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Diffusion from a Ground Level Point Source Experiment with Thermoluminescence Dosimeters and Kr 85 as Tracer Substance.

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DIFFUSION FROM A GROUND LEVEL POINT SOURCE

Experiment with thermoluminescence dosimeters and Kr 85 as tracer substance

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ABSTRACT

Within the framework of the IRIS-project (Iodine Research in Safety Project) an experiment to study diffusion at near-ground level was carried out on 19th December 1967 using Kr^{85} as the tracer element. The object of the experiment was

a) to test the method using β-sensitive thermoluminescence dosimeters under actual field conditions.

b) to study the initial dilution from a ground level point source.

The test area chosen was the Tranvik valley just south of Trobbofjärden, an inland bay of the Baltic. Dose distributions have been studied at two sections, 50 and 200 m respectively, from the release point.

At each level various dispersion parameters have been experimentally determined and their conformity to normal distribution have been calculated. Dilution factors valid for the centre of the plume are related to the values reported in the literature.

The experiment was made under ideal weather conditions above snow-free ground. Results of the next experiment, a point release at ground level from a building at Studsvik, are expected to yield valuable information concerning the effect of buildings on the diffusion pattern.

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CONTENTS

1. PLANNING OF THE EXPERIMENT

1.1 General

A great deal of experimental data is available for chimney releases. This material was obtained from meteorological investigations in Studsvik and Ågesta from 1960 to 1963. Concerning diffusion in near-ground layers similar experimental material is not available for Swedish conditions.

The method using thermoluminescence dosimeters to measure an active tracer substance (Bjärngard 1963, 1964) has been tried in initial experiments at Studsvik, both for release over ice and over level ground using A^{41}, which emits both γ-photons and β-particles.

When a γ-emitting tracer is used the dose distribution departs strongly from the concentration distribution since the dosimeter receives radiation from a relatively large volume. As a result of this certain theoretical difficulties associated with evaluations occur.

For β-particles, however, the range in air is very limited. By using pure β-emitters as tracers and β-sensitive dosimeters the concentration distribution can be studied more directly.

1.2 Objective

Within the framework of the IRIS-project an experiment to study diffusion at near-ground level was carried out at Studsvik in Dec. 1967 using Kr^{85} as the tracer element. The object of the experiment was:

a) to test the method using β-sensitive dosimeters under actual field conditions,

and

b) to study the initial dilution from a ground level point source.

Ideal release conditions, which rarely prevail in practice, were chosen for this first experiment. It has been considered desirable to start the series of experiments by measuring within as well-defined an environment as possible, so that a comparison can be made with theoretical calculations and with the results of diffusion experiments elsewhere, and with other methods, e.g. Praire Grass, Green Glow, etc. in the USA. At a later date a comparison will also be possible between results of point releases in an open field and releases from buildings.

2. EXPERIMENTAL METHOD

2.1 Test area

The test area chosen was just south of Trobbofjärden, an inland bay of the Baltic, in the Tranvik valley where experiments could be carried out for north or south winds. This area is indicated on the map (scale 1:50 000) on page 5. For a north wind the nearest farm is Tranvik, 1300 m from the release point.

A safety analysis showed that the diffusion 1 km from the release point would give rise to a concentration which, under neutral weather conditions and a wind speed of 5 m/sec., would be lower than that allowed for continuous exposure ($\frac{1}{10}$ MPC_{168}) i.e. the concentration permissible for population groups in the vicinity of a nuclear plant.

For a south wind the distance to the nearest habitation north of Trobbofjärden exceeds 3 km.

Wind directions during the experiments were as indicated on the map

in the Tranvik valley at the 10 m. level, 315^{o}
at the main meteorological tower at the 36 m. level, 305^{o}.

Thus the wind was blowing towards the Studsvik area.

2.2 Dosimeter sections

For determination of the initial dilution two sections were laid out (parts of circular arcs) at distances of 50 m and 200 m respectively from the release point. The intention was that the 50 m section should give a detailed picture of the dose within the zone where large concentration gradients still occur, whilst the section at 200 m should reflect the conditions within the central part of the plume only so that the maximum value of the concentration at this distance could be determined unambiguously.

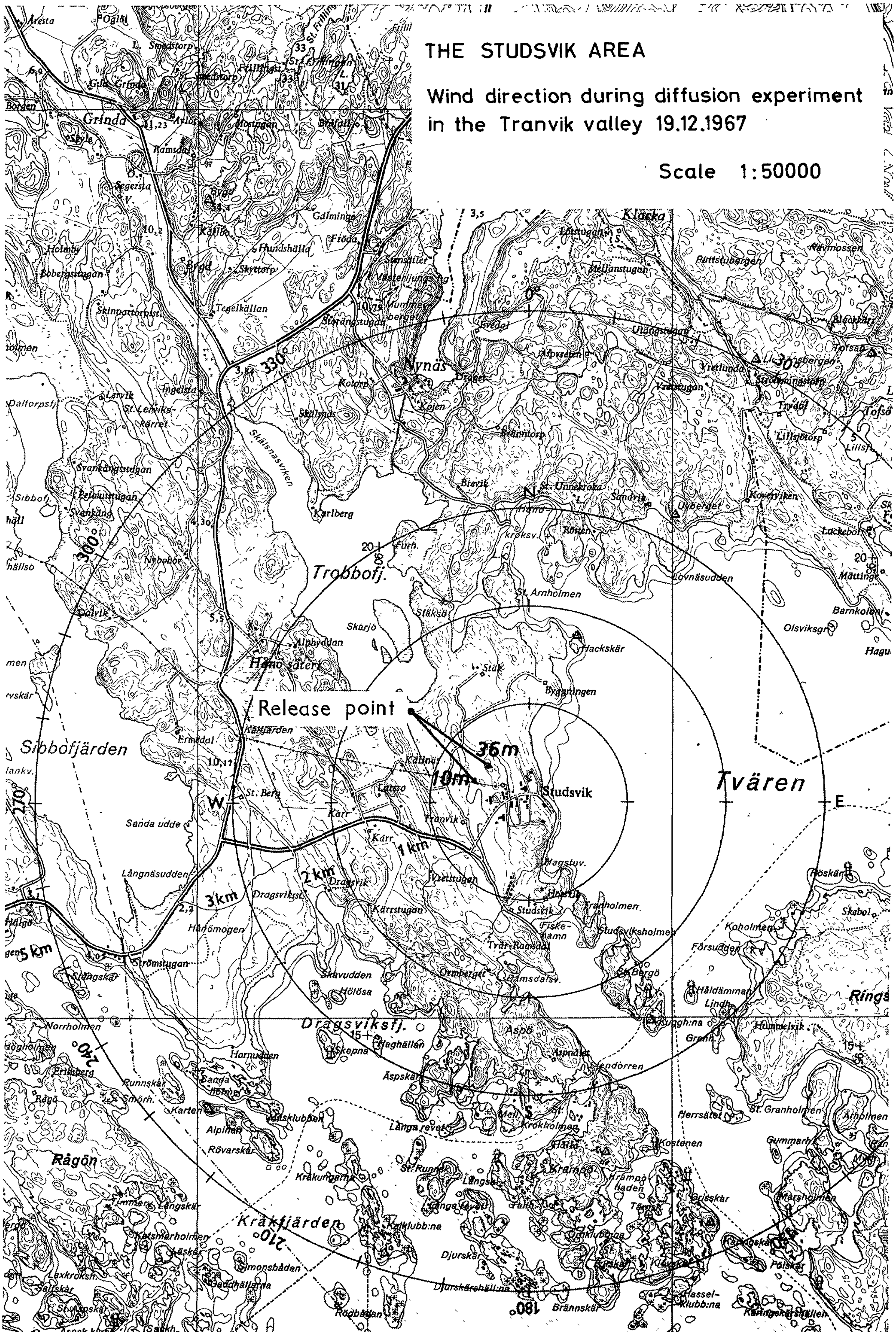

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Table 1 Dosimeter sections

Section	Width	Angle	Distance between verticals	Dosimeter levels	Nos of verticals	Nos of dosi-meters
50 m	50 m	1 radian	2.5 m	0, 2, 4, 6, 8 m	19	95
200 m	100 m	0.5 radian	10 m	0, 4, 8, m	11	33

19 dosimeters distributed on the various levels were used for measuring the background.

Before the start of the experiment certain minor changes were made of the dosimeter sections in order to adjust them for the actual wind direction. The final arrangement is apparent from the dose pattern shown on page 10.

3. RELEASE EQUIPMENT

The arrangement used for release of the tracer gas comprised the following. A reducing valve and throttling valve were connected to a gas tube. The gas flow rate leaving the gas tube was measured by a rotameter of max. capacity 400 litre/min, whilst the total volume of gas released was measured by a gasmeter.

Gas was released through an arrangement consisting of a conical funnel of 11.5 cm radius. This funnel was covered by a perforated plastic film. The rate of flow of gas through the holes has been calculated to be ca 3 m/sec.

It was intended to locate the release point as near ground as possible. Due to the roughness of the ground together with a slight uphill slope in the direction of flow the release point was placed 1 m above ground level in order to obviate the risk of ground contact in the immediate vicinity which would give rise to a continued irregular flow.

4. RADIOLOGICAL DATA

4.1 Tracer element

Kr^{85} is an almost pure β-emitter which emits 0.67 MeV (max. energy) β particles in 99.6 % of the disintegrations. Its half-life is 10 years. The range in air is 1.75 m which implies that a spherical cloud of 3.5 m diameter gives to a dosimeter at the cloud centre a dose which is identical with the dose from a cloud of infinite extent.

B-I Rudén (1965) has calculated, with reference to Hine & Brownell, that a cloud 1.5 m in diameter gives 97 % of the dose from an infinite cloud. For practical purposes the dose distribution can therefore be considered to coincide approximately with the concentration distribution.

Kr^{85}, in containers each holding 25 Ci, has been purchased from Oak Ridge National Laboratory, USA. The volume of each container was 300 ml, the pressure inside was 760 mm Hg, and the space between the container and the transport shield was filled with lead shot. For the diffusion experiment a greater volume was required and thus the active gas was transferred to a 40 litre compressed air tube. The filling was carried out at the Isotope Centre. Immediately before the experiment the tube was filled with air, and afterwards transferred to the test area.

Experimental data:

Amount of Kr^{85} released	24.1 Ci ± 5 %
Exposure time	52 min
Background, average for 19 dosimeters	108 μR

4.2 Dosimeters

The dosimeters are of type AE-$CaSO_4$:Mn with mylar film lids (1 mg/cm^2). B-I Rudén (1965) has carried out a fairly large number of calibration experiments with Kr^{85}. From these experiments the TLD constant for Kr^{85} was found to be

$$0.01 \frac{Ci}{m^3} \cdot \frac{hr}{R}$$

i.e. 0.01 x the exposure $(\frac{\mu R}{hr})$ = concentration $(\frac{\mu Ci}{m^3})$.

5. METEOROLOGICAL DATA

The following measurements have been made partly within the experimental area, and partly at the main meteorological tower at Studsvik.

Table 2 Meteorological data

Measurement	Type of instrument	Height, metres	Meteorological data prevailing during the experiment
Within the experimental area			
Wind speed	Lambrecht, record.	10	2.5 m/sec
Wind direction	AE Special,	10	310° - 320°
Wind speed	Fuess	1.5	1.1 m/sec
Temperature	Thermistor bridge, manually fed.	0.2 2 5 10	-9.5 - -8.8°C -9.7 - -8.9°C -9.7 - -9.0°C -9.7 - -9.0°C
At the main meteorological tower			
Wind speed	Lambrecht, rec.	36	3.3 m/sec
Wind speed	Lambrecht, "	72	5.8 m/sec
Wind direction	AE Special, "	36	300° - 310°
Wind direction	AE Special, "	72	340° - 360°
Temperature difference	Thermistor bridge, "	30-2	-0.2°C

On the basis of the temperature difference between 2 and 30 m and the wind speed at the 72 m level the diffusion parameter, λ, is found to be 0.3.

λ is defined as

$$\lambda = 10 \log \frac{\frac{\partial \theta}{\partial z}}{u_f^2} \cdot 10^3$$

where $\frac{\partial \theta}{\partial z}$ = vertical gradient of potential temperature, $^{o}C/100$ m

u_f = the wind speed above the friction layer, the so-called "free wind", m/sec.

6. RESULTS

6.1 Background

19 dosimeters were used for background measurements. The average value of the background exposure, m, was determined as follows:

$$m = \bar{x} \pm t_\alpha \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n(n-1)}}$$

where $\bar{x}$ = the arithmetic mean dose

x_i = the individual dose values

n = number of dosimeters

t_α = 2.101 for 5 % error probability

m = 108 ± 11 μR

The scatter of the individual dose values was somewhat larger than expected:

$2\sigma = 44\ \mu R$

6.2 Dose distribution

The dose values, after correcting for background, were plotted in a diagram and isodose lines were drawn (diagram 1, page 11).

6.3 Total quantity of activity

The total quantity of activity which passed the 50 m section has been checked. In drawing the isolines an accurate interpolation was made from curves showing the distribution in the vertical direction. The calculation was made by means of graphical integration and was limited to that part of the measuring plane within the 100 μR isoline. Dose values were subsequently transposed to concentrations. From the wind profile near the ground an average wind speed of 1.75 m/s was determined for the 0-10 m layer. The following results were obtained:

Quantity of activity released	24.1 Ci ± 5 %
Quantity of activity which passed the 50 m section	21 Ci ≃ 88 %

Some uncertainty is of course associated with a determination of this kind, but the check shows that the central parts of the active plume must have been located within the dosimeter grid during the whole experiment. This is also confirmed by wind direction data. Due to the method of interpolation used, the error in drawing the isolines should be small. The greatest error probably results from the use of an average wind speed for the 0-10 m layer. The total error associated with the calculation of the quantity of activity which passed the section is, however, unlikely to exceed ±10 %.

6.4 The diffusion parameters σ_y and σ_z

A formula for continuous ground level point release has been deduced by Högström (1964) on the Studsvik-Ågesta data:

$$\overline{X} = \frac{Q}{2\sqrt{\pi} \cdot I \cdot \sigma_y \cdot \sigma_z \cdot \overline{u}_{36}} \exp\left[-\frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2} \right]$$

$\overline{X}$	= concentration of material M at the points (x, y, z)	M/m^3
Q	= release rate of material M	M/s
x, y, z	= direction coordinates	m
σ_y	= horizontal diffusion parameter	m
σ_z	= vertical -"- -"-	m
$\overline{u}_{36}$	= wind speed at reference level 36 m	m/s
I	= a function of x obtained from the equation of continuity	

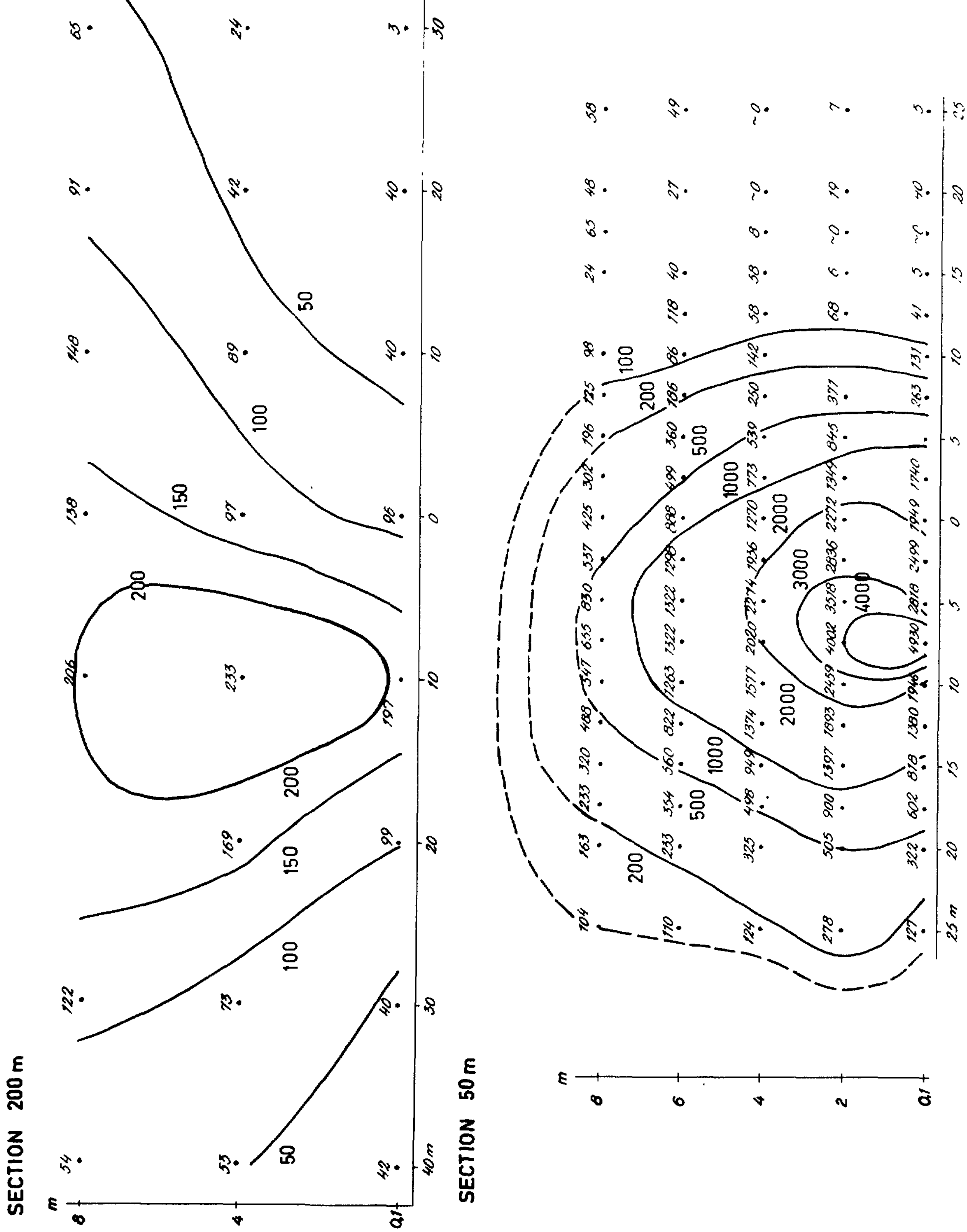
Diagram 1

DIFFUSION EXPERIMENT WITH Kr 85 IN THE TRANVIK VALLEY 19.12.1967.

DOSE, μR

BACKGROUND: MEAN VALUE OF 19 DOSIMETERS 108 μR

EXPOSURE TIME: 52 MIN. = 0.866 h.



In order to make a quantitative estimate of how well the distribution approximates to the normal distribution, a χ^2 test was made concerning the diffusion parameter σ_y. Each level was treated separately. The result of such a test does not, however, show where the discrepancies occur. Skew and excess were calculated in order to show which properties of the distribution are responsible for the deviations together with the variation of these with height. Table 3 below contains a collection of all the results obtained. In this context the average value is the distance from the easterly zero point of the dosimeter sections to the centre line of the plume.

Table 3 Statistical parameters

Section m	Height above ground m	Average value m	Diffusion parameter σ_y m	χ^2	No. of degrees of freedom	Risk level %	Skew	Excess
50	0.1	19.3	6.3	9.913	14	23	1.65	0.19
	2.0	18.3	6.9	3.376	15	<0.1	1.55	-0.16
	4.0	18.6	7.0	2.038	16	<0.1	1.61	0.14
	6.0	18.6	7.2	3.281	15	<0.1	1.63	0.07
	8.0	18.0	7.7	4.177	14	0.6	1.56	-0.25
200	0.1	29.8	15.0	3.588	6	27	1.62	-0.14
	4.0	29.1	15.3	1.772	6	6	0.29	0.27
	8.0	33.9	19.0	1.351	7	1.3	1.41	-0.83

From the table it can be seen, for example, that the centre line of the distribution at the 50 m section was 18-19 m from the section's easterly zero, and that the diffusion parameter σ_y shows a tendency to increase with increasing height above ground.

The χ^2 test shows that the deviations from the normal distribution were greatest at ground level and rapidly diminished at greater heights. At the 50 m section the risk level is <0.1 %. Risk level is defined as the risk of the diffusion pattern not being normally distributed. A detailed study showed that the excess varied about zero, i.e. the distribution has in the main been neither too narrow nor too broad. The deviation from the normal distribution found was mainly a certain positive skew, i.e. the dose was relatively greater to the right of the centre line, looking in the direction of the wind.

Diagrams 2 and 3, pages 14 and 15 respectively, show how the dose distributions in the y-direction compare with normal distributions.

Calculated values of the diffusion parameters σ_y and σ_z referring to the experiment in the Tranvik valley as well as corresponding theoretically computed values are given in table 4.

Table 4 The diffusion parameters σ_y and σ_z, the factor I

$\lambda = 0.3$

$\bar{u}_{36} = 3.3$ m/s

Distance	σ_y		σ_z		I	
	Studsvik-Ågesta	Tranvik	Studsvik-Ågesta	Tranvik	Studsvik-Ågesta	Tranvik
50 m	7.6	6.3	3.4	3.8	0.123*)	0.49
200 m	21.0	~15	8.3	~7	0.280*)	

*) Based on actual wind data for the ground layer 1,5-10 m within the test area, an I value of 0.36 and 0.48 respectively are obtained. Such divergences may arise as a result of local effects.

The diffusion parameters σ_y obtained from the experiment were somewhat smaller than the values given by the Studsvik-Ågesta data whilst for σ_z roughly the same values were obtained. The most noticeable difference occurs between the I-factors which for the experiment were calculated on the basis of the values obtained for σ_y, σ_z and the concentration at the plume centre line.

DIFFUSION FROM GROUND RELEASE

TRANVIK VALLEY 19.12.1967

Diagram 2

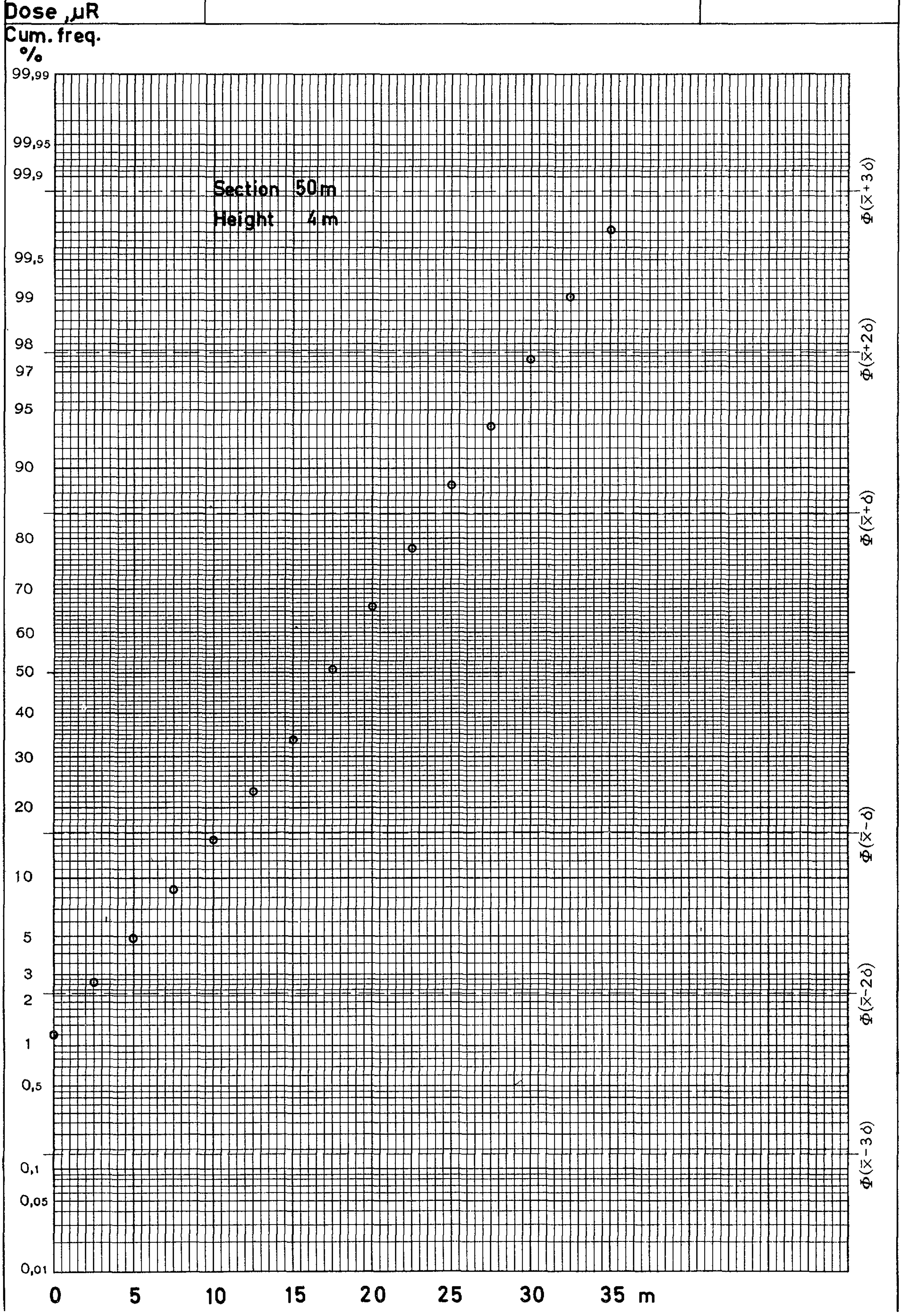
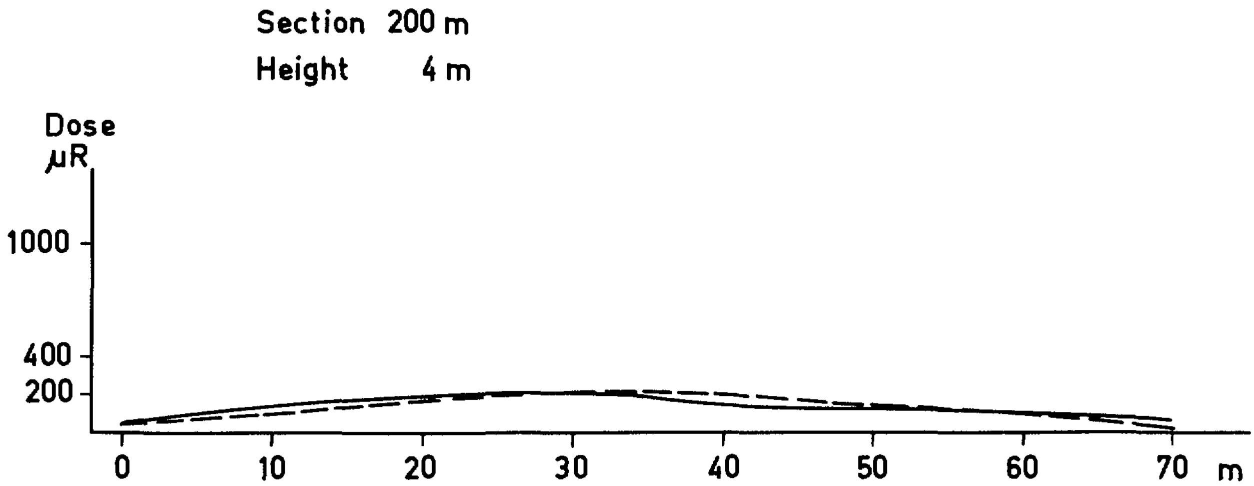
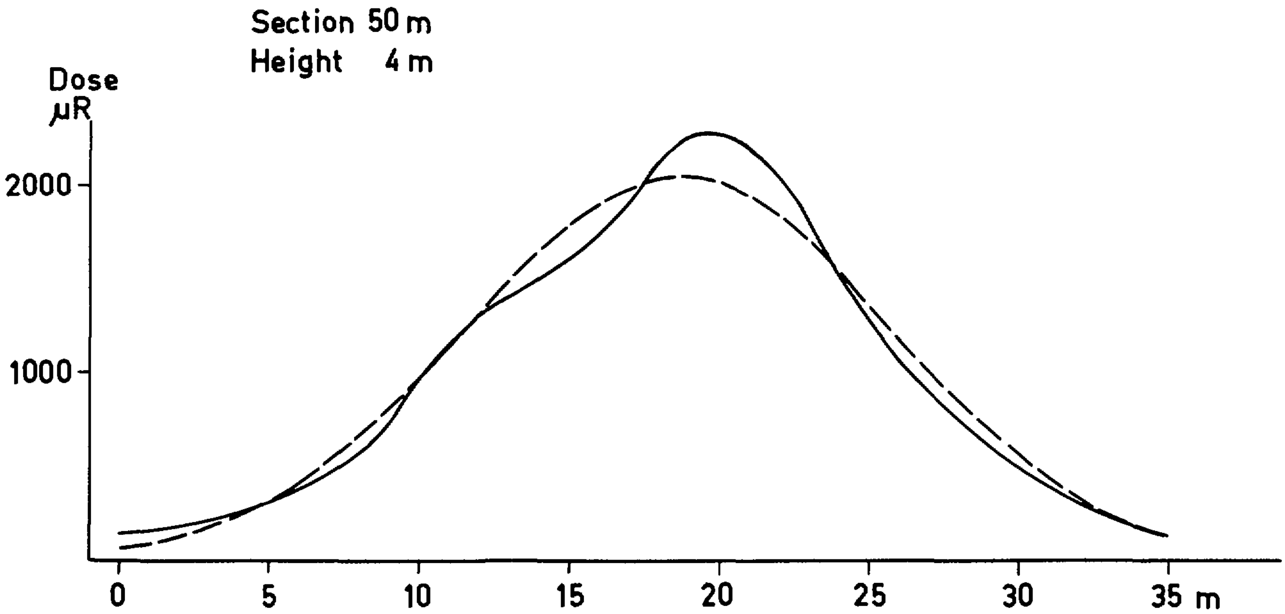


Diagram 3

DIFFUSION FROM GROUND RELEASE. TRANVIK VALLEY 19.12.1967.





——— Experimental results

– – – Normal distribution

6.5 Plume width

The total width to a point where the dose was zero can only be calculated approximately. Thus, in common with the practice reported elsewhere in the literature, the width to a point where the dose was $\frac{1}{10}$ of the dose at the centre line has been calculated. Table 5 contains values for the width of the plume expressed as $\pm 2\sigma_y$ and $\pm 3\sigma_y$ respectively, where σ_y was obtained from the experimental data.

Table 5 Plume width (metres)

Distance	From the experiment in the Tranvik valley 19.12.1967		
	$\frac{1}{10}$ of the dose at the centre line	$\pm 2\sigma_y$	$\pm 3\sigma_y$
50 m	25	25	38
200 m	80	61	92

6.6 Relative concentration, m^{-2}

A comparison has been made with those values which would have been obtained if the calculation had been carried out using the appropriate stability parameters derived from the values measured at the main meteorological tower. The results are shown in diagram 4, page 17. Included in this diagram are Pasquill's curves for stability classes A-F. The comparison shows:

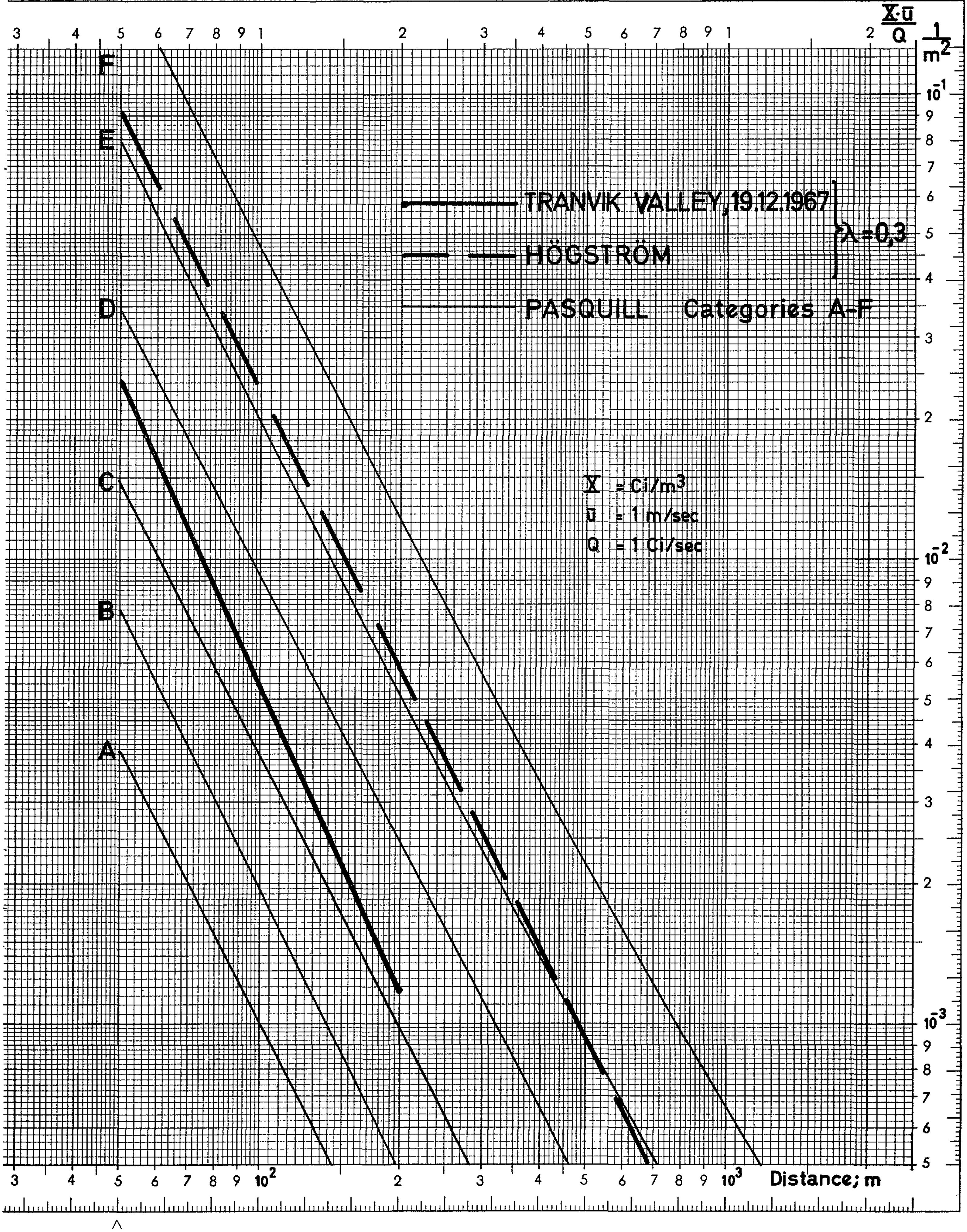
1) the diffusion according to the experiments carried out in the Tranvik valley was 3.7-5.0 times more efficient than that obtained theoretically from the Studsvik-Ågesta data.

2) the values fall between Pasquill's class C (slightly unstable conditions) and class D (neutral conditions).

3) the Studsvik-Ågesta curve (Högström) coincides approximately with Pasquill's class E (slightly stable conditions).

Diagram 4

DIFFUSION FROM GROUND RELEASE



With regard to the fact that the intention was to present the TLD and active tracer method under full scale experimental conditions, and at the same time obtain so detailed a dose pattern as possible, the experimental area was selected so that a certain guiding of the wind would be brought about when passing through Trobbofjärden and along the valley. The experimental conditions were therefore such that the resulting diffusion would be less than that calculated theoretically.

A reason why the diffusion was in fact better than that calculated may be discrepancies in the wind profile between the Studsvik site and the test area. (Högström, personal communication).

Such deviations may be involved when using data from the tower for determination of local diffusion conditions at ground level.

7. RADIATION PROTECTION

7.1 Control of safety analysis

From the experimental data the dose at the centre line of the plume and a distance of 1300 m. (Tranvik farm) was found to be 0.1 mrem. As can be seen from the map, page 5, the plume centre did not sweep over the Tranvik area during the experiment.

7.2 Relationship between source strength - sampling time - dose

Diagram 5 refers to the distance interval 0.1-1.0 km and sampling times 0.5-5 h for two completely different weather conditions, and is presented in order to give a clearer picture of the relationship between source strength - sampling time - dose when Kr85 is used as tracer. The diagram was designed using the diffusion formula for ground releases (Högström).

The following is an example of possible radiation exposure for a dosimeter, and for a person respectively in the centre of the dosimeter section.

It is assumed that inversion conditions prevail during the experiment so that the stability parameter $\lambda = 2.5$ (diagram 5:1).

Sampling time	2 h
Source strength	10 Ci/h
Diffusion is to be studied to a distance of	1 km

For the above experimental conditions the following doses should be obtained in the centre of the plume

Distance from release point	Dose to dosimeter in the measuring sections	Dose to humans in the measuring sections
250 m	ca 5600 μR	ca 190 MPC-hours
500 m	ca 1600 μR	ca 55 MPC-hours
1000 m	ca 470 μR	ca 15 MPC-hours

An MPC-hour is the product of exposure time and the average concentration expressed in MPC. The permissible yearly occupational exposure expressed in these units is 8766 MPC-hours.

The above example implies that a person standing at the centre of the 250 m section during the whole experiment (2 h), receives about 2 % of the permissible yearly dose. At a distance of 1 km, the dose received is less than 0.02 % of the permissible yearly dose to radiological workers i.e. 0.2 % of the permissible yearly dose to population groups in the vicinity of a nuclear plant.

8. CONCLUSION

Diffusion experiments with Kr85 as tracer substance and β-sensitive dosimeters have been carried out in the field with good results. Diffusion was studied in sections at 50 m and 200 m respectively from a point release at ground level.

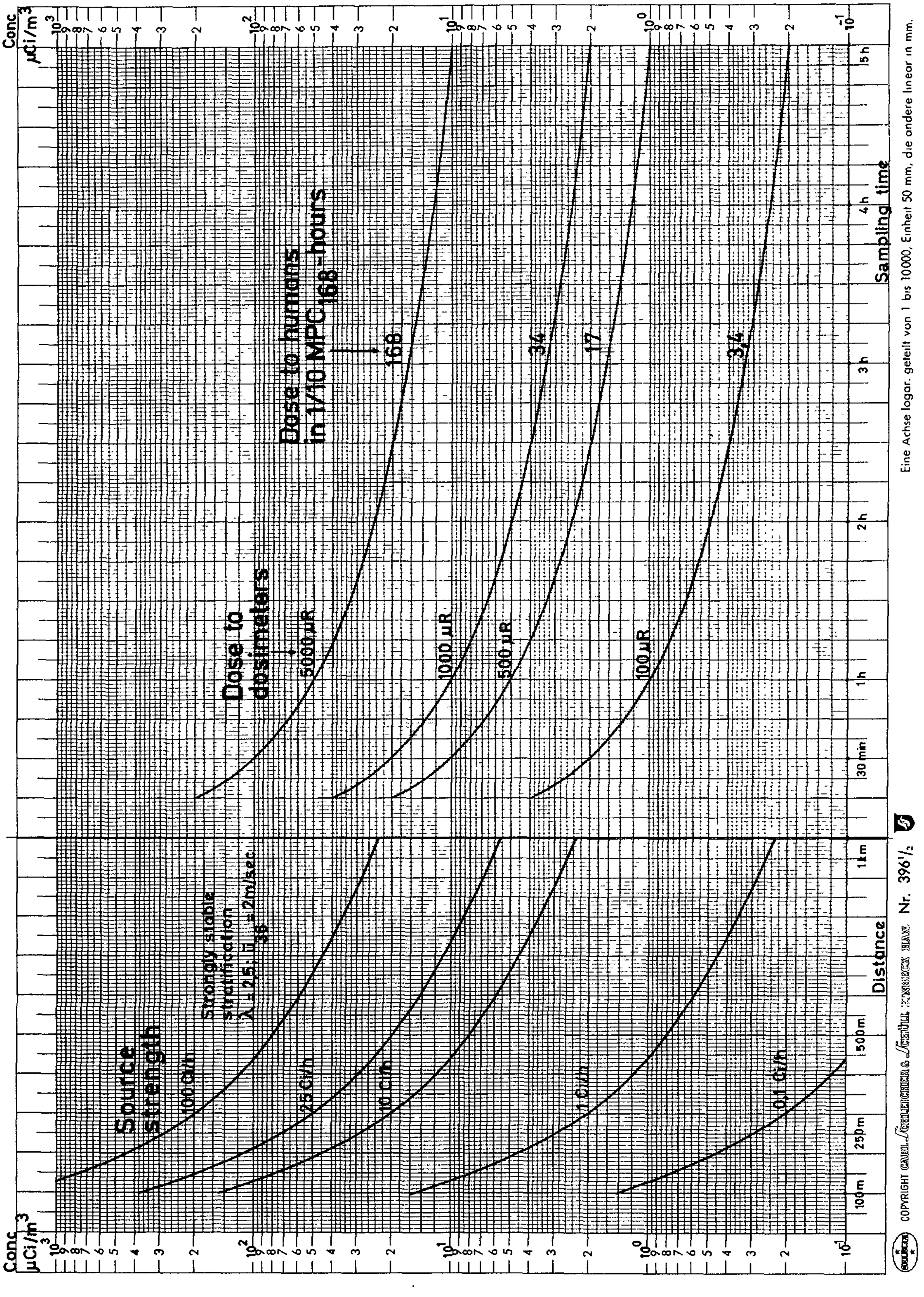
The dose distribution was approximately normal as verified by a χ^2 test. The parameters σ_y and σ_z were experimentally determined for initial diffusion to a distance of 200 m.

The maximum value for the dose and thus the relative concentration was determined. Dilution factors were 3.7-5.0 times greater than those arrived at theoretically, based on data obtained from the main meteorological tower.

A safety analysis showed that the dose to a person at the plume centre and at a distance of 1300 m, where the nearest farm is situated, was 0.1 mrem.

The experiment was made over snow free ground. A direct comparison will be made with the results obtained when releasing from a building.

Diagram 5:1


Conc
µCi/m3
Source strength
100 Ci/h
25 Ci/h
10 Ci/h
1 Ci/h
0,1 Ci/h
Strongly stable stratification
Distance
100 m
250 m
500 m
1 km
Dose to dosimeters
5000 µR
1000 µR
500 µR
100 µR
Dose to humans in 1/10 MPC168-hours
168
34
17
3,4
Sampling time
30 min
1 h
2 h
3 h
4 h
5 h
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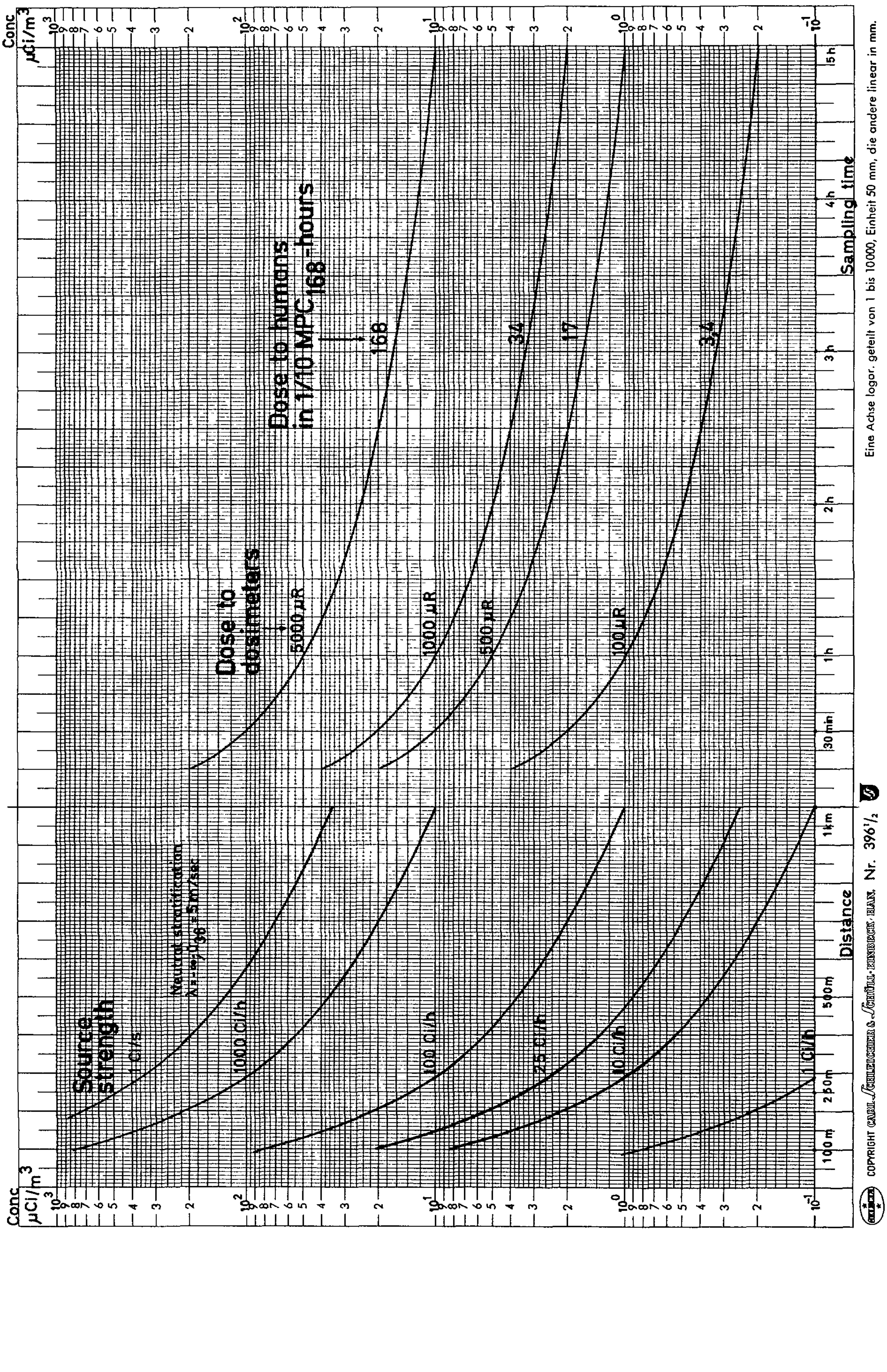
Eine Achse logar. geteilt von 1 bis 10000, Einheit 50 mm, die andere linear in mm.

Diagram 5:2


Conc µCi/m³
Source strength
1 Ci/s
1000 Ci/h
100 Ci/h
25 Ci/h
10 Ci/h
1 Ci/h
Distance
100 m
250 m
500 m
1 km
30 min
1 h
2 h
3 h
4 h
15 h
Sampling time
Dose to dosimeters
5000 µR
1000 µR
500 µR
100 µR
Dose to humans in 1/10 MPC168-hours
168
34
17
3,4
COPYRIGHT CARL SCHLEICHER & SCHÜLL · EINBECK/HAN. Nr. 396 1/2
Eine Achse logar. geteilt von 1 bis 10000, Einheit 50 mm, die andere linear in mm.

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