PUBLICATION 11/83
(Reprint of Report 16/82 and SAB 10/81)

HOME OFFICE

Blast overpressure and fallout radiation dose models for casualty assessment and other purposes

PR Bentley

SCIENTIFIC RESEARCH & DEVELOPMENT BRANCH

PUBLICATION 11/83 (Reprint of Report 16/82 and SAB 10/81)

First published April 1981

Revised edition December 1981

ISBN 0 86252 033 9

Published by

Home Office
50 Queen Anne's Gate
London SW1H 9AT

Copies available from

Home Office Library
Room 1007
50 Queen Anne's Gate
London SW1H 9AT

NOTE. This report is made available for information only. It describes a method at a particular stage of development, and should not be regarded as defining a method for planning purposes.

HOME OFFICE SCIENTIFIC RESEARCH & DEVELOPMENT BRANCH

BLAST OVERPRESSURE AND FALLOUT RADIATION DOSE MODELS FOR CASUALTY ASSESSMENT AND OTHER PURPOSES

by

P. R. Bentley

Revised edition

SUMMARY

The determination of blast overpressures and fallout radiation doses at points on a sufficiently fine grid, for any part or for the whole of the UK, and for any postulated attack, is an essential element in the systematic assessment of casualties, the estimation of numbers of homeless, and the evaluation of life-saving measures generally.

This report describes models which provide the required blast and dose values and which are intended to supersede existing models which were introduced in 1971.

The factors which affect blast and, more particularly, dose values are discussed, and the way in which various factors are modelled is described. The models are incorporated into separate computer programs which are described, the outputs of which are stored on magnetic tape for subsequent use as required.

Horseferry House,
Dean Ryle Street,
London SW1P 2AW.

CONTENTS

BLAST OVERPRESSURE AND FALLOUT RADIATION DOSE MODELS FOR CASUALTY ASSESSMENT AND OTHER PURPOSES

1. BACKGROUND

For many years Scientific Advisory Branch (SAB) has supplied casualty assessments to aid home defence planning and to provide inputs to exercises and studies. At one time the assessments resulted from desk calculations, but from 1971 more accurate and consistent estimates were produced, and much more quickly, using a computer[1]. As access to larger and more powerful computers became available, it became desirable to revise previous casualty assessment techniques in order to extract the greatest benefit from the capacity of these computers in terms of enhanced accuracy and reduced running time. As a result new models for blast overpressure and fallout radiation dose determination have been produced, which are described in this report.

2. INTRODUCTION

When a nuclear weapon is exploded the casualty-producing phenomena are blast, thermal radiation, initial nuclear radiation and, if the burst is on or sufficiently near the ground, residual radiation (from fallout). Of these, the most important, related to casualties, are blast and fallout radiation (in that order) for a population under cover. Later, it is intended to establish whether the effects of thermal and initial nuclear radiation make any significant difference to total casualty figures. For the present the philosophy of earlier work is followed and the effects of blast and fallout only are considered.

The level of casualties to be expected in the UK, for any particular postulated attack, will depend strongly upon the assumptions made regarding the relationships between blast and damage to typical British dwellings or other structures, eg. shelters. In addition the number of casualties due to fallout radiation will depend upon the way in which protective factors are attributed to dwellings, etc. Final casualty figures will also depend, among other factors, upon assumptions made about persons trapped and the interaction between blast injury and radiation dose received.

It must be stressed that the primary aim of this report is to present a way of producing the necessary blast and fallout dose inputs to casualty assessment and does not describe a casualty assessment model as such. However, a summary of an existing casualty model, that has been modified by the author, is given in Section 8, with further comments on this topic in Section 10.

A computer program is associated with each of the two models: the first program incorporates the blast model and calculates the maximum blast overpressure that would be experienced at the centre of each kilometre square in the UK from any given postulated attack. The kilometre squares correspond to those of a population tape file; the method of identification of the squares and other data is given elsewhere[2].

The second program incorporates the dose model and calculates the total fallout radiation dose received after 7 days in the open at the centres of kilometre squares or squares of side two kilometres. Dose values, unlike those of blast, change little when moving from one kilometre square to the next, and a negligible difference in the estimate of dose casualties occurs when using the larger square. The models are described in following sections while the computer programs are summarised in Section 6.

In general the SI system of units is used in this report but when referring to expressions and data drawn from references the original units are used. (See also footnote on page 22.)

3. THE ATTACK FILE

Certain basic data, concerning the postulated attack, is common to both models and is known as the Attack File. This consists of a list giving, for each bomb, the national grid co-ordinates (to the nearest kilometre) of the ground zero (GZ), the yield or power (in megatons) and the height of burst (in metres).

Two assumptions affect the Attack File; these are (a) the yield of any bomb in the attack will be one of a range of ten selected yields, namely

100 kt
200 kt
300 kt
500 kt
1 Mt
2 Mt
3 Mt
5 Mt
10 Mt
20 Mt

and (b) the height of burst of all non ground-burst bombs will be such as to maximise the ground range of an overpressure value chosen from the following values:

15 kPa	(2 psi)
30 kPa	(4 ")
45 kPa	(6 ")
75 kPa	(10 ")
150 kPa	(20 ")

In the context of this report a ground burst is taken to mean a burst that occurs strictly at ground level.

Because of a need to specify the data storage space needed when computer programs are run, some limit needs to be specified for the maximum number of bombs likely to occur in an attack file. At present the limit is set at 300 and is thus likely to meet most practical needs. However the limit may easily be increased if required.

4. THE BLAST MODEL

The American publication 'The Effects of Nuclear Weapons'(3) provides blast overpressure data for a 1 kt reference burst, from which overpressures for other yields can be derived by a cube root scaling law. The form of the data is illustrated (for low pressure values only) in Figure 1. Using this data it was established that pressure/distance values for a burst at any given height could be closely approximated by a pair of straight lines when the data is plotted on a log-log scale (eg true values shown by plotted points in Fig. 2). However, the lines are separated by a discontinuity for heights of burst greater than the corresponding scaled height of about 660 feet for a 1 kt burst.

Fig. 2 illustrates, as an example, the pair of lines applicable to a 1 kt burst at 750 feet and the expressions which define those lines. In these expressions the square of the distance is used for programming convenience. The upper line corresponds to the range of regular blast wave reflection and the lower line to the mach reflection range for this burst. The particular case of ground burst bombs is illustrated in Fig. 3. Again the plotted points show the true pressure/ distance values.

Blast overpressures for the 1 kt reference yield are modelled by expressions for a set of five pairs of lines for heights of burst corresponding to the maximisation of overpressure ranges on the ground for the discrete pressure values given in Section 3 and by the line pertaining to ground bursts. Appropriate scaling for actual weapon yields is carried out by the overpressure computer program.

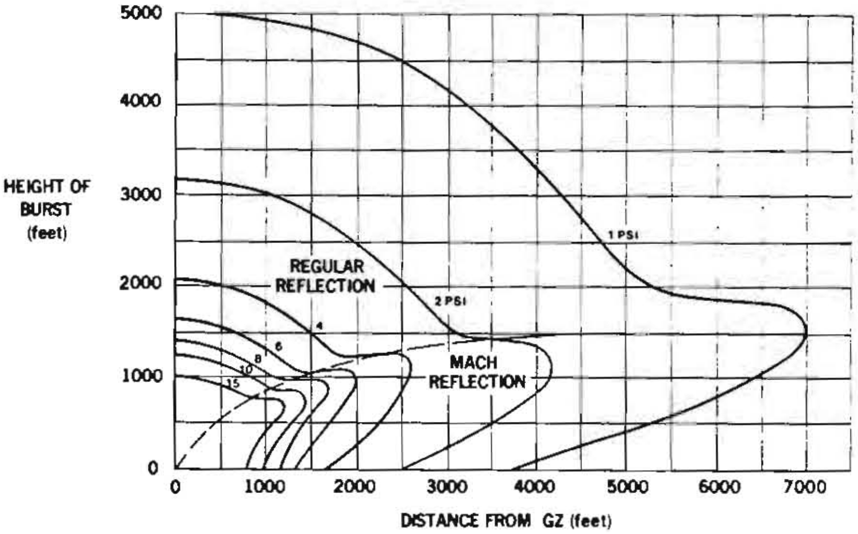

Fig. 1. Height of burst/distance relationships for various overpressure values, for a 1 kt reference explosion over relatively smooth terrain.

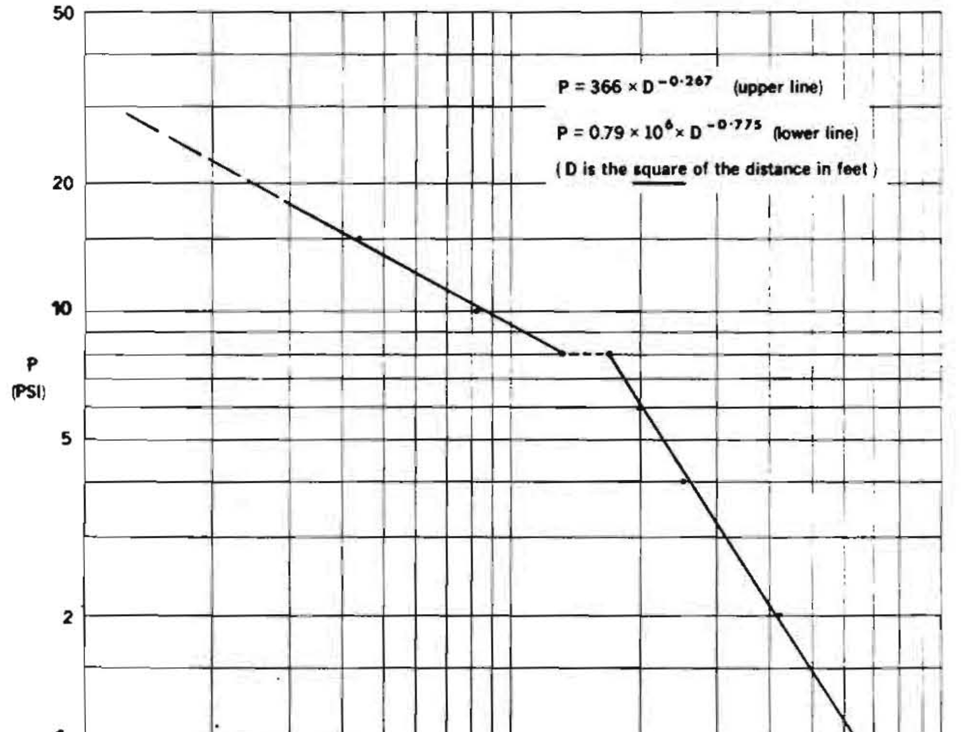

Fig. 2. Modelled overpressure/distance relationship for a 1 kt burst at 750 feet.

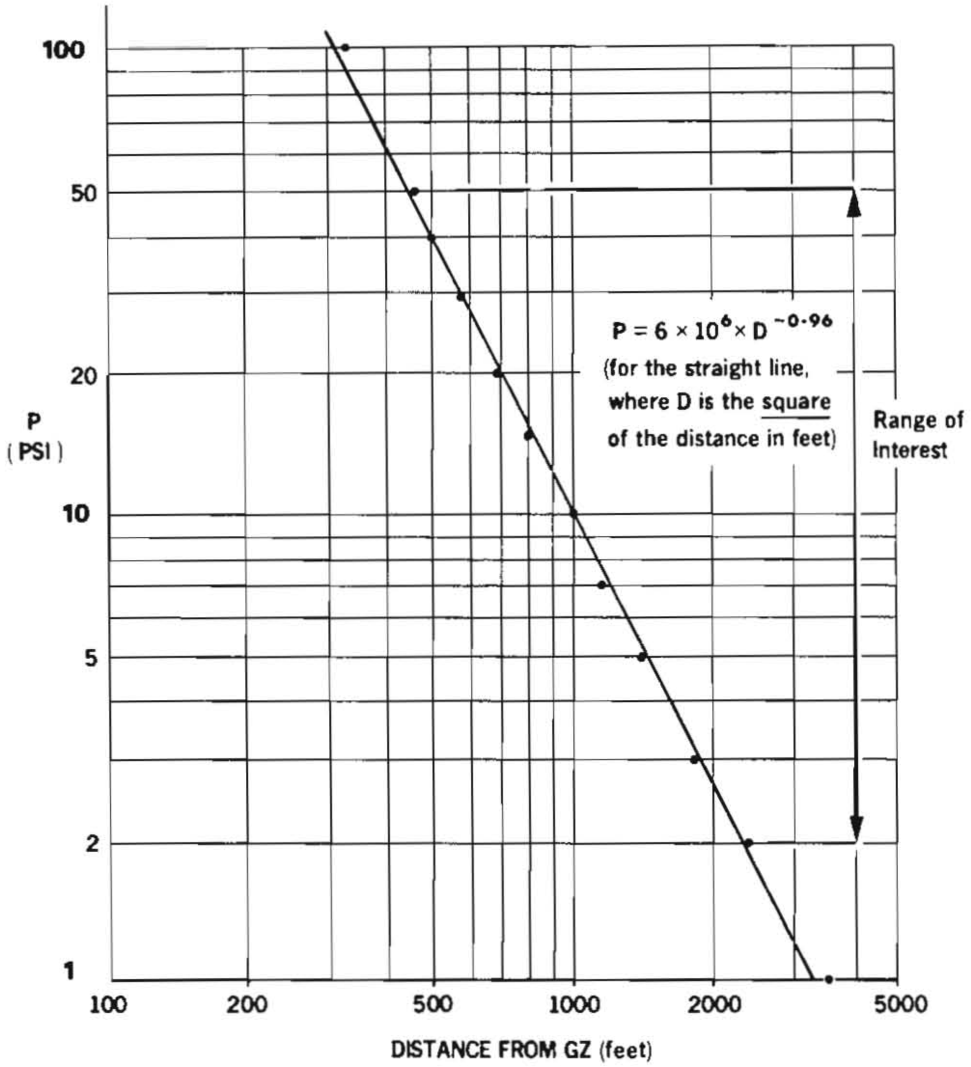

Fig. 3. Modelled overpressure/distance relationship for a 1 kt ground burst.

It is assumed that the overpressure is constant over the relatively small element of range covered by a discontinuity. In World War II fatalities due to blast started at an overpressure of about 3.5 psi and reached 100% at about 40 psi for people in their own homes*(1). Over this range the maximum error in overpressure for a given distance is about 5% when using the model compared with the original data except at ranges within a discontinuity where the maximum error may rise to about 15%, depending upon position within the discontinuity annulus. It should be stressed that the maximum error applies to a small element only of the range annulus covered by the discontinuity.

*The applicability of these values to nuclear weapons is being re-examined.

5. THE DOSE MODEL

Many factors affect the radiation dose that an individual may receive from fallout. The most important factors are those that affect the shape and size of a fallout plume on the ground; for any given nuclear burst these are:

i. Height of burst

ii. Weapon yield

iii. Upper air windspeeds and directions

iv. Amount of wind shear.

Other factors affecting dose are those which determine the dose-rates measurable on the ground during and after the deposition of fallout particles; these are:

v. Fission fraction of weapon

vi. Ground roughness

vii. General weather conditions

viii. Decay Rate

ix. Position relative to ground zero.

For a given fallout situation, defined by the above factors, one final factor will determine the actual dose received by an individual if in a refuge; this is:

x. Protective factor of refuge (i.e. the ratio of the external and internal dose rates).

As the objective of the dose model is to estimate the dose which would be received by a person in the open at any location, protective factors are not considered. This means that a single output from the dose model together with the output from the blast model may be used to produce various casualty assessments depending upon assumptions made about protective factors (and other variables) in a casualty model (see Section 8). Two of the remaining factors are not considered for reasons which will now be discussed; the remainder are taken into account and are discussed in Sections 5.1 to 5.7.

The effects of general weather conditions (factor vii) would tend to be localised; eg the eddying of fallout particles on the ground, due to surface winds, would create very local areas of high or low contamination, and the leaching action of rain could reduce dose rate levels locally. These and other effects of the general weather at ground level are not considered to be able to affect in any sensible way the casualty situation when considered on a nationwide basis. Wind shear (factor iv) is an extremely variable factor and difficult to reconcile with the simple idealised plume shapes that are adopted (see next section). Unusually large or small values of wind shear could create fallout contour patterns quite different from the idealised form, but the area within any given dose-rate contour would vary only a little. Because wind shear tends to increase with a decrease in wind speed it follows that the validity of the dose model will become doubtful for windspeeds of very low values. A fixed amount of effective wind shear, as described later, is incorporated into the idealised plumes and the resultant elliptical contour data may be regarded as a reasonable approximation for average UK winds.

5.1 Basic fallout contours

The precise shape of fallout contours on the ground for a given yield, height of burst and meteorological conditions is virtually impossible to predict accurately. Even sophisticated models (demanding large computing resources) give only an approximate agreement with patterns emerging from weapon trials(3). For casualty assessment purposes over a large area the approximation afforded by the use of idealised contours, as qualified by the observations above on wind shear, is considered to be the most practical expedient at the present time.

Idealised contour data has been taken from ref. 3 and forms the basis of the data used. Data, in graphical form, is given for downwind distance, maximum width and distance to maximum width as a function of yield for a series of DR1 values* over the range 1–3000 R/h, and for mean effective windspeeds of 10,20 and 40 knots (the effective wind is defined as the average of the mean wind vectors to the bottom and top of the nuclear cloud). Also upwind radius dimensions are given, these being presented as independent of windspeed. Fig. 4 shows an unscaled illustration of an idealised contour. The dimensions of the contours are based upon an effective wind shear of 15° (effective wind shear is defined as the angle between the directions of the mean wind vesctors to the bottom and top of the stabilised nuclear cloud).

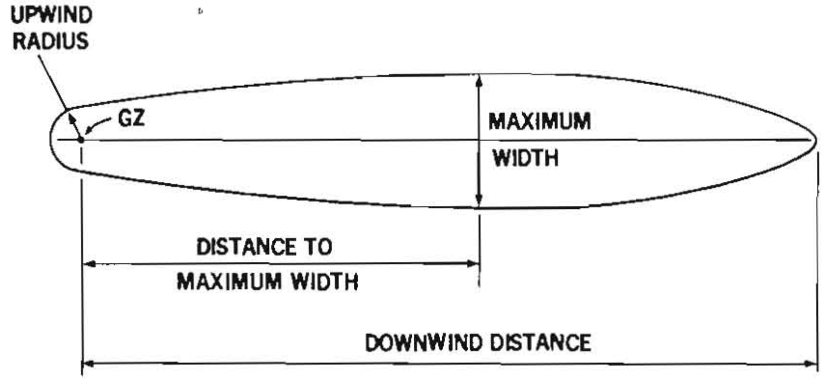

Fig. 4. Idealised fallout plume.

The downwind half of the idealised contour is elliptical and the upwind half is approximately so. Hence little additional error is introduced by the assumption in the model of an elliptical shape for the DR1 contours. Thus the upwind circle is omitted but some degree of compensation is made by shifting all DR1 contours upwind to share a common tangent with the upwind circle for the 10 R/h DR1 contour. Fig 5 shows that the resulting effective upwind movement of the GZ results in under-compensation for lower DR1 values but over-compensation for the higher values in the immediate area around the GZ. The overall difference in contour area as a result of the modification decreases with increasing wind speed, the true ellipse always giving a somewhat smaller area. For average effective winds in the UK the difference is about 2–3% but rises to about 10% for the low effective wind speed of 10 km/h.

The lowest value of DR1 to be considered in the model is 10 R/h. Contributions at this level from many overlapping plumes at a given point would be unlikely to lead to death or serious injury, and the marginal effect of several 10 R/h contributions to a high DR1 value may be ignored. Dose levels causing death and injury in the short term, analogues to casualties from blast, are summarised in Section 8.

Weapon tests have shown that contours seldom occur with a maximum DR1 value exceeding 4000 R/h in the vicinity of GZ. Hence the data of Ref. 3 has been extrapolated to take account of the possibility of a small area contour at the higher value. Also, by interpolation and extrapolation of the data for three wind-speeds (in knots) the range was expanded to cover seven speeds from 10–90 km/h.

---

*A DR1 is the dose rate for any point at a standard reference time of 1 hour after burst (the value will be hypothetical unless fallout has arrived and is complete within 1 hour, but the actual dose rate can always be expressed in terms of the DR1).

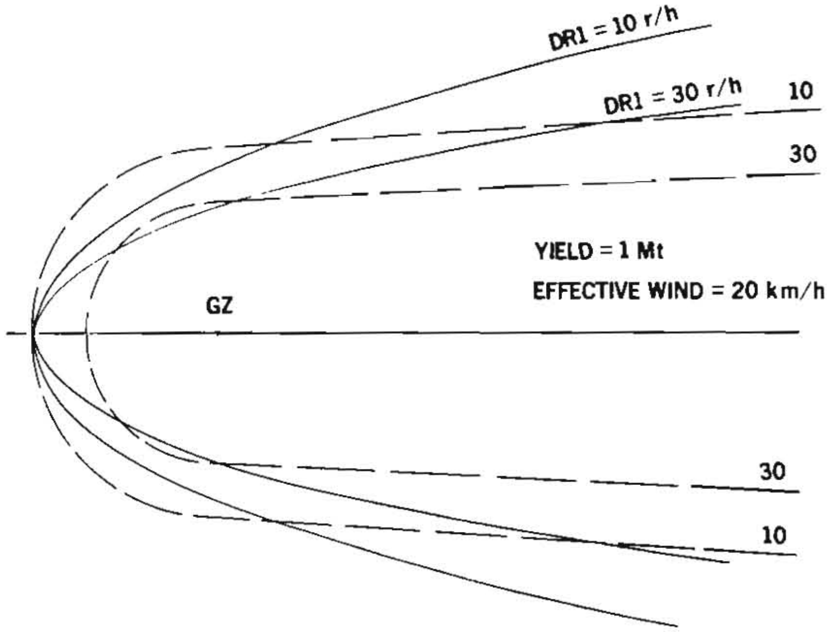

Fig. 5. Idealised fallout contours (broken line) and substitute elliptical contours in the vicinity of ground zero

5.2 Height of burst

A conservative estimate for the height of burst of a bomb from which little or no fallout would result is given[3] as $180W^{0.4}$ feet (W in kt). A burst at any greater height is designated as an air burst while a burst between this height and the ground is referred to as a transition zone burst, for which DR1 values need to be modified by an adjustment factor given as

$$\frac{\left(180 - \frac{h}{W^{0.4}}\right)^2 \left(360 + \frac{h}{W^{0.4}}\right)}{1.17 \times 10^7}$$

where h is the height of burst in feet.

These expressions have been incorporated into the dose model.

5.3 Wind speed and direction

Any wind direction may be designated for use with the dose model, but the value chosen is assumed at present to apply to the whole of the UK. The value chosen will be the effective wind as defined in Section 5.1 to be consistent with the DR1 contour data. The use of a single effective wind applied to all parts of the UK, and assumed to cover a range of bomb yields, is unlikely to produce large errors when dose results are applied to casualty calculations because of the averaging effect of population distribution over the large area of a fallout plume, particularly when a number of bombs are considered spread over the whole of the UK. However, the computer program could be adapted to cover wind variations over the UK if this were thought to be desirable.

A constraint imposed upon the dose model is that the speed of the effective wind should be one of seven in the range already referred to. These speeds are:

10	km/h	(6 mph)
20	"	
30	"	
40	"	
50	"	
70	"	
90	"	(56 mph)

5.4 Fission fraction

The fission fraction* of bombs used in an attack could vary according to whether individual bombs were 'clean' (ie low fission devices) or 'dirty' (ie high fission devices, particularly of the fission-fusion-fission type). Between the extremes there lies what might be termed the 'normal' bomb, ie one not deliberately manufactured to be particularly clean or dirty. Available evidence(3) based upon trials with normal weapons points to an average 50% fission yield as the appropriate value for use in Home Defence studies, and this is the value currently used. The value can easily be changed within the dose model if required.

5.5 Ground Roughness Factor

The DR1 contour data referred to in section 5.1 relates to theoretical dose rates measured at points 3 feet above a smooth infinite plane uniformly contaminated with fallout. Hence it is necessary to reduce these DR1 values to take account of the shielding effect due to ground roughness. A Ground Roughness Factor of 0.7 is suggested as suitable for reasonably level terrain(3), and this is the value incorporated into the dose model.

5.6 Decay rate

After the calculated time of fallout completion at any point (see next section) the gamma dose rate is assumed to decrease according to the well known $t^{-1.2}$ decay law, which generally approximates closely to the decay of the mixture of nuclides resulting from a nuclear explosion.

5.7 Position relative to GZ

At any point within a given fallout plume, the maximum dose rate and the dose that could be received up to some future time are governed by the downwind distance measured along the axis of the plume and the crosswind distance measured along a normal to the axis.

The build-up and decay of dose rate would be similar, graphically, to Fig. 6 (a). This process has been modelled by assuming a linear build-up from the time of arrival of fallout (TOA)† to the time of maximum dose rate (TOM) and a linear decay from TOM to the time when fallout deposition is complete (TOC), as shown in Fig. 6 (b). Thereafter the $t^{-1.2}$ decay law is used.

---

*The ratio of the energy release from fission to the total energy released in the explosion.

†For the purposes of this paper TOA, TOM and TOC are measured from the time of burst of a weapon (TOB), ie they are time differences and not clock times.

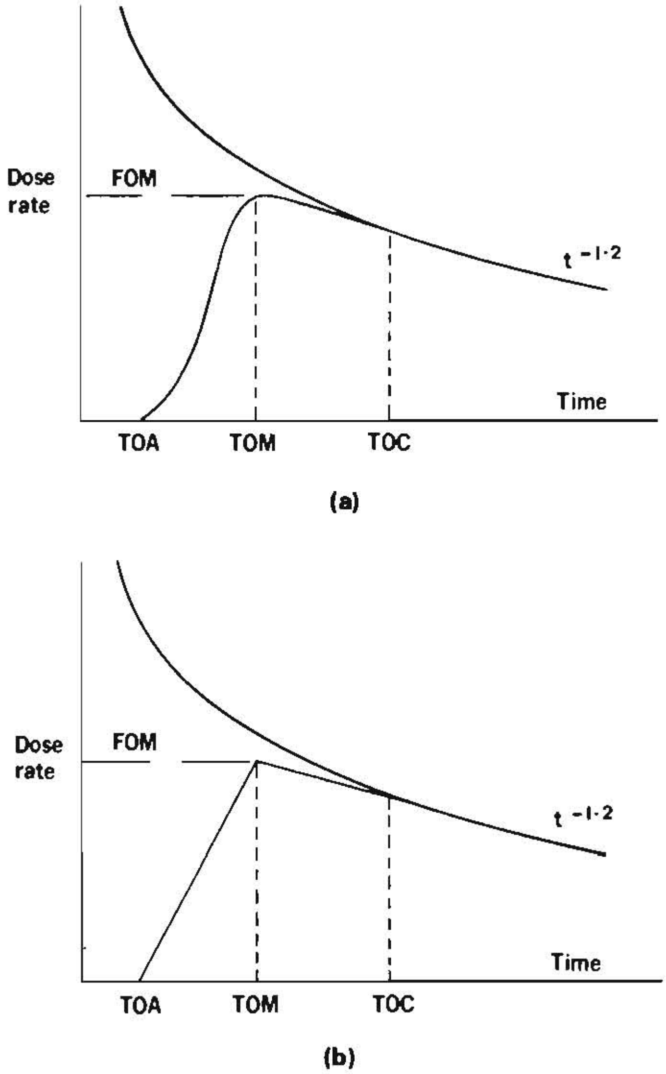

Fig. 6. (a) Typical form of actual dose-rate build-up and decay curves.
(b) Modelled build-up and decay.

The TOA at any point is calculated using the effective windspeed after making allowance for the start given to the fallout by the radius of the stabilised cloud, which forms in about ten minutes. (Eg the radius of the stabilised cloud for a 1 Mt explosion is about 18 km). Empirical evidence(4) suggests that the ratio between TOA and TOM may vary between extreme values of 1.1 and 5. The dose model assumes that TOM = 1.2 x TOA, thus keeping within the extreme values but assuming a rapid build-up as a conservative measure.

The time of completion is assumed to be proportional to the build-up time. In fact, for a given maximum dose rate the actual TOC is not too important as it can make only a slight difference to the total dose over an extended period such as the seven days currently considered in casualty calculations.

Hence it is assumed that TOC = TOM + ½(TOM – TOA). Another marginal factor in the seven-day dose context is the ratio of the amount of fallout actually on the ground at TOM to the total amount at TOC for any given location. This ratio, expressed as a percentage, is also assumed to be proportional to the build-up time by using the expression.

$$\% \text{ deposition (at TOM)} = 100 - 5t \quad (t \ngtr 6)$$

where t = TOM – TOA (hours)

This means that the % deposition reduces continuously to a minimum of 70 for TOA values rising to 30 hours. Thereafter the % deposition will remain constant at the value of 70. However values of TOA exceeding 30 hours, which could only exist in the UK for low-probability meteorological conditions, would be associated with negligible fallout maxima.

6. COMPUTER PROGRAM SUMMARIES

The following sub-sections provide a descriptive summary of the computer programs that calculate, for each 1 km square of the UK, the maximum blast overpressure and the fallout radiation dose that would have been received up to 7 days in the open, using the blast and dose models already described.

6.1 Blast calculations

Basic data for use in a run of the computer program that calculates blast over-pressure is stored in a separate data file which contains, together with certain fixed data, the variable data consisting of

i. Attack serial number

ii. Number of bombs in the attack

iii. Individual data for each bomb

iv. Overpressure option number

The option number used (which may vary between 1 and 5 inclusively) corresponds to the list of overpressure values given in Section 3. A value is selected according to the ground overpressure value of which the radius is postulated as being maximised in the attack. The postulate is applied to all airburst bombs in a particular attack. The data for each bomb consists of

i. Longitude measured in km on the National Grid) (These terms should not
) be confused with geographical
ii. Latitude measured in km on the National Grid) latitude and longitude)

iii. Power

iv. Height of burst

v. Bomb classification number

The height of burst is implicit in a chosen overpressure option number for any non groundburst bomb but the height is also needed explicitly for calculation of dose-rate reduction factor; this may be significant for low burst heights.

The bomb data is a common input to both blast and dose computer programs but it is the latter which needs the power and height of burst as such. The blast program uses bomb classification numbers in the range 1 to 10 which correspond with a bomb power in the list given in Section 3. The height of burst is needed in this program only in so far as the height is zero or non-zero.

The five items of data for each bomb are read from the data file, for all bombs in the attack, into an array. The initial order of the data will be the file order of increasing latitude. For each airburst bomb the radius of the 1.8 psi overpressure circle at ground level is selected from an array according to the power of the bomb and the selected option. In the case of groundbursts the 1.8 psi radius is selected from a separate array according to bomb power only. This pressure forms a bounding value below which no seriously injured casualties are considered to exist. The radius is used to calculate the South bound and North bound latitudes for each bomb, as defined in Fig. 7, which are then stored in the bomb data array. The program then re-orders this array so that the bombs appear in order of increasing South bound latitude.

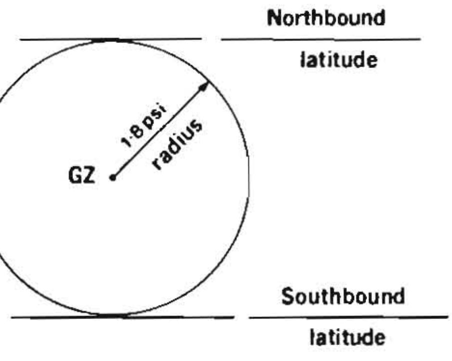

Fig. 7. Bounding latitudes for the 1.8 psi overpressure radius.

Data defining sequential lines of latitude is read from the UK population tape file starting at latitude −87 km (the southern tip of the Channel Islands) and proceeding by 1 km steps. Zero overpressure values are written to tape for all latitudes up to that preceding the first South bound. Thereafter for the latitude value of each successive line the program stores the array number of any bomb whose inclusive North bound and South bound values overlap that latitude. For each of these bombs in turn the program then examines the relative positions of the 1.8 psi circle and the line of latitude being considered. The possibilities are illustrated in Fig. 8. Overpressure values are then calculated for the centres of relevant 1 km squares along the line of latitude using the blast model already described.

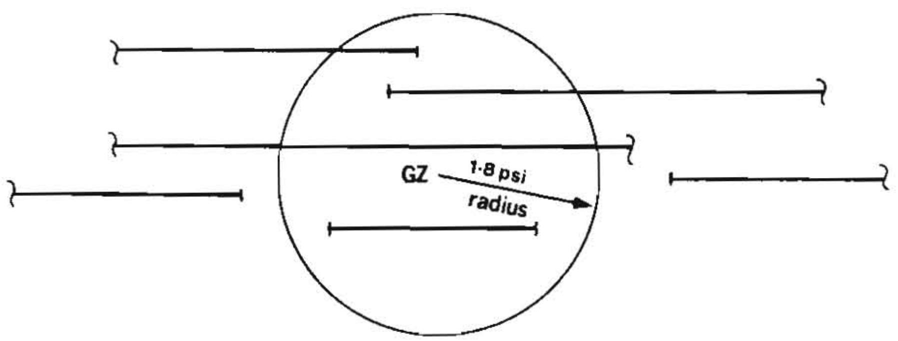

Fig. 8. The 6 possible interactions between the 1.8 psi radius and the West coast ⊢ or the East coast ⊣ on a line of latitude.

If the calculated pressure at any point is greater than a value previously calculated for that point then the higher value is stored for that point. When this purpose is completed for all bombs affecting the line of latitude the array containing the sequential pressure values for the whole of that line (including any zeros) is written to tape prefaced by a block containing the co-ordinates of the first kilometre square on the line and the total number of squares on the line, as read from the population tape.

The process continues until all bombs have been dealt with. If the final North bound is less than the maximum population tape latitude then zero overpressure values are written for remaining lines of latitude up to the end of the population tape (latitude 1217 km – northern tip of the Shetland Islands).

6.2 Dose calculations

There are points of similarity in technique in handling blast and dose calculations with a given grid of kilometre squares (governed by the population tape file). However, to preserve their separate identities and aims, this section is written to be self-contained.

Basic data is held in a separate file. The variable data in the file consists of:

i. Attack number

ii. Number of bombs in the attack

iii. Fission fraction

iv. Ground roughness factor

v. Effective wind velocity

vi. Effective wind direction

vii. Individual data for each bomb

The individual bomb data is as given in the previous section.

The data for each bomb in turn is read into an array. The program analyses the bomb data and, using the definition of section 5.2, will discard any air burst. The data for each fallout-producing bomb is transferred to a bomb data array together with a calculated dose rate reduction factor for any transition zone bomb. For each of the fallout-producing bombs North and South bounding latitudes are calculated for the 10 R/h elliptical contour according to the speed and direction of the wind. The bomb data is then rearranged in its array so that bombs appear in order of increasing South bound latitude.

Data defining lines of latitude is read from the population tape in blocks containing 50 or 100 lines. An array is formed using this data which then effectively holds an outline map of the slice of the UK covered by the block. Zero doses are written to a dose tape file for all relevant kilometre squares for all lines of latitude up to that preceding the first South bound. The calculation of doses then proceeds for all lines in the block for every bomb in turn having a South bound in that block. The calculations for an individual bomb proceed until either the North bound for that bomb is encountered or the last line of the block is reached; if the latter, then pick-up information is stored to enable calculations for the bomb to continue at the start of the next block. For each subsequent block, calculation commences with the unfinished plumes, taken in order, before continuing with bombs whose South bounds are encountered in the new block.

For each point that is considered within a particular plume a DR1 value, modified if necessary by the appropriate dose reduction factor, is calculated together with TOA, TOM, TOC and % deposition values for that point. Using these parameters the nominal dose that would be received in the open up to the end of the first seven days post-attack is calculated for the point. This dose is then modified by the fission fraction and the ground roughness factor. The main details of the DR1 determination and dose calculation methods are given in the following section.

When calculations for a block have been completed the dose array is output to the dose tape file as a series of sequential lines of latitude, each prefaced by the latitude and longitude of the first kilometre square and the number of squares on the line. The stored dose for any square is the total D + 7 day dose due to all fallout plumes affecting that square. Calculations and dose storage continue block by block until the end of the last block is reached (ie end of the population tape) or the last North bound is reached, in which case zero doses are written for all remaining squares.

7. SUMMARY OF DOSE CALCULATION METHOD

The following sub-sections describe the co-ordinate geometry used in connection with the elliptical DR1 contours, and assumptions concerning TOA and DR1 interpolation.

7.1 Determination of rows of kilometre squares to be considered for a given fallout plume

The equation of an ellipse, referred to axes through one end, is given by

$$y = \pm \frac{b}{a}(2ax - x^2)^{1/2} \quad \text{.......... (i)}$$

Where a, b are the semi-major and semi-minor axes of the ellipse respectively.

If Θ is the angle measured clockwise between North and the axis of the ellipse (ie the effective wind direction $- 180^o$), then the North bound and South bound tangent gradients are given by:

$$\pm \frac{b}{a} \frac{(a - x)}{(2ax - x^2)^{1/2}} = -\cot\Theta = k \text{ (say)}$$

Hence the values of x_s and x_n in Fig. 9 are given by

$$x = a \pm \frac{a^2k}{(a^2k^2 + b^2)^{1/2}}$$

The corresponding values of y (numerically equal but opposite in sign) are then found by substitution in equation (i).

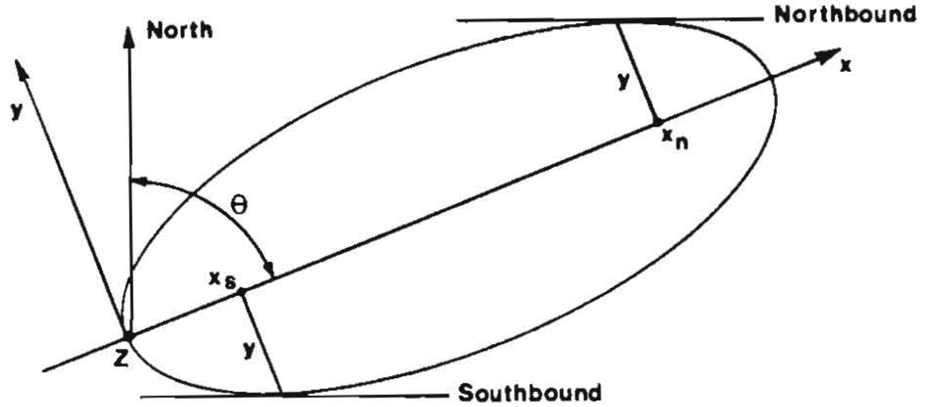

Fig. 9. Bounding latitudes for the 10 R/h fallout contour.

If l_s and l_n are the latitudes of the South bound and North bound relative to the groundzero Z, then

$$l_s = y\sin\Theta - x_s\cos\Theta$$
$$\text{and } l_n = y\sin\Theta + x_n\cos\Theta$$

The number of rows of kilometre squares to be considered is taken to be the sum of the integral parts of l_s and l_n, ie fractions of kilometre squares are omitted.

7.2 Determination of the number of kilometre squares within a plume along a given line of latitude

Any line of latitude intersecting the ellipse at points P_n, P'_n (see Fig. 10) is given by $y = -x\cot\Theta + n\,\mathrm{cosec}\,\Theta$ (referred to the axes of the ellipse) where n is the difference in latitudes between Z and $P_nP'_n$. If $m = -\cot\Theta$ and $c = n\,\mathrm{cosec}\,\Theta$, then intersections occur when

$$x = \frac{b - \frac{a}{b}mc + (b^2 - c^2 - 2amc)^{1/2}}{\frac{am^2}{b} + \frac{b}{a}} \qquad \text{(ii)}$$

(The expression is best left in this form for computing purposes).

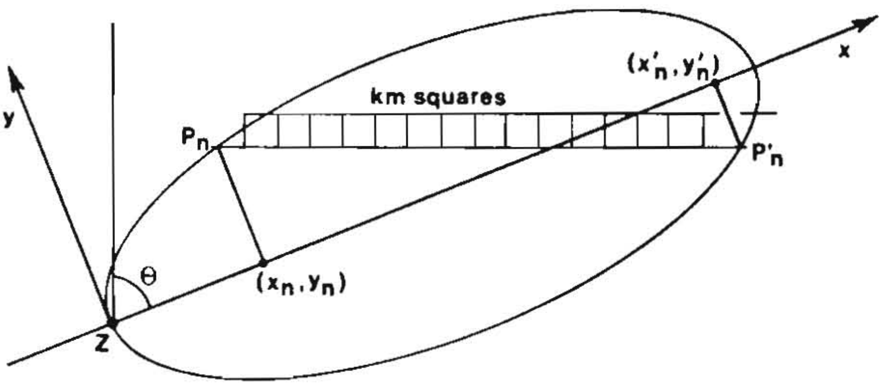

Fig. 10. 1 km squares along a line of latitude within the 10 R/h contour.

If x_n, y_n are the co-ordinates of P_n, then the easting of P_n relative to Z is given by $w = x_n\sin\Theta - y_n\cos\Theta$. If w is rounded up such that w + z is an integer, then the number of kilometre squares covered by the ellipse at this line of latitude is given by the integral part of $((x'_n - x_n)\cos\Theta - z) + 1$. It should be noted that the actual sequence or sequences of squares for which a dose is calculated will be determined by the computer program according to any intersection of the ellipse with the UK coastline. The co-ordinates of the SW corner of the first square on the line will be

$$x_1 = x_n + z\sin\Theta$$

$$y_1 = y_n - z\cos\Theta.$$

The next square (moving from West to East) will have co-ordinates $(x_1 + \sin\Theta, y_1 - \cos\Theta)$ and, in general,

$$x_i = x_1 + (i - 1)\sin\Theta$$

$$y_i = y_1 - (i - 1)\cos\Theta.$$

7.3 Determination of DR1 values

For the general square $P(x_i, y_i)$ in Fig. 11 the ordinate values for successive DR1 contours are calculated for the value x_i until the appropriate bounding values are determined. The DR1 value for P is then derived by linear interpolation between the bounding values, as recommended in Ref. 3.

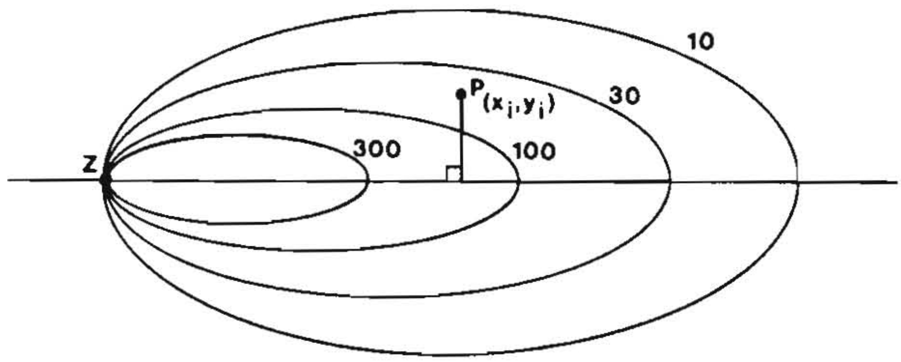

Fig 11. **Value of the DR1 for the general square at P is found by interpolation between the DR1 data contours.**

7.4 Actual dose received in the open

The time of arrival of fallout is assumed to be the same at all points lying at the same distance d from Z (Fig. 12). Allowance is made for the substantial cloud radius of megaton range weapons, assuming cloud stabilisation after 10 minutes.

$$\text{Hence} \qquad TOA = \frac{(x_i^2 + y_i^2)^{1/2} - R_n}{v} + 0.16$$

Where R_n is the cloud radius for weapon yield n and v is the effective wind speed.

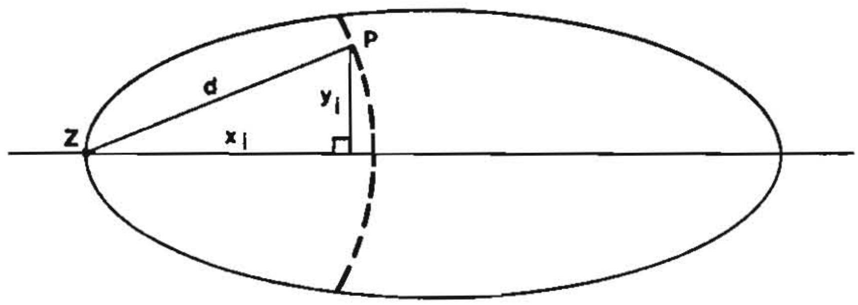

Fig. 12. **The time of arrival of fallout is assumed to be the same for all squares at a given distance downwind.**

Using the calculated TOA for a point, the corresponding values of the TOM and TOC for the point are then calculated according to the assumptions described in the dose model. The total fallout radiation dose that would be received in the open at this point up to 7 days is then calculated using these parameters, together with the assumed fallout decay rate and other modifying factors described in Section 5.

7.5 Subsequent lines of latitude and cut-off

Intersections of the next line of latitude with the ellipse are given by the modification of the constant c in equation (ii) from ncosecΘ to (n + 1) cosecΘ. Because lines of latitude defining the shape of the UK are input to the computer in blocks of 50 or 100 at a time (see Fig. 13), the calculation of doses along sequential lines of latitude for a particular bomb is curtailed when the last line in a block has been applied to that bomb. When all bombs that have all or part of their 10 R/h DR1 contour within a given block have been dealt with, the next block is input and calculation proceeds with those plumes, taken in their original order, that were cut off. This is effected for any bomb by storing the value of n corresponding to the first line of latitude in the next block against the appropriate bomb list number.

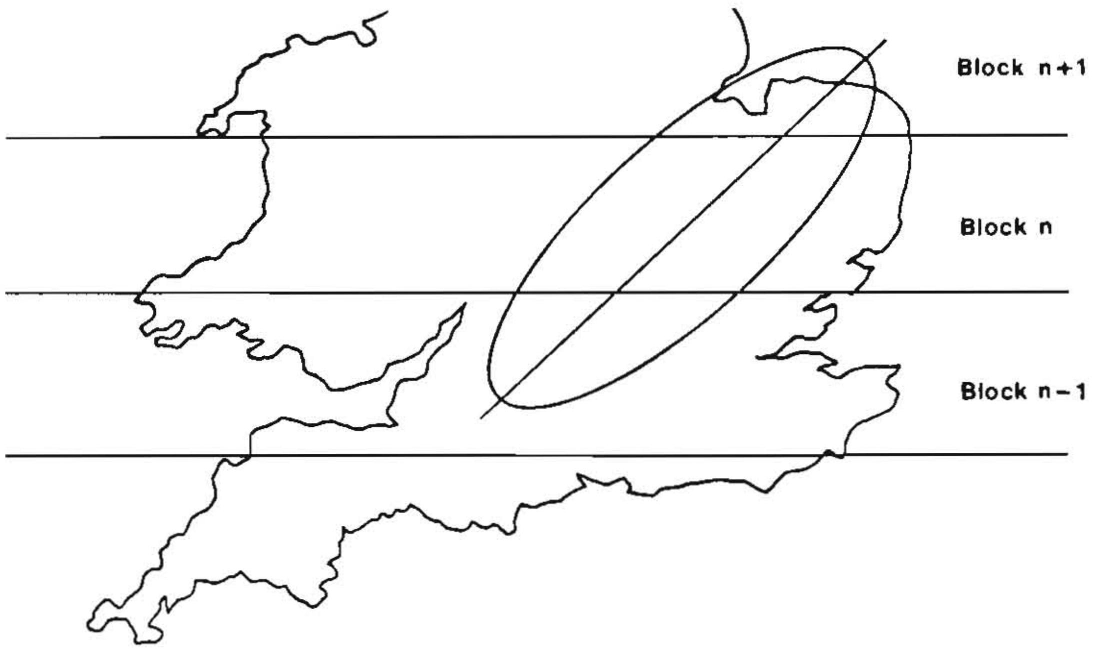

Fig. 13. A possible fallout plume relative to blocks of lines of latitude.

7.6 Size of square

The method of dose calculation that has been described is based upon the one kilometre square. However, as already indicated, virtually the same results may be obtained by using a larger 2 km by 2 km square, with the benefit of computer run time reduced by a factor of nearly four. Doses may be calculated for the larger square by the simple expedient of considering alternate 1 km squares on alternate lines of latitude. The dose for such squares, calculated for their southwest corners, ie for the centres of the 2 km squares, is then attributed to the centres of the four 1 km squares forming the larger square (see Fig. 14). The value for each calculated dose is written to its four appropriate array positions, being added to any existing dose in the square due to other bombs.

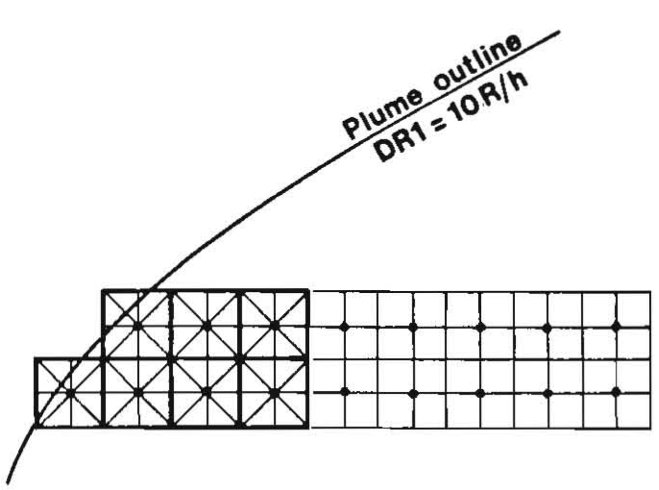

Fig. 14. Attribution to 1 km squares of the dose at the centre of a square of side 2 km.

8. CASUALTY ASSESSMENT

A casualty model is the third element needed to enable casualty assessments to be made using the blast and dose models described in this report. Reference 1 describes the casualty model that, with some modifications by the present author, has been used in conjunction with the blast and dose models described to obtain casualty assessments. In summary this model uses (a) a series of polynomials, based upon World War II blast data, to determine the percentage killed and seriously injured according to the blast overpressure level, (b) certain dose threshold values for the determination of fallout radiation casualties, again in killed and seriously injured categories, used in conjunction with an average protective factor spectrum that is currently assumed to be constant for the whole of the UK though the spectrum itself may be varied. It should be noticed that predicted radiation deaths may occur over several months with the bulk of such deaths within two to three months; (c) an assumption that a person in the seriously injured category for both blast and radiation will be killed; (d) an assumption that people trapped will die. Relevant parts of two computer programs from a suite of five described in Ref. 1 have been amalgamated and translated into the FORTRAN language to form a third (casualty assessment) program capable of using the outputs generated by the two programs described in this report.

The main modifications referred to above concern the criteria used to determine numbers of radiation casualties. Advice from the Protection against Ionizing Radiation Committe (PIRC) of the Medical Research Council to the Home Office on the question of the assessment of the relative radiological states of different groups of people at some number of days after a nuclear attack takes the form of the following simple expression for what is termed the Operational Evaluation Dose [5] : $OED = x - 200 - 15t$ rad, where x is the total dose accumulated after t days measured from the start of exposure. The value of x will be the calculated dose value for a kilometre square amended by the application of a protective factor (PF). It follows that the use of a PF spectrum, in the form of a discrete distribution, will result in a different value of x for each group of people, as defined by the spectrum, that make up the total population in a square.

The above OED expression is used in the current casualty model together with a dose/effects table (Table 1) which has been provided by the PIRC for use in Civil Defence studies. This data leads to the model illustrated by Fig. 15 and to the linear relationships shown below. It should be noted that the doses in Table 1 are mean bone marrow doses which are approximately three-quarters of the exposure dose measured in roentgens which would be displayed by current Civil Defence dosimeters. The latter dose is used in current calculations and is implied in the above form of the OED expression.

Killed category:

OED value for exposure dose (roentgens)	% killed
$378 < d \leq 822$	$0.225d - 85$

Seriously injured category:

OED value for exposure dose (roentgens)	% seriously injured
$270 < d \leq 400$	$0.346d - 93$
$400 < d \leq 600$	$0.025d + 35$
$600 < d \leq 822$	$185 - 0.225d$

Mean marrow dose for brief exposure (rads)	Expected mortality %	Expected second phase of incapacitation in 4th – 6th weeks	
		Symptoms	Effect on blood count
100	0	none	slight
200	0	none	moderate
300	0 – 5	severe in 50%	marked
450	about 50	severe in 100%	marked
600	95+	severe in 100%	marked

Table 1. Dose from energetic gamma rays and level of effect.

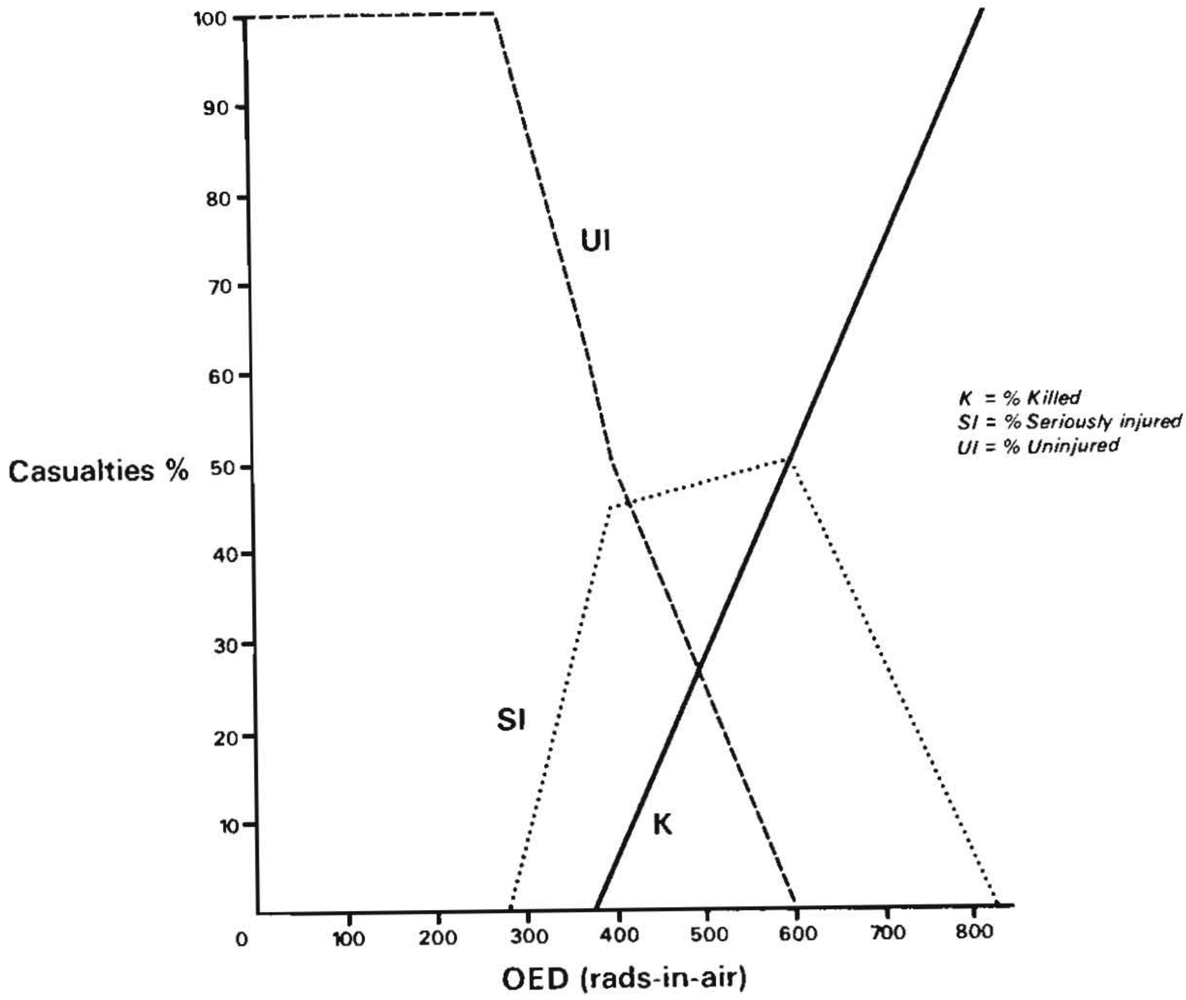

Fig. 15. Graphical representation of dose casualty model.

9. DISCUSSION

The blast and dose models that have been described have been produced primarily for the assessment of casualties in the UK as a whole following a major nuclear attack. Apart from this the blast model can play a fundamental part in computer assessments of numbers of homeless at local, regional or national level after a nuclear attack (6), and both models have applications in areas of home defence research involving studies of the post-attack economy and life-saving measures. Generally, the models are considered to be capable of yielding reliable quantitative results overall and suitable for support of strategic studies by the Home Office.

A good degree of confidence may be placed in the results from the blast model as this produces overpressures that approximate closely to the original data, for which the ground ranges are cited to be reliable to within + 15%. Less confidence, in general, can be placed in results from the dose model, largely because of the use of idealised fallout contours. At the same time, these contours form a reasonable practical basis for casualty assessment purposes as the alternative is recourse to complicated cloud models, which are prodigal in computer resources, and give an arguable increase in accuracy.

Because of the many variables involved, the dose model, unlike the blast model, is not entirely suited to casualty assessment on a local basis or in a single-bomb situation. However, because the total area bounded by a particular DR1 contour is reasonably approximated by the idealised form, then the averaging effect of population distribution is likely to lead to casualties of the right order for moderate to heavy attacks on the UK as a whole. In spite of this it would be unwise to regard a particular output of the model(ie one relating to a given set of values for the variables) in isolation, even though certain of the variables cannot affect the outcome radically.

The blast and dose models have been subjected to several validity tests and checks and were finally fully tested using a postulated heavy attack and assuming an average wind speed and direction. The output from the models was then used as input to the modified version of the casualty model that has been referred to, in order to obtain a casualty assessment.

The computer run time to provide blast and dose data for a typical attack, using the models described and using a Home Office ICL 1904S computer, was about 2 hours, involving a nominal cost of about £60. As blast data is independent of wind conditions, further runs with the same attack, but using different wind assumptions, involved the use of the dose program only and led to a reduced run time of about 1 hr with pro-rata cost. It is of interest to note that the programs have recently been run on one of the newer 'mini' computers and the total run time was about 10 minutes.

10. RECOMMENDATIONS

As already mentioned in the Introduction, the prime purpose of this report is to present adequate and tested models that are capable of determining the blast and dose effects for any postulated attack on the UK. However, any derived set of blast and dose data for an attack needs to be coupled with a casualty model to enable a UK total casualty assessment to be made. Such a model already exists and has been outlined in Section 8. However it is now believed that some of the assumptions made in the model should be re-examined, eg the longer positive pressure phase of the blast from nuclear weapons compared with conventional weapons seems certain to result in much greater house damage, and therefore more casualties, than references to maximum peak overpressures only would indicate.

At the same time it must be admitted that possible changes in the casualty model might only produce casualty figure variations that are not significant compared with the overall combined accuracy of the three models used to obtain the assessments. It is important to remember that most casualties in a population under cover are likely to be directly attributable to blast, and therefore emphasis should be placed upon those factors which affect these casualties.

Until such time as any revised casualty assessment model is introduced, it is suggested that the current version, as modified, should be used. In this context it is proposed that, initially, the dose model be used to obtain results for a variety of windspeeds and wind directions for a given attack. The resultant variable dose outputs, coupled with the single, constant blast results will lead to an average assessment of casualties for the chosen attack and the given population distribution. As many different attacks as seems reasonable may be treated in similar fashion thereafter.

It is clear that, for any given attack, the resultant casualties depend ultimately upon the population distribution in the affected area. As the populations in all 1 km squares in the population tape file are coded according to precise location and local authority district, it is a relatively simple matter to produce modified versions of population distribution, eg as a result of assumed dispersal or evacuation, and then re-calculate the casualties as above.

Program parameters may be changed quite readily when required so that the effects of, for example, a practical shelter policy could be examined, and likewise the effects of any changes in protective factor assumptions.

REFERENCES

1.	A D Perryman	SAB Report 1/71 (1971). Unpublished.
2.	P R Bentley	A population data file for the 1971 General Census. SAB Report 11/81 (1981).
3.	S Glasstone P J Dolan	The effects of nuclear weapons. US Department of Defence (1977).
4.	SIO Operational Notes	Home Office publication (Restricted) 1965.
5.	Home Office Scottish Home & Health Dept.	Nuclear Weapons. HMSO (1974).
6.	P R Bentley	SAB Memorandum 6/71 (1971). Unpublished.

Units, symbols and abbreviations used in the report

DR1	The reference dose rate at one hour after burst.
FOM	The fallout maximum, ie the maximum dose rate from fallout at a point.
GZ	Ground zero, ie the point on the ground where an explosion takes place or the point on the ground vertically beneath an explosion.
kPa	The kilo-pascal. The pascal unit of pressure represents the weight of one kilogram acting over an area of one square metre.
kt	The kilo-ton. Used as a unit of power for nuclear weapons and equivalent to 1000 tons of chemical high explosive.
km/h	Kilometres per hour.
mph	Miles per hour.
Mt	The mega-ton. This is the unit of power for high-yield nuclear weapons and is equivalent to one million tons of high explosive.
OED	Operational Equivalent Dose. The dose (of gamma radiation) used for injury assessment in wartime that takes account of certain bodily repair mechanisms.
PF	Protective Factor. The ratio of external to internal dose rate as a result of the shielding effect of buildings, etc.
psi	Pounds per square inch. An imperial unit of pressure representing the weight of one pound acting over an area of one square inch.
rad	The unit of whole-body absorbed dose from ionising radiation.
R/h	Rontgens per hour. A unit used for the measurement of exposure to radiation.
TOB	Time of burst.
TOA	Time of arrival of fallout.
TOM	Time of maximum intensity of dose rate.
TOC	Time of completion of fallout.
W	Symbol for nuclear weapon power (usually in kt).

The text of this report quotes units not only in the SI but also in other systems, particularly when it is convenient to quote rounded-off figures from other data sources. The use of units from different systems does not affect the calculations as the computer programs incorporate appropriate conversion factors.