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Deterministic calculations for source terms from ITER-FEAT

FINAL REPORT
ITER Task G 81 TD 05 (D452) Subtask 4

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Abstract

Dose assessments for ITER-Feat were performed with actual source terms defined beginning of 2001. This comprises deterministic calculations for accidental releases of tritium and activation products as well as for releases under normal operation conditions. For the latter scenarios, recorded meteorological data from the potential ITER candidate site of Cadarache was used. These calculations will be a complete set covering potential worst case and average release conditions.

Deterministische Dosisabschätzungen für Quellterme des ITER-FEAT

Zusammenfassung

Anfang des Jahres 2001 wurden neue Quellterme für den sogenannten ‚ITER-Feat' definiert. Mit diesen Quelltermen wurden deterministische Rechnungen sowohl für den Normalbetrieb als auch für potentielle Unfallszenarien durchgeführt. Im Falle der Normalbetriebsfreisetzung wurde Meteorologie des Standortes Cadarache verwendet. Die Rechnungen dienen dem Aufbau einer konsistenten Datenbasis, die sowohl typische Ausbreitungsbedingungen als auch ‚worst case' Szenarien enthält.

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1 Introduction

In the mid nineties, a first set of dose assessments for well defined deterministic release scenarios was outlined by the ITER programme. Calculations were requested for tritium and activation source terms as they were defined at this time in the ITER project. As the design of the machine has now considerably changed and new source terms became available, a second set of calculations was requested to serve as basis for future safety assessments. Again, deterministic calculations for tritium and activation product source terms under various meteorological conditions were defined.

2 Scenario description

2.1 Release conditions

Calculations for tritium and activation products have been performed with separate computer programs. There was no source term defined where both activation products and tritium were present.

The definition of the scenarios has to cover various aspects. This includes the release height, the weather conditions and the dispersion parameter set. As only deterministic calculations are requested, the following conditions were considered for the accidental cases:

Release height
- ground level releases taking building wake effects into account,
- release from the top of the building with high speed exhaust (jet)
- from a 100 m height stack

Weather conditions
- worst case without rain for each release height
- average weather for each release height
- with rain for each release height

Dispersion parameter set
- MOL [Bul72] (a conservative representation of EU HT dispersion parameters);
- P-G (Pasquill-Gifford) (official US dispersion set used by NRC, EPA, see e.g., [Jow90]);

In a first set of calculations, the relevant worst case weather conditions for each of the combinations of release height and dispersion parameter set were defined. The selected scenarios are presented in Table 1 and Table 2. A more detailed description on the selection process can be found in the Appendix. The average weather conditions were taken as dispersion category D and wind speed of 4 m/s. This led to the following set of combinations of release height, dispersion parameters and weather. It has to be noted that in case of the MOL dispersion parameter set, the reference height for the wind speed was always set to 10 m. The wind speed in release height is calculated according to the power law approach implemented in UFOTRI and COSYMA. In case of the P-G dispersion parameter set, the wind speed indicated is the wind speed in the release height. Only in case of the jet release, the no rain case was applied with the reference height of 10 m and wind speed was adjusted to the release height. Precipitation intensity was assumed to be 1 mm/h.

In case of the jet and the 10 m release, building wake is considered whereas for the 100 m stack, no influence of the building is assumed. The exhaust point for the jet is 4 m on top to the roof which leads to an initial release height of 60 m for the jet release.

Acronym	Dispersion parameter	Release height (m)	Weather conditions	Rain	Comment
A_NU_MOL_10_F_n	MOL	10	F, 0.5 m/s	No	Building wake
A_NU_MOL_10_D_n	MOL	10	D, 4 m/s	No	Building wake
A_NU_MOL_10_E_y	MOL	10	E, 1.2 m/s	Yes	Building wake
A_NU_MOL_100_F_n	MOL	100	F, 0.5 m/s at 10 m height	No	Wind speed adapted
A_NU_MOL_100_D_n	MOL	100	D, 4 m/s at 10 m height	No	Wind speed adapted
A_NU_MOL_100_E_y	MOL	100	E, 1.2 m/s at 10 m height	Yes	Wind speed adapted
A_NU_MOL_JET_E_n	MOL	Jet	E, 1.2 m/s at 10 m height	No	90 m release height, wind adapted
A_NU_MOL_JET_D_n	MOL	Jet	D, 4 m/s at 10 m height	No	70 m release height, wind adapted
A_NU_MOL_JET_E_y	MOL	Jet	E, 1.2 m/s at 10 m height	Yes	90 m release height, wind adapted
A_NU_PG_10_F_n	P-G	10	F, 1 m/s	No	Building wake
A_NU_PG_10_D_n	P-G	10	D, 4 m/s	No	Building wake
A_NU_PG_10_E_y	P-G	10	E, 1 m/s	Yes	Building wake
A_NU_PG_100_C_n	P-G	100	C, 1 m/s	No	1 m/s at release height
A_NU_PG_100_D_n	P-G	100	D, 4 m/s	No	4 m/s at release height
A_NU_PG_100_E_y	P-G	100	E, 1 m/s	Yes	1 m/s at release height
A_NU_PG_JET_E_n	P-G	Jet	E, variable	No	100 m release height, wind adapted
A_NU_PG_JET_D_n	P-G	Jet	D, 4 m/s	No	80 m release height, 4m/s at release height
A_NU_PG_JET_E_y	P-G	Jet	E, 1 m/s	Yes	183 m release height, 1m/s at release height

Table 1: Definition of the release scenarios for accidental releases (NU defines the source term)

Acronym	Dispersion parameter	Release height (m)	Weather conditions	Comment
R_NU_MOL_10	MOL	10	Cadarache	Building wake
R_NU_MOL_100	MOL	100	Cadarache	Wind speed adapted
R_NU_MOL_JET	MOL	Jet	Cadarache	Jet
R_NU_PG_10	P-G	10	Cadarache	Building wake
R_NU_PG_100	P-G	100	Cadarache	1 m/s in rel. h.
R_NU_PG_JET	P-G	Jet	Cadarache	Jet

Table 2: Definition of the release scenarios for routine releases (NU defines the source term)

2.2 Model descriptions

As the plume rise from a high speed exhaust is not part of the standard installation of COSYMA and UFOTRI, a specific submodule was developed and used in the present calculations.

2.2.1 Calculation of plume rise in case of high speed exhaust (jet)

Plume rise can be subdivided into buoyancy or momentum driven. The first one is associated with the temperature difference between the air in the plume and the ambient air. The vertical momentum of a plume is dependent on the exit velocity from the stack. Plume rise can lead to a significant increase in the release height, in particular when large amounts of thermal heat are involved. Therefore most computer codes include equations to treat plume rise dependent on thermal power involved.

Equations used in assessment codes are mainly adopted from work of Briggs performed in the late sixties and seventies. In his work he derived analytical solutions of equations representing fluid dynamics of the plume. These solutions were adjusted using field data. Briggs's approach for buoyancy driven plume rise is implemented in COSYMA and UFOTRI. For momentum driven plume rise no formula is included in the two codes. Besides the work of Briggs many other authors report equations based on observations. Davidson /DAV49/ presented a simple equation for momentum driven plume rise based on ratio of exit velocity and mean wind speed and the stack diameter.

$$\Delta h = DR^{1.4}$$

with:
Δh = momentum driven plume rise (new release height = stack height + Δh)
D = stack diameter
R = velocity ratio w_0 / u
w_0 = mean vertical wind speed
u = mean ambient wind speed

A comparison of both the formula of Briggs (equ. 8.100 /BRI84/) and Davidson show a rather good agreement in the final rise of the plume.

Scenario: 20 m/s exit velocity (v_s), stack diameter 1.8 m	Briggs	Davidson
Stability F, 0.5 m/s	270	310
Stability D, 4.0 m/s	17	17
Stability A, 2.0 m/s	40	45

Table 3: Final rise of the momentum driven plume derived from Briggs and Davidson

These equations discussed above are strictly speaking only applicable when the mechanical turbulence is limiting the plume rise. If the convective turbulence is the limiting factor, a further approximation has to be applied. Now, a stability factor is taken into account in addition to the exit velocity, stack diameter and wind speed of the ambient air. However, data base for these cases are sparse and the dependence on the stability parameter s is very weak ($s^{-1/6}$). In case of a high exhaust velocity and rather low wind speeds, the use of the equation for mechanical turbulence is recommended (if $v_s/u_s > 4$) /BRI69/. Therefore, in this study only the equation of Davidson was applied.

Having calculated the final rise and thus the effective release height, the influence of the building wake effects on the plume is considered.

2.2.2 Tritium

The computer program UFOTRI /RAS90/ and /RAS93/ for assessing the consequences of accidental tritium releases has been used for the dose assessments. Processes such as the conversion in soil of tritium gas (HT) into tritiated water (HTO), reemission after deposition and the conversion of HTO into organically bound tritium (OBT) are considered. For atmospheric dispersion and deposition calculations (dry and wet) the trajectory model MUSEMET /STR81/ implemented in UFOTRI was used. During the time period of the first few days, all the relevant transfer processes between the compartments of the biosphere (atmosphere, soil, plants, animals) are described dynamically. A first order compartment model calculates the longer term pathways of tritium in the foodchains. In its newest version all the exchange processes (atmosphere-soil; atmosphere-plant) are based on resistance approaches and will be re-evaluated dependent on the prevailing environmental conditions. A simple photosynthetic submodule, which calculates the actual transfer rate of HTO in plant water into organically bound tritium, improved the results for the ingestion pathways.

2.2.3 Activation products

Calculations for accidentally released activation products were performed with the version NL/95 of the program system COSYMA /COS91/ (subsystem NL), including extended data sets for activation products /HAY96/. For atmospheric dispersion and deposition calculations (dry and wet) the trajectory model MUSEMET implemented in COSYMA and UFOTRI was used. It was assumed, that the nuclides which appear in aerosol form have a mean diameter of 1 mμ AMAD, and the corresponding dry deposition velocity is set to be 1.0 E-3 m/s (see also Table 2). The doses by ingestion of contaminated foodstuffs are calculated assuming the local production and consumption method; that means, all foodstuffs are consumed in the grid element where they are harvested / produced. The foodchain information from the German model ECOSYS has been used in the calculations / HAY96/.

3 Definitions of the runs

3.1.1 Model input

The following Table 4 defines the most important input parameters for the calculations. There is little difference between accidental releases and normal operation conditions. In no cases were shielding factors not equal 1.0 applied. The parameters were selected similar to those used in previous calculations.

parameter	value
source term	variable
individual dose for the	Most Exposed Individual
release height (accidental)	10 m or 100 m or jet
release height (routine)	10 m or 100 m or jet
building dimensions (h x w)	56 m x 80 m
release duration	1 hr, 1 y
washout coefficient (w)	w = A*I**B (1/s)
with rain intensity I	in mm/hr (here 1 mm/hr)
coefficient A (nobel gas)	0.0 (hr s/mm)
coefficient B (nobel gas)	0.0
coefficient A (aerosol)	8.0 E-05 (hr s/mm)
coefficient B (aerosol)	0.8
coefficient A (HT)	0.0 (hr s/mm)
coefficient B (HT)	0.0
coefficient A (HTO)	9.0 E-05 (hr s/mm)
coefficient B (HTO)	0.6
deposition velocity (nobel gas)	0.0 m/s
deposition velocity (aerosol)	0.001 m/s
deposition velocity (HTO, routine)	0.005 m/s
deposition velocity (HTO, accidental)	variable
dose conversion factors act. prod.	nuclide dependent
dose conversion factor inhalation HT	6.8 E-16 Sv/Bq
dose conversion factor inhalation HTO	1.6 E-11 Sv/Bq
dose conversion factor ingestion HTO	1.6 E-11 Sv/Bq
dose conversion factor ingestion OBT	4.0 E-11 Sv/Bq
breathing rate	2.66 E-4 m**3/s
skin absorption rate (HTO)	1.60 E-4 m**3/s
ingestion rate veget. (root + grain)	180 kg/year
ingestion rate leafy vegetables	45 kg/year
ingestion rate meat	75 kg/year
ingestion rate milk	110 kg/year
shielding factor	1.0 (potential doses)
shielding factor	1.0 (protective measures)

Table 4: Input parameters for the accidental and routine release scenarios

3.1.2 Source terms for atmospheric releases

The following eight source terms were investigated. For each of them, the release scenarios defined in Table 1 and Table 2 were applied.

Release condition	Acronym	Type	Quantity	Comment
Normal operation	SN1	Tritium	1 g/year	HTO
Normal operation	SN1b	Tritium	1 g/year	HT
Normal operation	SN2	ACP	1 g/year	Specific activity Table 6
Normal operation	SN3	Tungsten dust (AP)	1 g/year	Specific activity Table 7
Off-normal	SO1	Tritium	1 g	HTO
Off-normal	SO1b	Tritium	1 g	HT
Off-normal	SO2	ACP	1 g	Specific activity Table 8
Off-normal	SO3	Tungsten dust (AP)	1 g	Specific Activity Table 7

Table 5: Definition of source terms

The nuclide specific composition of the tungsten dust (AP) and of the activated corrosion products (ACP) are listed in the following three Tables (Table 6 to Table 8). In case of tritium, one gram (equivalent to 3.7E+14 Bq) is released. Nuclides not considered in COSYMA do not play any significant role in the dose calculations. This has been assured by deriving fusion relevant dose conversion factors /GSF94/.

Activated Corrosion Products for routine releases					
isotope	**half life [y]**	**activity [Bq/kg]**	**activity [Bq/g]**	**COSYMA**	**COSYMA Ing**
Cr-51	7.59E-02	4.54E+08	4.54E+05	16	14
Mn-54	8.55E-01	3.49E+11	3.49E+08	20	17
Mn-56	2.94E-04	1.19E+13	1.19E+10	21	-
Fe-55	2.73E+00	9.61E+11	9.61E+08	23	19
Co-57	7.44E-01	4.96E+11	4.96E+08	27	23
Co-58	1.94E-01	3.92E+11	3.92E+08	29	24
Co-60	5.27E+00	2.39E+11	2.39E+08	31	25
Ni-57	4.07E-03	8.85E+10	8.85E+07	-	-

Table 6: Unit source term for ACP normal operation (ions and cruds) SN2, with the nuclide number of COSYMA

AP-Tungsten (W inboard, EPP)					
isotope	**half life [y]**	**activity [Bq/kg]**	**activity Bq/g**	**COSYMA**	**COSYMA Ing**
Ta-179	1.82E+00	2.74E+10	2.74E+07	155	69
Ta-182	3.15E-01	1.54E+11	1.54E+08	157	70
Ta-182m	3.01E-05	2.88E+10	2.88E+07	156	-
Ta-183	1.40E-02	6.18E+10	6.18E+07	158	71
Ta-184	9.93E-04	4.34E+10	4.34E+07	-	-
Ta-188		6.34E+10	6.34E+07	-	-
W-179	7.13E-05	2.56E+11	2.56E+08	-	-
W-179m	1.27E-05	1.02E+11	1.02E+08	-	-
W-181	3.32E-01	1.43E+13	1.43E+10	159	72
W-183m	1.65E-07	2.38E+14	2.38E+11	160	-
W-185	2.06E-01	3.71E+13	3.71E+10	161	73
W-185m	3.18E-06	3.64E+13	3.64E+10	-	-
W-187	2.73E-03	5.24E+14	5.24E+11	162	74
Re-184	1.04E-01	1.99E+10	1.99E+07	164	75
Re-186	1.03E-02	2.20E+12	2.20E+09	166	77
Re-188	1.94E-03	6.01E+12	6.01E+09	168	79
Re-188m	3.54E-05	5.79E+11	5.79E+08	167	-
Hf-183	1.07E-04	9.64E+09	9.64E+06	-	-

Table 7: Unit source term for Tungsten (as dust), with the nuclide number of COSYMA

Activated Corrosion Products for accidental releases					
isotope	**half life [y]**	**activity [Bq/kg]**	**activity [Bq/g]**	**COSYMA**	**COSYMA Ing**
Cr-51	7.59E-02	1.14E+11	1.14E+08	16	14
Mn-54	8.55E-01	9.86E+10	9.86E+07	20	17
Mn-56	2.94E-04	1.35E+12	1.35E+09	21	-
Fe-55	2.73E+00	2.07E+12	2.07E+09	23	19
Co-57	7.44E-01	2.64E+11	2.64E+08	27	23
Co-58	1.94E-01	1.06E+11	1.06E+08	29	24
Co-60	5.27E+00	1.41E+11	1.41E+08	31	25
Ni-57	4.07E-03	4.52E+10	4.52E+07	-	-

Table 8: Unit source term for ACP deposits (SO2), with the nuclide number of COSYMA

3.2 Definition of the calculated doses

Individual potential dose values (no shielding, no protective actions) for the most exposed individual (MEI) were calculated at 18 distances (ranging from 145 m up to 100 km). However, only the results for 1000 m are evaluated in detail as this distance may represent the proposed site boundaries for ITER. All further results are available in EXCEL files on a CD.

Four different types of doses have been investigated. In all cases, 70 years integration time (50 years for tritium) is assumed in the dose conversion factors.

1. Committed effective dose equivalent from the passing plume (here referred as **plume dose**). This includes the exposure pathways external exposure from the passing cloud (**CL**) and the internal exposure from inhalation + skin absorption (**IH**).

2. Committed effective dose equivalent for the first 7 days exposure (here referred as **early dose**). This includes the exposure pathways external exposure from the passing cloud (**CL**) and the first week external exposure from the ground (**GR**), the internal exposure from inhalation + skin absorption (**IH**) and the internal exposure from inhalation + skin absorption from the reemitted radionuclides (**IHR**) during the first week.
3. Committed effective dose equivalent without ingestion (here referred as **EDE, no ingestion**) results from chronic exposure and a 70 years integration time (50 years for tritium). The exposure pathways are the external exposure from the passing cloud and the ground, the internal exposure from inhalation + skin absorption from the passing cloud and the internal exposure from inhalation + skin absorption from reemitted radionuclides
4. Committed effective dose equivalent with ingestion (here referred as **EDE**) results from chronic exposure and a 70 years integration time (50 years for tritium). This dose includes all five exposure pathways.

In case of normal operation scenarios, only dose type number four is considered.

4 Results of the potential dose calculations

Deterministic calculations are often required in licensing procedures. However for tritium, the definition of a deterministic weather sequence with a fixed weather over the whole period does not represent the changing weather conditions which appear in reality. Moreover, as the ingestion dose significantly depends on the time after the plume passage, such deterministic scenarios have to be evaluated with care. As listed earlier, for each stability category, a certain solar irradiation intensity is defined. This should be more or less representative, but does not include the day and night changes as well as the variability which occurs under natural conditions. Therefore it is again warned not to lay too much emphasis on the doses with ingestion in case of releases of tritium.

4.1 Results for tritium releases

Tritium was released either in gaseous form (HT) or as tritiated water vapour (HTO). In all cases, 1g equivalent to 3.7E+14 Bq was released to the atmosphere. The results from the accidental scenarios with a release duration of one hour are described for HTO in chapter 4.1.1 and Table 9 (SO1) and for HT in chapter 4.1.2 and Table 10 (SO1b). Results from normal operation scenarios are described in chapter 4.1.3 and Table 11 (SN1) as well as in chapter 4.1.4 and Table 12 (SN1b) for HTO and HT, respectively.

4.1.1 SO1

Run definition	Plume dose	Early dose	EDE, no ing.	EDE
A_HTO_MOL_10_F_n	4.84E-04	5.38E-04	5.38E-04	2.10E-03
A_HTO_MOL_10_D_n	2.42E-05	3.27E-05	3.28E-05	3.50E-04
A_HTO_MOL_10_E_y	1.24E-04	1.60E-04	1.62E-04	2.38E-03
A_HTO_MOL_100_F_n	1.46E-05	1.49E-05	1.49E-05	5.83E-05
A_HTO_MOL_100_D_n	4.67E-06	5.28E-06	5.28E-06	5.80E-05
A_HTO_MOL_100_E_y	9.76E-06	1.21E-05	1.24E-05	5.05E-04
A_HTO_MOL_JET_E_n	6.38E-05	8.27E-05	8.28E-05	5.97E-04
A_HTO_MOL_JET_D_n	2.42E-05	3.27E-05	3.28E-05	3.50E-04
A_HTO_MOL_JET_E_y	6.07E-05	7.55E-05	7.60E-05	1.23E-03
A_HTO_PG_10_F_n	5.63E-04	6.36E-04	6.37E-04	2.98E-03
A_HTO_PG_10_D_n	6.18E-05	7.56E-05	7.57E-05	8.20E-04
A_HTO_PG_10_E_y	2.96E-04	3.42E-04	3.43E-04	4.23E-03
A_HTO_PG_100_C_n	4.00E-05	4.28E-05	4.28E-05	4.58E-04
A_HTO_PG_100_D_n	1.21E-07	1.27E-07	1.27E-07	1.45E-06
A_HTO_PG_100_E_y	2.57E-07	1.53E-06	2.67E-06	1.84E-03
A_HTO_PG_JET_E_n	4.75E-05	5.37E-05	5.37E-05	3.67E-04
A_HTO_PG_JET_D_n	6.36E-05	8.31E-05	8.31E-05	9.09E-04
A_HTO_PG_JET_E_y	4.28E-15	1.30E-06	2.44E-06	1.89E-03

Table 9: Doses in Sv for accidental release of 3.7 E14 Bq (1g) of HTO

Values from plume dose, early dose and EDE without ingestion are similar within the individual scenarios. Doses from the EDE, however are significantly higher which shows the impact from ingestion pathways. The highest doses without ingestion result from releases under very stable conditions and ground level, whereas rain events can dominate the total dose. Highest doses are similar for MOL and P-G cases within a factor of two, but P-G scenarios show the highest dose values obtained. Doses from ingestion have to be taken with care, as the deterministic scenario assumes constant meteorological conditions over the whole period of at least 70 hours used for the dispersion process. Nevertheless also earlier studies demonstrated that the influence of the ingestion is dominating the total dose (e.g. /RAS98/). Doses from the high speed exhaust events are not necessarily lower as from a stack. The reason is that always scenarios exist where building wake effects appear und thus the final rise is limited (see the Appendix for details).

4.1.2 SO1b

Run definition	Plume dose	Early dose	EDE, no ing.	EDE
A_HT_MOL_10_F_n	2.20E-08	5.80E-06	5.92E-06	2.07E-04
A_HT_MOL_10_D_n	1.08E-09	1.97E-07	2.00E-07	7.14E-06
A_HT_MOL_10_E_y	6.41E-09	3.99E-07	4.55E-07	8.77E-05
A_HT_MOL_100_F_n	6.21E-10	3.69E-08	4.02E-08	5.31E-06
A_HT_MOL_100_D_n	1.99E-10	1.53E-08	1.59E-08	1.16E-06
A_HT_MOL_100_E_y	4.29E-10	9.27E-09	1.29E-08	5.64E-06
A_HT_MOL_JET_E_n	2.80E-09	7.98E-07	8.10E-07	2.17E-05
A_HT_MOL_JET_D_n	1.08E-09	1.97E-07	2.00E-07	7.14E-06
A_HT_MOL_JET_E_y	2.80E-09	1.65E-07	1.89E-07	3.82E-05
A_HT_PG_10_F_n	2.65E-08	4.64E-06	4.77E-06	1.97E-04
A_HT_PG_10_D_n	2.81E-09	3.32E-07	3.41E-07	1.70E-05
A_HT_PG_10_E_y	6.41E-09	3.99E-07	4.55E-07	8.77E-05
A_HT_PG_100_C_n	1.71E-09	1.76E-07	1.82E-07	1.55E-05
A_HT_PG_100_D_n	5.14E-12	8.73E-11	1.04E-10	3.04E-08
A_HT_PG_100_E_y	0	0	0	0
A_HT_PG_JET_E_n	2.05E-09	2.89E-07	2.98E-07	1.48E-05
A_HT_PG_JET_D_n	2.86E-09	5.53E-07	5.63E-07	2.03E-05
A_HT_PG_JET_E_y	0	0	0	0

Table 10: Doses in Sv for accidental release of 3.7 E14 Bq (1g) of HT

Doses from HT releases are in general lower than from HTO. Plume doses are lowest as only the contribution from HT is considered. With reemission (early dose and EDE without ingestion) doses increase by about two orders of magnitude. Doses with ingestion are again highest but about one order of magnitude lower as those from HTO. Some scenarios exist where the dose is either 0 or very low. The reason is that the plume has not touched the ground at 1000m and washout is not present as rain does not affect the HT-plume. Doses from the high speed exhaust events are higher than those from the stack – for at least one worst case scenario considered.

4.1.3 SN1

Run definition	EDE
R_HTO_MOL_10	1.42E-05
R_HTO_MOL_100	3.01E-06
R_HTO_MOL_JET	2.67E-06
R_HTO_PG_10	2.66E-05
R_HTO_PG_100	1.52E-06
R_HTO_PG_JET	1.42E-06

Table 11: Doses in Sv for routine release of 3.7 E14 Bq (1g) of HTO

4.1.4 SN1b

Run definition	EDE
R_HT_MOL_10	5.95E-07
R_HT_MOL_100	1.07E-07
R_HT_MOL_JET	9.52E-08
R_HT_PG_10	1.66E-06
R_HT_PG_100	5.61E-08
R_HT_PG_JET	5.74E-08

Table 12:Doses in Sv for routine release of 3.7 E14 Bq (1g) of HT

In case of normal operation release (SN1 + SN1b), the high speed exhaust scenario shows the lowest doses for both chemical forms of tritium. This differs from the deterministic results but can be explained as here all events are considered, also those with a very high plume rise. Highest doses result from ground level releases. Releases from stack or with high speed exhaust are about 5 times lower than ground level releases. It is interesting to note, that P-G scenarios show the absolute highest doses for ground level releases but the doses from elevated sources are always lower than for MOL. This can be explained with the tighter plume geometry. In many cases, the plume has not or only slightly touched the ground for certain combinations of stability and release height.

4.2 Results for releases of activation products

Activation products were released either as activated dust (AP) or as activated corrosion product (ACP). In all cases, 1g was released to the atmosphere. The results from the accidental scenarios with a release duration of one hour are described for ACP in chapter 4.2.1 and Table 13 (SO2) and for AP in chapter 4.2.2 and Table 14 (SO3). Results from normal operation scenarios are described in chapter 4.2.3 and Table 15 (SN2) as well as in chapter 4.2.4 and Table 16 (SN3) for ACP and AP, respectively.

4.2.1 SO2

Run definition	Plume dose	Early dose	EDE, no ing.	EDE
A_ACP_MOL_10_F_n	3.44E-07	4.00E-07	6.94E-06	1.16E-05
A_ACP_MOL_10_D_n	1.76E-08	2.03E-08	3.48E-07	5.83E-07
A_ACP_MOL_10_E_y	9.42E-08	1.93E-07	1.19E-05	2.02E-05
A_ACP_MOL_100_F_n	1.09E-08	1.25E-08	2.01E-07	3.36E-07
A_ACP_MOL_100_D_n	3.30E-09	3.81E-09	6.42E-08	1.07E-07
A_ACP_MOL_100_E_y	7.03E-09	4.20E-08	4.14E-06	7.07E-06
A_ACP_MOL_JET_E_n	4.52E-08	5.24E-08	9.01E-07	1.51E-06
A_ACP_MOL_JET_D_n	1.76E-08	2.03E-08	3.48E-07	5.83E-07
A_ACP_MOL_JET_E_y	4.32E-08	9.82E-08	6.56E-06	1.12E-05
A_ACP_PG_10_F_n	4.23E-07	4.91E-07	8.51E-06	1.42E-05
A_ACP_PG_10_D_n	4.54E-08	5.27E-08	9.02E-07	1.51E-06
A_ACP_PG_10_E_y	2.27E-07	3.93E-07	2.00E-05	3.40E-05
A_ACP_PG_100_C_n	2.88E-08	3.32E-08	5.53E-07	9.25E-07
A_ACP_PG_100_D_n	1.43E-09	1.44E-09	3.01E-09	4.12E-09
A_ACP_PG_100_E_y	4.24E-09	1.45E-07	1.67E-05	2.86E-05
A_ACP_PG_JET_E_n	3.42E-08	3.95E-08	6.62E-07	1.11E-06
A_ACP_PG_JET_D_n	4.64E-08	4.64E-08	9.20E-07	1.54E-06
A_ACP_PG_JET_E_y	1.35E-09	1.42E-07	1.67E-05	2.86E-05

Table 13: Doses in Sv for accidental release of 1g of ACP

In case of ACP, plume dose and early doses are similar. EDE without ingestion is higher by at least a factor of 10. This is the result of the contribution from groundshine over the whole lifetime period of 70 years. Doses with ingestion are about two times higher as without ingestion. This differs slightly from tritium for which ingestion dominates the dose by about 80% of the total. Highest doses were obtained for scenarios with precipitation underlining the importance of the deposited material (groundshine + ingestion). Cobalt dominates the dose with a contribution of about 50% to the total.

4.2.2 SO3

Run definition	Plume dose	Early dose	EDE, no ing.	EDE
A_AP_MOL_10_F_n	2.31E-06	7.44E-06	8.57E-06	2.64E-05
A_AP_MOL_10_D_n	1.34E-07	3.94E-07	4.51E-07	1.35E-06
A_AP_MOL_10_E_y	6.65E-07	9.91E-06	1.19E-05	4.39E-05
A_AP_MOL_100_F_n	1.48E-07	2.98E-07	3.31E-07	8.47E-07
A_AP_MOL_100_D_n	2.99E-08	7.80E-08	8.85E-08	2.54E-07
A_AP_MOL_100_E_y	7.30E-08	3.33E-06	4.04E-06	1.53E-05
A_AP_MOL_JET_E_n	3.32E-07	1.01E-06	1.15E-06	3.48E-06
A_AP_MOL_JET_D_n	1.34E-07	3.94E-07	4.51E-07	1.35E-06
A_AP_MOL_JET_E_y	3.17E-07	5.45E-06	6.57E-06	2.43E-05
A_AP_PG_10_F_n	2.83E-06	9.17E-06	1.06E-05	3.25E-05
A_AP_PG_10_D_n	3.43E-07	1.02E-06	1.17E-06	3.49E-06
A_AP_PG_10_E_y	1.59E-06	1.71E-05	2.05E-05	7.42E-05
A_AP_PG_100_C_n	2.95E-07	7.06E-07	7.96E-07	2.22E-06
A_AP_PG_100_D_n	1.10E-07	1.11E-07	1.11E-07	1.16E-07
A_AP_PG_100_D_n	3.55E-07	1.04E-06	1.19E-06	3.57E-06
A_AP_PG_100_E_y	3.45E-07	1.35E-05	1.63E-05	6.18E-05
A_AP_PG_JET_E_n	3.30E-07	8.25E-07	9.32E-07	2.64E-06
A_AP_PG_JET_D_n	3.55E-07	1.04E-06	1.19E-06	3.57E-06
A_AP_PG_JET_E_y	1.14E-07	1.32E-05	1.61E-05	6.15E-05

Table 14 Doses in Sv for accidental release of 1g of AP

Releases of activation products are in general higher than those of activated corrosion products. In particular the doses from plume passage and early doses are much higher than for ACP. In case of the EDE, the difference declines to a factor of 2 to 3. The reason for this can be seen in the composition of the source term. The ACP-source term contains long living radionuclides with a high contribution from ground (Co-60). Nuclides in the AP-source term are rather short-living and thus the contribution of the longer term does not play such an important role. For AP, inhalation and cloudshine become more important, even if the exposure from ground still shows the highest contribution to the dose. Tungsten (W-185 and W-187) is the dominating nuclide for the present AP-source term.

4.2.3 SN2

Run definition	EDE
R_ACP_MOL_10	2.22E-07
R_ACP_MOL_100	4.99E-08
R_ACP_MOL_JET	3.83E-08
R_ACP_PG_10	4.68E-07
R_ACP_PG_100	3.38E-08
R_ACP_PG_JET	2.88E-08

Table 15 Doses in Sv for routine release of 1g of ACP

4.2.4 SN3

Run definition	EDE
R_AP_MOL_10	3.57E-07
R_AP_MOL_100	7.64E-08
R_AP_MOL_JET	6.03E-08
R_AP_PG_10	7.59E-07
R_AP_PG_100	5.01E-08
R_AP_PG_JET	4.24E-08

Table 16 Doses in Sv for routine release of 1g of AP

ACP and AP releases behave similar. Highest doses under normal operation conditions were obtained for the ground level release scenario with P-G dispersion parameters. Lowest doses were found for the high speed exhaust events. Doses from elevated releases are at least a factor of 5 lower as from ground level, in case of the use of P-G dispersion parameters, the difference is more than a factor of 10.

4.3 Special applications

4.3.1 Doses with shielding factors

One additional task was defined to calculate the dose to adults working as control personal inside the site boundary. They are located in 100 m – 200 m distance from the release point in a control room. To cope with this request, the basic calculations for the plume and early dose may be used by applying shielding factors for the external exposure from cloud and ground as well as for inhalation. Typical shielding factors can be taken from /COS91/. These shielding factors depend on structure and material of the building. Therefore it is necessary to define them for each case of application separately. Some typical values are presented in Table 17:

	Cloud	Ground	Inhalation
Low shielding	0.3	0.1	1
Medium shielding	0.05	0.03	1
High shielding	0.01	0.01	1

Table 17 Default shielding factors from COSYMA

Applying the shielding factors to the early dose from scenario A_AP_MOL_10_D_n, the following dose reduction is obtained:

A_AP_MOL_10_D_n	CL %	GR %	IH %	IG %	IHR%	DOSE (SV)
No shielding	4.79	72.17	23.04	0	0	3.00E-06
Low shielding	4.53	22.8	72.7	0	0	9.51E-07
Medium shielding	0.94	8.51	90.5	0	0	7.63E-07
High shielding	0.20	3.03	96.8	0	0	7.14E-07

Table 18 Application of the default shielding factors to the early dose of scenario A_AP_MOL_10_D_n at 145 m distance from the release point

Dependent on the application, dose reductions to values, where nearly only the contribution from inhalation remains, can be obtained. Shielding factors for inhalation can be applied. In recent publications, a reduction factor of about 2 is recommended for aerosols (e.g. /ROD00/)

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6 Appendix

6.1 Definition of weather sequences for the individual release scenarios

For each dispersion parameter set, four different scenarios were investigated. This included also two scenarios, which were not considered in the final dose assessments:

1. Release height of 100 m with building wake
2. Release height of 100 m without building wake
3. Release height of 150 m without building wake
4. Release from the roof with an increased exhaust speed (jet)

Within the discussion during the investigations it was clarified, that scenario 1 and 3 should not be considered in the dose assessments, however for completeness, the results are also reported here. The calculations were performed to obtain the maximum air concentration and also the maximum dry and wet deposition. To look at the deposition fields was necessary, as weather conditions with and without rain should be investigated. In case of rain, an intensity of 1 mm/hr is assumed.

For each scenario, a unit release of aerosols was assumed for each stability class. Within each stability class, three different assumptions about the wind speed are made:

1. the wind speed was set to 1 m/s at the release height. Abbreviation **1_f**
2. the wind speed was set to 1 m/s at 10 m height but changes with height of the release. Abbreviation **1_v**
3. A basic set is defined as presented in Table 19 which is similar to that used in German licensing procedures. The only exception is the wind speed for class F which is now set to 0.5 m/s due to model constraints. Abbreviation **g_v**

stability class	wind speed (m/s)	solar irradiation (W/m2)
A	0.9	350
B	1.3	300
C	1.7	250
D	2.0	200
E	1.2	120
F	0.5	80

Table 19 Definition of wind speed and stability classes for MOL parameter set (the solar irradiation is only used in case of tritium releases, however this is also valid for the P-G set)

This definition leads now to 8 cases (combination of four release scenario and two dispersion parameter sets) with 36 distance dependent curves (three wind speeds, dry and wet, six stability classes). The selection process reduces the number of results for each case to six, representing the maximum concentration in air and on ground for the various wind speed definitions. The maxima are presented in the Table 20 to Table 27 for the distance of 1000 m from the release point. The highest values of the normalised air and ground concentrations defines that combination of wind speed and stability class which is used for the dose assessments. The selection is presented in Table 28. A complete set of curves is shown in the figures. For the 10m release height, no detailed investigation is necessary, as the lowest wind speed with the stability class F gives always the highest concentrations. In case of rain, it was assumed that no rain is linked with very stable and very unstable stratification, therefore rain and stability classes A and F was omitted. This leads in most cases to a combination of stability class E with rain as maximum. In case of the stack release of 100 m without influence of buildings, the MOL dispersion parameter set shows the highest air contamination over a wide range of distances under stable atmospheric stratification. The P-G dispersion scheme differs for this scenario and unstable stratification results in the highest air concentrations. The situation is again different for the jet release, as in most cases some combinations of wind speed and stability class exist which result in building wake effects. This reduces the release height drastically and shows high air concentrations even for stable stratification. This effect of the building wake on jet releases also forced the decision to include for the P-G scheme one set with variable wind speed (1 m/s at 10 m height) in case of a jet release.

	Chi/Q air		Ground concentration dry + wet	
B100_1_f	D	4.11E-05	E	5.74E-07
B100_1_v	C	1.94E-05	E	2.76E-07
B100_g_v	F	3.82E-05	E	2.32E-07

Table 20 Maximum concentration from combinations of wind speed and stability classes for the release height of 100m with building wake effects with the P-G scheme

	Chi/Q air		Ground concentration dry + wet	
B100_1_f_no wake	C	1.58E-05	E	5.33E-07
B100_1_v_no wake	C	9.78E-06	E	2.08E-07
B100_g_v_no wake	B	7.53E-06	E	1.74E-07

Table 21 Maximum concentration from combinations of wind speed and stability classes for the release height of 100m without building wake effects with the P-G scheme

	Chi/Q air		Ground concentration dry + wet	
B150_1_f	B	8.63E-06	E	5.33E-07
B150_1_v	B	6.08E-06	C	1.75E-07
B150_g_v	B	4.68E-06	E	1.47E-07

Table 22 Maximum concentration from combinations of wind speed and stability classes for the release height of 150m without building wake effects with the P-G scheme

	Chi/Q air		Ground concentration dry + wet	
Bjet_1_f	B	6.23E-06	E	5.33E-07
Bjet_1_v	E	1.98E-05	E	2.78E-07
Bjet_g_v	E	3.58E-05	E	2.75E-07

Table 23 Maximum concentration from combinations of wind speed and stability classes for the jet scenario with the P-G scheme

	Chi/Q air		Ground concentration dry + wet	
M100_1_f	F	5.27E-05	E	4.40E-07
M100_1_v	F	2.42E-05	E	2.10E-07
M100_g_v	F	5.98E-05	E	1.77E-07

Table 24 Maximum concentration from combinations of wind speed and stability classes for the release height of 100m with building wake effects with the MOL scheme

	Chi/Q air		Ground concentration dry + wet	
M100_1_f_no wake	D	1.60E-05	E	4.12E-07
M100_1_v_no wake	C	8.25E-06	E	1.59E-07
M100_g_v_no wake	F	7.11E-06	E	1.33E-07

Table 25 Maximum concentration from combinations of wind speed and stability classes for the release height of 100m without building wake effects with the MOL scheme

	Chi/Q air		Ground concentration dry + wet	
M150_1_f	C	6.68E-06	E	4.01E-07
M150_1_v	A	4.46E-06	E	1.30E-07
M150_g_v	A	4.95E-06	E	1.09E-07

Table 26 Maximum concentration from combinations of wind speed and stability classes for the release height of 150m without building wake effects with the MOL scheme

	Chi/Q air		Ground concentration dry + wet	
Mjet_1_f	B	4.63E-06	E	4.00E-07
Mjet_1_v	F	2.48E-05	E	2.12E-07
Mjet_g_v	E	2.52E-05	E	2.07E-07

Table 27 Maximum concentration from combinations of wind speed and stability classes for the jet scenario with the MOL scheme

Dispersion parameter	**Release height (m)**	**Weather conditions**	**Rain**
MOL	100	F, variable 0.5 m/s at 10 m height	No
MOL	100	E, variable 1.2 m/s at 10 m height	Yes
MOL	Jet	E, variable 1.2 m/s at 10 m height	No
MOL	Jet	E, variable 1.2 m/s at 10 m height	Yes
P-G	100	C, 1 m/s at release height	No
P-G	100	E, 1 m/s at release height	Yes
P-G	Jet	E, variable 1 m/s at 10 m height	No
P-G	Jet	E, 1 m/s at release height	Yes

Table 28 Combinations of wind speed and stability classes for the stack and jet releases to be considered in the detailed dose assessments

6.2 Normalised air and ground concentrations for the different scenarios

6.2.1 Pasquill-Gifford scheme with stack release of 100 m, with building wake

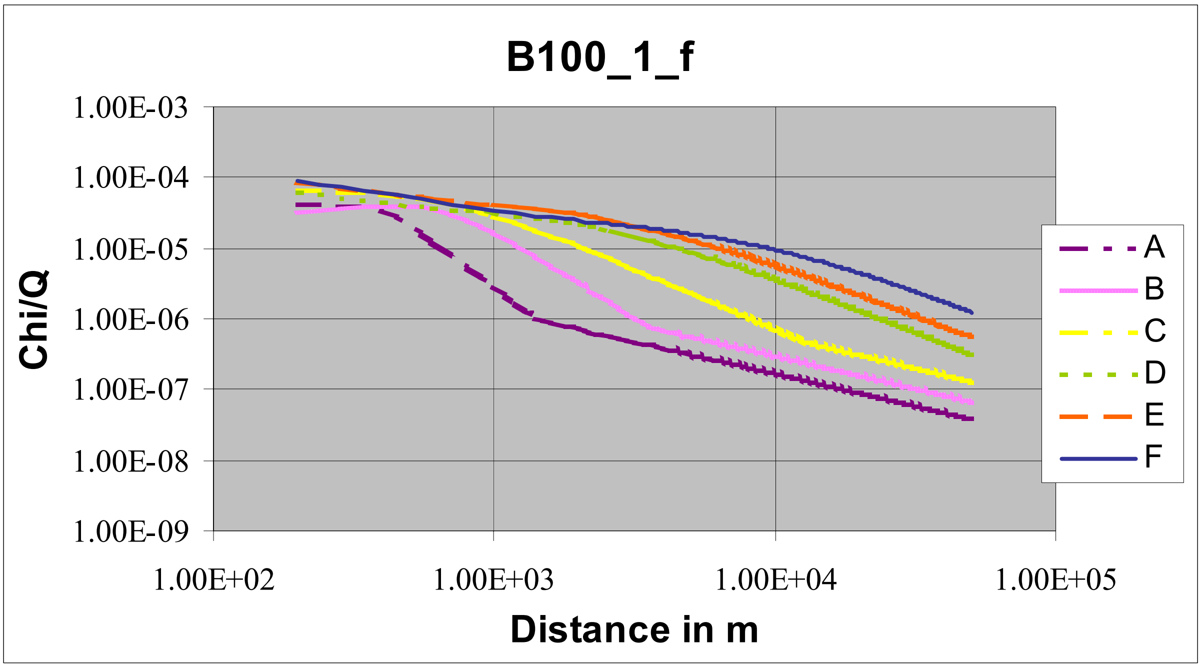

Figure 1: Distance dependent normalised air concentration for P-G scheme, fixed wind speed (1 m/s), 100 m stack with building wake

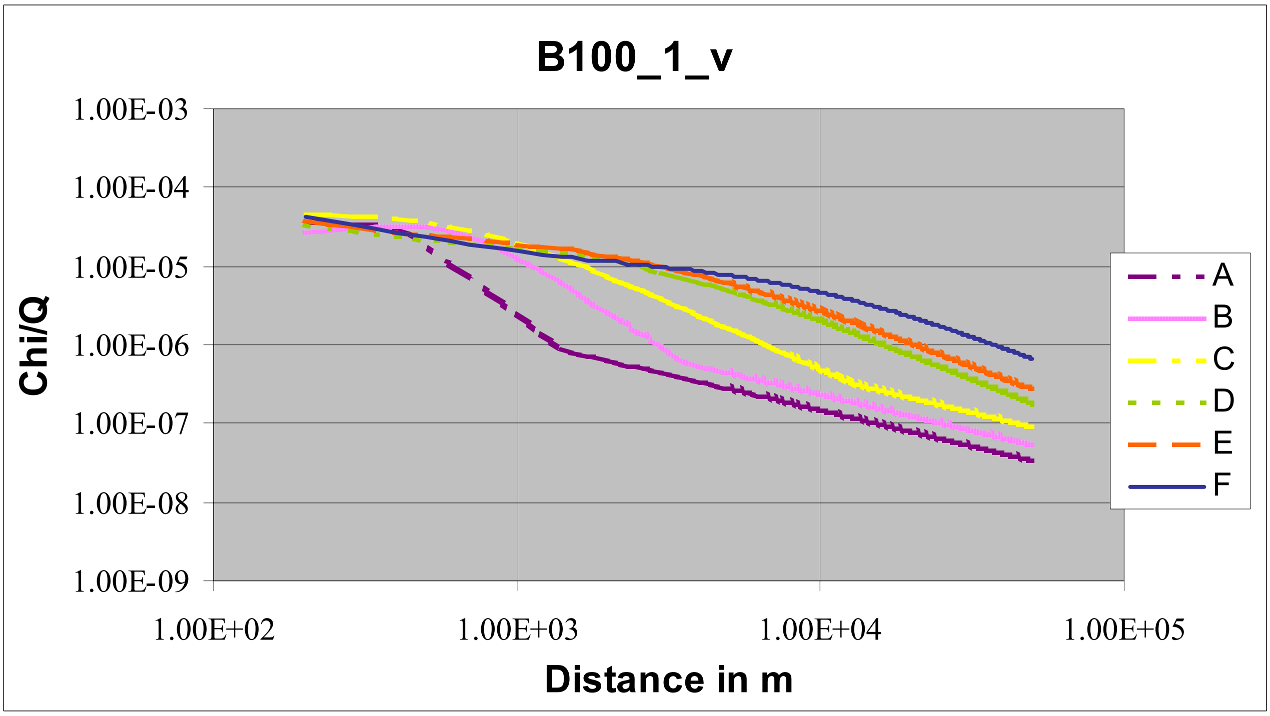

Figure 2: Distance dependent normalised air concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), 100 m stack with building wake

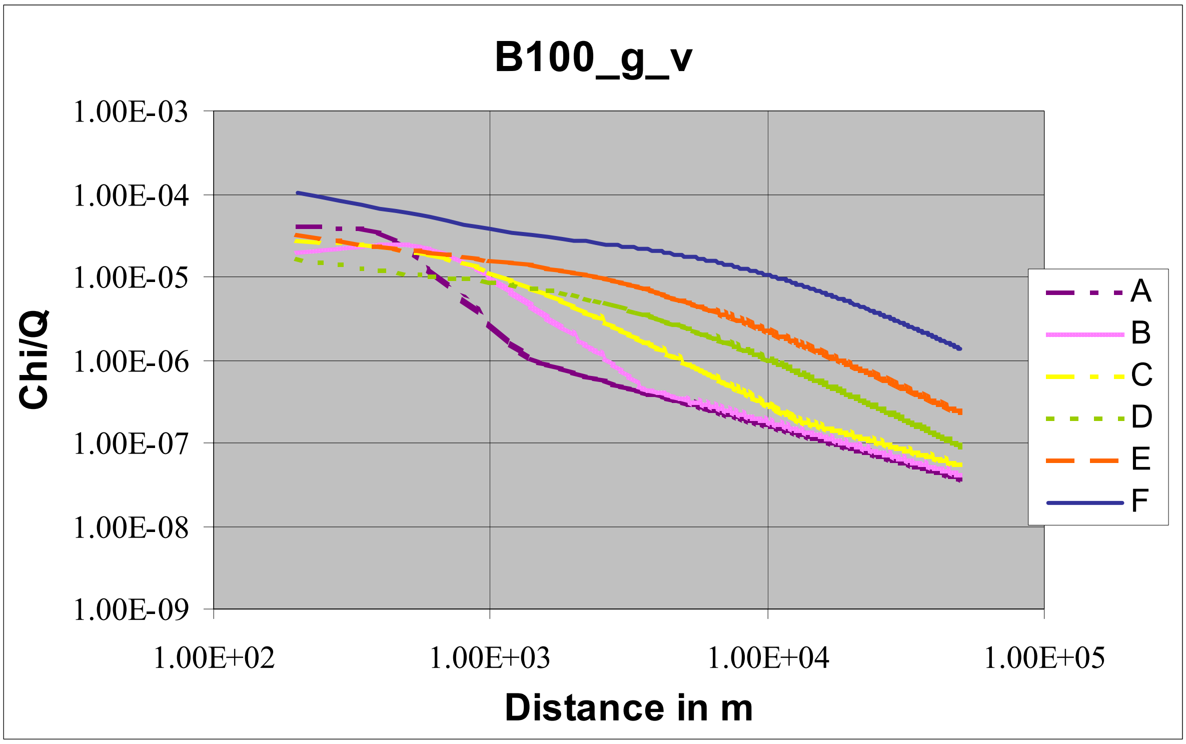

Figure 3 **Distance dependent normalised air concentration for P-G scheme, German like variable speed, 100 m stack with building wake**

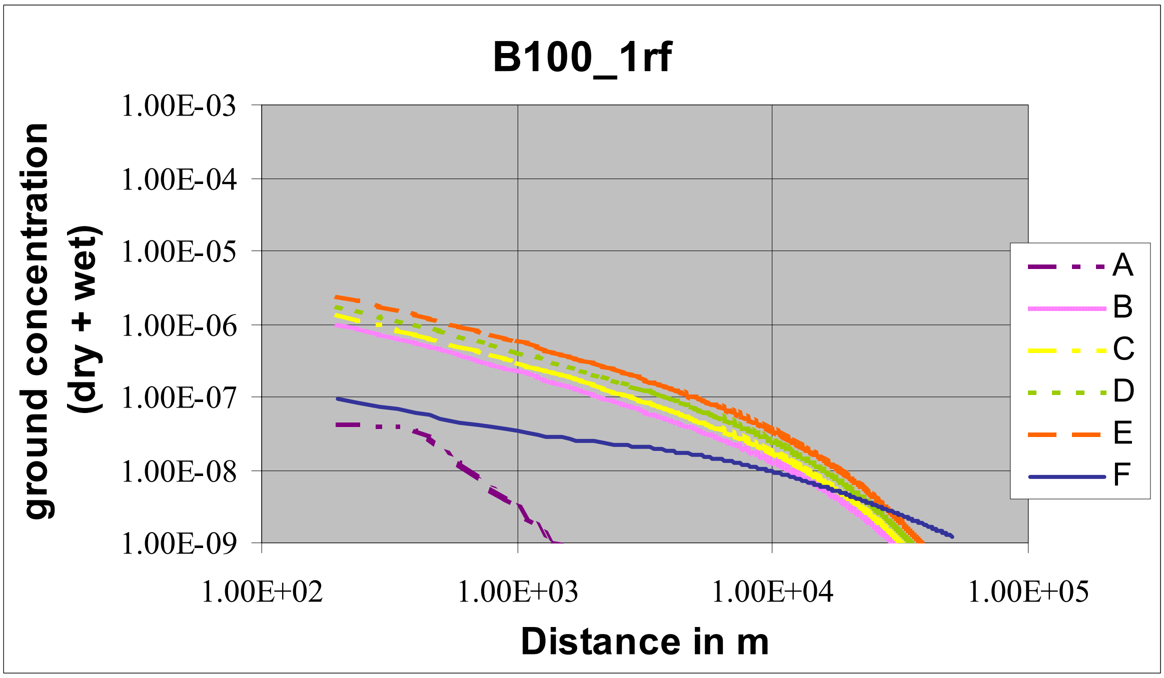

Figure 4 **Distance dependent normalised ground concentration for P-G scheme, fixed wind speed (1 m/s), 100 m stack with building wake**

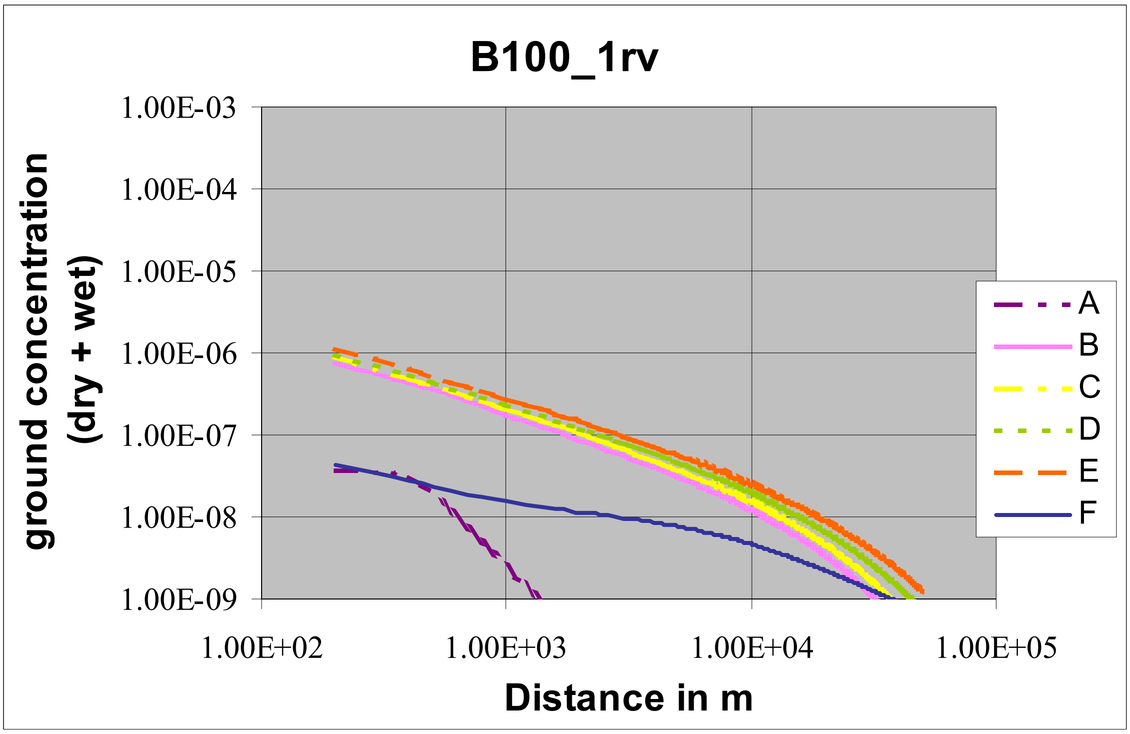

Figure 5 Distance dependent normalised ground concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), 100 m stack with building wake

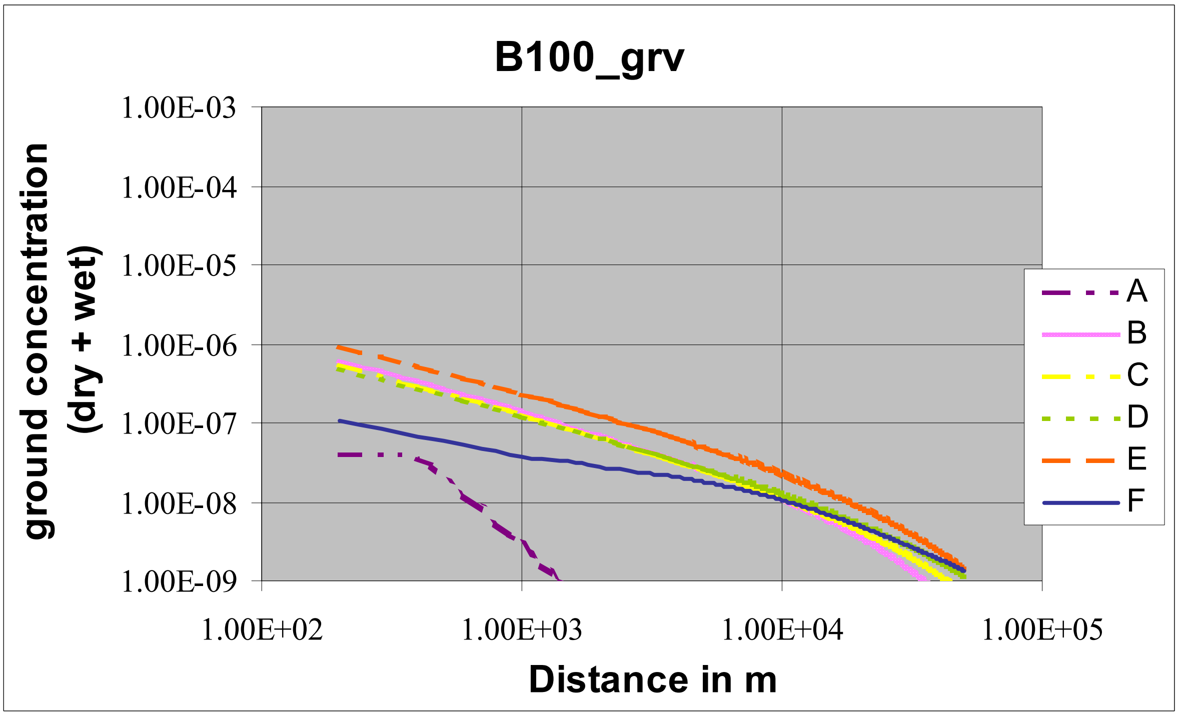

Figure 6 Distance dependent normalised ground concentration for P-G scheme, German like variable speed, 100 m stack with building wake

6.2.2 Pasquill-Gifford scheme with stack release of 100 m, without building wake

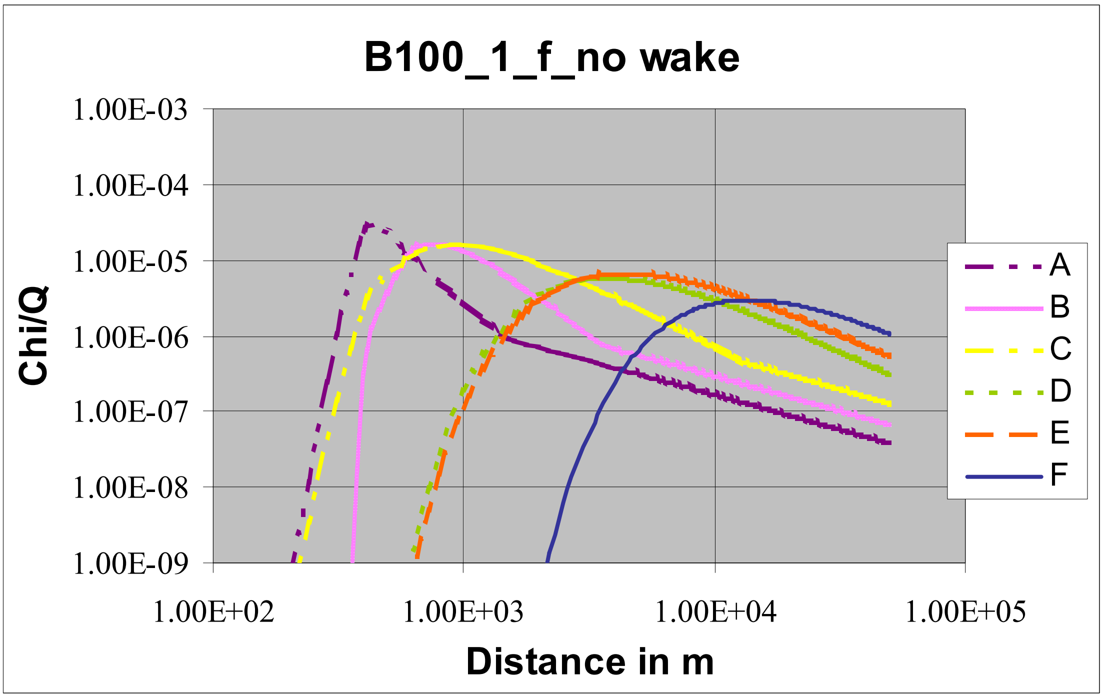

Figure 7 Distance dependent normalised air concentration for P-G scheme, fixed wind speed (1 m/s), 100 m stack without building wake

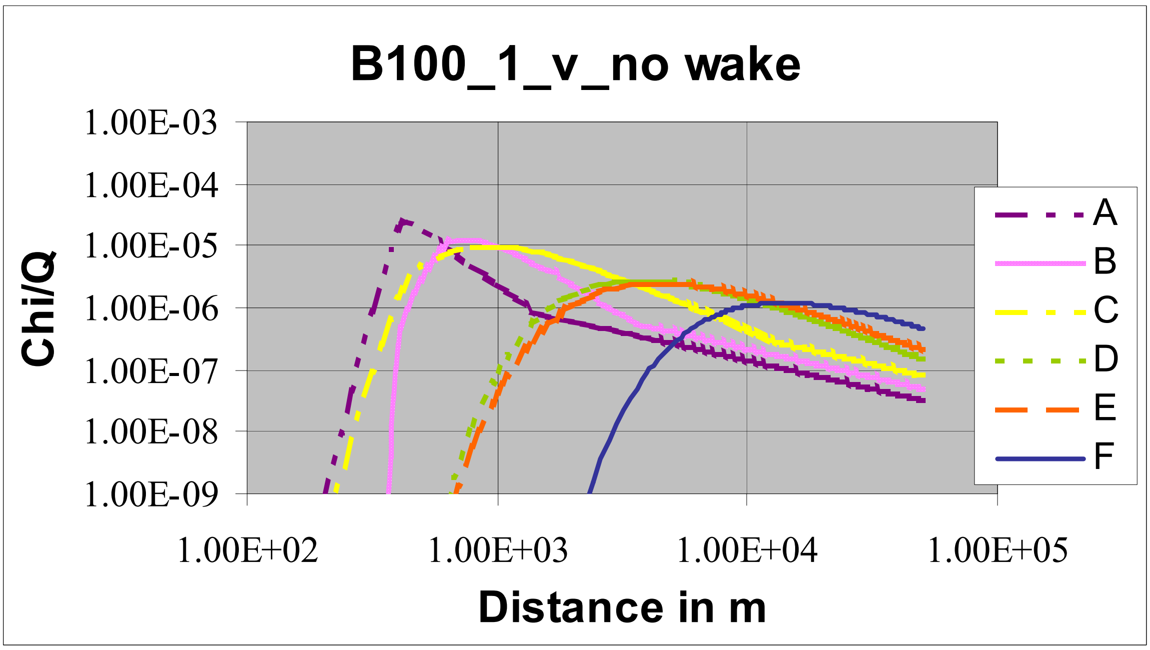

Figure 8 Distance dependent normalised air concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), 100 m stack without building wake

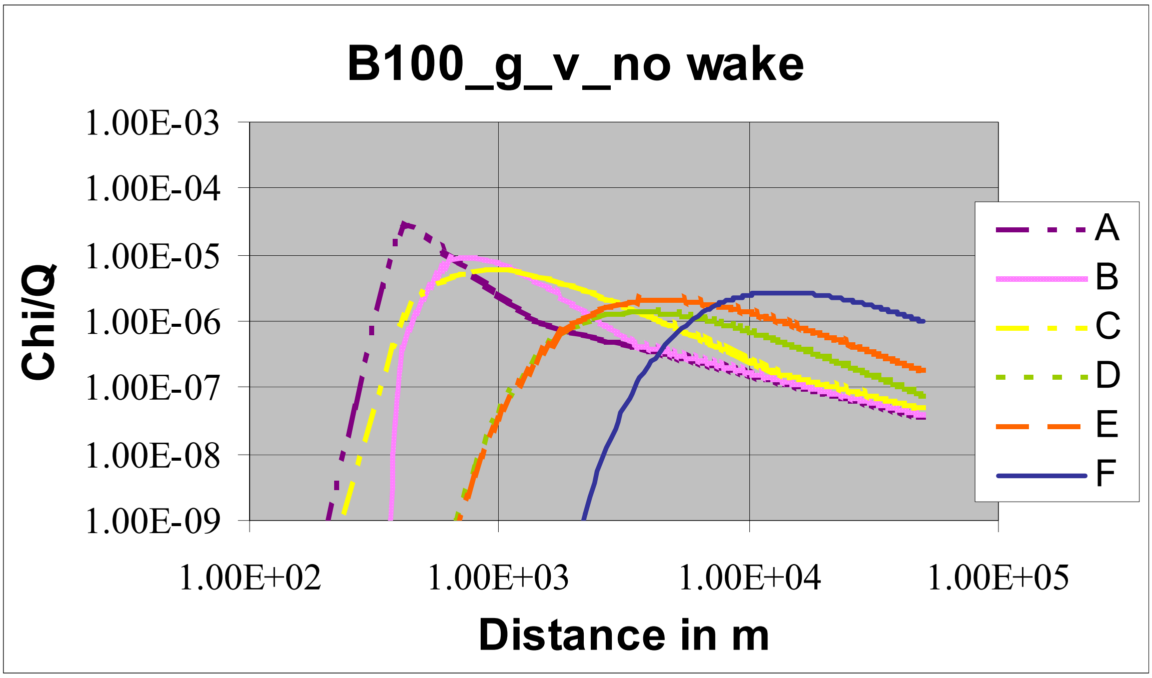

Figure 9 Distance dependent normalised air concentration for P-G scheme, German like variable speed, 100 m stack without building wake

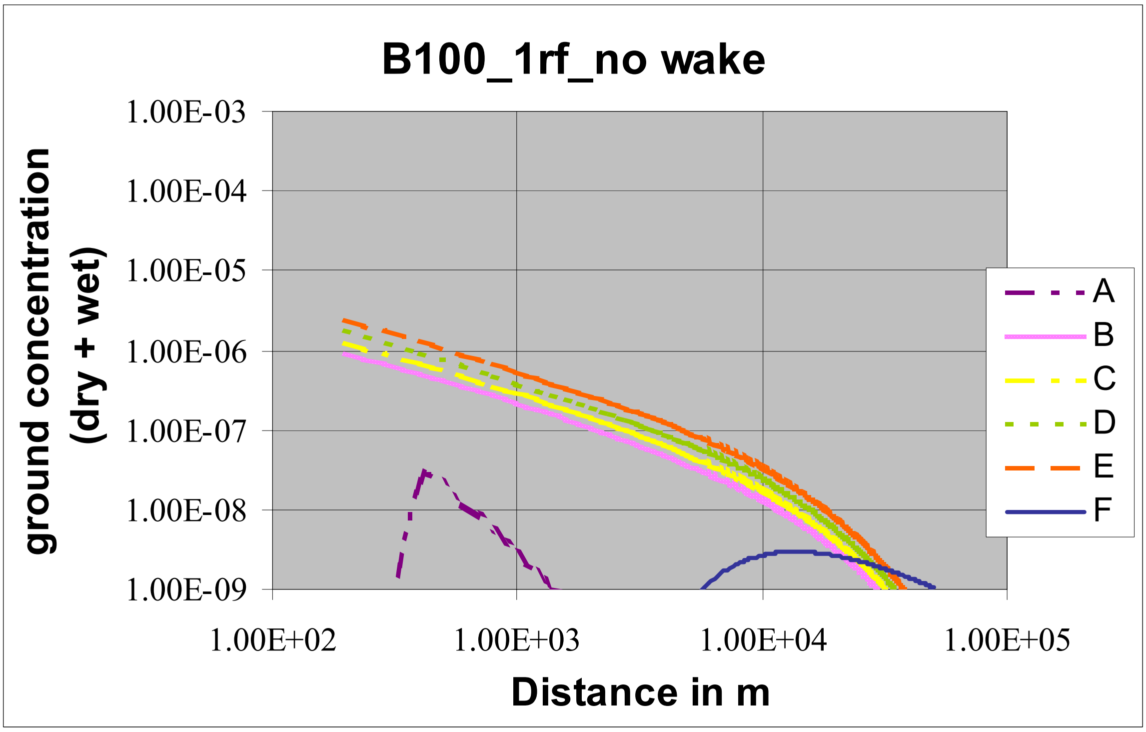

Figure 10 Distance dependent normalised ground concentration for P-G scheme, fixed wind speed (1 m/s), 100 m stack without building wake

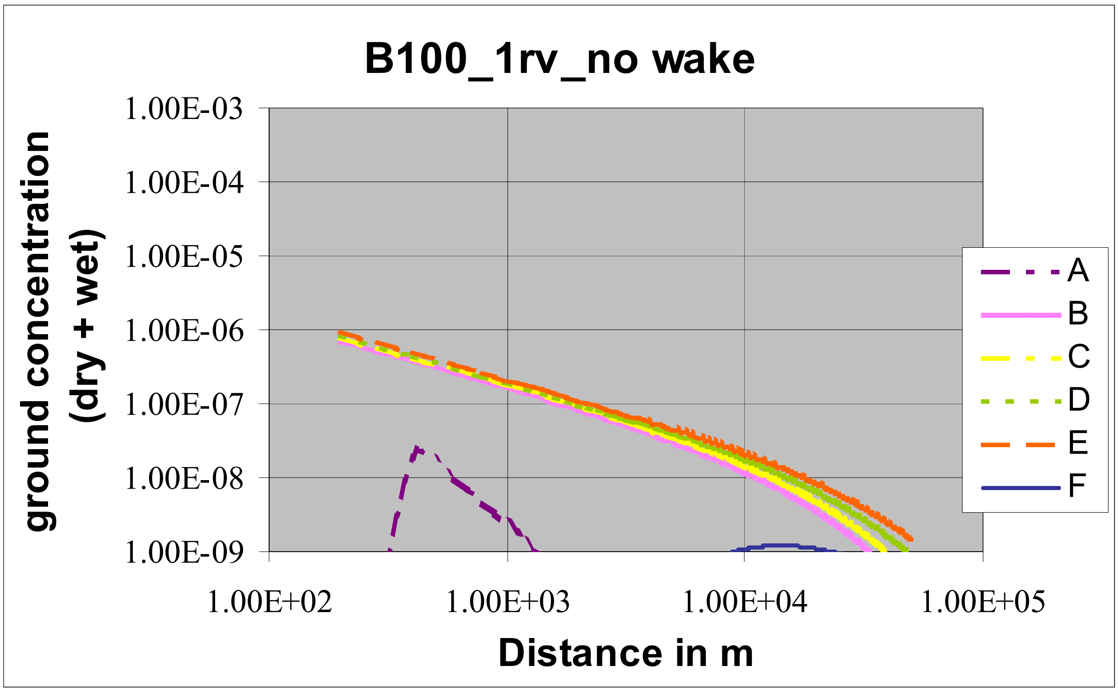

Figure 11 Distance dependent normalised ground concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), 100 m stack without building wake

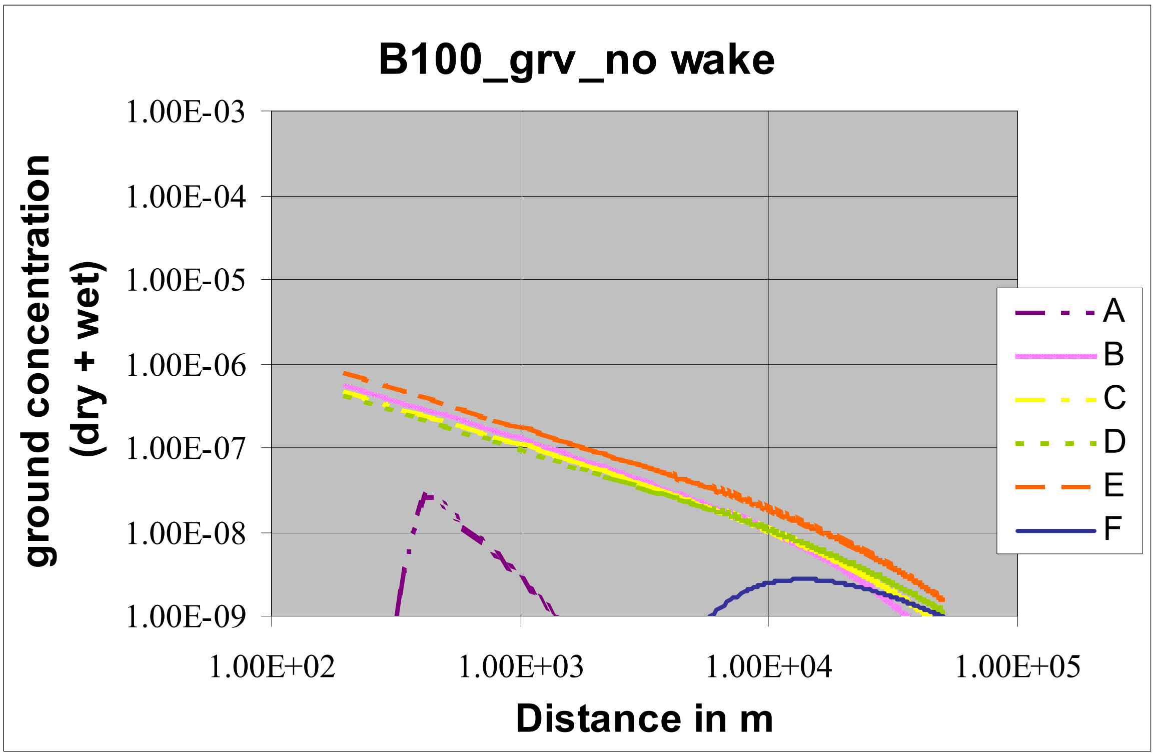

Figure 12 Distance dependent normalised ground concentration for P-G scheme, German like variable speed, 100 m stack without building wake

6.2.3 Pasquill-Giffort scheme with stack release of 150 m, without building wake

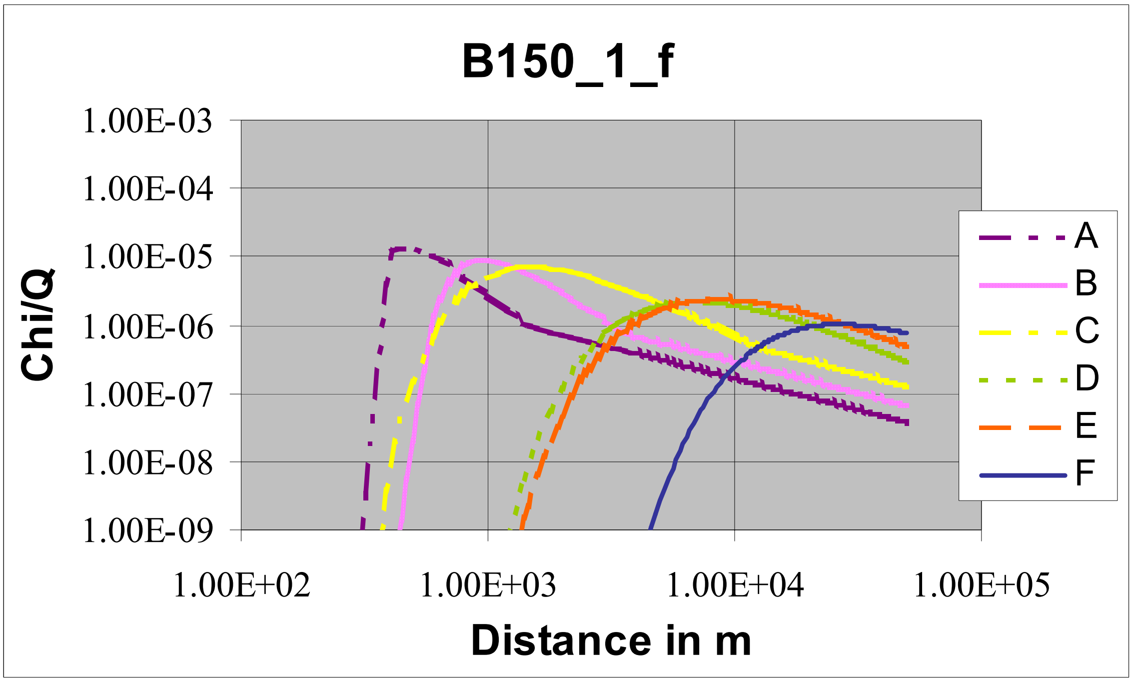

Figure 13 Distance dependent normalised air concentration for P-G scheme, fixed wind speed (1 m/s), 150 m stack without building wake

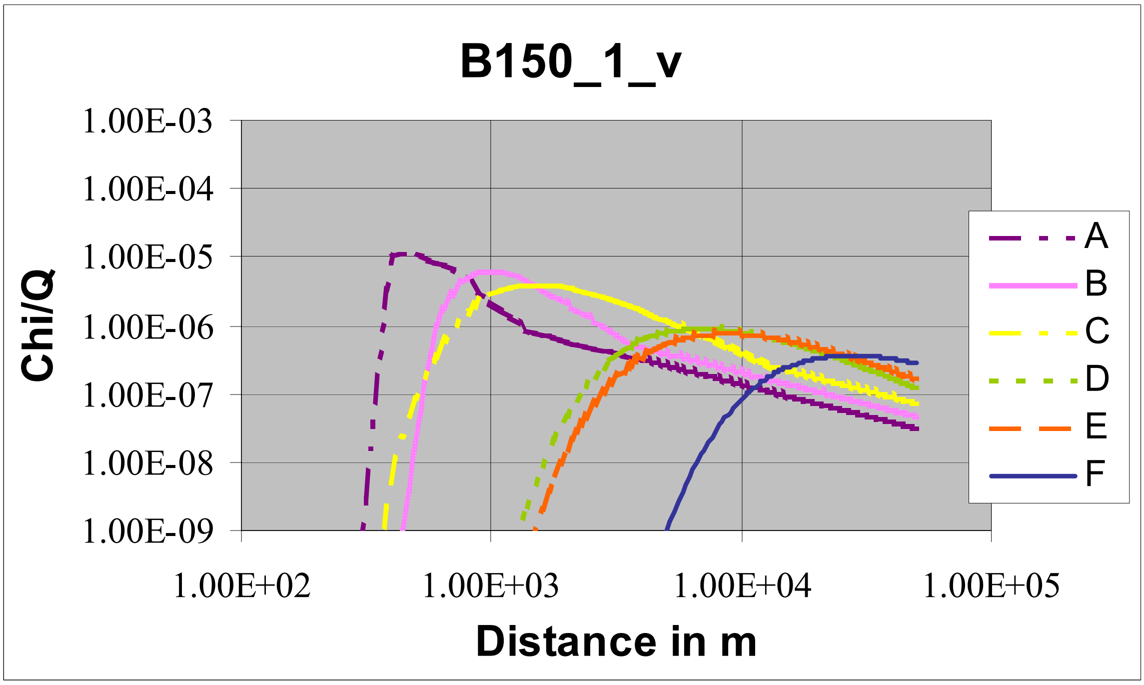

Figure 14 Distance dependent normalised air concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), 150 m stack without building wake

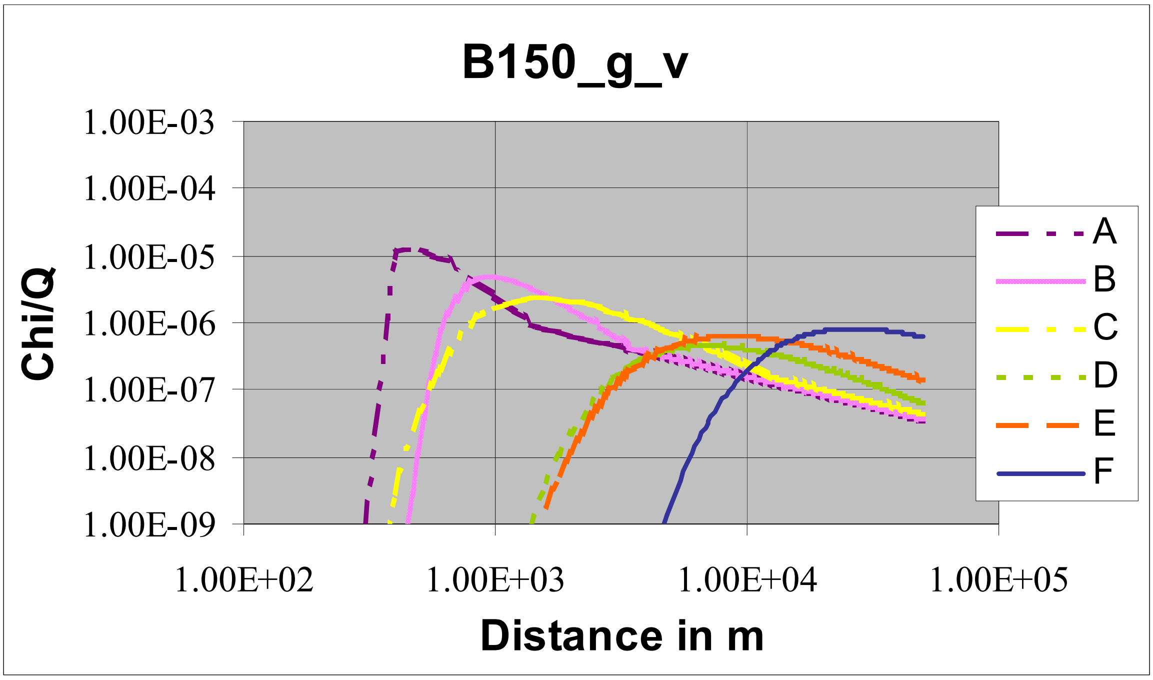

Figure 15 Distance dependent normalised air concentration for P-G scheme, German like variable speed, 150 m stack without building wake

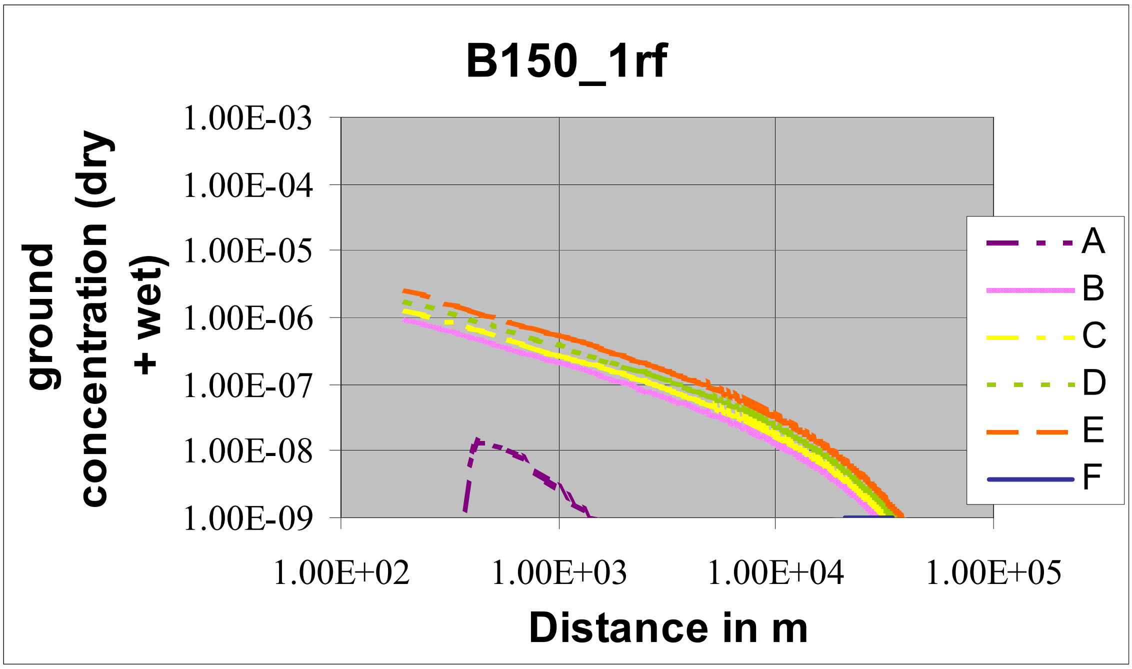

Figure 16 Distance dependent normalised ground concentration for P-G scheme, fixed wind speed (1 m/s), 150 m stack without building wake

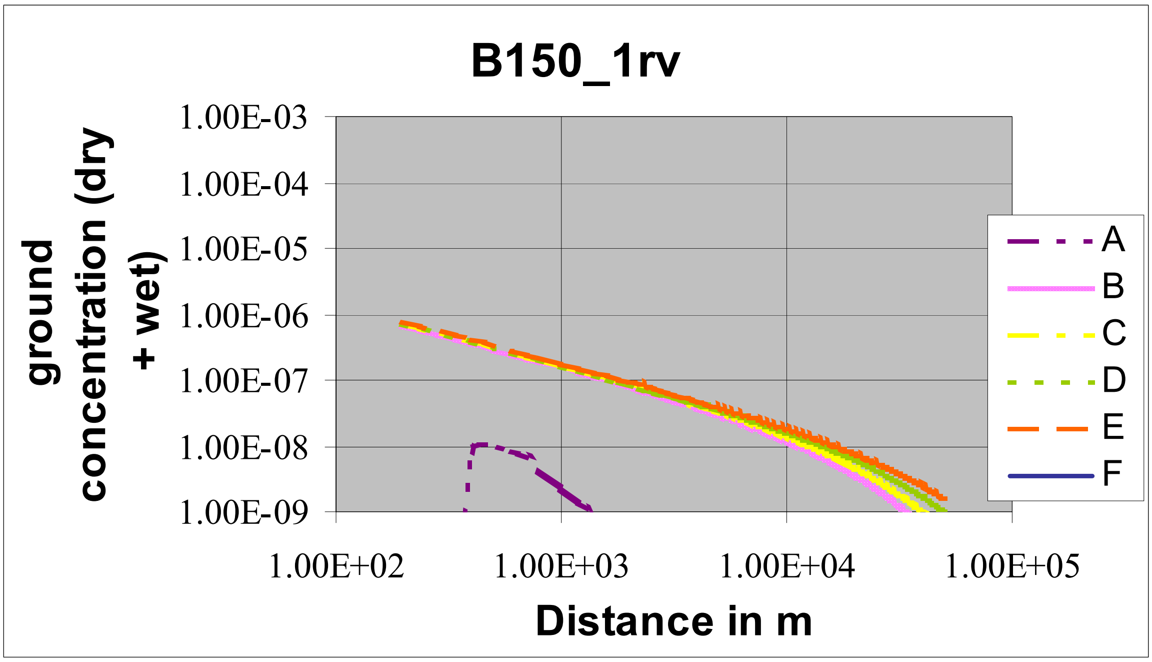

Figure 17 Distance dependent normalised ground concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), 150 m stack without building wake

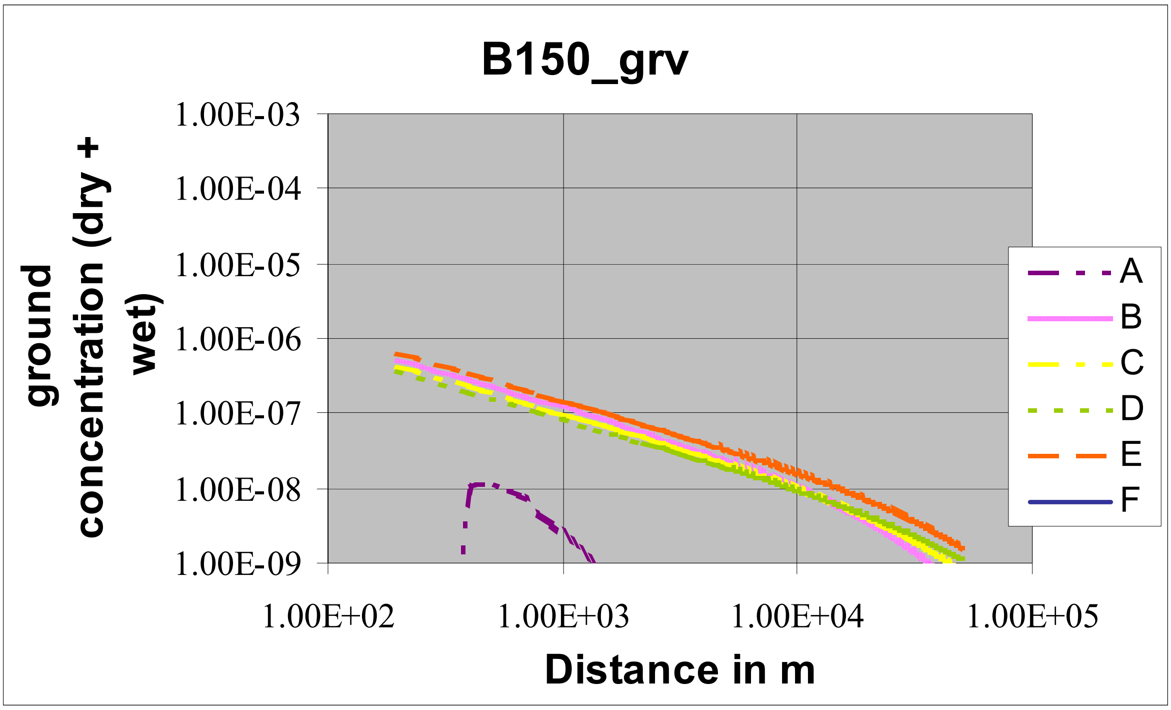

Figure 18 Distance dependent normalised ground concentration for P-G scheme, German like variable speed, 150 m stack without building wake

6.2.4 Pasquill-Giffort scheme with jet release, with building wake

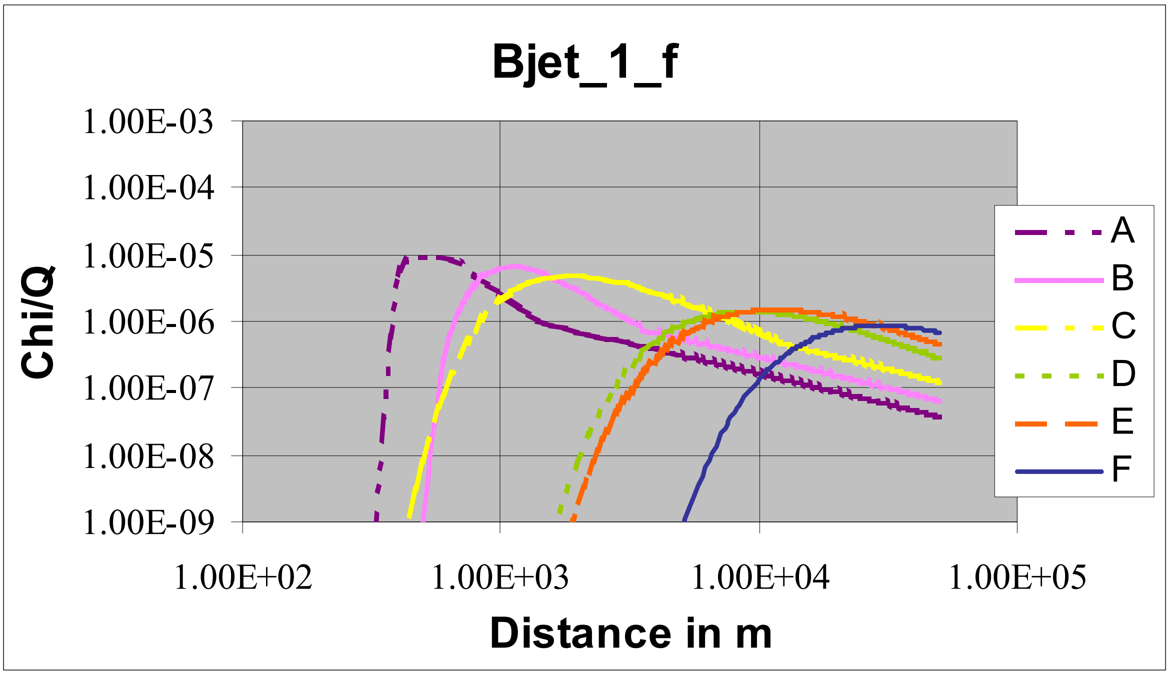

Figure 19 Distance dependent normalised air concentration for P-G scheme, fixed wind speed (1 m/s), jet release with building wake

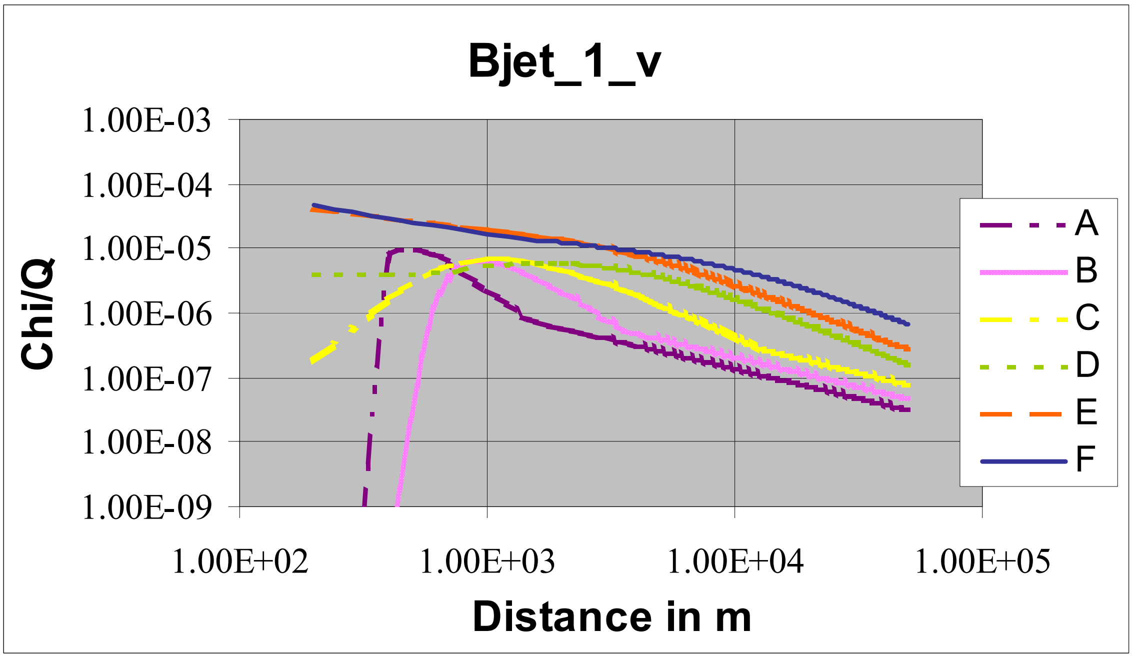

Figure 20 Distance dependent normalised air concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), jet release with building wake

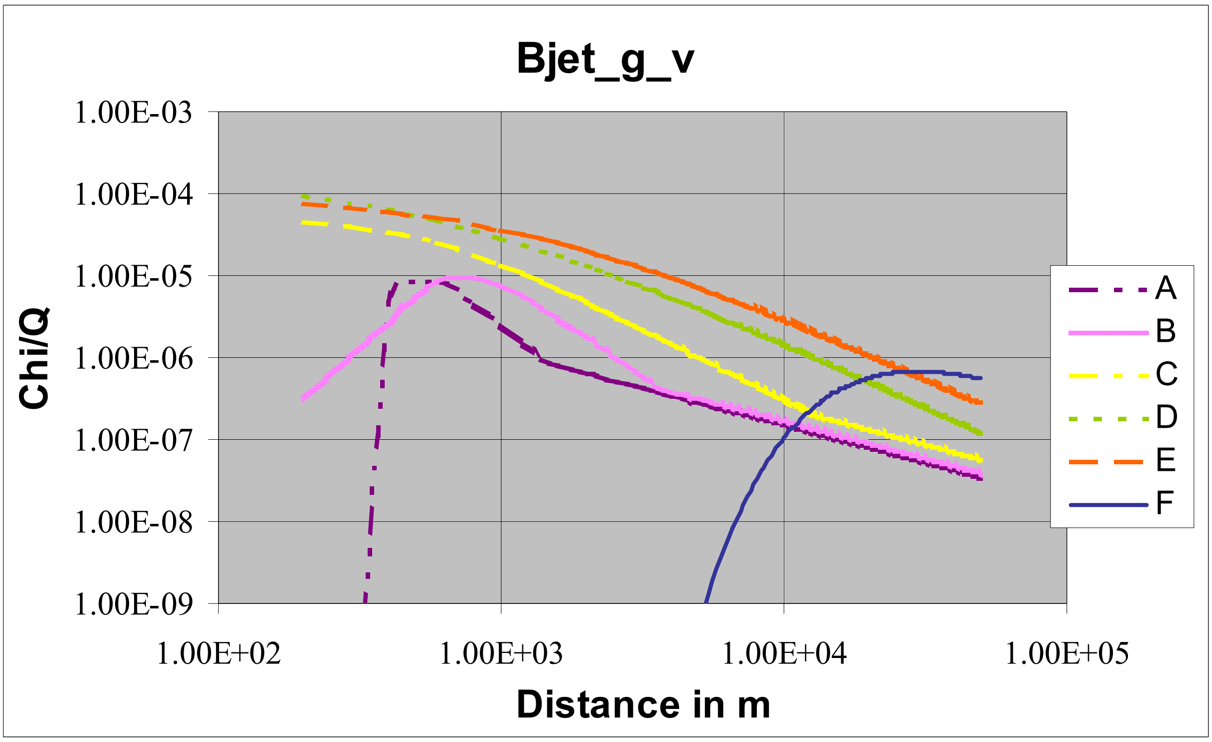

Figure 21 **Distance dependent normalised air concentration for P-G scheme, German like variable speed, jet release with building wake**

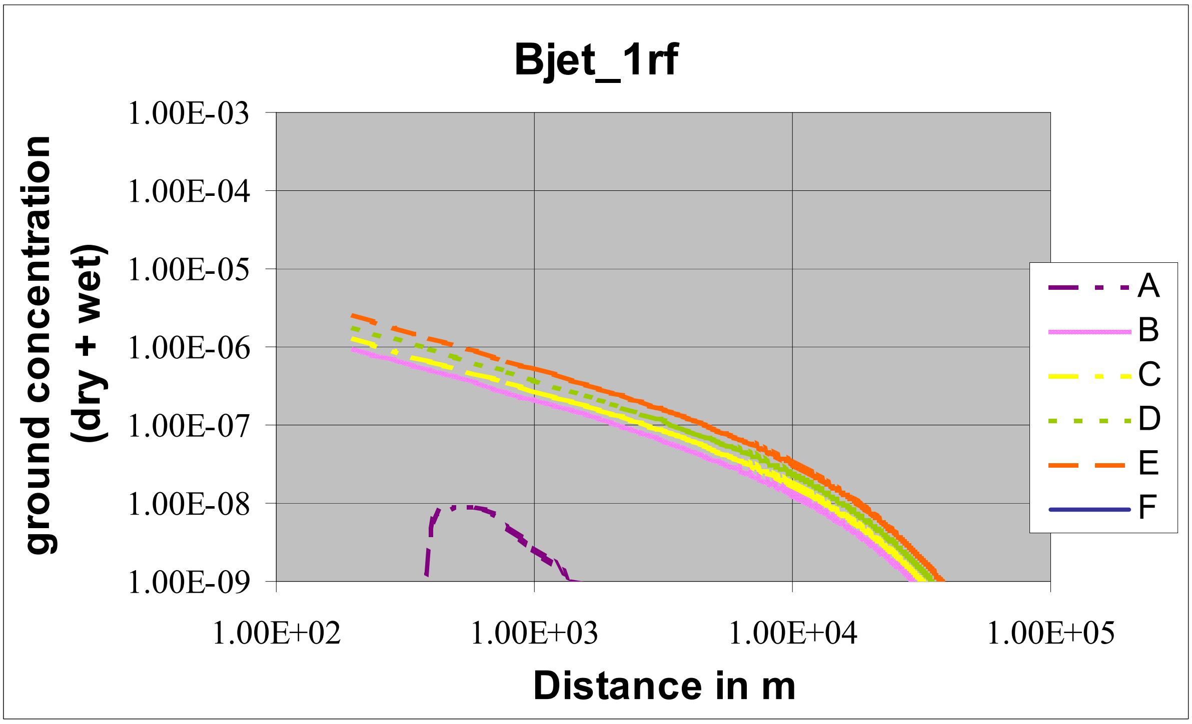

Figure 22 **Distance dependent normalised ground concentration for P-G scheme, fixed wind speed (1 m/s), jet release with building wake**

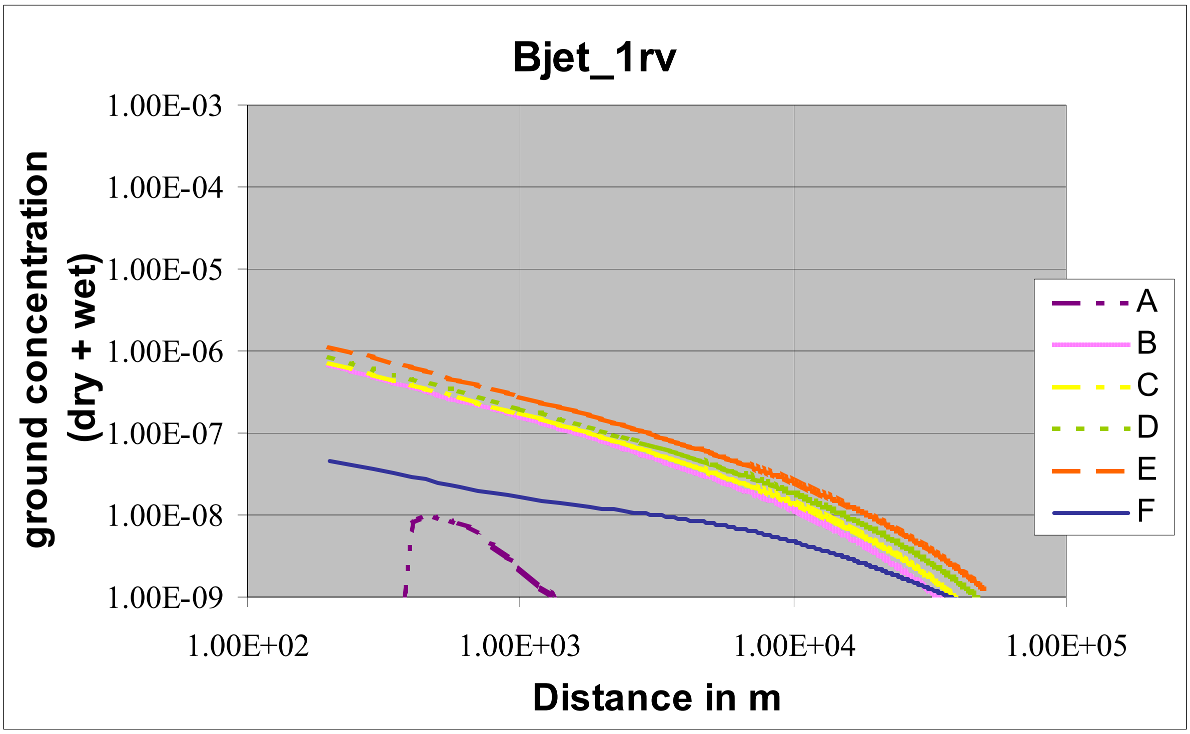

Figure 23 **Distance dependent normalised ground concentration for P-G scheme, variable wind speed (1 m/s at 10 m height), jet release with building wake**

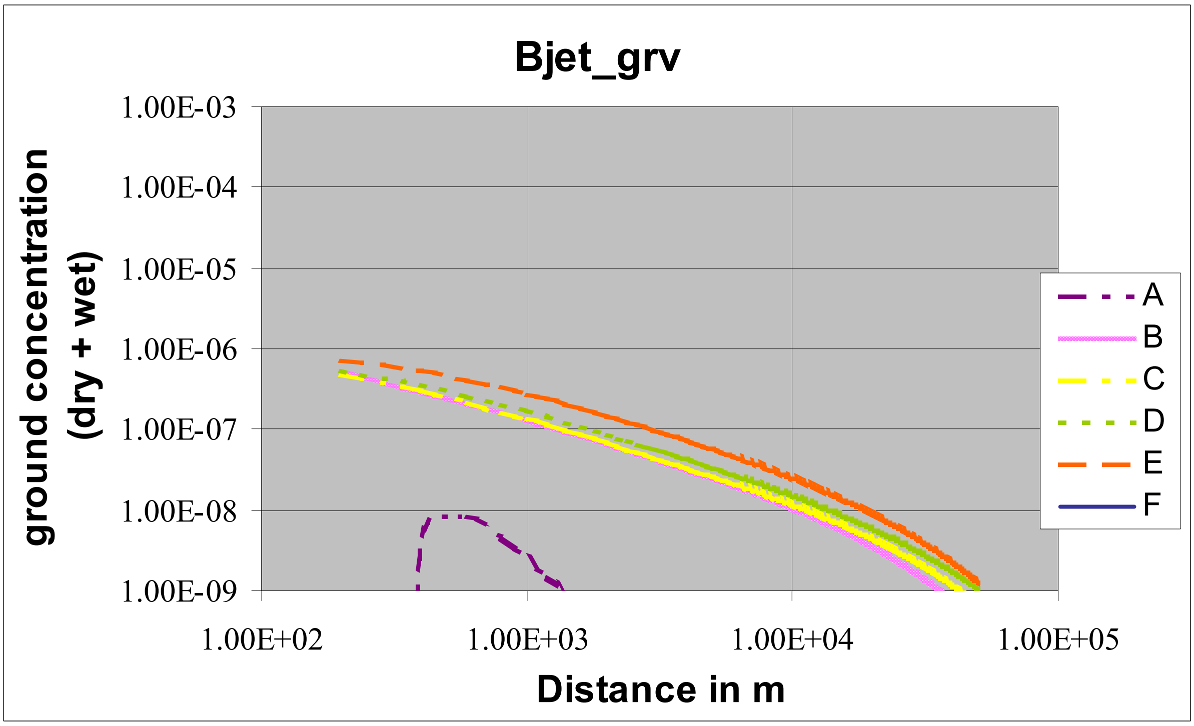

Figure 24 **Distance dependent normalised ground concentration for P-G scheme, German like variable speed, jet release with building wake**

6.2.5 MOL scheme with stack release of 100 m, with building wake

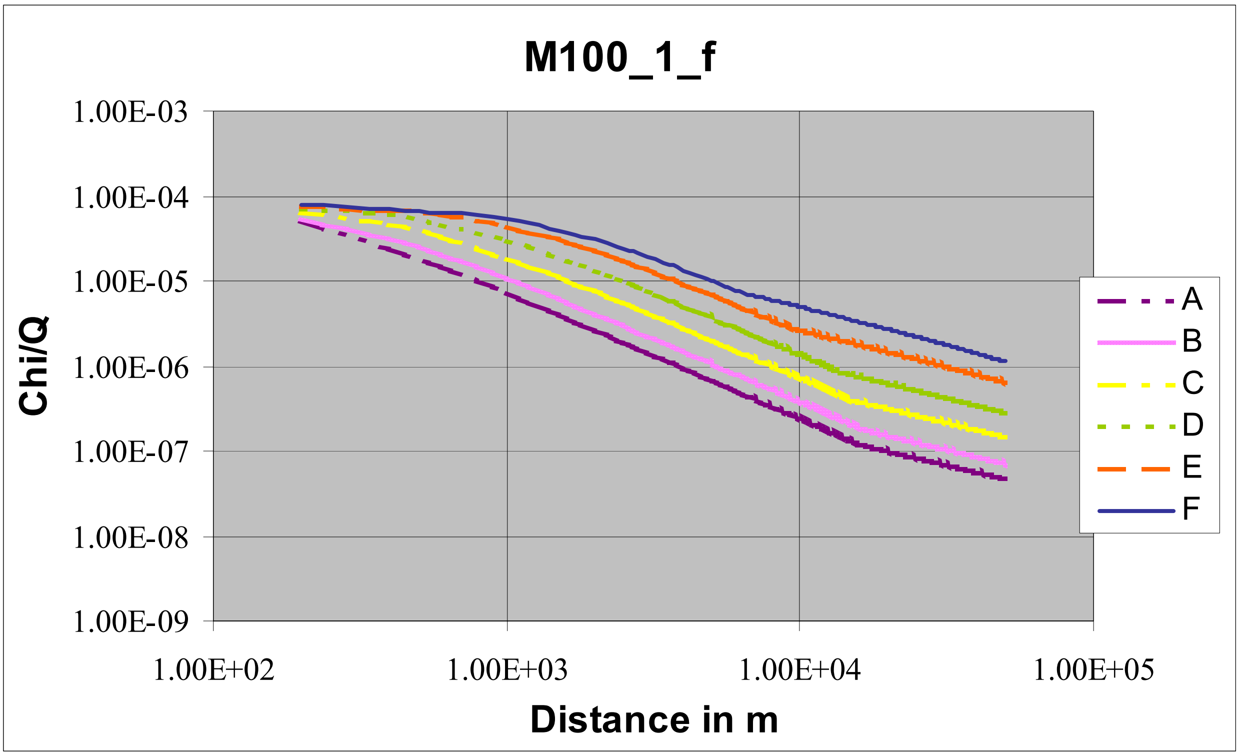

Figure 25 Distance dependent normalised air concentration for MOL scheme, fixed wind speed (1 m/s), 100 m stack with building wake

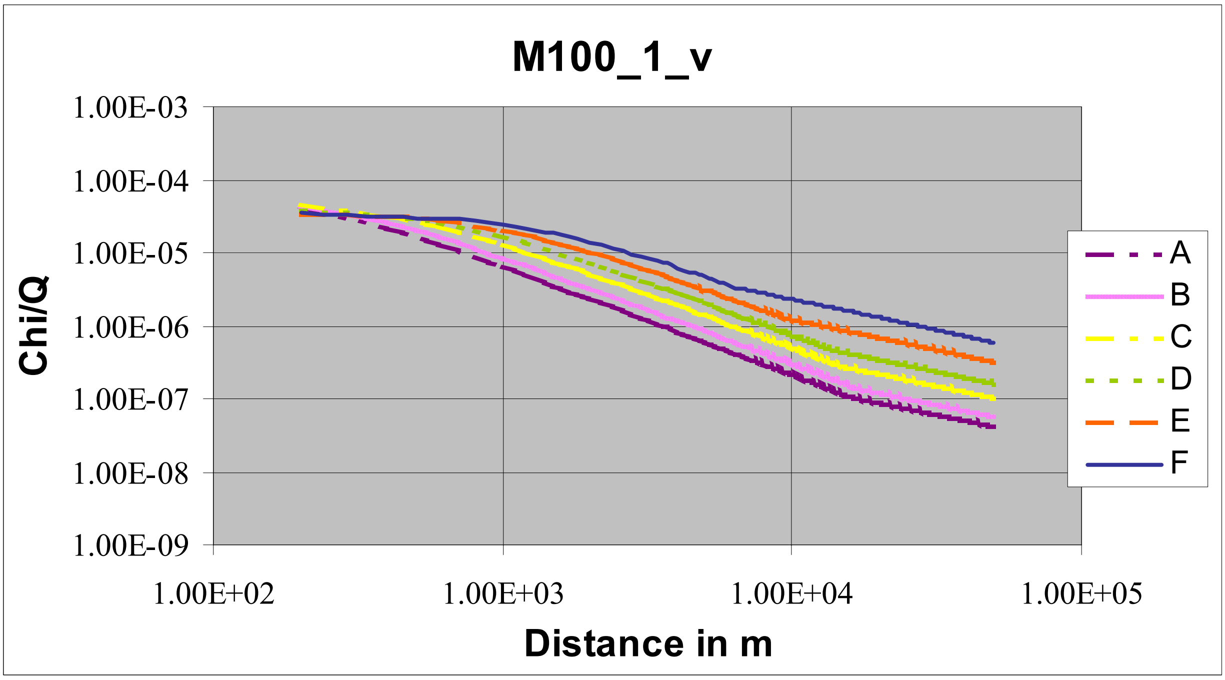

Figure 26 Distance dependent normalised air concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), 100 m stack with building wake

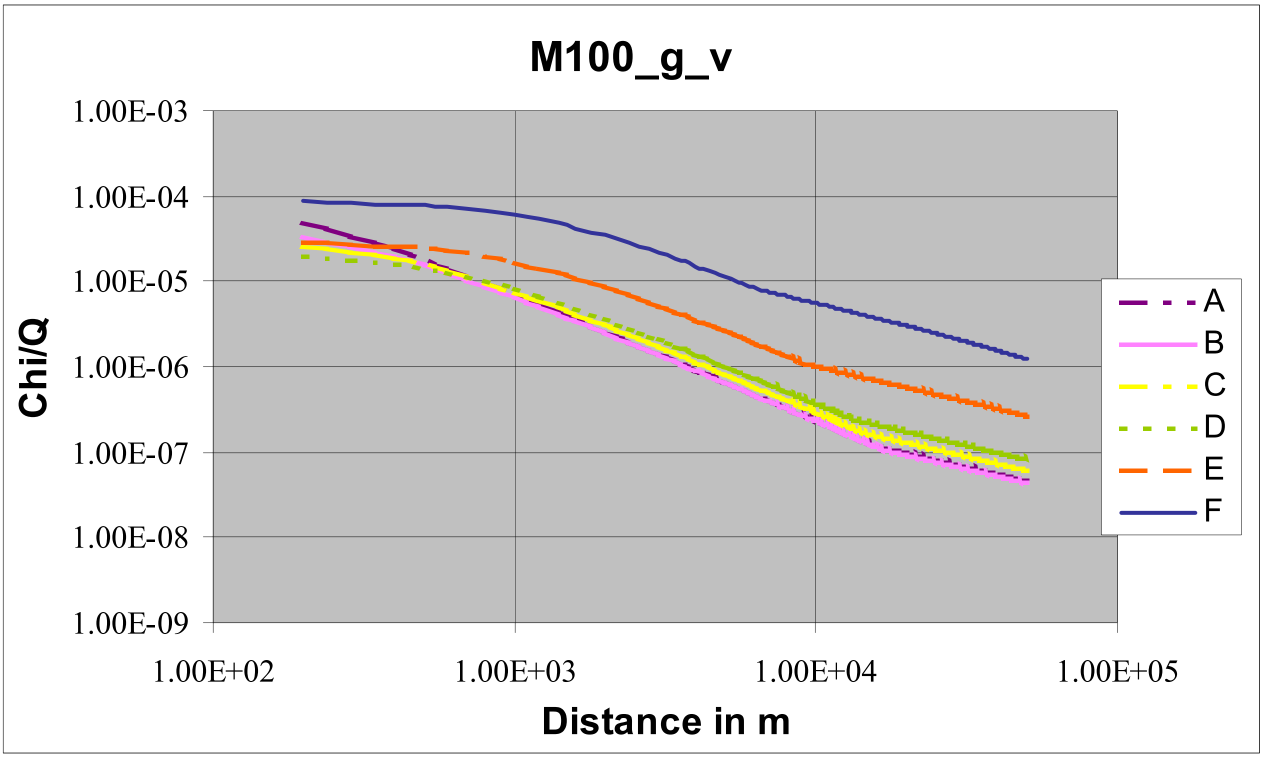

Figure 27 **Distance dependent normalised air concentration for MOL scheme, German like variable speed, 100 m stack with building wake**

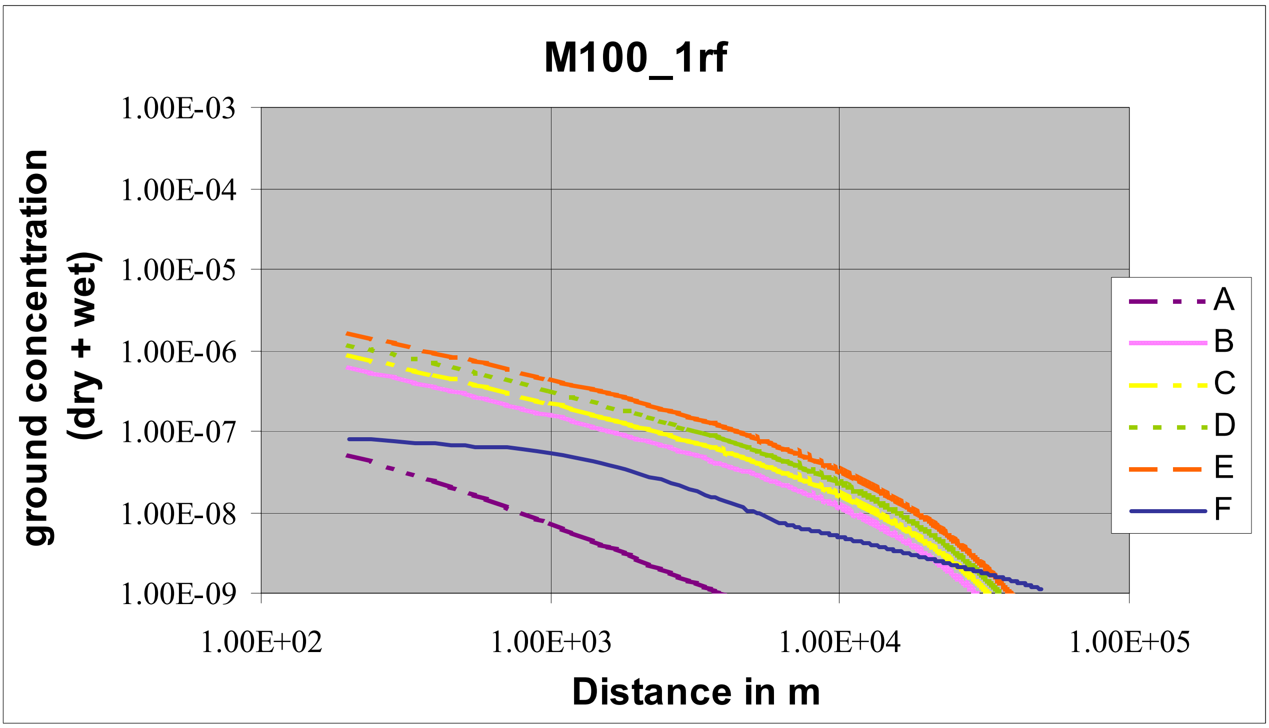

Figure 28 **Distance dependent normalised ground concentration for MOL scheme, fixed wind speed (1 m/s), 100 m stack with building wake**

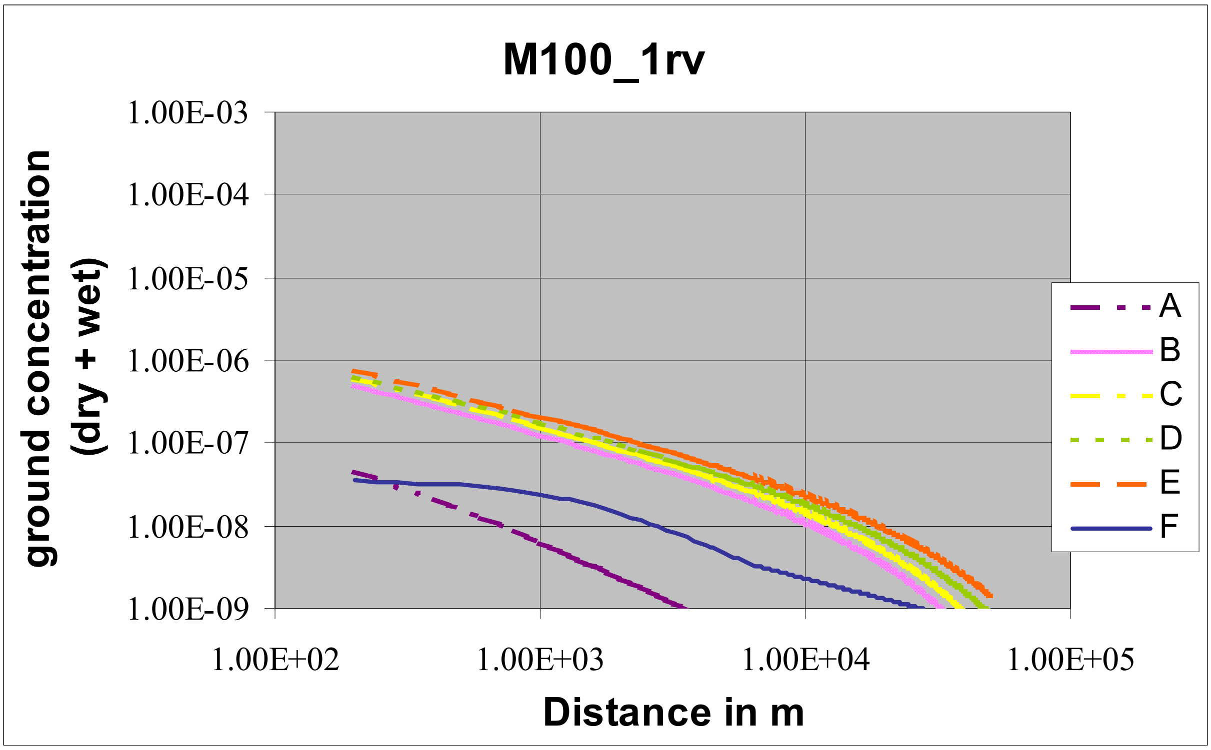

Figure 29 Distance dependent normalised ground concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), 100 m stack with building wake

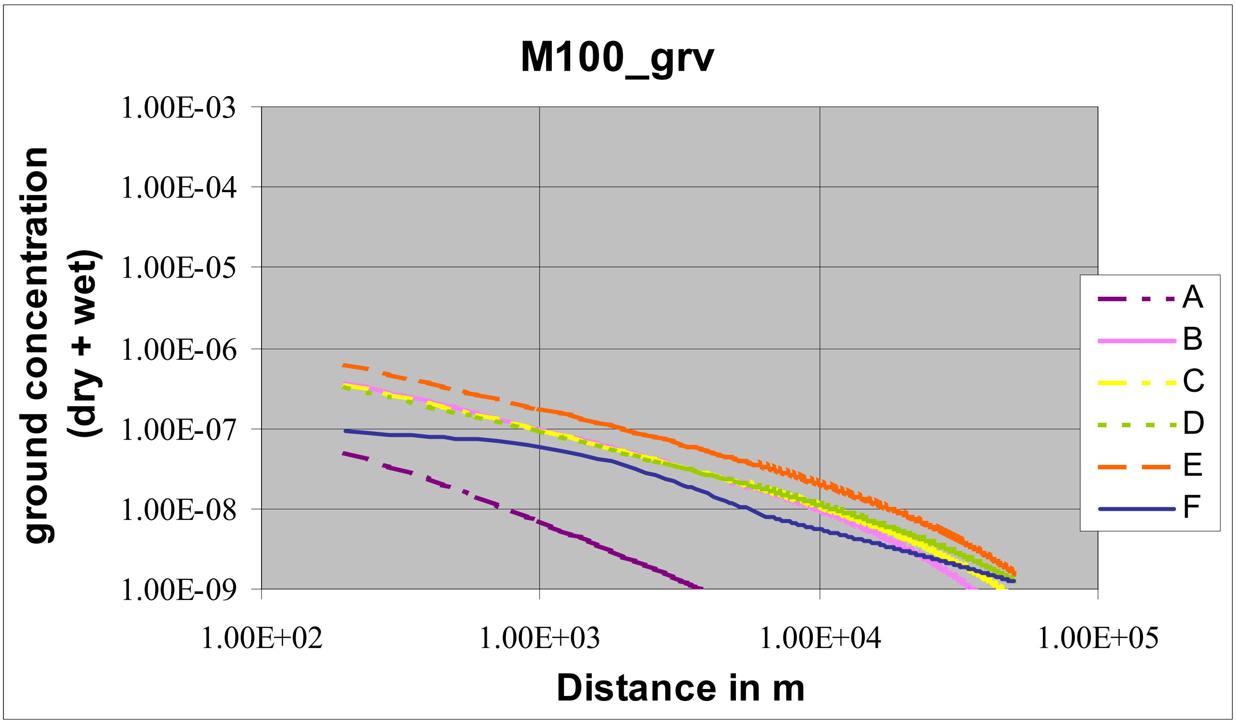

Figure 30 Distance dependent normalised ground concentration for MOL scheme, German like variable speed, 100 m stack with building wake

6.2.6 MOL scheme with stack release of 100 m, without building wake

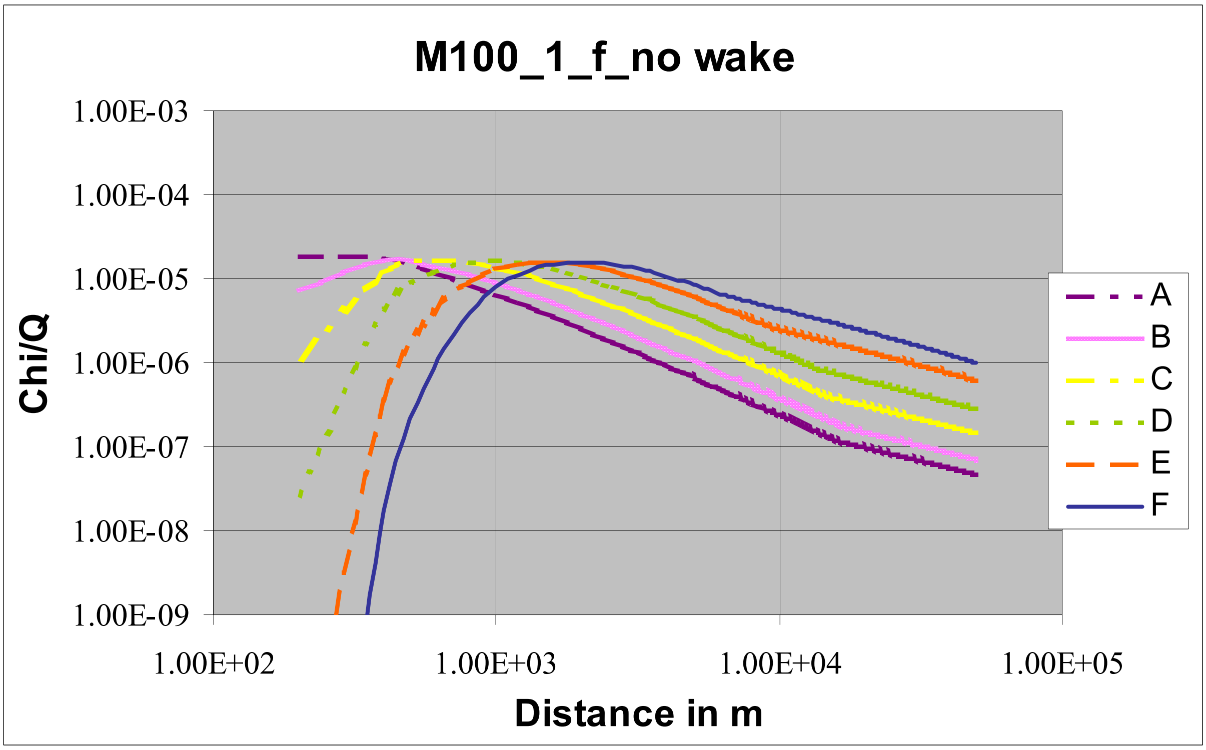

Figure 31 Distance dependent normalised air concentration for MOL scheme, fixed wind speed (1 m/s), 100 m stack without building wake

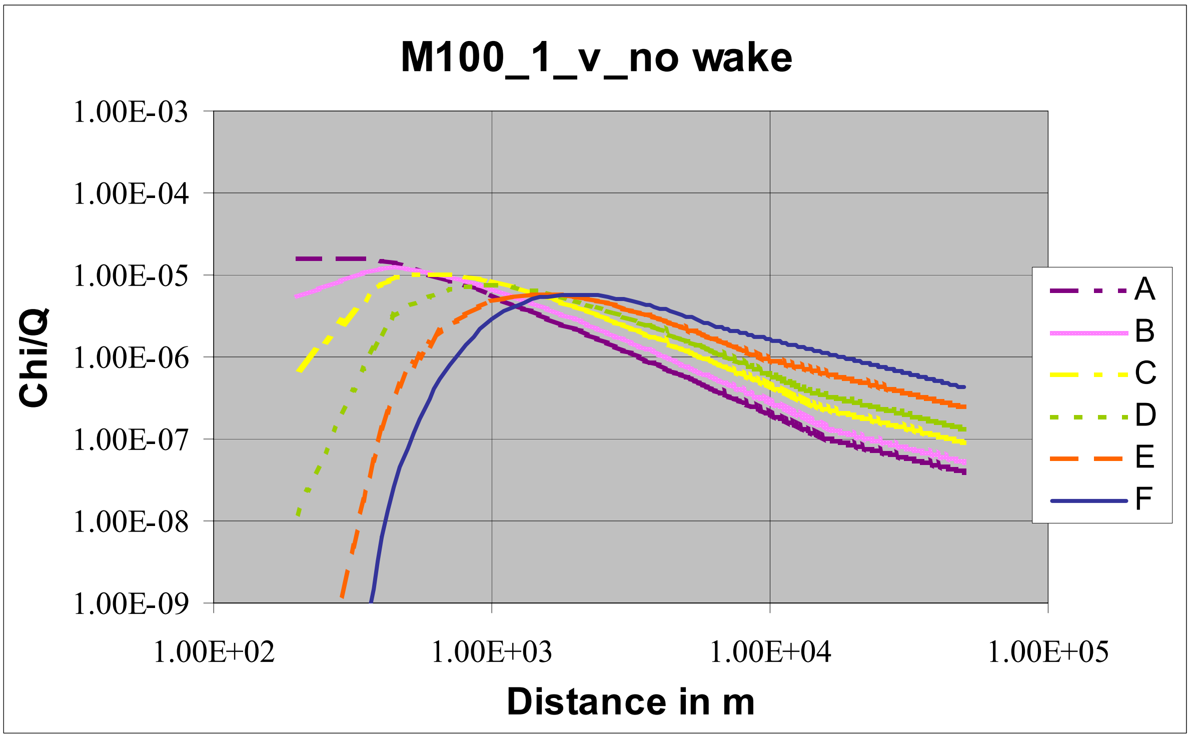

Figure 32 Distance dependent normalised air concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), 100 m stack without building wake

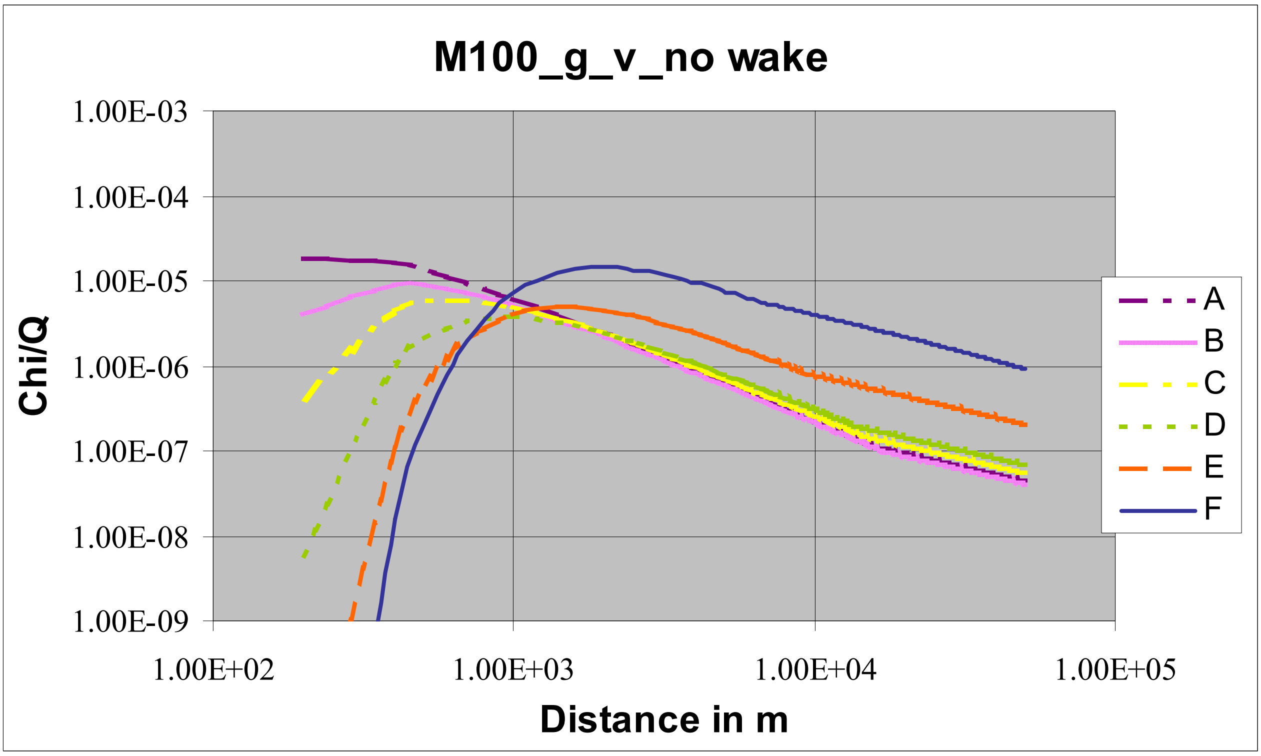

Figure 33 Distance dependent normalised air concentration for MOL scheme, German like variable speed, 100 m stack without building wake

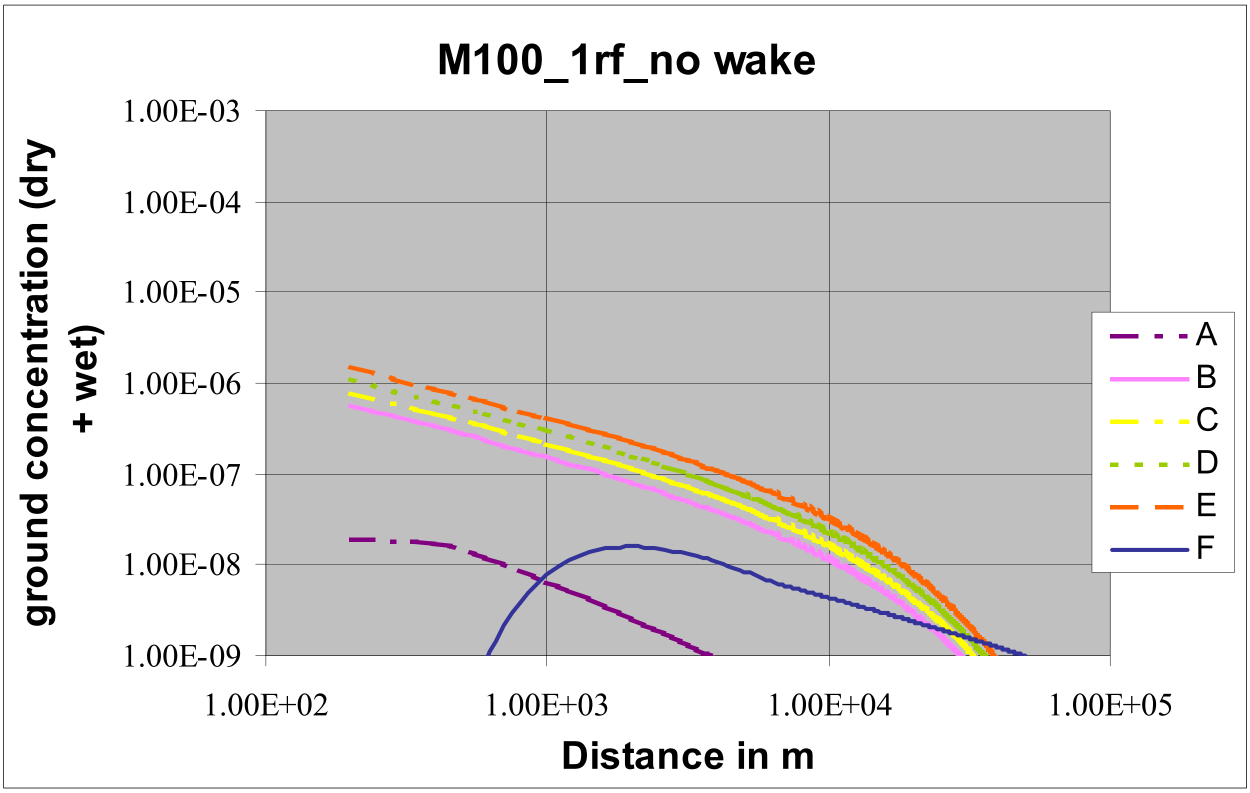

Figure 34 Distance dependent normalised ground concentration for MOL scheme, fixed wind speed (1 m/s), 100 m stack without building wake

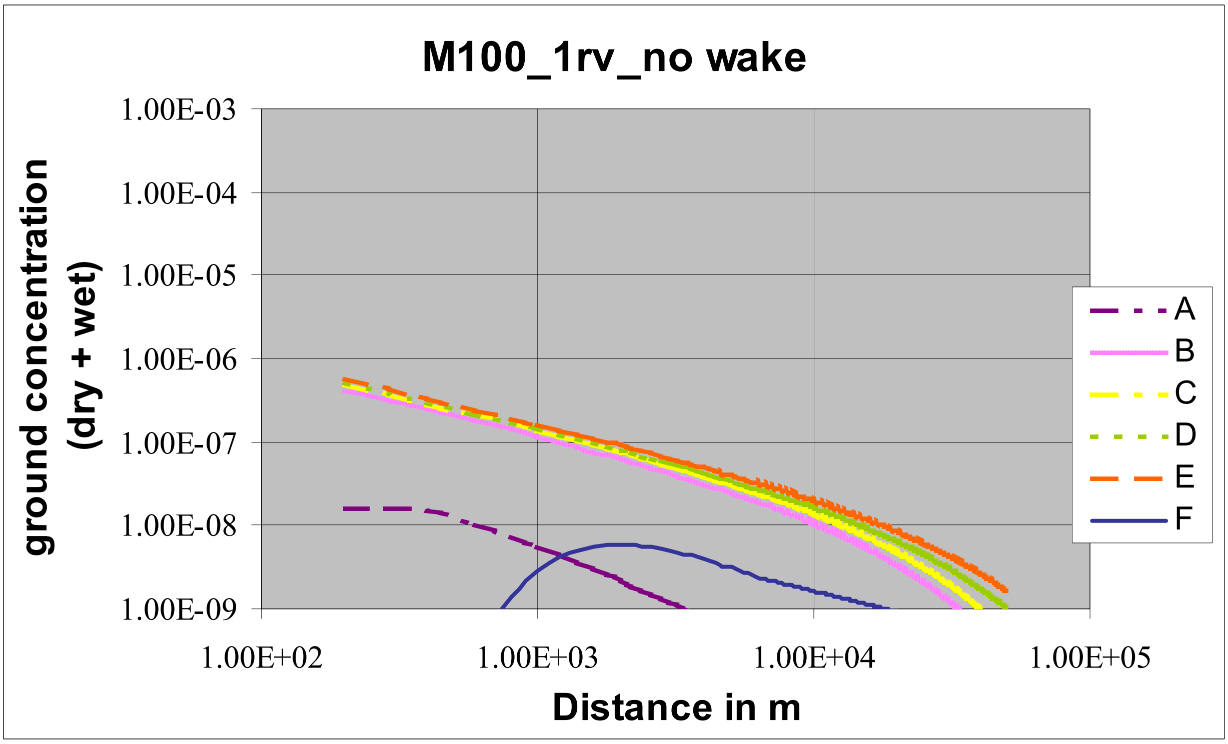

Figure 35 Distance dependent normalised ground concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), 100 m stack without building wake

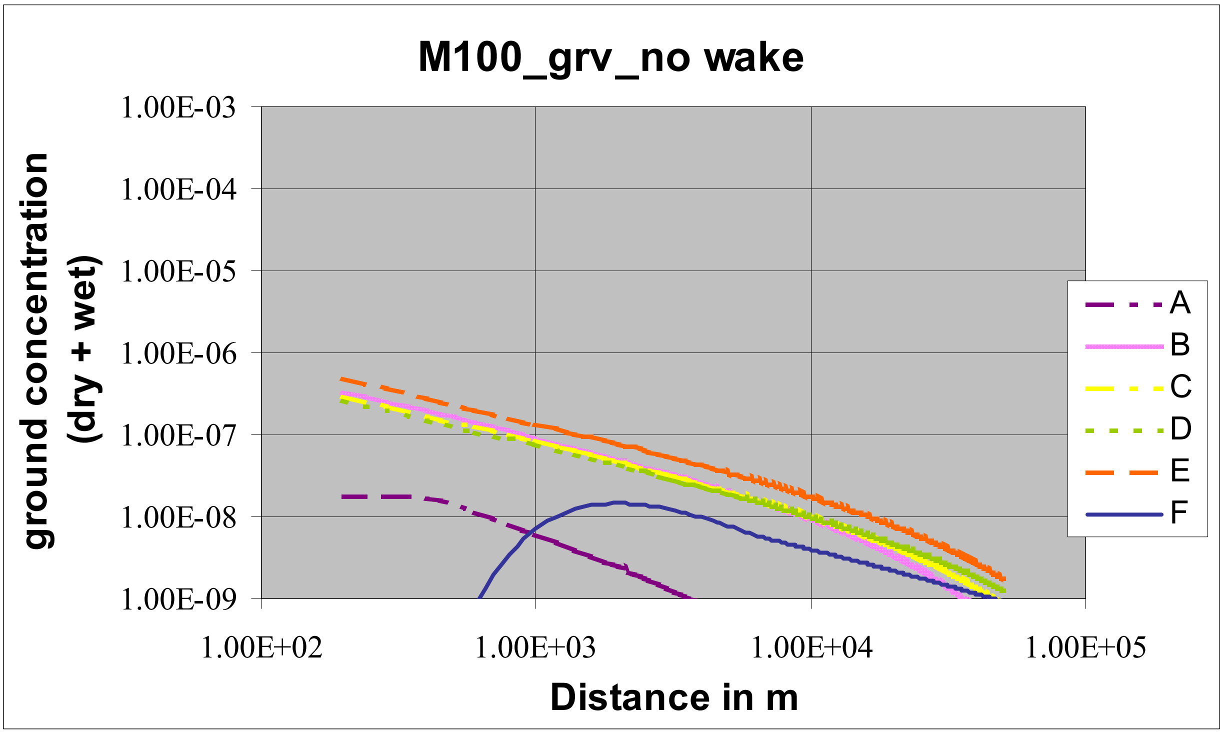

Figure 36 Distance dependent normalised ground concentration for MOL scheme, German like variable speed, 100 m stack without building wake

6.2.7 MOL scheme with stack release of 150 m, without building wake

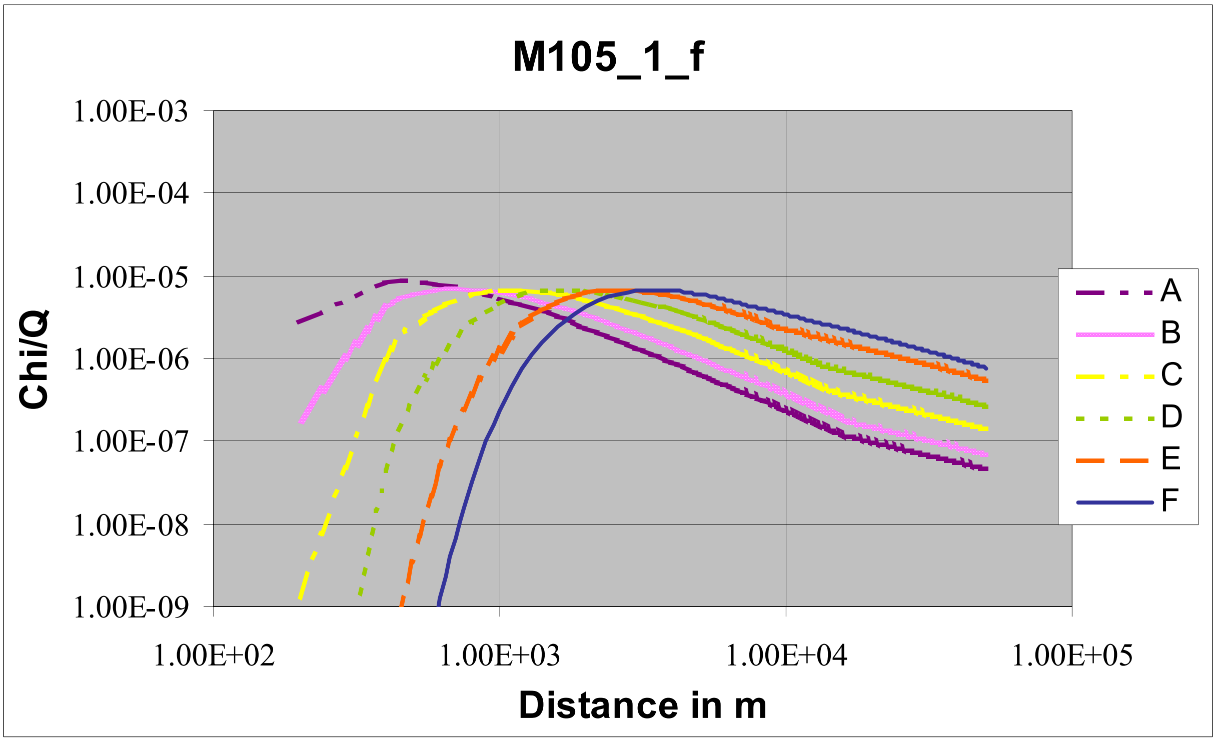

Figure 37 Distance dependent normalised air concentration for MOL scheme, fixed wind speed (1 m/s), 150 m stack without building wake

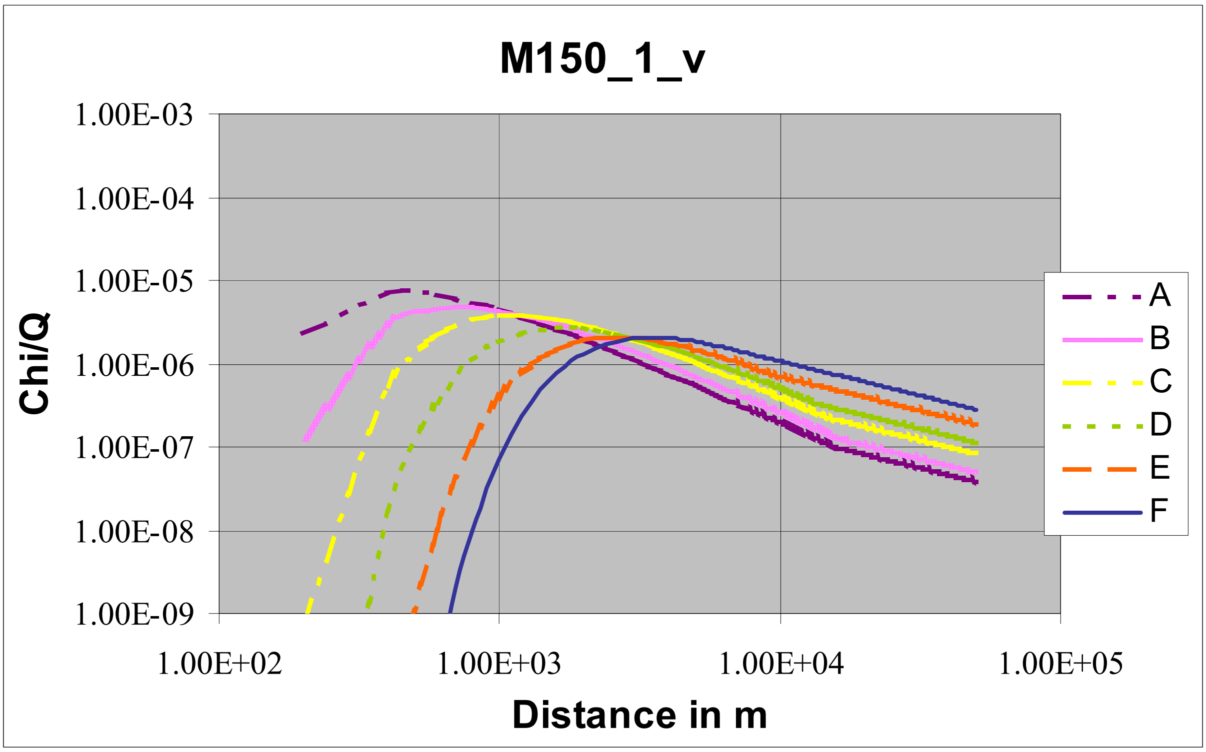

Figure 38 Distance dependent normalised air concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), 150 m stack without building wake

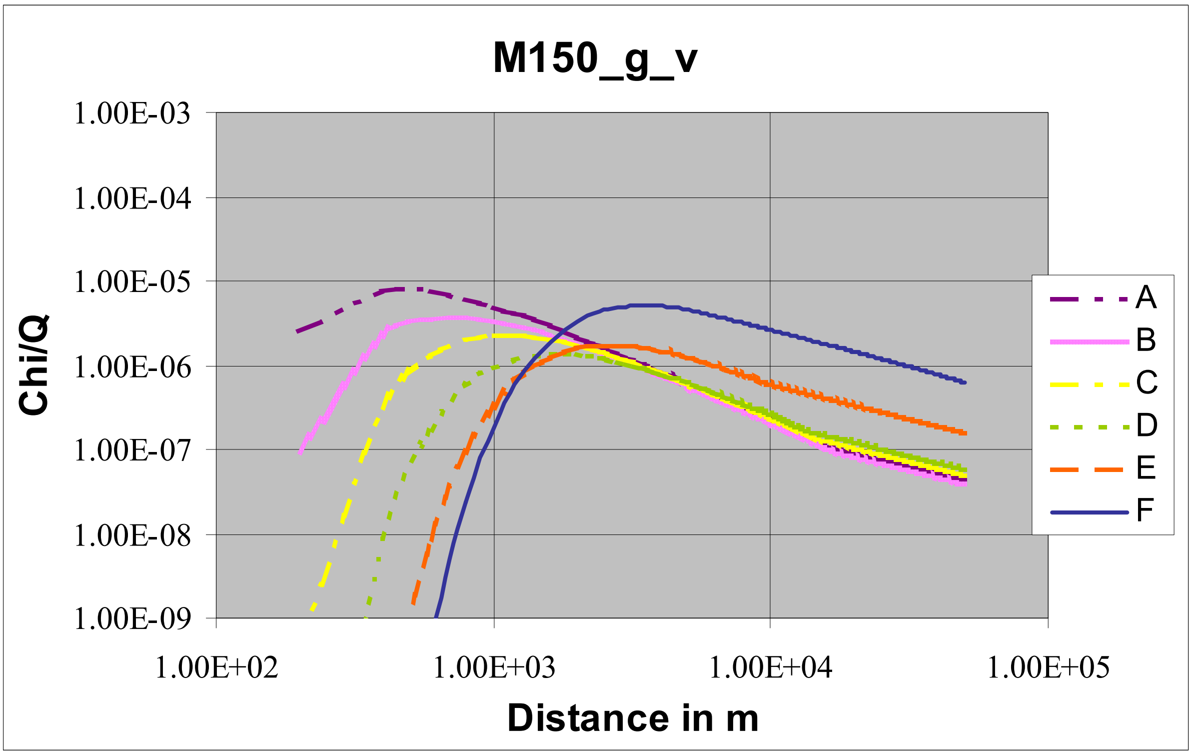

Figure 39 **Distance dependent normalised air concentration for MOL scheme, German like variable speed, 150 m stack without building wake**

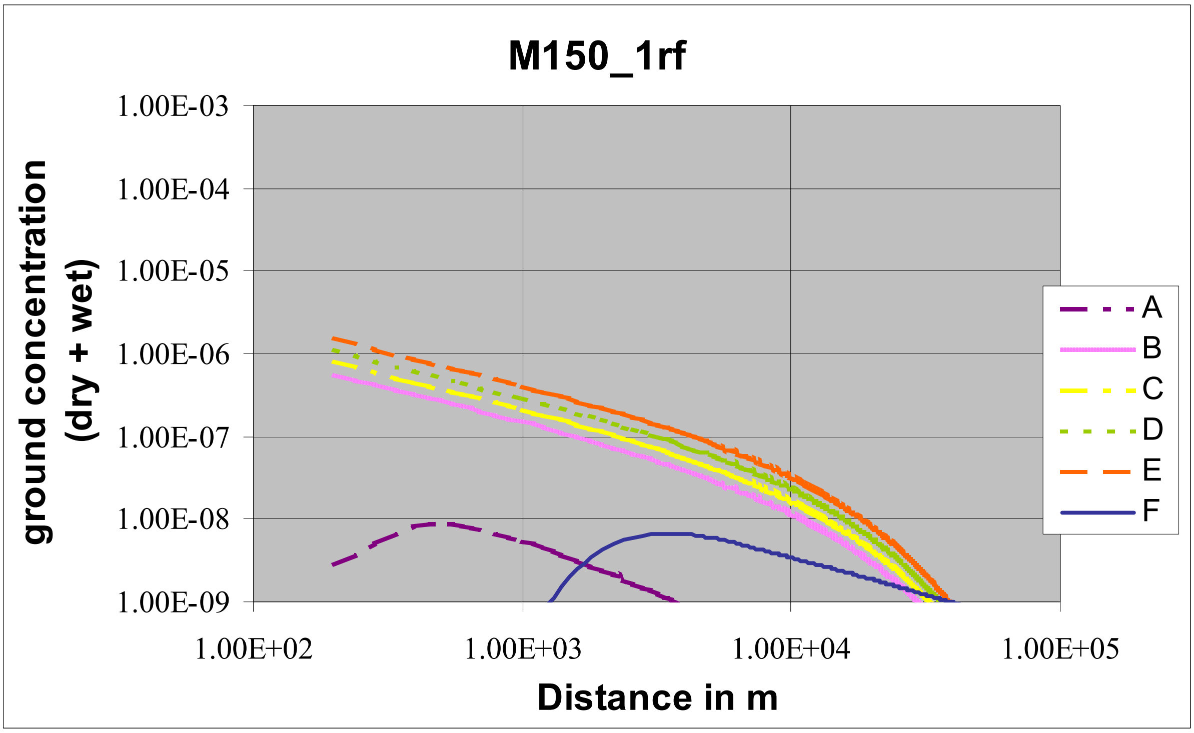

Figure 40 **Distance dependent normalised ground concentration for MOL scheme, fixed wind speed (1 m/s), 150 m stack without building wake**

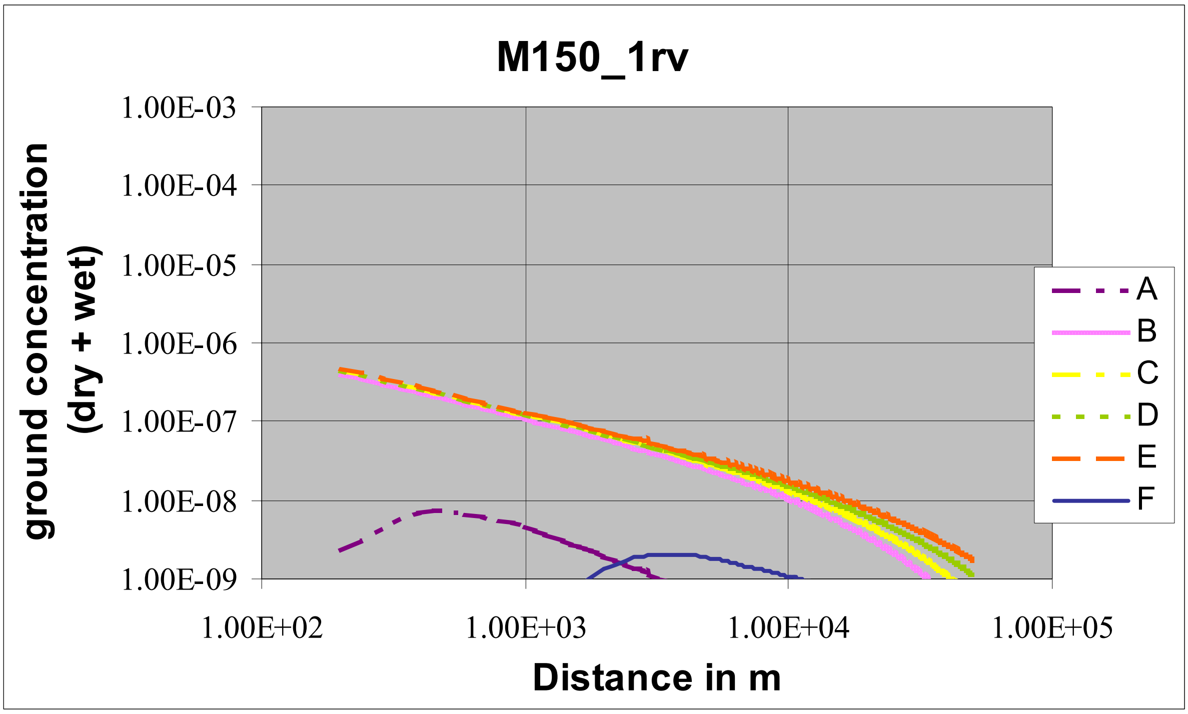

Figure 41 **Distance dependent normalised ground concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), 150 m stack without building wake**

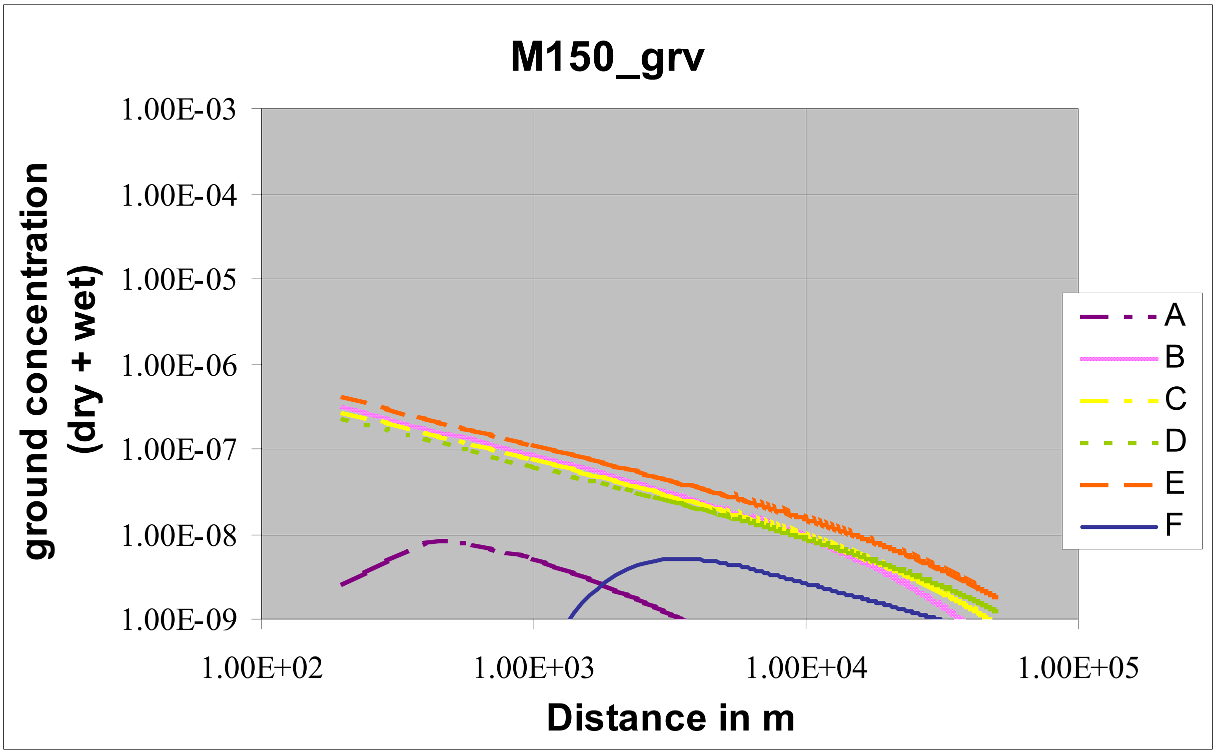

Figure 42 **Distance dependent normalised ground concentration for MOL scheme, German like variable speed, 150 m stack without building wake**

6.2.8 MOL scheme with jet release, with building wake

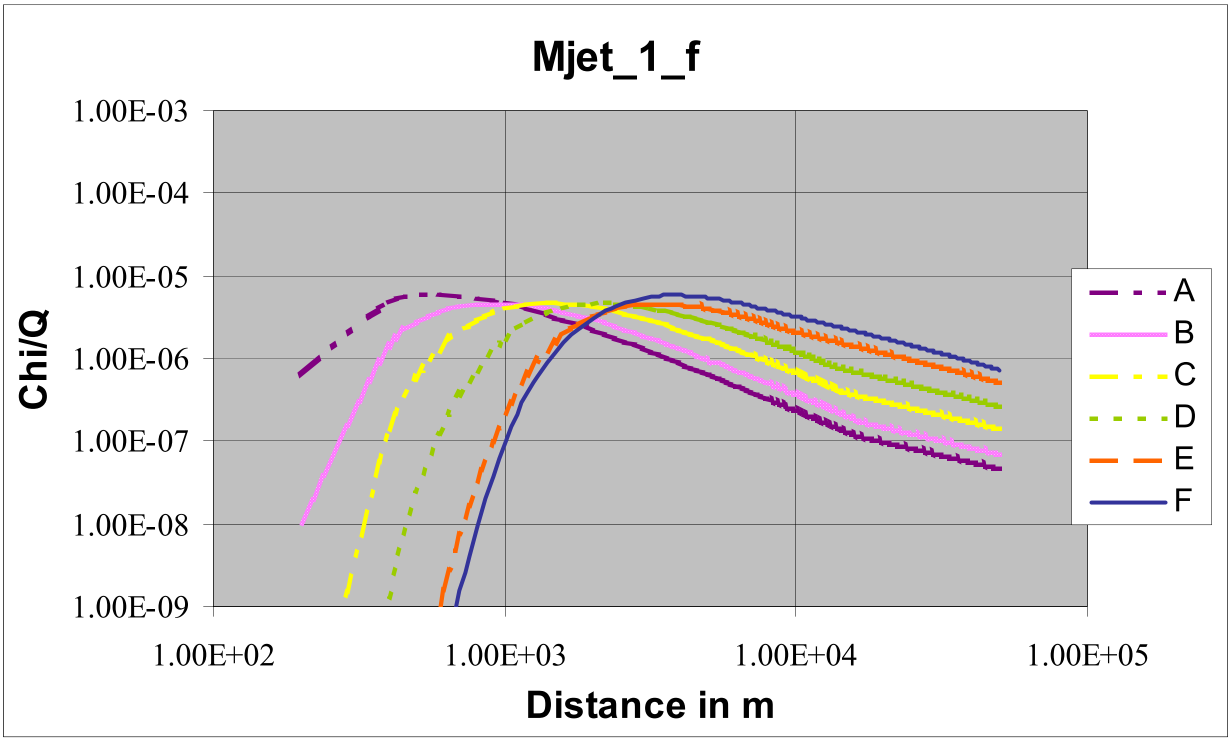

Figure 43 Distance dependent normalised air concentration for MOL scheme, fixed wind speed (1 m/s), jet release with building wake

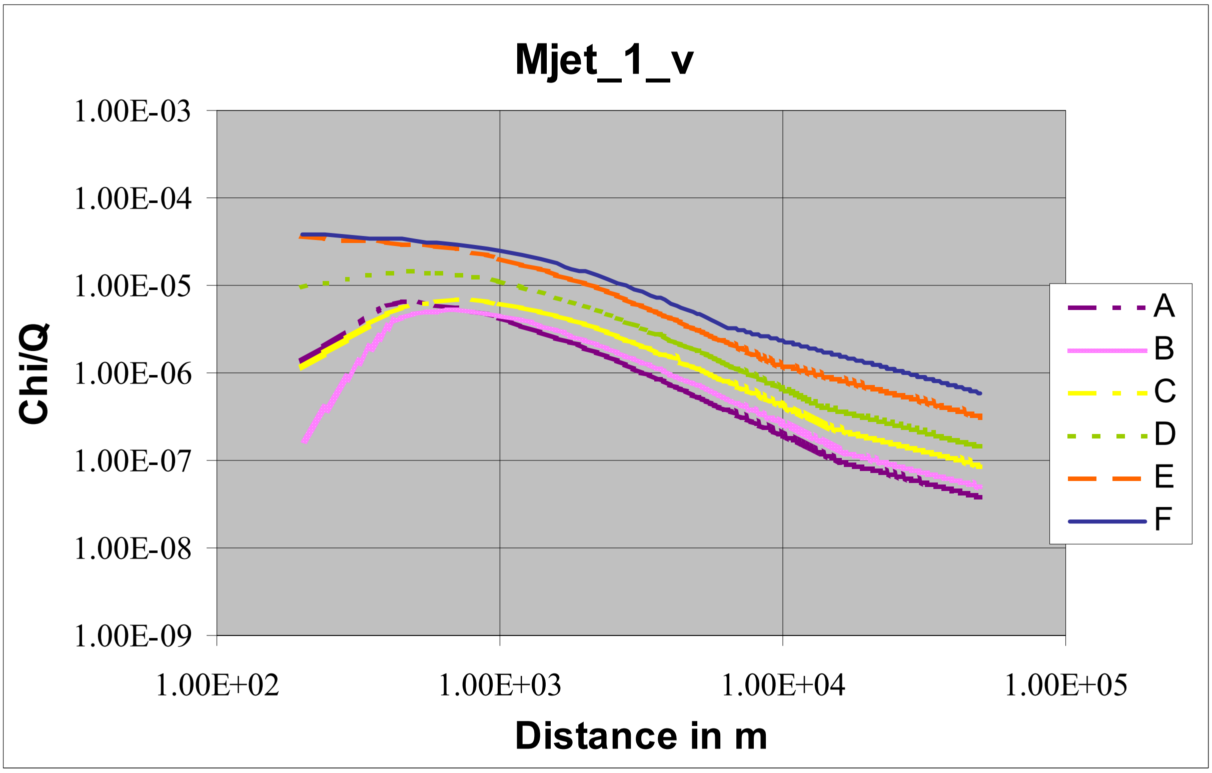

Figure 44 Distance dependent normalised air concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), jet release with building wake

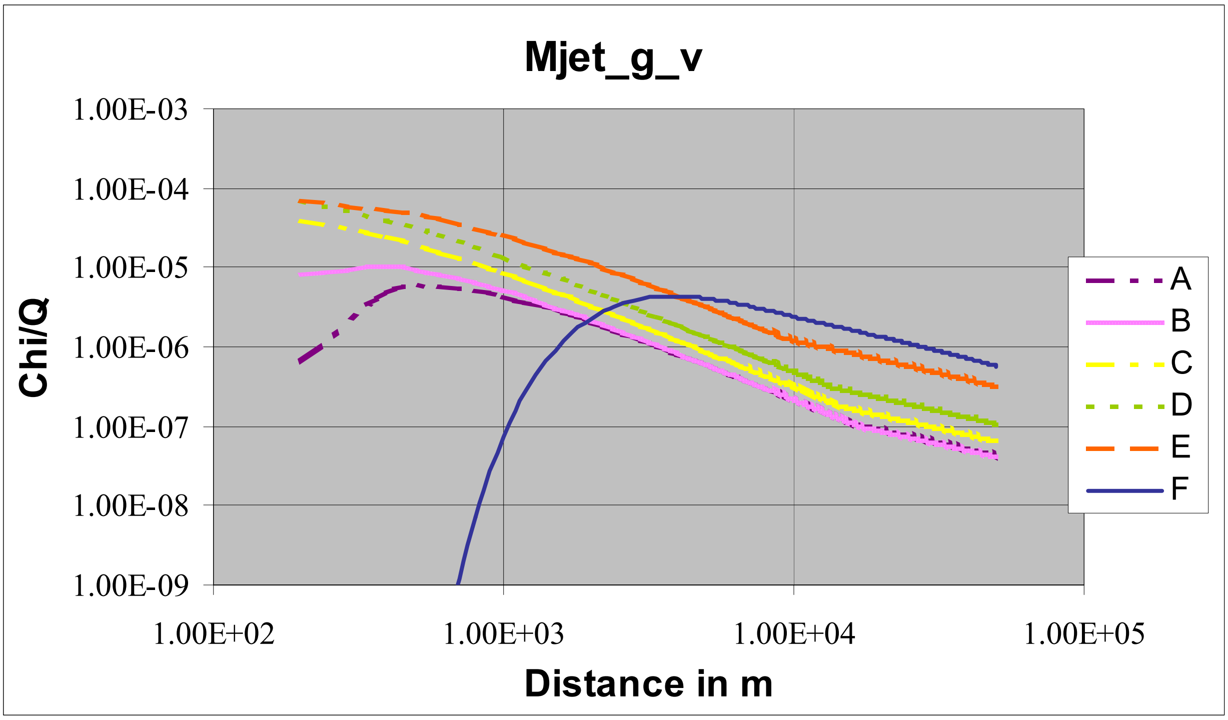

Figure 45 **Distance dependent normalised air concentration for MOL scheme, German like variable speed, jet release with building wake**

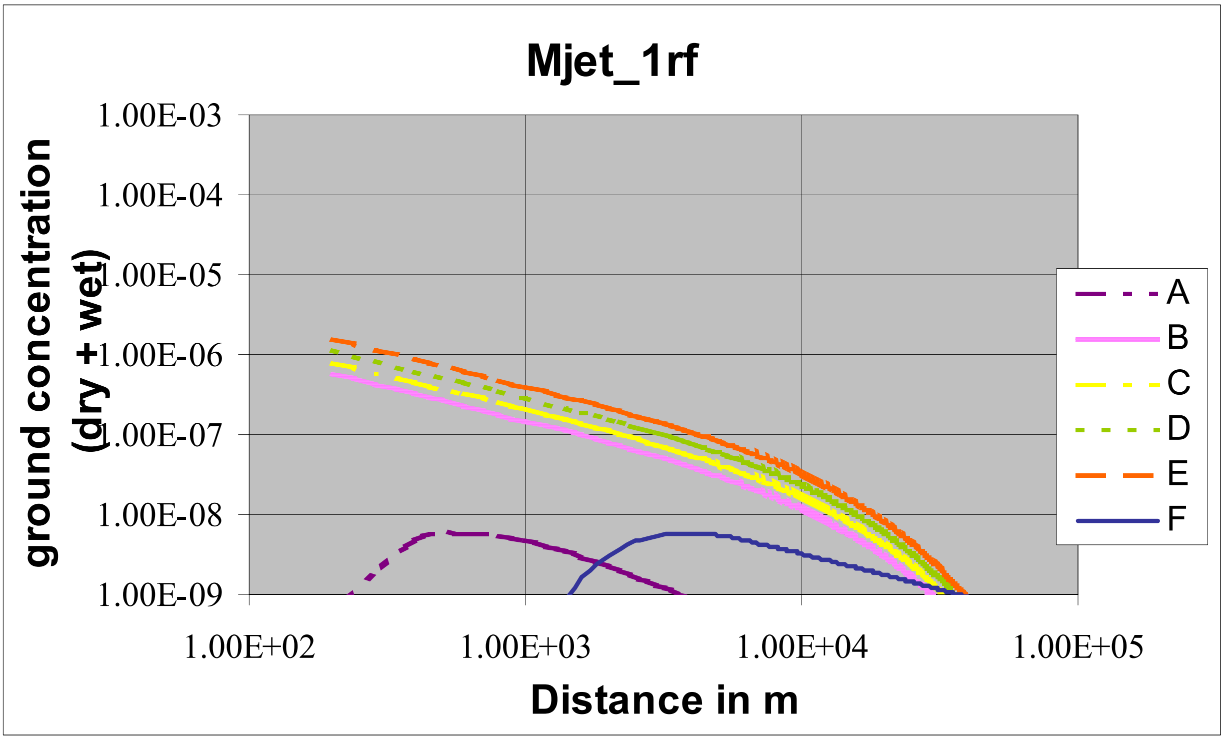

Figure 46 **Distance dependent normalised ground concentration for MOL scheme, fixed wind speed (1 m/s), jet release with building wake**

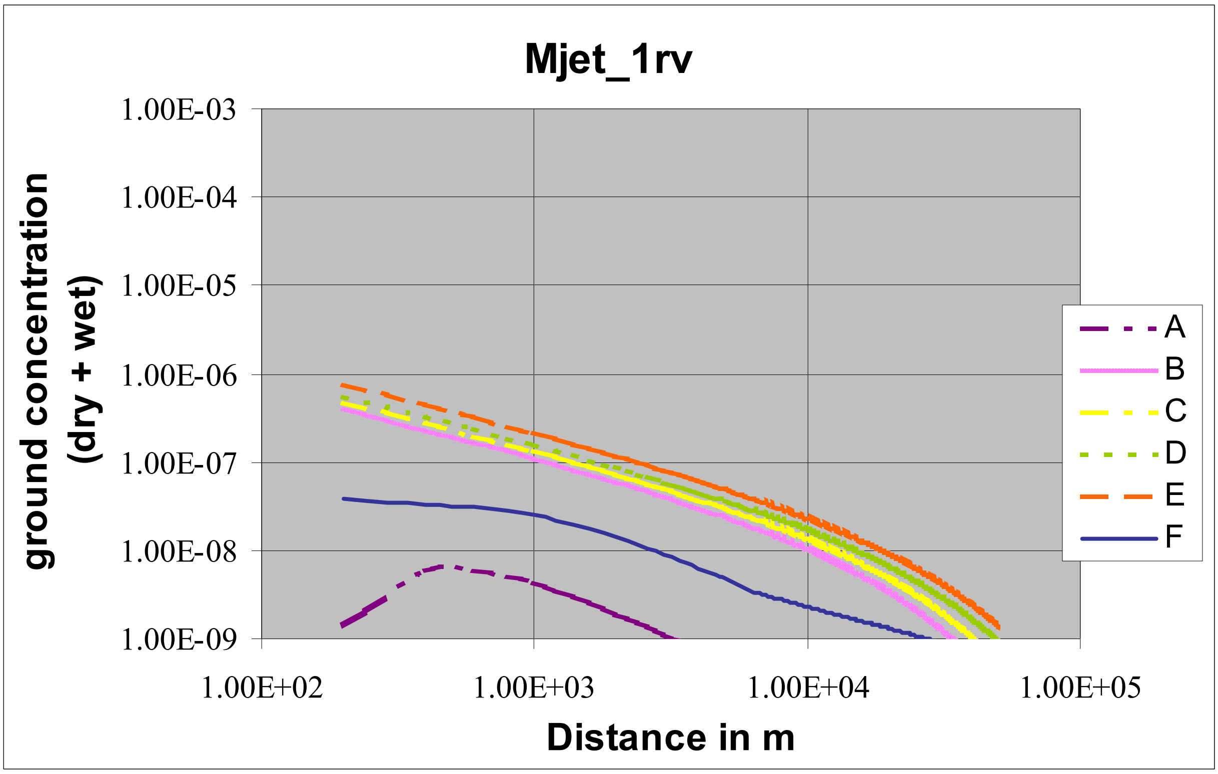

Figure 47 Distance dependent normalised ground concentration for MOL scheme, variable wind speed (1 m/s at 10 m height), jet release with building wake

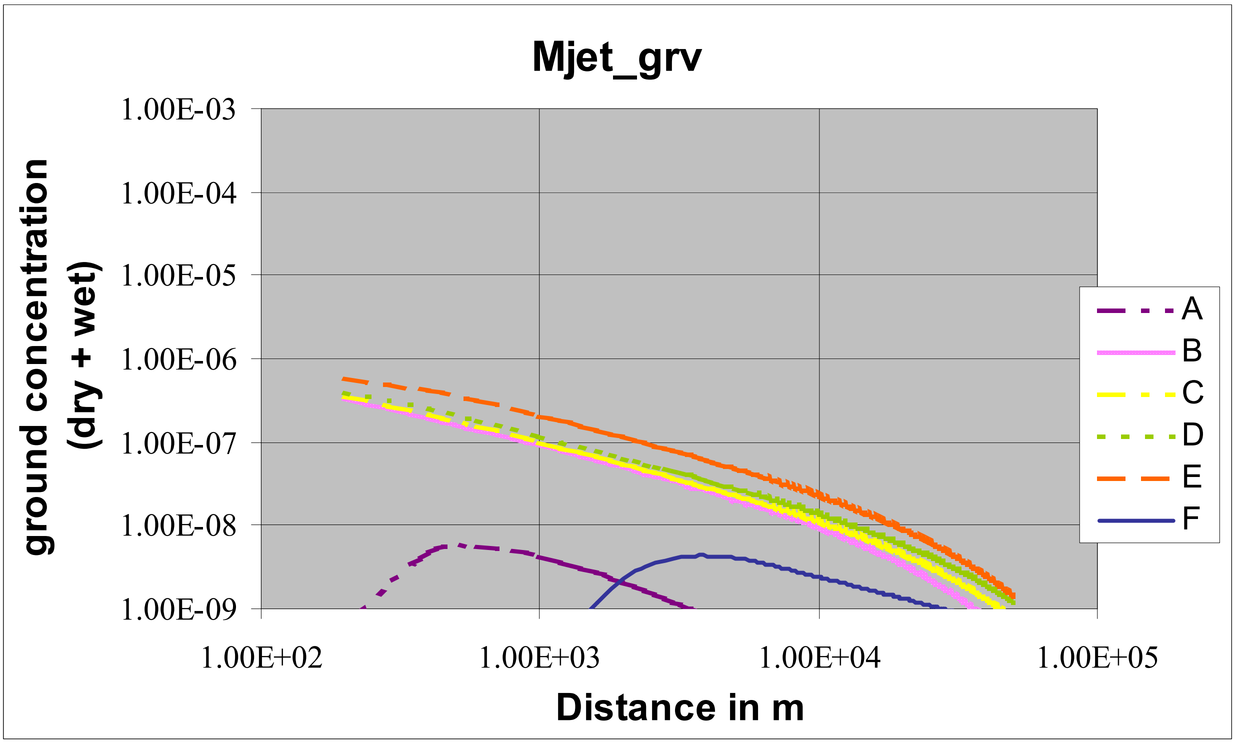

Figure 48 Distance dependent normalised ground concentration for MOL scheme, German like variable speed, jet release with building wake