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HEAVY GAS DISPERSION AND ENVIRONMENTAL CONDITIONS AS REVEALED BY THE THORNEY ISLAND EXPERIMENTS.

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NORSK INSTITUTT FOR LUFTFORSKNING

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NORWAY

FORORD

I april 1984 ble det i Sheffield holdt et symposium om spredningsforsøkene med tung gass på Thorney Island. Foredragene vil bli publisert samlet i Journal of Hazardous Materials. Mitt bidrag gir ingen oversikt over bakgrunn eller forsøksopplegg. Dette er derfor tatt med som vedlegg til denne rapport.

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SUMMARY

Time plots of average concentration values from the Thorney Island field experiments are used to draw cloud outlines. After the initial slumping, and a more or less pronounced formation of a vortex ring, redistribution of mass takes place. At later stages the highest concentrations are found well inside the cloud.

The increase of wind speed with height shears the cloud in the wind direction and creates a high front and a low trailing edge. Distances to specific concentrations levels seem independent of wind speed and air stability as assumed in the Eidsvik (NILU) box model. Distances to 1% concentration are well predicted. A too high decrease in concentration with time is offset by applying a too high transport speed set equal to wind speed at the 10 m level.

CONTENTS

HEAVY GAS DISPERSION AND ENVIRONMENTAL CONDITIONS AS REVEALED BY THE THORNEY ISLAND EXPERIMENTS.

1 INTRODUCTION

The objectives of this work have been to study the dependence of heavy gas dispersion on environmental conditions as revealed by the Thorney Island experiments, and how well it can be predicted by the Eidsvik (NILU) model.

Only Thorney Island, Phase I data will be considered, as Thorney Island Phase II involved physical obstacles. This gives flow effects not considered in the model.

The instantaneous release of a cloud heavier than air is charaterized by a rapid slumping followed by the formation of a vortex ring (or rings). This formation is most pronounced in calm conditions. To model this phase realistically involves physical and numerical problems which are not yet satisfactorily solved.

The vortex ring soon dissipates. During the next, intermediate phase, frontal entrainment no longer dominates the dilution process. Gravity is still the main driving force and turbulence tends to smooth concentration distributions. The entrainment is now mainly through the larger upper surface. It is for this phase Eidsvik has developed his box model [1]. This he tested against the Porton Down experiments [2] with good results. The model contains a minimum number of experimental coefficients and predictions are not overly sensitive to variations in the coefficients over their normal range of uncertainty. This is especially important in practical application, say, in forecasting hazard distances.

In the following, we will use the same numerical values used for the Porton data, and perform a test of the physical assumptions involved.

2 EXPERIMENTAL DATA

Data evaluation is based on the information in the hard copy records provided by the Health & Safety Executive (HSE) [3]. It gives time plots of 0.6 s averaged values. Concentration values at specific times are read off and plotted on the horizontal grid system. Isolines and cloud outline are drawn subjectively. This is believed to be the best way, considering the relatively few data points available.

At Thorney Island the initial phase lasted from 40 to 100 seconds. After that period, maximum concentrations were found well inside the cloud outline.

Concentration values at 40,80, 140, 100, 300, 300.... seconds after time of release are taken from the graphs. Only grid points with observed concentrations equal or above 0.1% are considered. Cloud outlines at the 0.4 m level are then drawn, and location of the maximum concentration is estimated. Figure 1a-c shows some examples from trial 8, 12 and 15.

Trial 15 has the lowest cloud release density. The cloud moved relatively fast, stayed rather narrow and hence each outline contained only a few grid points. Height of the cloud rapidly reached above the upper, 6.4 m, measuring level.

Trial 8 is representative of most of the trials. A streching of the cloud in the wind direction is evident. The cloud moved slowly, and up to 9 grid points are within a specific outline.

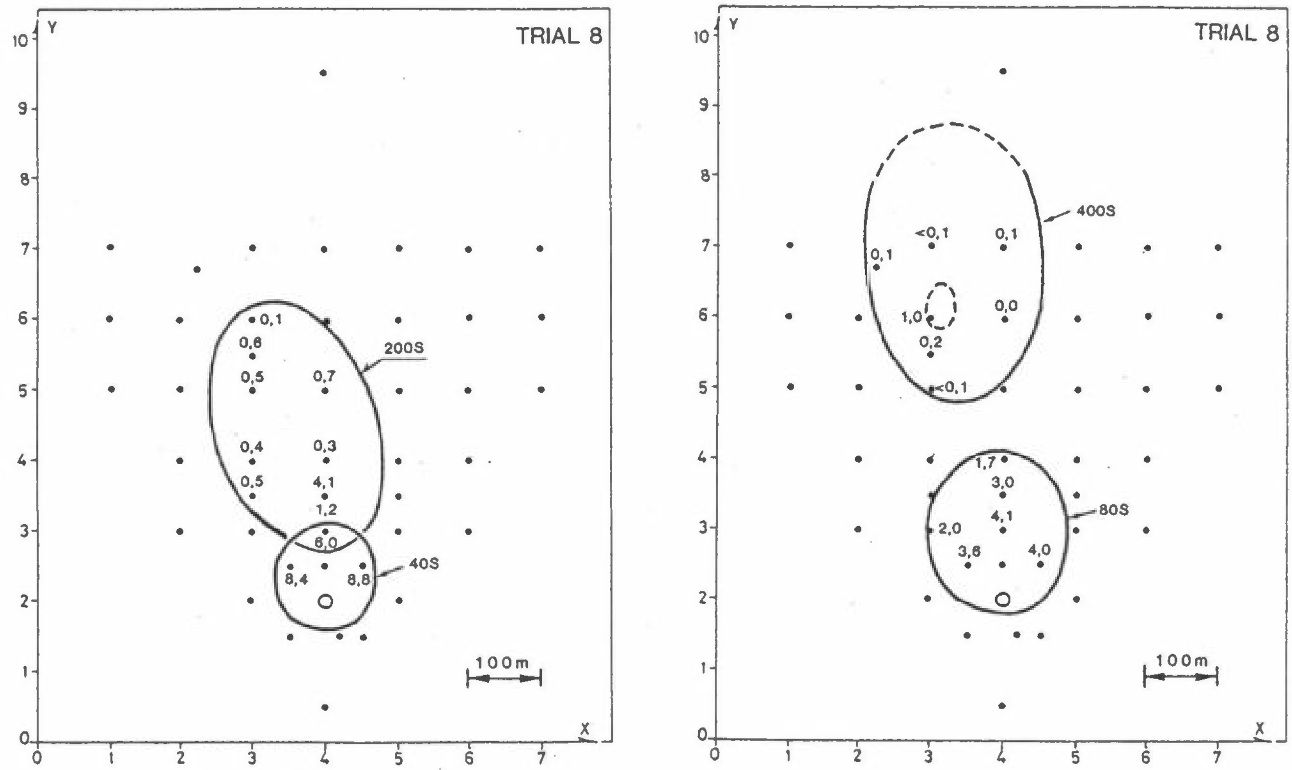


Figure 1a: Trial 8.
Cloud outlines and observed concentrations at 0.4 m. Relative density: 1.63; Wind (10 m level): 2.4 m/s; Stability (class): neutral (D).

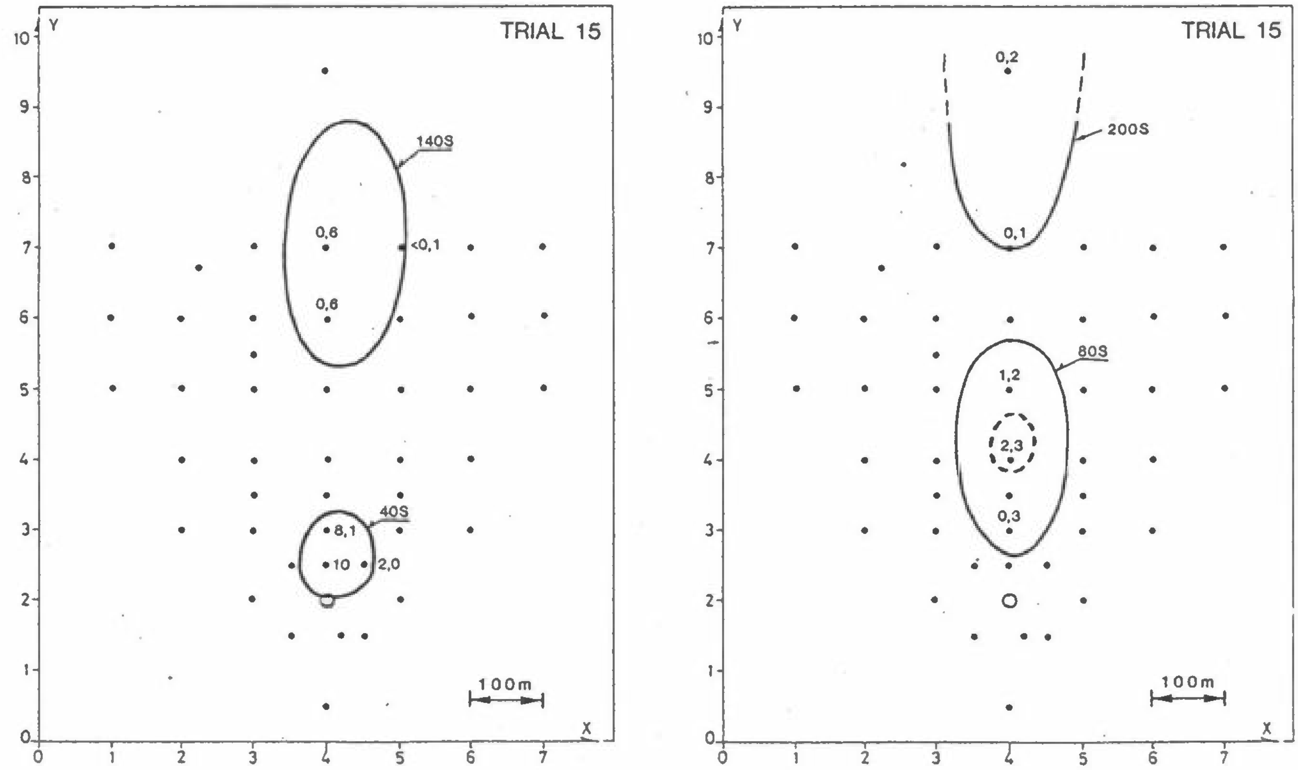


Figure 1b: Trial 15.
Cloud outlines and observed concentrations at 0.4 m. Relative density: 1.41; Wind (10 m level): 5.4 m/s; Stability: neutral (C/D).

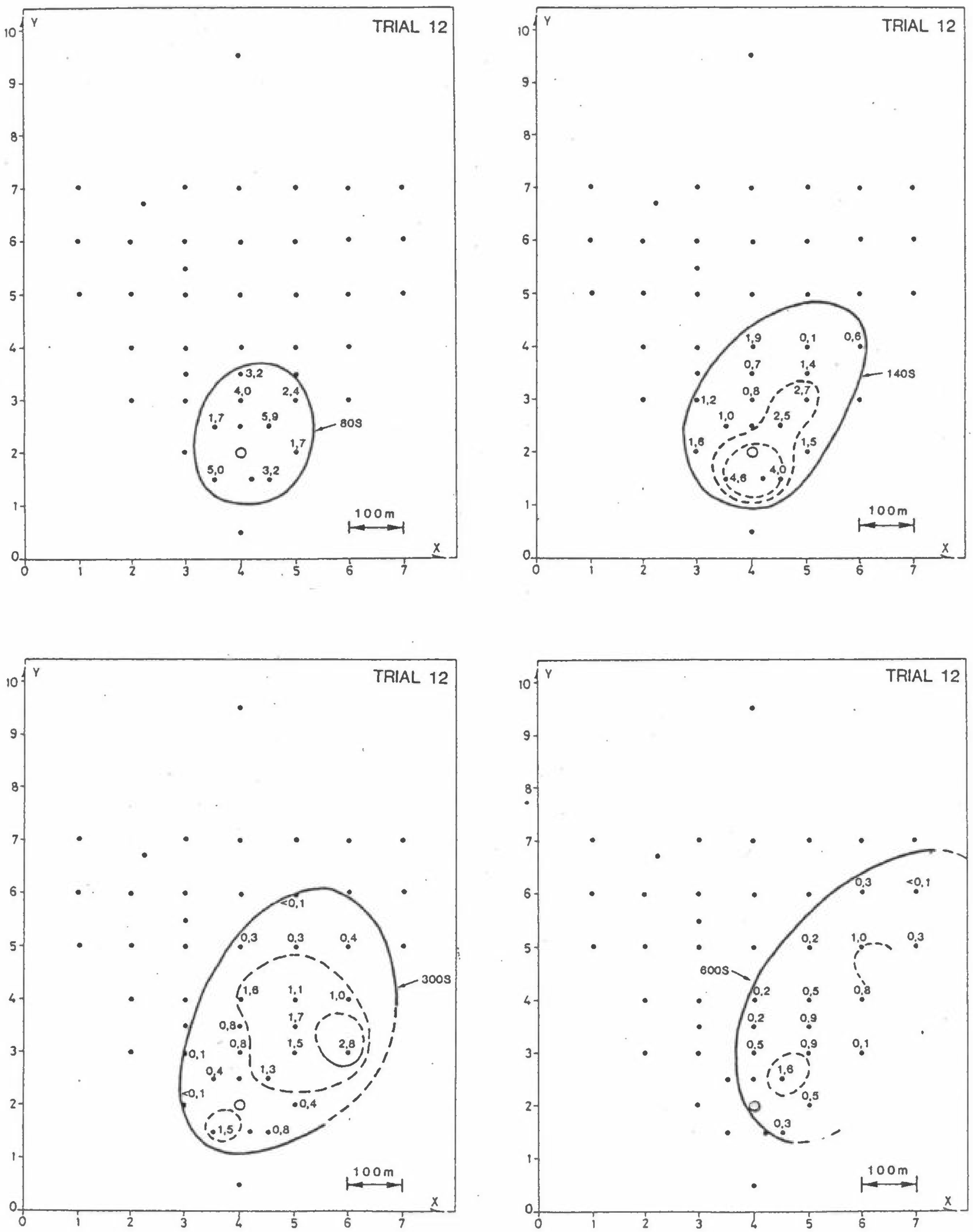


Figure 1c: Trial 12.
Cloud outlines and observed concentrations at 0.4 m. Relative density: 2.6; Wind (10 m level): 2.6 m/s; Stability: Stable (E).

A particular feature is the small area of high concentrations at 200 seconds, lagging behind the main center. The cloud height is here at minimum. It is an open question, whether areas of high concentrations below 0.4 m are lost, the gas being kept in the grass. The same question arises especially in Trial 12. Parts of the cloud lingered behind and 0.5% concentration was observed 100 m from the release point 900 seconds after release. Cloud heights were the lowest. Concentrations were measured at 0.4 m, 2.4 m, 4.4 m and 6.4 m. All but traces of gas, 0.2% or less, are measured at the three upper levels and may be due to the vortex ring. No other trial shows similar low cloud height. (In Trial 17, with density 4.2, the cloud center did not stay completely within the grid of masts, probably due to change in wind direction.)

Speeds of the cloud fronts are shown in Figure 2. They are affected by both the increase of wind speed with height above the ground, as well as by cloud density. In Trial 12 the gravity markedly affects the front speed during the first 200 seconds. In Trial 15 the top of the gas cloud is picked up by the higher wind speeds.

Downward mixing creates a relatively high, vertical cloud front. The trailing edge, on the other hand, will consist of slow moving gas and keeps close to the ground.

3 INFLUENCE OF ATMOSPHERIC PARAMETERS

The Eidsvik model predicts hazard distances for a release of an explosive, heavy gas to be fairly independent of wind speed and air stability. The decrease of concentration with time, however, will highly depend on these parameters. We have chosen to look how distances to the concentration levels 5%, 1% and 0.5%, and the time to reach 1% depend on the 10 m wind speed and turbulence.

Figure 3 shows remarkably similar distances for Trials 8, 12 and 15.

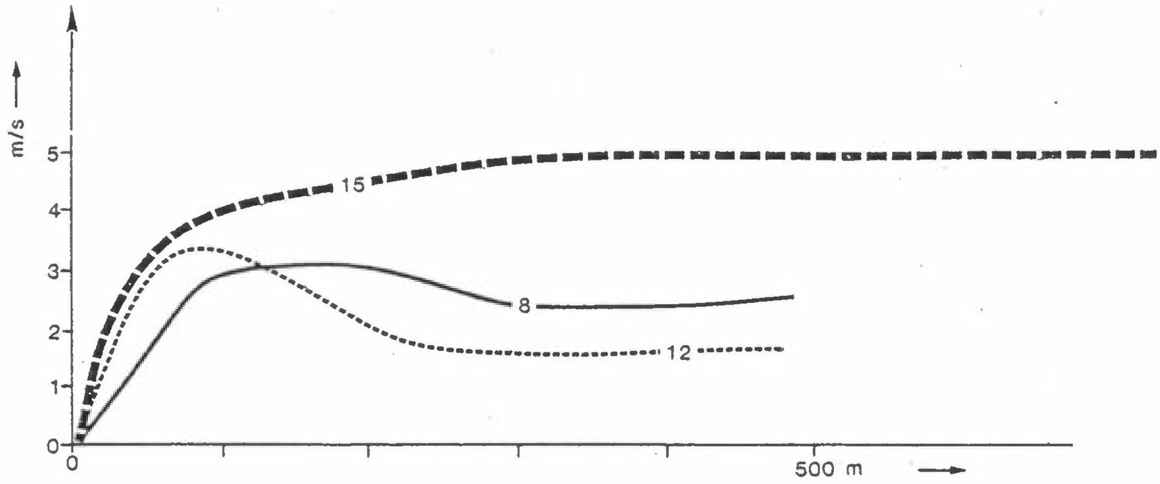


Figure 2: Speed of cloud fronts - Trials 8, 12 and 15.

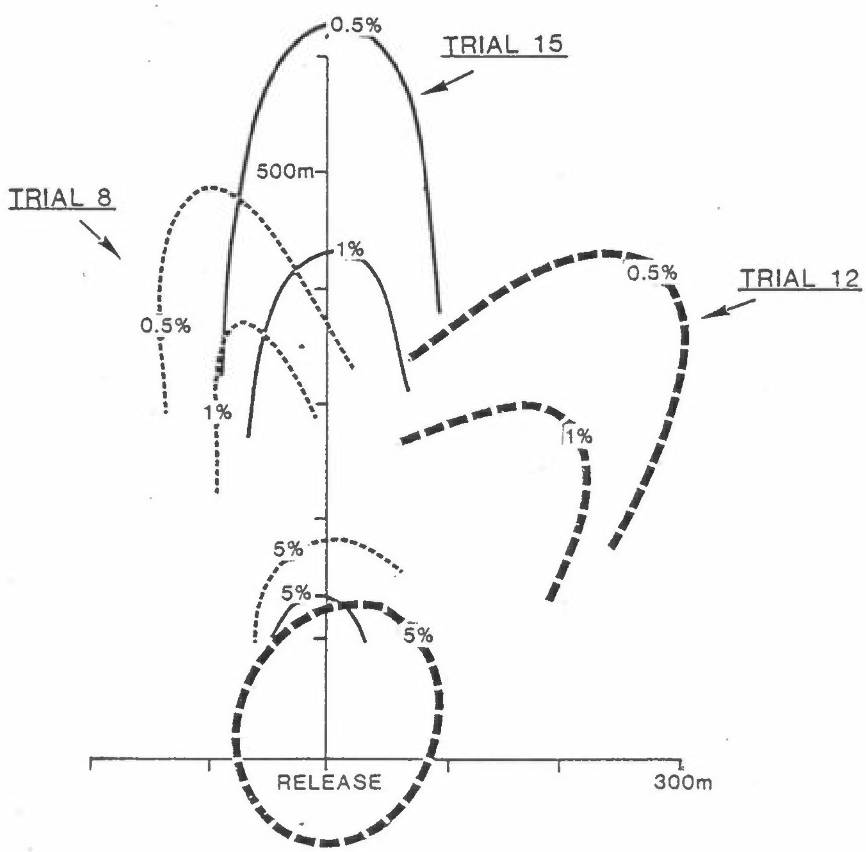


Figure 3: Maximum distances to 5%, 1% and 0.5% concentrations.
Trials 8, 12 and 15.

The commonly used Pasquill stability classes are not suited for numerical treatment. We therefore will use vertical velocity fluctuations, closely related to the top entrainment. The R.M.S. values are also closely related to the inferred atmospheric stability conditions given by HSE.

Table 1 shows the said distances, time to reach 1% concentration, environmental factor, and front- and center speeds.

Table 1 confirms the rather small variation in "hazard" distances. Variation in time to reach 1% concentration is, on the other hand, considerable.

Table 1: Experimental data - Thorney Island.

Trial No.	Distance C=5%	C=1%	C=0.5%	Time C=1% (S)	Rel. dens.	Wind speed (m/s)	Turb (m/s) vert-RMS	Speed (m/s) Front	Center
7	150	400	520	270	1.75	3.2	0.27	3.2	1.8
8	150	385	500	350	1.63	2.4	.25	2.5	1.1
9	125	360	475	800	1.60	1.7	.08	2.5	.4
10	110	-	-	-	1.80	2.4	.26	-	-
11	160	280	340	190	1.96	5.1	.44	4.0	1.6
12	130	350	525	750	2.37	2.6	.14	2.0	.4
13	140	400	550	130	2.00	7.5	.47	7.0	4.0
14	125	425	500	120	1.76	6.8	.43	5.0	4.3
15	190	450	550	140	1.41	5.4	.47	4.9	4.3
16	150	400	550	190	1.68	4.8	.35	3.5	2.8
17*	(80)	(220)	(320)	(150)	(4.20)	(5.0)	(.43)	(3.5)	-
18	100	300	450	60	1.87	7.4	.58	6.2	3.8
19	120	320	450	130	2.12	6.4	.44	4.5	3.2
Mean	138	370	492	285	1.83	4.6	.35	4.1	2.5
St.dev.	23	51	60	243	0.25	2.0	.14	1.5	1.4

*Values omitted in calculations of means and standard deviation.

Although the sample size is small, considering stochastic variabilities, we have made a statistical analyses. Table 2 shows calculated correlation coefficients. Coefficients below 0.5 are considered not significant. When we further omit self-evident correlations, the significant results are:

1. critical distances are independent of atmospheric conditions;
2. time to 1% concentration decreases with wind speed.

An increase with atmospheric stability (turbulence) may not be considered significant.

There is also a tendency for critical distances to decrease with increased density. This can be explained by higher clouds moving faster due to the vertical wind shear. Air entrainment through the upper surface then has shorter time to dilute the cloud.

Table 2: Correlations (Trial 17 omitted).
U-10 m = wind speed at 10 m (m/s)
U-front = mean speed of cloud front (m/s)
U-center = mean speed of cloud center (m/s)

Dist-5%	1.00								
Dist-1%	.49	1.00							
Dist-0.5%	.21	.83	1.00						
Time-1%	.12	.07	.08	1.00					
Rel.dens	-.44	-.56	-.24	-.17	1.00				
U-10 m	-.06	-.06	-.08	-.83	-	1.00			
Turb.	.26	-.02	-.11	-.42	-	-.03	-1.00		
U-front	-.14	.04	.02	-.76	.15	.94	-.03	1.00	
U-center	.04	.34	.22	-.85	-.21	.90	.04	.88	1.00
	Dist-5%	Dist-1%	Dist-0.5%	Time 1%	Rel. dens.	U-10 m	Turb	U-front	U center

4 MODEL PREDICTIONS OF THE THORNEY ISLAND TRIALS USING THE EIDSVIK BOX MODEL

The model predicts time to specific concentration levels, cloud radius and cloud heights.

When we compare with observed values we must consider that the model assumes a homogeneous concentration distribution within the cloud at all times. This we do by using mean concentrations at the 0.4 m level. A characteristic cloud height can be estimated applying a constant vertical distribution or mass conservation and cloud radius. The radius may be estimated from the equivalent cloud area, or from cloud height and mass concervation. Both methods have been applied. Considering the uncertainties final results can only be tentative. Figure 4 shows values from Trial 8. The following features are quite representative for all trials:

- predicted cloud radius is too high, but an increase, proportional to the square root of time, is fairly well established;

- predicted cloud heights are also too great, resulting in too low concentrations, but again, variation with time is quite good.

These general statements do not apply to Trial 12, where the cloud height stayed exceptionally low and concentrations very high.

Maximum values were about twice the mean values and are not plotted.

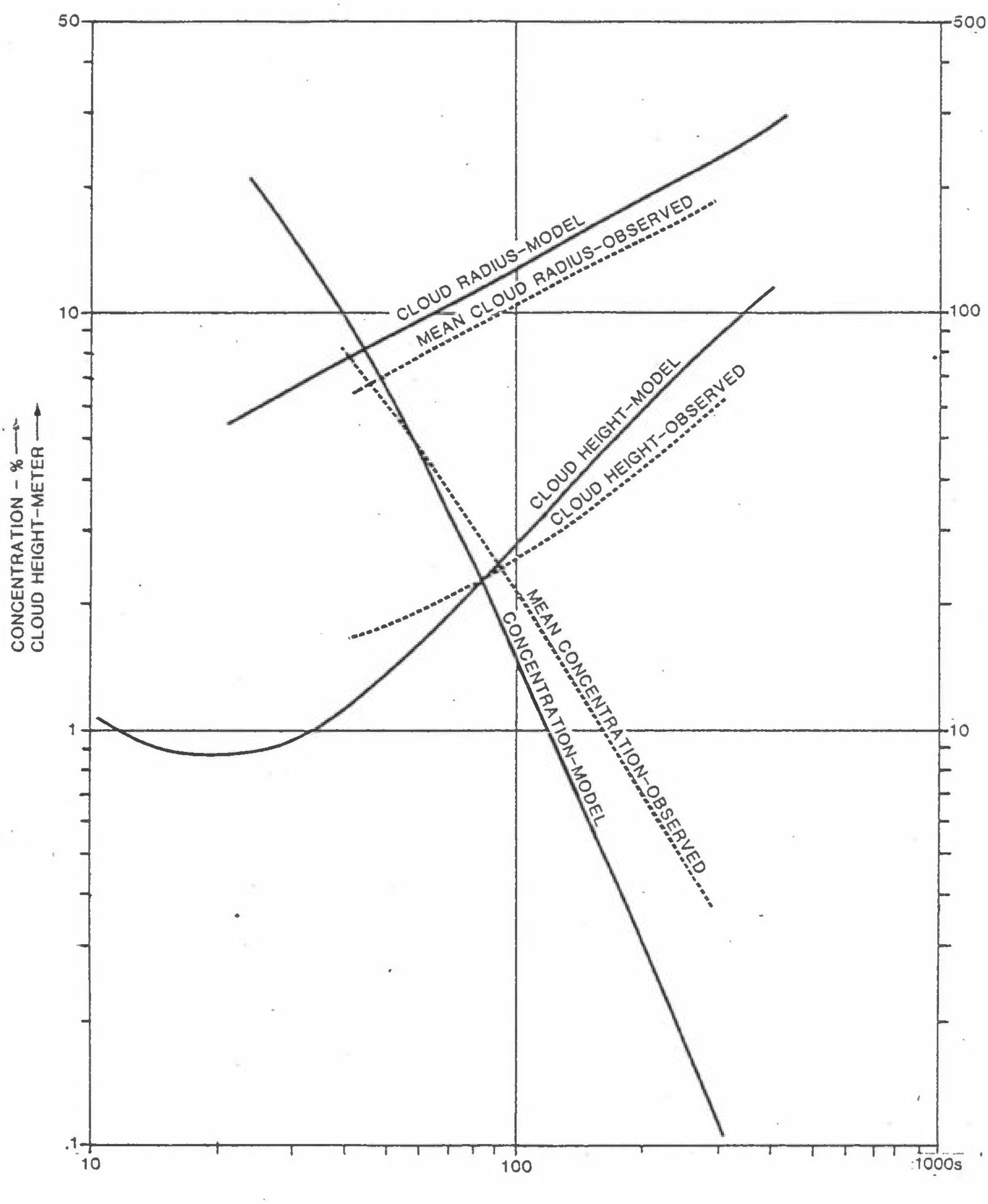


Figure 4: Model predictions and observed mean concentrations, cloud radius and cloud heights - Trials 8.

Of great importance in practical applications is the prediction of maximum distances to hazard concentrations. For explosive gases these are of order 1%. The model predicts the distance, D, to concentration C = A%, to be:

$$D = U_{10} * t(C=A\%) + R(C=A\%)$$

where U_{10} is the 10 m wind speed, t time, and R cloud radius.

Table 3 shows maximum distances to the 5%, 1% and 0.5% concentration levels. Here maximum observed values are considered, not mean values as in Figure 3. Also shown is time, in seconds, to concentration 1%. Predicted distances are on the "safe" side, in the mean by a factor of 1.3 for 1% and 0.5%, and 1.7 for 5%. Most importantly, variations in this factor are small, and Trial 12 no longer is an exception. Predicted time to concentration 1% is about half of observed time. Here the variations are relatively much greater.

Table 3: Predicted and observed critical distances (m) and time (s).

Trial No	Distances to concentration levels											
	5%			1%			0.5%			Time to 1%		
	Model	OBS	F	Model	OBS	F	Model	OBS	F	Model	OBS	F
7	239	150	1.5	430	400	1.1	565	520	1.1	130	270	0.5
8	220	150	1.5	410	385	1.1	545	500	1.1	160	350	0.5
9	220	125	1.8	410	360	1.1	495	475	1.0	190	800	0.2
10	185	110	1.7	327	-	-	435	-	-	155	-	-
11	240	160	1.5	450	280	1.6	620	340	1.8	95	190	0.5
12	235	130	1.8	410	350	1.2	511	525	1.0	130	750	0.2
13	250	140	1.8	515	400	1.3	645	550	1.2	70	130	0.5
14	330	125	1.9	510	425	1.2	700	500	1.4	85	120	0.7
15	255	190	1.3	520	450	1.2	685	550	1.2	105	140	0.8
16	225	150	1.5	455	400	1.1	635	550	1.2	105	190	0.6
17*	(237)	(80)	(3.0)	(440)	(220)	(2)	535	320	(1.7)	(75)	(150)	0.5
18	251	100	2.5	300	300	1.7	675	450	1.5	75	60	(1.3)
19	250	120	2.0	480	320	1.5	640	450	1.4	80	130	0.6
	Mean		1.7			1.3			1.3			0.6
	St.dev.		0.3			0.2			0.2			0.3
	Max		2.5			1.7			1.8			1.3
	Min		1.3			1.1			1.0			0.2

*Trial 17 data omitted in calculations.

5 CONCLUSIONS

After the initial slumping, and a more or less pronounced formation of a vortex ring, redistribution of mass takes place. At later stages the highest concentrations are found well inside the cloud. Wind speed increase with height and surface drag shears the cloud in the direction of the wind. They also creates a high front and a low trailing edge. Some trial measurements suggest high gas concentration below 0.4 meters, which could be due to gas withheld in the grass at low wind speeds.

The field data verify the model assumption and prediction that maximum distances to critical concentrations are independent of wind speed and air stability. Predicted distances are on the safe side and remarkably accurate, when we consider that all experimental coefficients are kept unaltered, since the model was compared with the Porton experimental data. This suggests that a simple box model is well suited for prediction of hazard distances. The too high decrease in concentration with time is offset by applying the 10 m wind and disregarding the wind profile.

6 REFERENCES

1. K.J. Eidsvik — A model for heavy gas dispersion in the atmosphere. Atmos.Env., 14, 769-777, 1981.

2. K.G. Picknett — Dispersion of dense gas puffs released in the atmosphere at ground level. Atm. Env., 14, 509-525, 1981.

(3) Health and Safety Executive — Data for Heavy Gas Dispersion Trials Thorney Island 1982-83, Research and Laboratory Services Division, Health and Safety Executive, Sheffield S3 7HQ.

VEDLEGG

Bakgrunn for Thorney Island forsøkene og måleopplegget
(fra Y. Gotaas "Spredning av tunge gasser, Thorney Island"
(NILU OR 6/84.)

BAKGRUNN

Den økende industrielle utvikling, spesielt innen petrokjemisk industri, øker faren for ukontrollerte utslipp av brann/-eksplosjonsfarlige eller giftige gasser. Når disse oppbevares i flytende form, kan de etter utstrømning ved brudd og lekkasjer på lagertanker eller rør, danne skyer tyngre enn luft. Dette kan skje ved avdamping av væske, ved ekspansjon og avkjøling av utstrømmende gass og ved aerosoldannelse. Så lenge tettheten er vesentlig større enn luftens, vil gassskyen synke ned mot bakken, følge denne og kunne samle seg i lavereliggende deler av terrenget.

De grunnleggende og karakteristiske trekk ved spredningen av tunge gasser er relativt lite kjent, og det rår ennå stor usikkerhet og uenighet om utstrekning av fareområder. All erfaring tilsier at en ikke får svar på vitale spørsmål uten å gjennomføre spredningsforsøk i felt, idet såvel numeriske beregninger som modellforsøk i vanntanker eller vindtunneler trenger verifiseringer. Vitale parametre må bestemmes ved atmosfæreforsøk. I 1980-1984 er det utført spredningsforsøk med tunge gass-skyer på Thorney Island, en nedlagt flyplass på sørkysten av England. Dette er de hittil mest omfattende og nøyaktig gjennomførte forsøk, og på større skala enn tidligere. Initiativet var tatt av de engelske helsemyndigheter ved Health and Safety Executive (HSE), som hele tiden har stått som koordinator av det internasjonale samarbeidsprosjektet. Feltarbeidet ble utført på kontrakt av National Maritime Institute (NMI).

Ialt har 37 organisasjoner fra 10 forskjellige land deltatt. De dannet en styringskomité, som fattet vedtak om hovedlinjene. En teknisk komité utarbeidet detaljerte retningslinjer. De nordiske land var representert ved Forsvarets Forskningsanstalt (FOA) fra Sverige og NILU fra Norge. NILU deltok med støtte fra Miljøverndepartementet, Statens forurensningstilsyn og Norges Teknisk Vitenskapelige Forskningsråd. Siden høsten 1983 har også Norsk Hydro, Statoil og Borregaard A/S støttet prosjektet.

Forsøkene på Thorney Island er gjennomført i to faser: Fase I tok sikte på å gi data for verifisering av modeller, samt øke forståelsen av de fysiske prosesser. Disse forsøkene ble avsluttet sommeren 1983. For å utnytte det meget verdifulle og unike opplegget til videre spredningsstudier av tunge gassskyer ble det besluttet å gjennomføre en fase II, støttet av de samme organisasjoner som sto bak fase I. Fase II har tatt for seg innvirknignen på strømningsmønsteret av forskjellige typer fysiske hindringer: En vegg, en bygning og et sett gjennomtrengelige kamuflasjenett som simulerte en skog. Disse forsøkene ble avsluttet i 1984. Utstyr og instrumentering ble overtatt av National Maritime Institute, som i 1984 har utført spesialforsøk for amerikanske institusjoner. Dette skjer vederlagsfritt, mot at tidligere sponsorer får delaktighet i resultatene.

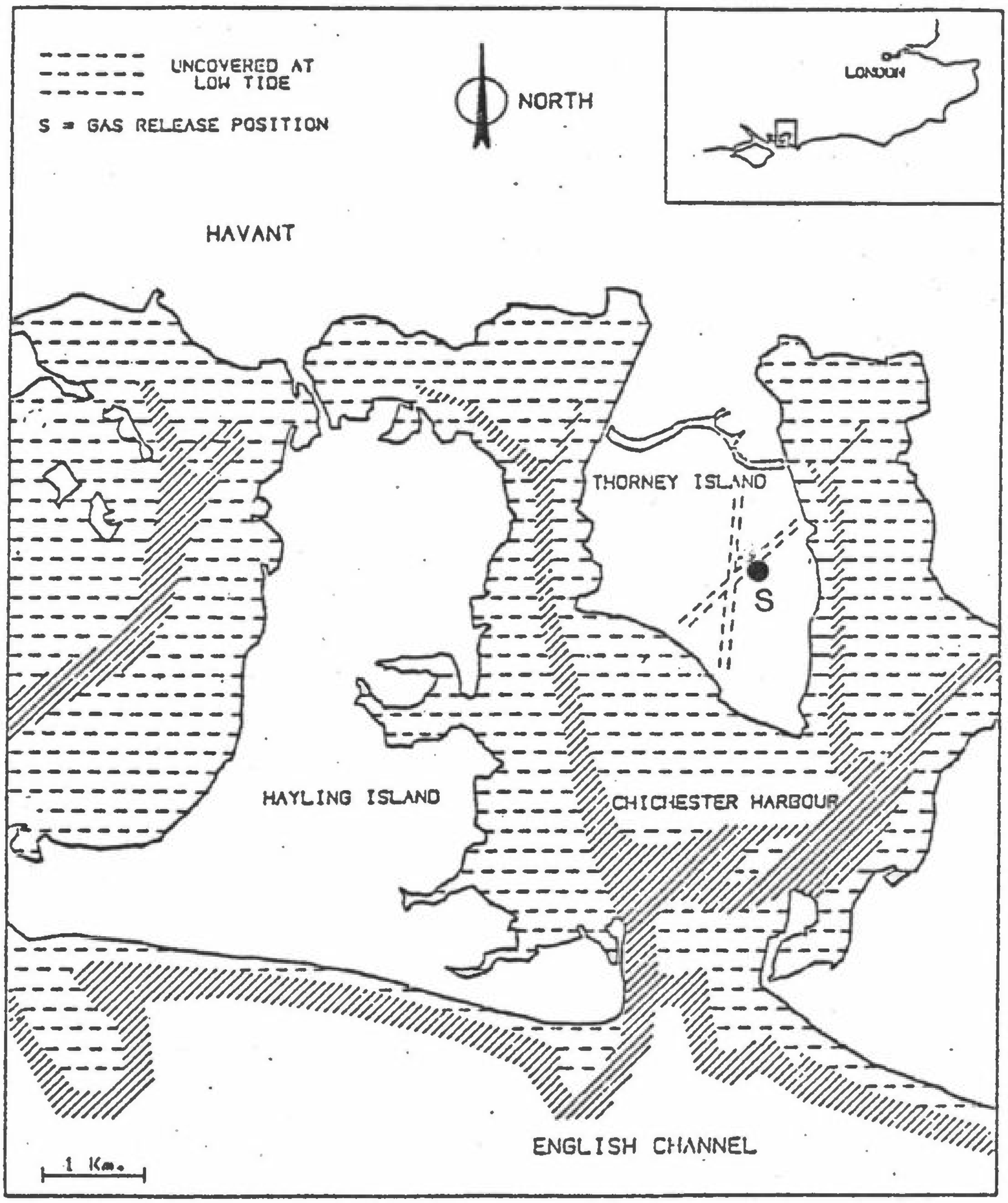
FORSØKSOPPLEGG - FASE I

En blanding av nitrogen og freon utgjorde den tunge gassskyen. Uttynningen ble registrert ved å måle oksygeninnholdet. Tidsoppløsningen var i Hz, med enkelte målinger på 10 Hz. Meteorologiske parametre ble målt i en egen mast oppvinds, samt flere steder i feltet. Figur 1 viser beliggenheten av Thorney Island og figur 2 instrumentplasseringen. Gassblandingen, 2000 m^3, ble fylt i et telt med diameter 14 m og høyde 13 m. Vegger og tak ble plutselig fjernet, gassøylen falt hurtig sammen, og gassen spredte seg langs bakken. For lettere å bestemme skyform og drift ble skyen gjort synlig ved å blande inn fargestoff. Gasstemperaturen var den samme som i den omgivende luft. Metoden ga nøyaktige utslippsbetingelser.

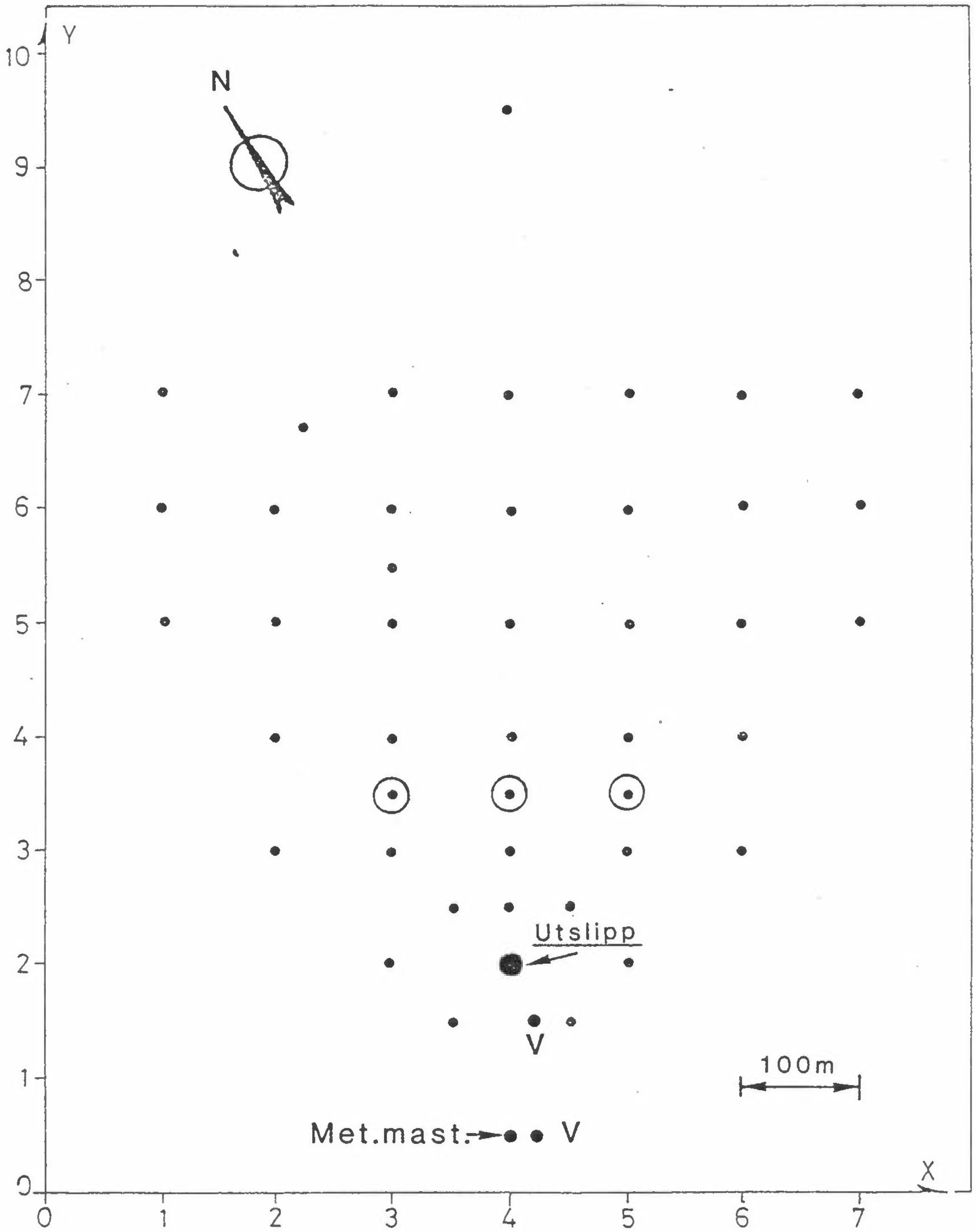
Det ble ialt utført 19 forsøk. De tre første var prøver for å teste utstyr samt prosedyrer for datainnsamlingen. Det fjerde var utslipp av ren nitrogen iblandet fargestoff. I de øvrige 14 var den relative tetthet rundt 2, i ett tilfelle lik 4.

DATA

Alle registreringer er skjedd med en frekvens på 20 Hz. Dataene blir så kontrollert og lagt på magnetbånd. Health & Safety Executive (HSE) har laget 0.6 sekund midler og presenterer diagrammer for hver enkelt sensor. Bare data fra Fase I har hittil vært tilgjengelig for nærmere studier.



Figur 1: Thorney Island - beliggenhet-(fra Health and Safety Executive).



Figur 2: Forsøksfeltet - instrumentering.
•Konsentrasjon (1 Hz) i 0.4, 2.4, 4.4, 6.4 M
- Konsentrasjon (10 Hz),
⊙- Turbulens
- Temperatur
V - Vind

I ulike høyder inntil 12 m

NORSK INSTITUTT FOR LUFTFORSKNING (NILU)
NORWEGIAN INSTITUTE FOR AIR RESEARCH

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OPPDRAGSGIVER (NAVN OG ADRESSE) NTNF, Styringskomitéen for prosjekt: Tung gass spredning v/Geir Berge, Statoil, Box 300, 4001 Stavanger			
3 STIKKORD (à maks. 20 anslag) Tunge gasser	Spredningsforsøk	Gassutslipp	

REFERAT (maks. 300 anslag, 7 linjer)

Tidsplot av midlere konsentrasjoner viser avstand til 1% konsentrasjonsnivå uavhengig av vindstyrke og av luftstabilitet, som antatt i Eidsvik (NILU) modellen.

TITLE Heavy gas dispersion and environmental conditions as revealed by the Thorney Island experiments.

ABSTRACT (max. 300 characters, 7 lines)

Time plots of average concentration show distances to 1% concentration level independent of wind speed and air stability, as assumed in the Eidsvik (NILU) model.

*Kategorier:	Åpen - kan bestilles fra NILU	A
	Må bestilles gjennom oppdragsgiver	B
	Kan ikke utleveres	C