	0.07

Table 5.4 expresses a comparison between the carcinogenic PAHs in the screening smoke and the carcinogenic PAHs in cigarettes. Other components than carcinogenic PAHs (such as tar and nicotine) are not compared.

Based upon the figures in Table 5.4, the conclusion can be drawn that beyond 100 m from the smoke source of a 155 mm canister, and beyond 40-60 m from the smoke sources of a 76 mm grenade, the carcinogenic effects from exposure to PAHs in the screening smoke is less than the carcinogenic effects of PAH exposure through occasional cigarette smoking, and much less than the PAH exposure from daily cigarette smoking.

5.2 Exposure to PCDD/PCDF

The World Health Organization (WHO) and several European health authorities estimate the tolerable daily intake (TDI) of PCDD/PCDF to be

TDI = 10 pg i-TE/kg body weight and day.

This means that a person wit 75 kg body weight can have a daily intake of 750 pg i-TE without any toxic effect.

In Tables 4.3 and 4.4 the average concentration is given for PCDD/PCDF in screening smoke from a 155 mm canister and a 76 mm grenade at a wind velocity of 1 m/s. In chapter 5.1 the total air inhalation of a physical stressed person is estimated: during the passage of the smoke screen from a 155 mm canister the person will breathe in (inhale) about 100 l air and 30 l for the 76 mm grenade.

Thus, the intake of PCDD/PCDF for person at 20 m distance from the 155 mm canister can be calculated to 0.463 pg i-TE and to 0.083 pg i-TE for 20 m distance from the 76 mm grenade. This exposure to PCDD/PCDF is more than a factor 1000 below the guideline given by WHO.

6. References

Briggs, G.A. (1974) Diffusion Estimation for Small Emissions. Atmospheric Turbulence and Diffusion Laboratory, Oak Ride, Tenn., (Report ATDL-106, NOAA).

Grimmer et al. (1987) Gaschromatographic determination of polycyclic aromatic hydrocarbons, AZA-arenes, aromatic amines in the particle and vapor phase of mainstream and sidstream smoke of cigarettes. *Toxicology Letters*, *35*, 117-124.

Appendix A

Analysis of PAH

Analysis of PAH

Short description of the method, NILU-O-3.

Sample preparation
Internal standards were added to the dust sample and soxhlet extraction carried out with cyclohexane for 24 hours.

Sample clean-up
The volume of the extract was reduced by means of evaporation in a rotary evaporator system under reduced pressure. The PAH was separated from the sample matrix (extract) by liquid/liquid partition between diemthylformamide and cyclohexane. Further purification of the PAH extract was carried out on an HPLC system equipped with a deactivated silica column. The cleaned PAH extract was concentrated through evaporation under reduced pressure with a stream of pure nitrogen onto the surface of the solution.

Quantification
A Hewlett Packard (HP) 5880A gas chromatograph equipped with a splitless injection system and a flmae ionization detector (FID) is used for quantification. The GC is connected to a desk computer, HP 5880A serices GC therminal, level four. The column used is a 25 m fused silica, CP-Sil 8 CB. The quantification of the individual PAH in the sample is based upon the response factors related to the internal standards and the amount of internal standards in the sample.

Appendix B

Analysis of Dioxins (PCDD/PCDF)

Sample preparation: The dust sample was spiked with ^{13}C labelled 2,3,7,8-chloro-substituted PCDD and PCDF congeners and soxhlet extracted with warm toluene.

Sample clean-up: Most of the sample matrix was removed with multi column chromatography on different types of silica gel and on activated charcoal. A final treatment was done on sulphuric acid coated silica and aluminium oxide. Just before quantification, the sample was spiked with a recovery control standard.

Quantification: The isomer identification and quantification was done with GC/MS. The separation of the PCDD and PCDF isomers was carried out on 30 m Rtx-2330 fused silica column. The quantification of all 2,3,7,8-chloro-substituted congeners and the determination of the sum of all isomers with the same degree of chlorination werre done by high resolution mass spectrometry (res>10000) using electron impact ionisation. Two masses were monitored for each isomer group. The added ^{13}C-labelled isomers were used as internal standard for each group. Additionally, the recovery of the added internal standard compounds were determined.

Results: The concentration of the toxic 2,3,7,8-chloro-substituted congeners were determined. For all these congeners, the 2,3,7,8-TCDD toxicity equivalent (TE) was calculated according to the international (NATO/CCMS) and the Nordic model. The TE is a measure for the total PCDD/PCDF toxicity of a sample, where the toxicity of all the 2,3,7,8-chloro congeners were compared to 2,3,7,8-TCDD. Furthermore, the total concentration (sum) of each group of isomers was determined.

Quality assurance: The following conditions must be fulfilled for an unequivocal identification and quantification of the PCDD and PCDF congeners:

1. The retention time must be in a window of + 3 to 0 s compared to the corresponding ^{13}C-labelled isomer.
2. The isotope ratio of the two monitored isotopes must be within $\pm$20% of the theoretical value.
3. The signal/noise must be >3/1 for quantification.
4. The recovery of the added ^{13}C-labelled internal standards must be within 40 to 120%.

Before each new series of samples the blank values of the complete clean-up and quantification procedures are determined. Clean-up of the sample only started when a sufficiently low blank value is obtained (not detectable or at least 10 times lower than the lowest expected results).

Results of PCDD/PCDF Analysis

Encl. to measuring report:
NILU sample number: 94/62
Customer: F.F.I
Customers sample ID:
:
Sample type: Dust
Sample amount: 10,1 g
Concentration units: pg/g
Data files: CD051081, CD053181

Lillestrøm, 24.03.94

Compound	Concentration pg/g	TE (nordic) pg/g	i-TE pg/g
2378-TCDD	< 20,0	20,0	
SUM TCDD	**< 20,0**		
12378-PeCDD	< 9,00	4,50	
SUM PeCDD	**< 9,00**		
123478-HxCDD	1,00 (i)	0,10	
123678-HxCDD	2,90 (i)	0,29	
123789-HxCDD	2,90	0,29	
SUM HxCDD	**23,0**		
1234678-HpCDD	8,70	0,09	
SUM HpCDD	**18,0**		
OCDD	26,0	0,03	
SUM PCDD	**96,0**	**25,3**	
2378-TCDF	42,0	4,20	
SUM TCDF	**164**		
12378/12348-PeCDF	87,0	0,87	4,35
23478-PeCDF	45,0	22,5	
SUM PeCDF	**537**		
123478/123479-HxCDF	49,0	4,90	
123678-HxCDF	22,0	2,20	
123789-HxCDF	8,80	0,88	
234678-HxCDF	11,0	1,10	
SUM HxCDF	**238**		
1234678-HpCDF	35,0	0,35	
1234789-HpCDF	24,0	0,24	
SUM HpCDF	**59,0**		
OCDF	123	0,12	
SUM PCDF	**1 121**	**37,4**	**40,8**
SUM PCDD/PCDF	**1 217**	**62,7**	**66,1**

<: Lower than detection limit at signal-to-noise 3 to 1

TE (nordic): 2378-TCDD toxicity equivalents according to the nordic model

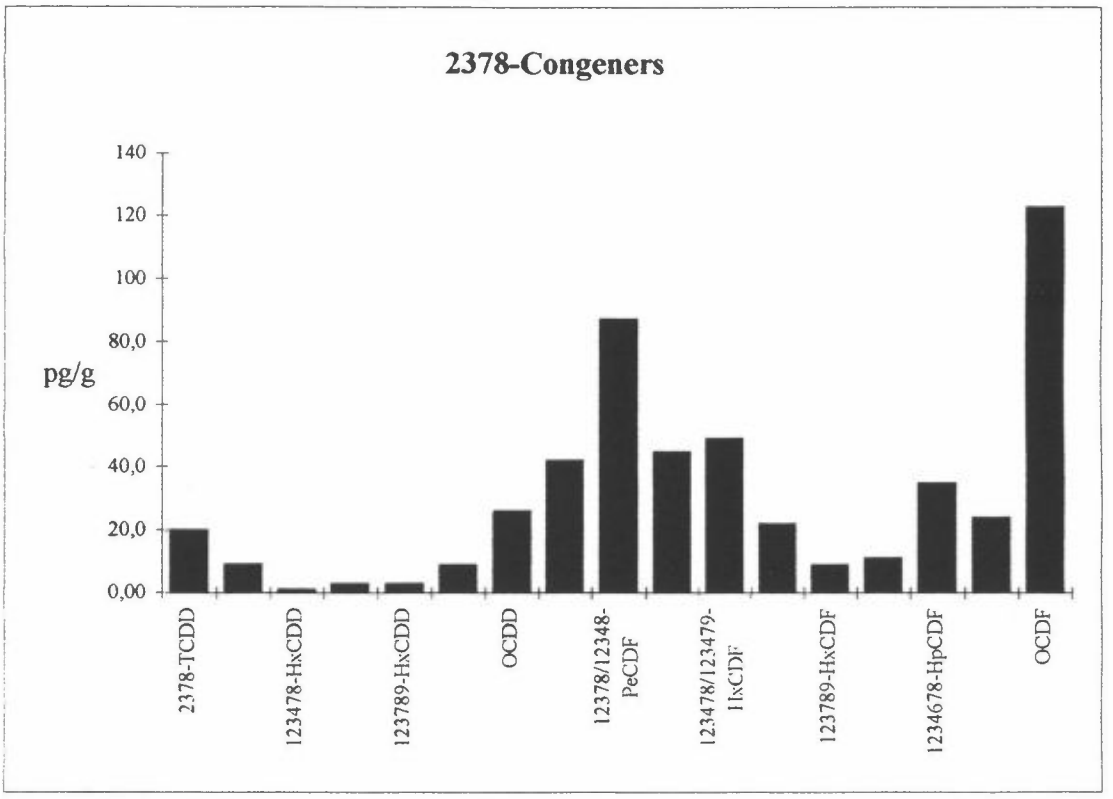
i-TE: 2378-TCDD toxicity equivalents according to the international model

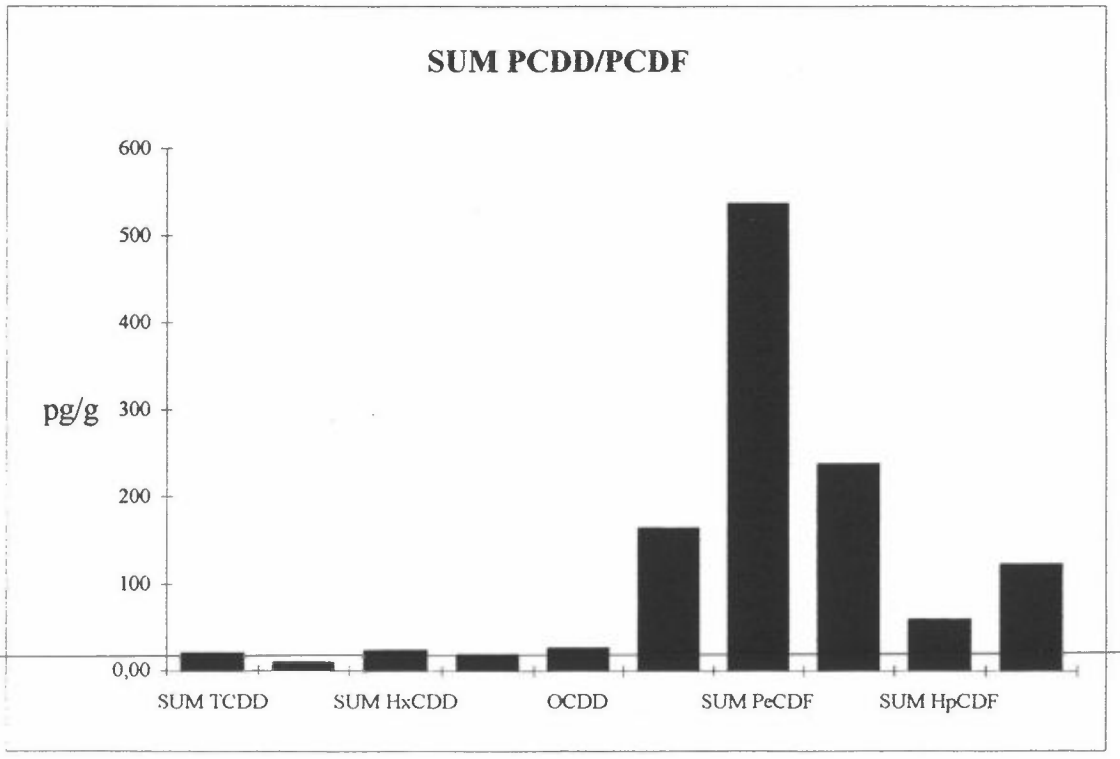
(i): Isotope ratio deviates more than 20 % from theoretical value.
This may be due to instrumental noise or/and chemical interference

Results of PCDD/PCDF Analysis

Encl. to measuring report:
NILU sample number: 94/62

Lillestrøm, 24.03.94





Appendix C

Air concentrations of PAH at different distances downwind from a 155 mm canister.

KOV/BHau
21.02.95

POLYCYCLIC AROMATIC HYDROCARBONS (PAH) IN CARBON FROM BURNING NDRE/RA-IR-SMOKE AND THEIR CONCENTRATION IN THE AIR AS FUNCTION OF DISTANCE IN WIND DIRECTION AND WINDSPEED 3 m/s

NILU Test No. 94/62		Distance from the smoke canister (m)				
PAH		20	100	150	200	250
	µg/g Carbon	µg/m3	µg/m3	µg/m3	µg/m3	µg/m3
Naphthalene	468	33	2,3	1,2	0,83	0,60
2-Methylnaphthalene	17,9	1,25	0,09	0,05	0,03	0,02
1-Methylnaphthalene	8,3	0,58	0,04	0,02	0,02	0,01
Biphenyl	192	13,40	1,00	0,50	0,30	0,20
Acenaphthylene	14,0	1,00	0,07	0,04	0,02	0,01
Dibenzofuran	199	14,00	1,04	0,51	0,30	0,20
Fluorene	207	14,40	1,07	0,54	0,30	0,20
Dibenzothiophen	12,2	0,90	0,06	0,03	0,02	0,01
Phenanthrene	1494	104	8,00	4,00	2,6	2,00
Anthracene	4929	345	25,60	12,70	8,7	6,3
Fluoranthene	637	43	3,30	1,70	1,2	0,80
Pyrene	13,5	0,90	0,07	0,03	0,02	0,01
Benzo(a)fluorene	2,5	0,17	0,02	0,01	<0,01	<0,01
Benzo(ghi)fluoranthene	34	2,40	0,18	0,09	0,06	0,04
Benz(a)anthracene	22,0	1,90	0,12	0,06	0,04	0,03
Chrysen/phenylene	27	1,90	0,14	0,07	0,05	0,03
Benzo(bjk)fluoranthenes	122	8,50	0,63	0,32	0,17	0,12
Benzo(a)fluoranthene	9,6	0,70	0,05	0,03	0,02	0,01
Benzo(e)pyrene	10,7	0,74	0,07	0,03	0,02	0,01
Benzo(a)pyrene	1,8	0,13	0,01	<0,01	<0,01	<0,01
Perylene	5,1	0,35	0,03	0,01	<0,01	<0,01
Inden (1,23-cd)pyrene	18,6	2,00	0,15	0,07	0,05	0,04
Dibenzo(ac/ah)anthracene	9,1	0,63	0,05	0,03	0,02	0,01
Benzo(ghi)perylene	5,7	0,40	0,03	0,02	0,01	<0,01
Anthanthrene	4,5	0,32	0,03	0,01	0,01	<0,01
Coronene	15,5	1,07	0,08	0,04	0,03	0,02
Total PAH in Carbon	2,5%					

Appendix D

PAH in cigarette smoke.

Table D1: Polycyclic Aromatic Hydrocarbons in Cigarette Smoke[a]

Constituent	Mainstream (ng/cigt)		Sidestream (ng/cigt)		Total (ng/cigt)		SS/MS ratio
	Particle Filter	Porapak PS	Particle Filter	Porapak PS	MS	SS	
Phenanthrene	74.8	2.1	2149	248	76.9	2397	31
Anthracene	23.6	0.1	670	40	23.7	710	30
Fluoranthene	61.3	1.8	669	16.9	63.1	686	11
Pyrene	43.0	1.9	466	10.3	44.9	476	11
Benzo(b)naphtho (2,1-d)thiophene	2.8	0.21	50	1.1	3.0	51.1	17
Benz(a)anthracene*	13.3	0.09	201	2.5	13.4	203	15
Chrysene + Triphenylene*	19.5	0.56	492	5.3	20.0	497	25
Benzofluoranthenes (b+j+k)*	20.5	0.22	196	1.38	20.7	197	9
Benzo(e)pyrene	6.7	0.13	75	0.74	6.8	75.7	11
Benzo(a)pyrene*	10.9	0.08	103	0.48	11.0	103	9
Indeno(1,2,3-cd)pyrene*	8.1	0.17	51	0.36	8.3	51.4	6
Benzo(ghi)perylene	7.1	0.09	41	0.62	7.2	41.6	6

a Grimmer et al. (1987)
*

Appendix E

Graphical presentation of some PAH concentration

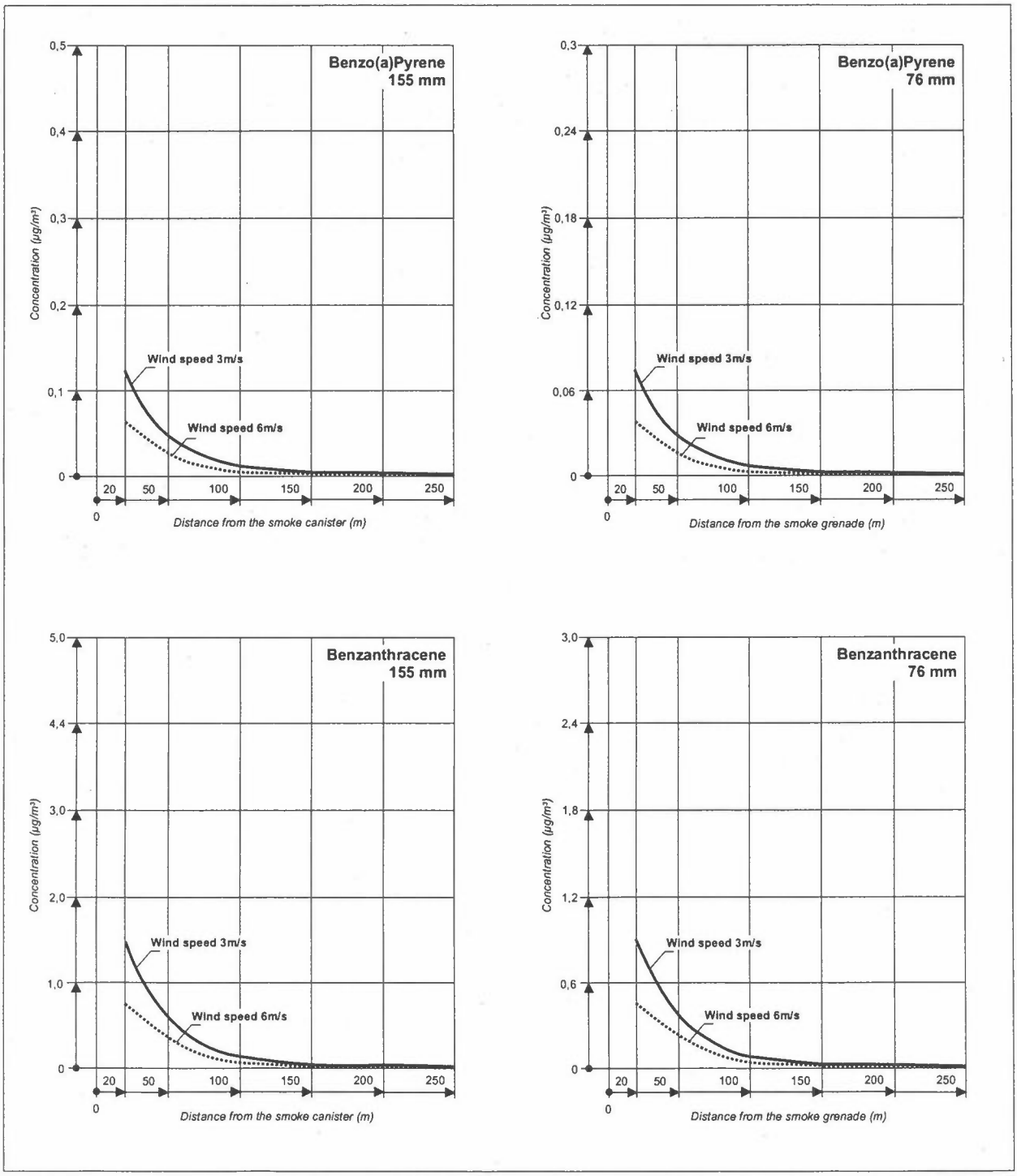


Figure E1: Concentration in the air as a function of distance in the wind direction from source at wind speeds of 3 m/s and 6 m/s.

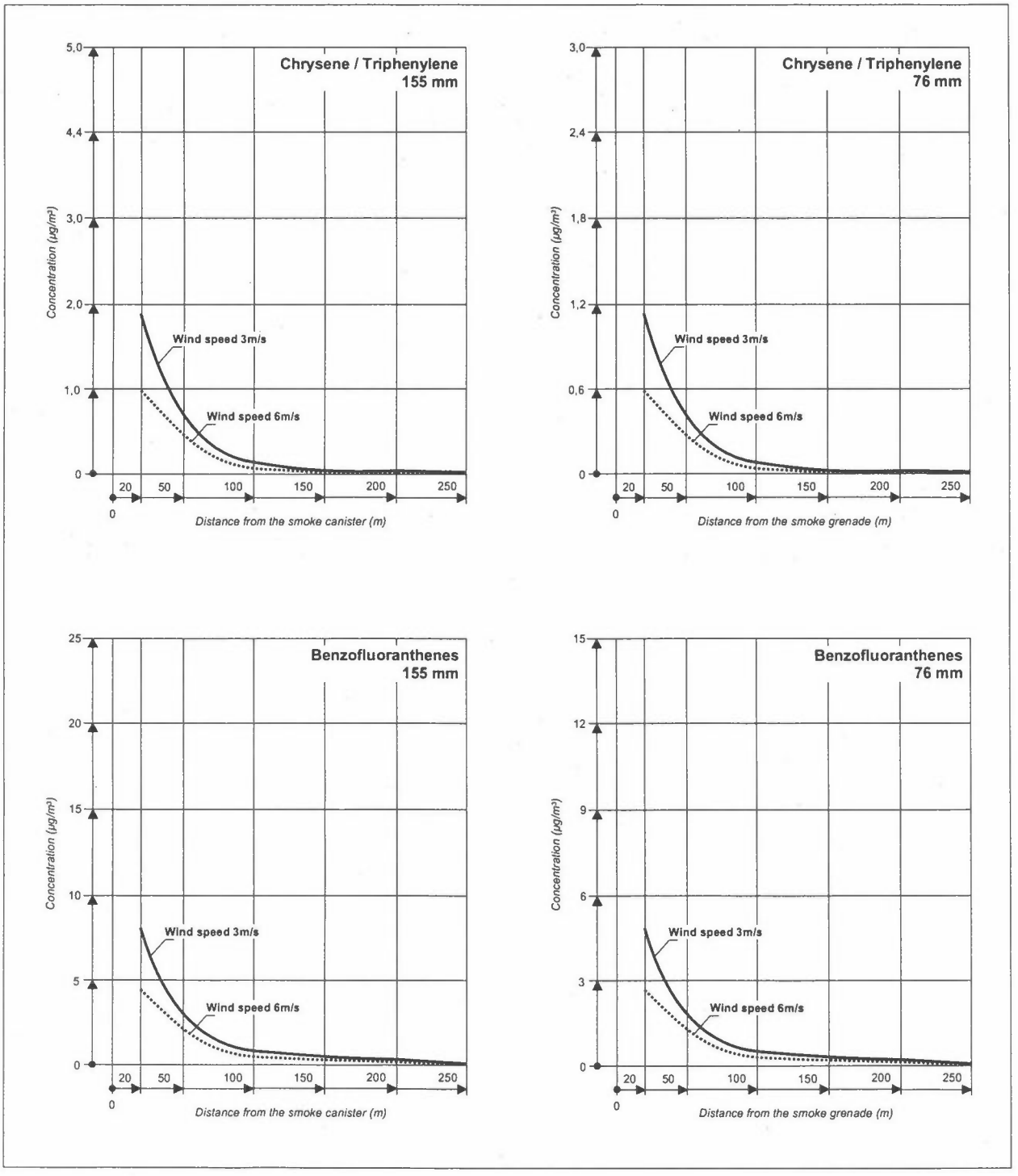


Figure E2: Concentration in the air as a function of distance in the wind direction from source at wind speeds of 3 m/s and 6 m/s.

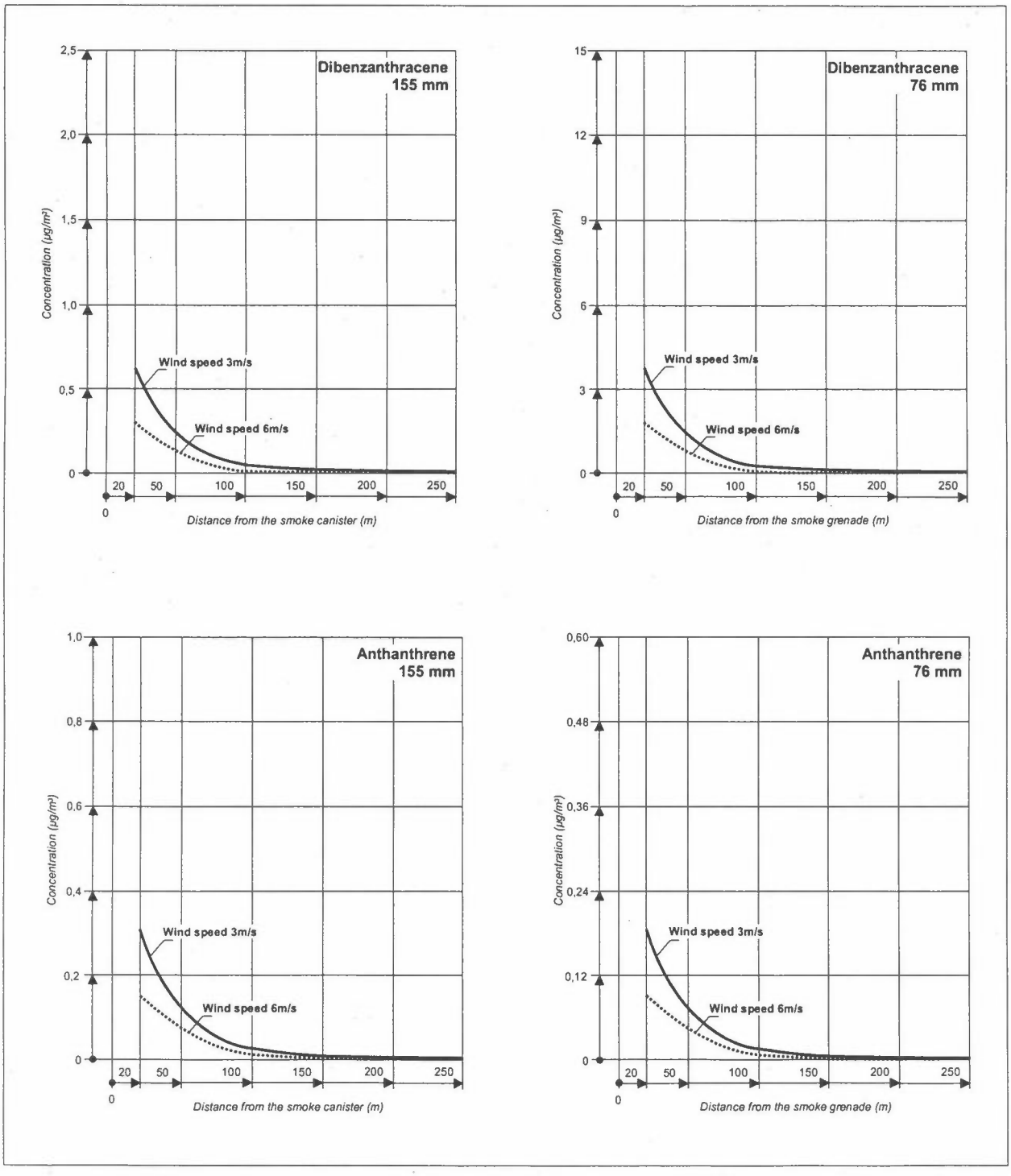


Figure E3: Concentration in the air as a function of distance in the wind direction from source at wind speeds of 3 m/s and 6 m/s.

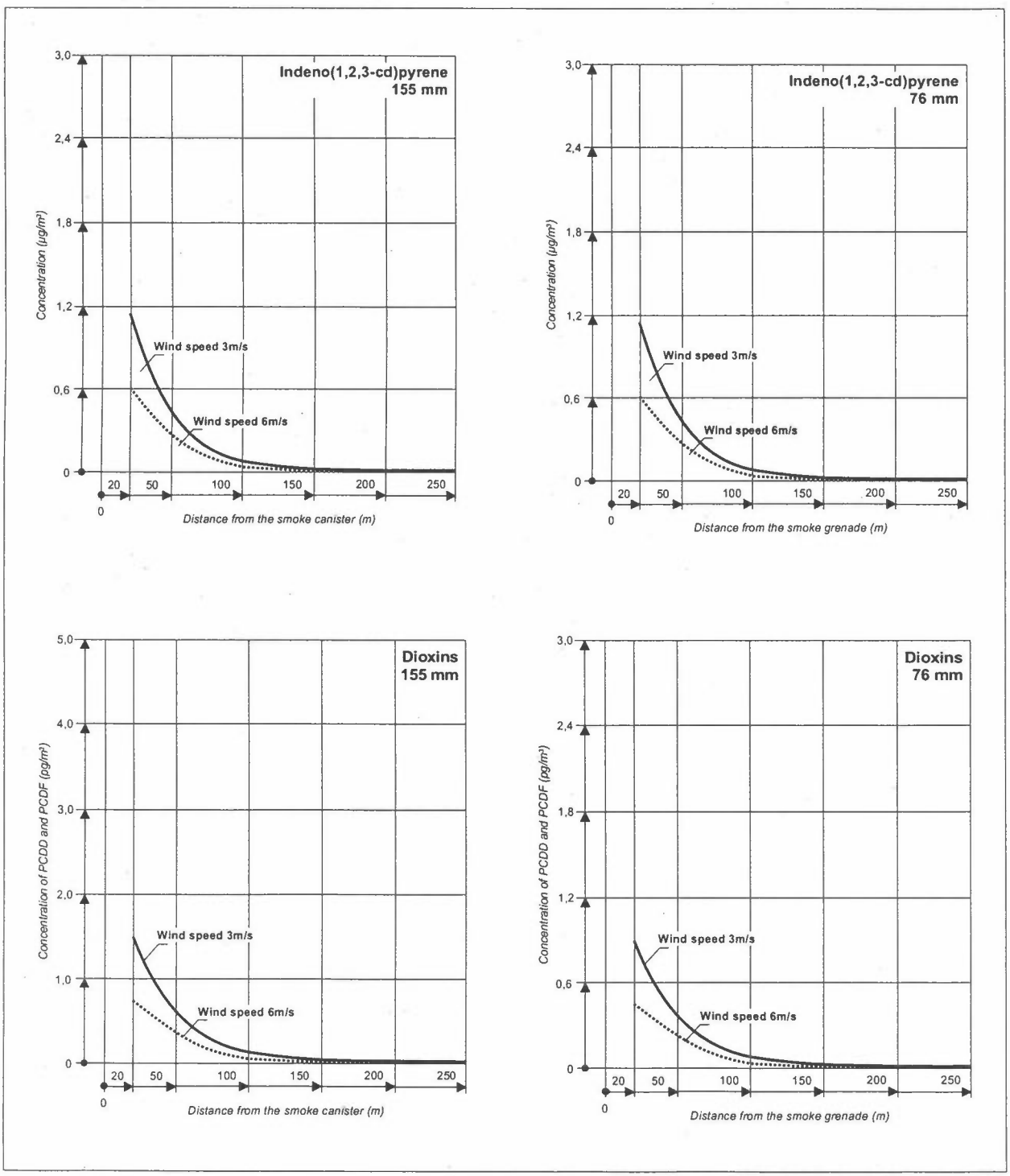


Figure E4: Concentration in the air as a function of distance in the wind direction from source at wind speeds of 3 m/s and 6 m/s.

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TITLE

Hazard evaluation of infrared smoke grenades based on the dispersion and the composition of the smoke.

PROJECT LEADER

Adler Mikalsen

NILU PROJECT NO.

O-1705

AUTHOR(S)

Dag Tønnesen, Adler Mikalsen and Martin Schlabach

CLASSIFICATION *

A

CLIENT'S REF.

CLIENT
Raufoss Technology
Postboks 77
2831 RAUFOSS

ABSTRACT

Analysis of PAHs and dioxins in smoke from 155 mm smoke canisters and 76 mm smoke grenades show that the generation of carcinogenic PAHs is 644 µg/g soot, and 66.2 pg/g soot for dioxins. At 100 m from the smoke source of 155 mm canister, the exposure to carcinogenic PAHs is equivalent to smoking less than two cigarettes. At 20 m from the smoke screen of 76 mm grenade, the exposure is equivalent to smoking three cigaretes.

NORWEGIAN TITLE

Farevurdering av infrarød skjermingsrøyk basert på sammensetning og spredning av røyken.

DESCRIPTORS		
PAH	Dispersion	Exposure

ABSTRACT (in Norwegian)
Analyse av PAH og dioksiner i røyk fra 155 mm røykboks og 76 mm røykgranat viser at det dannes 644 µg PAH og 66,2 pg dioksiner for hvert gram sot. 100 m fra en 155 mm røykboks er eksponeringen til kreftfremkallende PAH den samme som eksponering til disse ved å røyke under to sigaretter. På 20 m avstand fra 76 mm granat er tilsvarende eksponering lik eksponeringen ved å røyke tre sigaretter.

* *Classification*

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- *C Classified (not to be distributed)*