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Uncertainty Analyses of the Countermeasures Module of the Program System UFOMOD

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UNCERTAINTY ANALYSES OF THE COUNTERMEASURES MODULE OF THE PROGRAM SYSTEM UFOMOD

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Abstract

This report refers to uncertainty analyses of the countermeasures submodule of the program system UFOMOD, version NE 87 /1, whose most important input parameters are linked with probability distributions derived from expert judgement.

Uncertainty bands show how much variability exists, sensitivity measures determine what causes this variability in consequences.

Results are presented as confidence bands of complementary cumulative frequency distributions (CCFDs) of individual acute organ doses (lung, bone marrow), individual risks (pulmonary and hematopoietic syndrome) and the corresponding number of early fatalities, partially as a function of distance from the site. In addition the ranked influence of the uncertain parameters on the different consequence types is shown. For the estimation of confidence bands a model parameter sample size of $n = 60$ equal to 3 times the number of uncertain model parameters is chosen. For a reduced set of nine model parameters a sample size of $n = 50$ is selected.

A total of 20 uncertain parameters is considered in this report. The most sensitive parameters of the countermeasures submodule of UFOMOD appeared to be the initial delay of emergency actions in a keyhole shaped area A and the fractions of the population evacuating area A spontaneously during the sheltering period or staying outdoors. Under the conditions of the source term used in this report the influence on the overall uncertainty in the consequence variables - individual acute organ doses, individual risks and early fatalities - of driving times to leave the evacuation area is rather small.

Unsicherheitsanalysen für den Teilmodul 'Schutz - und Gegenmaßnahmen' des Programmsystems UFOMOD

Diese Untersuchung bezieht sich auf den Schutz- und Gegenmaßnahmen - Teilmodul des Programmsystems UFOMOD, Version NE 87 / 1. Den wichtigsten Parametern liegen Wahrscheinlichkeitsverteilungen zugrunde, die in Zusammenarbeit mit Experten erstellt wurden.

Unsicherheitsanalysen liefern quantitative Aussagen über den Einfluß von Parametervariationen auf den Schwankungsbereich der Ergebnisse aus solchen Computer-Codes, während *Sensitivitätsanalysen* die für die Ergebnisschwankungen verantwortlichen Parameter ermitteln.

Resultate werden präsentiert als Konfidenzbänder für komplementäre kumulative Häufigkeitsverteilungen (CCFDs) von Aktivitätskonzentrationen, Organdosen, gesundheitlichen Schäden, sowie der Schutz- und Gegenmaßnahmen (z.T. als Funktion der Entfernung von der kerntechnischen Anlage). Anschließend wird der nach Rangfolge geordnete Einfluß der unsicheren Modellparameter auf die jeweiligen Konsequenzen erörtert.

Für die Unsicherheitsanalysen wird ein Stichprobenumfang von $n = 60$ gewählt, der das 3-fache der Anzahl der unsicheren Modellparameter beträgt. Für eine reduzierte Anzahl von neun Modellparametern wird ein Stichprobenumfang von $n = 50$ angenommen.

Insgesamt 20 Modellparameter finden in diesem Bericht als unsichere Einflußgrößen Berücksichtigung. Als hauptverantwortliche Parameter für Schwankungen der Konsequenzvariablen des Schutz- und Gegenmaßnahmen - Teilmoduls von UFOMOD wurden identifiziert die Vorwarnzeit für Aktionen in einem schlüssellochförmigen Gebiet A sowie der Bruchteil der Bevölkerung, der spontan evakuiert bzw. sich während der Schutzphase im Freien befindet.

Unter den Annahmen des Quellterms, der in diesem Bericht verwendet wird, ist der Einfluß der Fahrzeiten, um das Evakuierungsgebiet zu verlassen, für die Gesamtunsicherheit der Konsequenzvariablen - akute Individual-Organdosen, Individualrisiken, Frühschäden - eher gering.

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1. Introduction

The assessment of the radiological consequences of severe accidents at nuclear installations is a complex undertaking. Modelling the transfer of radioactive material through the environment following a release to the atmosphere requires an understanding of atmospheric dispersion, the processes of removal of material from the atmosphere leading to deposition on ground, and the subsequent behaviour in the terrestrial environment. The atmospheric dispersion and deposition model predicts the spatial and temporal distributions of activity, taking account of the meteorological conditions during the release and time of travel of the plume. Mechanisms for removal of activity from the plume are also included, these being radioactive decay and dry and wet deposition processes.

Once the spatial and temporal distribution of the radioactive material in the atmosphere and on the ground is estimated, it can be converted to distributions of dose in man. The major exposure pathways are external irradiation from the plume and from deposited activity, and internal irradiation from radioactive material taken into the body by inhalation and by ingestion of contaminated food. Since people spend a good deal of their time inside buildings, either at home or at work, and in transport systems, due consideration of shielding by the material between the source of radiation and the individual is necessary.

A variety of possible countermeasures may be taken following an accidental release, their extent and duration being dependent on the scale of the accident. A realistic estimate of the exposure of the population must therefore take appropriate account of such protective actions. The major countermeasures affecting people which may be taken in the early phases of an accidental release are sheltering, evacuation and the issue of stable iodine tablets. Countermeasure may also be applied to restrict the production and distribution of contaminated foods.

Finally, the incidence of each of the major types of health effects from the distribution of dose in the exposed population after taking due account of the application of protective actions and interdictions is evaluated. Early health effects occur if relatively high threshold doses are exceeded and they may arise within days, weeks or months after exposure. They include death and varying forms of health impairment which may be temporary or more prolonged (e.g. vomiting, sterility, cataracts).

The accident consequence assessment (ACA) code system UFOMOD consists of a sequence of models and data, which describe the various complex processes mentioned above, and which involve significant uncertainties.

In applying accident consequence analyses codes to specific sites, it is of considerable importance to understand the nature and magnitude of uncertainties that are associated with the various models and parameters that are used in the code and the effects of these uncer-

tainties on predicted consequences. This is not only a prerequisite for safety goal comparative studies but also facilitates the identification of modelling weakpoints and thus areas for further improvements and supporting research and development activities.

Although the main goal of uncertainty analysis is the quantification of the uncertainties in the assessed consequences, it fades into sensitivity analysis whenever the effect of each single parameter (or a group of parameters) on the total uncertainty is being considered.

Carefully designed procedures are to be used to determine the impact of uncertain parameters in individual submodels on the predictions of accident consequence assessments. Some general aspects of the role and importance of uncertainty and sensitivity analyses are described in a previous paper [7].

The accuracy of the description of uncertainties of the model parameters depends on the information available, finally condensed in a probability distribution for each parameter. The construction of these distributions may be based on expert opinion procedures and/or on experimental data. And additionally, following [1], the estimated distribution of the consequence variables can only be meaningful in a probabilistic sense if the model parameters have meaningful probability distributions associated with them. For the determination of those parameters that contribute significantly to sensitivity, the form of the distribution is not as important as the representation of each parameter over its physically possible range and the possible intercorrelations between parameters.

Following [14], the examination of the uncertainty in large accident consequence assessment models is a very complex undertaking and is reasonably performed in a sequential manner. The analysis should first involve the individual components of the system, and then, at a later stage the model should be examined in its entirety. In the first stage, much effort is directed at understanding and simplifying the individual components in the model. In the second stage, effort is directed at pulling this understanding together for use in an integrated analysis.

The first module of the program system UFOMOD models the dispersion of radioactive material in the atmosphere and the processes of removal of material from the atmosphere leading to deposition on ground.

A detailed uncertainty analysis for this module has been presented in [9]. The investigations described in [9] refer to the segmented plume model MUSEMET [23], which calculates Gaussian type concentration distributions along trajectories.

The countermeasures submodule of the program system UFOMOD models protective actions in the case of an uncontrolled release of radionuclides. Depending on the type and amount of release, the dispersion conditions, the distance to the source, and time, the countermeasures may cover the whole range between minor important restrictions, almost

without any impact on the average citizen, and disruption of normal living due to evacuation or relocation. Countermeasures are implemented with the aim of reducing either acute exposure during and shortly after the accident or continuing and long - term exposure due to deposited or incorporated radionuclides. In accident consequence assessment codes countermeasures are modelled in order to obtain realistic predictions of the consequences of an accidental release of radionuclides.

There are several types of countermeasures and each of them may exhibit a large variety of possible features characterized by parameters in the program system UFOMOD. In its version NE for assessing early consequences, the types of countermeasures modelled are sheltering and/or evacuation of areas as immediate actions against short - term exposure.
Special attention is given to the initial delay time of actions in a keyhole shaped area A with automatically imposed actions, the delay time between end of release and the end of sheltering period in this area, the driving time to leave the area (with respect to population density).

The results presented in this report require and use calculations from the atmospheric dispersion submodule of UFOMOD as precalculated input for the countermeasures submodule.

Before starting the uncertainty and sensitivity analyses, a detailed discussion of the parameter variations in the countermeasures module took place together with experts. It led to a list of twenty parameters given in Table 3 and Table 4 of Chapter 2.

The following aspects of accident consequence assessments are investigated: The variability of the averaged[1] individual acute doses (lung, bone marrow), indidual risks (pulmonary, hematopoietic syndrome) at three distances: D1 (.875 km), D2 (4.9 km) and D3 (8.75 km) and the corresponding number of early fatalities.

Appropriate techniques of propagating parameter uncertainties through accident consequence assessment models like UFOMOD consist of performing stochastic calculations using Monte Carlo simulations. Due to [20], for these simulations a number of vectors are sampled from the distribution functions. The various modules of the ACA codes are run repeatedly for different model parameter vectors. *Random sampling* techniques require a large number of runs to ensure that all combinations of parameter values are considered. *Stratified sampling* techniques, e.g. Latin Hypercube Sampling (LHS), aim at optimizing the sample selection in order to ensure that all relevant parameter values and their combinations are included in the calculations, even for a relatively small number of runs.

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1 averaged over 144 weather sequences sampled from synoptic records of the two years 1982/83

Chapter 3.1 briefly describes the IMAN / CONOVER procedure for inducing a special type of correlation between model parameters. The estimation of confidence bounds is indicated in Chap 3.2.

The identification of important contributors to variations in consequences is done by the use of a sensitivity measure, the so-called partial (rank) correlation coefficient, PCC or PRCC. Both sensitivity measures, PCC or PRCC, respectively, are measures that quantify the relation between the uncertainty in consequences and those of model parameters. When a nonlinear relationship is involved it is often more revealing to calculate PCCs between parameter *ranks* than between the *actual* values for the parameters. The numerical value of the PRCCs can be used for hypothesis testing to quantify the confidence in the correlation itself, i.e. by statistical reasons one can determine which PRCC values indicate really an importance (significance) of a parameter or which PRCC values are simply due to 'white noise'. This is described in Chapter 3.3 or more explicitely in Appendix A.3. Moreover, as it is pointed out in Appendix A.4, it is possible to calculate the percentage contribution of each uncertain model parameter to uncertainty in consequences by use of so-called *coefficients of determination* (R^2).

The last step in performing uncertainty analyses is to present and interprete the results of the analyses. Chapter 3.4 condenses the information obtained from the uncertainty analysis for the countermeasures submodule of the program system UFOMOD, version NE 87/1 and gives a guideline to understand the detailed figures and tables in the Appendices B and C.

2. Countermeasures Models

2.1 General features

For an uncontrolled release of radionuclides, the exposure of members of the public can only be limited by actions usually termed *protective actions*, *countermeasures*, or simply *measures*. Depending on the type and amount of release, the dispersion conditions, the distance to the source, and time, the countermeasures may cover the whole range between minor restrictions, almost without any impact on the average citizen, and disruption of normal living due to evacuation or relocation. Countermeasures are implemented with the aim of reducing either acute exposure during and shortly after the accident or continuing and long - term exposure due to deposited or incorporated radionuclides. In accident consequence assessment codes countermeasures are modelled in order to obtain realistic predictions of the consequences of an accidental release of radionuclides.

There are several types of countermeasures and each of them may exhibit a large variety of possible features characterized by parameters in the program system UFOMOD.

The types of countermeasures are

- sheltering
- evacuation
- interdiction of areas

as immediate actions against short - term exposure and

- ban of food, feed and water
- land decontamination
- relocation

as subsequent or continuing actions against long - term exposure. The types of parameters are given by the program system, their values, however, may be defined by the user of the code at run - time (intervention levels, delay / response times, shielding factors, fractions of the population taking certain actions etc.). The initial delay chosen by the user, e.g., determines whether an evacuation is prophylactic or in response to an ongoing or already finished release. Thus UFOMOD is a flexible tool for investigation of alternatives in emergency response planning and emergency management, and for studies about the influence of the behaviour of the population on the efficiency of countermeasures.

UFOMOD is subdivided into a near range and a far range part. In the area covered by the near range subsystems, protective actions against both short - term and chronic exposure

may be required, whereas in the far range countermeasures against chronic exposure are sufficient.

2.2 *Countermeasures in the near range subsystems of UFOMOD*

The area covered by the near range subsystems of the new program system UFOMOD is chosen in such a manner that exclusively in this area fast protective actions may be necessary and early health effects may occur.

As alternative or sequential countermeasures in the near range, evacuation of a keyhole shaped area (A) determined by two radii (r,R) and an angle and / or evacuation of an area (B) determined by an isodose line are modelled (see Figure 1).
Since radii and angles are easier to be established than isodose lines, evacuation of area A is modelled to take place first. If areas A and B are overlapping, the common part is assigned to A.

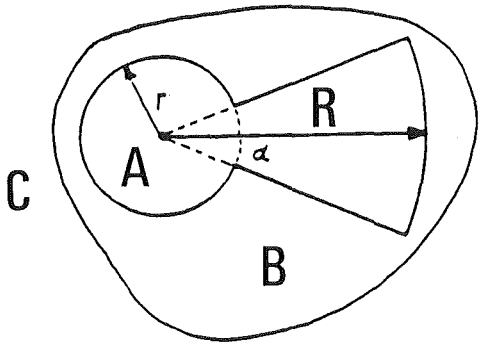
Sheltering, unintended reactions of the population, like spontaneous evacuation (flight) and disregard and misinterpretation of alarm signals and requests of the authorities, and the possible existence of unattainable persons, are taken into account as explained below.

2.2.1 Evacuation of a keyhole shaped area

Modelling of a keyhole shaped area of evacuation (A) allows for consideration of this countermeasure even in cases when isodose lines are not (yet) determined or available. Area, features, sequence of actions and input parameters are presented in Figure 1, Figure 2, Figure 3.

After an initial delay (TINA), the population in area A is assumed to be partly sheltered and partly evacuating spontaneously. An additional part remaining outdoors for whatever reasons may be determined. The end of the sheltering / outdoor period is given by the source term parameter 'end of release' (TREND) plus an additional delay (TDELA) for initiation of the subsequent evacuation requested by the authorities. All remaining persons are then evacuating.

The spectrum of individual driving times (TDRA) for leaving area A is approximated by four three-step distribution functions. Each distribution function is representative of a certain range of the population density in area A (see Table 1).



long-term countermeasures

area A:

actions: sheltering and/or evacuation

definition: keyhole shaped area with inner radius r, outer radius R and sector angle α ($r = 2.4$ km, $R = 5.6$ km, $\alpha = 60^o$)

area B:

actions: sheltering, evacuation

definition: acute dose to lung, bone marrow or GI-tract > 500 mSv

Figure 1. UFOMOD: Characterization of keyhole shaped areas: Modelling of protective actions in the early phase and current intervention levels

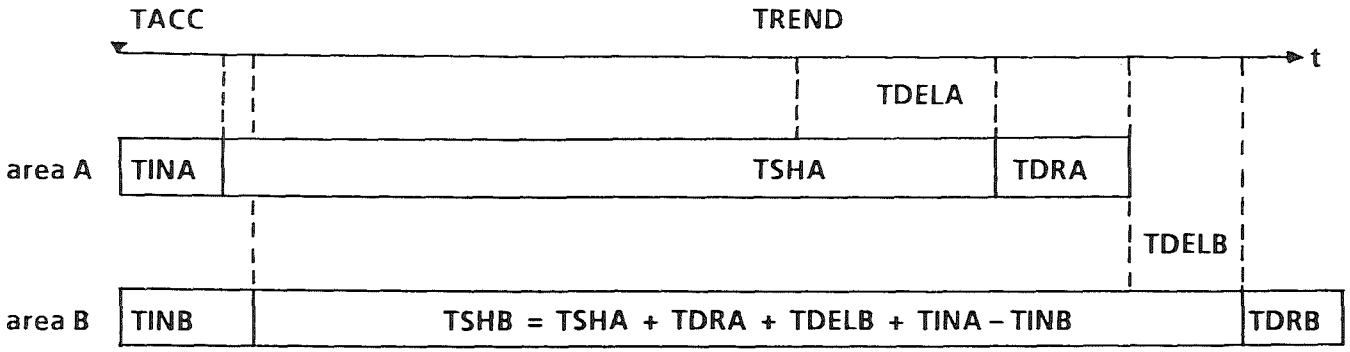


Figure 2. Timing of early protective actions

TACC	=	time of accident (end of chain reaction)
TREND	=	time of end of release (≈ 95 %)
TINA, TINB	=	initial delay, area A, B
TSHA, TSHB	=	duration of sheltering period, area A, B
TDELA	=	delay time between end of release and end of sheltering period, area A
TDELB	=	delay time between end of evacuation in area A and begin of evacuation in area B
TDRA, TDRB	=	driving time to leave area A, B

	Limit(s) or shape of the area	Sequence of measures/behaviour of the population
V	Keyhole consisting of a full disk + forecast downwind sector	Initial delay, evacuation in 3 groups with different speed, evacuation speeds depending on population density
A	Keyhole consisting of a full disk + downwind sector	Initial delay, spontaneous evacuation of a part of the population (0-100%), sheltering of the remaining part of the population, evacuation after the passage of the plume. Disregarding or misinterpreting persons see B.
B	Isodose line of exposure to bone marrow, lung or GI-tract, whichever is more restrictive	Initial delay, sheltering, evacuation after passage of the plume but not before the end of evacuation in area A. % of persons disregarding or misinterpreting alarm or advice or being unattainable.

Figure 3. Correlation between areas, countermeasures and behaviour of the population in UFOMOD

Population density PD [P/km^2]	Percentage of population corresponding: (Percentile of driving time)	Driving time [min] (daytime) for	
		R = 6 km	R = 10 km
PD ≤ 100	10 (99)	13.2	13.4
	40 (90)	10.9	11.8
	50 (50)	5.7	5.3
100 < PD ≤ 500	10 (99)	24.6	49.7
	40 (90)	17.6	34.7
	50 (50)	7.7	11.3
500 < PD ≤ 1000	10 (99)	69.1	125.1
	40 (90)	49.2	86.4
	50 (50)	15.6	15.7
1000 < PD	10 (99)	160.9	506.0
	40 (90)	107.4	290.1
	50 (50)	25.6	62.0

Table 1. Parameterization of driving time: Mean values of driving time percentiles for 6 km and 10 km radius taken from generic distribution functions

The default values of the driving times have been derived for two distance bands of the keyhole: up to 6 km and up to 10 km (see [24] and [25]).

Example:

Driving times for PD≤100, R = 10 km:
The 50th percentile, i.e. 5.3 min, is applied to 50 % of the people to be evacuated. Concerning the other 50 % of the people the value for the 90th percentile, i.e. 11.8 min, is used for 40 % of the population, the 99th percentile, i.e. 13.4 min, of driving time is applied to the last 10 % of the people.
□

Dependent on the outer radius of the area A, the corresponding data set is used. Exposure during evacuation is taken into account in the dose calculations.

Special cases like prophylactic evacuation (V), evacuation of a disk shaped or sector shaped area, no evacuation of a geometrically defined area etc. are covered due to the possibility of choosing the input data accordingly (e.g. 100 % spontaneous evacuation or R = r, R = r = 0, respectively). Shielding factors are discussed in [6].

2.2.1.1 *Driving times*

In order to estimate the driving times needed to leave the evacuation area, simulation runs [25] with the evacuation simulation code EVAS were performed. 36 keyhole shaped areas were investigated, the sectors having a radius of 10 km (6 km in two cases) and an aperture of 60° or 67.5°, the disk shaped parts having a radius between 1.5 and 2 km. 2*12 runs were performed with the data of two German sites moving the keyhole clockwise around the sites in steps of 30°. The remaining 12 keyholes comprised areas difficult to evacuate near other German sites. Driving time is defined as the time span between leaving the home and leaving the area. Driving time plus the delay before setting out is termed evacuation time. Since the final aim of the effort was the calculation of exposure of evacuees, driving time characterized by poor shielding in cars is the more important quantity.

The results of the simulation runs used in this context were driving time not exceeded by 50%, 90% and 99%, respectively, of the evacuees, the so-called *percentiles of the driving time.*

According to [25] the driving times are mainly depending on the population density in the evacuation area. Therefore the driving times are parameterized according to four population density classes (see Table 1). according to four population density classes The aim is to set up matrices of representative percentile values for each density class (for the 6 km and 10 km radii). Filling these matrices is not trivial because of the spread of the simulated percentile values within a class. Based on the sample of simulated percentile values it is of interest to work out a so-called 'generic' distribution which reflects the variability of this percentile among all sectors that are within the population density class. The mean values of the generic distributions serve as 'best estimate' or 'reference' values and build the matrix (see Table 1) of representative driving times. So, if for a specific sector an estimate of this percentile of the driving time is needed and only the density class is known (e.g. no direct EVAS simulation value is available), the corresponding generic distribution can serve as subjective probability distribution modelling the uncertainty about the appropriate percentile value.

2.2.2 Evacuation based on dose criteria

Another area of (subsequent) evacuation is defined by a dose intervention level for short - term exposure of the red bone marrow, the lung or the gastrointestinal tract. The acute exposure pathways considered in the dose calculations can be preselected. Default values may be used or criteria may be provided by the user. All grid elements where any of the three criteria is exceeded are assigned to area B (if not belonging to A).

Evacuation of area B is modelled in a way similar to that of area A, but the value of the parameters may be substantially different. After an initial delay (TINB) fractions of the

population are sheltering, remaining outdoors, or evacuating spontaneously. In contrast to A, the starting time of evacuation of area B is not related to the development of the release but to the end of the evacuation of area A. Again, evacuation is characterized by four triplets of driving times (see [25] and Table 1).

2.2.3 Sheltering persons

Sheltering persons may stay in various parts of houses differing by size, shape, design, construction material, ventilation rate etc.. Thus a broad spectrum of shielding factors and a complex correlation between these shielding factors and the corresponding fraction of the population exists in reality. UFOMOD allows for the definition of both three shielding factors and three fractions of the population to be correlated with them. In addition an average shielding factor for cars used to leave the areas A and B is required. Each of the above mentioned shielding factors must be defined for both radiation from the plume (cloudshine) and from deposited material (groundshine). Since shielding factors are defined as the ratio of indoor to outdoor dose, the doublet of shielding factors for persons remaining outdoors is (1.00/1.00) by definition. A classification scheme and the default values provided by UFOMOD are presented in Table 2:

Percentage of population	Residence	Shielding factor cloudshine	Shielding factor groundshine *)
30 %	in cars (spontaneous evacuation)	1.00	0.70
30 %	in cellars	0.05	0.03
15 %	in buildings with low shielding	0.30	0.10
15 %	in buildings with high shielding	0.01	0.01
10 %	outside, rural area	1.00	1.00

Note:
*) normalized to external radiation from ground surface, i.e. shielding effect of ground roughness not included

Table 2. Probabilistic treatment of population behaviour in areas A and B and corresponding shielding factors

Shielding due to ground roughness is taken into account implicitly in the dose factors (see [6]). During the initial delay an average shielding factor for cloud - and groundshine is applied, except the population group remaining outdoors during sheltering.

2.2.4 Source term used

As Phase B of the German Risk Study was not yet completed at the time of this analysis uncertainty calculations were performed assuming a release which was gained from release

category FK 2 of the German Risk Study - Phase A (see [2]) by multiplying the amount of iodine and aerosols with the arbitrary factor 0.2, leaving the noble gases unchanged and disregarding the energy content of the release. The release meets the following requirements:

- it is a short early release
- it is severe enough to lead to fast countermeasures and early fatalities.

For details see [4].

2.3 Parameter selection

2.3.1 Parameters contributing to uncertainty in this analysis

In the early countermeasures module of UFOMOD, twenty (or nine, respectively) independent parameters were identified for consideration in this analysis. They are given in the following list and tables together with their meaning and some rationale for the selection of ranges, distributions and correlation given in Table 3, Table 4 and Table 5.

TINA (TINB) **initial delay of actions in area A (B) [h]**
Sheltering and spontaneous evacuation starts in areas A and B with a time delay of TINA and TINB hours after reactor shutdown. During the normal working time, the emergency management will act relatively quickly after the pre-alarm from the plant. Therefore, alerting of the population is assumed to occur between half an hour and one hour after shutdown, so that the earliest time that people are sheltered will be about one hour. Under night time conditions, adverse weather situations or failing organisational arrangements, warning of the population might be considerably delayed. But it is assumed that not more than 5 hours will be necessary. A perfect (i.e. 100 %) correlation of delay times for A and B is assumed, since the reasons for delay are the same in both areas.

TDELA **delay time between end of release and end of sheltering period in area A [h]**
Uncertainties in the judgement of the amount of release, its time dependence and especially its end may cause a delay in the decision about the evacuation of people sheltered during the release period. The delay time was assumed to be up to four hours with a median value of two hours.

PAUFA(i) (PAUFB(i))

fraction of population with different behaviour during the sheltering period in area A (B)

- i = 1:

  spontaneous evacuation in cars at the start of the sheltering period. The percentage of population was assessed to be between 10 % and 50 %.

- i = 5:

  percentage of people who cannot be reached by the warning systems or stay **outdoors** intentionally. Since normally people show a risk averting behaviour and the emergency management will try to reach everybody, not more than 10 % will be within that population group.

- i = 2,3,4:

  percentage of peoples sheltered in cellars and in buildings with low and high shielding factors, respectively. In parameter studies [4] it has been shown, that the percentage of population spontaneously evacuating and staying outdoors dominates the early health effects. Therefore and due to lack of information, the relative fractions of people belonging to these shielding groups were assumed to be constant. The condition $\sum_{i=1}^{5} PAUFA(i) = 1$ led to the formulas given in Table 3 and Table 5.

GRWRTB

intervention dose level (IL) for emergency actions in area B

Outside area A, people are sheltered and subsequently evacuated, if the doses to lung, bone marrow or gastrointestinal tract exceed 500 mSv (lower intervention level of ICRP 40). It was assumed, that the emergency management will recommend to lower ILs to 100 mSv rather than to increase them.

IEVA2

index of last outer radius of the keyhole-shaped area A

The default value is 5.6 km (i.e. radius no. i = 10). It might be possible that a smaller keyhole of 4.2 km (i = 9) or a larger one of 7.5 km (i = 11) is evacuated.

WGRNZA

angle of keyhole sector of area A (in degrees)

The German regulations provide some flexibility in the choice of this sector according to the weather situation and the population distribution. The smallest evacuation unit is a 30° sector, and for the release assumed, more than a 90° sector will probably not be automatically evacuated.

WSHIFT

azimuthal shift of the keyhole sector of area A against the wind direction of the first release phase (WSHIFT>0: rotation clockwise)

Due to inaccurate predictions of wind direction, the evacuation sector may not be symmetrically located to the centerline of the plume. A deviation of ± 15° is possible due to measurement errors.

TDRA(X,Y) **Y - fractile of driving time to leave area A at 6 km (10 km) radius (daytime) with respect to population density class X [X ∈ population density class 1 to 4, Y ∈ (50th, 90th, 99th) percentile**
The reference values, ranges and distributions are derived from [24] and [25], see Table 1.

No.	Parameter	Reference value	Distribution	Additional characteristics	Range of variation			Correlation of parameters
					w_1 *)	w_0 *)	w_2 *)	
1	TINA	2	triangular		0.5	1	2.5	TINB 100% correlated to TINA
	TINB							
2	TDELA	0	triangular		0	2	4	
3	PAUFA(1)	0.3	triangular		0.333	1	1.666	$\sum_{i=1}^{5} PAUFA(i) = 1$
4	PAUFA(5)	0.1	uniform		0		1	
	PAUFA(2)	$= [1 - (PAUFA(1) + PAUFA(5))]/2$						
	PAUFA(3)	$= [1 - (PAUFA(1) + PAUFA(5))]/4$						
	PAUFA(4)	$= [1 - (PAUFA(1) + PAUFA(5))]/4$						
	PAUFB(1)							PAUFB 100 % correlated to PAUFA
	PAUFB(2)							
	PAUFB(3)							
	PAUFB(4)							
	PAUFB(5)							
5	GRWRTB	0.5	uniform		0.2		1	
6	IEVA2	10	discrete		0.9	1.0	1.1	
7	WGRNZA	60	triangular		0.5	1.0	1.5	
8	WSHIFT	0	uniform		-15		+15	

Note:
*) $w_1 = w_1$ $w_0 = w_{50}$ = 50 % quantile $w_2 = w_2$
For TINA: w_0 means the peak value between w_1 and w_2. In this case w_{50} is 1.28.

Table 3. Transformed parameter distribution table

No.	Parameter	Reference value	Distribution	Additional characteristics	Range of variation			Correlation of parameters
					w_1		w_2	
9	TA(1,50)	5.7	beta +)	p=3.135 q=1.100	0.35		1.23	(9,10) corr.=0.50 (10,11) corr.=0.50 (9,11) corr.=0.25
10	TA(1,90)	10.9		p=2.366 q=1.082	0.37		1.28	
11	TA(1,99)	13.2		p=1.793 q=1.06	0.38		1.36	
12	TA(2,50)	7.7	beta +)	p=0.513 q=2.383	0.65		2.60	(12,13) corr.=0.50 (13,14) corr.=0.50 (12,14) corr.=0.25
13	TA(2,90)	17.6		p=0.386 q=1.898	0.51		3.41	
14	TA(2,99)	24.6		p=0.393 q=1.768	0.41		3.66	
15	TA(3,50)	15.6	beta +)	p=0.556 q=2.321	0.32		3.85	(15,16) corr.=0.50 (16,17) corr.=0.50 (15,17) corr.=0.25
16	TA(3,90)	49.2		p=0.523 q=1.701	0.18		3.66	
17	TA(3,99)	69.1		p=0.658 q=1.905	0.14		3.47	
18	TA(4,50)	25.6	beta +)	p=0.938 q=1.405	0.23		2.15	(18,19) corr.=0.50 (19,20) corr.=0.50 (18,20) corr.=0.25
19	TA(4,90)	107.4		p=0.802 q=1.009	0.17		2.05	
20	TA(4,99)	160.9		p=1.024 q=1.636	0.19		2.30	

Note:

+):

TA (as an abbreviation for TDRA) means driving time in 6 km distance. For each population density class the TA values for 10 km distance for each population density class are averaged and derived from the TA values for 6 km distance:

```
TDRA10(1,Y)  =          TA(1,Y)          TDRA10(2,Y) = 1.8  *  TA(2,Y)
TDRA10(3,Y)  =  1.6  * TA(3,Y)           TDRA10(4,Y) = 2.8  *  TA(4,Y)

                where Y ∈ (50, 90, 99) and from Table 1:

1.8  =  ( 49.7/ 24.6  +   34.7/ 17.6  +  11.3/ 7.7)/3
1.6  =  (125.1/ 69.1  +   86.4/ 49.2  +  15.7/15.6)/3
2.8  =  (506.0/160.9  +  250.1/107.4  +  62.0/25.6)/3
```

Table 4. Transformed parameter distribution table (cont'd)

No.	Parameter	Reference value	Distribution	Additional characteristics	Range of variation			Correlation of parameters
					w_1 *)	w_0 *)	w_2 *)	
1	TINA	2	triangular		0.5	1	2.5	TINB 100% correlated to TINA
	TINB							
2	TDELA	0	triangular		0	2	4	
3	PAUFA(1)	0.3	triangular		0.333	1	1.666	$\sum_{i=1}^{5} PAUFA(i) \equiv 1$
4	PAUFA(5)	0.1	uniform		0		1	
	PAUFA(2)	$= [1 - (PAUFA(1) + PAUFA(5))]/2$						
	PAUFA(3)	$= [1 - (PAUFA(1) + PAUFA(5))]/4$						
	PAUFA(4)	$= [1 - (PAUFA(1) + PAUFA(5))]/4$						
	PAUFB(1)							PAUFB 100 % correlated to PAUFA
	PAUFB(2)							
	PAUFB(3)							
	PAUFB(4)							
	PAUFB(5)							
5	GRWRTB	0.5	uniform		0.2		1	
6	IEVA2	10	discrete	$p_{1,2,3} = \frac{1}{3}$	0.9	1.0	1.1	
7	WGRNZA	60	triangular		0.5	1.0	1.5	
8	WSHIFT	0	uniform		-15		+15	
9	TDRA	11.3	beta +)	p = 0.376 q = 1.216	0.35		3.10	

Note:

*) $w_1 = w_1$ $w_0 = w_{50}$ = 50 % quantile $w_2 = w_2$

For TINA: w_0 means the peak value between w_1 and w_2. In this case w_{50} is 1.28.

+) :

TDRA means the 50th percentile of driving time in 10 km distance for the second population density class. All other driving time parameter are completely correlated to TDRA ≡ TA(2,50) (10 km) in the following manner (see Table 1):

```
TA(1,90) = ( 11.8/  5.3) * TA(1,50)   TA(1,99) = ( 13.4/  5.3) * TA(1,50)
TA(2,90) = ( 34.7/ 11.3) * TA(2,50)   TA(2,99) = ( 49.7/ 11.3) * TA(2,50)
TA(3,90) = ( 86.4/ 15.7) * TA(3,50)   TA(3,99) = (125.1/ 15.7) * TA(3,50)
TA(4,90) = (290.1/ 62.0) * TA(4,50)   TA(4,99) = (506.0/ 62.0) * TA(4,50)
```

and

```
TA(1,50) = (  5.3/ 11.3) * TA(2,50)
TA(3,50) = ( 15.7/ 11.3) * TA(2,50)
TA(4,50) = ( 62.0/ 11.3) * TA(2,50)
```

Table 5. Reduced transformed parameter distribution table

For the purpose of clearness all uncertain parameters (except TDELA and WSHIFT) have been split into two factors:

$$Par = w \cdot Par_{ref} \quad \text{and} \quad Par \neq \text{TDELA, WSHIFT} \qquad [1]$$

the first of them being a random variable w with a suitable frequency distribution, and the second one being the best estimate or reference value.

For example, the original TINA - values used in UFOMOD vary within the range of 1 and 5. This corresponds to Table 3 and Table 5 in the following manner:

$$TINA = w \cdot TINA_{ref} \in [1,5] \qquad [2]$$

But we have to set

$$Par = w + Par_{ref} \quad \text{for} \quad Par = \text{TDELA, WSHIFT} \qquad [3]$$

3. Uncertainty Analysis

The preceding chapter described to some extent ranges, distributions and correlations of the model parameters, respectively.

Prior to the actual analysis performed with the program system UFOMOD it is necessary to define specific vectors of the uncertain model input parameters to be used in each run of UFOMOD. The selection of these sets of specific parameter values is done by a suitable *sampling scheme*. With *one* parameter set each run produces *one* complementary cumulative distribution function (CCFD). From all runs a family of curves results, which visualizes the variability of the CCFDs of consequences. Confidence bands can be derived together with sensitivity measures, which determine what causes this variability in consequences.

Important questions are, how to construct CCFD curves and confidence bands, how to calculate sensitivity measures and how many UFOMOD-runs are necessary to get reliable uncertainty and sensitivity results?

Uncertainty analysis methods may need much computer runs and time if there are a lot of model parameters and the accident consequence code is long-running. Therefore, on one hand the designer of a sampling scheme should aim at a low number of runs, on the other hand the number of runs should be large enough to get stable and thrustworthy results.

3.1 The sampling scheme

From the various possible sampling strategies the Latin hypercube sampling (LHS) approach was selected. LHS is a modified random sampling with stratified samples and is found to have very good sampling characteristics when compared to other methods (see [14] and [21] (Vol. 3 K-5)).

The sampling procedure forces the value of each model parameter to be spread across its entire range. In random sampling it is possible by chance to choose only a portion of the range of model parameters, leaving out another part of the possible range that could greatly influence the consequence variables. The intent of LHS is to make more efficient use of computer runs than random sampling even for *smaller* sample sizes. For *large* sample sizes there is little difference between the two techniques.

A Latin hypercube sample of size n stratifies the range of each model parameter into "n" nonoverlapping intervals on the basis of equal probability. Randomly a value is selected from each of these intervals. Let X_i (i= 1,...,k) be the model parameters. The n values

obtained for X_1 are paired at random with the n values obtained for X_2. These n pairs are combined in a random manner with the n values for X_3 to form n triples. The process is continued until a set of n k-tuples is formed.

There may exist "spurious" correlations between model parameter values within a Latin hypercube sample, due to the random pairing of the model parameter values in the generation of the sample. This is most likely when n is small in relation to k. Such correlations can be avoided by modifying the generation of the sample through use of a technique introduced by R.I. Iman and W.J. Conover [12]. This technique preserves the fundamental nature of LHS, but replaces the random pairing of model parameter values with a pairing that keeps all of the pairwise rank[2] correlations among the k model parameters close to zero.

The Iman/Conover-technique can also be used to induce a desired rank correlation structure among the model parameters. The procedure is distribution free and allows exact marginal distributions to remain intact. This is used for the UFOMOD - LHS - design (The SANDIA LHS program [15] is used.). For some mathematical details see [12] and [8].

3.2 Estimation of confidence bounds

The next task is to run the accident consequence code with the sampled input parameter values from the LHS-design.

The following distinctions are necessary:

- There are stochastic variations e.g. in weather conditions or wind directions. Each run of UFOMOD therefore produces one frequency distribution (CCFD) of consequences.
- Due to lack of knowledge about the actual model parameter values there is an uncertainty in these results. This can quantitatively be expressed by confidence intervals of the frequency distribution of consequences.

CCFD curves are generated by considering the probability of equaling or exceeding each consequence level on the x-axis. To construct a CCFD keep in mind 144 weather sequences with different probabilities, say PWET(L) (L = 1,...,144), and 72 azimuthal sectors of 5 ° each, are considered. For each radius (distance) there exist 144 × 72 point values with the probability PWET(L)/72. The 144 × 72 consequence values are sorted into 90 classes (which

---

2 The rank order statistic for a random sample is any set of constants which indicate the order of observations. The actual magnitude of any observation is used only in the determination of its relative position in the sample array and is thereafter ignored in any analysis based on rank order statistics.

correspond for instance to nine decades of consequence values on a logarithmic x-scale). Each class has its own probability of occurrence given by summing up the probabilities of the members of the class. Adding the probabilities of the classes stepwise from the right to the left will give the CCFD.

To get confidence curves for each consequence level so-called p-quantiles are calculated from the number n_0 of associated probability values at this consequence level x.

Example:

Suppose $n_0 = 60$ UFOMOD - runs, i.e. there are 60 CCFDs and - corresponding for each consequence level x - 60 probability points. To get a (p %) - confidence the following procedure has been adopted:
For each consequence level x find the (p %) - smallest probability value of n_0 ordered values. For all individual consequence levels these selected probability points are connected to obtain the estimated (p %) - confidence curve.

Particularly for the 5 % (95 %) - confidence curves connect the $p \times n_0$ -th numbers from the bottom in the ordered list of n_0 probability points, i.e. in our example connect the 3-rd and the 57-th values from the bottom, respectively. Mean and median curves can be created in a similar manner.
□

[3] It has been tested that different samples for n = 50 (all driving time parameters, TDRA, are completely correlated) and for n = 60 (TDRA parameters are partly correlated) do not change the 5%-95%-confidence bands. Figure 4 shows 60 estimated complementary cumulative frequency distributions for the acute individual dose values at the distance of .875 km.

Figure 5 shows the corresponding estimated so-called *reference CCFD* (all uncertain input model parameters are at their point value (50%-quantile)) and the empirical 5%-95%-quantiles at each consequence level. The 5%-95%-'confidence curves' were generated by considering the probability of equaling or exceeding each consequence level appearing on the x-axis. For each consequence level the 5% and 95%-quantiles (or other values: mean, median etc.) were calculated from the 60 associated probability values. These probability estimates for individual consequence levels were then connected to obtain the empirical 5%-95%-confidence curves (see [1]).

---

[3] In [14] is stated, that good results can be obtained even with n = 4/3 times the number of uncertain model parameters. For n < k it seems appropriate to use the LHS - technique in a piecewise fashion on subsets of the k model parameters. For details see [12].

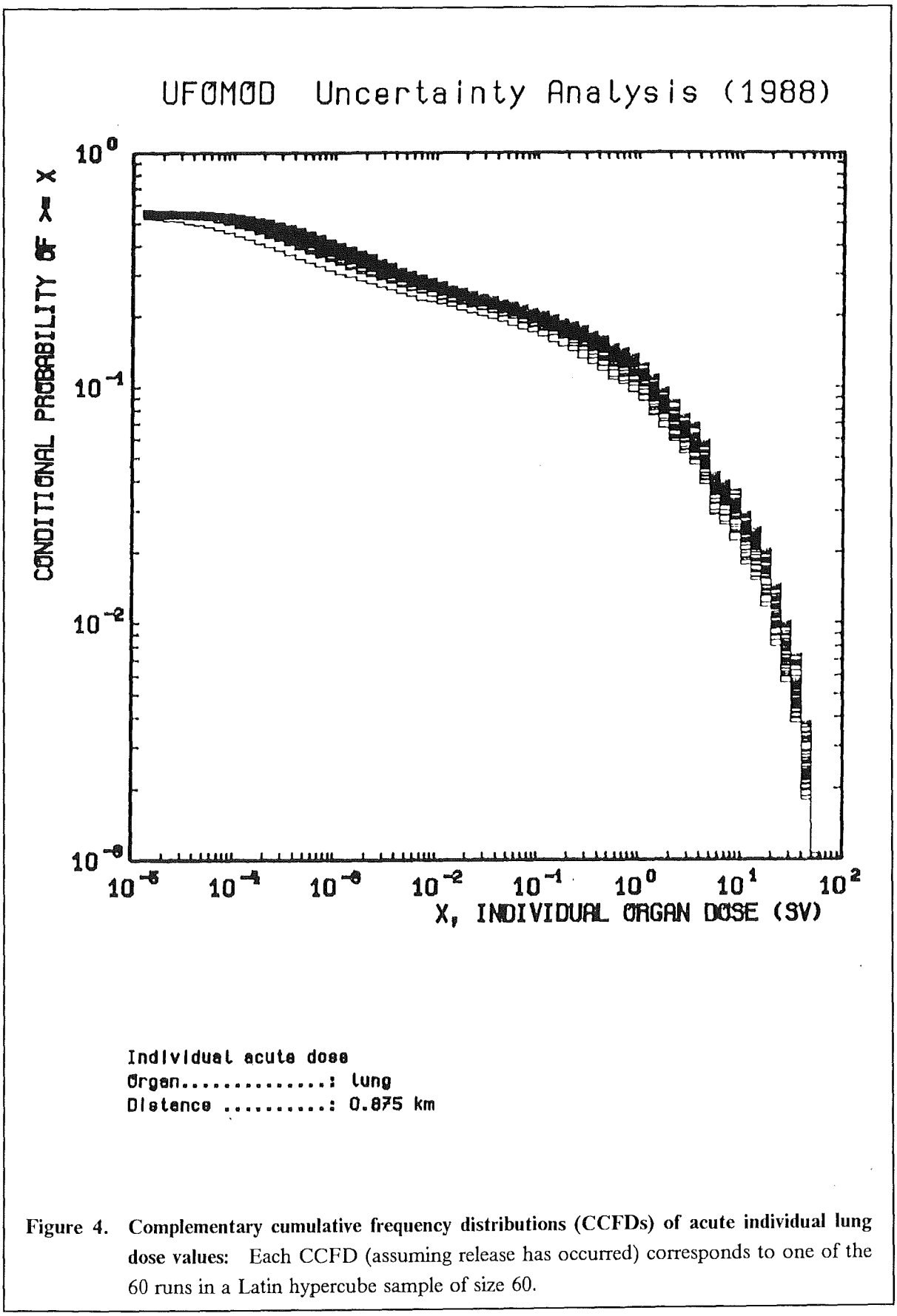


Figure 4. Complementary cumulative frequency distributions (CCFDs) of acute individual lung dose values: Each CCFD (assuming release has occurred) corresponds to one of the 60 runs in a Latin hypercube sample of size 60.

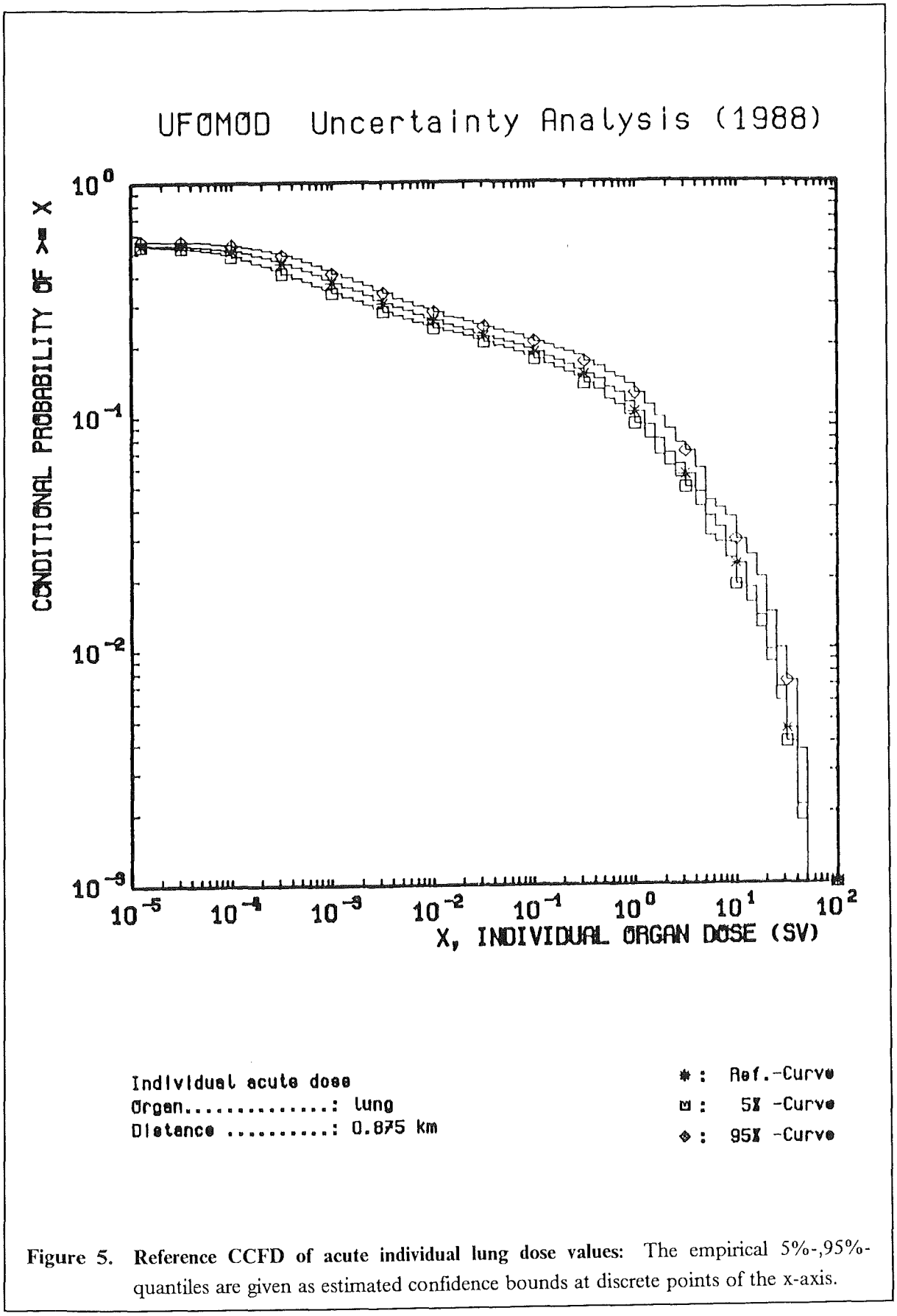


Figure 5. Reference CCFD of acute individual lung dose values: The empirical 5%-,95%-quantiles are given as estimated confidence bounds at discrete points of the x-axis.

So, the confidence bounds have to be interpreted as follows:

There is 90%-confidence that the conditional probability for the acute individual lung dose values, x, at 0.875 km distance, is

- below the ordinate value at x of the 95%-curve,and
- above the ordinate value at x of the 5%-curve.

The width of the CCFD-confidence band is an indicator of the sensitivity of model predictions with respect to variations in parameters, which are imprecisely known.

3.3 Sensitivity analysis

Those uncertain input model parameters have to be identified which are important contributors to variations in consequences. Following [14], there are several methods for quantifying the relative importance of the uncertain model parameters to the output of the accident consequence model. Usually, each of the uncertain model parameters is ranked on the basis of its influence on the consequences. Some methods provide such an overall ranking while others (e.g. stepwise regression) are designed to select subsets consisting of only the most influential parameters.

- Rankings beyond the first few most important uncertain parameters usually have little or no meaning in an absolute ordering, since only a small number of the total number of uncertain parameters actually turns out to be significant. This will be explained later in more detail.
- Sensitivity analysis in conjunction with any form of sampling or design is easiest to carry out *if a regression model is fitted* between the model consequences and the model parameter values. Such a regression model is inherent in the calculation of correlation coefficients. But, regression techniques are influenced by extreme observations and nonlinearities. Therefore it seems to be appropriate to transform the data.

A method which

- is regression based,
- ranks either all uncertain model parameters or only those within a subset, and additionally
- avoids sophisticated transformations

is the ranking on the basis of *partial rank correlation coefficients.*

Now, *regression analyses* define the mathematical relationship between two (or more) variables, while *correlations* measure the strength of the relationship between two variables.

But do all correlation numbers indicate a significant relationship between variables, i.e. is there an actual relationship or only one by chance ('white noise')? Up to which level (**'white noise'-level, critical value**) the correlation numbers are treated as garbage?

The numerical values of correlation coefficients or partial (rank) correlations coefficients can be used for significance testing of the correlation, or with other words, for hypothesis testing to quantify the confidence in the correlation itself. For details see Appendix A.3.

But to summarize the main results in advance:

To get **statistically stable results for sensitivity analyses** larger sample sizes than for confidence bounds calculations have to be chosen. The number of uncertain model parameters, which have a sensitivity measure value above the so-called 'white noise level' increase with sample size. For details see Appendix A and the sensitivity tables in Appendix C, which compare the results for n = 50, 60 computer runs.

The **partial correlation coefficient (PCC)** is a measure that explains the linear relation between for instance a consequence variable and one or more uncertain model parameters with the possible linear effects of the remaining parameters removed. Following [10], when nonlinear relationships are involved, it is often more revealing to calculate PCCs between variable *ranks* than between the *actual values* for the variables. Such coefficients are known as **partial rank correlation coefficients (PRCCs)**. Specifically, the smallest value of each variable is assigned the rank 1, the largest value is assigned the rank n (n denotes the number of observations). The partial correlations are then calculated on these ranks.

The next step is to pick out the relevant sensitivity information of the bulk of hidden messages within the CCFDs.

There are various possible ways to condense the extensive data:

- Estimate fractiles, the estimated mean values etc. of the n CCFDs *at certain consequence levels*. There will be possibly divergent 'importance rankings' for different consequence values.
- Estimate *one* fractile, *one* estimated mean value etc. for each of the n consequence curves.

The second procedure is used for the UFOMOD - uncertainty and sensitivity analyses. To find the most important contributors to uncertainty in the consequences partial rank correlation coefficients (PRCCs) are used under assistance of the SANDIA PRCC-code (see [16]).

Importance ranking is done by taking *absolute* values of the PRCC values. The model parameter associated with the largest absolute PRCC value is called the **most important** one responsible for uncertainty in consequences and gets **importance rank 1.**

This differs from the definition of *ranks of sample values*, where the smallest values has rank 1, the next smallest has rank 2 and so on.

Example:

On the basis of 60 UFOMOD - runs with LHS, the most important uncertain parameters including their PRCC and *importance rank* for each consequence (e.g.: acute individual lung dose values at the distance of .875 km) are identified. By statistical reasons (as explained before), a parameter is significant with confidence 95%, if the absolute value of the corresponding PRCC is greater than .31 (for n = 60). The absolute value describes the strength of the input-output dependency, while the (+,-)-sign indicates increasing (decreasing) model consequences for increasing uncertain parameter values. The initial delay time of actions in area A, TINA, and the fraction of population, PAUFA(1), which evacuates spontaneously, are the most important sources of variation for the individual acute lung dose values with PRCC-values of .97 and -.84, respectively. Increasing TINA and decreasing PAUFA(1) lead to a strong increase of individual acute lung dose values (see Appendices).
□

In addition to evaluating the influence of each uncertain model parameter on the model consequences, the calculation of PCCs or PRCCs provide a good indicator of the 'fit of the analysis' to the model behaviour: the **coefficient of determination, R^2**, which is a measure of how well the linear regression model based on PCCs (or the corresponding standardized regression coefficients) can reproduce the actual consequence values. Or, in other words, it reflects the fraction of the variance in model consequences which can be explained by regression, i.e. it is possible to calculate the *percentage contribution* of each uncertain model parameter to variations in consequences. R^2 varies between 0 and 1 and is the square of the corresponding PCC. The closer R^2 is to unit, the better is the model performance.

3.4 Results

This chapter summarizes the main conclusions of the uncertainty and sensitivity investigations for the UFOMOD/NE87 countermeasures submodule. For details the reader is referred to the Appendices B and C.

The following results of accident consequence assessments are investigated:

- acute individual organ doses
  (lung, bone marrow)
- individual risks
  (pulmonary syndrome, hematopoietic syndrome)
- number of early fatalities
  (pulmonary syndrome, hematopoietic syndrome)

considering the variability of averaged[4] acute individual doses, individual risks and numbers of early fatalities, respectively, at three distances D1 (.875 km), D2 (4.9 km) and D3 (8.75 km).

Due to the weather sequences considered each UFOMOD run produces *one* frequency distribution (CCFD) of consequences.

In Chap 3.2 the way of construction of CCFDs and corresponding confidence curves has been indicated. The calculation of sensitivity measures has been outlined in Chap 3.3.

DISTANCE [*km*]	DOSLU [*Sv*]			DOSBM [*Sv*]		
	5 % value	95 % value	factor	5 % value	95 % value	factor
0.875	$8.03\ 10^{-1}$	$1.17\ 10^{0}$	$1.46\ 10^{0}$	$1.38\ 10^{-1}$	$2.34\ 10^{-1}$	$1.70\ 10^{0}$
4.9	$3.00\ 10^{-2}$	$4.35\ 10^{-2}$	$1.45\ 10^{0}$	$6.82\ 10^{-3}$	$1.30\ 10^{-2}$	$1.90\ 10^{0}$
8.75	$1.11\ 10^{-2}$	$1.55\ 10^{-2}$	$1.40\ 10^{0}$	$3.46\ 10^{-3}$	$6.52\ 10^{-3}$	$1.89\ 10^{0}$
Note: *) factor = 95 % value / 5 % value sample size n=50 DOSLU, DOSBM = acute individual doses (lung, bone marrow)						

Table 6. (5 %, 95 %) values of countermeasures consequence variables (acute individual doses)

Table 6 shows decreasing dose values from near to far distances and only a small width of confidence bands. The 5 % and 95 % values of the ordered n (n = 50) mean values vary with a factor 1.4 to 1.46 for DOSLU and 1.7 to 1.9 for DOSBM.[5]
There is nearly no change in the 'factors' of Table 6 if the sample size is n = 60.

---

4 (averaged over 144 weather sequences sampled from synoptic data of the two years 1982 / 83)

5 Each of the n UFOMOD runs produces *one* CCFD of consequences. *One* mean consequence value is estimated from each CCFD. The 5 % and 95 % values in the ordered sequence of n mean values are a measure for the variability of mean consequence values.

DISTANCE [km]	RSKLU			RSKBM		
	5 % value	95 % value	factor	5 % value	95 % value	factor
0.875	$2.22\ 10^{-2}$	$3.03\ 10^{-2}$	$1.36\ 10^{0}$	$6.22\ 10^{-4}$	$3.08\ 10^{-3}$	$4.96\ 10^{0}$
4.9	0	0	0	0	0	0
8.75	0	0	0	0	0	0
Note: *) factor = 95 % value / 5 % value sample size n=50 RSKLU, RSKBM = individual risks (pulm. syndrome, hemat. syndrome)						

Table 7. (5 %, 95 %) values of countermeasures consequence variables (individual risks)

	POP(LU)			POP(BM)		
	5 % value	95 % value	factor	5 % value	95 % value	factor
	$1.79\ 10^{+1}$	$3.01\ 10^{+1}$	$1.68\ 10^{0}$	$1.05\ 10^{0}$	$3.21\ 10^{0}$	$3.05\ 10^{0}$
Note: *) factor = 95 % value / 5 % value sample size n=50 POP(LU), POP(BM) = early fatalities (pulm. syndrome, hemat. syndrome)						

Table 8. (5 %, 95 %) values of countermeasures consequence variables (early fatalities)

No individual risks and therefore no early fatalities are calculated at the second and third distance 4.9 km and 8.75 km. While the individual risks for the pulmonary syndrome only show a small variability (the 5 % and 95 % values for RSKLU vary by a factor 1.36), the risks for the hematopoetic syndrome have a larger width of confidence bands, (the 5 % and 95 % values vary by a factor of about 5) (see Table 7).

This can be explained by the way how individual risks are calculated in UFOMOD. As described in Chapter 2.2, the detailed modeling of early protective actions distinguishes between five population groups with different behaviour and corrresponding percentages PAUFA(NA) NA = 1,...,5 , four driving time classes NF for different population densities and three population groups NFZ with different driving times (see Table 1). The corresponding probabilities are given by PFD(NF, NFZ). To save storage, the individual risks resulting from each combination NA,NFZ are averaged due to

$$\overline{RSK}(NF) = \sum_{NA,NFZ} RSK(NA,NF,NFZ) \times PAUFA(NA) \times PFD(NF,NFZ) \qquad [4]$$

and then written on a permanent file. The CCFDs evaluated in the uncertainty analyses are calculated from the $\overline{RSK}$ - values.

Acute bone marrow doses result to a high percentage from external γ-radiation (cloudshine and groundshine), and the large dose values above the threshold (2.3 Sv) for the hematopoietic syndrome mainly occur in the population group staying outdoors without shielding during the sheltering period. Therefore a large variation of $\overline{RSK}$ results when multiplying the percentages PAUFA(5) (which are between 0 and 10 %, see Table 3 and Table 5) with risk values ≤ 1. This can easily be seen in the figures in Appendix B which show the individual risk curves (hematopoietic syndrome) at 0.875 km distance: the probabilities concentrate below risk values of 0.1.

Acute lung doses are caused to a high percentage by inhalation of radioactive material. No reduction factor is assumed for this exposure pathway during the sheltering period. Therefore, the same dose values and individual risks are calculated for all population groups except those who evacuate spontaneously (see Figure 6). This is confirmed by the fact, that TINA and PAUFA(1) are the most sensitive parameters for early deaths from pulmonary syndrome (see Table 10), because they determine the duration of the inhalation of radioactive material and the percentage of people evacuating spontaneously. As a result the variation of $\overline{RSK}$ due to Eq. [4] is considerably smaller than for the hematopoietic syndrome.

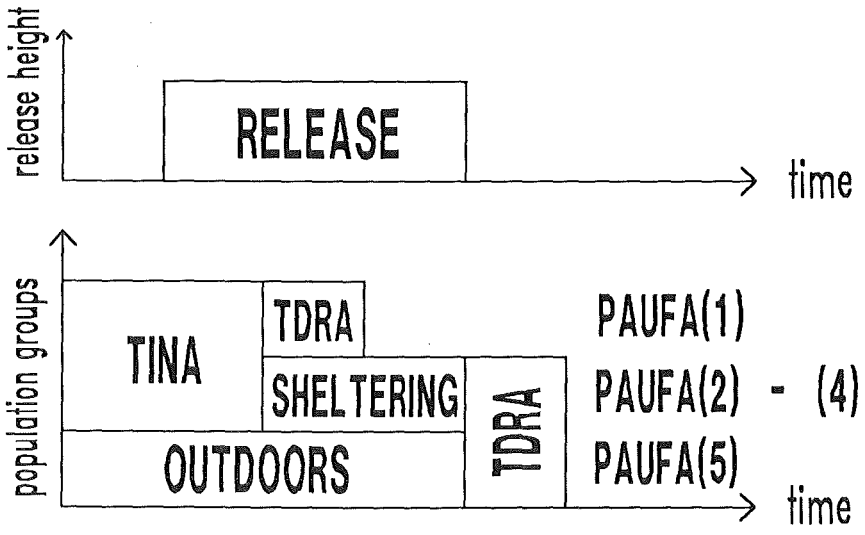


Figure 6. Time dependence of release and emergency actions

Conse-quence variable	Particu-larity	Important parameters	Impor-tance ranking	PRCC 60P	R^2 in (%) 60P	PRCC 50C	R^2 in (%) 50C
DOSLUD1		TINA	1	.97	86	.96	81
		PAUFA(1)	2	-.84	11	-.87	15
	60P	PAUFA(5)	3	.46	1		
	50C	TDRA	3			.58	2 *)
	50C	PAUFA(5)	4			.56	3
DOSLUD2		TINA	1	.91	64	.91	50
		PAUFA(1)	2	-.81	26	-.88	33
	60P	GRWRTB	3	.46	2		
	50C	PAUFA(5)	3			.64	11
DOSLUD3		GRWRTB	1	.97	75	.96	73
		PAUFA(1)	2	-.90	18	-.87	21
		TINA	3	.77	7	.57	2
DOSBMD1		TINA	1	.99	86	.98	78
		PAUFA(5)	2	.89	9	.86	12
	60P	PAUFA(1)	3	-.75	3		
	50C	TDRA	3			.80	6 *)
	50C	PAUFA(1)	4			-.73	4
DOSBMD2		TINA	1	.82	54	.75	37
	60P	IEVA2	2	-.69	19		
	60P	GRWRTB	3	.54	15		
	50C	GRWRTB	2			.69	8.75
	50C	IEVA2	3			-.64	23
DOSBMD3		GRWRTB	1	1.00	98	.99	96
	60P	PAUFA(1)	2	-.73	2		
	60P	TINA	3	.69	1		
	50C	TINA	2			.67	1
	50C	PAUFA(1)	3			-.63	1

Note:
*) The R^2 - values are calculated for the total group of correlated TDRA - parameters.

Table 9. Most important parameters for uncertainties in dose calculations: This table indicates the most important parameters (including ranking, range of PRCC - and R^2 - values) for the variability in consequences for different sample sizes (50, 60)
((P) or (C) means all driving time parameters are partly (completely) correlated)

Table 9 and Table 10 to summarize the main sensitivity information given in Appendix C. The most important parameters are listed together with their for PRCC- and R^2-values, respectively. Some particularities are detected and appear in the tables.

Conse-quence variable	Particu-larity	Important parameters	Impor-tance ranking	PRCC 60P	R^2 in (%) 60P	PRCC 50C	R^2 in (%) 50C
RSKLUD1		TINA	1	.95	78	.96	72
		PAUFA(1)	2	-.83	17	-.87	19
RSKBMD1		PAUFA(5)	1	.97	80	.98	80
		TINA	2	.83	13	.86	14
	60P	TDELA	3	.55	1		
	50C	TDRA	3			.74	4
POP(LU)		TINA	1	.96	76	.96	68
		PAUFA(1)	2	-.84	16	-.89	20
POP(BM)		PAUFA(5)	1	.97	75	.98	76
		TINA	2	.88	17	.92	20

Table 10. Most important parameters for uncertainties in individual risks and early fatalities: This table indicates the most important parameters (including ranking, range of PRCC - and R^2 - values) for the variability in consequences for different sample sizes (50, 60)
((P) or (C) means all driving time parameters are partly (completely) correlated)

As explained above, the initial delay of actions in area A, TINA, and the fraction of population which evacuates spontaneously, PAUFA(1), or remains outside, PAUFA(5), are the dominating sensitive parameters.

Only in the first distance (.875 km) the driving time parameters, TDRA, play a certain role as third most important parameter (group), but the percentage contribution of TDRA to the overall uncertainty is rather small (between 2% and 6%).

Two different cases are distinguished:
the driving time parameters are partly (P) or completely (C) correlated. This is done to compare the uncertainty results of simple and rather detailed modelling of driving times. (see [24] and [25]) of the parameter 'driving time' in evacuations in the accident consequence code UFOMOD of the German Risk Study Phase B. The contribution of driving time to uncertainty in consequences can be answered by sensitivity analyses. The partly or completely correlated driving time parameters, TDRA, are in competition with PAUFA(1) or PAUFA(5) for the importance rank 3. To get a conclusion: The importance of driving times does not change if only *one* driving time parameter (e.g. TDRA≡TA(2,50) 10 km) is varied, while all other driving time parameters are completely correlated to this TDRA≡TA(2,50) (10 km) parameter.

For the acute bone marrow dose in 4.9 km distance the index of the last outer radius belonging to area A, IEVA2, gets an importance rank 2 (60P-case) or rank 3 (50C-case). But the percentage contribution to uncertainty in the consequence variable DOSBMD2 is only between 19% and 23%.

The intervention criteria for evacuation of area B, GRWRTB, becomes important in the second (4.9 km) and third (8.75 km) distance, because it determines the extent of dose reducing emergency actions outside area A.

For the second (4.9 km) and the third (8.75 km) distance the analysis does not show any individual risks and early fatalities.

4. Summary

The investigation presented in this report was performed as a guidance on important parameters in the countermeasures submodule of UFOMOD and to study the effect of uncertainties.

Results are presented as confidence bands of complementary cumulative frequency distributions (CCFDs) of individual acute organ doses (lung, bone marrow), individual risks (pulmonary, hematopoietic syndrome) and the corresponding early fatalities, partially as a function of distance from the site. In addition the ranked influence of the uncertain parameters on the different consequence types is shown. For the estimation of confidence bands a model parameter sample size of $n = 60$ equal to 3 times the number of uncertain model parameters is chosen. For a reduced set of nine model parameters a sample size of $n = 50$ is selected. Different samples or the different sample sizes did not change the 5%-95% - confidence bands. The selected sample sizes are sufficient to get statistically stable results of the sensitivity analysis.

A total of 20 parameters was considered in this report. The most sensitive parameters of the countermeasures submodule of UFOMOD appeared to be the initial delay of emergency actions in a keyhole shaped area A and the fraction of the population evacuating area A spontaneously during the sheltering period or staying outdoors. Under the conditions of the source term used in this report the influence on the overall uncertainty in the consequence variables - individual acute organ doses, individual risks and early fatalities - of driving times to leave the evacuation area is rather small.

More Details, Figures and Tables

Appendix A.1 describes the partial (rank) correlation coefficient and some significance testing problems.

Appendix A.2 gives some remarks concerning the coefficient of determination, R^2.

Appendices B and C comprise a detailed set of figures for uncertainty and sensitivity analyses, respectively. If necessary some legends to understand abbreviations are added. The figures and tables are given in the following sequence:

- UNCERTAINTY (CCFDs and confidence curves)
  - **Acute individual doses** (lung, bone marrow)
  - **Individual risks** (pulmonary syndrome, hematopoietic syndrome)
  - **Early fatalities** (pulmonary syndrome, hematopoietic syndrome)

- **SENSITIVITY** (Tables of PRCC values)
  - Comparison of countermeasure runs for n = 50, 60

Appendix A. Some Mathematical Details

A.1 Partial correlation coefficients

A.1.1 Definition

This paragraph follows some results presented in [10].

Sensitivity analysis in conjunction with Latin hypercube sampling is based on the construction of regression models. The observations

$$(X_{1i}, X_{2i}, \ldots, X_{ki}, Y_i) \qquad i = 1,\ldots,n$$

are used to construct models of the form

$$Y_{est} = b_0 + \sum_q b_q Z_q$$

subject to the constraint that

$$\Sigma(Y - Y_{est})^2$$

be minimized. b_0 , B_q are constants and each Z_q is a function of $X_1, \ldots, X_k$.

An important property of least squares regression is that

$$\Sigma(Y - Y_m)^2 = \Sigma(Y - Y_{est})^2 + \Sigma(Y_{est} - Y_m)^2$$

where Y_m is the mean of the Y_i-values.

The R^2 - value (**coefficient of determination**) for a regression falls between 0 and 1 and is defined by

$$R^2 = \frac{\Sigma(Y_{est} - Y_m)^2}{\Sigma(Y - Y_m)^2}$$

The closeness of an R^2 - value to 1 provides an indication of how successful the regression model is in accounting for the variation in Y.

For a regression model of the form

$$Y_{est} = b_0 + b_1 Z$$

with an R^2 - value of r^2, the number $sign(b_1)|r|$ is called the correlation coefficient between Y and Z, where $sign(b_1) = 1$ if $b_1 \geq 1$, and $sign(b_1) = -1$ if $b_1 < 1$. This number provides a measure of linear relationship between these two variables. When more than one independent variable is under consideration, *partial correlation coefficients* are used to provide a measure of the linear relationships between Y and the individual independent variables. The *partial correlation coefficient* between Y and an individual variable Z_p is obtained from the use of a sequence of regression models. The following two regression models are constructed:

$$Y'_{est} = a_0 + \sum_{q \neq p} a_q Z_q \quad \text{and}$$

$$Z'_{est} = c_0 + \sum_{q \neq p} c_q Z_q \ .$$

Then, the results of the two preceding regressions are used to define the new variables $Y - Y'_{est}$ and $Z_p - Z'_p$. By definition, the **partial correlation coefficient between** Y and Z_p is the simple correlation coefficient between $Y - Y'_{est}$ and $Z_p - Z'_p$. Therefore, the partial correlation coefficient provides a measure of the linear relationship between Y and Z_p with the linear effects of the other variables removed.

Example:

Sometimes the apparent correlation between two variables may be due in part to the direct influence on both of the other variables: Y and X_1 are correlated, but are both influenced by a variable X_2 . The influence of X_2 on Y and X_1 must be removed. *Simple linear regression* of Y resp. X_1 on X_2 gives:

$$Y' = \beta_0 + \beta_1 X_2, \quad X'_1 = \gamma_0 + \gamma_1 X_2$$

Define new variables (Y - Y') and $(X_1 - X'_1)$. The simple correlation (based on the Pearson product moment correlation) between the 'residuals' (Y - Y') and $(X_1 - X'_1)$ is called the **partial correlation coefficient between Y and X_1, given X_2** (i.e., the linear influence of X_2 on both Y and X_1 removed), and is denoted by $r_{1Y.2}$:

$$r_{1Y.2} = \frac{r_{1Y} - r_{12} r_{Y2}}{\sqrt{(1 - r_{12}^2)(1 - r_{Y2}^2)}} \qquad [5]$$

r_{1Y} , r_{12} , r_{Y2} are simple Pearson product moment correlations of the corresponding variables. For more details see [14], [10], [11], [16] and [26].
□

A.1.2 Significance tests

Following [5], the well-known Pearson product-moment correlation formula can be used to estimate Pearson's partial correlation coefficient. Spearman's rank correlation ρ has also been extended to measure partial rank correlation.

Partial correlation coefficients (PRCs) are correlation coefficients on conditional distributions. The distribution of the partial correlation coefficients depends on the multivariate distribution function of the underlying variables. Therefore PRCs may not be directly used as test statistics in nonparametric tests.

Starting from some well-known theorems, we may nevertheless do some approximative tests and analyses.

Step 1:

Find the distribution of the sampling correlation coefficient for random variables (X,Y) with bivariate normal distribution.

Theorem (Pitman's test): (see [17])

Let $u_i = (x_i, y_i)$ (i = 1,...,n) be a random sample from a bivariate normal distribution with correlation r. Let r_s be the sample correlation coefficient (Pearson's product moment coefficient):

$$r_s = \frac{\sum_i (y_i - y_m)(x_i - x_m)}{\left[\sum_i (y_i - y_m)^2 \sum_i (x_i - x_m)^2\right]^{\frac{1}{2}}} \qquad [6]$$

Let r = 0 then

$$T_s = r_s \sqrt{\frac{(n-2)}{(1 - r_s^2)}} \qquad [7]$$

is distributed as Student' t with (n-2) degrees of freedom.
□

Theorem: (see [18] or [22])

Let $(z_1, \ldots, z_k)$ be a random sample from a k-dimensional normal distribution and $r_{ij,u_1,\ldots,u_p} = 0$ where $r_{ij,u_1,\ldots,u_p}$ is the partial correlation coefficient) of order p (p=k-2). $u_1, \ldots, u_p$ are p=k-2 numbers from {1,...k} which are different from i and j. That means the *partial* correlation between Z_i and Z_j is tested, say, while the indirect correlation due to $Z_{u_1}, \ldots, Z_{u_p}$ is eliminated. Let $r_{s;ij,u_1,\ldots,u_p}$ be the sample partial correlation coefficient) of order p (p=k-2). Take n samples from the vector z, then

$$T_s = r_{s;ij,u_1,\ldots,u_p} \sqrt{\frac{(n-2-p)}{(1-r^2_{s;ij,u_1,\ldots,u_p})}} \qquad [8]$$

is distributed as Student' t with (n-2-p) degrees of freedom.
□

Step 2:

Try to find adequate approximate formulas for non-normal situations.

Let $w_i = (u_i, v_i)$ (i=1,...,n) be a random sample from a bivariate distribution with correlation r. Let r_s be the sample correlation coefficient. Transform the sample values $(u_1, \ldots, u_n)$ and $(v_1, \ldots, v_n)$ into their order statistics $(u_{(1)}, \ldots, u_{(n)})$ and $(v_{(1)}, \ldots, v_{(n)})$. Then do an *expected normal scores transformation:* Replace the order statistics of the (u,v)-variables by the expected value of the corresponding order statistics of standard normal variates (X,Y). Then r_s transforms approximately to ψ_s:

$$r_s \sim \psi_s = \frac{\sum_i E(x_{(i)})E(y_{(i)})}{\sqrt{\sum_i E^2(x_{(i)}) \sum_i E^2(y_{(i)})}} \qquad [9]$$

(This is clear from the hint that for a N(0,1)-distributed variable X one has $\Sigma E(X_{(i)}) = 0$ because of $E(X_{(i)}) = -E(X_{(n-i+1)})$.

ψ_s can be used for an expected normal scores test of the hypothesis that U and V are uncorrelated.

[5] explains the role of the expected normal scores as well defined numbers which replace the unpleasant behaviour connected with using the order statistics from normal variables themselves. The procedure is based only on the ranks of the observations and is therefore a *rank test.*

Fisher and Yates (see [3]) suggested the analogue to Pitman's test using the exact normal scores instead of the the original data and applied the usual parametric procedures to these expected normal scores as a nonparametric procedure.

Step 3:

Give the significance test procedure.

The procedure is as follows:

The 'null' hypothesis reads: "No *partial* correlation exists between Y (the consequence variable) and X_i (one of the uncertain model parameters)", while the indirect influence due to to the other model parameters is eliminated.

Then, for a sample of size n, the partial sample rank correlation, $\rho_{s;Y_i,u_1,\ldots,u_p}$, between Y and X_i has to be calculated. ρ_s is then compared with the quantiles of the distribution of the test statistic. The comparison is made at a certain prescribed level of significance, α.

The 'null' hypothesis of *no* correlation is rejected, if the correlation value ρ_s leads to $|\rho_s| \geq T_{\alpha/2,n}$, the **critical value**, where $T_{\alpha/2,n}$ is a quantile of the test statistic's distribution.

$$T_{\alpha/2,n} \sim \frac{t_{\alpha/2,n-k}}{\sqrt{n-k+t^2_{\alpha/2,n-k}}} \qquad [10]$$

$t_{\alpha/2,n-k}$ is the (1 - α/2)-quantile of the t-distribution with n-k degrees of freedom (compare [13] or [19]). Eq. [10] is easily derived from Eq. [8] .

Example:

For k = 20 uncertain input model parameters and α = 0.05 significance level, the partial rank correlation value (PRCC), ρ, is significant, if its absolute value is greater than 0.43 (40 runs), 0.25 (80 runs) or 0.16 (100 runs) , respectively.

A.2 Remarks to R^2- values

Here some additional hints for motivation of the *coefficient of determination*, R^2, are given.

The *total variation* of the consequence variable, Y, is defined as $\Sigma(Y - Y_m)^2$, i.e. the sum of squares of the deviation of values of Y from the mean Y_m.

$$\Sigma(Y - Y_m)^2 = \Sigma(Y - Y_{est})^2 + \Sigma(Y_{est} - Y_m)^2$$

The first term on the right is called the *unexplained variation* while the second term is called the *explained variation* (by a regression model), so called because the deviations $(Y_{est} - Y_m)$ have a defined pattern while the deviations $(Y - Y_{est})$ behave in a random or unpredictable manner.

The ratio of explained variation to the total variation is called the *coefficient of determination*, R^2

$$R^2 = \frac{\Sigma(Y_{est} - Y_m)^2}{\Sigma(Y - Y_m)^2}$$

Remark:

In this report all R^2 - values R^2_s are normalized by R^2_t .

$$R^2 = \left(\frac{R^2_s}{R^2_t}\right) \times 100,$$

where R^2_s , R^2_t are calculated by the SANDIA - PRCSRC-code (see [16]) and the R^2_t - values are calculated with *all* (i.e. the complete set of) model parameters.

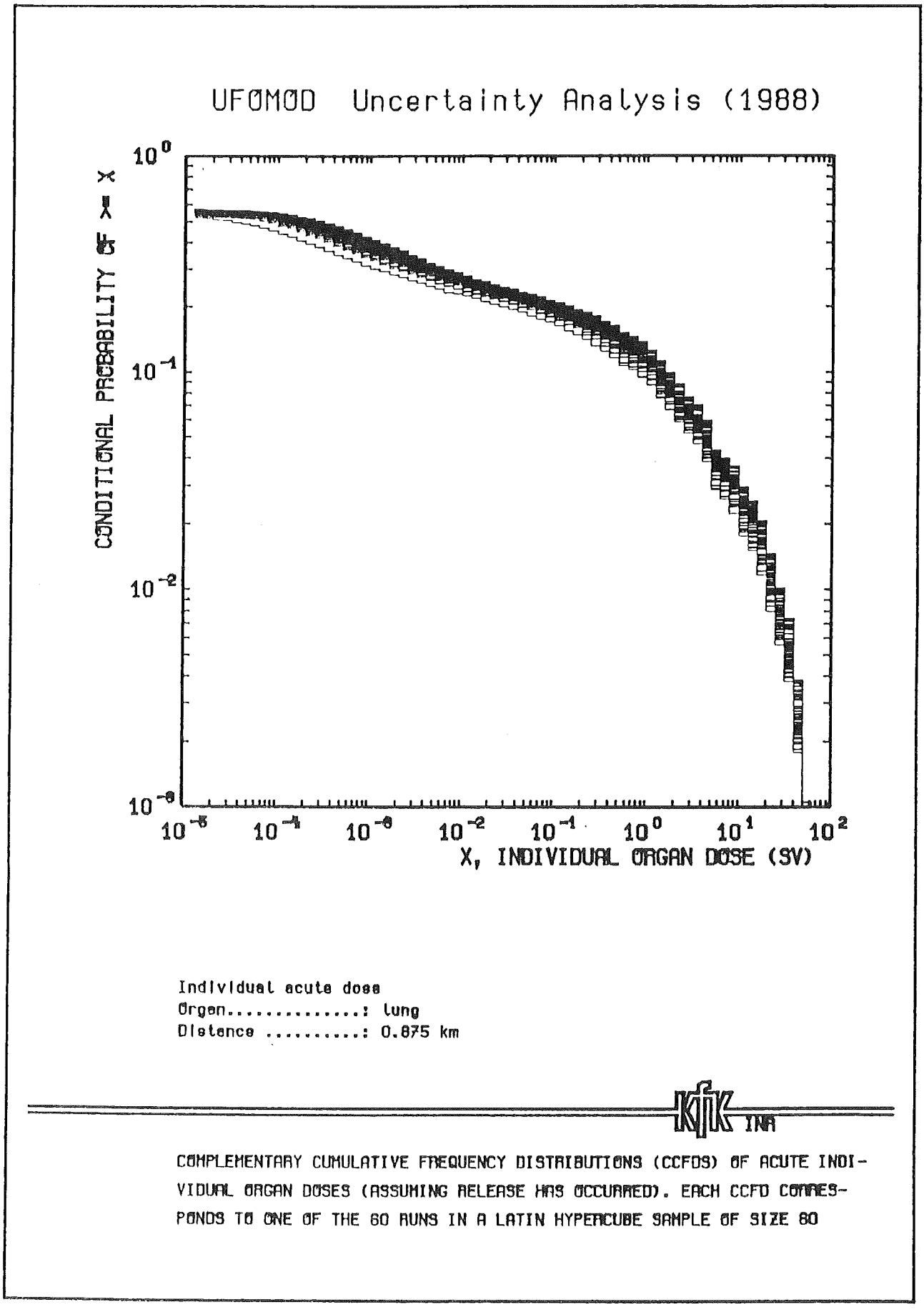
Appendix B. Uncertainty Analyses (Figures)

B.1 Doses, risks, early fatalities

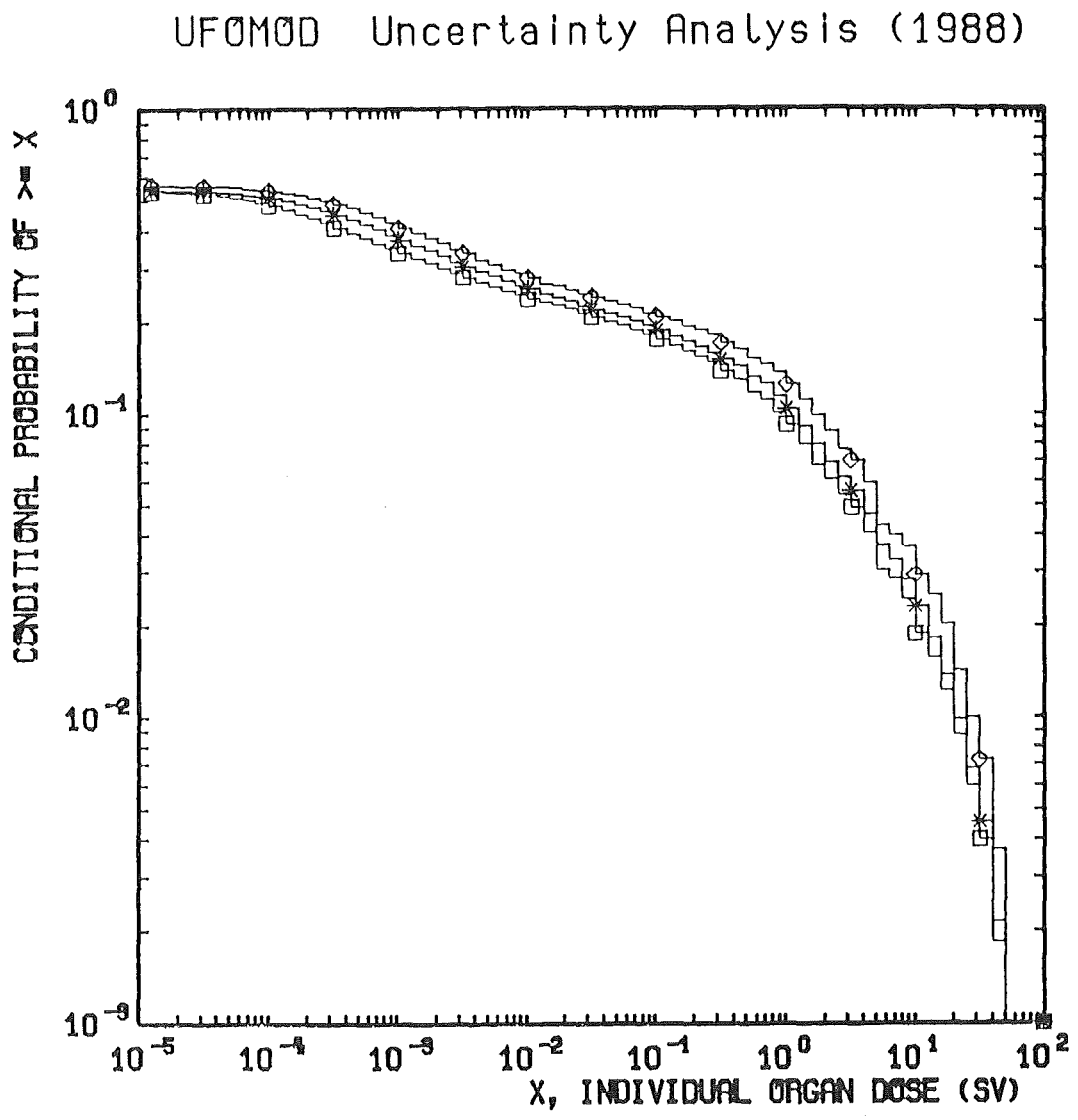
In this section CCFDs and the corresponding confidence curves are shown for individual acute doses at three distance intervals for lung and bone marrow; individual risks (pulmonary, hematopoietic syndrome); early fatalities (pulmonary, hematopoietic syndrome).

Sequence of figures:

- Individual acute doses (lung)
  - at distance 0.875 km
  - at distance 4.9 km
  - at distance 8.75 km
- Individual acute doses (bone marrow)
  - at distance 0.875 km
  - at distance 4.9 km
  - at distance 8.75 km
- Individual risk (pulmonary syndrome)
  - at distance 0.875 km
- Individual risk (hematopoietic syndrome)
  - at distance 0.875 km
- Early fatalities
  - hematopoietic syndrome
  - pulmonary syndrome



COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60

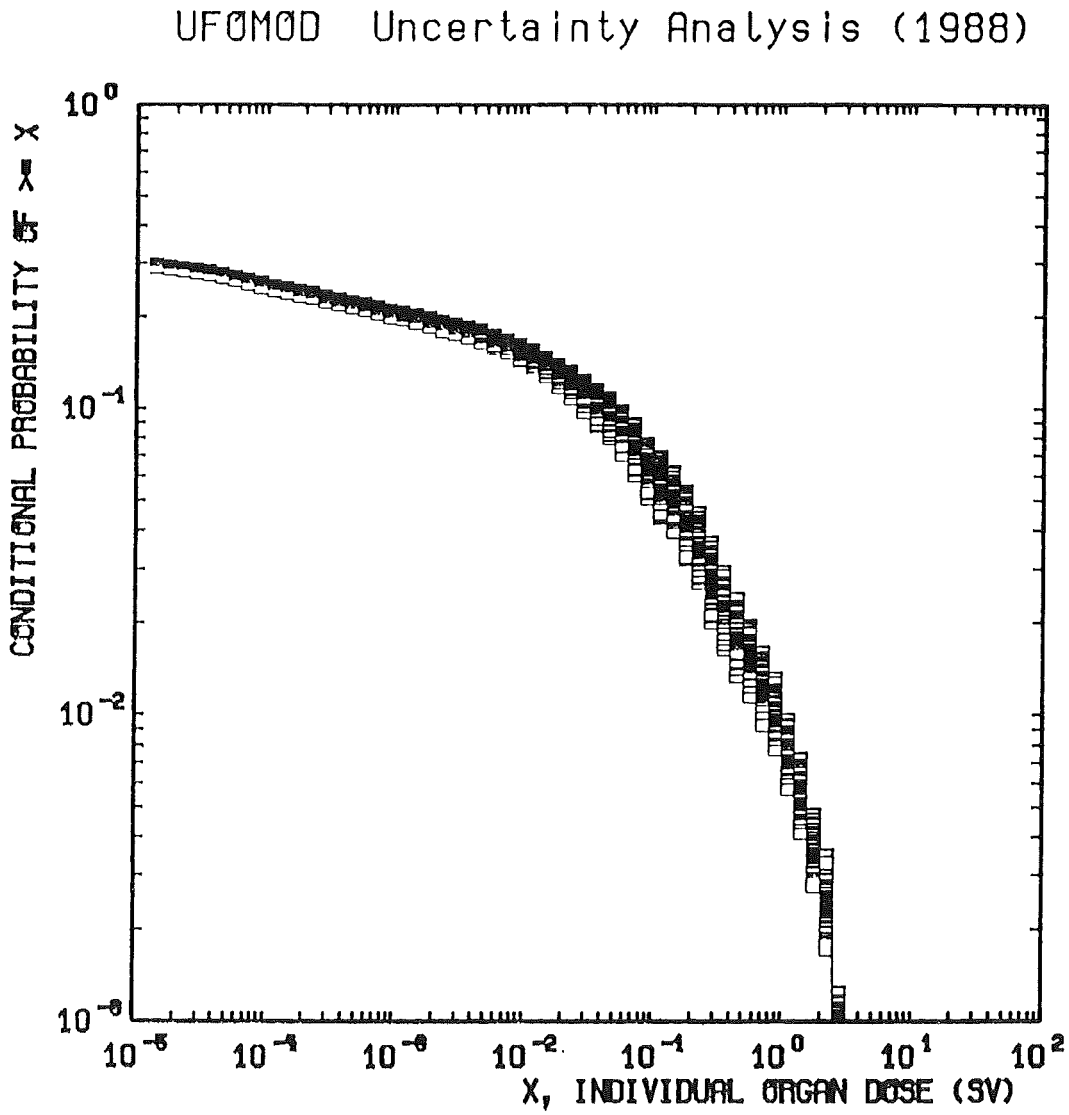


Individual acute dose
Organ.....: lung
Distance .....: 0.875 km

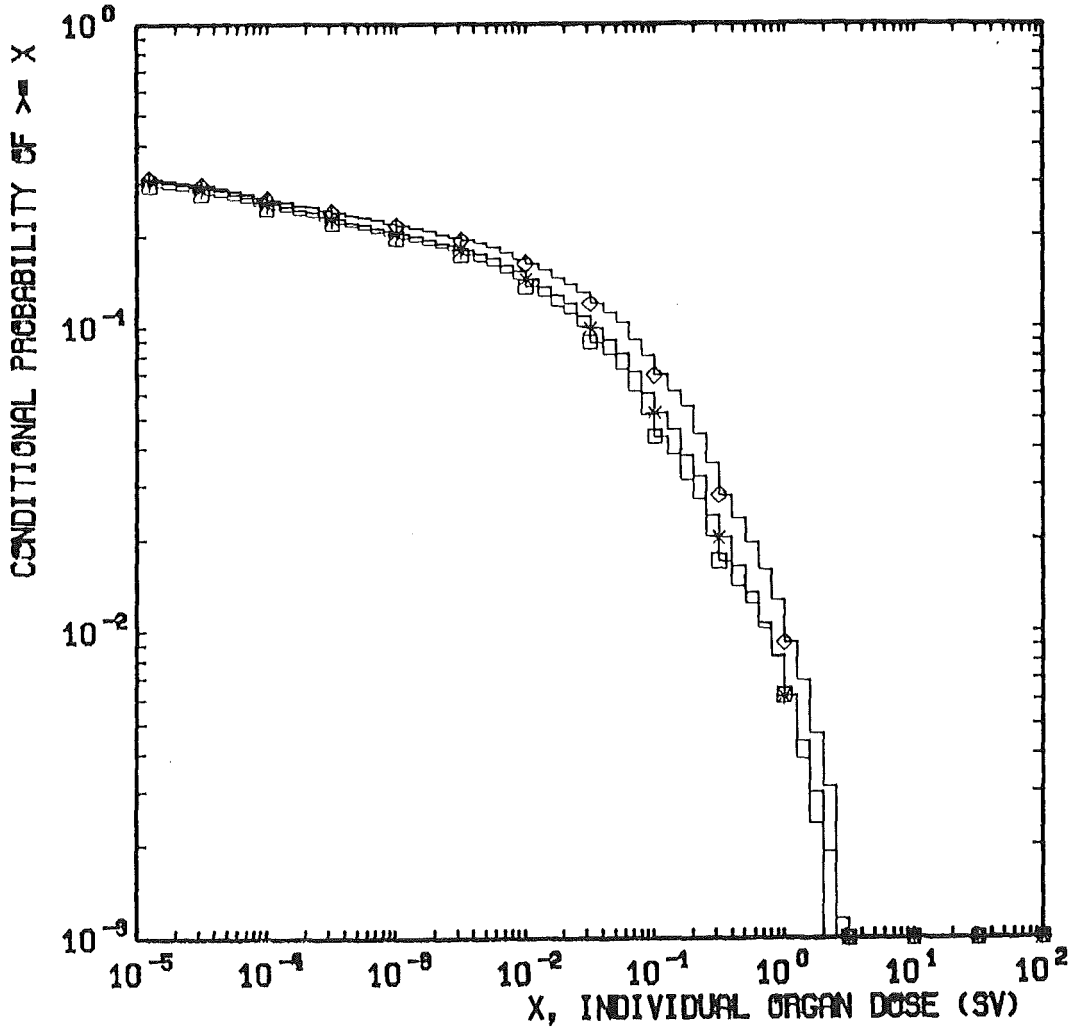
* : Ref.-Curve
▫ : 5% -Curve
◆ : 95% -Curve

KfK INR

REFERENCE CCFD OF THE ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS



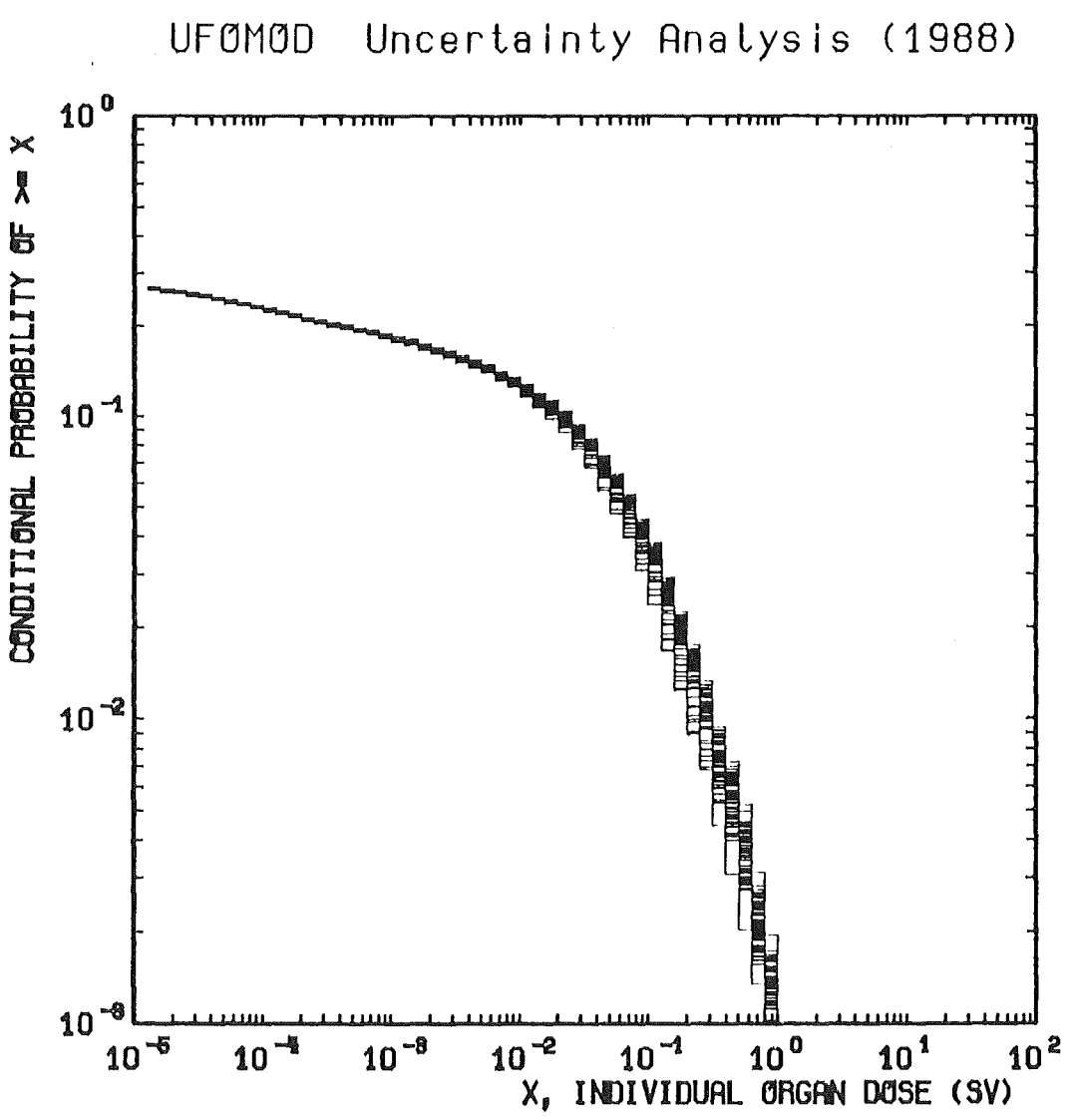
COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60



Individual acute dose
Organ.....: lung
Distance .....: 4.9 km

* : Ref.-Curve
□ : 5% -Curve
◇ : 95% -Curve

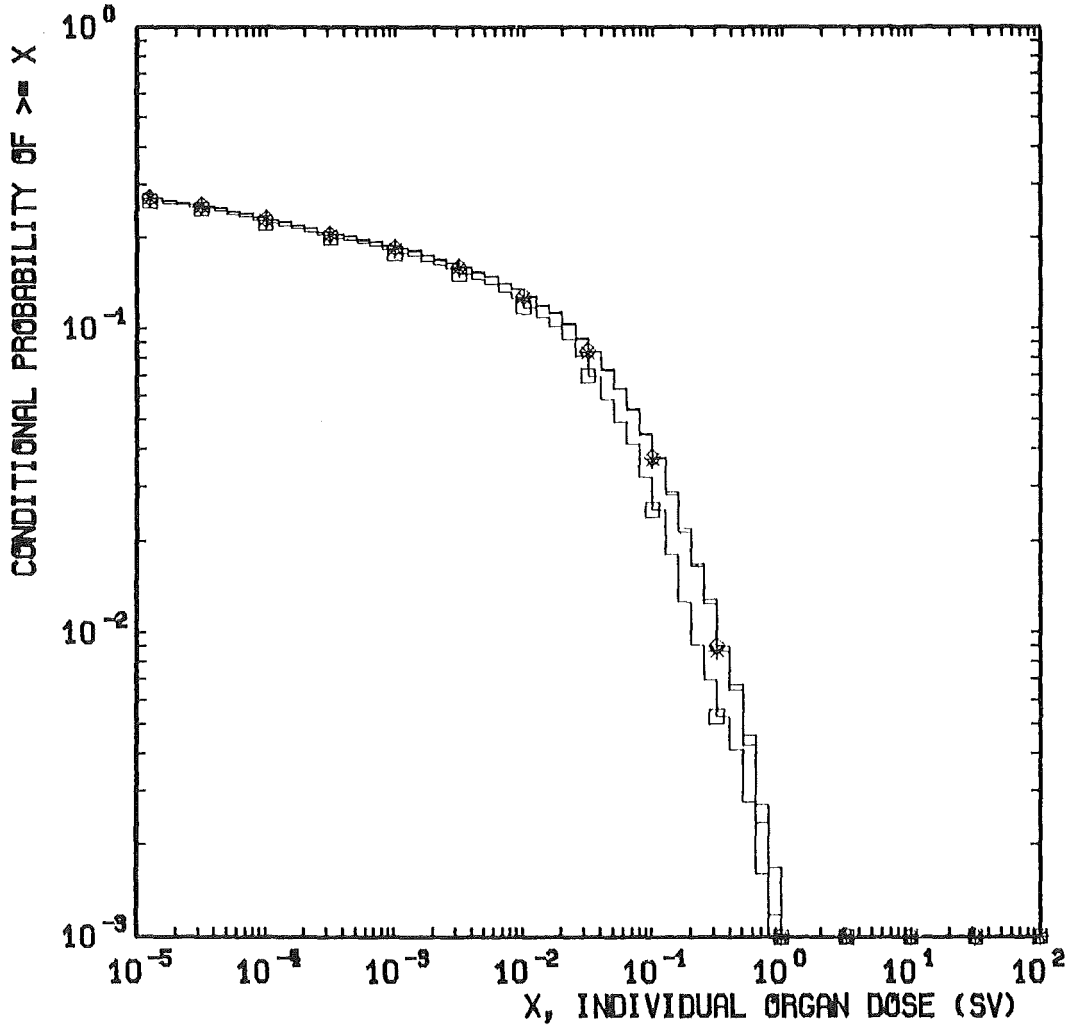
REFERENCE CCFD OF THE ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS



Individual acute dose
Organ.....: lung
Distance .....: 8.75 km

KfK INR

COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60

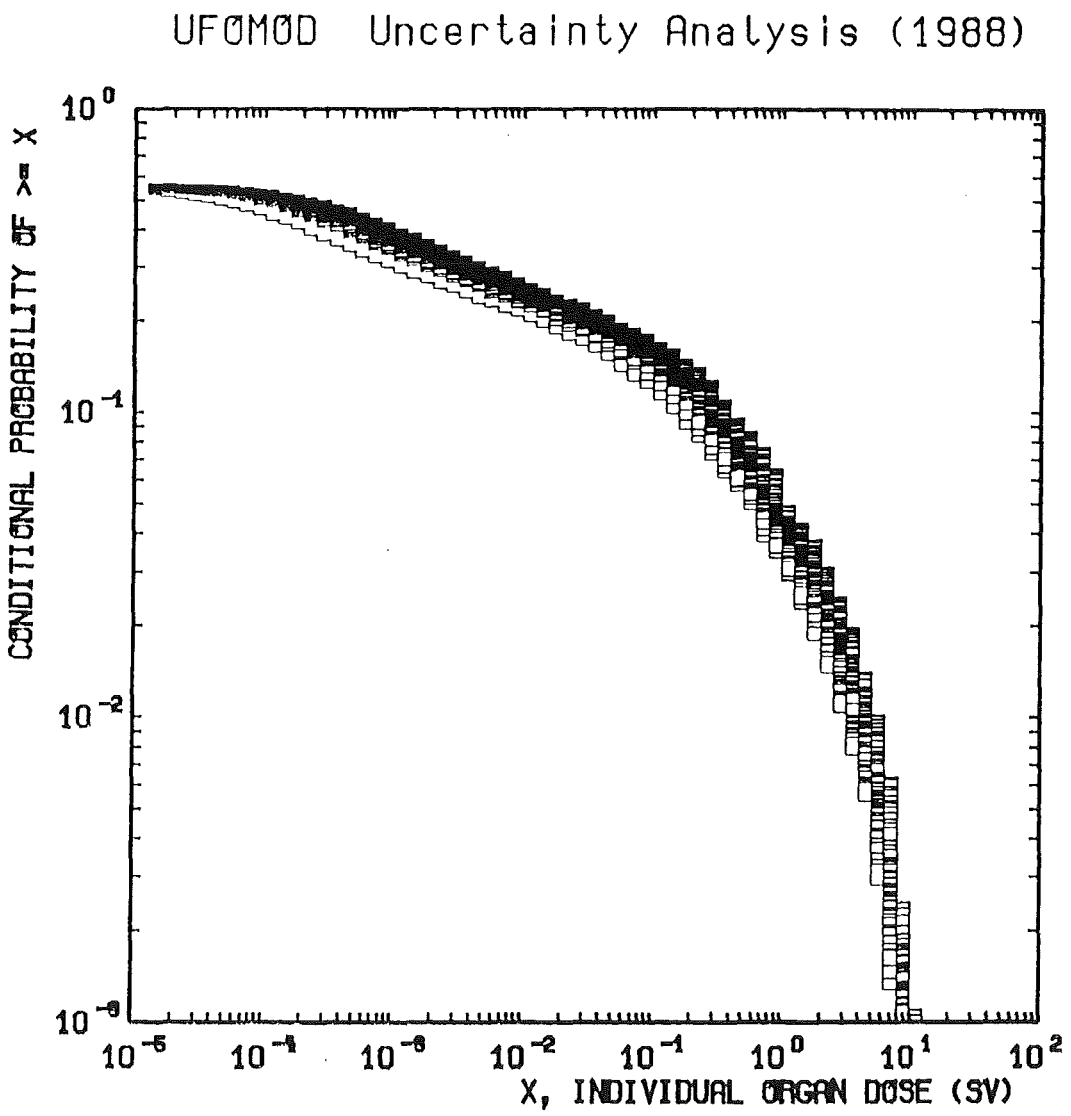


Individual acute dose
Organ.....: lung
Distance .....: 8.75 km

* : Ref.-Curve
□ : 5% -Curve
◇ : 95% -Curve

KfK INR

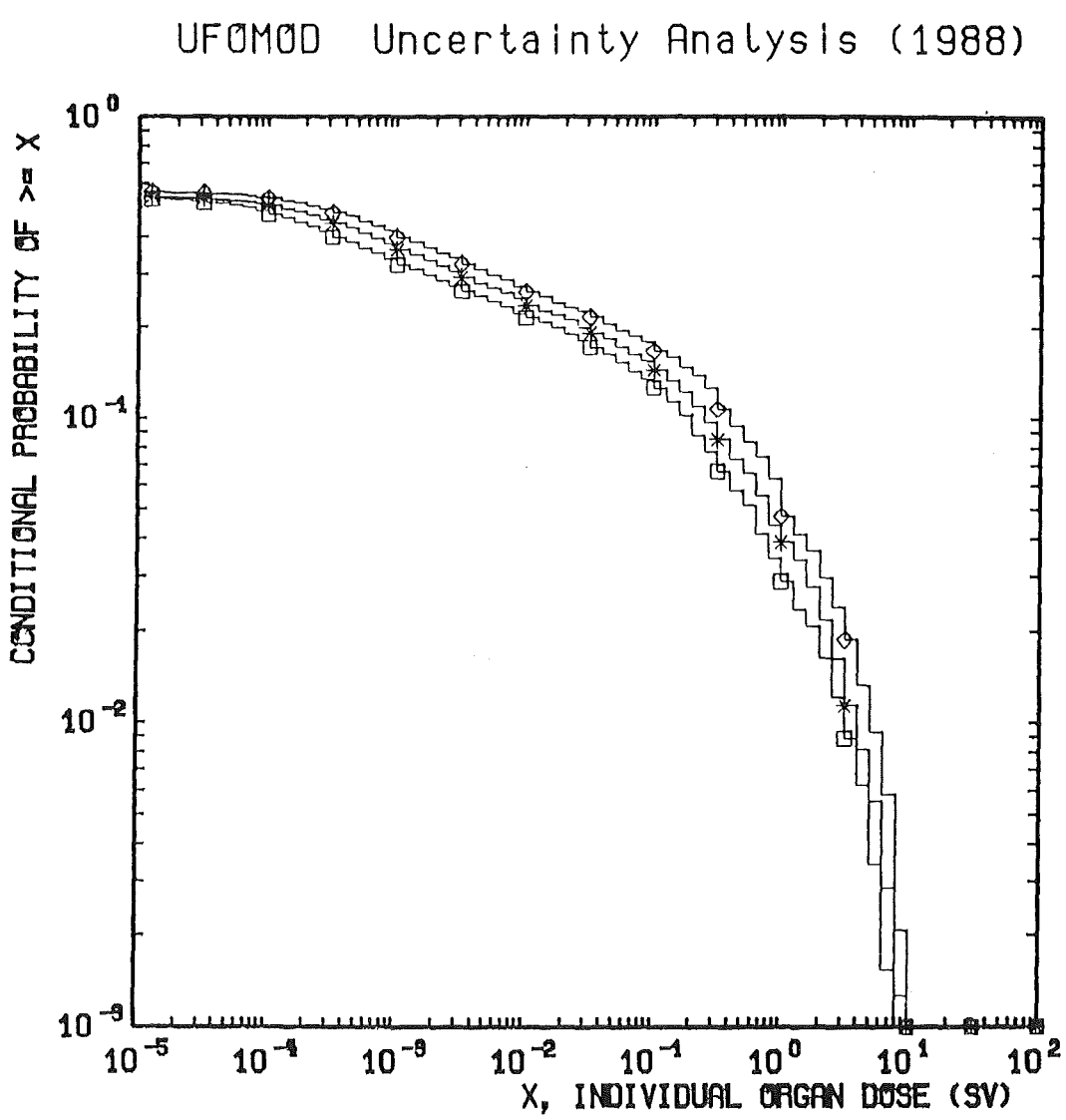
REFERENCE CCFD OF THE ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS



Individual acute dose
Organ.....: bone marrow
Distance .....: 0.875 km

KfK INR

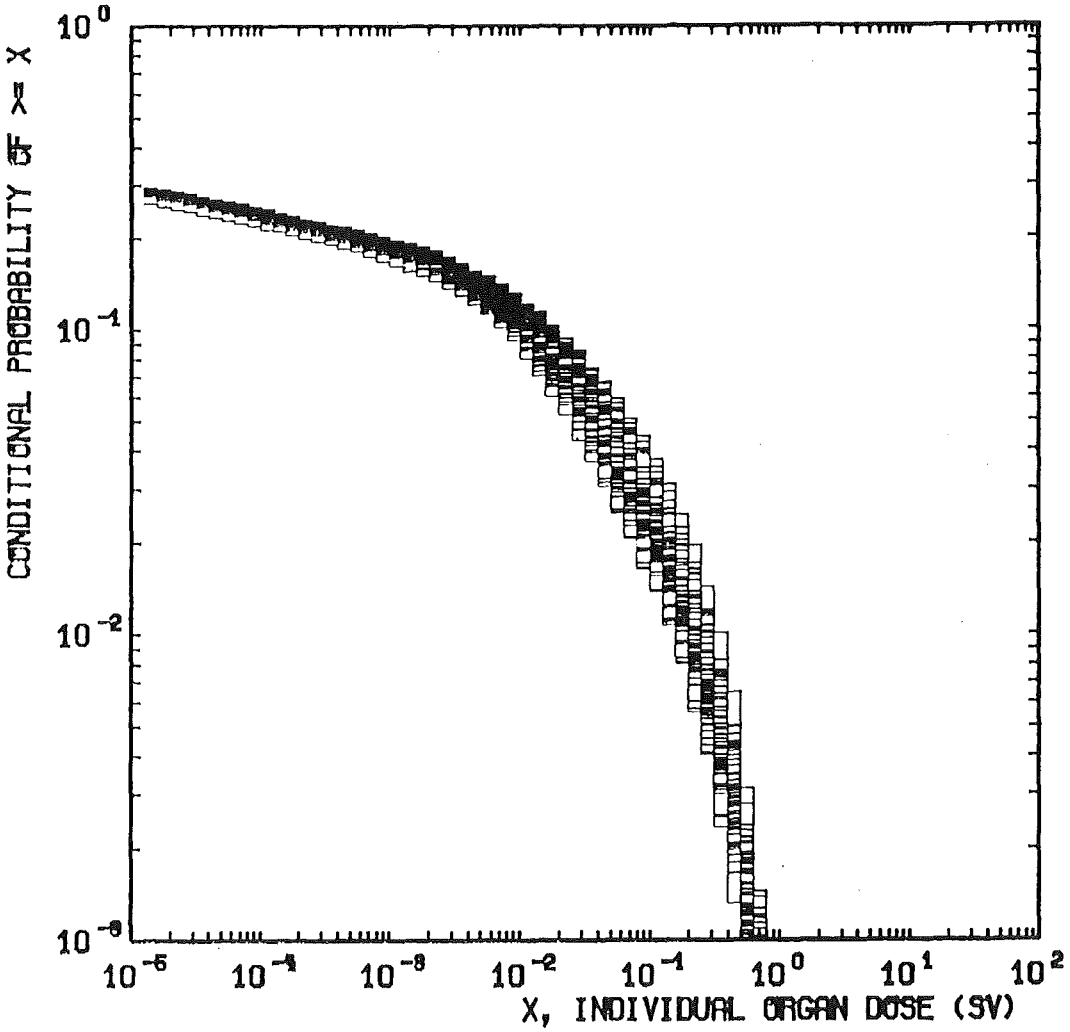
COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60



Individual acute dose
Organ.....: bone marrow
Distance .....: 0.875 km

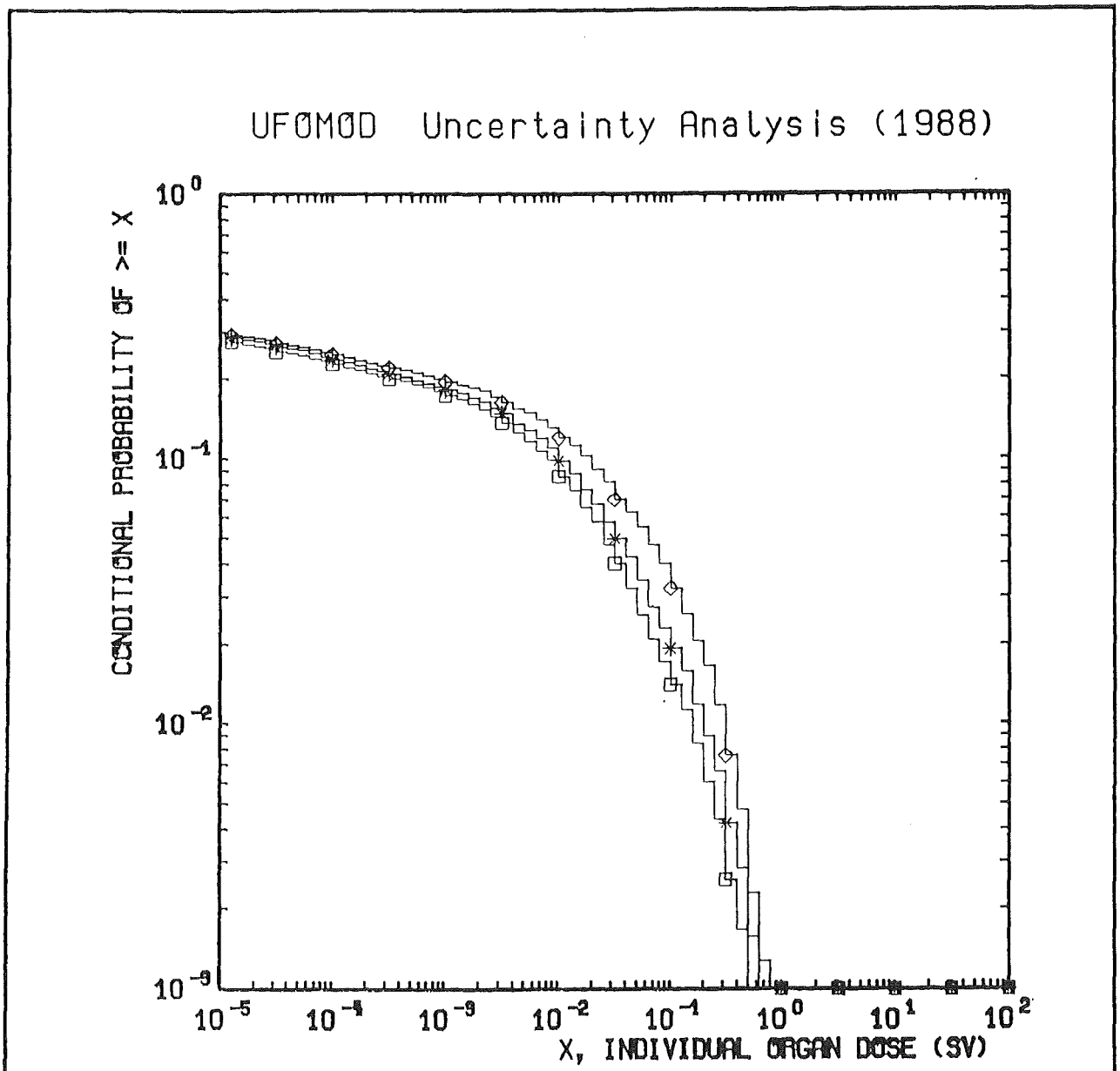
* : Ref.-Curve
□ : 5% -Curve
◇ : 95% -Curve

REFERENCE CCFD OF THE ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS

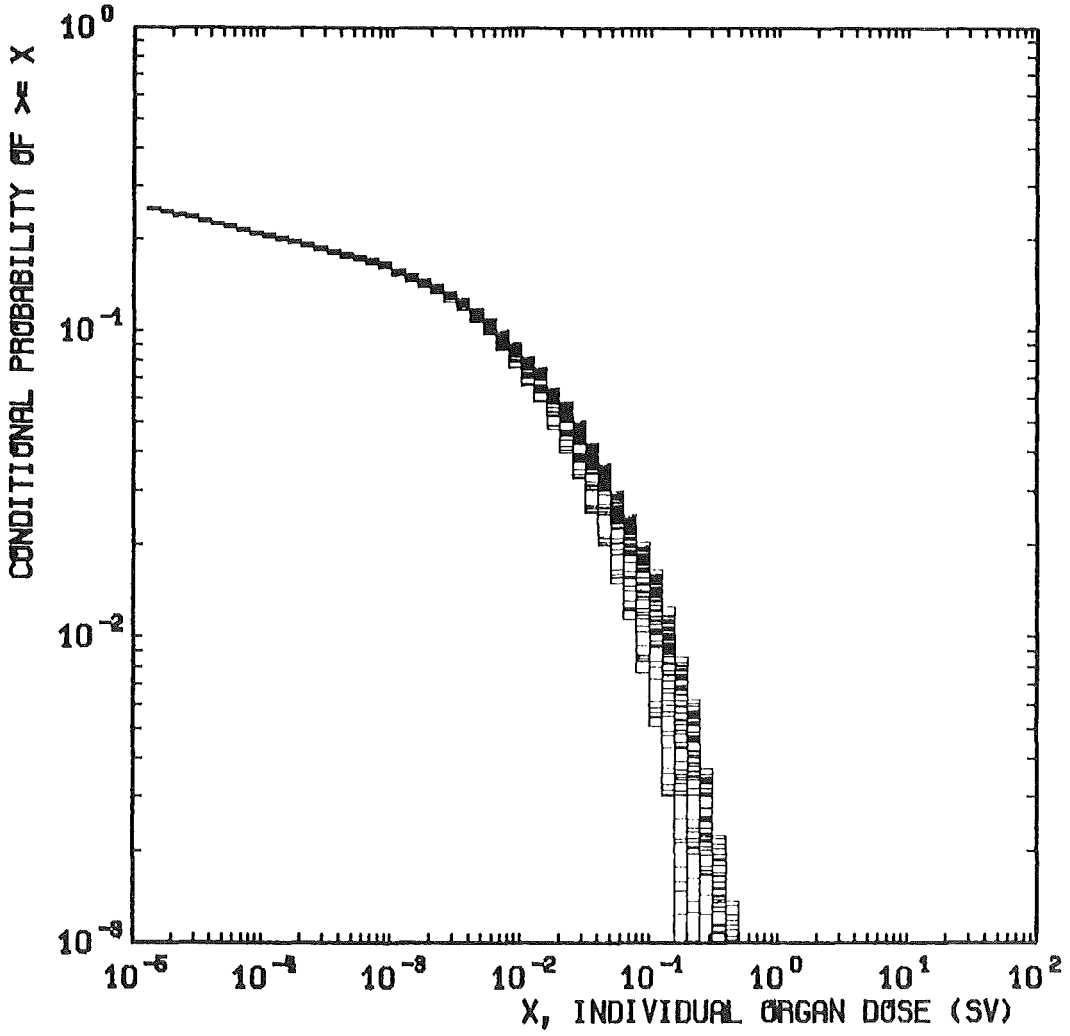


Individual acute dose
Organ.....: bone marrow
Distance .....: 4.9 km

COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60



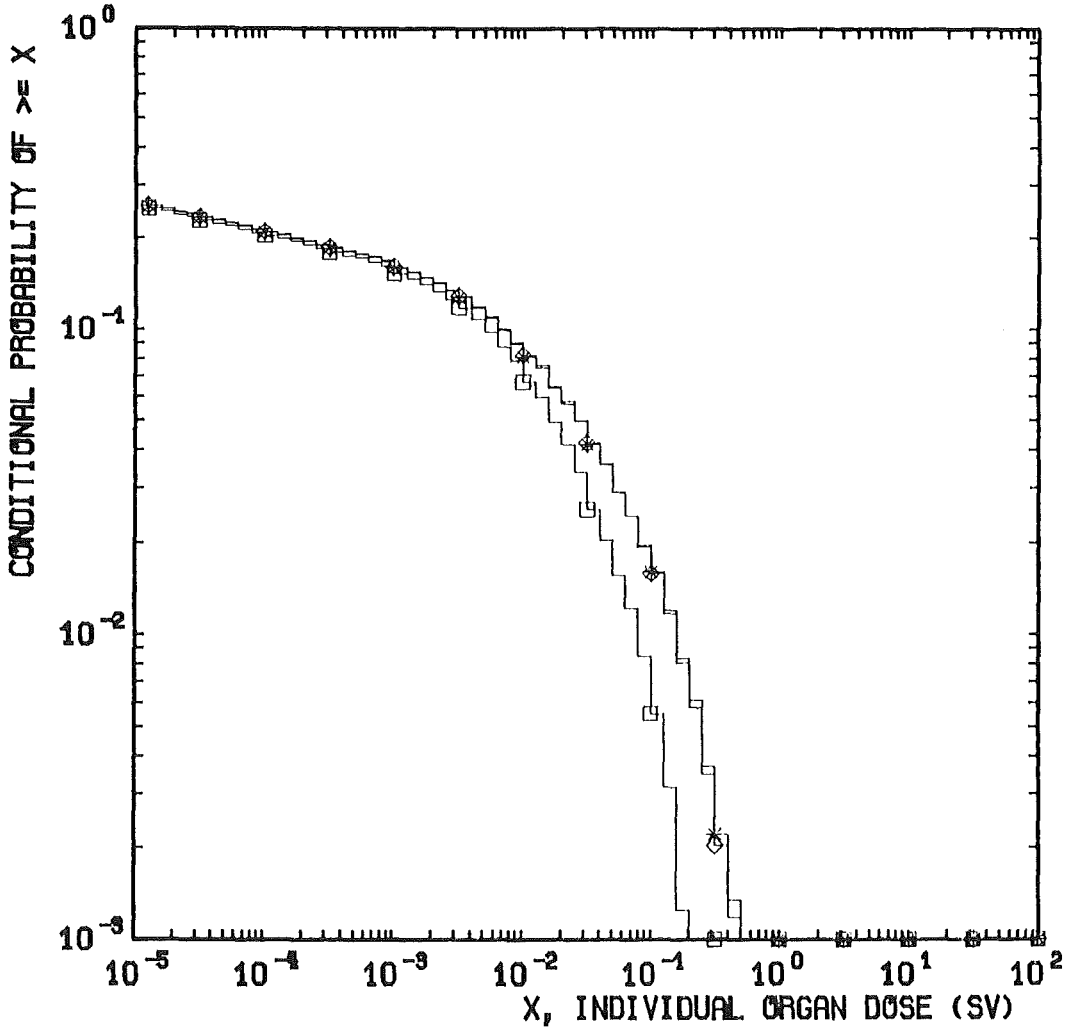
REFERENCE CCFD OF THE ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS



Individual acute dose
Organ.....: bone marrow
Distance .....: 8.75 km

KfK INR

COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF ACUTE INDIVIDUAL ORGAN DOSES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60

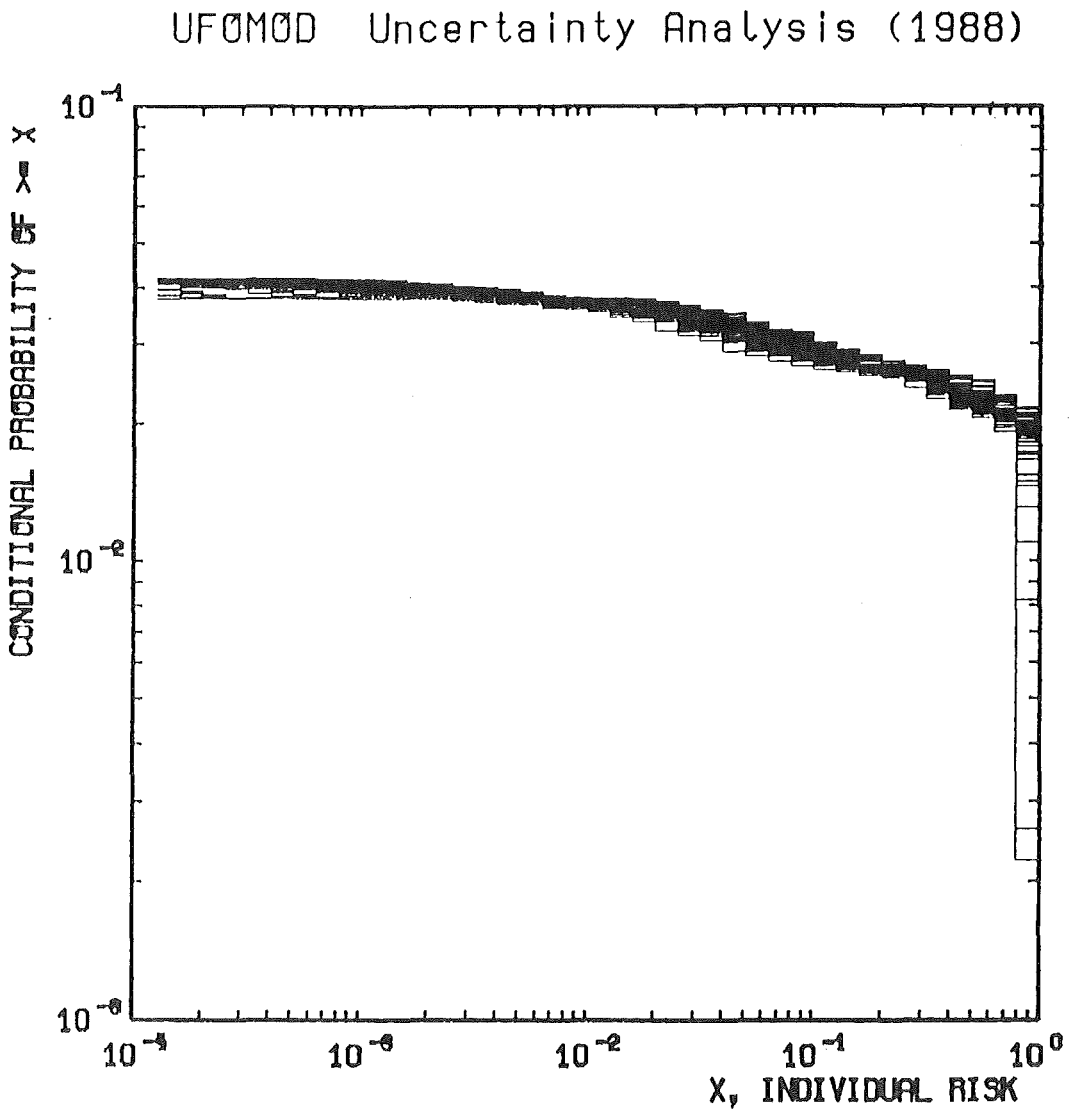


Individual acute dose
Organ.....: bone marrow
Distance .....: 8.75 km

* : Ref.-Curve
⊡ : 5% -Curve
◇ : 95% -Curve

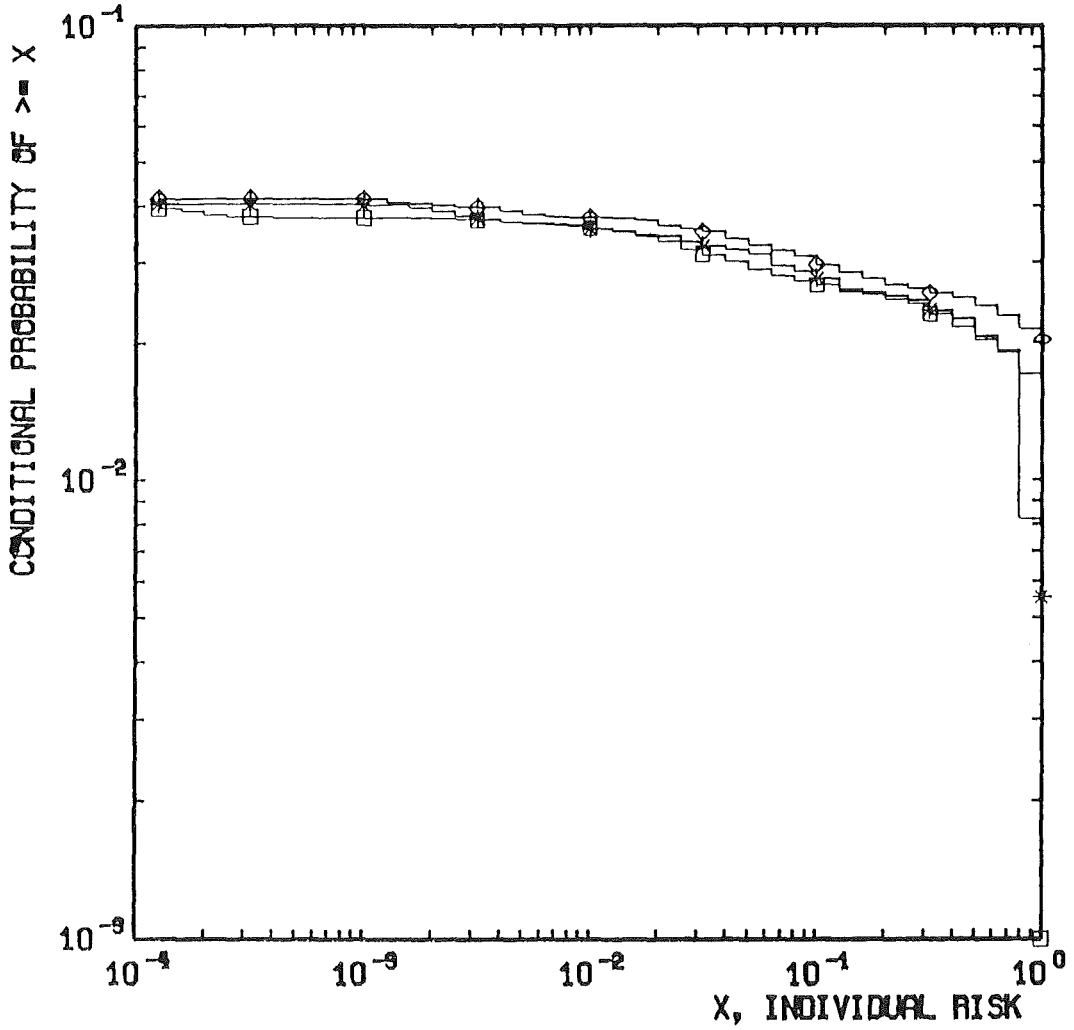
KfK INR

REFERENCE CCFD ØF THE ACUTE INDIVIDUAL ØRGAN DØSES (ASSUMING RELEASE HAS ØCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BØUNDS AT DISCRETE POINTS ØF THE X - AXIS



Individual risk
Health effect.....: pulmonary syndrome
Distance .....: 0.875 km

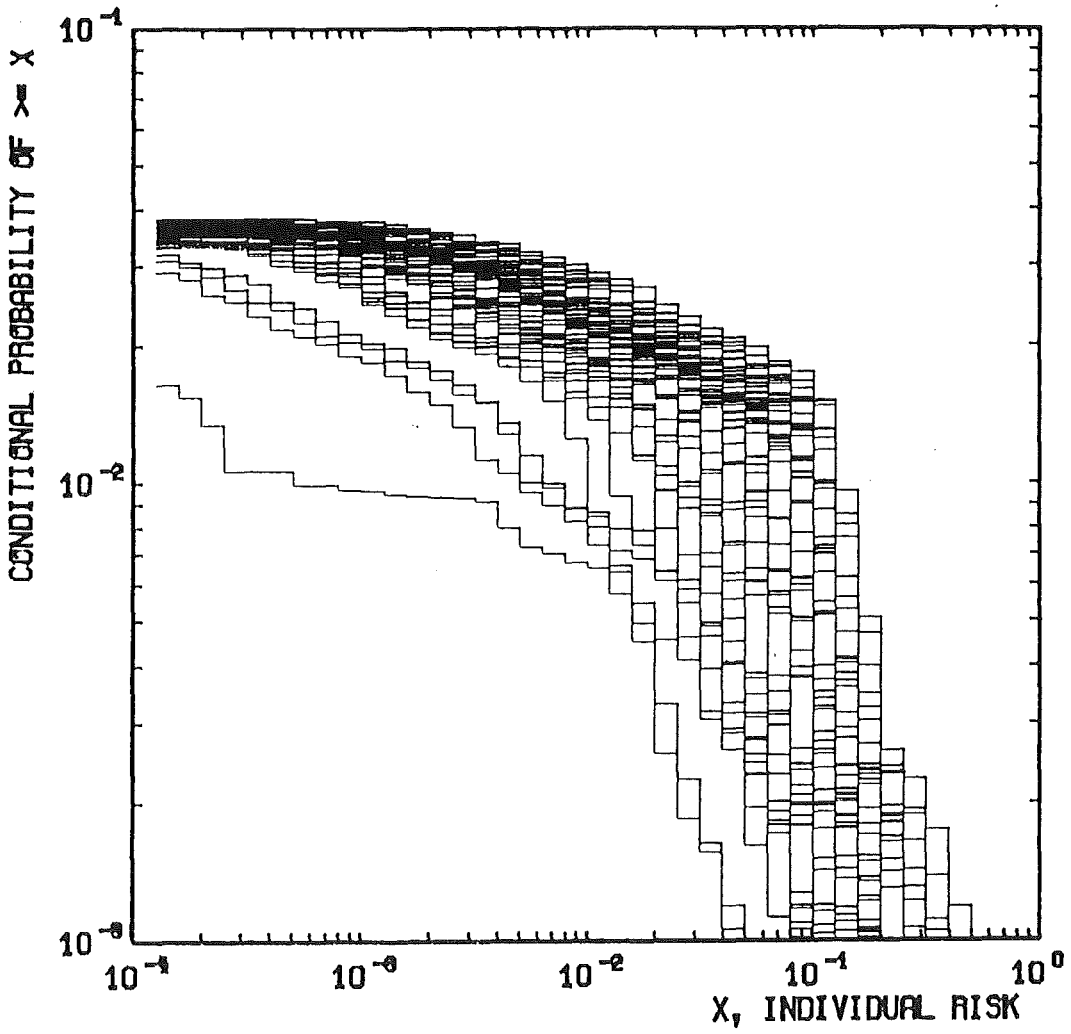
COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF INDIVIDUAL RISKS (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60.



Individual risk
Health effect.....: pulmonary syndrome
Distance .....: 0.875 km

* : Ref.-Curve
⊡ : 5% -Curve
◇ : 95% -Curve

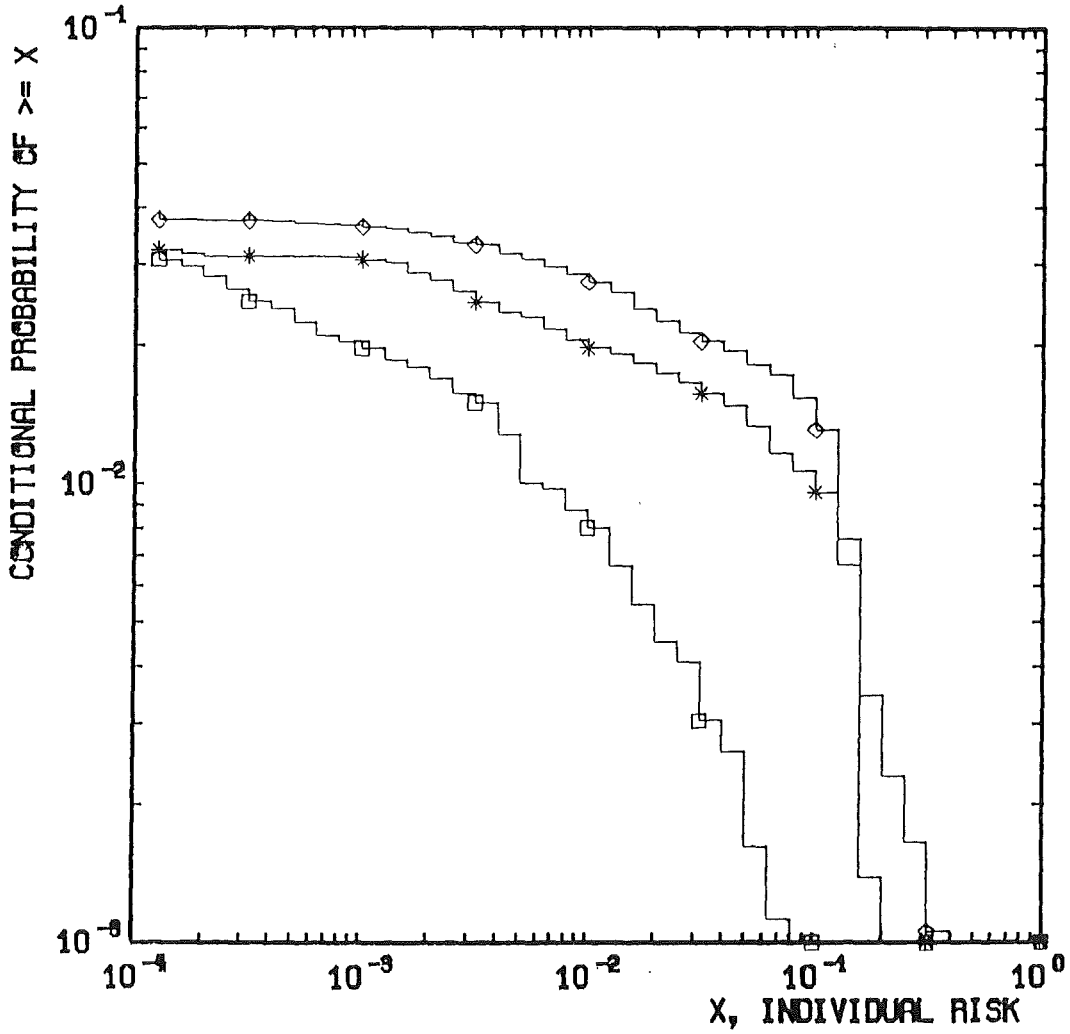
REFERENCE CCFD OF THE INDIVIDUAL RISKS (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS.



Individual risk
Health effect.....: hematopoietic syndrome
Distance .....: 0.875 km

KfK INR

COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF INDIVIDUAL RISKS (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60.

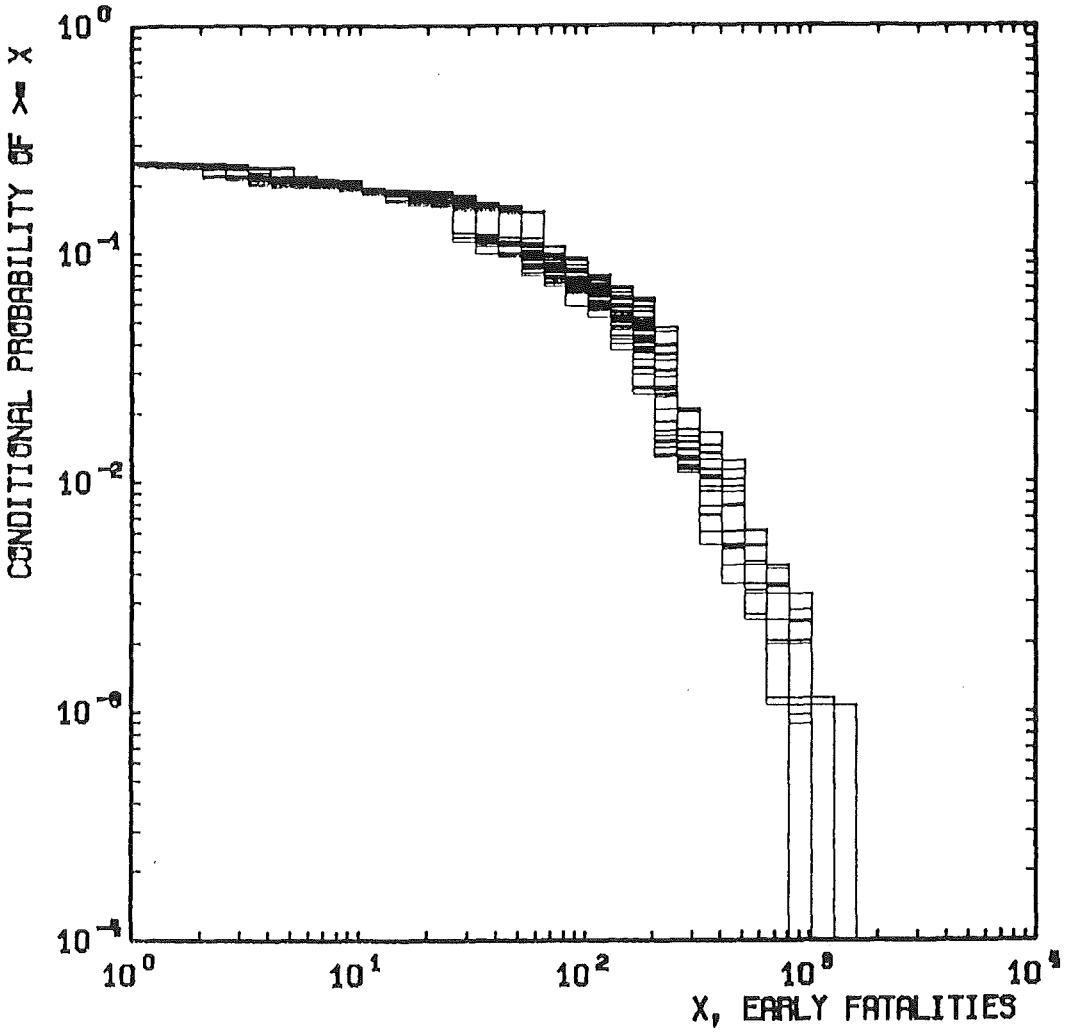


Individual risk
Health effect.....: hematopoietic syndrome
Distance .....: 0.875 km

* : Ref.-Curve
□ : 5% -Curve
◇ : 95% -Curve

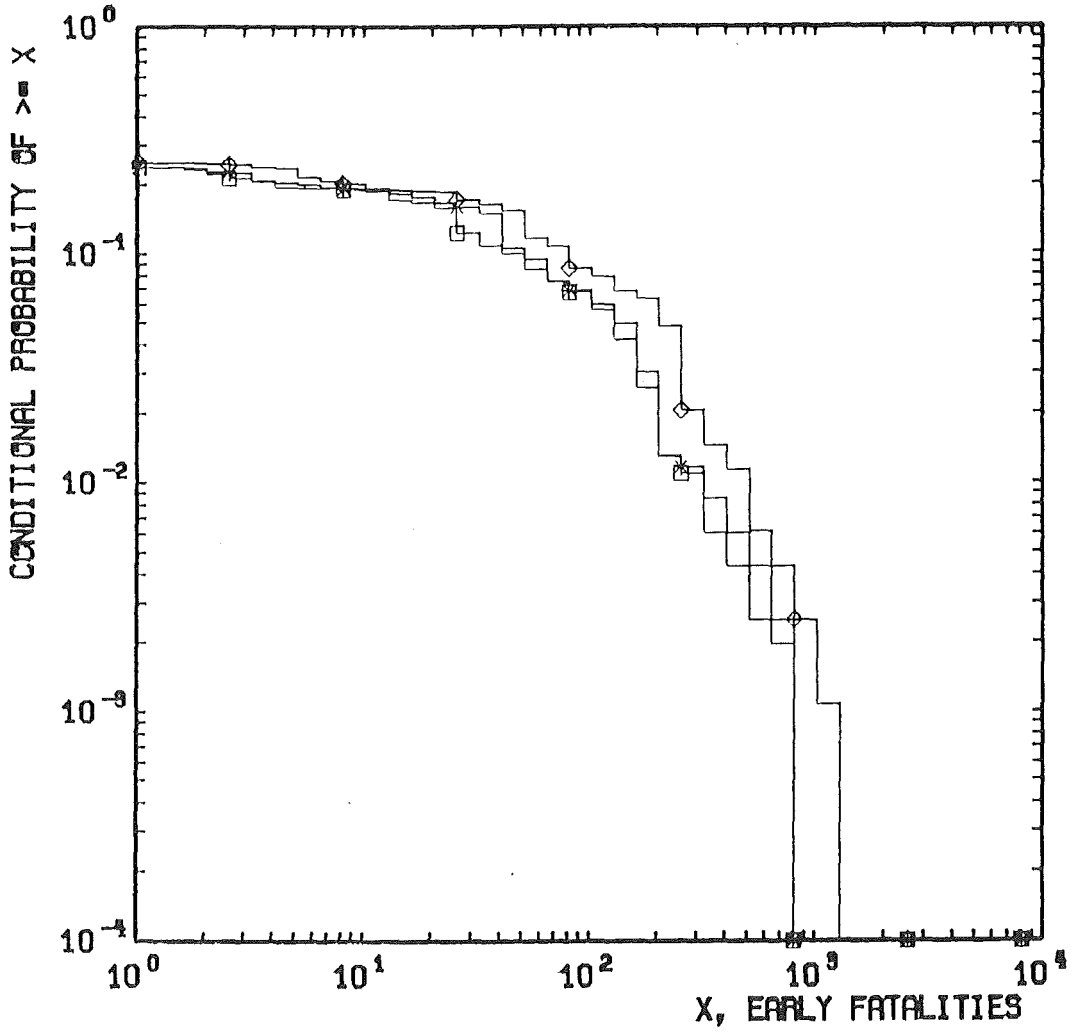
KfK INR

REFERENCE CCFD OF THE INDIVIDUAL RISKS (ASSUMING RELEASE HAS OCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE POINTS OF THE X - AXIS.



Early fatalities
Health effect.....: pulmonary syndrome

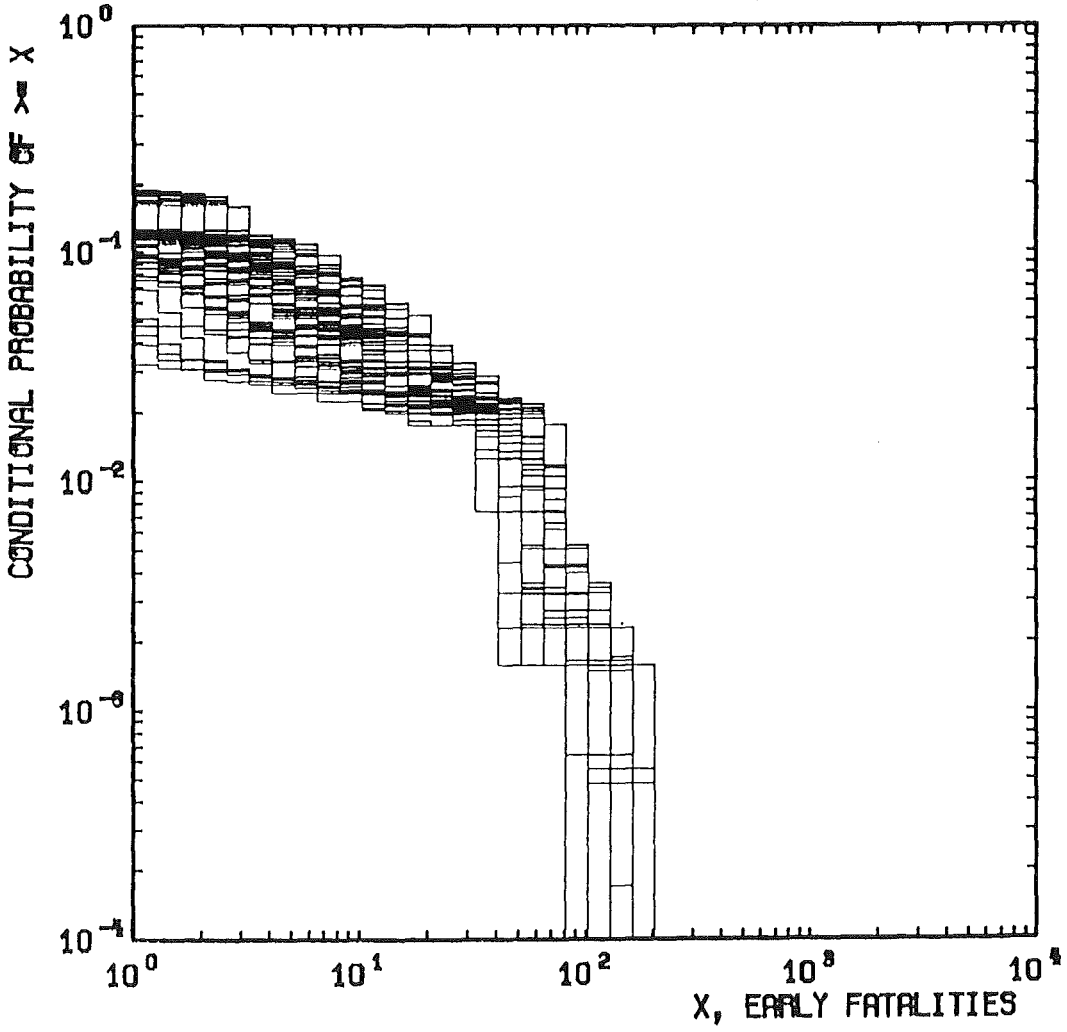
COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF EARLY FATALITIES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60.



Early fatalities
Health effect.....: pulmonary syndrome

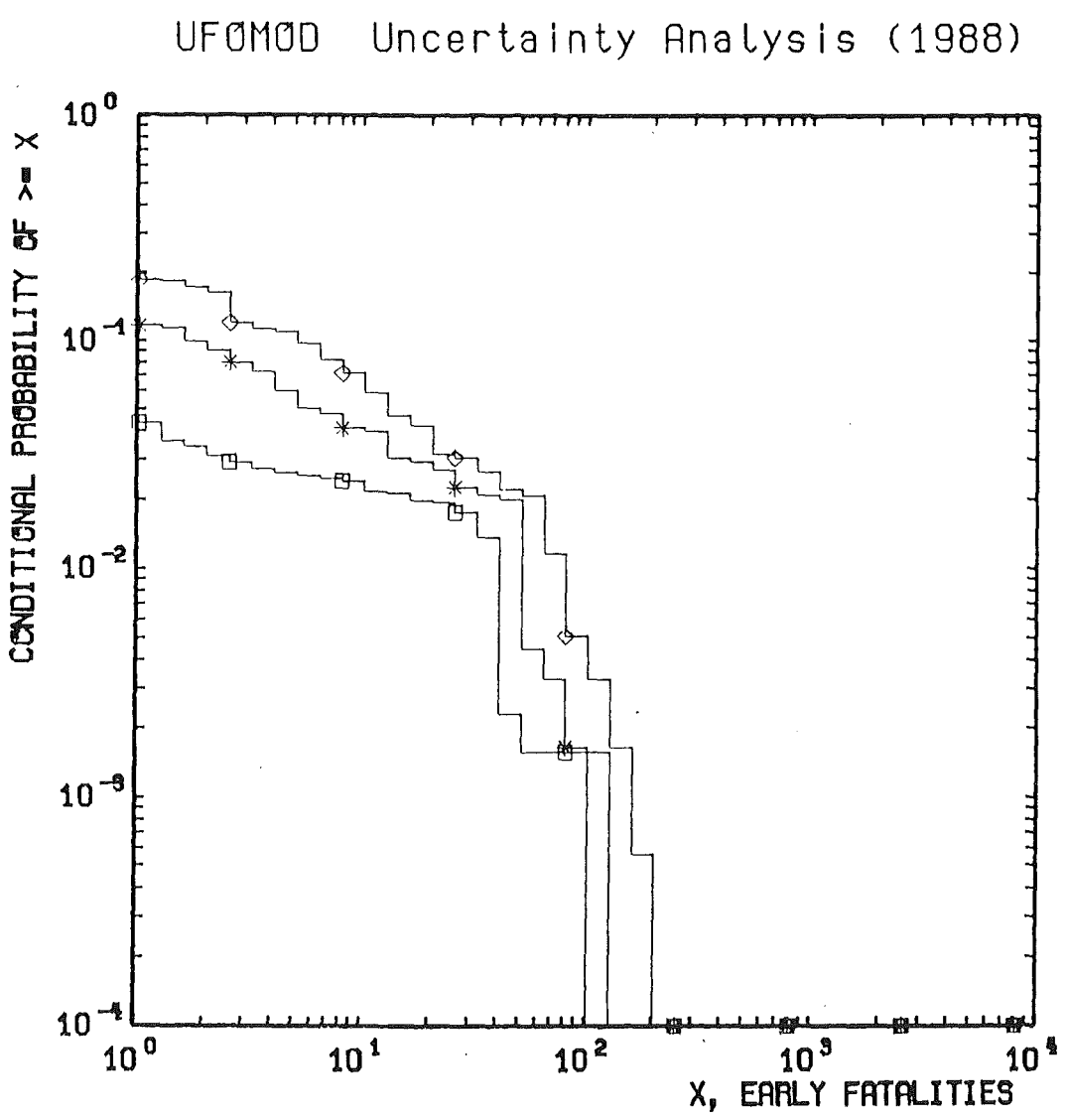
* : Ref.-Curve
□ : 5% -Curve
◇ : 95% -Curve

REFERENCE CCFD ØF EARLY FATALITIES (ASSUMING RELEASE HAS ØCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CONFIDENCE BOUNDS AT DISCRETE PØINTS ØF THE X - AXIS.



Early fatalities
Health effect.....: hematopoietic syndrome

COMPLEMENTARY CUMULATIVE FREQUENCY DISTRIBUTIONS (CCFDS) OF EARLY FATALITIES (ASSUMING RELEASE HAS OCCURRED). EACH CCFD CORRESPONDS TO ONE OF THE 60 RUNS IN A LATIN HYPERCUBE SAMPLE OF SIZE 60.



Early fatalities
Health effect.....: hematopoietic syndrome

* : Ref.-Curve
□ : 5% -Curve
◇ : 95% -Curve

KfK INR

REFERENCE CCFD ØF EARLY FATALITIES (ASSUMING RELEASE HAS ØCCURRED) AND THE EMPIRICAL 5% -, 95% - QUANTILES RESPECTIVELY ARE GIVEN AS ESTIMATED CØNFIDENCE BØUNDS AT DISCRETE PØINTS ØF THE X - AXIS.

Appendix C. Sensitivity Analyses (Tables of PRCC values)

Legends for reading the PRCC - tables

The following list gives the name and the meaning of the parameters:

TINA	initial delay of actions in area A [h]
TDELA	delay time between end of release and end of sheltering period in area A [h]
PAUFA(i)	fraction of population with different behaviour during the sheltering period in area A 1. in cars (spontaneous evacuation) 2. in cellars 3. in buildings with low shielding 4. in buildings with high shielding 5. outside, rural area
GRWRTB	intervention dose level (IL) for emergency actions in area B
IEVA2	index of last outer radius of the keyhole-shaped area A
WGRNZA	angle of keyhole sector of area A (in degrees)
WSHIFT	azimuthal shift of the sector in area A against the wind direction of the first release phase (WSHIFT>0: rotation clockwise)
TDRA(X,Y)	Y - fractile of driving time to leave area A at 6 km (10 km) radius (daytime) with respect to population density class X [X ∈ population density class 1 to 4, Y ∈ (50th, 90th, 99th) percentile see Table 1]

The following list gives the name and the meaning of the consequence variables:

DOSLUD1	individual acute dose (lung)	at D1 (0.875 km)
DOSLUD2	individual acute dose (lung)	at D2 (4.9 km)
DOSLUD3	individual acute dose (lung)	at D3 (8.75 km)
DOSBMD1	individual acute dose (bone marrow)	at D1 (0.875 km)
DOSBMD2	individual acute dose (bone marrow)	at D2 (4.9 km)
DOSBMD3	individual acute dose (bone marrow)	at D3 (8.75 km)
RSKLUD1	individual risk (pulmonary syndrome)	at D1 (0.875 km)
RSKBMD1	individual risk (hematopoietic syndrome)	at D1 (0.875 km)
POP(LU)	early fatalities (pulmonary syndrome)	
POP(BM)	early fatalities (hematopoietic syndrome)	

C.1 Comparison of countermeasures runs (LHS; n = 50,60)

In this section PRCCs are shown for individual acute doses at three distance intervals for lung and bone marrow; individual risks (pulmonary, hematopoietic syndrome); early fatalities (pulmonary, hematopoietic syndrome).

TABLE ENTRIES REPRESENT THE VALUE OF THE PARTIAL RANK CORRELATION COEFFICIENT (AND ITS RANK) FOR EACH COMBINATION OF SELECTED INDEPENDENT AND SELECTED DEPENDENT VARIABLE, PROVIDED THAT THE ABSOLUTE VALUE OF THIS COEFFICIENT IS GREATER THAN T(ALPHA) = 0.31 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.05 SIGNIFICANCE LEVEL
(E.G. THE CRITICAL VALUE IS T(ALPHA) = 0.49 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.001 SIGNIFICANCE LEVEL)

THE PERCENTAGE CONTRIBUTIONS TO UNCERTAINTY ARE GIVEN FOR EACH INDEPENDENT PARAMETER OR GROUPS OF INDEPENDENT PARAMETERS (TA(xx,yy))

60P /50C, (P) or (C) MEANS: THE TDRA (I.E. TA) PARAMETERS ARE PARTLY (P) OR COMPLETELY (C) CORRELATED

	DOSLUD1		DOSLUD1		DOSLUD2		DOSLUD2		DOSLUD3		DOSLUD3	
#RUNS	60P	(%)	50C	(%)	60P	(%)	50C	(%)	60P	(%)	50C	(%)
TINA	.97(1)	86	.97(1)	81	.91(1)	64	.91(1)	50	.77(3)	7	.57(3)	2
TDELA					.33(5)		.40(6)		.68(4)	3	.53(4)	
PAUFA(1)	-.84(2)	11	-.87(2)	15	-.81(2)	26	-.88(2)	33	-.90(2)	18	-.87(2)	21
PAUFA(5)	.46(3)	1	.56(4)	3	.33(6)	1	.64(3)	11				
GRWRTB		1			.46(3)	2	.58(4)	3	.97(1)	75	.96(1)	73
IEVA2		1			-.41(4)	2	-.42(5)	7				1
WGRNZA			.31(5)				-.33(8)	1		1		
WSHIFT												
TA(1,50) (P)												
TA(1,90) (P)												
TA(1,99) (P)												
TA(2,50) (P)	-.32(5)											
TA(2,90) (P)												
TA(2,99) (P)												
TA(3,50) (P)												
		1				7				5		
TA(3,90) (P)												
TA(3,99) (P)												
TA(4,50) (P)												
TA(4,90) (P)	-.37(4)											
TA(4,99) (P)												
TDRA (C)			.58(3)	2			.39(7)	1			.42(5)	2

TABLE ENTRIES REPRESENT THE VALUE OF THE PARTIAL RANK CORRELATION COEFFICIENT (AND ITS RANK) FOR EACH COMBINATION OF SELECTED INDEPENDENT AND SELECTED DEPENDENT VARIABLE, PROVIDED THAT THE ABSOLUTE VALUE OF THIS COEFFICIENT IS GREATER THAN T(ALPHA) = 0.31 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.05 SIGNIFICANCE LEVEL
(E.G. THE CRITICAL VALUE IS T(ALPHA) = 0.49 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.001 SIGNIFICANCE LEVEL)

THE PERCENTAGE CONTRIBUTIONS TO UNCERTAINTY ARE GIVEN FOR EACH INDEPENDENT PARAMETER OR GROUPS OF INDEPENDENT PARAMETERS (TA(xx,yy))

60P /50C, (P) or (C) MEANS: THE TDRA (I.E. TA) PARAMETERS ARE PARTLY (P) OR COMPLETELY (C) CORRELATED

	DOSBMD1		DOSBMD1		DOSBMD2		DOSBMD2		DOSBMD3		DOSBMD3	
#RUNS	60P	(%)	50C	(%)	60P	(%)	50C	(%)	60P	(%)	50C	(%)
TINA	.99(1)	86	.98(1)	78	.82(1)	54	.75(1)	37	.69(3)	1	.67(2)	1
TDELA	.45(4)			1		1			.49(5)			
PAUFA(1)	-.75(3)	3	-.73(4)	4	-.33(5)	4	-.49(5)	9	-.73(2)	2	-.63(3)	1
PAUFA(5)	.89(2)	9	.86(2)	12	.42(4)	3	.62(4)	22	.60(4)		.54(4)	
GRWRTB					.54(3)	15	.69(2)	27	1.00(1)	98	.99(1)	96
IEVA2	.39(5)	2	.39(5)		-.65(2)	19	-.64(3)	23				
WGRNZA												
WSHIFT				1								
TA(1,50) (P)												
TA(1,90) (P)												
TA(1,99) (P)												
TA(2,50) (P)												
TA(2,90) (P)	-.38(6)											
TA(2,99) (P)												
TA(3,50) (P)												
TA(3,90) (P)		9				5				6		
TA(3,99) (P)												
TA(4,50) (P)												
TA(4,90) (P)												
TA(4,99) (P)												
TDRA (C)			.80(3)	6			.41(6)	4			.56(4)	1

TABLE ENTRIES REPRESENT THE VALUE OF THE PARTIAL RANK CORRELATION COEFFICIENT (AND ITS RANK) FOR EACH COMBINATION OF SELECTED INDEPENDENT AND SELECTED DEPENDENT VARIABLE, PROVIDED THAT THE ABSOLUTE VALUE OF THIS COEFFICIENT IS GREATER THAN T(ALPHA) = 0.31 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.05 SIGNIFICANCE LEVEL
(E.G. THE CRITICAL VALUE IS T(ALPHA) = 0.49 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.001 SIGNIFICANCE LEVEL)

THE PERCENTAGE CONTRIBUTIONS TO UNCERTAINTY ARE GIVEN FOR EACH INDEPENDENT PARAMETER OR GROUPS OF INDEPENDENT PARAMETERS (TA(xx,yy))

60P /50C, (P) or (C) MEANS: THE TDRA (I.E. TA) PARAMETERS ARE PARTLY (P) OR COMPLETELY (C) CORRELATED

	RSKLUD1		RSKLUD1		RSKBMD1		RSKBMD1	
#RUNS	60P	(%)	50C	(%)	60P	(%)	50C	(%)
TINA	.95(1)	78	.96(1)	72	.83(2)	13	.86(2)	14
TDELA					.55(3)	1	.65(4)	4
PAUFA(1)	-.83(2)	17	-.87(2)	19	-.37(5)		-.45(5)	1
PAUFA(5)	.32(4)	1	.68(3)	7	.97(1)	80	.98(1)	80
GRWRTB		1						
IEVA2		1	.35(5)		.41(4)	6		2
WGRNZA			-.32(6)				-.41(6)	
WSHIFT				1				2
TA(1,50) (P)								
TA(1,90) (P)								
TA(1,99) (P)								
TA(2,50) (P)								
TA(2,90) (P)	.31(5)							
TA(2,99) (P)								
TA(3,50) (P)								
TA(3,90) (P)								
TA(3,99) (P)								
TA(4,50) (P)								
TA(4,90) (P)	-.39(3)							
TA(4,99) (P)								
TDRA (C)			.56(4)	2			.74(3)	4

TABLE ENTRIES REPRESENT THE VALUE OF THE PARTIAL RANK CORRELATION COEFFICIENT (AND ITS RANK) FOR EACH COMBINATION OF SELECTED INDEPENDENT AND SELECTED DEPENDENT VARIABLE, PROVIDED THAT THE ABSOLUTE VALUE OF THIS COEFFICIENT IS GREATER THAN T(ALPHA) = 0.31 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.05 SIGNIFICANCE LEVEL
(E.G. THE CRITICAL VALUE IS T(ALPHA) = 0.49 (50 RUNS, 9 PARAMETERS) OR (60 RUNS, 20 PARAMETERS) RESPECTIVELY FOR ALPHA = 0.001 SIGNIFICANCE LEVEL)

THE PERCENTAGE CONTRIBUTIONS TO UNCERTAINTY ARE GIVEN FOR EACH INDEPENDENT PARAMETER OR GROUPS OF INDEPENDENT PARAMETERS (TA(xx,yy))

60P /50C, (P) or (C) MEANS: THE TDRA (I.E. TA) PARAMETERS ARE PARTLY (P) OR COMPLETELY (C) CORRELATED

	POP(LU)		POP(LU)		POP(BM)		POP(BM)	
#RUNS	60P	(%)	50C	(%)	60P	(%)	50C	(%)
TINA	.96(1)	76	.96(1)	68	.88(2)	17	.92(2)	20
TDELA					.68(3)	2	.68(3)	4
PAUFA(1)	-.84(2)	16	-.89(2)	20	-.45(4)	1	-.63(5)	2
PAUFA(5)	.65(3)	5	.77(3)	9	.97(1)	75	.98(1)	76
GRWRTB		1						
IEVA2	.43(4)	3	.42(5)		.36(5)	5		3
WGRNZA			-.41(6)				-.31(7)	
WSHIFT			-.32(7)	1		1	-.33(6)	2
TA(1,50) (P)								
TA(1,90) (P)								
TA(1,99) (P)								
TA(2,50) (P)								
TA(2,90) (P)								
TA(2,99) (P)								
TA(3,50) (P)								
TA(3,90) (P)		6				4		
TA(3,99) (P)								
TA(4,50) (P)								
TA(4,90) (P)								
TA(4,99) (P)								
TDRA (C)			.61(4)	3			.68(4)	2

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