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Risk calculations involved in storing explosives

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Risk calculations involved in storing explosives

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Summary

This report gives a description of the structure and contents of RISKANAL, a computer program developed at the TNO Prins Maurits Laboratory, The Netherlands. It can also be used as a manual for RISKANAL.
The internal and external risks involved in storing explosives can be calculated with RISKANAL. The program uses the quantity-distances according to the NATO AC/258 recommendations [1] and the probit functions as given in the Dutch 'Green Book' [2].
The final result of the program is the average number of lethalities to be expected if a magazine on a complex should accidentally explode. With these figures, it can be decided whether a situation is acceptable or not by including the probability of an accidental explosion.

Samenvatting

Dit rapport geeft een beschrijving van de structuur en inhoud van RISKANAL, een computerprogramma ontwikkeld op het Prins Maurits Laboratorium TNO, Nederland. Het kan tevens als handleiding voor RISKANAL gebruikt worden. RISKANAL berekent inwendige en uitwendige risico's behorende bij een explosievenopslag. Het programma gebruikt de veiligheidsafstanden volgens de aanbevelingen van NATO AC/258 [1] en de probit functies zoals die gegeven worden in het "Groene Boek" [2].
Het uiteindelijke resultaat van het programma is het gemiddeld aantal slachtoffers dat verwacht kan worden wanneer een magazijn op een complex zou exploderen. Met deze getallen kan dan beslist worden of een situatie al of niet aanvaardbaar is door de kans op een accidentele explosie er bij te betrekken.

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1 INTRODUCTION

The possibility of performing a risk analysis serves a dual purpose. First, one can calculate the internal and external safety of an existing storage site, and secondly, if new sites are to be constructed, this can be done in an optimal way.

At the Prins Maurits Laboratory, a program called RISKANAL was developed to calculate the internal and external risks involved in storing high explosives and ammunition. By internal risk, we mean the possibility of sympathetic detonations within a storage site when one magazine explodes. The external risk is defined as the possibility of lethal and serious injury to people in the surroundings of the storage site. The AC/258 recommendations [1] are used for the internal risk calculations and for the quantification of the explosion effects. To calculate the consequences (external risk calculations), the probability functions for lethality and injury given in the Dutch 'Green Book' [2] are used.

The main assumptions for the calculation of the explosion effects are:

- blast parameters are deduced from hemispherical TNT charges exploded at ground level in the open air;
- effect calculations originate with flat terrain and do not involve the influence of slopes, vegetation or other obstacles, and;
- the blast parameters are valid for scaled distances ranging from 0.0674 to 40.0 $kg/m^{1/3}$.

For each donor magazine with its total involved quantity of explosives, the side-on and reflected pressure, the side-on and reflected impulse, the positive phase duration, the radiation intensity and the exposed time are calculated with the formulae given in AC/258, Part II [1]. The fragment density is calculated with formulae derived from fitting experimental data obtained from ESKIMO and Yuma tests. With the results, the effects on surrounding objects are estimated using the probability functions given in the Dutch 'Green Book' [2].

The program will be described by means of an "excursion" into the program itself. All necessary input is unformatted and becomes self-explanatory as the program is run.

RISKANAL can be divided into four parts; successively handling the input, the internal safety, the external safety and the output (Figure 1). The next four chapters describe each of these parts seperately.

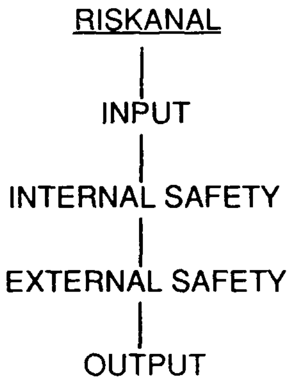

Figure 1 Diagram of the program

2 INPUT

The main topics of the input part of the program are given in Figure 2, while a flowchart with all subroutines is given in Annex 1.

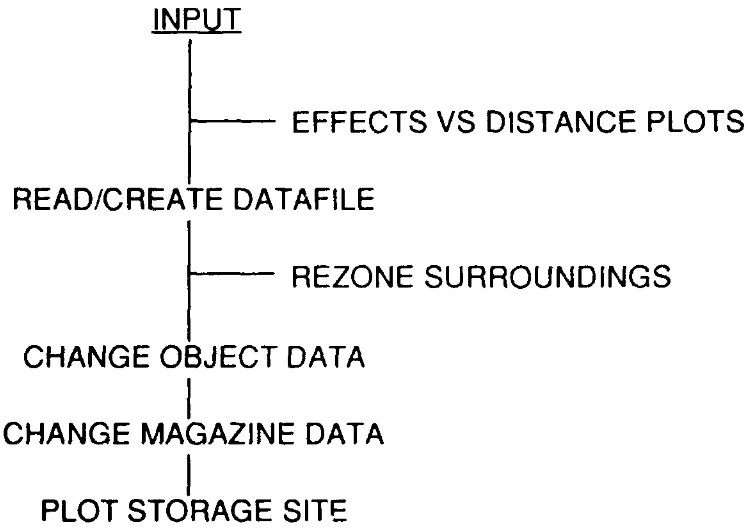

Figure 2 Diagram of the input part

The first option of the program is the possibility to create special plots of effects (probability of lethality/injury) versus distances for (maximum) five quantities of hazard division 1.1 explosives. If these plots are wanted, an extra run through the program will be made controlled by subroutine

EFECTS. The situation "one magazine and one person in a house or in the free field" at several distances is calculated. This option can be performed with or without the effects of fragments and debris. The same topics as described later are used for the calculations (see parts II and III). An example of the plots is given in Annex 2. If no more plots of this kind are wanted, the program can be exited at this point.

If the program is not exited, the name of the input file is asked for. This name may contain a maximum of nine characters and must have a .DAT extension. An already existing input file will be read, a new input file will be created interactively.
It has to be expected that many input data are necessary to describe the complex with its surroundings. Because these data are mostly already available and formatted for the storage sites in The Netherlands, no special attention is paid to a preprocessor program, for instance with a graphic tablet, for creating such an input file.
The input file must contain information about the complex itself (type and orientation of the magazine(s) with its high explosive contents and its hazard division) and about its surroundings (type and position of objects with the number of people involved).
The size and orientation of a magazine is defined by its coordinates. The first two coordinates define the entry wall of the magazine, the third coordinate is for the back wall in a right- or left-handed rotatory system. These coordinates are required to determine its orientation, assuming that the magazine is rectangular.
Several types of magazines are involved, each with a characteristic code:

- I7 : igloos designed for 7 bar;
- I3 : igloos designed for 3 bar;
- ID : earth covered buildings with a headwall and door(s) resistant to high velocity projections if facing to a potential explosion site;
- IB : earth covered buildings with a barricaded door if facing to a potential explosion site;
- IE : unbarricaded earth covered buildings;
- BR : heavy-walled buildings (0.7 m concrete, brick or equivalent) and protective roof (0.15 m concrete with suitable support) and a barricaded door if facing to a potential explosion site;
- BD : heavy-walled buildings and a barricaded door if facing to a potential explosion site;
- OB : on 3 sides barricaded open-air stack or light structure;
- OT : on 4 sides barricaded open-air stack or light structure;
- OP : unbarricaded open-air stack or light structure.

The explosive contents of hazard division 1.1 must be given in kg TNT. Other options are explosives of hazard division 1.2, 1.3a, 1.3b, and 1.4. If other types of 1.1 explosives are involved, the stored amount must be given in equivalent TNT values. Table 1 gives some TNT equivalence values.

Table 1 TNT equivalences for some high explosives

Explosives	Density (kg/m^3)	TNT equivalences based on peak pressure	TNT equivalences based on impulse
TNT	1600	1.00	1.00
cyclotol	1710	1.14	1.09
RDX	1790	1.19	1.16
Comp B	1710	1.13	1.06
Pentolite	1690	1.16	1.15
H6	1710	1.27	1.38

Also, several types of surrounding objects are involved, each with a characteristic code:
- HS : inhabited buildings;
- HF : inhabited buildings with more than four floors;
- HU : people in tents, parks, etc. (unprotected people);
- RD : public traffic roads;
- PL : POL-facilities (petroleum, oils, lubricants).

Each object is represented by one coordinate, except roads, which are represented by the start and end points of straight lines. So, a road with 3 straight parts can be described by 4 coordinates.
With a (pre-determined) average number of people per unit, the total number of people involved with each object can be tied up by a number of units coupled with each surrounding object. For instance, when the average number of people is 2.5, a group of 10 people in a park can be defined by 4 units ('4 HU'). For public traffic routes, the 24-hour traffic intensities for cars and for cyclists/pedestrians must be known or estimated.

The format of the input file with an example is given in Annex 3.

When a new input file must be created, the following input data are asked for interactively:

- the number of magazines;
- the number of surrounding objects;
- the number of object coordinates;
- the mean number of people per unit;
- the name of the complex;
- for each magazine :
  - the type of magazine;
  - the name of the magazine;
  - the explosive contents of the magazine;
  - the hazard division of the contents;
  - 3 corner coordinates of the rectangular magazine;
- for each surrounding object:
  - the name of the object;
  - the type of object;
  - array row number of first coordinate (k)*;
  - array row number of last coordinate (n)*;
  - the number of units, or the 24-hour traffic intensity of cars and cyclists/pedestrians (for roads);
  - the object centre coordinates, or first road coordinates;
  - the next (n-k) coordinates (roads).

* Note that for all objects except roads, k equals n.

The program's next option is the possibility of rezoning the data. When a data file contains a complex with an extensive area and a run must be made for this complex with a small amount of stored explosives, the surrounding objects outside a specified safety range will be neglected.

The possibility to interactively change one or more data of magazines or surrounding objects is available. Also a new item can be added or an existing item can be deleted at this point.

If the user so desires he has the opportunity to interactively change the results of the internal safety calculation. This may be necessary when a specific magazine or situation is not covered by the program: the calculation results in sympathetic reactions which will not occur in reality, or vice versa.

Several questions must be answered to control the output on screen or printer. Plots of the complex can also be made with or without its surrounding objects on screen or plotter.

For the internal and external safety calculations, two parameters must be defined. The first one determines which safety distance according to AC/258 must be used, the maximum distance or a shorter one. In some cases the shorter distances can be used, for instance if no primary or very sensitive hazard division 1.1 explosives are involved, or if only small calibers of hazard division 1.2 explosives are involved. The second parameter makes it possible to calculate with or without the effects of fragments and debris. The construction of a magazine or the protection of a surrounding object can exist in such a way that the fragment effects can be eliminated.

The input part ends with some calculations and output options:

- the fourth coordinate of each magazine is calculated;
- the initial data can be printed on screen or printer (Annex 3 gives an example);
- the initial plots are made (only magazines, magazines with surrounding objects, surrounding objects with symbol 'X' or with a pictogramme, thick or thin lines, A3 or A4 format, see Annex 3 for an example);
- the total amount of explosive involved in spite of its hazard division is calculated, to bypass objects lying outside the safety radius of this total amount;
- each magazine will be characterized by a number depending on its contents (1 for hazard division 1.1, 2 for hazard division 1.2, 3 for hazard division 1.3a, 4 for hazard division 1.3b and 5 for hazard division 1.4).

3 INTERNAL SAFETY

This part of the program can be divided into three sections as shown in Figure 3.

<u>INTERNAL SAFETY</u>

CALCULATE INTER-MAGAZINE DISTANCES

EXAMINE SYMPATHETIC REACTIONS

CHANGE CALCULATED RESULTS

Figure 3 Diagram of the internal safety part

A complex is called internally safe if there is no sympathetic reaction when any one magazine explodes. First, the quantity-distances (QD) according to the AC/258 recommendations [1] and the (shortest) real distances (DIST) are calculated for each possible donor-acceptor combination. For the QD of igloos, the orientation between the magazines is taken into account too.

The QD is characterized by a row and column number of the relevant matrices as given by AC/258, Part I, Annex A, Section II [1]. The matrices used are given in Annex 4.

The QD is determined by the row and column number and the involved amount of high explosives. For each donor, possible sympathetic reactions are examined by comparing QD and DIST. In other words, the program examines if other magazines are activated too (acceptor magazines) by letting each magazine detonate one by one (donor magazines). All possible explosive sites with all sympathetically reacting exposed sites are stored.

If a sympathetic reaction occurs, the acceptor magazine in its turn can cause sympathetic reactions in other magazines. Several calculation rules are used for the different situations, largely in accordance with AC/258 [1]. Tables 2 to 4 give a review of the used calculation rules (QD is quantity distance, CD is conversion distance). This conversion distance is taken as the 'level' for the QD 'minus one'. For instance if the QD for 1.1 is $D9 = 4.8Q^{1/3}$, then the CD is $D8 = 3.6Q^{1/3}$ (see Annex 4). The introduction of the CD is meant to create the possibility that hazard division 1.2 or 1.3 explosives will be charged as hazard division 1.1 when they are stored too close to a 1.1 source.

Table 2 Calculation rules for a 1.1 donor

Donor D Hazard div.	Acceptor A Hazard div.	Calculation rules
1.1	1.1	A within 1.1 QD of D gives a sympathetic reaction of A
1.1	1.2/1.3	A within 1.1 QD of D gives a sympathetic reaction of A
		A also within 1.1 CD of D means the contents of A will be charged as 1.1

Table 3 Calculation rules for a 1.2 donor

Donor D Hazard div.	Acceptor A Hazard div.	Calculation rules
1.2	1.1	A within 1.2 QD of D gives a sympathetic reaction of A
		A also within 1.1 CD of D means the contents of D will be charged as 1.1
1.2, as 1.1	1.1	A within maximum of 1.1 and 1.2 QD of D gives a sympathetic reaction of A
1.2, as 1.1	1.2/1.3	A within maximum of 1.1 and 1.2 QD of D gives a sympathetic reaction of A
		A also within 1.1 CD of D means the contents of A will be charged as 1.1
1.2	1.2/1.3	A within 1.2 QD of D gives a sympathetic reaction of A

Table 4 Calculation rules for a 1.3 donor

Donor D Hazard div.	Acceptor A Hazard div.	Calculation rules
1.3	1.1	A within 1.3 QD of D gives a sympathetic reaction of A
		A also within 1.1 CD of D means 50 % of the contents of D will be charged as 1.1 (partly burned before reaction occurs)
1.3, as 1.1	1.1	A within maximum of 1.1 and 1.3 QD of D gives a sympathetic reaction of A
1.3, as 1.1	1.2/1.3	A within maximum of 1.1 and 1.3 QD of D gives a sympathetic reaction of A
		A also within 1.1 CD of D means the contents of A will be charged as 1.1
1.3	1.2/1.3	A within 1.3 QD of D gives a sympathetic reaction of A

The program adds the total amount of hazard division 1.1 explosives for each possible donor and stores each sympathetically reacting magazine. The centre (point of initiation) of the 1.1 detonation is the donor magazine itself, when it contains explosives of hazard division 1.1. If not, it may be possible that one or more acceptor magazines containing 1.1 react sympathetically. In this case the acceptor closest to the donor is taken as the centre.

A flowchart with all subroutines of the internal safety part is given in Annex 5. When all potential explosive sites (donors) are treated this way, a table with the obtained results is written on the screen as well to a data file.

At this point the possibility to make manual correction(s) for cases not covered by the QD matrices (Annex 4) is created. This can be done interactively and a new table with the changed results is given. Annex 6 gives an example of such a table.

The results of the internal safety calculations can be summarized as follows:

- each potential explosive source (donor magazine) with all sympathetically reacting exposed magazines (acceptor magazines);
- the total amount of explosives of hazard division 1.1 involved with each donor magazine;
- the centre of the 1.1 detonation, and;
- the involved explosives of other hazard divisions not reacting as 1.1, per involved site.

4 EXTERNAL SAFETY

When only internal safety calculations are wanted, the program can be left or a restart can be made here. This part can be divided into three topics as shown in Figure 4.

EXTERNAL SAFETY

QUANTIFICATION OF PHYSICAL EFFECTS

EFFECTS ON ENVIRONMENT

PROBABILITIES OF LETHALITY

Figure 4 Diagram of the external safety calculation part

The following calculations are made for *each donor magazine*.
Sometimes clusters of magazines react sympathetically and in a similar way, and each magazine (donor) involved gives the same external effects. To reduce calculation time, the calculations of the effects can be omitted by equalizing with formerly calculated effects.
The contents will be defined for each sympathetic reacting magazine . The intermediate results of the calculations can be printed on screen and/or written to file.
Roads are divided into 25 m segments, each of which will be treated as an object positioned by the centre coordinates of the segment.
To quantify the physical effects, a loop for *all surrounding objects* is performed. The distance between each object and the reacting magazine is determined.
When the object is a POL facility, positioned within 25 or 60 m of the magazine, a message will be printed on screen and written to file.

The physical effects due to the explosion are quantified according to the AC/258 recommendations [1]. These effects involve side-on and reflected pressure, fragment density, side-on and reflected impulse, positive phase duration, arrival time of shock wave, shock front velocity, radiation intensity, and exposed time. For the fragment density, fitted formulae of experimental data obtained from literature [3,4,5] are used. These formulae were validated by comparing calculated results with more recent data [6,7,8] and no contradiction has been found. The other physical effects are calculated with the fitted formulae as given in [1]. An overview of all formulae used is given in Annex 7, while Annex 8 shows a flowchart of all subroutines used for the calculations done up to this point.

With these quantified physical parameters, the effects on humans are predicted by means of probit functions. These probit functions have been developed at the TNO-PML from experimental data found in literature and obtained from our own experiments. They are described in the 'Green Book' [2] containing vulnerability models for the effects of hazard materials on humans. The general form of these probit functions is:

$$Pr = a + b.\ln S$$

where a and b are constants and S is a variable. Depending on the value of S, the magnitude of Pr determines the probability of a certain event (in this case, generally the probability of lethality). The probabilities (in %) belonging to the Pr values (probits) are given in Table 5.

Table 5 Relation between probabilities and probits

%	0	1	2	3	4	5	6	7	8	9
0	0.00	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.897	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33

If $Pr < 0$, the probability is assumed to be zero and if $Pr > 7.33$, the probability is assumed to be 100 %. For a Pr value of 4.88 for instance, the corresponding probability is taken as 46 %. An overview of all probit functions used in the program is given in Annex 9.

The effects involved in the program are:

- the effects due to fragments and debris;
- the effects due to blast (pressure and impulse), subdivided into:
  - serious injury involving ear damage;
  - lethal injury involving lung damage;
  - serious/lethal injury by damage or total collapse of houses;
  - serious/lethal injury by window-pane breakage, and;
  - serious/lethal injury by head and total body impact.
- the effects of heat radiation.

To calculate the effects of fragments and debris, the known fragment density is divided into three mass classes: $m_1 < 0.1$ kg, 0.1 kg $< m_2 <$ 4.5 kg, and $m_3 > 4.5$ kg. For 1.2 explosions all fragment masses are supposed to be < 0.1 kg. This division is made as a function of the scaled distance (sc) as shown in Table 6.

Table 6 Division of fragment mass distribution

Scaled distance ($m/kg^{1/3}$)	mass distribution (%) m_1	m_2	m_3
sc < 1	75	20	5
1 < sc < 2	70	26	4
2 < sc < 3	65	31	4
3 < sc < 4	60	36	4
4 < sc < 5	55	41	4
5 < sc < 6	50	47	3
6 < sc < 7	45	52	3
7 < sc < 8	40	57	3
8 < sc	35	62	3

For each mass class, the probability of lethality by impact on human beings is calculated. The lethal area for human beings is estimated to be 0.58 m^2 for standing people (this area is used to calculate the probability of hit).

The average initial velocity of small fragments (m_1) is set at 1500 m/s (Gurney) when the object is situated at the door side of an igloo type magazine, otherwise it is set at 1200 m/s. For fragments and debris of medium fragments (m_2) the initial velocity is set at 800 m/s and for the heavy fragments (m_3) at 300 m/s.

The velocity V_x at the object distance x is calculated from the initial velocity V_o by [1]:

$$V_x = V_o.e^{-x/L}$$

where L is a parameter defined by $L = 2(k^2.m)^{1/3}/(C_D.\rho)$, with m the fragment mass. If geometrically similar fragments whose presented area and mass are related by shape factor k=2.61 g/cm^3, drag coefficient C_D=1.28 and air density ρ, are assumed, this leads to $L = 247.m^{1/3}$ in air at standard conditions for forged steel projectiles and fragmentation bombs, and ignorance of gravity (AC/258, Part II).

Next, the ballistic limit velocities V_{50} for 0.22 m brick/concrete (houses), skin or 1.5 mm steel (cars) of 0.1, 1.0 and 4.5 kg fragments, respectively, are calculated. With the velocities V_x and V_{50} the residual velocity after perforation of a 'protective' barrier (concrete, skin or steel), V_r, can be calculated:

$$V_r = \sqrt{(V_X^2 - V_{50}^2)}$$

The formulae used to calculate the ballistic limit velocities are given in Annex 10.

The effects of the penetration of window panes are treated separately, see Annex 9.

When all effects are calculated, a correction will be made for the storage of small quantities of explosives (less than 500 kg). In that case, the adjusted safety distances as given in [12] and Table 7 are used.

Table 7 Adjusted safety distances for the storage of small quantities of explosives

Quantity (kg)	Inhabited building distances (m) Hazard division 1.1 and 1.2 No hazard	Light structural damage	Hazard division 1.3
< 50	75	45	15
51 - 100	105	65	15
101 - 150	125	75	25
151 - 200	135	75	25
201 - 250	145	85	25
251 - 300	155	85	30
301 - 350	165	95	30
351 - 400	175	95	30
401 - 450	175	105	35
451 - 500	185	105	35

When a surrounding object is situated between the distances belonging to 'no hazard' and 'light structural damage', the resulting probabilities of lethality are divided by ten, and for objects outside the latter distance they are set to zero.

The first part of Annex 11 shows a flowchart with all subroutines used for these probability calculations (only effects on humans are considered).

At this point, all probabilities of lethality for all objects and all sources of this donor are calculated. A statistical addition of all probabilities of all objects can be performed.

Some assumptions are made here:

- 5 % of the lethal glass fragments cause lethal injury, depending on the probability of presence at 1.75 m behind a window at the time of the explosion;
- the number of injuries due to the collapse of buildings is supposed to be twice the number of lethalities;
- the number of injuries due to fragment effects is supposed to be twice the number of lethalities;
- the number of injuries due to head and total body impact is supposed to be twice the number of lethalities.

The probability of lethality for each object and the source is printed on screen and written to file. Now the effects for all objects of all sources of this donor can be calculated. For roads an average value for the probabilities of lethality for cars and for cyclists/pedestrians is taken (assuming an average velocity of 60 km/hr for cars and of 15 km/hr for cyclists/pedestrians). The probability of lethality of the object is the probability of lethality times the number of units times the average occupation of the object, and where appropriate, the probability of lethality times the traffic intensity. Finally, the effects of all donors of the storage site for all objects can be determined. The last part of Annex 11 shows the subroutines used to calculate the probabilities, while Annex 12 shows an example of the detailed and default output created by the program.

5 OUTPUT

The effects of all possible donors of the complex are known and an overview involving the total effects (personnel risks) of the complex is given on screen and on file. Averaging these results (total number of lethalities and total number of potential donors) gives the average individual risks for this site, presented as default output on screen and on file. The collective risk is calculated by adding the total number of lethalities for each donor, dividing by the number of donors and multiplying by the probability of an accidental explosion, assumed to be 10^{-5} per magazine per year. An example is given in Annex 13.

Plots can be made now on screen or on a plotter of all objects with probabilities of lethality and/or injury (surrounding objects with symbol 'X' or with a pictogramme, thick or thin lines, A3 or A4 format, see Annex 14 for an example).

To end the session, several questions must be answered:

- Do you want to create a new data file?
- Do you want to make a new run?
- If so, do you want to read the input file again?

Annex 15 shows a flowchart with all subroutines used to generate the output.

6 CONCLUSIONS

A detailed description of the Dutch interactive program to calculate the internal and external safety of an ammunition storage complex is presented.

This program, called RISKANAL, is based on a combination of the AC/258 recommendations (NATO) and the most updated consequence criteria as described in the Dutch 'Green Book'. The AC/258 recommendations are used for the internal safety of a complex and for the calculation of the explosion effects. The formulae given in the 'Green Book' are used for the external safety calculations. Although the validity of some of these criteria is limited, the final results seem to be very realistic.

The program is organized in such a way that it will be very easy to replace the equations by more sophisticated ones.

With the interactive capabilities of the program, the input data can be easily adjusted and the effects of these changes are shown quickly.

The uncertainties in using the formulae can be relatively large. Therefore the absolute figures should be handled with caution. However, the obtained quantified results are a good tool for comparing relative figures of the external safety.

7 AUTHENTICATION

R.J.M. van Amelsfort
(project leader/author)

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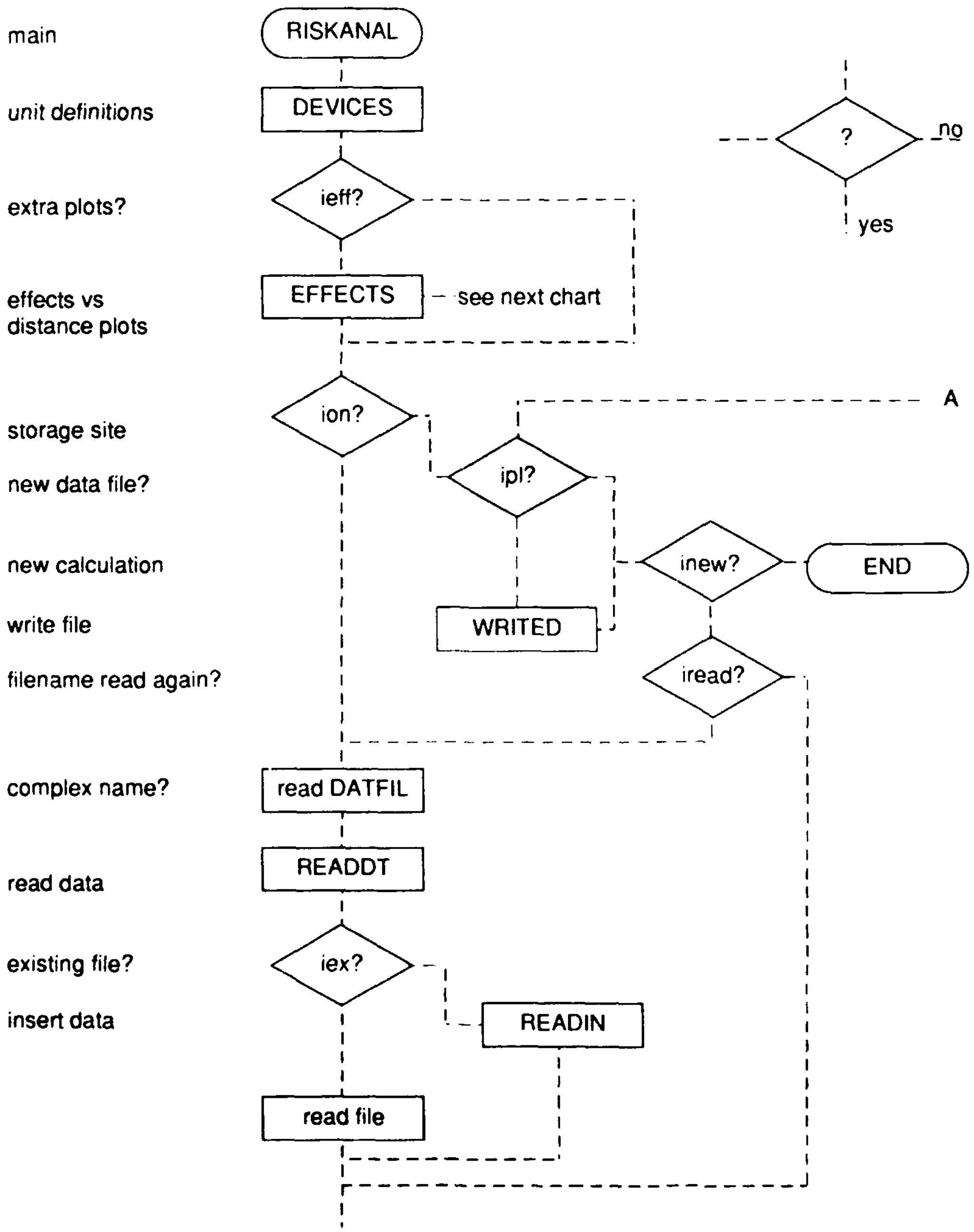
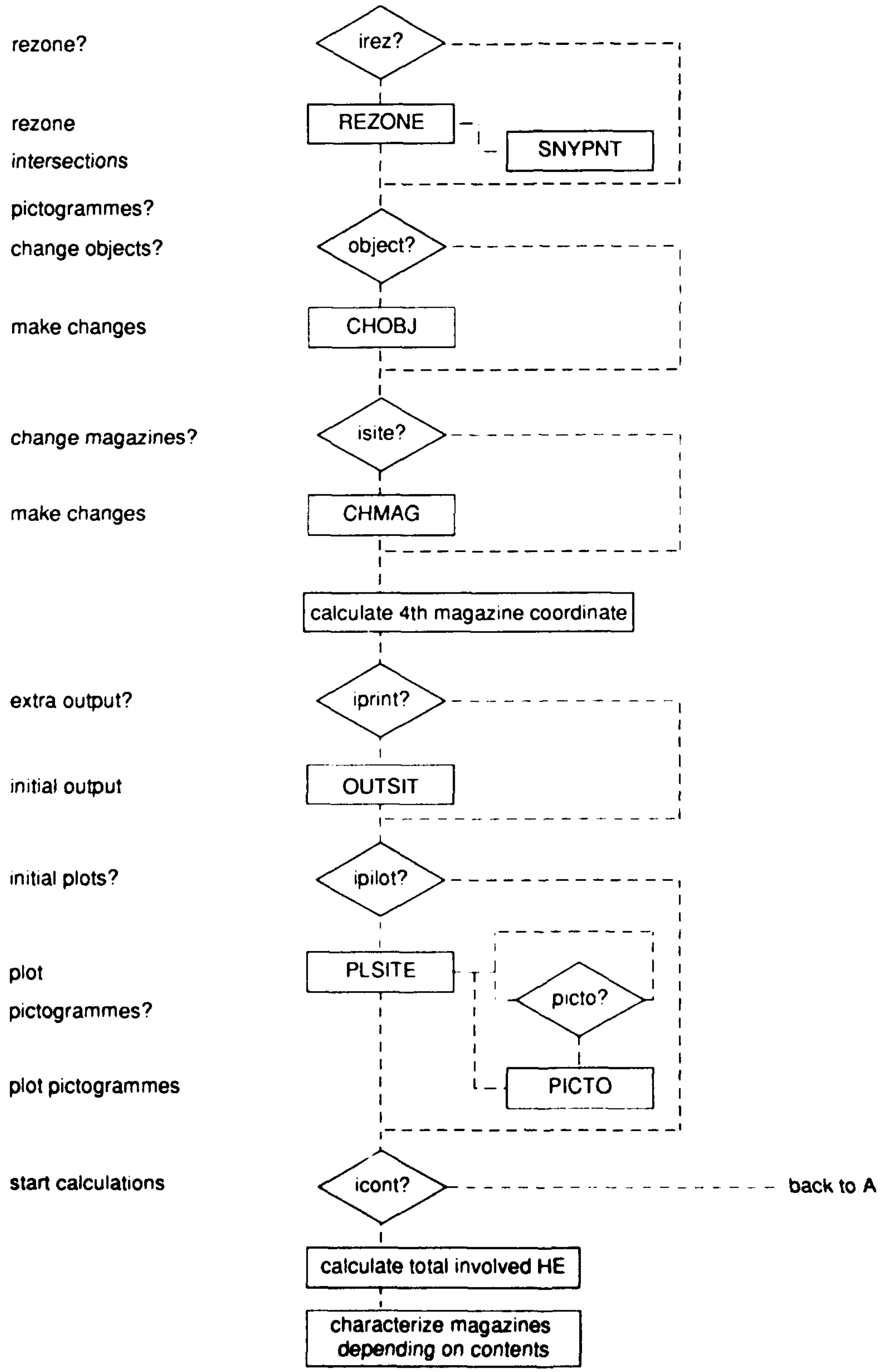
PML 1992-1 (in Dutch)

ANNEX 1 A FLOWCHART OF THE INPUT PART

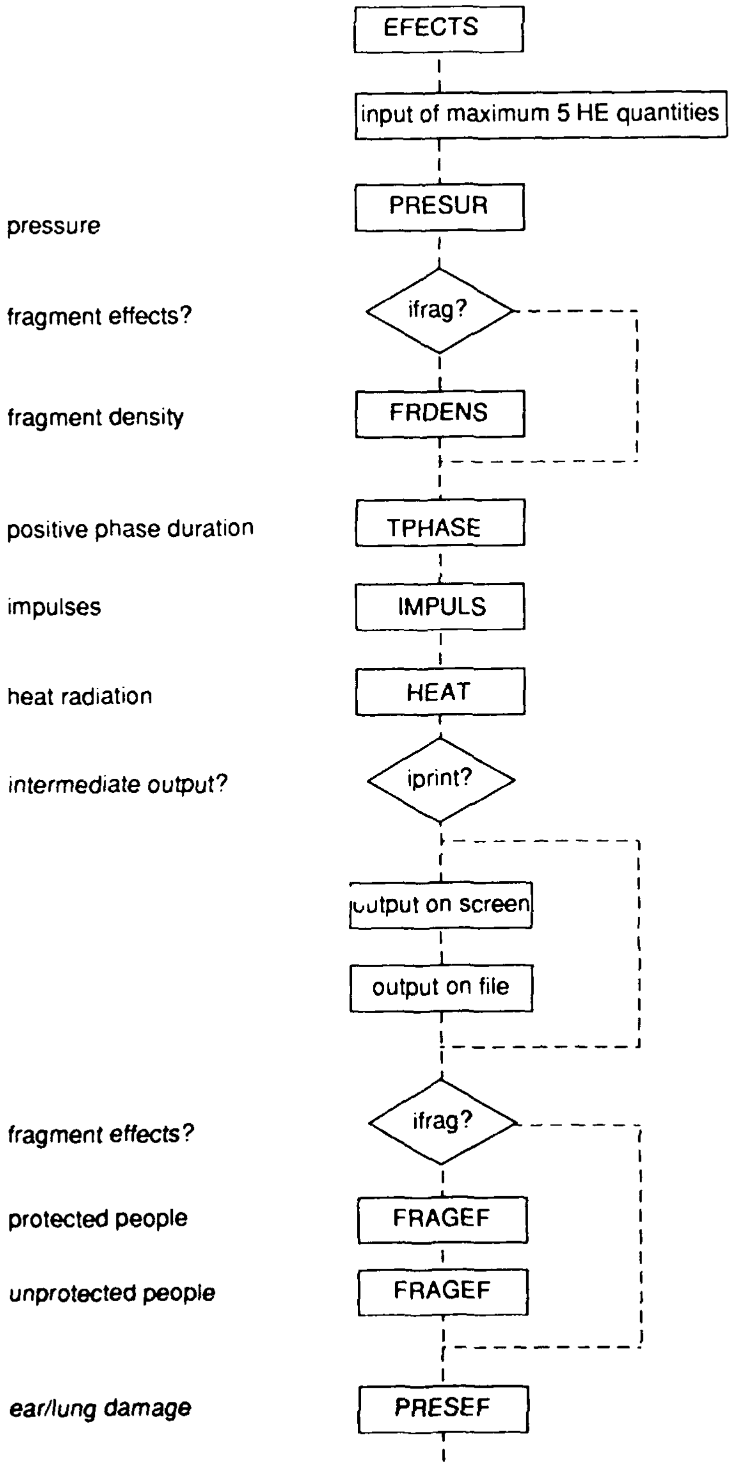
Interactive questions (to be answered with yes ('Y', 'y', 'J', or 'j') or no (any other symbol) are arranged by subroutine QUEST. Plot routines are initiated with subroutine PLOTIN and end with subroutine PLOTOUT. They also involve a subroutine PMLTNO, which plots the laboratory's vignette in each plot.

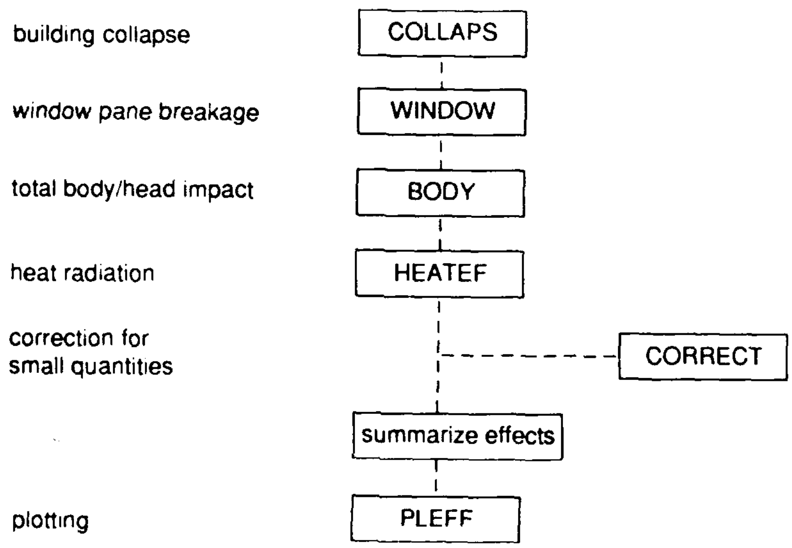



rezone?
irez?
rezone
intersections
REZONE
SNYPNT
pictogrammes?
change objects?
object?
make changes
CHOBJ
change magazines?
isite?
make changes
CHMAG
calculate 4th magazine coordinate
extra output?
iprint?
initial output
OUTSIT
initial plots?
ipilot?
plot
pictogrammes?
PLSITE
picto?
plot pictogrammes
PICTO
start calculations
icont?
back to A
calculate total involved HE
characterize magazines
depending on contents

Flowchart of the option for effects versus distance plots

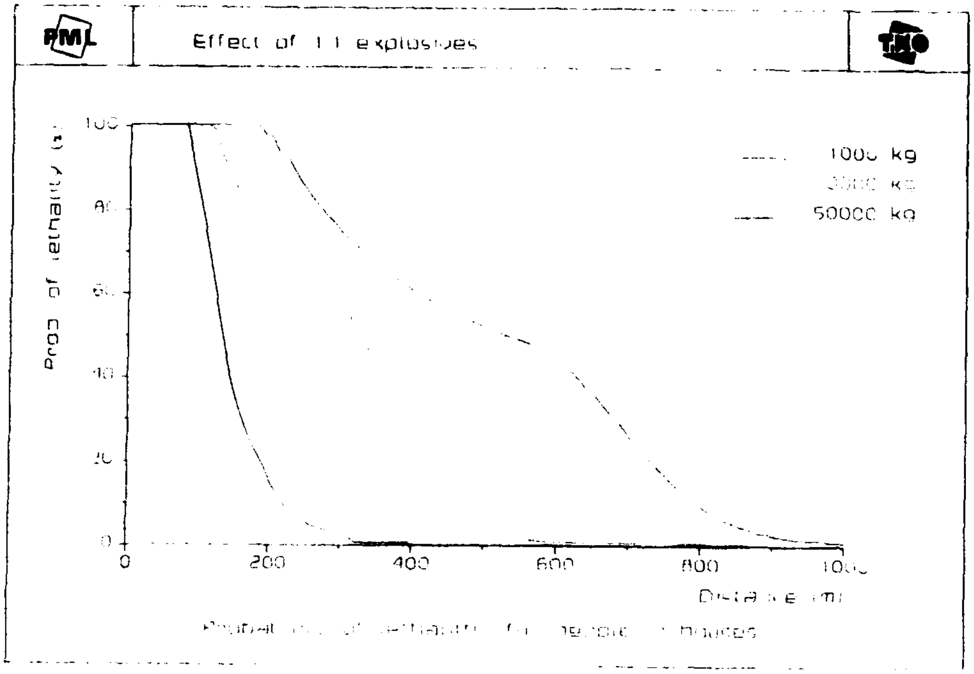
The contents of the routines mentioned here are described in Chapter 4.

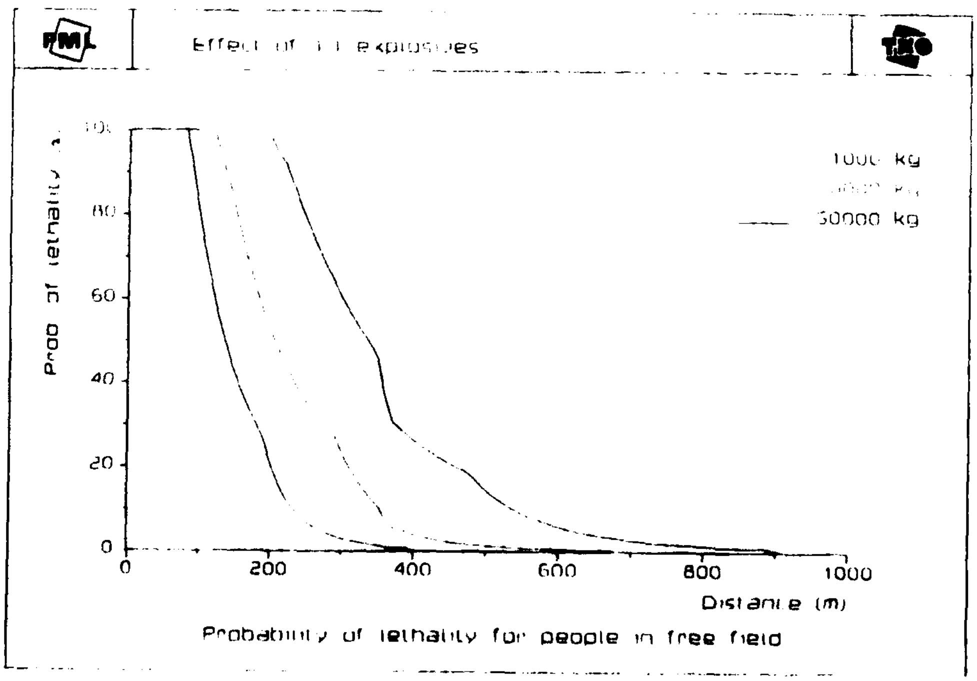



building collapse
COLLAPS
window pane breakage
WINDOW
total body/head impact
BODY
heat radiation
HEATEF
correction for
small quantities
CORRECT
summarize effects
plotting
PLEFF

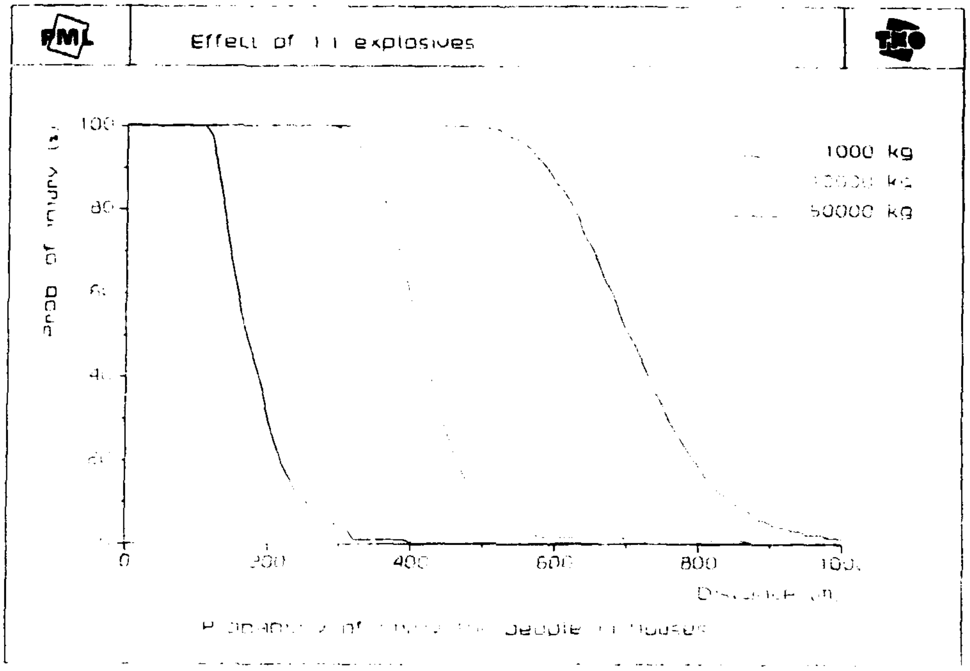
ANNEX 2 EFFECTS VERSUS DISTANCES FOR SEVERAL EXPLOSIVE QUANTITIES

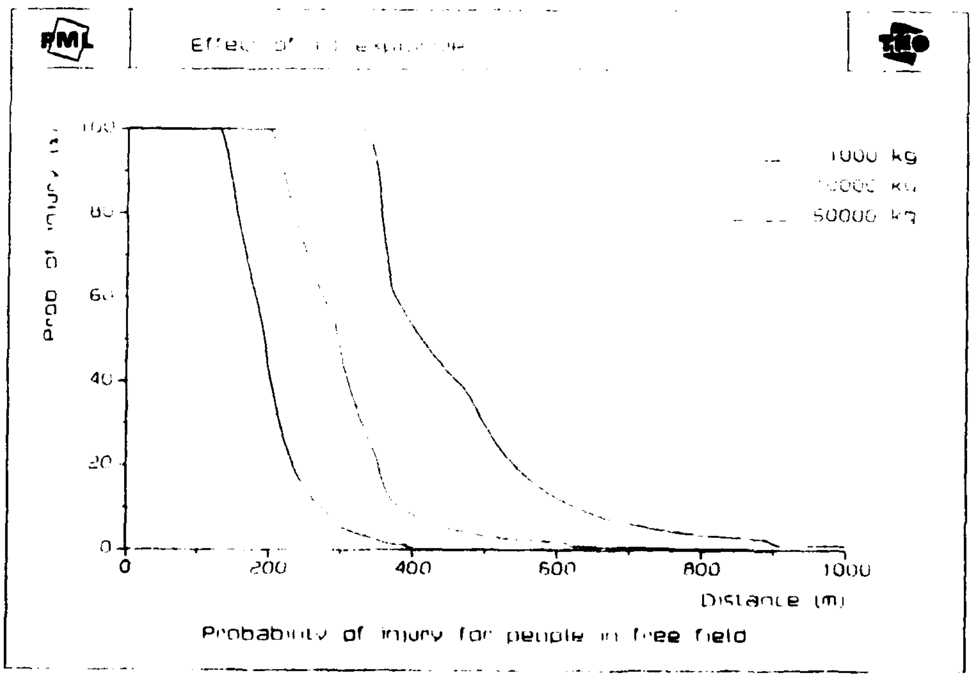
Plots of effects (probability of lethality) versus distances for three quantities of hazard division 1.1 explosives with the effects of fragments and debris.



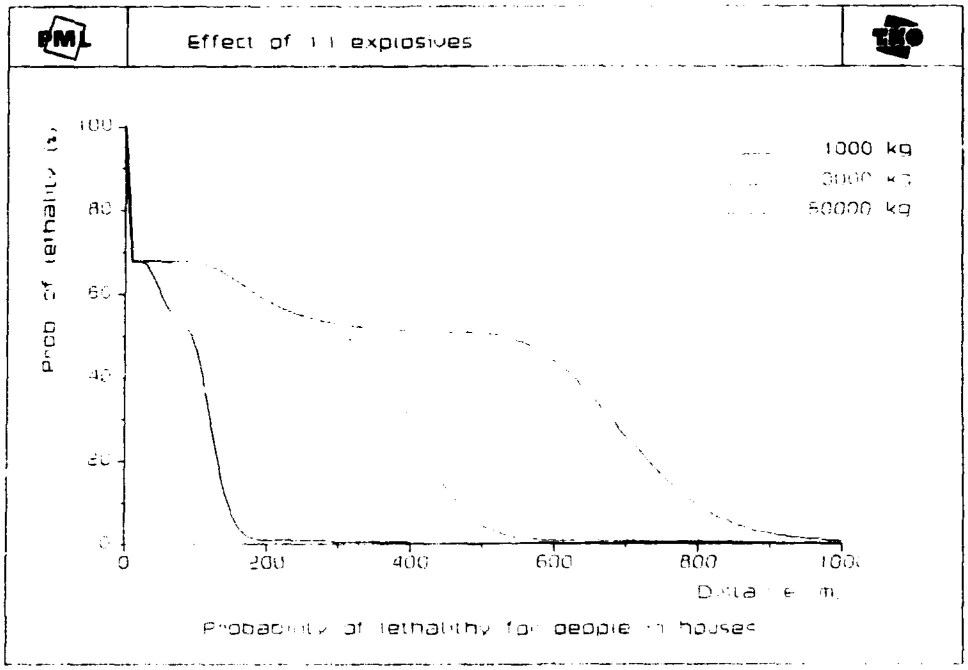


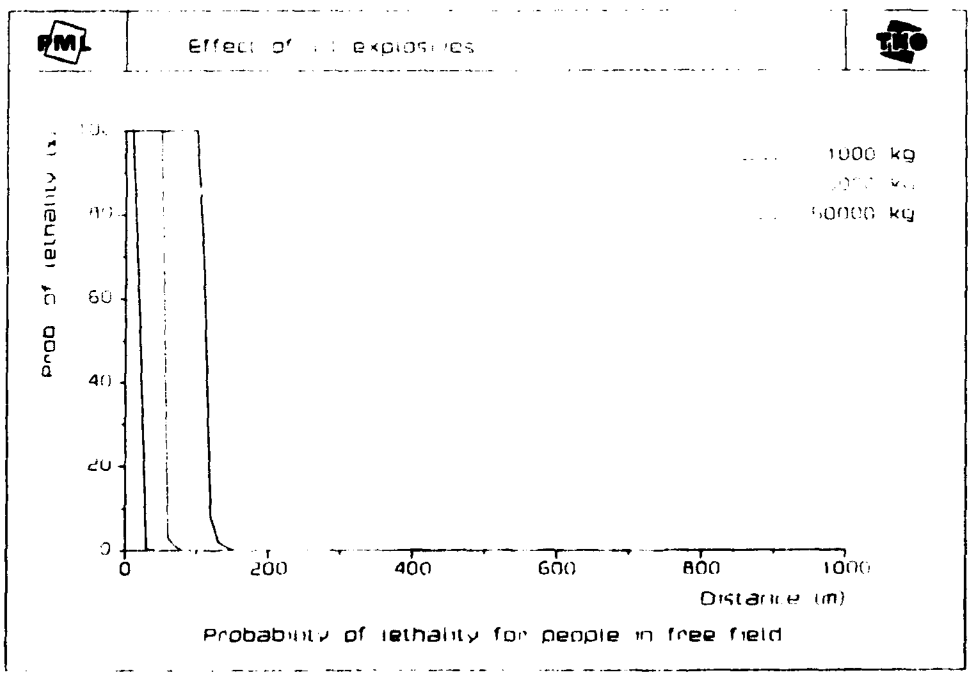
Plots of effects (probability of injury) versus distances for three quantities of hazard division 1.1 explosives with the effects of fragments and debris.



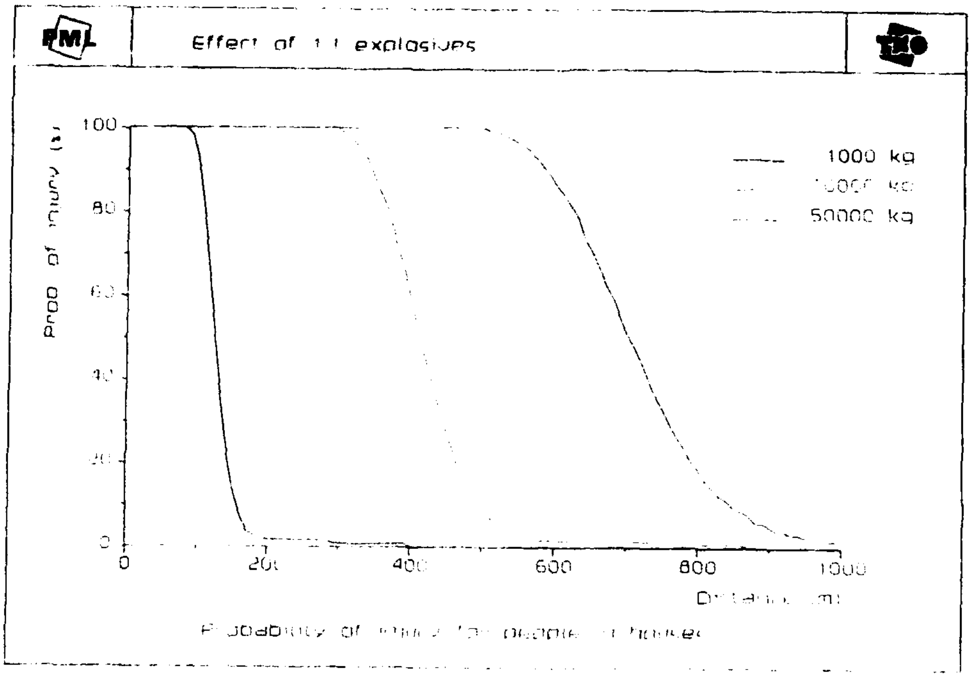


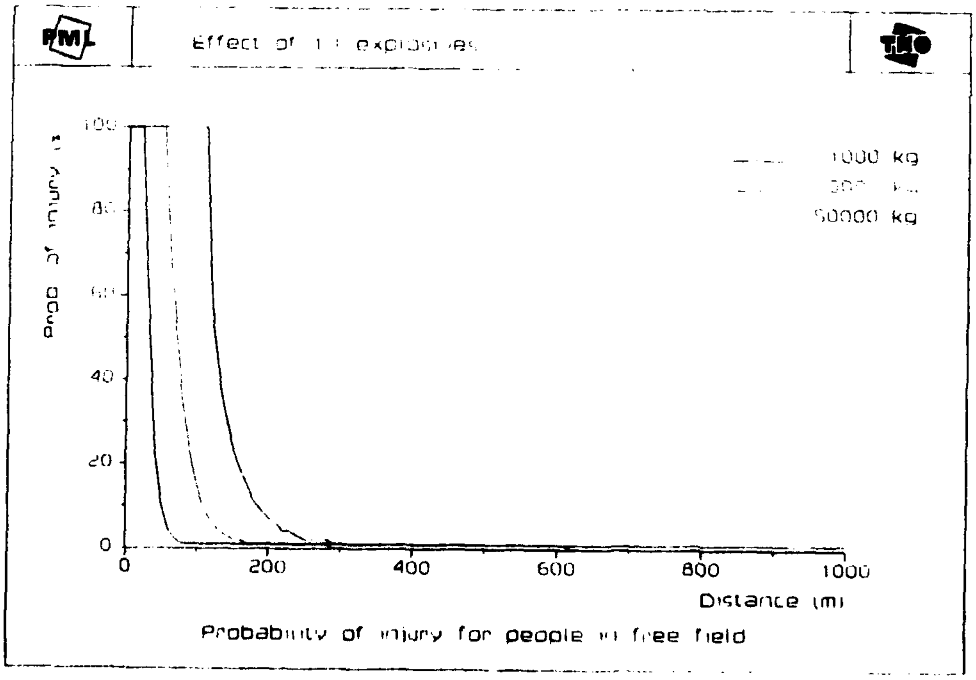
Plots of effects (probability of lethality) versus distances for three quantities of hazard division 1.1 explosives without the effects of fragments and debris.





Plots of effects (probability of injury) versus distances for three quantities of hazard division 1.1 explosives without the effects of fragments and debris.





ANNEX 3 DATA FILE FORMAT WITH EXAMPLE

Card 1:	-	1X
	number of magazines	I4
	number of surrounding objects	I4
	number of object coordinates	I4
	-	1X
	average number of people in houses	F5.2
	-	1X
	complex name	A50

For each magazine:

Card 2:	-	1X
	magazine code	A2
	-	2X
	magazine name	A6
	-	2X
	explosive contents (kg)	F10.0
	-	2X
	hazard division	A4
Card 3:	-	1X
	3 corner coordinates	6F12.5

For each surrounding object:

Card 4:	-	1X
	object name	A6
	-	1X
	object code	A2
	-	1X
	first coordinate number	I4
	last coordinate number	I4
	number of houses/road intensity	I6
	-/cyclist and pedestrian intensity	I4
	-	1X
	object centre or first road coordinates	2F12.5
Card 5:	-	1X
	next road coordinates	6F12.5

Example of an input file for RISKANAL

```
     5     14     20     3.25  EXAMPLE
I3      IGLOO1    15000.      1.1
   112.5          125.0       122.5     125.0     122.5     150.0
OB      EARTH2    50000.      1.3a
   250.0          100.0       250.0     90.0      275.0     90.0
I3      IGLOO3    15000.      1.1
   250.0          37.5        250.0     27.5      275.0     27.5
OP      OPEN4     20000.      1.2
   250.0          -25.0       250.0     -35.0     275.0     -35.0
I3      IGLOO5    15000.      1.1
   175.0          -110.0      175.0     -120.0    200.0     -120.0
HS1   HS   1    1     5     0    75.0     600.0
HS2   HS   2    2     8     0    150.0    690.0
HS3   HS   3    3     5     0    230.0    600.0
CM4   HU   4    4     90    0    550.0    200.0
CM5   HU   5    5     90    0    800.0    700.0
HS6   HS   6    6     5     0    420.0    250.0
PK7   HU   7    7     5     0    950.0    140.0
HS8   HS   8    8     5     0    420.0    50.0
HS9   HS   9    9     2     0    190.0    -245.0
HS10  HS   10   10    1     0    10.0     -245.0
HS11  HS   11   11    1     0    -150.0   50.0
RD1   RD   12   13    1000  50   -450.0   650.0
  1000.0   650.0
RD2   RD   14   18    100   10   -50.0    650.0
   -50.0   -200.0        350.0     -200.0     450.0     -100.0
  1000.0   -100.0
RD3   RD   19   20    10   100   395.0    -160.0
   395.0   700.0
```

Example of the program output of the input file

Calculation with maximum quantity distances

Calculation with fragment hazards

The following data concern the storage sites:

IGLOO1	Type I3	High explosive contents			15000. kg	Hazard Division 1.1	
112.50	125.00	122.50	125.00	122.50	150.00	112.50	150.00
EARTH2	Type OB	High explosive contents			50000. kg	Hazard Division 1.3a	
250.00	100.00	250.00	90.00	275.00	90.00	275.00	100.00
IGLOO3	Type I3	High explosive contents			15000. kg	Hazard Division 1.1	
250.00	37.50	250.00	27.50	275.00	27.50	275.00	37.50
OPEN4	Type OP	High explosive contents			20000.kg	Hazard Division 1.2	
250.00	-25.00	250.00	-35.00	275.00	-35.00	275.00	-25.00
IGLOO5	Type I3	High explosive contents			15000. kg	Hazard Division 1.1	
175.00	-110.00	175.00	-120.00	200.00	-120.00	200.00	-110.00

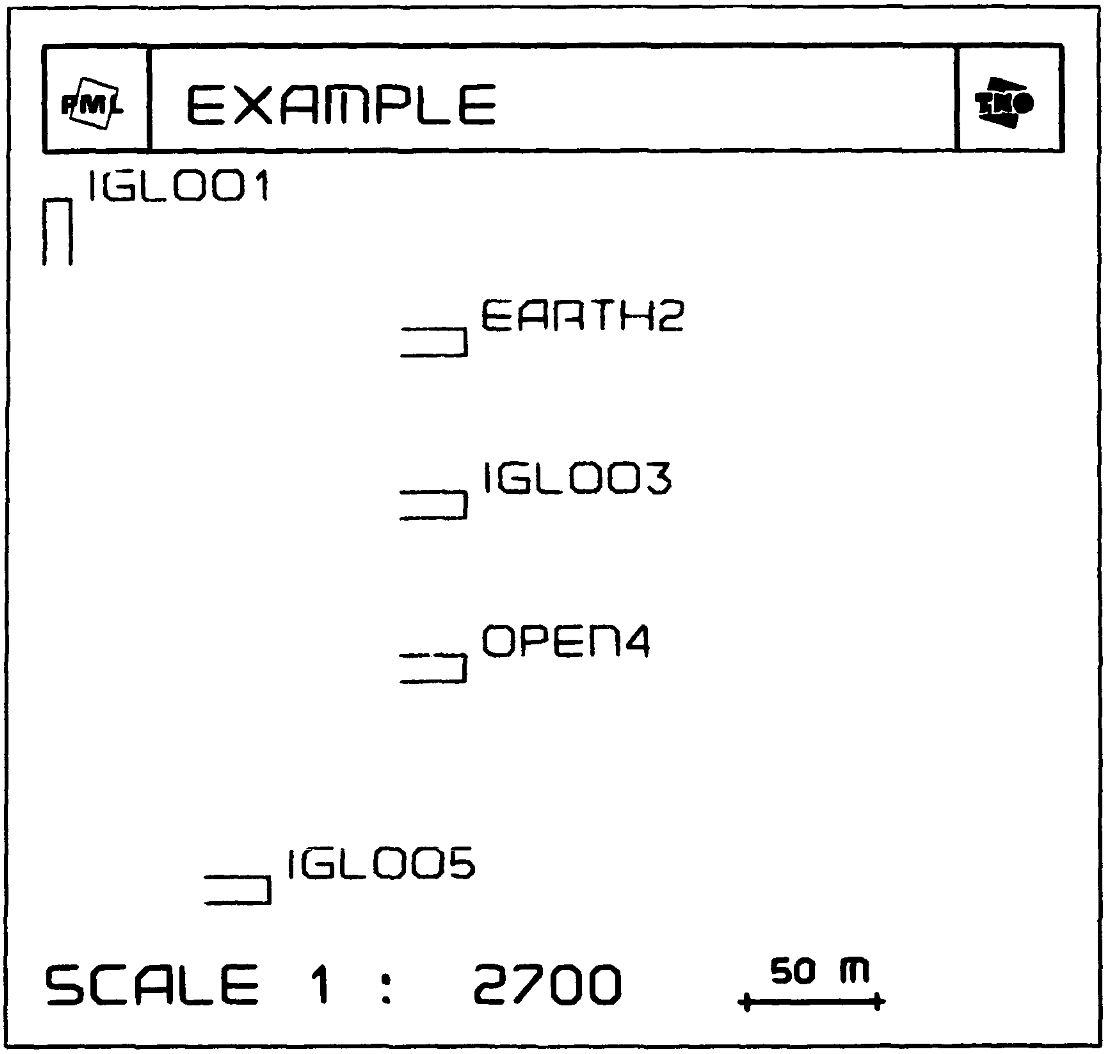
The following data concern the surroundings:

Average number of people in houses (units) is 3.25

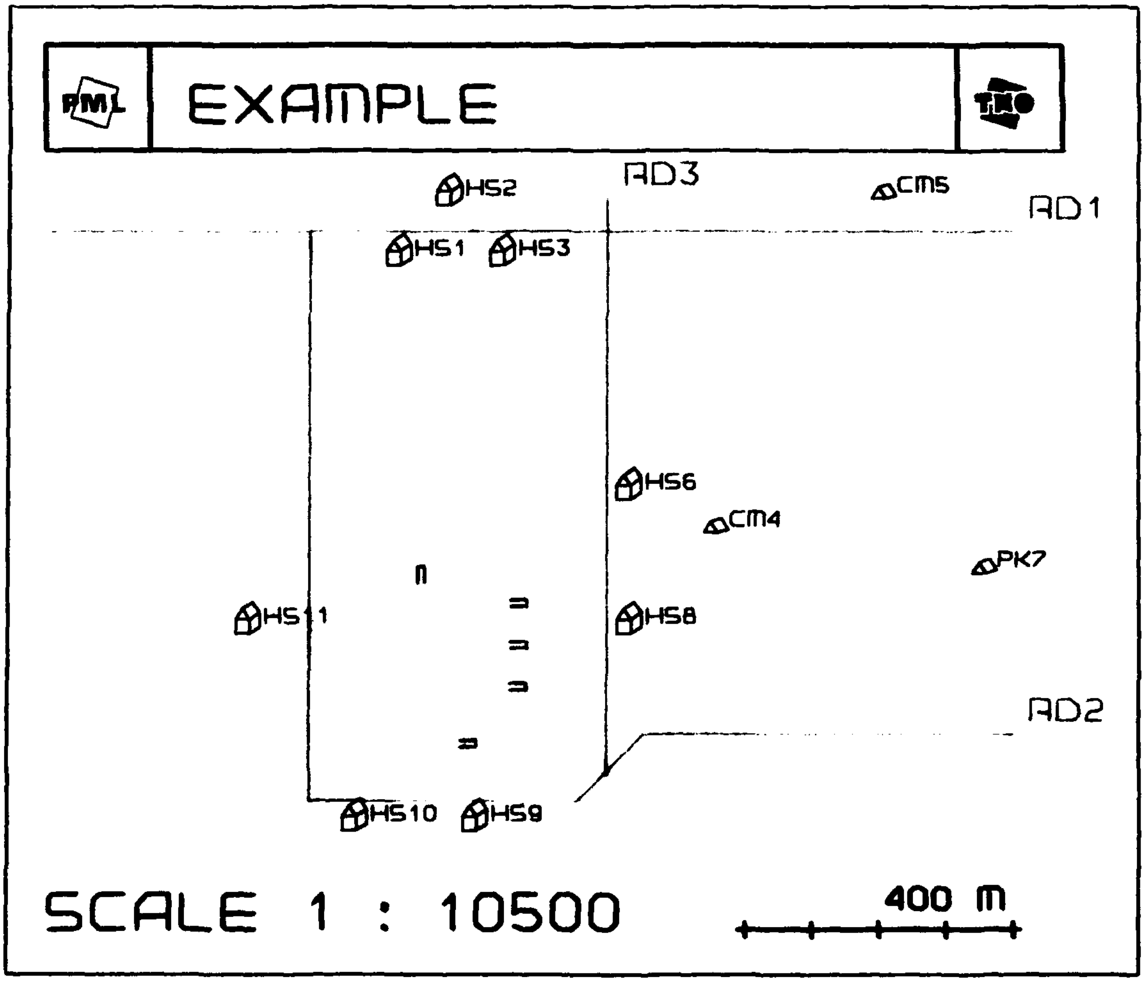
HS1	Type HS	Number of houses	5	75.00	600.00
HS2	Type HS	Number of houses	8	150.00	690.00
HS3	Type HS	Number of houses	5	230.00	600.00
CM4	Type HU	Number of houses	90	550.00	200.00
CM5	Type HU	Number of houses	90	800.00	700.00
HS6	Type HS	Number of houses	5	420.00	250.00
PK7	Type HU	Number of houses	5	950.00	140.00
HS8	Type HS	Number of houses	5	420.00	50.00
HS9	Type HS	Number of houses	2	190.00	-245.00
HS10	Type HS	Number of houses	1	10.00	-245.00
HS11	Type HS	Number of houses	1	-150.00	50.00

RD1	Type RD	24 Hours intensity	1000	Number of cyclists	50
	-450.00	650.00			
	1000.00	650.00			
RD2	Type RD	24 Hours intensity	100	Number of cyclists	10
	-50.00	650.00			
	-50.00	-200.00			
	350.00	-200.00			
	450.00	-100.00			
	1000.00	-100.00			
RD3	Type RD	24 Hours intensity	10	Number of cyclists	100
	395.00	-160.00			
	395.00	700.00			

An ammunition storage complex called EXAMPLE



The complex EXAMPLE with its surroundings



ANNEX 4 QUANTITY-DISTANCES ACCORDING TO AC/258

Table 4.1 Quantity-distance tables for hazard division 1.1 according to AC/258 [1] (simplified)

Exposed Sites	Position Explosion Site	DONOR MAGAZINES I7,I3,ID,IB,IE back	I7,I3,ID,IB,IE side	BR,BD	OB,OT	OP	I7,I3,ID,IB,IE front
	I7, back	-3	-3	-5	-5	-5	-4
	I3, back	-3	-3	-5	-5	-5	-4
	IE, back	-4;-5	-4;-5	-6	-6	-6	-4;-6
A	I7, side	-3	-3	-5	-5	-5	-5
C	I3, side	-3	-3	-6	-6	-6	-5
C	IE, side	-4;-6	-4;-6	-6	-6	-6	-6
E	I7, front	-4	-4;-5	-9;-12	-7	-7	-7
P	I3, front	-6	-6	-9;-12	-8	-8	-8
T	ID, front	-4;-7	-4;-7	-9	-4;-9	-9	-9
O	IB, front	-4;-7	-4;-7	-9	-9	-9	-9
R	IE, front	-4;-7	-4;-7	-9	-4;-9	-9	-9
S	BR	-4;-7	-4;-7	-4;-7	-4;-7	-4;-7	-5;-7
	BD	-4;-7	-4;-7	-4;-7	-4;-7	-4;-7	-5;-7
	OB, OT	-4;-7	-4;-7	-4;-7	-4;-7	-4;-7	-4;-7
	OP	-4;-7	-4;-7	-9;-12	-4;-7	-9;-12	-9;-12

Meaning of the figures: -1 corresponds with quantity distance $D_1 = 0.35.Q^{1/3}$
-2 ,, ,, ,, ,, $D_2 = 0.44.Q^{1/3}$
-3 ,, ,, ,, ,, $D_3 = 0.50.Q^{1/3}$
-4 ,, ,, ,, ,, $D_4 = 0.80.Q^{1/3}$
-5 ,, ,, ,, ,, $D_5 = 1.10.Q^{1/3}$
-6 ,, ,, ,, ,, $D_6 = 1.80.Q^{1/3}$
-7 ,, ,, ,, ,, $D_7 = 2.40.Q^{1/3}$
-8 ,, ,, ,, ,, $D_8 = 3.60.Q^{1/3}$
-9 ,, ,, ,, ,, $D_9 = 4.80.Q^{1/3}$
-10 ,, ,, ,, ,, $D_{10} = 8.00.Q^{1/3}$
-11 ,, ,, ,, ,, $D_{11} = 14.80.Q^{1/3}$
-12 ,, ,, ,, ,, $D_{12} = 22.20.Q^{1/3}$

Q is the involved amount of explosive in kg

Table 4.2 Quantity-distance tables for hazard division 1.2 according to AC/258 [1] (simplified)

Exposed Sites	Potential Explosion Site	DONOR MAGAZINES I7,I3,ID,IB,IE back	I7,I3,ID,IB,IE side	BR,BD	OB,OT	OP	I7,I3,ID,IB,IE front
	I7, back	2	2	2	2	2	2
	I3, back	2	2	2	2	2	2
	IE, back	2	2	2	2	2	2
A	I7, side	2	2	2	2	2	2
C	I3, side	2	2	2	2	2	2
C	IE, side	2	2	2	2	2	2
E	I7, front	2	2	25;90	10;25	25;90	25;90
P	I3, front	2	2	25;90	10;25	25;90	25;90
T	ID, front	2	2	10;25	10	25;90	25;90
O	IB, front	2	2	10;25	10;25	25;90	25;90
R	IE, front	90	90	90	90	90	90
S	BR	2	2	10	10	10	10
	BD	90	90	90	90	90	90
	OB, OT	90	90	90	90	90	90
	OP	90	90	90	90	90	90

The figures correspond with metres

Table 4.3 Quantity-distance tables for hazard division 1.3a according to AC/258 (simplified)

Exposed Sites	Potential Explosion Site	DONOR MAGAZINES I7,I3,ID,IB,IE back	I7,I3,ID,IB,IE side	BR,BD	OB,OT	OP	I7,I3,ID,IB,IE front
	I7, back	2	2	2	10;25	10;25	10;25
	I3, back	2	2	2	10;25	10;25	10;25
	IE, back	2	2	2	25	25	-13
A	I7, side	2	2	2	10;25	10;25	10;25
C	I3, side	2	2	2	10;25	10;25	10;25
C	IE, side	10;25	10;25	10;25	-13	-13	-13
E	I7, front	2;25	2;25	2;25	25;-13	25;-13	240;-13
P	I3, front	2;25	2;25	2;25	25;-13	25;-13	240;-13
T	ID, front	2	2	2	25	25	-13
O	IB, front	10;25	10;25	10;25	-13	-13	240;-13
R	IE, front	25	-13	-13	-13	-13	240
S	BR	2	2	2	10;25	10;25	-13
	BD	25	-13	-13	-13	-13	240
	OB, OT	25	-13	-13	-13	-13	240
	OP	25	-13	-13	-13	-13	240

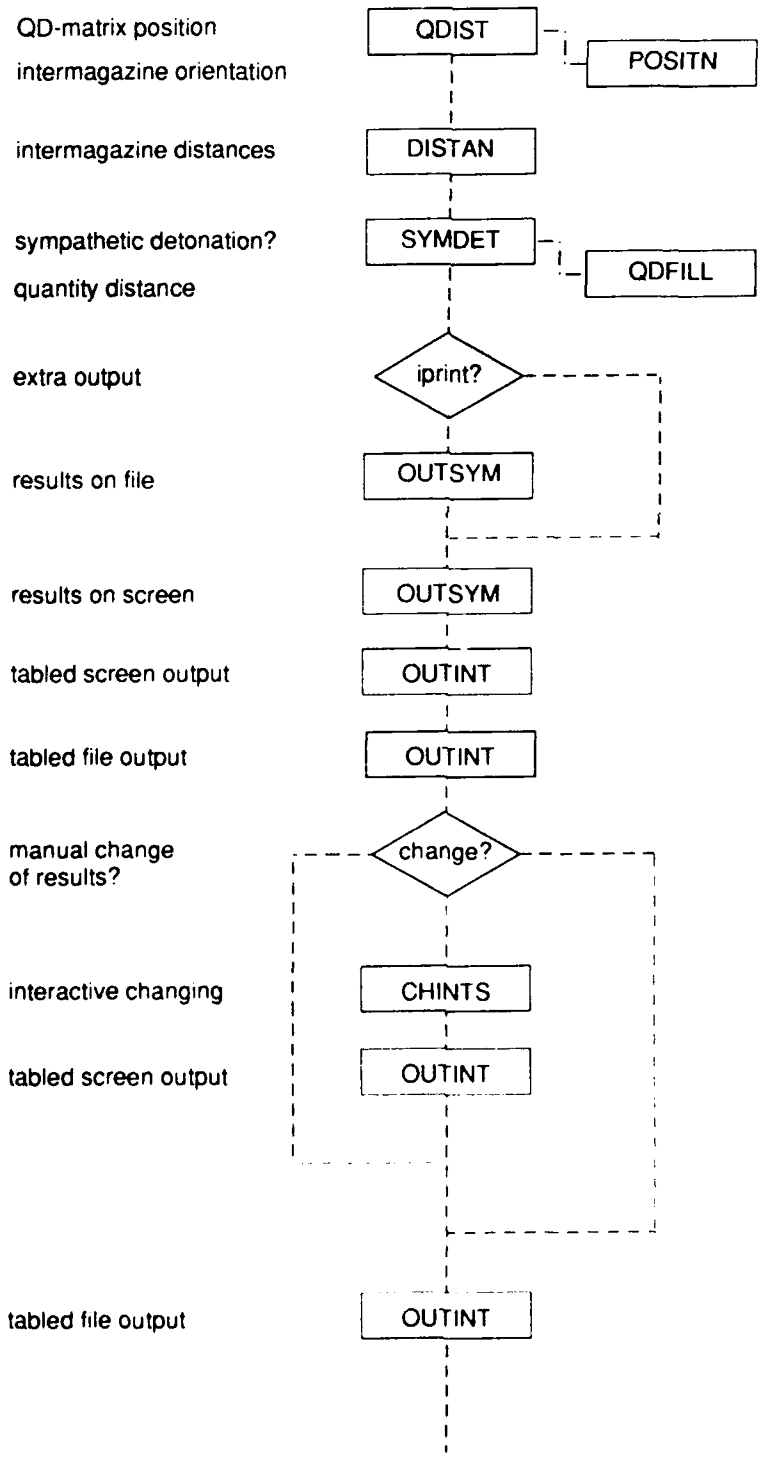
Meaning of the figures: -13 corresponds with quantity distance $D_I = 0.225.Q^{1/2}$
positive figures correspond with metres

Table 4.4 Quantity-distance tables for hazard division 1.3b according to AC/258 (simplified)

	Potential Explosion Site / Exposed Sites	DONOR MAGAZINES I7,I3,ID,IB,IE back	I7,I3,ID,IB,IE side	BR,BD	OB,OT	OP	I7,I3,ID,IB,IE front
	I7, back	2	2	2	2	2	2
	I3, back	2	2	2	2	2	2
	IE, back	2	2	2	2	2	2
A	I7, side	2	2	2	2	2	2
C	I3, side	2	2	2	2	2	2
C	IE, side	2	2	2	2	2	2
E	I7, front	2	2	10;25	10;25	10;25	25;60
P	I3, front	2	2	10;25	10;25	10;25	25;60
T	ID, front	2	2	10	10	10	25
O	IB, front	2	2	10;25	10;25	25;60	25;60
R	IE, front	25;60	25;60	25;60	60	60	60
S	BR	2	2	10	10	10	10
	BD	25;60	25;60	25;60	60	60	60
	OB, OT	25;60	25;60	25;60	60	60	60
	OP	25;60	25;60	25;60	60	60	60

The figures correspond with metres

ANNEX 5 A FLOWCHART OF THE INTERNAL SAFETY PART



ANNEX 6 EXAMPLE OF THE RESULTS OF AN INTERNAL SAFETY CALCULATION

Example of the results of the internal safety calculations (detailed output)

Donor storage site IGLOO1 type I3 contents 15000. kg 1.1 explosives

No sympathetic reactions.

Donor storage site EARTH2 type OB contents 50000. kg 1.3a explosives

No sympathetic reactions.

Donor storage site IGLOO3 type I3 contents 15000. kg 1.1 explosives

The following magazines react sympathetically:
EARTH2 , type OB, contents 50000. kg 1.3a explosives, 15000. kg 1.1 involved
OPEN4 , type OP, contents 20000. kg 1.2 explosives, 15000. kg 1.1 involved

Donor storage site OPEN4 type OP contents 20000. kg 1.2 explosives

No sympathetic reactions.

Donor storage site IGLOO5 type I3 contents 15000. kg 1.1 explosives

No sympathetic reactions.

Example of the results of the internal safety calculations (default output)

Example:

This complex contains 5 magazines

The total quantity of high explosives is 115000. kg

Storage site	Type	Contents (kg)	Hazard division	Sympathetic detonation (kg) 1.1	1.2	1.3	1.4
IGLOO1	I3	15000.	1.1	15000.	0.	0.	0.
EARTH2	OB	50000.	1.3a	0.	0.	50000.	0.
IGLOO3	I3	15000.	1.1	15000.	20000.	50000.	0.
	Sympathetic reactions of EARTH2 , not 1.1-reaction						
	Sympathetic reactions of OPEN4 , not 1.1-reaction						
OPEN4	OP	20000.	1.2	0.	20000.	0.	0.
IGLOO5	I3	15000.	1.1	15000.	0.	0.	0.

ANNEX 7 FORMULAE USED FOR THE QUANTIFICATION OF THE PHYSICAL EFFECTS

1 Fragment density (1.1 and 1.2 sources)

The formulae used here are the fitted results of experimental data obtained from ESKIMO 1 (M107 grenades, 10900 kg, Weals, 1973) and ESKIMO 2 (M117 bombs, 10900 kg, Weals, 1974) and Yuma (M117 bombs, 2970 kg, Feinstein, 1972) tests [3,4,5].
The calculated results for the fragment density at a certain distance, obtained with these data, do not contradict more recent experimental results obtained from the joint Australian/UK stack fragmentation trials Phase 1 (1982), 2 (1985) and 3 (1987). See minutes of the 21st, 22nd and 23rd Explosives Safety Seminar [6,7,8].
The calculations are performed with the total amount of 1.1 explosives or with 10 % of the 1.2 contents of a magazine. It is assumed is that explosives of hazard division 1.2 do not all explode at once. The orientation of the igloos with respect to the object is also taken into account.

* Perhaps it is better to consider the most common package units of 1.2 explosives instead of this 10 %.

Symbols used: x = distance in m

Q = involved amount of explosive in kg

q = fragment density in $1/m^2$

Extrapolation to values of q above 0.5 per square metre is risky and a quadratic increase of the q with decreasing distance is supposed:

Fragment density for non-igloo type magazines containing less than 3000 kg:

$$\log q = 9.7591 - 5.1203 \log (x / Q^{0.104})$$

$$\text{if } q > 0.5: Z = (11.484.10^9.Q^{0.541})^{0.1953}$$

$$q = 0.5 (Z / x)^2$$

Fragment density for non-igloo type magazines containing more than 3000 kg:

$$\log q = 6.00252 - 5.08955 \log (x / Q^{0.306})$$

$$\text{if } q > 0.5: Z = (2.012.10^6.Q^{1.557})^{0.19648}$$

$$q = 0.5 (Z / x)^2$$

Fragment density at the side of an igloo type magazine:

$$\log q = 5.64185 - 5.3782 \log (x / Q^{0.306})$$

for a 1.2 donor q = 0

$$\text{if } q > 0.5: Z = (8.7676.10^5.Q^{1.6457})^{0.18594}$$

$$q = 0.5 (Z / x)^2$$

Fragment density at the back of an igloo type magazine:

$$\log q = 4.10427 - 4.43798 \log (x / Q^{0.306})$$

for a 1.2 donor q = 0

$$\text{if } q > 0.5: Z = (2.5428.10^4.Q^{1.358})^{0.22533}$$

$$q = 0.5 (Z / x)^2$$

Fragment density at the front of an igloo type magazine:

$$\log q = 6.00252 - 5.08955 \log (x / Q^{0.306})$$

$$\text{if 1.1 donor and } q > 0.5: Z = (2.012.10^6.Q^{1.557})^{0.19648}$$

$$q = 0.5 (Z / x)^2$$

2 Other physical effects

All next mentioned effects are described with the fitted formulae as given in the AC/258 Manual on NATO safety principles for the storage of ammunition and explosives, 1977, Part II. 724.c April 1987.

Symbols used:
- P_s = side-on pressure in kPa
- P_r = reflected pressure in kPa
- I_s = side-on impulse in kPas
- I_r = reflected impulse in kPas
- T_a = time of shock wave arrival in s
- V_s = shock front velocity in m/s
- T_p = positive phase duration in s
- R_c = fireball radius in m
- R_g = fireball radius at ground level in m
- W = heat radiation intensity in kW/m2
- t = exposed time in s
- Q = involved amount of explosives in kg
- x = distance in m
- sc = scaled distance in m/kg$^{1/3}$: sc = $x / Q^{1/3}$

Pressures (1.1 sources):

For the rear and side of igloos, and for earth covered (0.6 m) magazines, the pressure is calculated as for 10 % of the contents, except for large distances (> 6 m/kg$^{1/3}$) according to AC/258.

* This is an older statement of AC/258 (Part I, Paragraph 453). The more recent statement must still be inserted.

$sc < 0.0674 \quad : P_s = 10^5$
$sc > 40 \quad : P_s = 0$
$0.0674 < sc < 40$:

$$U = -0.214362789151 + 1.35034249993 \log(sc)$$

$$Y = +2.78076916577 - 1.6958988741.U - 0.154159376846.U^2 + 0.514060730593.U^3$$
$$+ 0.0988534365274.U^4 - 0.293912623038.U^5 - 0.0268112345019.U^6 + 0.109097496421.U^7$$
$$+ 0.00162846756311.U^8 - 0.0214631030242.U^9 + 0.0001456723382.U^{10} + 0.00167847752266.U^{11}$$

$$\log P_s = Y$$

$sc < 0.0674 \quad : P_r = 10^6$
$sc > 40 \quad : P_r = 0$
$0.0674 < sc < 40$:

$$U = -0.240657322658 + 1.36637719229 \log(sc)$$

$$Y = +3.40283217581 - 2.21030870597.U - 0.218536586295.U^2 + 0.895319589372.U^3$$
$$+ 0.24989009775.U^4 - 0.569249436807.U^5 - 0.11791682383.U^6 + 0.224131161411.U^7$$
$$+ 0.0245620259375.U^8 - 0.0455116002694.U^9 - 0.00190930738887.U^{10} + 0.00361471193389.U^{11}$$

$$\log P_r = Y$$

Impulses (1.1 sources):

$sc < 0.0674 \quad : I_s = 10$
$sc > 40 \quad : I_s = 0$
$0.0674 < sc < 0.955$:

$$U = +2.06761908721 + 3.0760329666 \log(sc)$$

$$Y = +2.52455620925 - 0.502992763686.U + 0.171335645235.U^2 + 0.0450176963051.U^3$$
$$- 0.0118964626402.U^4$$

$0.955 < sc < 40 \quad :$

$$U = -1.94708846747 + 2.40697745406 \log(sc)$$

$$Y = +1.67281645863 - 0.384519026965.U - 0.0260816706301.U^2 + 0.00595798753822.U^3$$
$$+ 0.014544526107.U^4 - 0.00663289334734.U^5 - 0.00284189327204.U^6 + 0.0013644816227.U^7$$

$$\log S_{imp} = Y$$

$$I_s = 0.001\ S_{imp}\ Q^{1/3}$$

$sc < 0.0674 \quad : I_r = 100$

$sc > 40 \quad : I_r = 0$

$0.0674 < sc < 40$:

$$U = -0.246208804814 + 1.33422049854 \log(sc)$$

$$Y = +2.70588058103 - 0.949516092853.U + 0.112136118689.U^2 - 0.0250659183287.U^3$$

$$\log S_{imp} = Y$$

$$I_r = 0.001\, S_{imp}\, Q^{1/3}$$

Time of arrival (1.1 sources):

$sc < 0.0674 \quad : T_a = 10^{-5}$

$sc > 40 \quad : T_a = 0$

$0.0674 < sc < 40$:

$$U = -0.202425716178 + 1.37784223635 \log(sc)$$

$$Y = -0.0591634288046 + 1.35706496258.U + 0.052492798645.U^2 - 0.196563954086.U^3 - 0.0601770052288.U^4 + 0.0696360270891.U^5 + 0.0215297490092.U^6 - 0.0161658930785.U^7 - 0.00232531970294.U^8 + 0.00147752067524.U^9$$

$$\log S_{tim} = Y$$

$$T_a = 0.001\, S_{tim}\, Q^{1/3}$$

Shock front velocity (1.1 sources):

$sc < 0.0674 \quad : V_s = 100$

$sc > 40 \quad : V_s = 0$

$0.0674 < sc < 40$:

$$U = -0.202425716178 + 1.37784223635 \log(sc)$$

$$Y = -0.06621072854 - 0.698029762594.U + 0.158916781906.U^2 + 0.443812098136.U^3 - 0.11340202392l.U^4 - 0.369887075049.U^5 + 0.129230567449.U^6 + 0.19857981197.U^7 - 0.0867636217397.U^8 - 0.0620391900135.U^9 + 0.0307482926566.U^{10} + 0.010265723407.U^{11} - 0.00546533250772.U^{12} - 0.000693180974.U^{13} + 0.00038474949l6.U^{14}$$

$$\log S_{vel} = Y$$

$$V_s = S_{vel}\, Q^{1/3}$$

Positive phase duration (1.1 sources):

$sc < 0.178 \quad : T_p = 10^{-4}$

$sc > 40 \quad : Tp = 0$

$0.178 < sc < 1.01$:

$$U = +1.92946154068 + 5.25099193925 \log(sc)$$

$$Y = -0.614227603559 + 0.130143717675.U + 0.134872511954.U^2 + 0.0391574276906.U^3 - 0.00475933664702.U^4 - 0.00428144598008.U^5$$

$1.01 < sc < 2.78$:

$$U = -2.12492525216 + 9.2996288611 \log(sc)$$

$$Y = +0.315409245784 - 0.0297944268976.U + 0.030632954288.U^2 + 0.0183405574086.U^3 - 0.0173964666211.U^4 - 0.00106321963633.U^5 + 0.00562060030977.U^6 + 0.0001618217499.U^7 - 0.0006860188944.U^8$$

$2.78 < sc < 40$:

$$U = -3.53626218091 + 3.46349745571 \log(sc)$$

$$Y = +0.686906642409 + 0.0933035304009.U - 0.0005849420883.U^2 - 0.00226884995013.U^3 - 0.00295908591505.U^4 + 0.00148029868929.U^5$$

$$\log S_{pos} = Y$$

$$T_p = 0.001\ S_{pos}\ Q^{1/3}$$

Heat radiation effects (1.1 and 1.3 sources):

For 1.3 explosives, 10 % of the total contents is taken, while for igloos containing 1.3, heat radiation is only calculated at the front side.

$$R_c = 2.8.Q^{0.28}$$

$$R_g = 0.45.Q^{0.44}$$

$$t = 0.93.Q^{0.21}$$

$$W = 19.Q^{0.82} / x^2$$

When $x < R_g$ (object within fireball) values for W and t are adjusted, so lethality calculations will result in lethal probabilities of 100 %: t = 6; W = 200

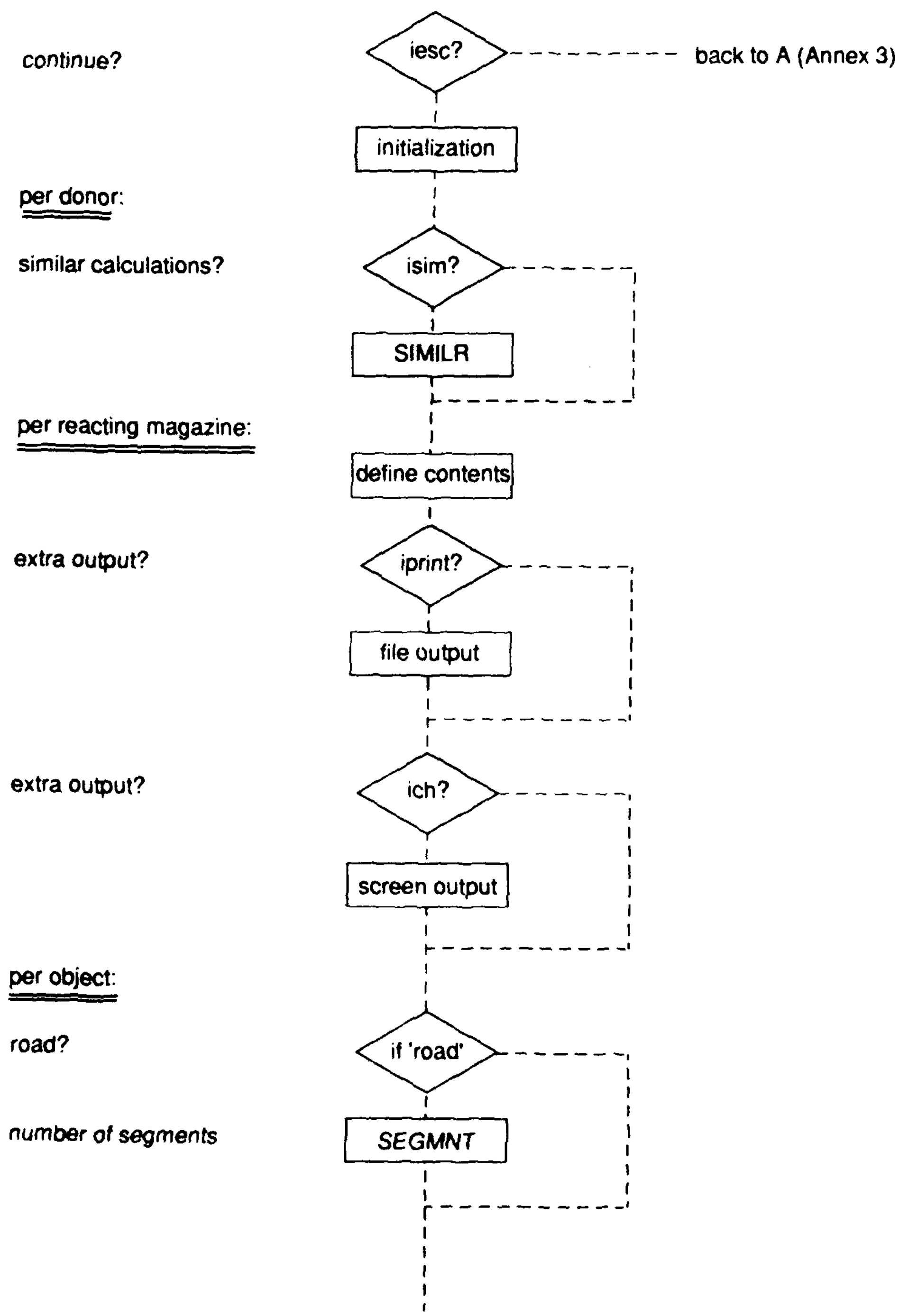
When $x < R_g$ (object within fireball) values for W and t are adjusted, so lethality calculations will result in lethal probabilities of 100 %: t = 6; W = 200

3 Formulae for (manual) control of the results obtained with the fitted formulae mentioned above

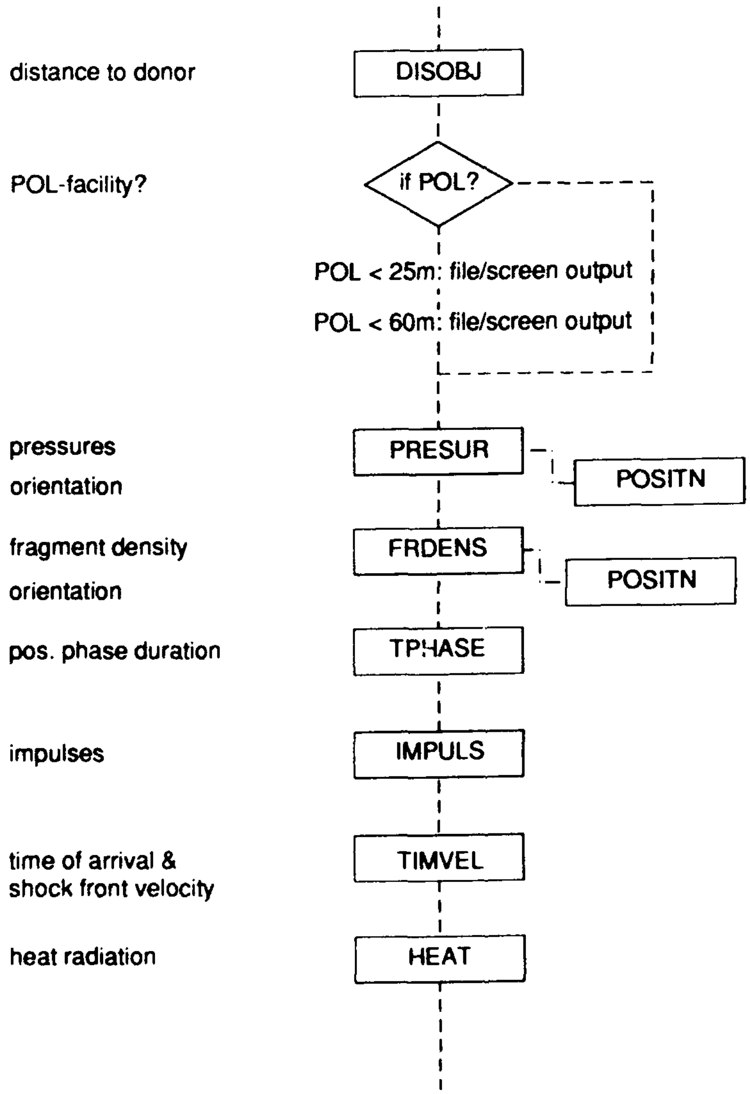
Shock velocity	: $V_s = C_o.\sqrt{(1 + 6P_s / 7P_o)}$
Particle velocity	: $u = 5.P_s / 7P_o.V_s / (1 + 6P_s/7P_o)$
Dynamic pressure	: $P_d = 5 / 2\ Ps^2 / (7P_o + P_s)$
Reflected overpressure	: $P_r = 2P_s\ [(7P_o + 4P_s) / (7P_o + P_s)]$

Now all explosion effects are known for this source (donor) and this distance (object).

ANNEX 8 A FLOWCHART OF THE QUANTIFICATION OF THE EXTERNAL SAFETY PART



per coordinate:



ANNEX 9 PROBIT FUNCTIONS USED FOR THE CACULATION OF THE EFFECTS ON HUMANS

Probit functions used for the calculation of effects on humans as given in the 'Green Book' [2]

Because of the restricted valuability of these functions, one has to be very careful with the results.

The effects of fragments on people:

Symbols: V_r = hit velocity in m/s

m = fragment mass in kg

m_i = mass distribution percentage

Fragment masses $0.001 < m < 0.1$ kg; m set to 0.1:

For this fragment range, a criterion for human skin perforation is used (Annex 10).

$$S = m.V_r^{5.115}$$

Derived from probabilities of 1, 50 and 99 % for S values of $3.78.10^6$, $11.56.10^6$ and $35.32.10^6$

$$Pr_1 = -28.99 + 2.09 \ln S$$

Fragment masses $0.1 < m < 4.5$ kg; m set to 1.0:

For this fragment range, an energy criterion (79 J) is used.

$$S = 0.5 \, m.V_r^2$$

Derived from probabilities of 1, 50 and 99 % for impact energies of 46, 71 and 110 J

$$Pr_2 = -17.86 + 5.36 \ln S$$

Fragment masses $m > 4.5$ kg; m set to 4.5:

For this fragment range, a criterion for fracture of the skull is used.

Derived from probabilities of 1 and 99 % for impact velocities of 4.5 and 7.0 m/s

$$Pr_3 = -13.19 + 10.54 \ln V_r$$

With the fragment density q, the probability of lethality per mass class (s_i) and the exposed area of standing people (0.58 m^2), the probability of elimination by fragments (P_{fragm}) can be calculated:

$$S_1 = 0.58.q.m_1.Pr_1$$

$$S_2 = 0.58.q.m_2.Pr_2$$

$$S_3 = 0.58.q.m_3.Pr_3$$

$$P_{fragm} = S_1 + S_2 + S_3 - S_1.S_2/100 - S_2.S_3/100 - S_1.S_3/100 + S_1.S_2.S_3/10000$$

The effects of overpressure on human beings:

Symbols: P_s = side-on pressure in kPa

P_o = atmospheric pressure = 100 kPa

m = mass of human beings = 70 kg (assumed)

I_s = side-on impulse in kPas

$$P_{sc} = P_s / P_o = 0.01\ P_s$$

$$I_{sc} = I_s / (m^{1/3}.P_o^{1/2}) = 0.7673\ Is$$

Probability of lung injury (lethal injury):

50 % lethality for scaled pressure 4.2 and scaled impulse 1.3

$$S = 4.2 / P_{sc} + 1.3 / I_{sc}$$

Derived from probabilities of 50 and 90 % for S equals 1.0 and 0.8

$$Pr = 5.00 - 5.74 \ln S$$

Probability of ear damage (eardrum rupture):

Derived from probabilities of 50 and 90 % for pressures of 103.8 and 240.4 kPa

$$Pr = -12.56 + 1.524 \ln (1000\ P_s)$$

The effects of collapse of houses:

When a house collapses, 35% is assumed for lethal injuries, 5% when structural damage occurs and 1% when there is only light damage. The probability of lethality by the collapse of houses is calculated by means of average values, taken from data of collapsing buildings by earthquakes (20 - 50 % lethal injuries).

Symbols: P_s = side-on pressure in kPa
I_s = side-on impulse in kPas
f = eigenfrequency in Hz
Pr = probit for collapsing, structural damage or light damage

Collapse of houses (limit values of P_s = 40 kPa and I_s = 0.45 kPas):

Houses with less than 4 floors:

$$S = (40 / P_s)^{7.4} + (0.46 / I_s)^{11.3}$$

$$Pr = 5.00 - 0.22 \ln S$$

Houses with more than 4 floors (flats):

P_{st} = 3.445 kPa is taken for the static strength of the building and for the eigenfrequency f = 1.5 Hz (assuming a 30 m high building of concrete (elasticity 25.10^6 kPa and specific mass 200 kg/m^3), with ten floors and a safety coefficient of 3).

$$P_{sc} = Ps / P_{st} = 0.29\ P_s$$

$$I_{sc} = I_s.2\pi f / P_{st} = 2.74\ I_s$$

Due to shock wave:

$$S = (0.9 / P_{sc})^{1.4} + (3.0 / I_{sc})^{2.7}$$

$$Pr = 5.00 - 2.92 \ln S$$

Due to pressure wave:

$$S = (1.25 / P_{sc})^{1.9} + (3.0 / I_{sc})^{2.5}$$

$$Pr = 5.00 - 2.14 \ln S$$

Probability of lethal injury by collapse of houses:

$P_{collapse} = 0.35$. Probability of collapse (maximum value for flats)

Structural damage of houses (limit values of P_s = 20 kPa and I_s = 0.3 kPas):

For both houses and flats:

$$S = (17.5 / P_s)^{8.4} + (0.29 / I_s)^{9.3}$$

$$Pr = 5.00 - 0.26 \ln S$$

Probability of lethal injury by structural damage of houses:

$P_{struct} = 0.05$. Probability of structural damage

Light damage of houses (limit values of P_s = 4 kPa and I_s = 0.1 kPas):

For both houses and flats:

$$S = (4.6 / P_s)^{3.9} + (0.11 / I_s)^{5.0}$$

$$Pr = 5.00 - 0.26 \ln S$$

Probability of lethal injury by light damage of houses:

$P_{light} = 0.01$. Probability of light damage

The effects of window-pane breakage:

Symbols: P_s = side-on pressure in kPa
P_{st} = static strength of the window
DLF = dynamic load factor
f = eigenfrequency in Hz
T = 1 / f in s
T_{pos} = positive phase duration

P_{st} = 8.430 kPa (for a window of 5 mm thickness and 1.5 m x 1.0 m dimensions), a ductility of 1 and an eigenfrequency of 15 Hz (T = 0.07 s) is assumed.

Probability of window-pane crack:

$$P_{sc} = Ps / P_{st} = 0.29\ P_s$$

$$I_{sc} = I_s.2\pi f / P_{st} = 10.65\ I_s$$

If $P_{sc} < 0.5$ or $I_{sc} < 1.0$ no breakage assumed.

Two relations are available for breakage depending on the age of the houses:

Houses built before 1975: $Pr_{cr} = -11.97 + 2.12 \ln P_s$

Houses built after 1975 : $Pr_{cr} = -16.58 + 2.53 \ln P_s$

The program uses the first probit function for the older houses.

Probability of injury (head injury) by glass fragments for people at 1.75 m behind the window:

$$S = DLF.P_s / P_{st}$$

where DLF is assumed to increase linearly with T_{pos}/T to a maximum value of 2 for $T_{pos}/T = 1.5$:

$T_{pos}/T < 1.5$: DLF = 1.11 T_{pos}/T + 0.33

$T_{pos}/T > 1.5$: DLF = 2.0

Derived from probabilities of 1 and 94 % for S equals 1 and 2.

$$Pr_l = 2.67 + 5.62 \ln S$$

Now combine both probabilities:

$$Pr = Pr_{cr} * Pr_{l}$$

This probability will be reduced by assuming an average of 5 % probability of presence of human beings 1.75 m behind the window (this value is low for offices during office-hours and high for houses).

The effects of head and total body impact:

Symbols: P_s = side-on pressure in kPa

I_s = side-on impulse in kPas

Probability S_1 of lethal injury by head impact:

For high impulse values, the pressure with an impact velocity of 5.5 m/s approaches 2.43 kPa; for low values of the impulse and pressures smaller than 0.4-0.5 MPa, the value of pressure times impulse approaches 4.10^8 Pa^2s.

$$S = 2.43 / P_s + 400 / (P_s.I_s)$$

Derived from probabilities of 1 and 99 % for S values of 1.45 and 0.80.

$$Pr = 5.59 - 7.90 \ln S$$

Probability S_2 of lethal injury by total body impact:

For high impulse values, the pressure with an impact velocity of 16.5 m/s approaches 7.28 kPa; for low impulse values and pressures smaller than 0.5-0.9 MPa, the value of pressure times impulse approaches $1.3.10^9$ Pa^2s.

$$S = 7.28 / P_s + 1300 / (P_s.I_s)$$

Derived from probabilities of 1, 50 and 99 % for S values of 2.57, 1.00 and 0.38.

$$Pr = 5.00 - 2.44 \ln S$$

Combine the effects of both probabilities:

$$P_{body} = S_1 + S_2 - S_1.S_2 / 100$$

The effects of heat radiation:

The probability of lethality for unprotected human beings due to radiation heat effects is derived from carburetted hydrogen fires. AC/258 criteria for lethal and second degree burning are taken into account.

Symbols: W = heat radiation intensity in kW/m^2

t = exposed time in s

$S = t \cdot (1000\ W)^{4/3}$

Probability of lethality:

$$Pr_1 = -36.38 + 2.56 \ln S$$

Probability of second degree burning:

$$Pr_2 = -43.14 + 3.0186 \ln S - Pr_1$$

ANNEX 10 FORMULAE USED FOR THE CALCULATION OF THE BALLISTIC LIMIT VELOCITIES

People in houses are protected by a *concrete or brick wall.* For the penetration of concrete, the penetration function given in [9] is taken:

$$G(z) = K.N.D.d^{0.2}.V^{1.8} = z - 1 \text{ for } z > 2,$$

with z = calibre penetration = x/d,

x = penetration depth (in),

K = concrete penetrability constant = $6.53/\sqrt{f_c}$,

f_c = concrete compressive strength, assumed to be 5 ksi = 34.5 MPa,

N = nose shape factor = 0.845 (for standard fragment shape),

D = calibre density = 0.186 lb/in^3 (for standard fragment shape),

d = missile diameter (in), and

V = striking velocity (kfps).

For standard fragments, the fragment weight is calculated [9] as $W_f = 0.186.d^3$ (lb). This leads to

$$d = (W_f/0.186)^{1/3} = 1.75.W_f^{\ 1/3} \text{ (in)}$$

When a wall of 0.22 m (8.66 in) and a fragment mass of 4.5 kg (9.9 lb) is taken, this leads to a diameter d = 3.75 (in), and the assumption $z > 2$ is justified.

The penetration function can be rewritten as:

$$x = K.N.D.d^{1.2}.V^{1.8} + d \text{ (in)}$$

Substituting the values for K, N and D as given above results in:

$$x = 0.459.d^{1.2}.V^{1.8} + d \text{ (in)}$$

Finally, inserting $d = 1.75.W_f^{1/3}$ gives:

$$x = 0.898.W_f^{0.4}.V^{1.8} + 1.75.W_f^{1/3} \text{ (in)}$$

This formula can be rewritten as

$$V = \left(\frac{x - 1.75.W_f^{1/3}}{0.898.W_f^{1/3}} \right)^{0.5555} \text{(kfps)}$$

This formula is valid for the penetration of armour piercing fragments into concrete. A similar penetration formula for the penetration of mild steel fragments into brick is assumed.
A conversion into SI units (1kfps = 304.8 m/s, 1 in = 0.0254 m and 1 lb = 0.4536 kg) and substitution of x = 0.22 m (neglecting the influence of the wall thickness in the penetration depth) gives the ballistic limit velocities used in the program:

$$V_{50} = 304.8 \left(\frac{8.66 - 2.28.m^{1/3}}{1.23.m^{0.4}} \right)^{0.5555} \text{ (m/s)},$$

with fragment mass m in kg.
This leads to ballistic limit velocities of 1398, 761 and 470 m/s for concrete penetration with fragment masses of 0.1, 1 and 4.5 kg, respectively.

People in cars are assumed to be protected by a *mild steel plate* of 1.5 mm. For the penetration of mild steel plates, the penetration function given in [9] is taken:

$$x = 0.21.W_f^{0.33}.V^{1.22} \text{ (in)},$$

with W_f = fragment weight in ounces,
V = striking velocity in kfps, and
x = penetration depth in inches

Substition of x = 1.5 mm = 0.059 in. and rewriting leads to:

$$V = 0.353.W_f^{-0.27} \text{ (kfps)}$$

A conversion into SI units (1kfps = 304.8 m/s and 1 oz. = 0.02835 kg) gives the ballistic limit velocities for mild steel plates used in the program:

$$V_{50} = 41.11.m^{-0.27} \text{ (m/s)}$$

This leads to ballistic limit velocities of 76.5, 41.1 and 27.4 m/s for mild steel penetration with fragment masses of 0.1, 1 and 4.5 kg, respectively

For *unprotected people hit* by fragments, the ballistic limit velocity for *skin perforation* is considered. The formula given in [10] is:

$$V_{50} = 1247.1.A/m + 22.03 \text{ (m/s)}$$

with m = fragment mass (kg) and
A = presented area (m^2).

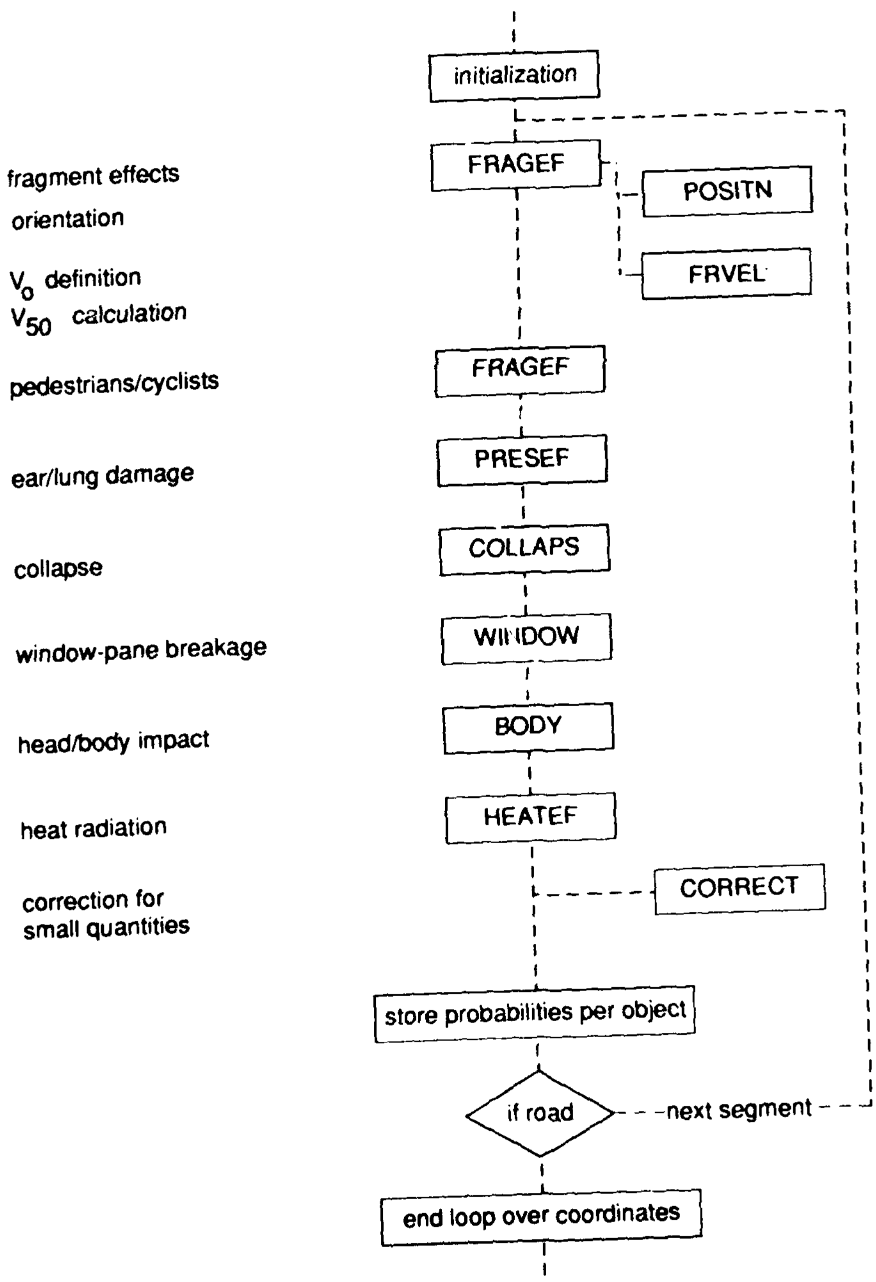
A residual velocity high enough to cause serious injuries after skin perforation is assumed.
A value for A is not very suitable for practical applications. Therefore a commonly used shape factor $k = m/A^{3/2}$ [11] is introduced. Substitution leads to:

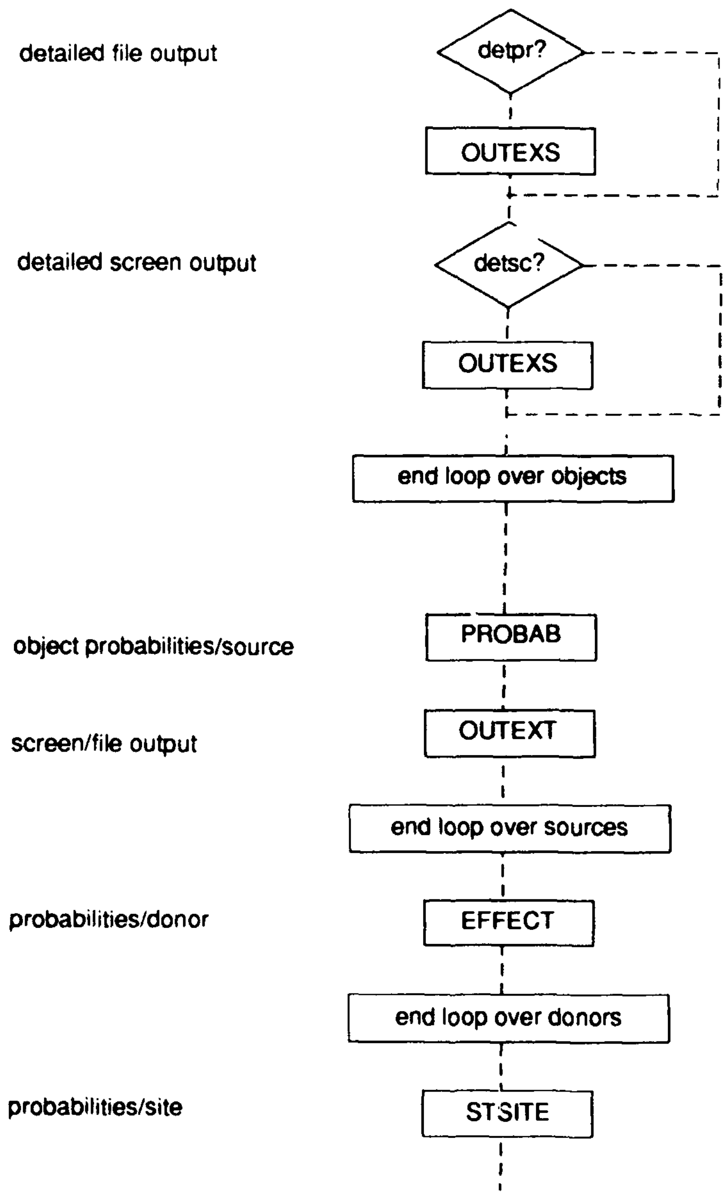
$$V_{50} = 1247.1.(k^2.m)^{-1/3} + 22.03 \text{ (m/s)}$$

For most effective fragments the value for k is 4740 $kg/m^{1/3}$, for natural fragments this value is 2370 $kg/m^{1/3}$. The latter is used in the program.

ANNEX 11 A FLOWCHART OF THE PROBABILITY CALCULATIONS OF THE EXTERNAL SAFETY PART

A flowchart with all subroutines used for the environmental effects and probability of lethality calculations of the external safety part.




detailed file output
detpr?
OUTEXS
detailed screen output
detsc?
OUTEXS
end loop over objects
object probabilities/source
PROBAB
screen/file output
OUTEXT
end loop over sources
probabilities/donor
EFFECT
end loop over donors
probabilities/site
STSITE

ANNEX 12 DETAILED AND DEFAULT OUTPUT OF AN EXTERNAL RISK CALCULATION

Symbols used:

Symbols used:	P	= side-on pressure (kPa)
	I	= side impulse (kPas)
	q	= fragment density ($1/m^2$)
	T	= positive phase duration (s)
	Q	= heat radiation (kQ/m^2)
	t	= exposed time to Q (s)
	Ear	= probability of ear damage (%)
	Lung	= probability of lung damage (%)
	Frag	= probability of lethality by fragments (%)
	Frgm	= probability of lethality by fragments for cyclists/pedestrians (%)
	Coll	= probability of lethality by collapse of houses (%)
	Window	= probability of lethality by window-pane breakage (%)
	Body	= probability of lethality by head/total body impact (%)
	Burn	= probability of lethality by heat radiation (%)
	Bur2	= probability of second degree burning (%)

*** detailed output

Donor IGLOO1 (Source IGLOO1) with Contents:

15000. kg 1.1, 0. kg 1.2, 0. kg 1.3 and 0. kg 1.4 (ihst=2)
Overestimated values for small quantities and "not-open" sites.

Object HS1 , Coordinates (75., 600.), Distance 464., Scaled dist. 19.
P= 6.5 kPa, I= 415. Pa.s, q= 0.0 1/m2, T= 144. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 54, Body 0, Burn 0, Bur2 0

Object HS2 , Coordinates (150., 690.), Distance 553., Scaled dist. 22.
P= 5.2 kPa, I= 350. Pa.s, q= 0.0 1/m2, T= 151. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 12, Body 0, Burn 0, Bur2 0

Object HS3 , Coordinates (230., 600.), Distance 476., Scaled dist. 19.

P= 6.3 kPa, I= 405. Pa.s, q= 0.0 1/m2, T= 145. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 47, Body 0, Burn 0, Bur2 0

Object CM4 , Coordinates (550., 200.), Distance 437., Scaled dist. 18.

P= 7.1 kPa, I= 440. Pa.s, q= 0.0 1/m2, T= 141. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 1, Lung 0, Frag 1, Frgm 0 Coll 0, Window 0, Body 0, Burn 0, Bur2 0

Object HS6 , Coordinates (420., 250.), Distance 323., Scaled dist. 13.

P= 10.3 kPa, I= 589. Pa.s, q= 0.1 1/m2, T= 129. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object HS8 , Coordinates (420., 50.), Distance 315., Scaled dist. 13.

P= 10.7 kPa, I= 604. Pa.s, q= 0.1 1/m2, T= 128. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 5, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object HS9 , Coordinates (190., -245.), Distance 389., Scaled dist. 16.

P= 8.2 kPa, I= 492. Pa.s, q= 0.2 1/m2, T= 136. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 91, Body 0, Burn 0, Bur2 0

Object HS10 , Coordinates (10., -245.), Distance 397., Scaled dist. 16.

P= 7.9 kPa, I= 482. Pa.s, q= 0.2 1/m2, T= 137. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 89, Body 0, Burn 0, Bur2 0

Object HS11 , Coordinates (-150., 50.), Distance 281., Scaled dist. 11.

P= 12.4 kPa, I= 673. Pa.s, q= 0.2 1/m2, T= 123. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 8, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object RD2 , Coordinates (450., -100.), Distance 409., Scaled dist. 17.

P= 7.7 kPa, I= 469. Pa.s, q= 0.0 1/m2, T= 138. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 1, Lung 0, Frag 1, Frgm 2 Coll 0, Window 32, Body 0, Burn 0, Bur2 0

Object RD3 , Coordinates (395., -160.), Distance 407., Scaled dist. 16.

P= 7.7 kPa, I= 471. Pa.s, q= 0.0 1/m2, T= 138. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 17, Body 0, Burn 0, Bur2 0

*** default output

Donor IGLOO1 and source IGLOO1 give lethality or injury probabilities for:

Object HS1 ,	type HS, lethality:	0.03 and *0.00, injury:	0.06 and *0.00
Object HS2 ,	type HS, lethality:	0.01 and 0.00, injury:	0.02 and 0.00
Object HS3 ,	type HS, lethality:	0.03 and 0.00, injury:	0.05 and 0.00
Object CM4 ,	type HU, lethality:	0.01 and 0.00, injury:	0.02 and 0.00
Object HS6 ,	type HS, lethality:	0.06 and 0.00, injury:	0.12 and 0.00
Object HS8 ,	type HS, lethality:	0.10 and 0.00, injury:	0.19 and 0.00
Object HS9 ,	type HS, lethality:	0.05 and 0.00, injury:	0.10 and 0.00
Object HS10 ,	type HS, lethality:	0.05 and 0.00, injury:	0.10 and 0.00
Object HS11 ,	type HS, lethality:	0.14 and 0.00, injury:	0.26 and 0.00
Object RD2 ,	type RD, lethality:	0.03 and 0.02, injury:	0.06 and 0.04
Object RD3 ,	type RD, lethality:	0.01 and 0.00, injury:	0.02 and 0.01

* second figure for cyclists/pedestrians

Donor IGLOO1, Type I3, gives 7.0 Lethal and 14.5 Serious Injuries

(Included 0.0 lethalities on roads)

*** detailed output

Donor EARTH2 (Source EARTH2) with Contents:

0. kg 1.1, 0. kg 1.2, 50000. kg 1.3 and 0. kg 1.4 (ihst=1)
Overestimated values for small quantities and "not-open" sites.

*** default output

Donor EARTH2 and source EARTH2 give lethality or injury probabilities for:

Donor EARTH2, Type OB, gives 0.0 Lethal and 0.0 Serious Injuries

(Included 0.0 lethalities on roads)

*** detailed output

Donor IGLOO3 (Source IGLOO3) with Contents:

15000. kg 1.1, 0. kg 1.2, 0. kg 1.3 and 0. kg 1.4 (ihst=2)
Overestimated values for small quantities and "not-open" sites.

Object HS1 , Coordinates (75., 600.), Distance 598., Scaled dist. 24.
P= 4.7 kPa, I= 324. Pa.s, q= 0.0 1/m2, T= 154. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 4, Body 0, Burn 0, Bur2 0

Object HS3 , Coordinates (230., 600.), Distance 568., Scaled dist. 23.
P= 5.1 kPa, I= 341. Pa.s, q= 0.0 1/m2, T= 152. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 9, Body 0, Burn 0, Bur2 0

Object CM4 , Coordinates (550., 200.), Distance 333., Scaled dist. 13.
P= 10.0 kPa, I= 572. Pa.s, q= 0.0 1/m2, T= 130. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 1, Lung 0, Frag 2, Frgm 0 Coll 0, Window 0, Body 0, Burn 0, Bur2 0

Object HS6 , Coordinates (420., 250.), Distance 269., Scaled dist. 11.
P= 13.2 kPa, I= 704. Pa.s, q= 0.3 1/m2, T= 121. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 11, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object HS8 , Coordinates (420., 50.), Distance 158., Scaled dist. 6.
P= 28.4 kPa, I= 1163. Pa.s, q= 0.7 1/m2, T= 102. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 26, Frgm 0 Coll 10, Window100, Body 0, Burn 0, Bur2 0

Object HS9 , Coordinates (190., -245.), Distance 287., Scaled dist. 12.
P= 12.1 kPa, I= 661. Pa.s, q= 0.2 1/m2, T= 124. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 7, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object HS10 , Coordinates (10., -245.), Distance 375., Scaled dist. 15.
P= 8.5 kPa, I= 510. Pa.s, q= 0.0 1/m2, T= 135. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 95, Body 0, Burn 0, Bur2 0

Object HS11 , Coordinates (-150., 50.), Distance 413., Scaled dist. 17.
P= 7.6 kPa, I= 465. Pa.s, q= 0.2 1/m2, T= 139. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 82, Body 0, Burn 0, Bur2 0

Object RD2 , Coordinates (450., -100.), Distance 230., Scaled dist. 9.
P= 16.4 kPa, I= 819. Pa.s, q= 0.6 1/m2, T= 115. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 1, Lung 0, Frag 6, Frgm 6 Coll 0, Window 31, Body 0, Burn 0, Bur2 0

Object RD3 , Coordinates (395., -160.), Distance 234., Scaled dist. 9.
P= 16.0 kPa, I= 805. Pa.s, q= 0.5 1/m2, T= 116. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 6, Frgm 6 Coll 0, Window 20, Body 0, Burn 0, Bur2 0

*** default output

Donor IGLOO3 and source IGLOO3 give lethality or injury probabilities for:

Object HS3	, type HS, lethality:	0.01 and	0.00, injury:	0.02 and	0.00
Object CM4	, type HU, lethality:	0.02 and	0.00, injury:	0.03 and	0.00
Object HS6	, type HS, lethality:	0.16 and	0.00, injury:	0.31 and	0.00
Object HS8	, type HS, lethality:	0.37 and	0.00, injury:	0.65 and	0.00
Object HS9	, type HS, lethality:	0.13 and	0.00, injury:	0.25 and	0.00
Object HS10	, type HS, lethality:	0.05 and	0.00, injury:	0.10 and	0.00
Object HS11	, type HS, lethality:	0.05 and	0.00, injury:	0.09 and	0.00
Object RD2	, type RD, lethality:	0.07 and	0.06, injury:	0.15 and	0.12
Object RD3	, type RD, lethality:	0.07 and	0.06, injury:	0.13 and	0.12

*** detailed output

Donor IGLOO3 (Source EARTH2) with Contents:

0. kg 1.1, 0. kg 1.2, 50000. kg 1.3 and 0. kg 1.4 (ihst=1)
Overestimated values for small quantities and "not-open" sites.

*** default output

Donor IGLOO3 and source EARTH2 give lethality or injury probabilities for:

*** detailed output

Donor IGLOO3 (Source OPEN4) with Contents:

0. kg 1.1, 20000. kg 1.2, 0. kg 1.3 and 0. kg 1.4 (ihst=1)
Overestimated values for small quantities and "not-open" sites.

Object RD2 , Coordinates (450., -100.), Distance 200., Scaled dist. 0.
P= 0.0 kPa, I= 0. Pa.s, q= 0.5 1/m2, T= 0. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 6, Frgm 6 Coll 0, Window 0, Body 0, Burn 0, Bur2 0

Object RD3 , Coordinates (395., -160.), Distance 186., Scaled dist. 0.
P= 0.0 kPa, I= 0. Pa.s, q= 0.6 1/m2, T= 0. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 7, Frgm 7 Coll 0, Window 0, Body 0, Burn 0, Bur2 0

*** default output

Donor IGLOO3 and source OPEN4 give lethality or injury probabilities for:

Object RD2 , type RD, lethality: 0.06 and 0.06, injury: 0.13 and 0.13
Object RD3 , type RD, lethality: 0.07 and 0.07, injury: 0.14 and 0.14

Donor IGLOO3, Type I3, gives 16.7 Lethal and 28.3 Serious Injuries

(Included 0.1 lethalities on roads)

*** detailed output

Donor OPEN4 (Source OPEN4) with Contents:

0. kg 1.1, 20000. kg 1.2, 0. kg 1.3 and 0. kg 1.4 (ihst=1)
Overestimated values for small quantities and "not-open" sites.

Object RD2 , Coordinates (450., -100.), Distance 200., Scaled dist. 0.
P= 0.0 kPa, I= 0. Pa.s, q= 0.5 1/m2, T= 0. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 6, Frgm 6 Coll 0, Window 0, Body 0, Burn 0, Bur2 0

Object RD3 , Coordinates (395., -160.), Distance 186., Scaled dist. 0.

P= 0.0 kPa, I= 0. Pa.s, q= 0.6 1/m2, T= 0. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 7, Frgm 7 Coll 0, Window 0, Body 0, Burn 0, Bur2 0

*** default output

Donor OPEN4 and source OPEN4 give lethality or injury probabilities for:

Object RD2 , type RD, lethality: 0.06 and 0.06, injury: 0.13 and 0.13

Object RD3 , type RD, lethality: 0.07 and 0.07, injury: 0.14 and 0.14

Donor OPEN4 , Type OP, gives 0.1 Lethal and 0.1 Serious Injuries

(Included 0.0 lethalities on roads)

*** detailed output

Donor IGLOO5 (Source IGLOO5) with Contents:

15000. kg 1.1, 0. kg 1.2, 0. kg 1.3 and 0. kg 1.4 (ihst=2)

Overestimated values for small quantities and "not-open" sites.

Object HS6 , Coordinates (420., 250.), Distance 433., Scaled dist. 18.

P= 7.1 kPa, I= 444. Pa.s, q= 0.0 1/m2, T= 141. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 72, Body 0, Burn 0, Bur2 0

Object HS8 , Coordinates (420., 50.), Distance 285., Scaled dist. 12.

P= 12.2 kPa, I= 665. Pa.s, q= 0.2 1/m2, T= 124. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 8, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object HS9 , Coordinates (190., -245.), Distance 130., Scaled dist. 5.

P= 12.5 kPa, I= 1393. Pa.s, q= 1.7 1/m2, T= 95. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 53, Frgm 0 Coll 1, Window100, Body 0, Burn 0, Bur2 0

Object HS10 , Coordinates (10., -245.), Distance 220., Scaled dist. 9.

P= 17.4 kPa, I= 853. Pa.s, q= 0.6 1/m2, T= 114. ms, Q= 0.0 kW/m2, t= 0.0 s

Prob: Ear 0, Lung 0, Frag 22, Frgm 0 Coll 3, Window100, Body 0, Burn 0, Bur2 0

Object HS11 , Coordinates (-150., 50.), Distance 376., Scaled dist. 15.
P= 8.5 kPa, I= 509. Pa.s, q= 0.3 1/m2, T= 135. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 0, Frgm 0 Coll 0, Window 94, Body 0, Burn 0, Bur2 0

Object RD2 , Coordinates (450., -100.), Distance 263., Scaled dist. 11.
P= 13.6 kPa, I= 719. Pa.s, q= 0.1 1/m2, T= 121. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 7, Frgm 7 Coll 0, Window 32, Body 0, Burn 0, Bur2 0

Object RD3 , Coordinates (395., -160.), Distance 212., Scaled dist. 9.
P= 18.3 kPa, I= 883. Pa.s, q= 0.3 1/m2, T= 112. ms, Q= 0.0 kW/m2, t= 0.0 s
Prob: Ear 0, Lung 0, Frag 3, Frgm 3 Coll 0, Window 20, Body 0, Burn 0, Bur2 0

*** default output

Donor IGLOO5 and source IGLOO5 give lethality or injury probabilities for:

Object HS6 ,	type HS, lethality:	0.04 and 0.00, injury:	0.08 and 0.00
Object HS8 ,	type HS, lethality:	0.13 and 0.00, injury:	0.25 and 0.00
Object HS9 ,	type HS, lethality:	0.56 and 0.00, injury:	1.00 and 0.00
Object HS10 ,	type HS, lethality:	0.29 and 0.00, injury:	0.54 and 0.00
Object HS11 ,	type HS, lethality:	0.05 and 0.00, injury:	0.11 and 0.00
Object RD2 ,	type RD, lethality:	0.09 and 0.07, injury:	0.17 and 0.15
Object RD3 ,	type RD, lethality:	0.04 and 0.03, injury:	0.08 and 0.06

Donor IGLOO5, Type I3, gives 9.2 Lethal and 18.8 Serious Injuries

(Included 0.0 lethalities on roads)

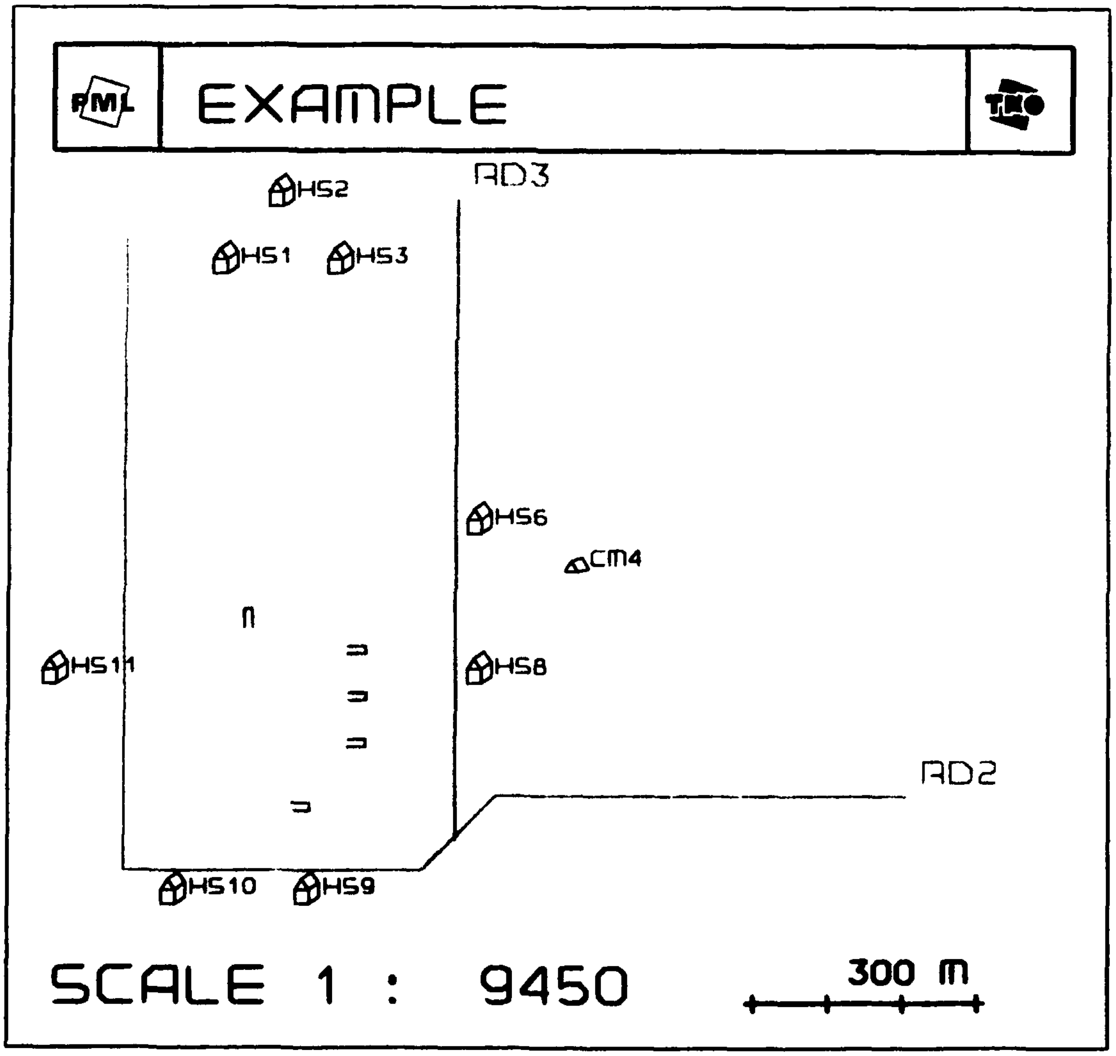
ANNEX 13 DEFAULT OUTPUT OF THE FINAL RESULTS OF THE OUTPUT PART

```
*******************************************************************
*   Average number of lethalities for this complex :  6.6        *
*   Average number of serious injuries             :  12.3       *
*   Collective risk                                :  33.1 * 10-5 *
*******************************************************************
```

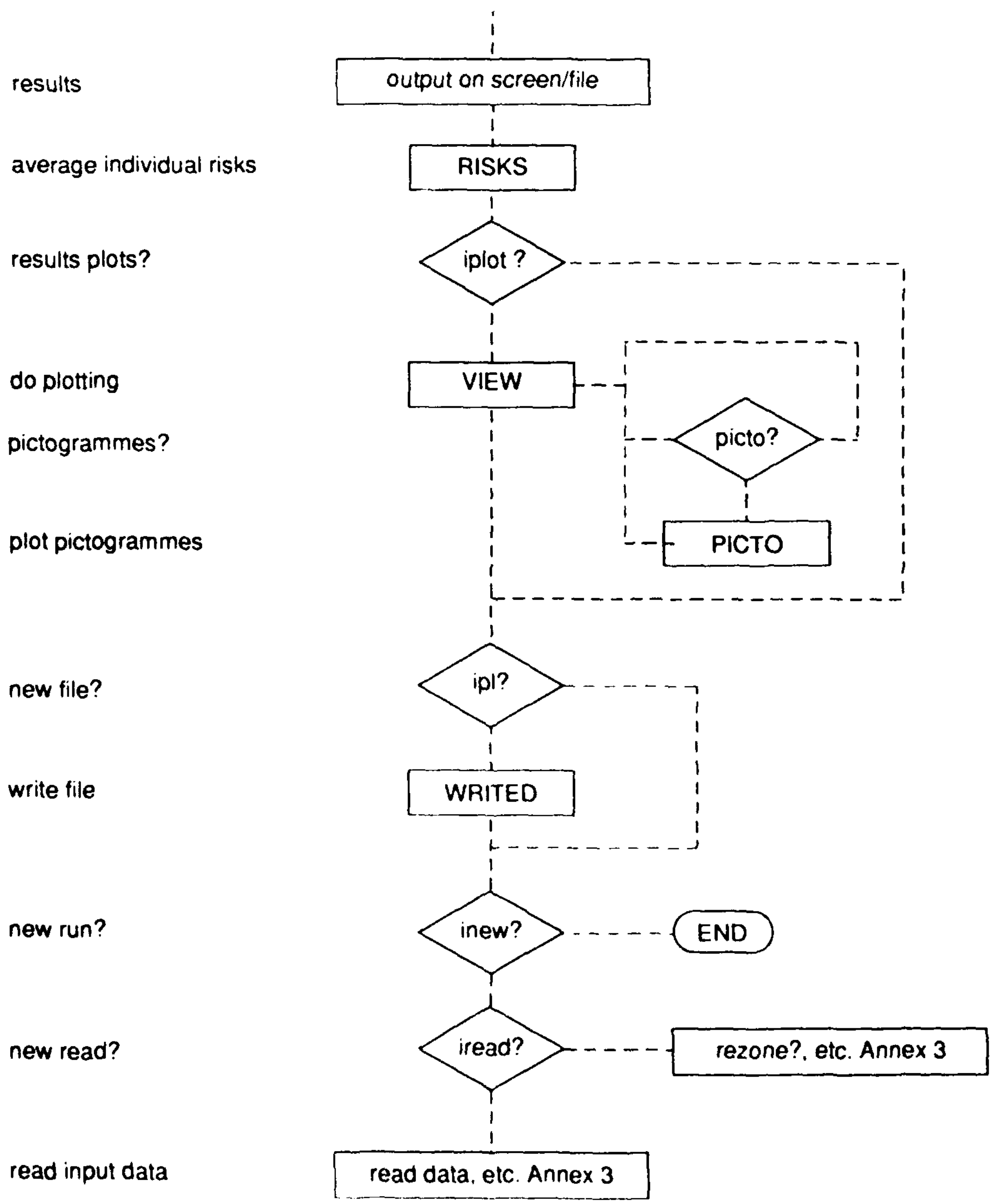
Probability of lethality (%)

Code of object	Number of objects	Average	Maximum	Source with maximum
HS1	5	0.8	3.0	IGLOO1
HS3	5	0.8	2.7	IGLOO1
CM4	90	0.7	2.2	IGLOO3
HS6	5	5.2	16.3	IGLOO3
HS8	5	12.0	36.7	IGLOO3
HS9	2	14.9	56.3	IGLOO5
HS10	1	7.8	28.7	IGLOO5
HS11	1	4.8	13.7	IGLOO1
RD2	100	5.9	12.7	IGLOO3
RD3	10	4.8	12.8	IGLOO3

ANNEX 14 THE COMPLEX EXAMPLE WITH ITS THREATENED SURROUNDINGS



ANNEX 15 A FLOWCHART OF THE OUTPUT PART



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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

This report gives a description of the structure and contents of RISKANAL, a computer program developed at the TNO Prins Maurits Laboratory, The Netherlands. It can also be used as a manual for RISKANAL.
The internal and external risks involved in storing explosives can be calculated with RISKANAL. The program uses the quantity-distances according to the NATO AC/258 recommendations [1] and the probit functions as given in the Dutch 'Green Book' [2].
The final result of the program is the average number of lethalities to be expected if a magazine on a complex should accidentally explode. With these figures, it can be decided whether a situation is acceptable or not by including the probability of an accidental explosion.

16 DESCRIPTORS	IDENTIFIERS
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