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PROTECTION AFFORDED BY TOWNS AGAINST FALLOUT FROM TACTICAL NUCLEAR WEAPONS

Methodology and Sample Results

Mathematical Applications Group, Inc.
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The fallout field produced by the employment of a tactical nuclear weapon (TNW) can vary significantly in activity over distances of the order of tens of meters. Since typical towns have diameters on the order of hundreds of meters, the effects of such fallout can also vary significantly over the area of the town.

In this study a methodolcgy was developed to investigate fallout effects upon a representative West German town. Basement, first and second story and

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20. ABSTRACT (Continued)

outdoor detectors were considered. Included in the investigation are the effects of local decontamination procedures.

It is demonstrated that assumptions of a uniform fallout field cannot, in general, be applied to the situation of tactical nuclear warfare. Not only are the 50-hour exposure doses a function of position in town, but the protection factors, for the four different detector locations in and around a home, also vary with position in town - particularly for towns on the fringes of the fallout pattern.

Although the methodology developed is applicable to the general TNW fallout situation, the numerical results presented, herein, are for a single town model located in three positions in and around the fallout field from a single weapon-wind scenario. Hence, care should be exercised in drawing general conclusions about the magnitude of the exposure dose distributions and town protection factors. Such general conclusions, however, could be drawn if future sensitivity analyses are performed.

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SECTION 1 - INTRODUCTION

Some current scenarios involve the deployment of tactical nuclear weapons (TNW) by NATO forces for the defense of West Germany.

Of concern is the potentially unacceptable fallout collateral damage to the civilian population. With this thought in mind, Mathematical Applications Group, Inc. (MAGI) has performed investigations, reported herein, to assess the fallout collateral damage throughout a representative West German town. This town is considered to lie at three different locations in and around the fallout field produced by the employment of a 1 Kt surface burst fission source TNW*.

The fallout field generated by a TNW can vary rapidly in activity over distances of the order of tens of meters (as will be seen in Section 2). Since the towns considered have diameters of the order of hundreds of meters, the fallout field can change rapidly over the area of the town. This is in contrast to the higher yield "strategic" nuclear weapon situation for which a uniform fallout field is generally assumed throughout the whole town.

Since significant contributions to the exposure dose at a point inside a fallout field, come from ranges as great as 250 meters (see Appendix A) there is a fundamental difference in the approach which should be taken for the "strategic" and "tactical" fallout situations. That is, for the former, it is valid to assign a constant fallout activity throughout the town and to assume that the exposure dose at any point in town depends only upon the immediate geometry and this average activity. For the latter case, however, the exposure dose at a given point in town is a complex function of the geometry, the immediate (i.e., local) activity and the activity as far away as 250 meters from that point.

*The three town locations are: (1) centered in the fallout field, (2) tangent to the fallout field, and (3) partially in the fallout field.

In this study, a methodology has been developed to treat the situation of TNW fallout fields. Applied to one town located at three positions in the fallout field produced by one given weapon-and-average wind velocity scenario, the methodology is, nevertheless, applicable to all such TNW scenarios and could, in the future, be applied to a wider range of TNW fallout investigations.

In Section 2, which follows, descriptions of the TNW fallout field and the locations of the town within such a field are provided.

In Section 3, protection factors and dose distributions across the town are presented for the air-over-ground geometry; that is, for no structures in town. Results obtained for the "strategic" and "tactical" approaches to the fallout problem are compared.

In Section 4, a town geometry is placed within the town limits and results are obtained at first floor, second floor, basement and outdoor locations. Again, comparisons are made between the "strategic" and "tactical" approaches.

Section 5 provides a summary of the results of this study.

SECTION 2 - FALLOUT FIELD AND LOCATIONS OF TOWNS

2.1 DELFIC Computer Code

In order to examine the effects of fallout from a TNW upon a hypothetical West German town, it was first necessary to generate an adequate description of a typical TNW fallout field, and then to decide where to locate the towns within this field.

The fallout field used in these calculations was that predicted by the DELFIC computer code*. DELFIC was run for a 1 Kt fission surface burst with constant 15 Km/hr winds. The DELFIC output was the exposure rate (r/hr), at time H+1 hour, specified at discrete points on a 60 by 50 meter grid mesh; the finest mesh the code could treat for these parameters**. The downwind range, for which exposure rates were provided, was 0 to 6.25 Km.

2.2 Criteria for Positioning of Towns

In order to select the positions of the town within the fallout field, two DNA-specified siting criteria were adhered to:

1 - The towns should be far enough removed from the point of TNW employment so that initial radiation (IR) effects are negligible.

2 - The maximum outdoor exposure dose (within the town) should be of the order of ∿450 rads in the 50 hour period following the detonation.***

---

* At the request of DNA, the Radiation Engineering Branch, Vulnerability Laboratory, of the U. S. Army Ballistic Research Laboratories (BRL) performed the fallout prediction computation for MAGI. BRL used the DELFIC MARK V Code.

** By four-point linear interpolation, this was subsequently expanded into a finer 30 by 25 meter mesh.

*** 450 rads is the assumed LD-50 value; that is, a person receiving a dose of 450 rads (without immediate medical treatment), has a fifty percent probability of dying within sixty days.

The first criterion was satisfied by positioning the center of all towns 1.75 Km (downwind) from the TNW. Previous studies have shown that the initial radiation dose from a 1 Kt weapon, for this range is well below 1 rad[1].

In order to satisfy the second criterion, it was necessary to convert the DELFIC H+1 hour exposure doses (r/hr.) to the equivalent 50 hour dose (rads).

According to Glasstone[2], the decay of fallout activity at a given location, for times up to 200 days, may be approximated by

$$R_t \approx R_1 t^{-\alpha} \qquad (2.1)$$

where R_t is the dose rate at time t (hours) and R_1 is the dose rate at unit time (1 hour). Measurements made on actual fallout from weapons tests indicate that, α, the decay constant varies from 0.9 to 2.0, although 1.2 is usually taken as an acceptable average.[2]

Integration of (2.1) from time t_a to time t_b yields:

$$D \approx R_1 \int_{t_a}^{t_b} t^{-1.2} dt = 5R_1 (t_a^{-0.2} - t_b^{-0.2}) \qquad (2.2)$$

In this case t_b=50 hours. Although the fallout begins to arrive in the town as early as

$$t_a = \frac{1.75 \text{ Km}}{15 \text{ Km/hour}} = .12 \text{ hours}$$

(where 1.75 Km is the downwind range and 15 Km/hour is the wind velocity) most fallout will arrive at a later time. For the purposes of this calculation t_a was taken as 0.30 hours*.

Substitution of these t_a and t_b values into (2.2) yields:

D(r for 50 hours) = R(r/hr at 1 hour) x 4.1

*This assumption affects only slightly the positioning of the towns and has no appreciable effect on the protection factors and other data derived from this investigation.

An additional factor of 0.877, used to convert r(air) to rads[3], leads to an H+1 hour allowable value of

$$\frac{450 \text{ (50 hour·rads)}}{4.1 \left(\frac{50 \text{ hour·r}}{\text{r/hr at H+1 hour}}\right)} \times \frac{1 \text{ r}}{.877 \text{ rads}} \approx 125 \text{ r/hr.}$$

Finally, assuming *a priori* a protection factor of ∿1.6 for outdoor locations in town*, the second of the two siting criteria is satisfied by positioning the town within the DELFIC fallout pattern, so that a 125x1.6 = 200 r/hr value is not exceeded within the town limits.

2.3 Location of Towns

Figure 1a shows the digitized DELFIC exposure rates, at H+1 hour, at a downwind range of 1.25-2.25 Km. The decimal points in the output correspond to the location of the spatial mesh points. The superscripts are powers of 10. Hence, for example, the value in the lower left,

$$3.607^{1}$$

should be read as:

$$3.607 \times 10^{1} \text{ r/hr.}$$

The spatial mesh shown is 50 meters (downwind) by 60 meters (perpendicular direction). Subsequently, the mesh was made into a finer 25 by 30 meter mesh but this is not shown here for clarity. There is symmetry about the downwind axis.

Sketched on the DELFIC output are the r/hr. contours in increments of 100 r/hr. The complex nature of the fallout pattern is clearly visible. Note that the code predicts dose rate levels along the fringe of the fallout field as low as ∿5 r/hr. Beyond the fringe values, DELFIC predicts zero dose rates at all remaining grid points.

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*This is a good rule of thumb for initial radiation at an angle of elevation at 90° for a town such as the one considered herein[4]. It is subsequently confirmed, below, for fallout radiation as well.

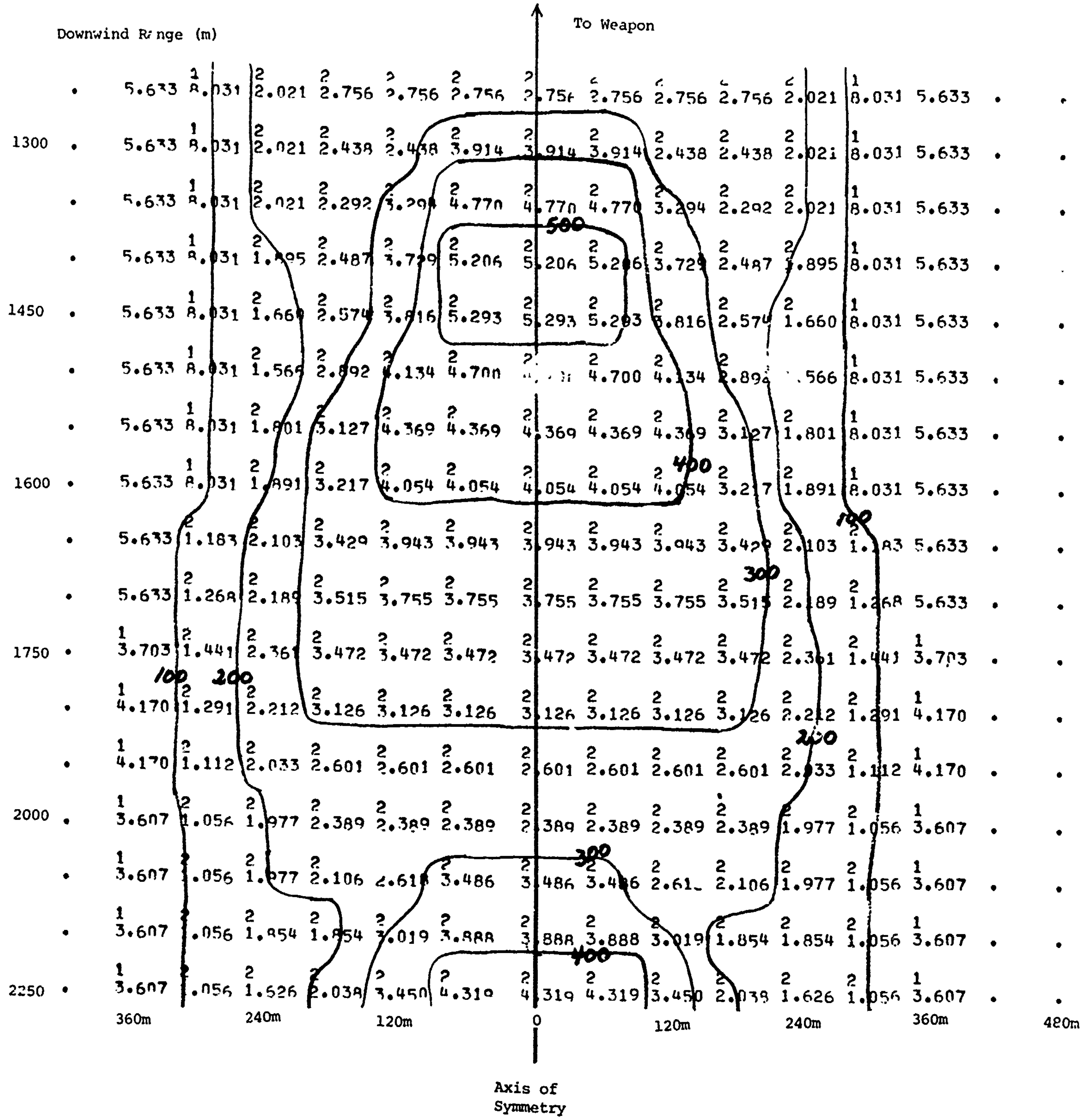

Figure 1a. DELFIC fallout

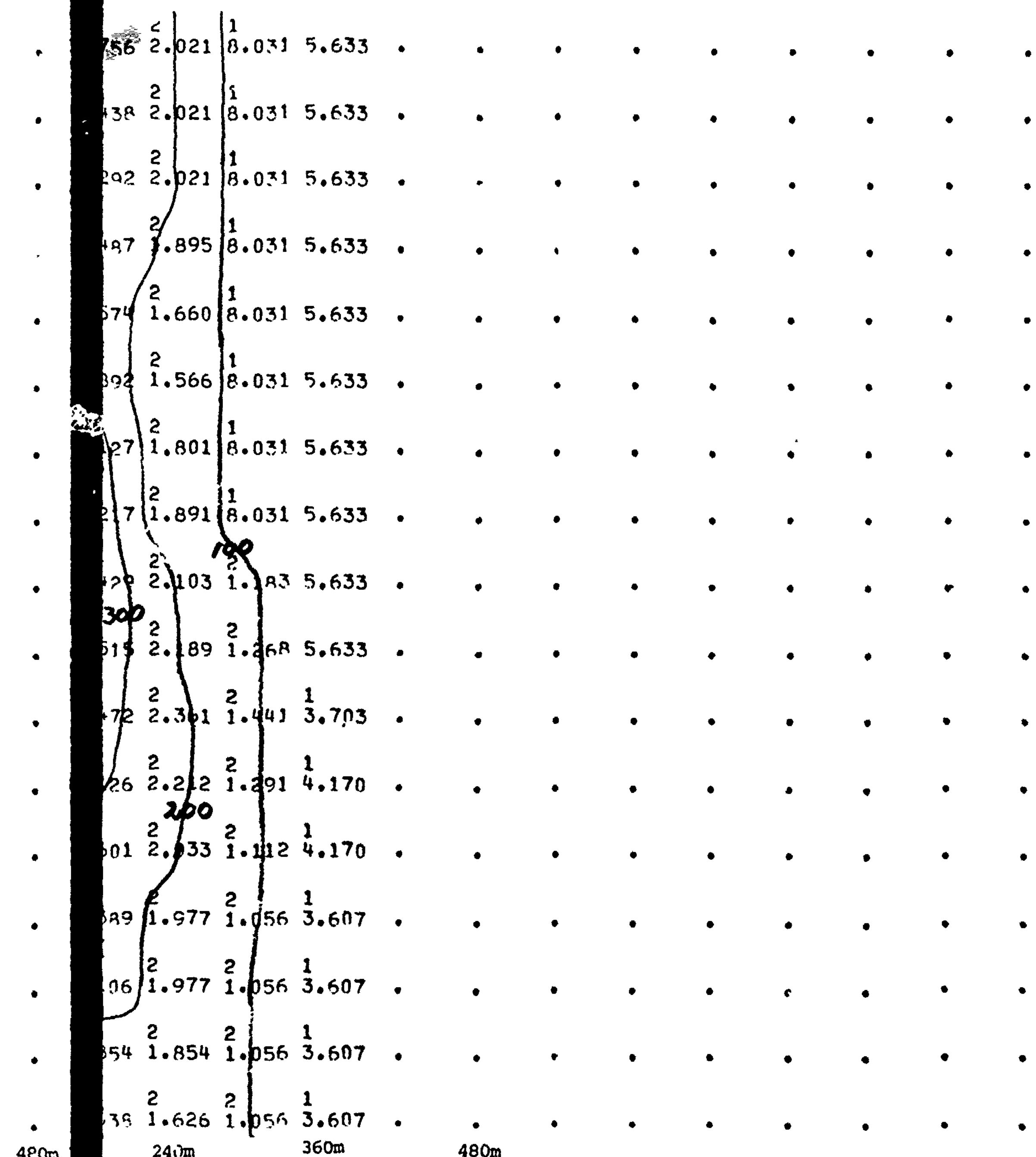

Figure 1a. DELFIC fallout pattern 1.25-2.25 Km downwind.

Three circular 500 meter diameter towns were positioned inside the DELFIC pattern as shown in Figures 1b and 1c. The first and basic model approaches, but does not include the nominal 200 r/hr. contour. This town will be referred to below as "Partial-Town" because it lies partially in and partially out of the DELFIC fallout pattern.

The second town lies outside of, but is tangent to, the fallout field. It is referred to below as "Tangent-Town". Note that any methodology which does not include the transport of fallout gamma radiation would predict zero exposure levels throughout "Tangent-Town". (In Figure 1c, Tangent-Town has been reflected, for clarity, about the axis of symmetry.)

The third town is situated in the center of the fallout pattern thus exceeding the nominal 200 r/hr. maximum value. This town was selected because it lies completely within the fallout field. It is referred to as "Center-Town".

2.4 Usage of DELFIC Output in These Calculations

The calculations described in Sections 3 and 4 require, as input, a description of the fallout field in terms of the activity (Ci/m^2) at the local points of the 30 by 25 meter mesh.

DELFIC, as coded, initially estimates fission fragment activity at a point (for many isotopes) and then bases its predictions of local exposure rates (at that point) by converting the local activities to an exposure dose. In the studies reported, herein, for the three towns, the DELFIC-predicted local exposure rates were assumed to be from a cobalt-60 spectrum only, with a 1.17 Mev and 1.33 Mev gamma ray emitted per spontaneous disintegration*. Hence the DELFIC exposure rates were converted to cobalt-60 activity, as is now described.

*This assumption is a very common procedure for studies of fallout radiation effects.

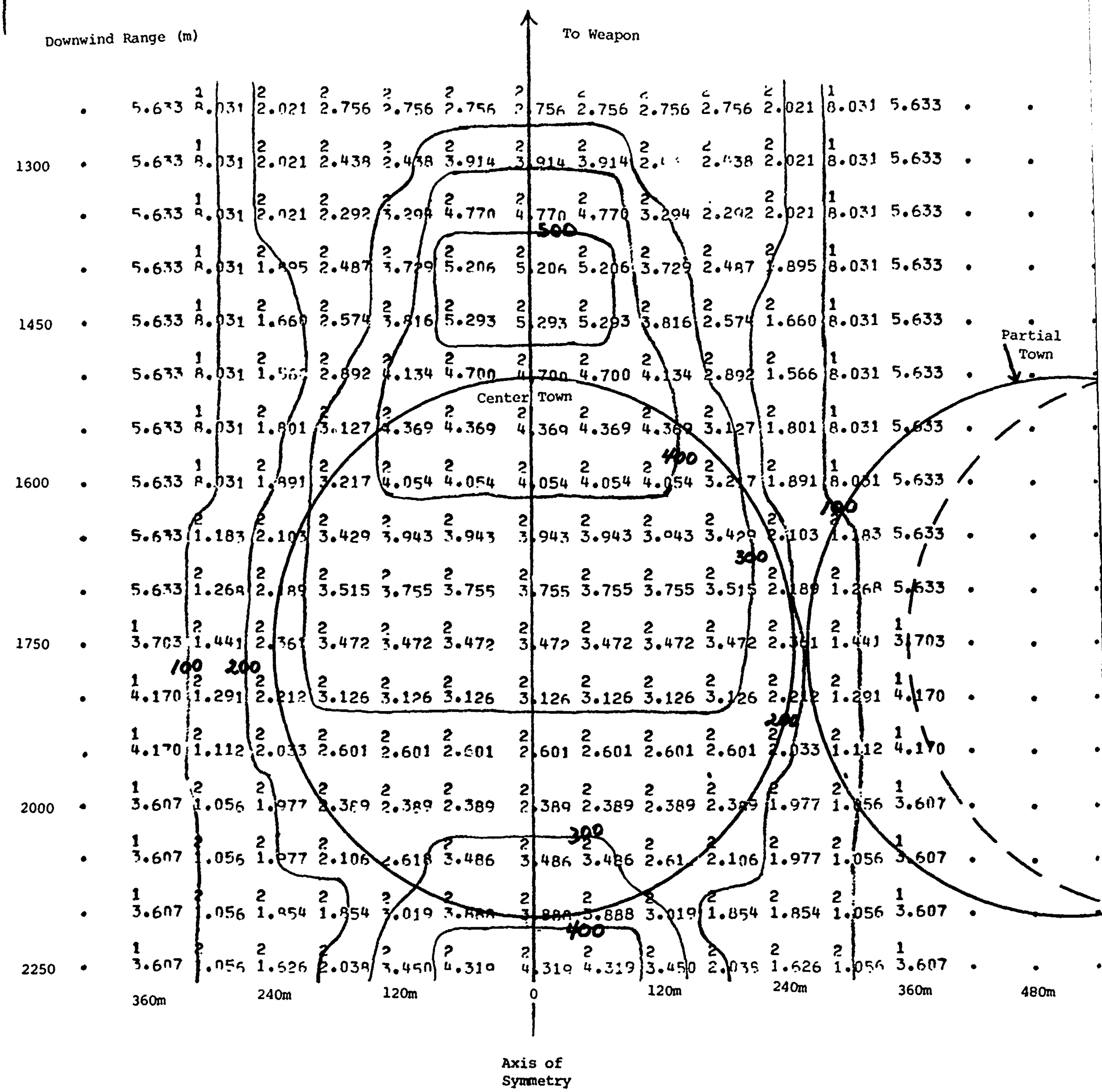

Figure 1b. Location of to

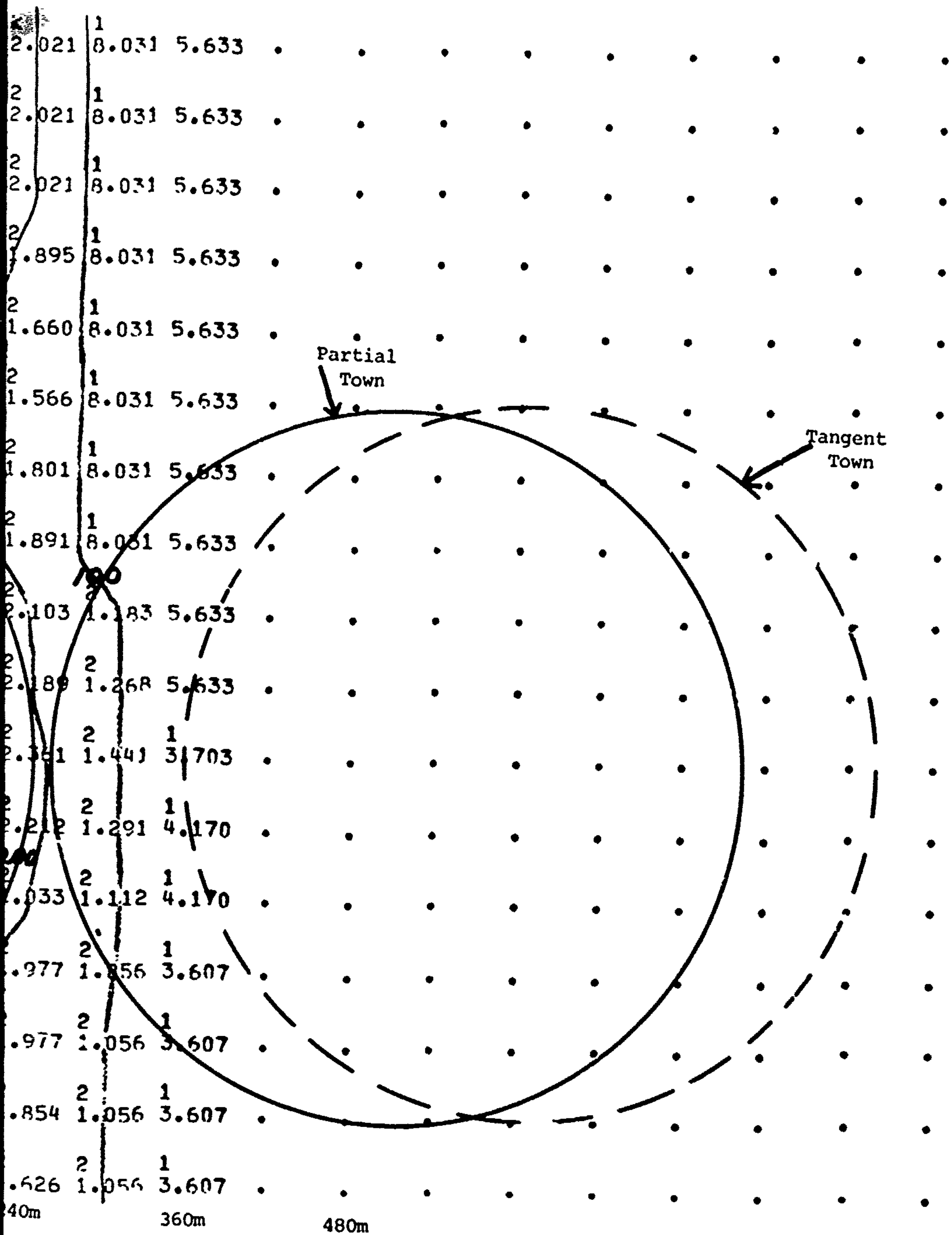

Figure 1b. Location of towns in fallout pattern.

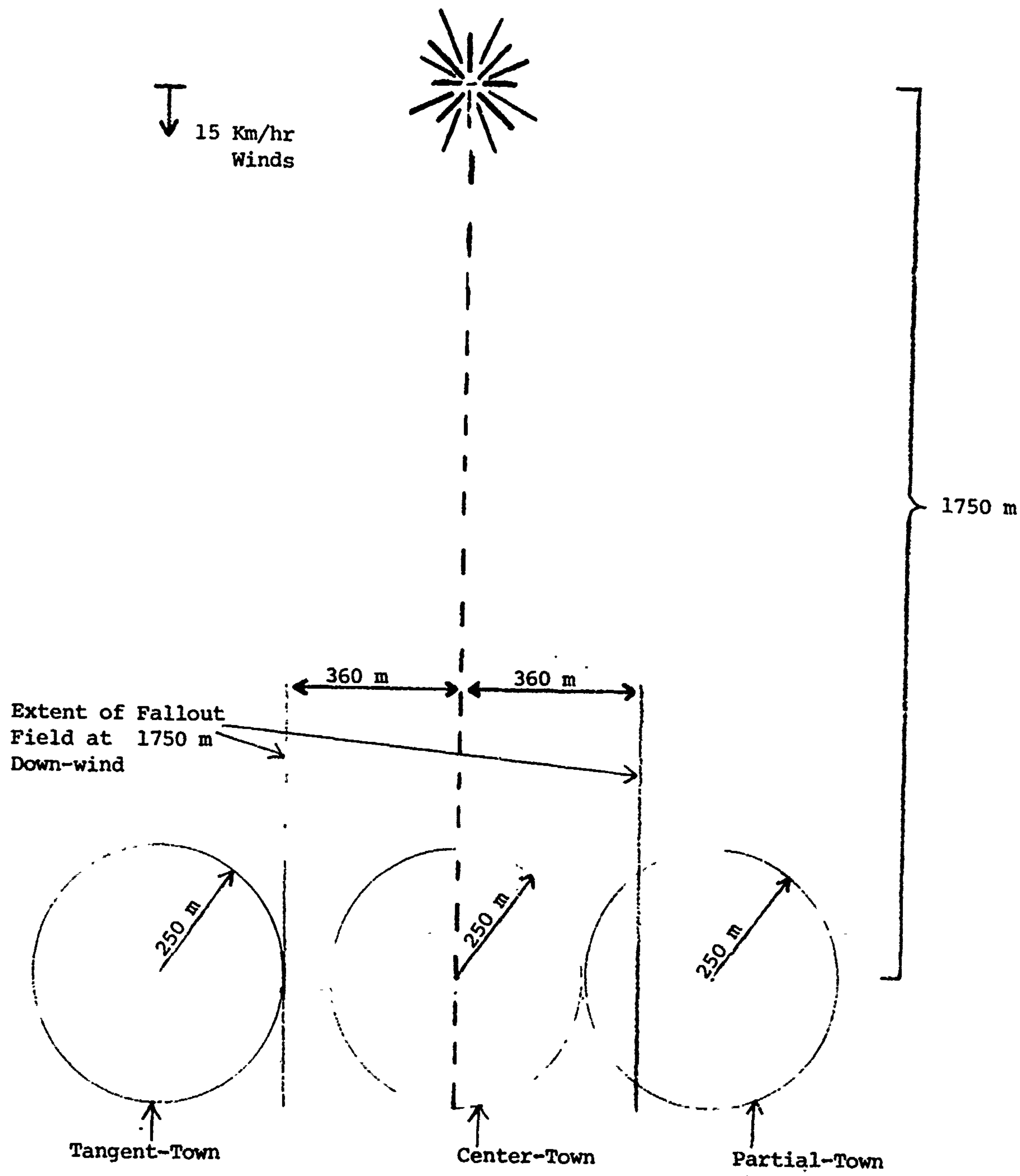

Figure 1c. Location of towns relative to TNW (to scale).

An infinite fallout field of cobalt-60, emitting 1 photon per cm^2 per sec., will generate, at a 0.9144 meter (3 feet) high detector, air exposure rate of 5.99×10^{-6} r/hr.[5] Therefore,

$$1 \text{ r/hr} \rightarrow \frac{1}{5.99 \times 10^{-6}} \frac{\text{photon}}{\text{cm}^2\text{sec}} \times \frac{1 \text{ disint.}}{2 \text{ photons}} \times \frac{1 \text{ curie}}{3.7 \times 10^{10} \text{ disint.}} \times \frac{10^4 \text{cm}^2}{\text{m}^2}$$

$$= 0.0225 \text{ Ci/m}^2$$

This factor of 0.0225 was then used, in the calculations reported below, to convert the DELFIC output (r/hr.) to local cobalt-60 activity (Ci/m^2).

SECTION 3 - DOSE DISTRIBUTIONS FROM FALLOUT - NO STRUCTURES IN TOWN

3.1 Theoretical Models

A series of calculations were performed to assess the fallout dose distributions which would be predicted, within the town limits, in the limiting case of no structures (i.e., zero building density). These results, then, are the simple air-over-flat ground geometry results and will be used, below, in the determination of the protection factors against fallout radiation provided by a hypothetical town.

In these air-over-ground computations, the 50-hour exposure doses were obtained, for each of the three towns, at 320 point detectors. These detectors were 0.9144 meters (3 feet) above the ground and were uniformly spread throughout the town. The 320 individual scores (for each town) were then sorted into dose bins to obtain cumulative dose distribution functions, such as is illustrated in Figure 2, wherein dose, D, is the abscissa, and cumulative fraction of the population receiving a dose greater or equal to D, is the ordinate*. From these cumulative dose distributions, one can conveniently determine maximum dose, 10% maximum dose, median dose, or the fraction of the population receiving a dose greater than any specified amount. In addition, these distributions may be conveniently folded-in with mortality, permanent or temporary incapacitation, or other appropriate human response data.

The 50-hour exposure doses, at each of the 320 detectors referred to above, were obtained by three different methods - each of which makes different assumptions about the nature of doses generated from fallout fields. Each of these three methods is now described:

*In these, and in all discussions which follow a uniform distribution of population across the town is assumed. However, as discussed below, the methodology is not restricted to this assumption.

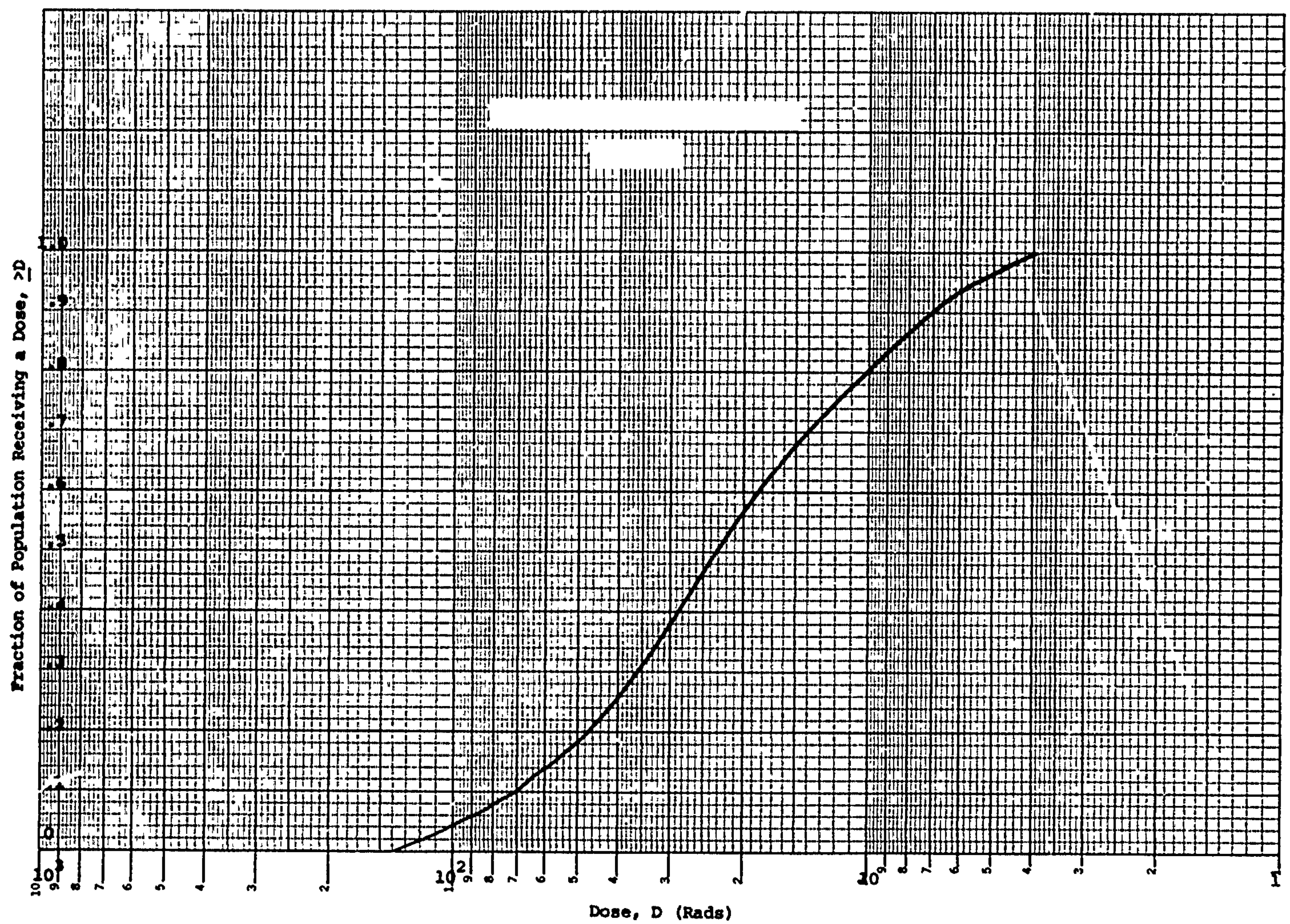

Figure 2. Sample dose distribution curve.

Method 1 - The methodology treats the fallout in and around the town as if it were deposited in the course of strategic nuclear warfare. That is, it assumes that the dimensions of the town are small compared to the dimensions between significant changes in fallout activity contours, and thus it assigns a uniform average fallout activity throughout the town.

Method 2 - The methodology is a simple tactical nuclear warfare treatment. It assumes that the fallout activity does vary throughout the town (and uses the DELFIC output to describe the fallout field), but also assumes that the dose at a given point detector is directly proportional to the fallout activity on the ground directly below the detector.

Method 3 - The methodology is a more detailed tactical nuclear warfare model. As in Method 2, it uses the DELFIC output to describe the fallout field. In addition, it treats contributions to the exposure dose at a point detector, from the fallout activity from all portions of the fallout plane.

3.2 Computer Code

FOLD, a rapidly running computer code requiring only seconds of CDC 6600 time per run, was written to predict the cumulative dose distributions (for each of the three towns), for each of the three methodologies described in the previous section. Input to the code is the digitized fallout field activity as derived from DELFIC, the position and radii of the three towns, and the number of detectors to be located uniformly throughout a town. For Method 3, additional input data are also required, as described below.

For Method 1, FOLD averages the fallout activity throughout the town limits and predicts that all detectors will receive an exposure dose which is proportional to the averaged activity. For Tangent-Town, which lies completely outside the fallout field, this dose is, of course, zero. For the other two towns, a step function will be obtained for the cumulative dose distributions since all detectors receive the same non-zero doses.

For Method 2, FOLD first determines the fallout activity immediately below a given point detector. If this point does not correspond exactly to a spatial point on the output mesh from DELFIC, four-point linear interpolation is used to obtain the appropriate fallout activity. Then for each detector, a dose proportional to the fallout activity is determined and stored in the proper output dose bin. For Center-Town, which lies completely within the fallout field, all detectors receive a predicted non-zero dose. For Partial-Town, which lies partially within the fallout field, only those detectors inside the fallout field receive a predicted non-zero dose. For Tangent-Town, as for Method 1, all detectors receive a predicted zero dose.

For Method 3, the situation is more complex. In this case, a detector receives dose contributions from an extensive portion of the fallout plane*. Hence, one no longer assumes that the dose at a point is proportional to the fallout strength on the ground immediately below. To obtain the dose distribution for Method 3, the following procedure is performed for <u>each</u> of the point detectors within the town. (Refer to Figure 3).

Consider an arbitrary point, P, within the town. Divide the fallout plane about P into N_R radial bins and N_ϕ azimuthal bins, where N_R and N_ϕ are input parameters to FOLD**. The azimuthal bins are evenly spaced but the spacing of the radial bins is arbitrary***. The largest radial dimension is also arbitrary****.

---

*Beyond a certain distance from the detector contributions from the fallout plane become negligible.

**N_R and N_ϕ were 17 and 36, respectively, in these computations.

***A complete description of the radial bins actually used is given in Appendix A.

****The maximum radius of this study was 244 meters; see Appendix A.

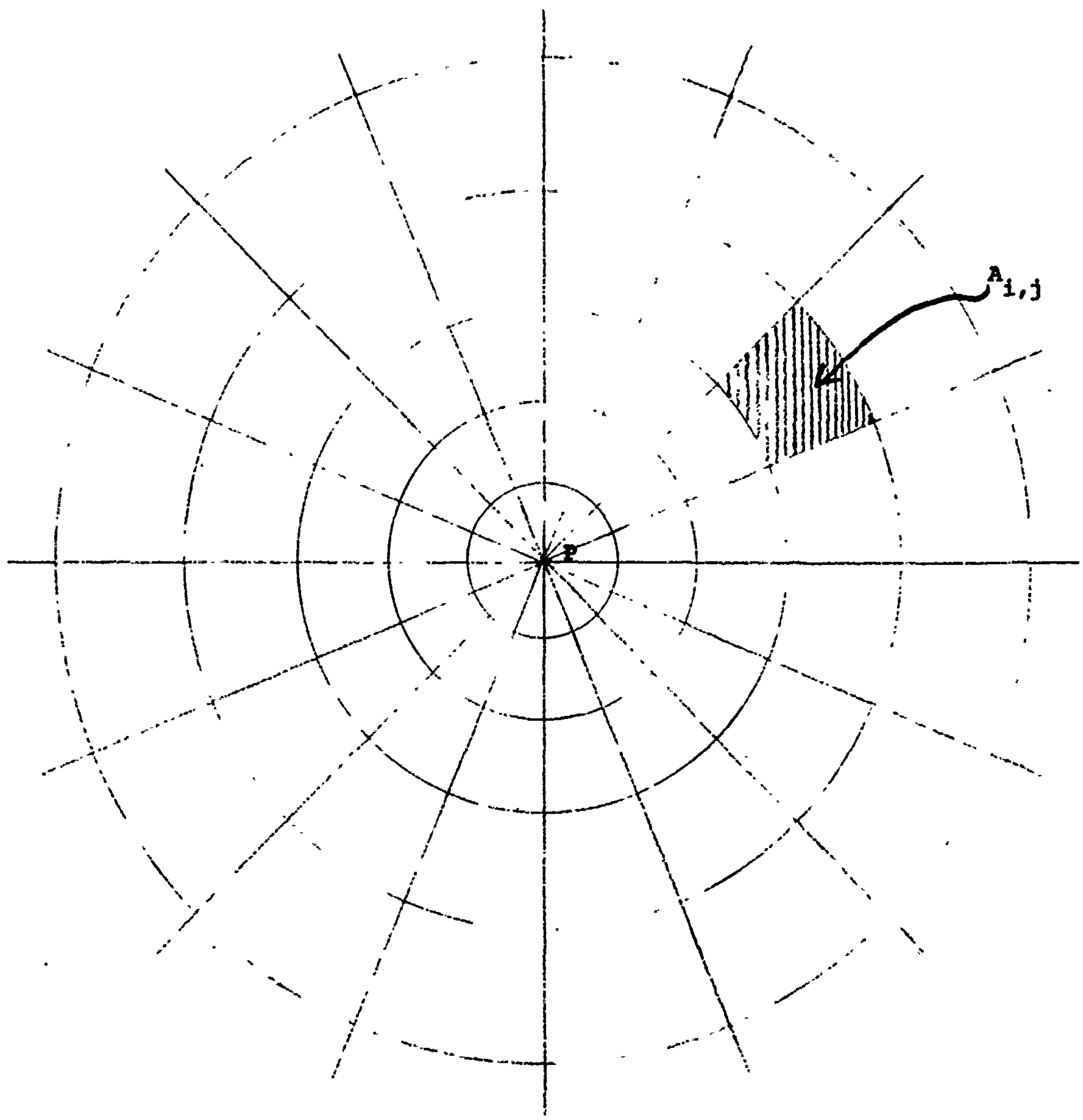

Figure 3. Radial and azimuthal bins about Point P.

Consider a differential area, $A_{i,j}$, in the "i-th" radial bin and the "j-th" azimuthal bin, as shown in Figure 3, above. The contribution of this differential area of the fallout field, to a point detector at P, is given by:

$$R_{i,j}\ (H+1) = \overline{S}_{i,j} \times \overline{J}_i \times A_{i,j}$$

where:

$R_{i,j}(H+1)$	=	dose rate (rad/hr.), at time H+1 hour, due to contributions from area $A_{i,j}$
$\overline{S}_{i,j}$	=	average fallout activity in area $A_{i,j}$ (Ci/m^2) at H+1 hour
$\overline{J}_i$	=	average contribution of fallout in this "i-th" radial bin to the detector at P. $\overline{J}$ is in units of rads/hr. per Ci and is a function of radial bin (i.e., distance from P) only
$A_{i,j}$	=	differential area (m^2)

Using the factor of 4.1 (Section 2.2) to convert dose rate at H+1 hour to 50-hour total dose:

$$D_{i,j}\ (50\text{-hour}) = \overline{S}_{i,j} \times \overline{J}_i \times A_{i,j} \times 4.1 \qquad (3.1)$$

$\overline{S}_{i,j}$ is derived by FOLD, by first determining the center of each $A_{i,j}$ area and by then finding the fallout activity at this point from the DELFIC output by four-point linear interpolation*. The user provides as input the $\overline{J}_i$ solutions - which are functions of radial bin only. These are available, from the literature, for cobalt-60 and are provided in Appendix A. Note that since the $\overline{J}_i$ solutions give the dose at the detector per Ci/m^2 of activity, they are referred to in the remainder of this report as the "adjoint" dose solutions.

---

*More exact determination of $\overline{S}_{i,j}$ can be implemented into FOLD, but this was not felt to be necessary for the purposes of this study.

Having available the $A_{i,j}$ descriptions and the $\bar{S}_{i,j}$, and $\bar{J}_i$ solutions, FOLD is able to compute $D_{i,j}$ as given in expression (3.1). Once this is done for all values of i and j, FOLD computes the total dose at P, by:

$$D = \sum_i \sum_j D_{i,j} \tag{3.2}$$

The code then examines the value of D at this location, P, and makes a score of [1/(No. of Detectors)] in the output dose bin which brackets the score, D*.

This procedure is repeated for each of the detectors in town and thus a differential dose probability distribution is determined. As a final step, FOLD computes the cumulative dose probability distribution, too, (from the differential probability data) and prints out both the differential and cumulative probability distributions.

FOLD, although it performs many arithmetic operations, is essentially a simple data manipulation code. It generally requires ∿10 seconds of computer running time on a CDC 6600 machine.

---

*Note that if the population is nonuniformly distributed across the town, information must be supplied to FOLD so that it can compute at each point P, f_p, a factor proportional to the population density, where

$$(\sum_N f_p)/N = 1$$

N = no. of uniformly distributed detectors, and

f_p = 1., for all N, for the uniform population density

FOLD would then score [f_p/(No. of Detectors)] in the proper output dose bin.

At the present time FOLD assumes f_p=1., everywhere. However, the inclusion of this extra capability into the code would be a trivial assignment.

3.3 Results - No Structures in Town

3.3.1 Center-Town

Figure 4 shows the Center-Town dose distributions which are predicted by the three fallout methodologies. Before proceeding, refer again to Figure 1b (page 8) which shows that Center-Town lies completely within the fallout zone and that for the combination of weapon-wind parameters of this study, DELFIC does not show any rapid variation of fallout activity in or immediately around the town limits.

From Figure 4, it is seen that Method 1 (that is, the "strategic" model with a uniform fallout throughout the town) predicts that everyone in town would receive a 50-hour dose of ∿1220 rads. Methods 2 and 3 predict about the same distributions; both showing a maximum dose of ∿1800 rads and a minimum dose of ∿700 rads. Hence a range of ∿2.6 (1800/700), appears in the actual dose distribution which is, of course, completely absent from the strategic fallout model.

3.3.2 Partial-Town

Figure 5 shows the Partial-Town distributions predicted by the three methods. Method 1 predicts that everyone would receive a 50-hour dose of 52 rads. In this case, however, over 82% of the town lies outside the fallout field and the activity averaging procedure of Method 1 is highly unsatisfactory. Method 2, the simple tactical model, predicts a maximum of ∿700 rads and that ∿82% of the population receive no dose at all. Method 3, the tactical model which includes contributions from over the fallout plane, also shows a maximum dose of ∿700 rads, but also shows that some of the people, outside the fallout plane do receive a noticeable dose. It predicts, for example, that about twice as many people receive doses greater than 17 rads, than is predicted by Method 2.

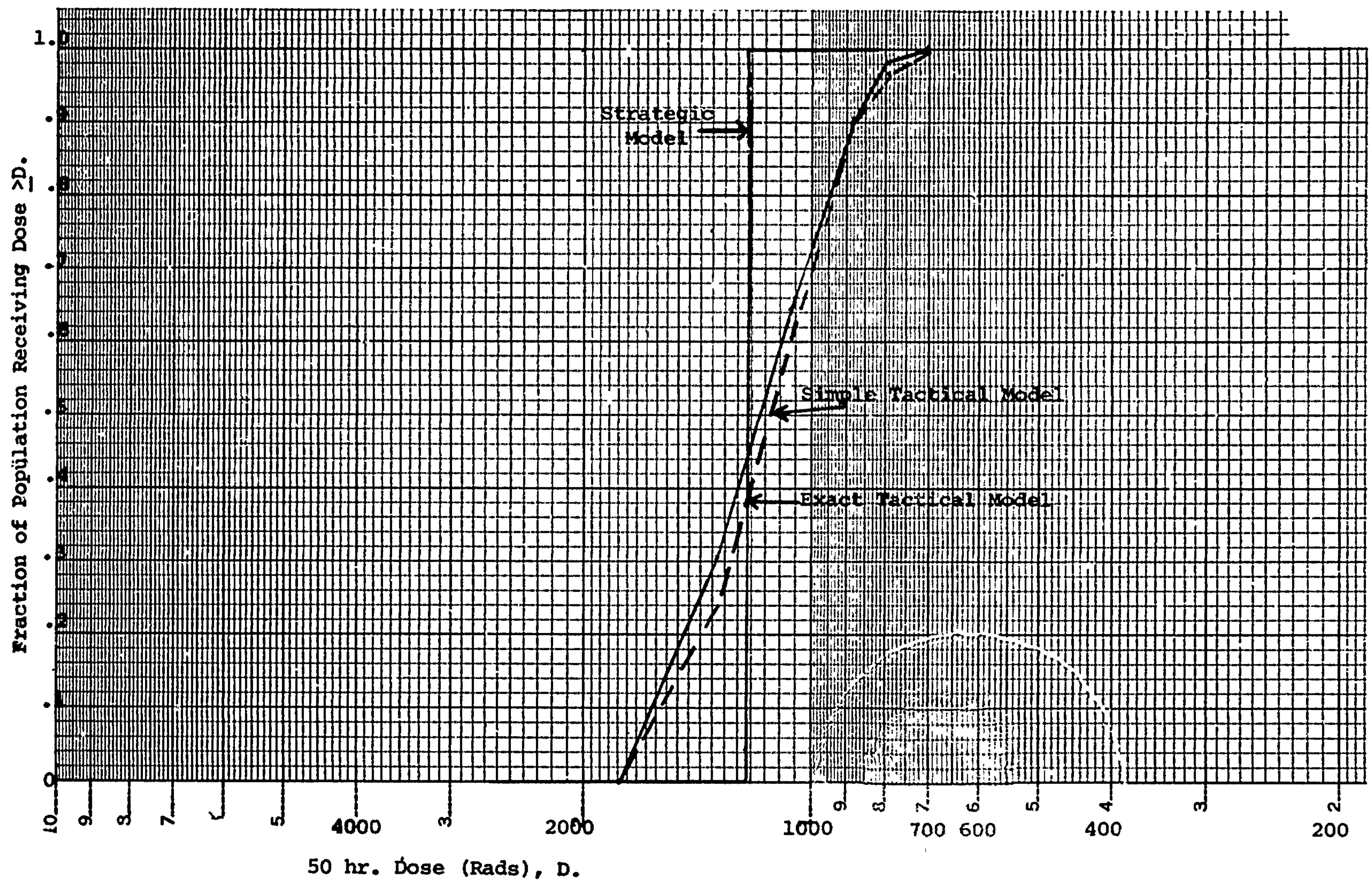

Figure 4. Center-town with no structures.

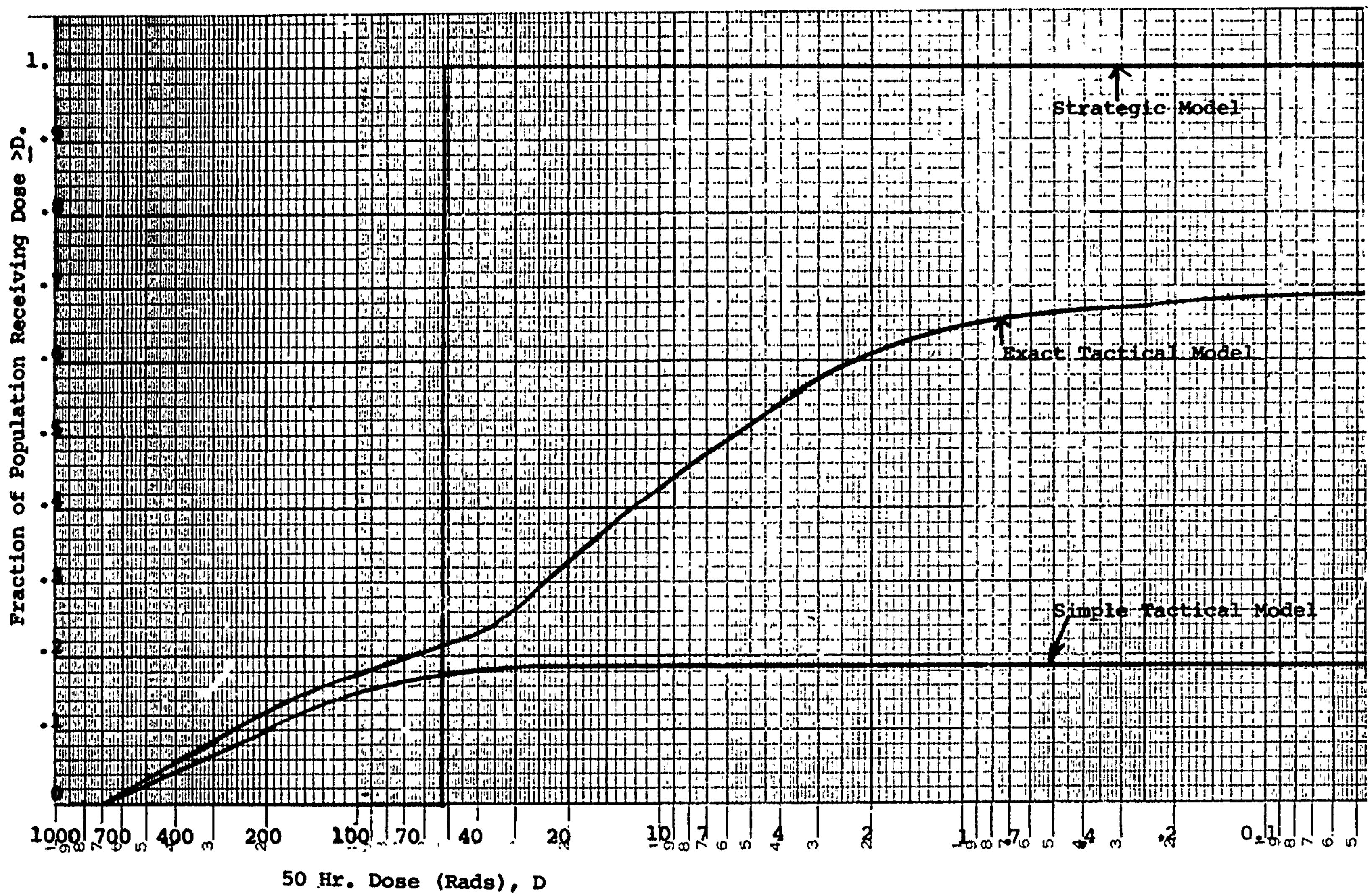

Figure 5. Partial-town with no structures.

3.3.3 Tangent-Town

For Tangent-Town, Methods 1 and 2 erroneously predict that no one in town receives any dose. Figure 6 shows, in contrast, that Method 3 predicts a maximum 50-hour dose of ∿125 rads.

3.4 Conclusions - No Structures in Town

It has been seen that the "strategic" model of Method 1, is noticeably incorrect for all three towns. Method 2, the simple tactical model, is reasonably adequate for Center-Town, which lies well within the fallout pattern predicted by the selected DELFIC computer run*. Method 2, however, becomes increasingly less appropriate as the town is positioned nearer to the fringes of the fallout pattern. For towns outside or tangent to the fallout pattern, Method 2 is, of course, an invalid approach.

In the studies which follow in Section 4, for a hypothetical town, the general procedures of Method 3 will thus be adopted.

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*It has not yet been determined how adequate Method 2 might be well within other DELFIC patterns.

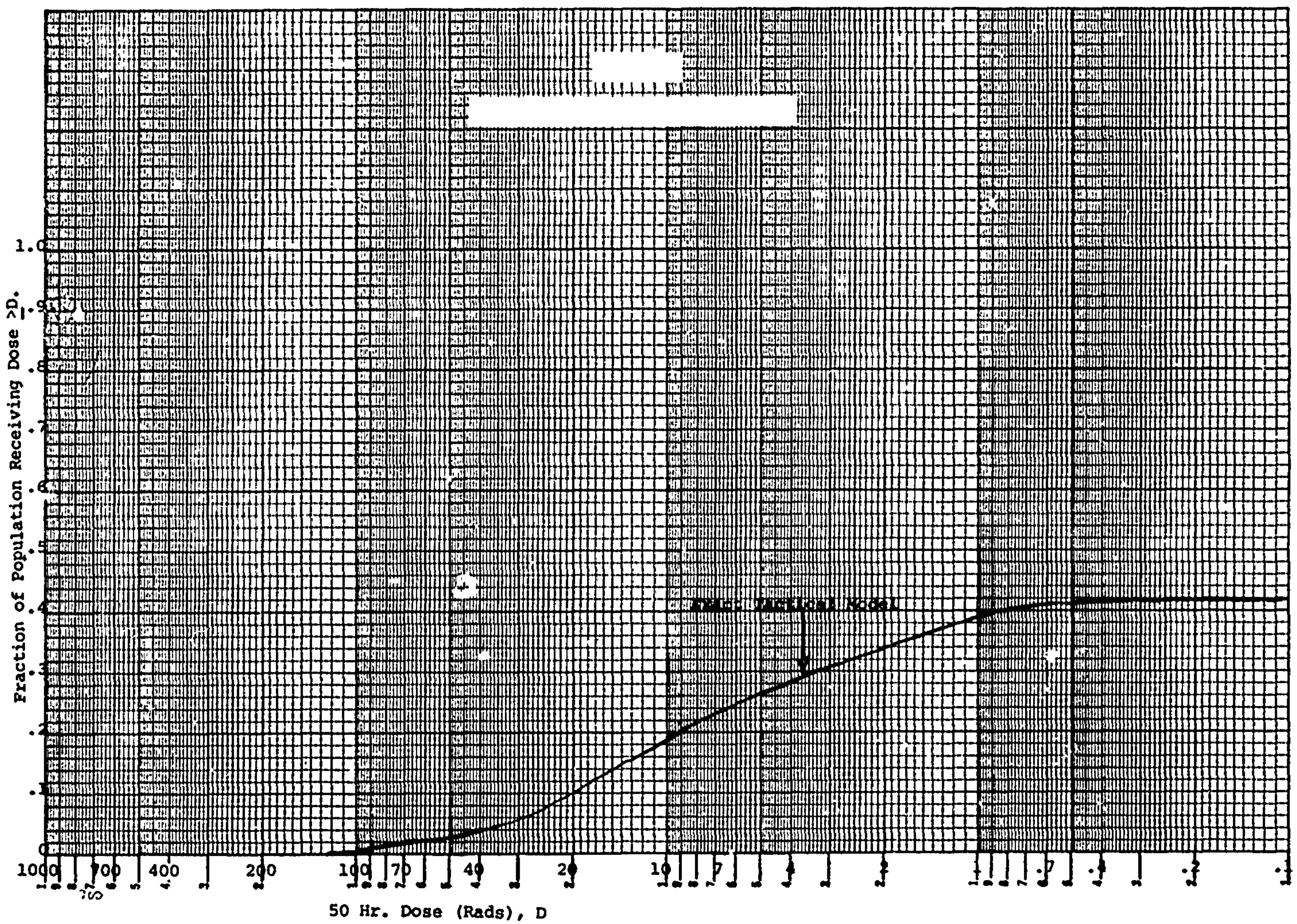

Figure 6. Tangent-town with no structures.

SECTION 4 - DOSE DISTRIBUTIONS FROM FALLOUT - STRUCTURES IN TOWN

4.1 Town Model

A town model, similar to one of two towns previously examined by MAGI for TNW initial radiation effects[6], was used in this study. This town geometry was used for Center-Town, Partial-Town and Tangent-Town.

The model is that of a 500 meter diameter densely-populated, heavily mutually-shielded town. The nominal population for this town is 3000. The basic structures are two-story attached row houses which are also back-to-back with a second row of houses. (An aerial scene is given in Figure 7, where the dotted lines are the tops of the pitched roofs, and the double dashed lines are the walls between the back-to-back rows of homes.) This pattern is repeated throughout the town. The combined depth of the double row of houses is 24.8 meters and the street width is 15.9 meters. Hence, buildings occupy ∿61% of the town area.

The basic home has a 6.7 x 12.4 meter floor area and each story is 3.1 meters high. Each home has a 2.0 meter deep basement. Atop the second floor is an attic with a roof pitched at a 55° angle.

The roof is 3" Spanish Tile (heavy) on 2" Oak planking with a total thickness of ∿10.5 g/cm^2. The attic floor is a mixture of plaster, wood, and lathe with a total thickness of ∿6 g/cm^2. Both the main and second story floors are heavy timber of ∿3.5 g/cm^2. The outer walls are thin, being lathe with plaster on both sides with a total thickness of ∿10 g/cm^2. Between the back-to-back rows of attached rows are double walls (i.e., one from each home) ∿20 g/cm^2. The atomic concentrations for the various building materials are given in Appendix B.

A sketch of a model home and one of its attached neighbors is given in Figure 8. Additional views of the basic house and the village geometry are given in Appendix C.

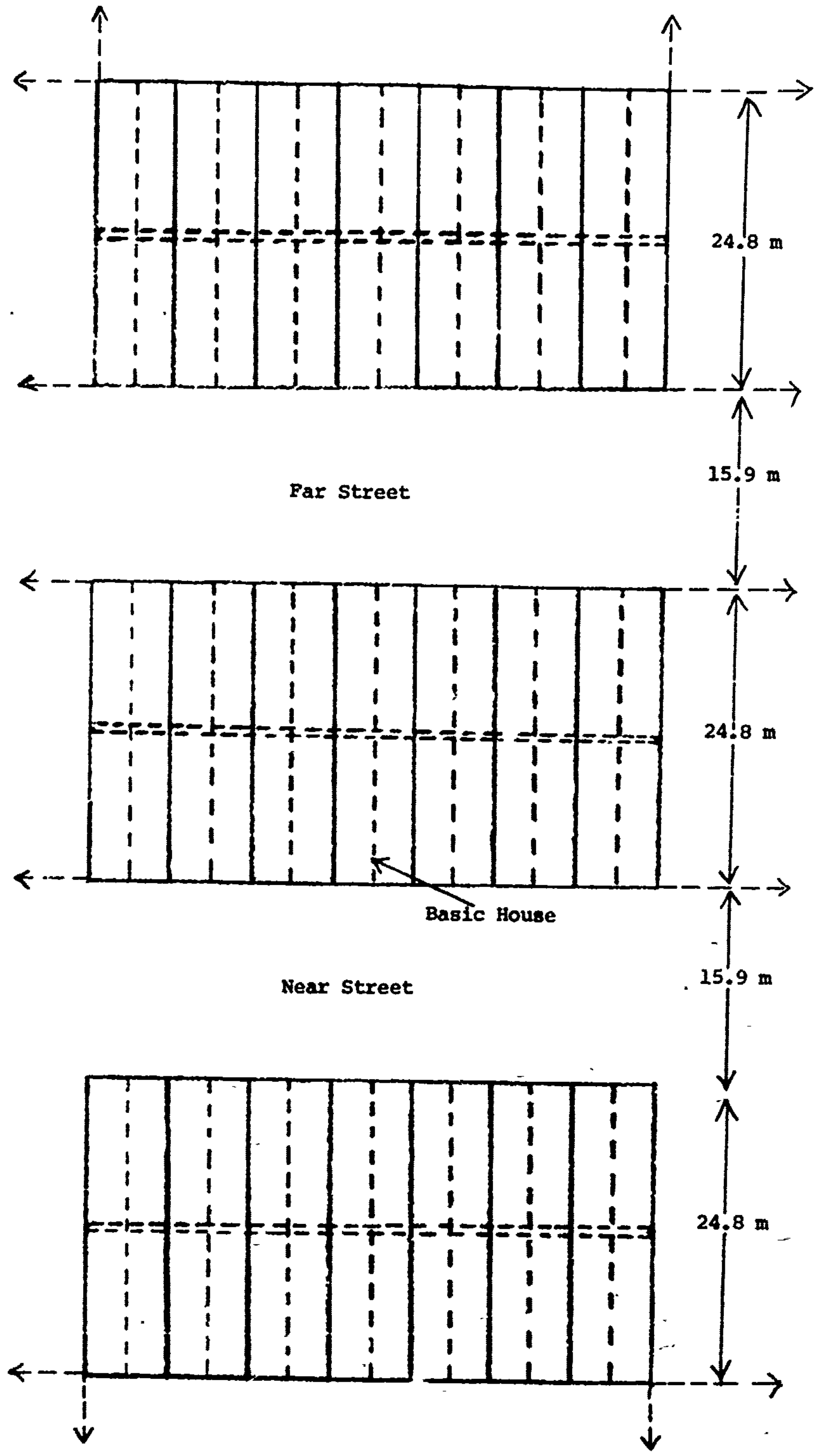

Figure 7. Aerial view of town.

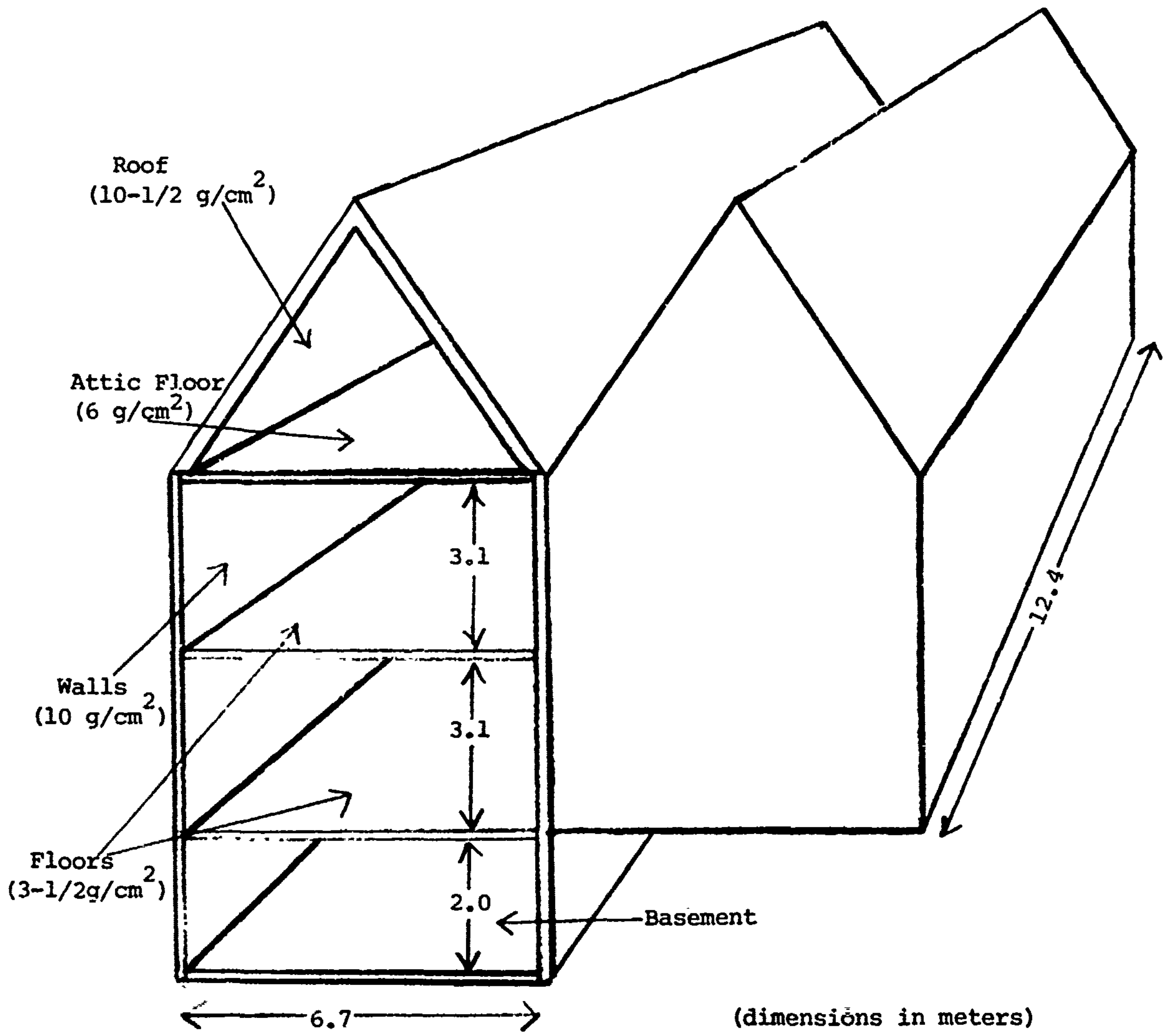

Figure 8. Model home showing one attached neighbor.

4.2 Theoretical Fallout Model

A series of calculations were performed to assess the fallout dose distributions across each of the three towns. In these computations, the 50-hour exposure doses were obtained at the same 320 positions in town as in the air-over-ground studies. However, at each town "position" 4 detectors were considered; one 0.9144 meters (3 feet) above the center of the basement, the first story and the second story floors, and the fourth, 0.9144 meters above the middle of the street. This is shown in Figure 9.

Once again, the DELFIC output was used to describe the fallout activity across the town. The more detailed treatment of Method 3 was used wherein contributions to the exposure dose at a point detector were considered from fallout throughout the town.

As described below, FOLD was then further modified to combine DELFIC fallout patterns, town geometry, and town "adjoint solutions" to generate the cumulative dose distributions across each of the three towns.

4.3 Computer Code

FOLD was upgraded to predict the cumulative dose distributions (for each of the three towns) for basement, first story, second story and outdoor detectors. Input to the code is the digitized fallout activity, as predicted by DELFIC, deposited in this case either on the roofs or on the street instead of on a horizontal fallout plane. Additional input to the code is the position and radii of the towns and the number of positions uniformly located throughout a town. In this case a "position" implies the 3 house detectors (on a common vertical axis) running through the center of a house and a fourth outdoor detector displaced 7.95 meters from the first floor detector as in Figure 9.

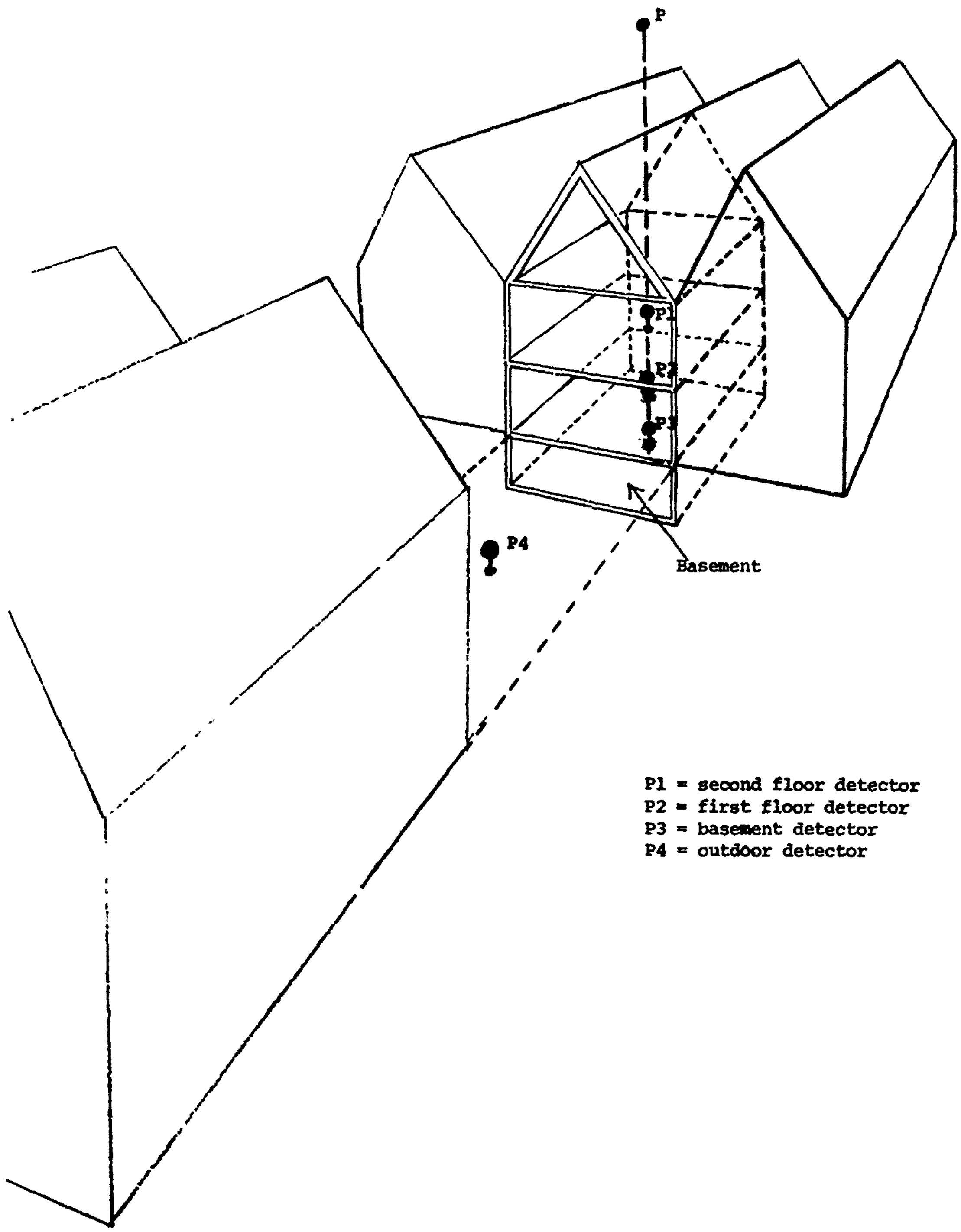

Figure 9. Second floor, first floor, basement and outdoor detectors for a given "Position", P, in town.

A common local geometry of attached homes and parallel rows of homes (see Figure 11 below) was assumed for all positions. For positions near the edge-of-town, the neighboring homes were allowed to "spill-over" outside the town boundary and so for this study edge-of-town effects were not treated. To obtain the desired dose distributions, for each of the four types of detectors, the following procedure is followed by FOLD:

Consider an arbitrary location in town, P, with its associated detectors at P1, P2, P3 and P4 as was shown in Figure 9.

Next, consider an arbitrary surface area such as roof area A_i in Figure 10. Then the contribution of this A_i surface to the p-th detector (p=1,2,3,4) is:

$$D_{p,i} = \overline{S}_i \times \overline{J}_{p,i} \times A_i \times 4.1 \qquad (4.1)$$

where

$D_{p,i}$ = 50-hour dose, at detector p, due to surface i

$\overline{S}_i$ = average fallout activity on area A_i (Ci/m^2) at H+1 hour

$\overline{J}_{p,i}$ = average contribution of fallout on surface A_i per unit activity, to the p-th detector (rads/hr. per Ci)

A_i = Surface area (m^2)

and 4.1 is the conversion factor from dose rate at H+1 hour to the 50-hour total dose.

The $\overline{S}_i$ values are determined, as in the air-over-ground case, by four-point linear interpolation of DELFIC output. The $\overline{J}_{p,i}$ adjoint solutions were pre-determined by SAM-CE Monte Carlo calculations. (These J-solutions are tabulated and discussed in Section 4.4, which follows.)

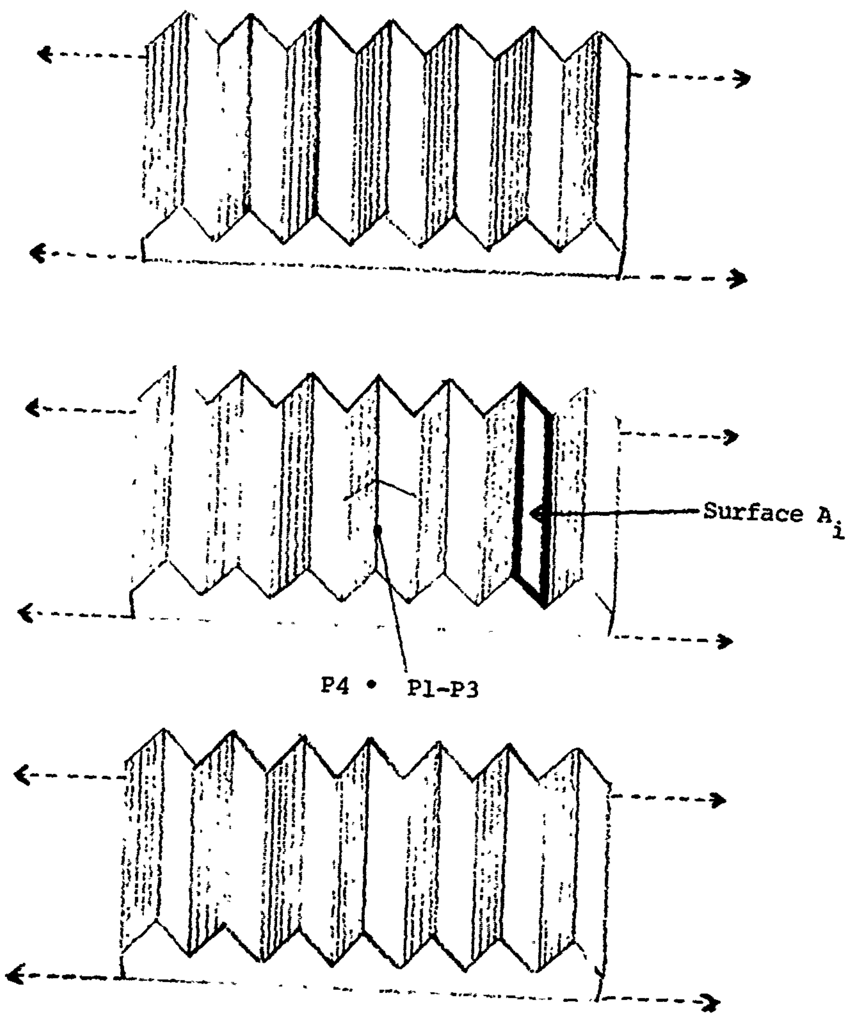

Figure 10. Surface A_i.

Having available the $\bar{S}_i$ and $\bar{J}_{p,i}$ solutions, FOLD is able to compute $D_{p,i}$ as given in (4.1). Once this is done, for all values of p,i, FOLD computes to total dose at each "p-th" detector at location P in town, by:

$$D_p = \sum_{\text{all } i} D_{p,i} \qquad (4.2)$$

where the summation over "i" is over all the contributing roof and street areas.

FOLD has four dose output tabulation bins corresponding to each of the four "p" detectors. For each of the p detectors, the code examines the value D_p at this location, P, and makes a score of

$$\left[\frac{1}{\text{No. of Positions in Town}} \right]$$

in the output dose bin (in the proper "p-th" array), which brackets the score, D_p. Again, as was the case for the air-over-ground problem, these scores can be modified by an assumed population density factor.

This procedure is repeated at each of the locations in town and thus the desired differential and cumulative dose distributions are obtained.

4.4 Adjoint Solutions

Unlike the air-over-ground problem, for which the radial adjoint solutions were obtainable from the literature, the adjoint solutions for the model village must be calculated. They are, of course, functions of the town model which, in this case, exhibits heavy roofs and relatively thin walls. Nevertheless, the relative solutions, as functions of position from the detector, are informative for many village geometries as to the processes which come into play in the radiation transport.

The SAM-CE Monte Carlo radiation transport code[7] was used to determine the adjoint solutions. The geometry of the basic house and its row of homes, the back-to-back-row of homes, the double row of homes across the near street, the double row of homes across the far street, and the near and far streets (see Figure 11) were all simulated. Additional rows and streets were not included because preliminary calculations (confirmed below) showed that the contribution to the dose at detectors $P_{1,2,3,4}$ from such further removed locations would not be significant.

The roofs and streets were divided into the various surface areas as shown in Figure 11. Note the sub-division of some of the near roofs and the symmetry about the ordinate axis. The surface regions are identified in Table 1.

Preliminary calculations showed that the displayed length of the rows and streets need be no longer than as shown. Surface areas 25-27 were necessary only for the P_4 (outdoor) results. The buildings surrounding areas 23-27 were necessary for their effect upon the area 23-27 calculations only; that is, fallout upon these buildings produced a negligible effect at detectors $P_{1,2,3,4}$.

Upon each of the surface areas shown, simulated fallout radiation (cobalt-60) was deposited and a sufficient number of Monte Carlo histories (source-to-each of the four detectors) were started from each of these areas so as to determine (with better than 10% average accuracy for the important areas) the dose at each detector, per curie of fallout activity on each of the surface areas. In this way, all the required $J_{p,i}$ solutions were obtained. The results are presented for detectors P_1 to P_4 in Figures 12 to 15, respectively. Note that the units of each $J_{p,i}$ solution are in rads/hr. per curie $(^{60}Co)/m^2$.

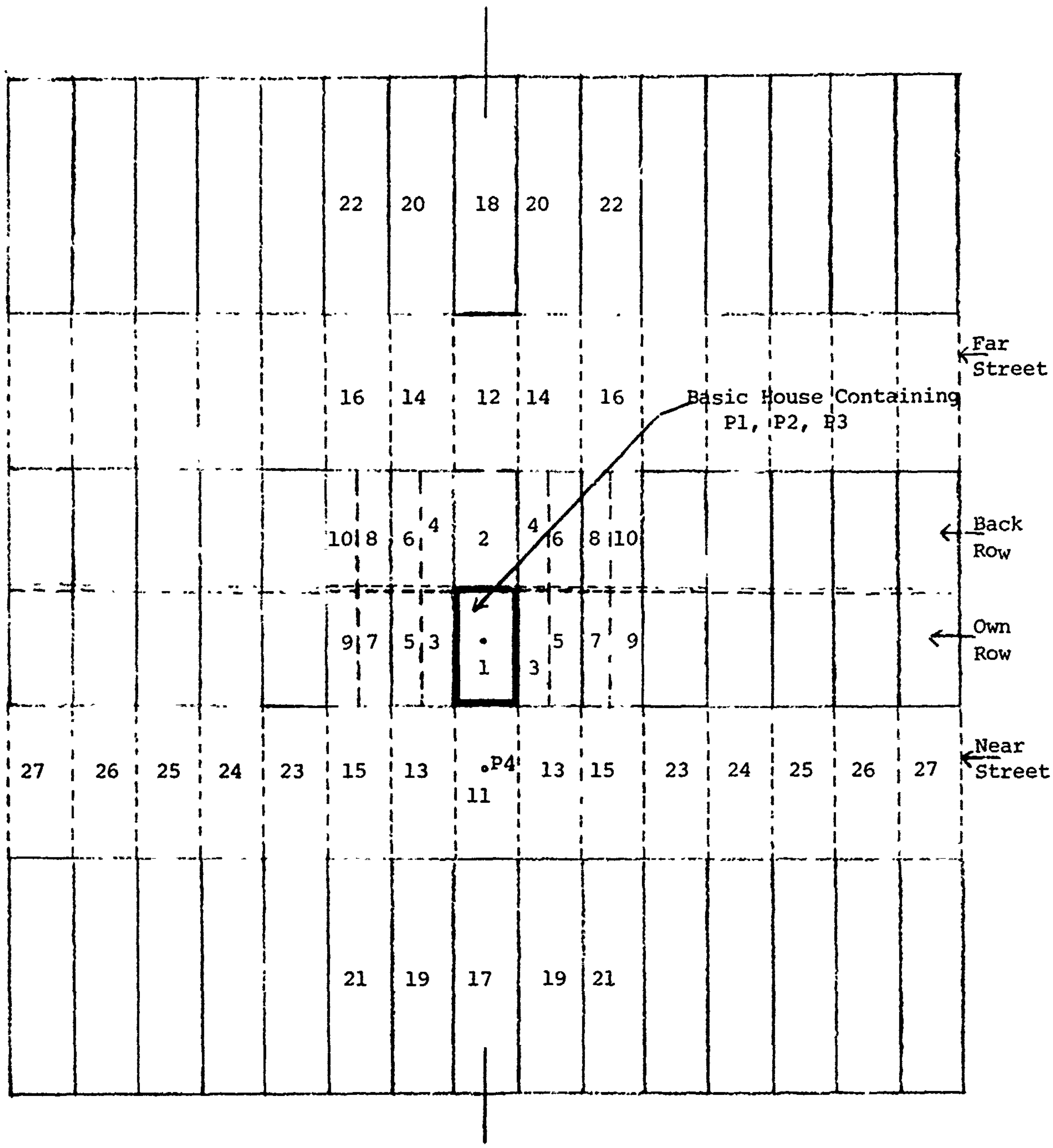

Figure 11. Surface areas defined.

TABLE 1 - Surface Areas Defined

AREA	DESCRIPTION
1	Own Roof
2	Back Row Roof
3	Own Row, First Neighbor, Near Side of Roof
4	Back Row, First Neighbor, Near Side of Roof
5	Own Row, First Neighbor, Far Side of Roof
6	Back Row, First Neighbor, Far Side of Roof
7	Own Row, Second Neighbor, Near Side of Roof
8	Back Row, Second Neighbor, Near Side of Roof
9	Own Row, Second Neighbor, Far Side of Roof
10	Back Row, Second Neighbor, Far Side of Roof
11	Near Street, Front of Own House
12	Far Street, Front of Own [illegible]
13	Near Street, Front of First Neighbor
14	Far Street, Front of First Neighbor
15	Near Street, Front of Second Neighbor
16	Far Street, Front of Second Neighbor
17	Across Front Street
18	Across Back Street
19	Front Street Across First Neighbor
20	Back Street Across First Neighbor
21	Front Street Across Second Neighbor
22	Back Street Across Second Neighbor
23	Near Street Front of Third Neighbor
24	Near Street Front of Fourth Neighbor
25	Near Street Front of Fifth Neighbor
26	Near Street Front of Sixth Neighbor
27	Near Street Front of Seventh Neighbor

Hence, the relative importance of each surface can be compared directly with the free field dose at a detector, 0.9144 m above a smooth infinite cobalt-60 fallout field which is equal to 38.9 rads/hr. per Ci/m^2 (see Appendix A).

Note in Figure 12 to 15 that, for simplicity, only the areas to the right of the axis of symmetry are shown, but that the results are the total doses from both halves of each of the designated surfaces.

Figure 12, for the second floor detector, shows that the most important adjoint solutions are for the house roof and the near side of the roof of the neighboring house. Adjoint solutions for both rows of houses across the (near and far) streets are very low as are the solutions from the far street. Of second-order importance are some of the other neighboring roofs and the near street. In Section 4.5, these adjoint solutions will be folded-in with the source strengths predicted by DELFIC. If, however, at this time, one assumes a uniform fallout field, then the adjoint solutions can be summed for a total of ∿8.0 rads/hr. per Ci/m^2. This compares with an infinite air-over-ground solution of 38.9 rads/hr. per Ci/m^2 for an overall village protection factor of ∿4.9 for the second floor detector. Note for further discussion, below, that only ∿.93/8.0=11.6% of the dose comes from fallout on the street although it represents 39% of the town surface area.

Figure 13 for a first floor detector, shows that the street in front of the house, and the street in front of the neighboring house have joined the roof and the near side of the neighboring roof, as the most important adjoint solutions. For a uniform fallout field assumption, the sum of the adjoint solutions is ∿4.3 rads/hr. per Ci/m^2 for an overall village protection factor of ∿9.1 for the first floor detector. The ground areas contribute ∿1.34/4.26 = 31.4% of the total dose.

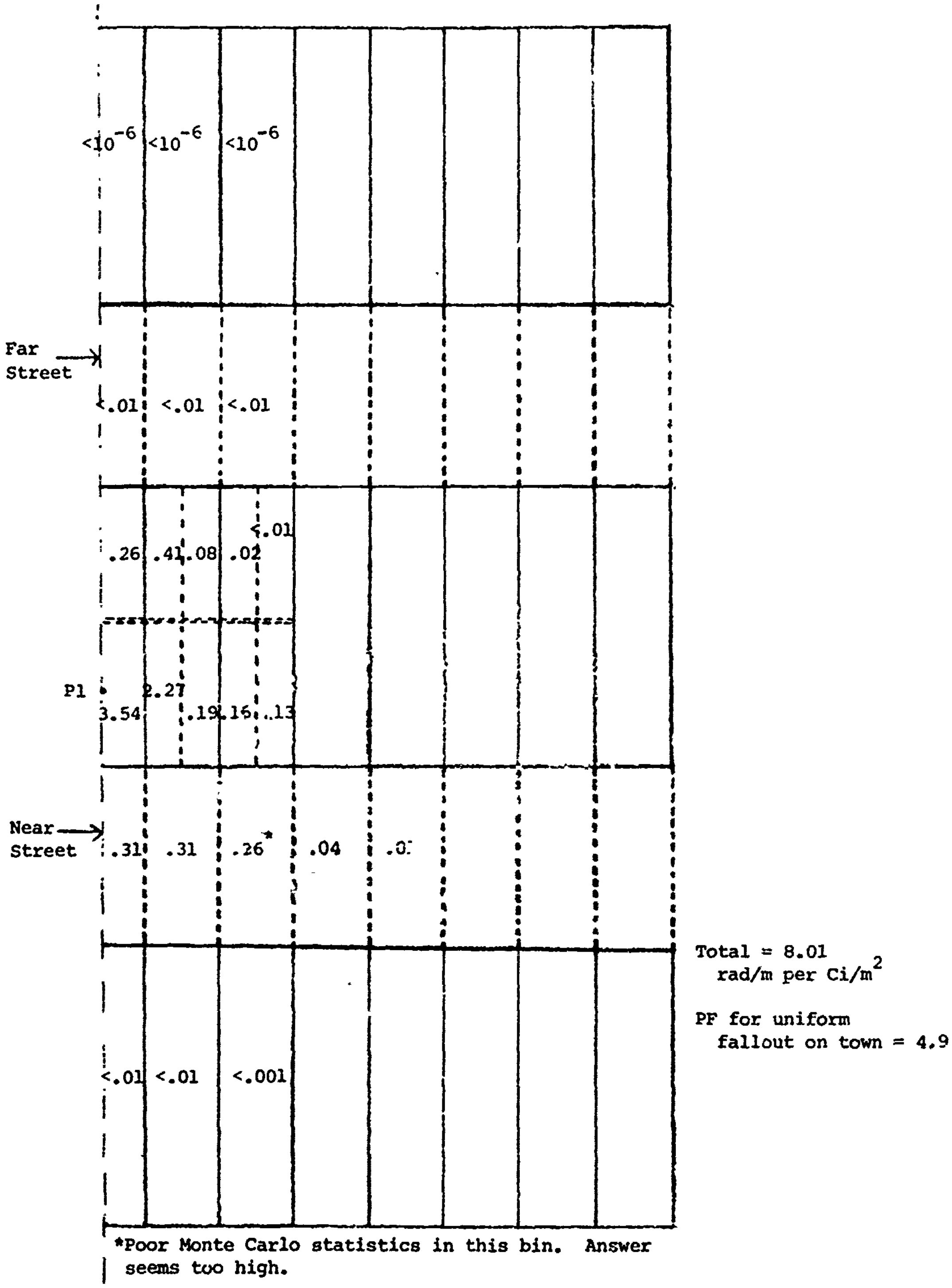

Figure 12. Adjoint solutions for second floor detector (P1), (rad/hr. per Ci/m^2).

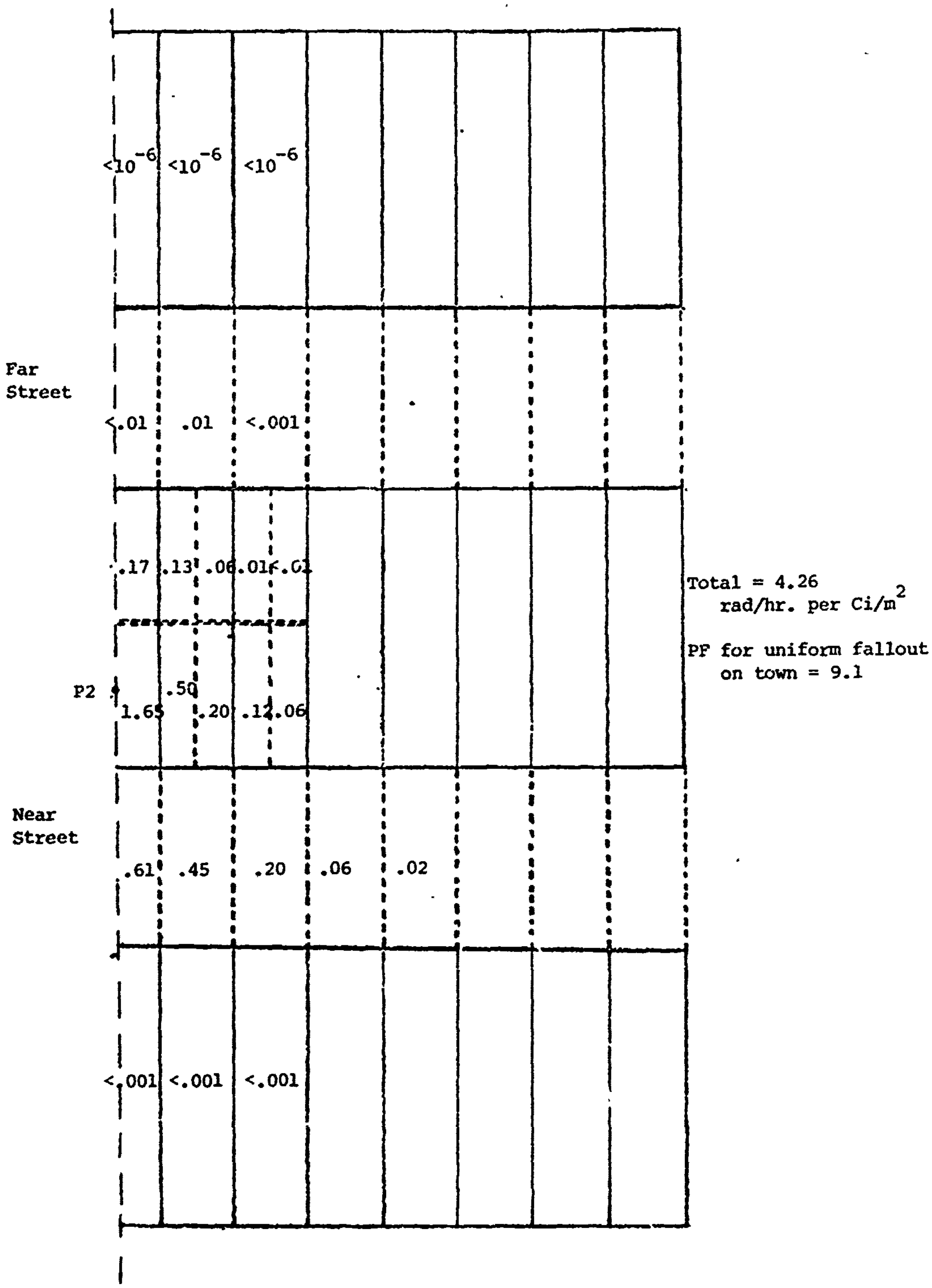

Figure 13. Adjoint solutions for first floor detector (P2), (rad/hr. per Ci/m^2).

Figure 14, for a basement detector, shows that the overhead roof is clearly the most important adjoint solution. For uniform fallout field assumption, the sum of the adjoint solutions is ∿1.43 rad/hr. per Ci/m^2 for an overall village protection factor of ∿27 for basement detectors. The ground areas contribute only .168/1.43=11.7% of the total dose.

Figure 15, for an outdoor detector, shows that the street adjoint solutions are most important. For a uniform fallout asumption, the sum of the adjoint solutions is ∿22.86 rad/hr. per Ci/m^2 for an overall village protection factor of ∿1.7 for an outdoor detector in the center of the street*. The ground areas contribute 21.28/22.86= 93% of the total dose.

The overall results for the four detectors are summarized in Table 2.

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*This is seen to be in good agreement with the assumed nominal value of 1.6 in Section 2.2.

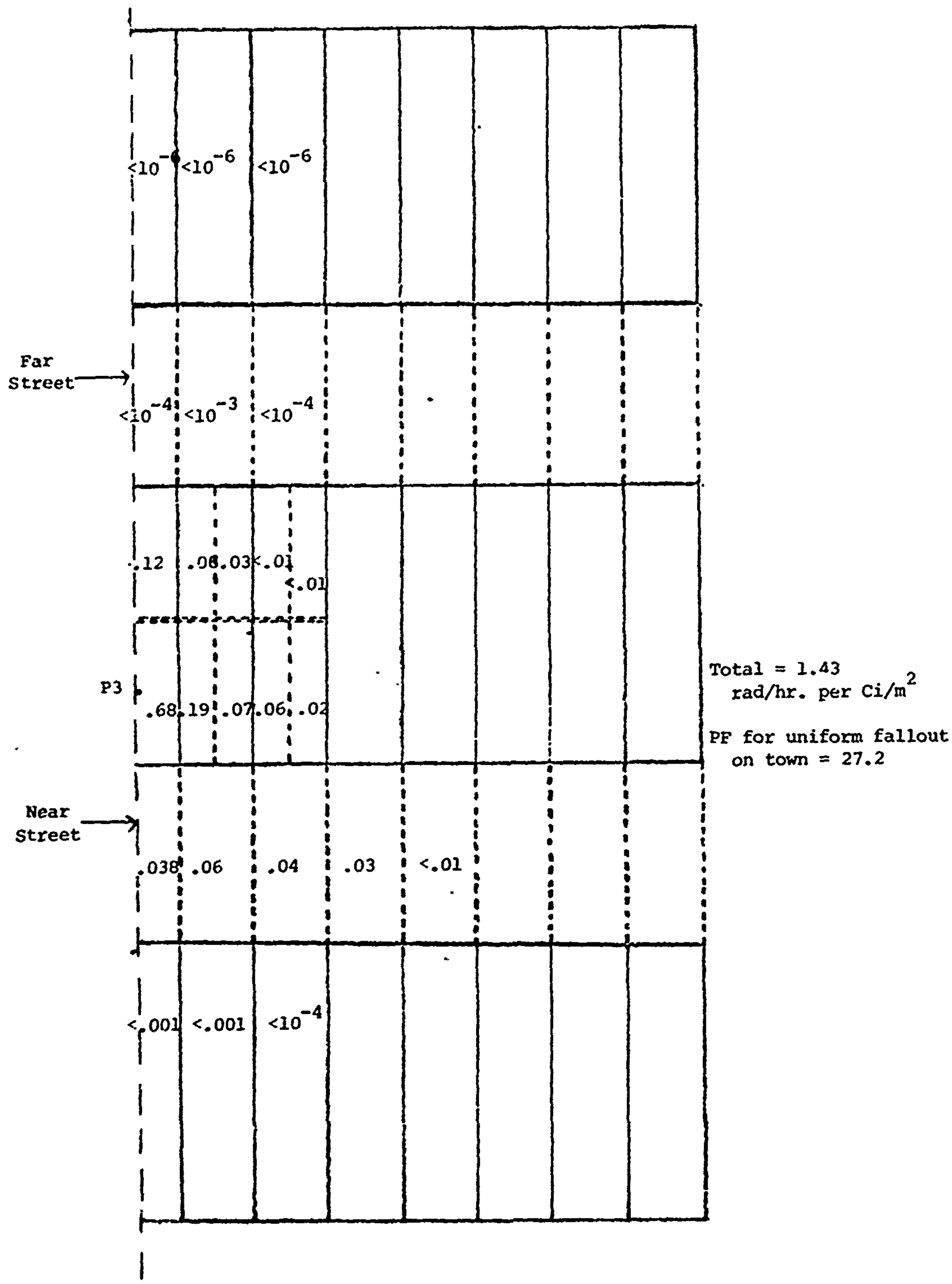

Figure 14. Adjoint solutions for basement detector (P3), (rad/hr. per Ci/m^2).

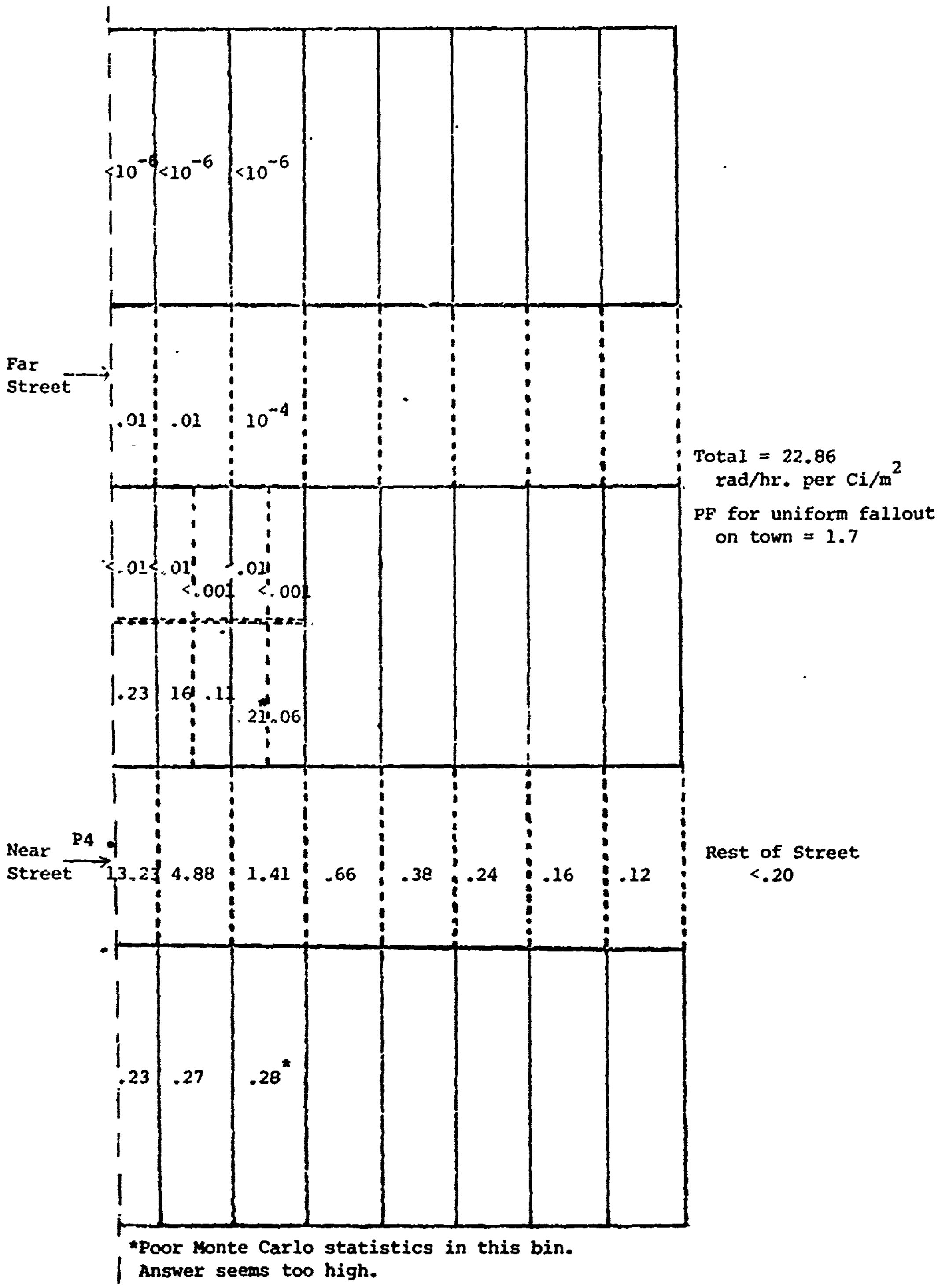

Figure 15. Adjoint solutions for outdoor detector (P4), (rad/hr. per Ci/m^2).

TABLE 2 - Results for Uniform Fallout Across Town with Structures*

DETECTOR LOCATION	PROTECTION FACTOR (PF)	PERCENTAGE OF DOSE FROM FALLOUT ON STREET
Outdoors**	1.7	93.0
Second Floor***	4.9	11.6
First Floor***	9.1	31.4
Basement***	27.2	11.7

*Assuming a uniform fallout plane of ^{60}Co

**Center of Street

***Center of Room

Note that the model of this town had heavy roofs and thin walls. Decreasing the roof thickness would decrease the PF values for the indoor detectors and have little effect upon the outdoor detector. Increasing the wall thicknesses would affect significantly only the first floor detector (for which 31.4% of the dose came from fallout on the street) and would give rise to a somewhat greater PF in this case.

4.5 Town Results

4.5.1 Center-Town

The adjoint solutions presented in the previous section, were combined by FOLD with the DELFIC fallout activity predictions, as described in Section 4.3, to obtain the dose distributions across Center-Town, for the four detector locations. These are presented in Figure 16, along with the air-over-ground distribution presented previously in Figure 4.

It is seen that the shape of the distributions is similar for all five cases; that is to say an "average" protection can be applied for all four detector types in town. These are for outdoors, first floor, second floor and basement detectors, about 1.8, 4.5, 9.0, and 30 respectively which are essentially the values given above in Table 2, for the uniform fallout case.

4.5.2 Partial-Town

The distributions for the four detectors and air-over-ground, are given for Partial-Town, in Figure 17. Partial-Town lies ∿82% outside the fallout field and the effects of non-uniform fallout across town are clearly visible. For example, the air-over-ground results show that over 60% of the population would receive some dose; however, due to mutual shielding only ∿20% of the population in town receives a non-zero dose. Hence, the PF values, for a given type of detector, vary through the town. Table 3 shows the ranges of PF, for Partial-Town. These are compared with the similar results for Center-Town.

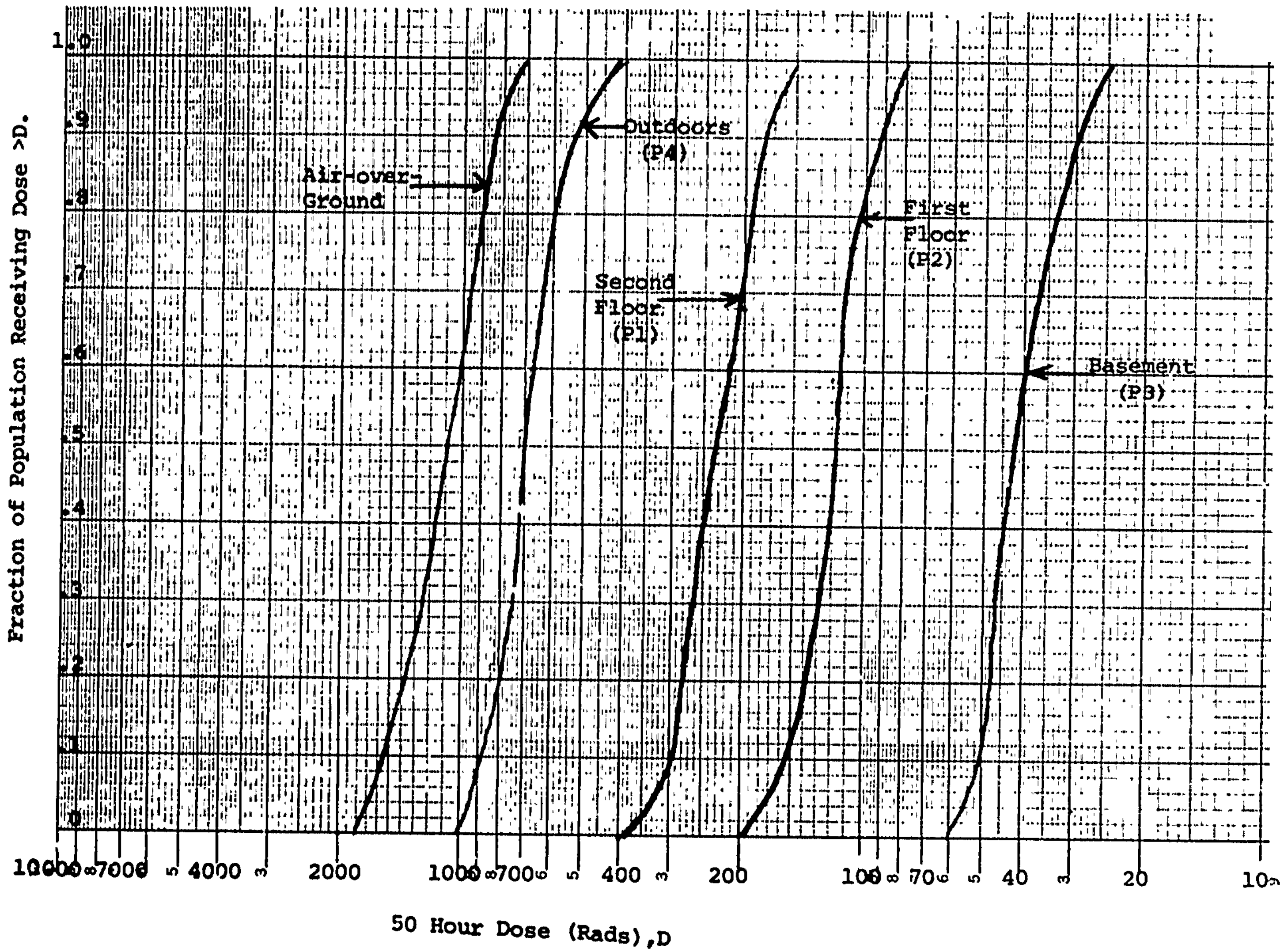

Figure 16. Center-town with structures.

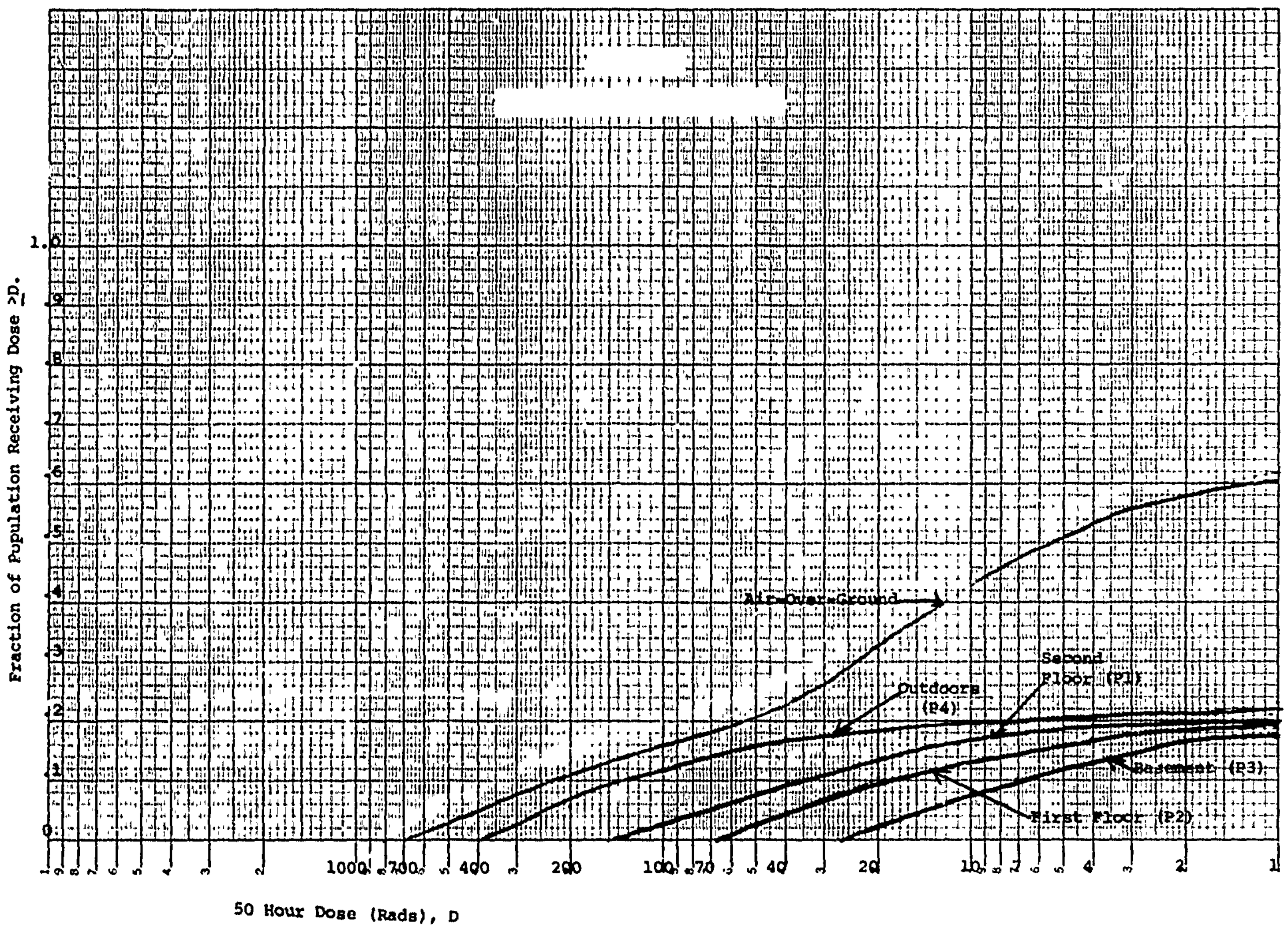

Figure 17. Partial-town with structures.

TABLE 3 - Protection Factor Variation for Partial-Town with Structures

DETECTOR	FOR PERSON RECEIVING THE MAXIMUM DOSE	FOR PERSON AT THE DOSE LEVEL WHERE 10% OF POPULATION RECEIVES A GREATER DOSE	FOR PERSON AT THE DOSE LEVEL WHERE 20% OF POPULATION RECEIVES A GREATER DOSE	CENTER-TOWN
Outdoors	1.7	1.7	5.5	1.8
Second Floor	4.7	6.6	~55	4.5
First Floor	10.2	12.8	>100	9.0
Basement	25.9	35.4	>100	30.

It is seen, from Figure 17 and Table 3, that the complex nature of fallout pattern across Partial-Town, gives rise to protection factors which vary with percentile*. Since the dose levels (in Partial-Town) decrease as one moves away from the center of the fallout field, it is then obvious from Table 3 that not only the dose levels, but the protection factors themselves, vary with position in town!

The two left hand data columns of Table 3 show that the PF variation is not very great for individuals in the 0 to 10 percentile range, which in this problem is the only range of interest since the dose levels fall away very rapidly beyond the 10 percentile (see Figure 17). (In the 0-10 percentile, the PF values also agree fairly well with the results for Center-Town.) However, other fallout field-town scenarios need to be studied before general conclusions about protection factor variation can be drawn.

4.5.3 Tangent-Town

Figure 18 shows the distributions for the air-over-ground and first floor and outdoor detectors for Tangent-Town**. It is clearly seen that the mutual shielding effectively screens out all fallout effects except for a very small fraction of the town population***.

The PF values at the maximum dose level for outdoors, second floor, first floor and basement detectors are 2.8, 8.5, 16.0 and 48., respectively. These are higher than the PF (maximum dose) value for the other two towns since Tangent-Town lies outside of the fallout field and the mutual shielding effect (even for the maximum dose case) is greater.

* "Percentile" is the position on the ordinate axis of the cumulative distribution curves (expressed as a percentage).

** For clarity not all the detectors are shown in Figure 18.

*** This would be somewhat worse, however, if edge-of-town effects had been considered in the town model - see Section 4.3.

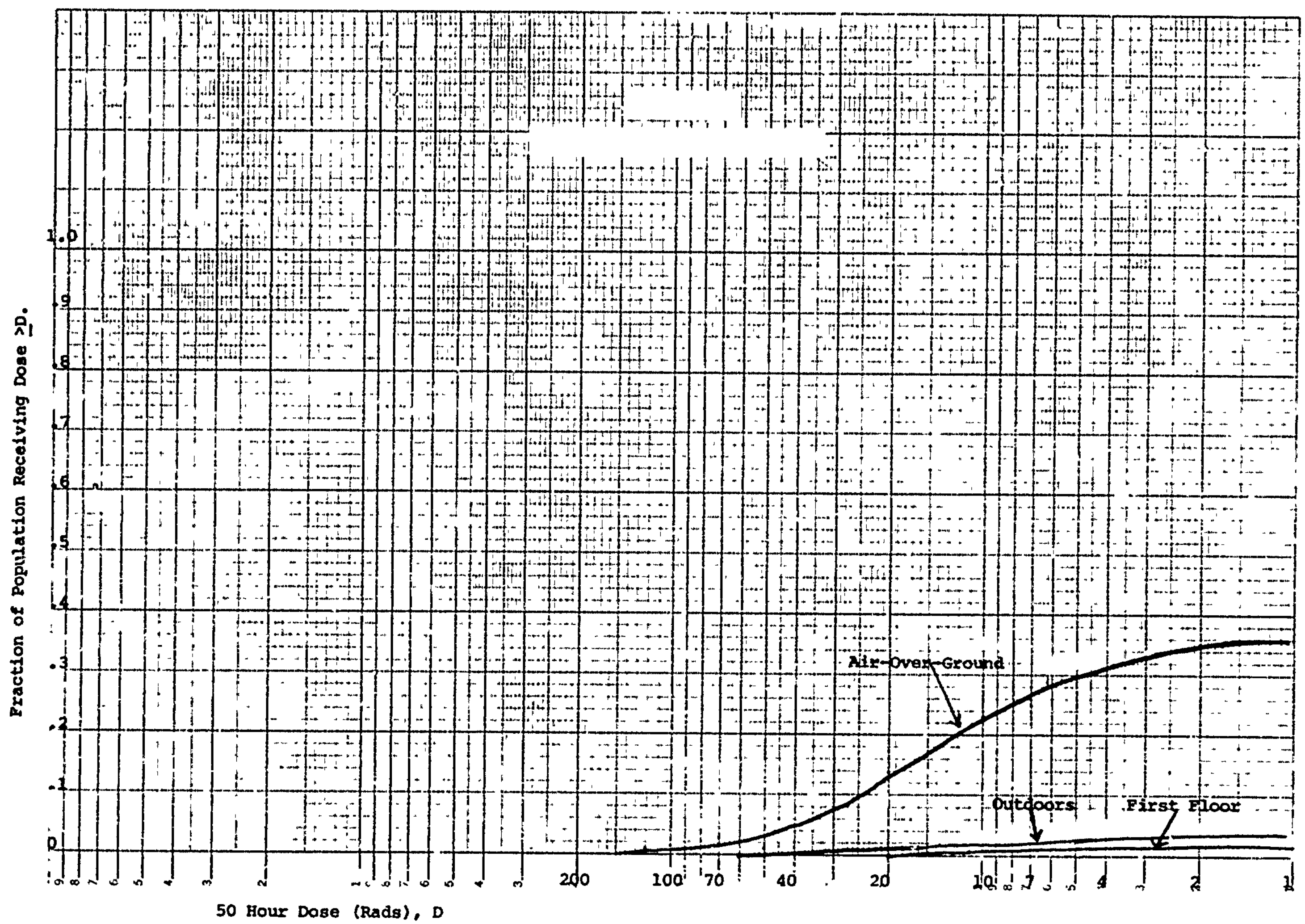

Figure 18. Tangent-town with structures.

4.6 Decontamination Studies

In Section 4 4, it was seen that the largest adjoint solutions in and in front of a given house were for the house roof and the street in front of the house Excluding Tangent-Town and the portion of Partial-Town outside the fallout field*, it follows that the most important contributions at detectors in or in front of a house will come from these immediate roof and street surfaces. In order to further reduce exposure doses from fallout either the roof or the portion o. the street in front of the house, or both, could be decontaminated.

FOLD provides a simple technique for studying the effects of decontamination By setting the adjoint solution for the house roof and the street in front of the house to zero one is, in effect, instructing the code that fallout that was originally deposited upon these surfaces is now producing no effect; that is, the surfaces have been decontaminated.

The FOLD runs for Center-Town were repeated for three new scenarios:

1 - decontamination of house roof

2 - decontamination of street in front of house

3 - decontamination of both these surfaces

and the results are shown in Table 4. (Similar results were achieved for that portion of Partial-Town within the fallout field.)

In Table 4 it is seen that decontamination of the street has great effect upon the outdoor detector (PF goes from 1.83 to 4.7) negligible effect upon the second floor and basement detectors and a small effect (PF goes from 9.0 to 10.4) upon the first floor detector. It is also seen that decontaminating the roof has an effect of almost a factor of two upon all three indoor detectors but a negligible effect upon the outdoor detector. The combined decontamination effects are also shown in the final column of Table 4.

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*Where, of course, the source activity is zero.

TABLE 4 - Effect of Decontamination on Center-Town Protection Factors*

	DECONTAMINATION CONDITION			
DETECTOR	NONE	STREET IN FRONT OF HOUSE	HOUSE ROOF	BOTH HOUSE ROOF AND STREET IN FRONT OF HOUSE
Outdoors	1.83	4.7	1.87	5.0
Second Floor	4.5	4.7	8.1	8.7
First Floor	9.0	10.4	14.8	19.1
Basement	30.0	30.8	57.6	60.6

*Based on maximum dose levels.

4.7 Conclusions - Structures in Town

For Partial-Town and Tangent-Town, the dose distributions have been seen to vary by several orders of magnitude across the town and are, in shape, very much a function of the position of the detector in and around a given house. For Center-Town, the distributions do not vary significantly with position in and around the house and are not as widespread as for the other two towns. Nevertheless, the distributions do cover a range exceeding a factor of [illegible] o which would be completely absent from the results of a study based on the "strategic" average fallout activity model.

SECTION 5 - EVALUATION

The methodology developed in the course of this investigation has demonstrated that strategic nuclear weapon fallout assumptions cannot, in general, be applied to the situation of fallout from a TNW. This is especially true for towns that do not lie well within the fallout pattern but are situated along its fringes.

FOLD is a rapid computer aid which can conveniently combine DELFIC (or other model) fallout predictions with SAM-CE (or other model) adjoint solutions, some of which are available in the literature, to obtain predictions of exposure distributions and protection factors across typical towns. FOLD has shown that even the protection factor, at given types of locations in or around a house, varies with position in town - particularly for towns on the fringes of the fallout pattern. The investigation has also shown that 50 hour exposure doses as high as 125 rads can be obtained (for Tangent-Town) for situations where a "strategic" model would predict no exposure doses at all.

The numerical results presented herein are, of course, for a given weapon-wind-town scenario. Local redistribution of fallout due to weathering effects - which could increase the range of the exposure doses that could be anticipated - was not examined (although it could be included in the future). For these reasons care should be exercised in drawing general conclusions about the magnitude of the dose distributions and protection factors from the results of this single investigation. Such general conclusions, however, could be drawn if additional work, involving sensitivity analyses, was carried out. Since this would involve no additional methodology development such surveys can be effectively and rapidly performed.

6. REFERENCES

1. M. O. Cohen, "Protection Afforded by West German Villages Against Initial Radiation from Tactical Nuclear Weapons; Methodology and Sample Results", MR-7045, DNA number to be assigned (Aug. 1975).

2. S. Glasstone (ed.), "The Effects of Nuclear Weapons" published by the USAEC, pp. 488-490 (Feb. 1964).

3. H. Goldstein, "Fundamental Aspects of Reactor Shielding", Addison-Wesley Publ. Co., Reading, Mass., p. 13 (1959).

4. M. O. Cohen, *op. cit.*

5. J. H. Price and R. L. French, "Monte Carlo Study of Interior Partition Effects on Fallout Shielding", RRA-T91, p. 6 (Jan. 1969).

6. M. O. Cohen, *op. cit.*

7. M. O. Cohen, *et al.*, "SAM-CE: A Three Dimensional Monte Carlo Code for the Solution of the Forward Neutron and Forward and Adjoint Gamma Ray Transport Equations - Revision C, DNA 2830F, Rev. C/ MR-7021, Rev. C. (July, 1974).

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APPENDIX A

Adjoint Dose Solutions for a Plane Source of Cobalt-60

In Section 3, it is shown how the air-over-ground solutions for dose distributions across the towns are obtained (by FOLD) by combining the DELFIC fallout cobalt-60 activity predictions with adjoint dose solutions. The required adjoint solutions, are dose at a point detector 0.9144 meters (3 feet) above an air-ground smooth plane*, as a function of the radii of annular strips centered about the detector.

Table A.1 is taken from the work of Kalos[A.1] where the units of the adjoint solutions have been converted to those desired in this study; i.e., rads/hr. per Ci of $^{60}Co/m^2$. From Table A.1 it is seen that only ∿4% of the total dose arises from source activity beyond 244 meters (800 feet)** and thus 244 meters was taken as the maximum radius of this study.

The radial band structure out to 800 feet (as given in Table A.1), and the associated adjoint solutions for each radial bin were used in the calculations described in Section 3.

*For the no structures in town case of Section 3, it is assumed that the surface area of the town is smooth pavement. Hence ground roughness factors are not considered in the adjoint solutions. Ground roughness effects can easily be incorporated into FOLD at a later date.

**That is the cumulative sum up to and including the 700-800 foot annulus is ∿0.96 of the total dose.

Reference

A.1 M. H. Kalos, Nuc. Sci. and Eng., 33, No. 3, p. 288 (Sept. 1968).

TABLE A.1

Dose at a Point Three Feet* Above an Air-Ground Interface Resulting from Uniformly Contaminated Annular Strips of Cobalt-60.

Inner Radius, ft.	Adjoint Solution (Dose from Annular Strip) Rads/hr. per Ci/m^2	Cumulative Dose	Cumulative Fraction of Total Dose
0	15.07	15.07	.38
20	5.18	20.25	.52
40	2.92	23.17	.59
60	2.31	25.48	.65
80	1.46	26.94	.69
100	2.67	29.61	.76
150	1.73	31.34	.80
200	1.28	32.62	.84
250	1.01	33.63	.87
300	.78	34.41	.89
350	.58	34.98	.90
400	.54	35.53	.91
450	.42	35.95	.93
500	.69	36.64	.94
600	.49	37.13	.96
700	.36	37.49	.96
800	.52	38.01	.98
1000	.84	38.85	1.00
2000	.01	38.86	1.00
3000	>.01	38.86	1.00
1000	>.01	38.86	1.00

*Three feet = 0.9144 meters.

APPENDIX B

Atomic Concentrations in Model Home

B.1 Roof (Spanish Tile on Hard Wood)

ELEMENT	ATOMIC DENSITY (atoms/barn·cm)
Hydrogen	.0108
Carbon	.0054
Oxygen	.0192
Silicon	.0069

B.2 Walls (Wood Lathe with Plaster on Both Sides)

ELEMENT	ATOMIC DENSITY (atoms/barn·cm)
Hydrogen	.0240
Carbon	.0085
Oxygen	.0256
Calcium	.0057

B.3 Floors (Wood)

ELEMENT	ATOMIC DENSITY (atoms/barn·cm)
Hydrogen	.0270
Carbon	.0135
Oxygen	.0135

APPENDIX C

Views of Town Model*

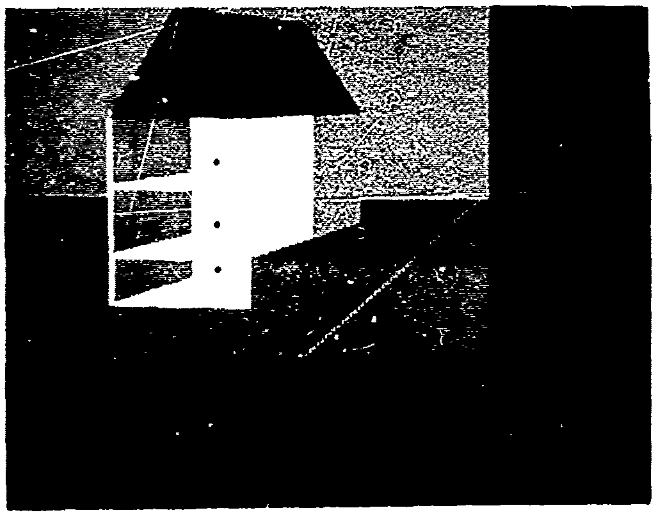

Figure C.1
Model Home
(Dots are Detector Locations)

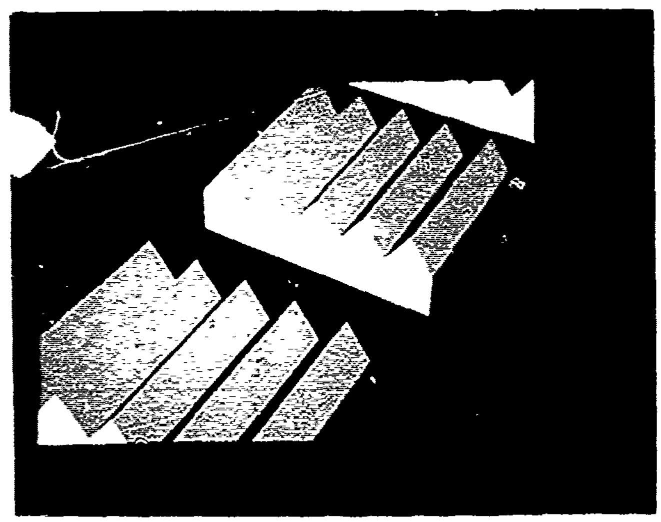

Figure C.2
Attached Homes

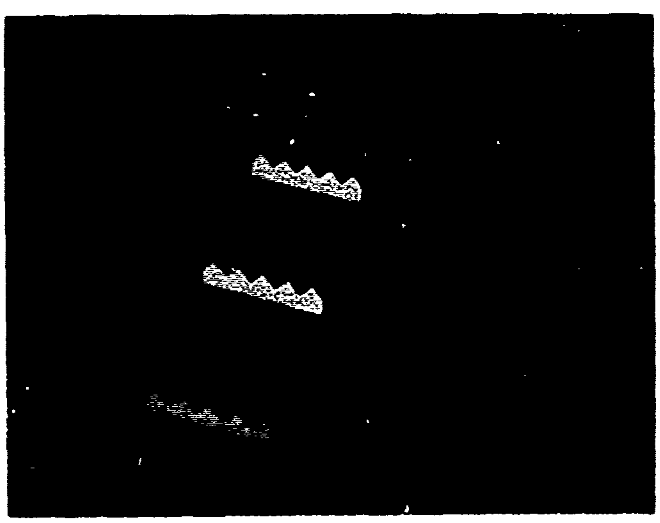

Figure C.3
Aerial View

*Only five homes in each row are shown. All other aspects are to scale.

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