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CALCULATED SHIELDING FACTORS FOR SELECTED EUROPEAN HOUSES

Per Hedemann Jensen

Abstract. Shielding factors for gamma radiation from activity deposited on structures and ground surfaces have been calculated with the computer model DEPSHIELD for single-family and multi-storey buildings in France, United Kingdom and Denmark. For all three countries it was found that the shielding factors for single-family houses are approximately a factor of 2 - 10 higher than those for buildings with five or more storeys. Away from doors and windows the shielding factors for French, British, and Danish single-family houses are in the range 0.03 - 0.1, 0.06 - 0.4, and 0.07 - 0.3, respectively. The uncertainties of the calculations are discussed and DEPSHIELD-results are compared with other methods as well as with experimental results.

INIS-describtors: APARTMENT BUILDINGS; COMPUTER CALCULATIONS; DOSE RATES; EXTERNAL IRRADIATION; FALLOUT DEPOSITS; GAMMA RADIATION; RADIATION DOSES; SHIELDING; SURFACE CONTAMINATION; SURFACES; HOUSES

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1. INTRODUCTION

In studies of the potential radiological consequences from hypothetical nuclear reactor accidents where radioactivity is released to the atmosphere, very little concern has so far been given to the long-term radiation doses originating from activity deposited on structures and ground surfaces.

In calculations of the γ-radiation doses from deposited activity the dose rate one meter above an infinite smooth, plane source is normally used as a reference. The actual dose rate at a given location is then found by multiplying this reference dose rate with a modifying factor - the so-called shielding factor.

The shielding factor is usually defined as the ratio of the indoor dose rate from deposited activity on an infinite ground surface to the reference dose rate noted above.

More realistic dose calculations for urban areas need shielding factors that also include radiation from deposited activity on outer walls and roofs, and which consider the finite size of the surrounding ground surface. Further, the shielding factor must take into consideration the building construction regarding building size, position of the apartment, window areas, and thickness of walls, floors, and roofs.

2. DEFINITIONS AND CALCULATING MODEL

2.1. Definition of the shielding factor

The shielding factor is defined as

$$S = \frac{\dot{D}}{\dot{D}_{ref}}$$

where $\dot{D}$ is the actual dose rate and $\dot{D}_{ref}$ a reference dose rate.

In this study the reference dose rate is chosen as the dose rate 1 meter above an infinite, smooth surface source having a uniform activity concentration.

2.2. Outdoor shielding factor

A person staying out-of-doors in a contaminated urban area will receive radiation doses from the contaminated roads as well as from contaminated house walls. However, the buildings will act both as radiation sources and as shields for radiation from distant parts of the ground surface. The dose rate in urban areas will therefore normally be less than that on an infinite surface source with the same activity concentration. The outdoor shielding factor S_{out} is given as:

$$S_{out} = \frac{\dot{D}_{out,g} + \dot{D}_{out,w1} + \dot{D}_{out,w2}}{\dot{D}_{ref}}$$

where $\dot{D}_{out,g}$ is the outdoor dose rate from activity deposited on the ground and $\dot{D}_{out,w1}$ and $\dot{D}_{out,w2}$ are the dose rates from the activity deposited at the vertical walls at each side of the road. The outdoor radiation at ground level from activity deposited on roofs is neglected, because a substantial part of it will be absorbed in the building materials.

The outdoor shielding factor has been calculated to 0.5-0.8 for urban areas. The shielding factor for cars and busses has been measured to 0.3-0.7 (LAURIDSEN, B. et. al.).

2.3. Shielding factor for a residence

The radiation dose rate at an indoor residence in a multistorey building or a single-family house will come from contaminated roads, gardens, house walls, and roofs. Neighbouring houses will act both as a shield for the radiation from distant parts of the ground surface, and as a radiation source. In this study, the radiation from neighbouring houses is neglected, as their contribution to the total indoor dose rate normally is insignificant.

The indoor shielding factor is given by:

$$S_{in} = \frac{\dot{D}_{in,g} + \dot{D}_{in,w} + \dot{D}_{in,r}}{\dot{D}_{ref}}$$

where $\dot{D}_{in,g}$ is the indoor dose rate from activity deposited on the ground and $\dot{D}_{in,w}$ and $\dot{D}_{in,r}$ are the indoor dose rates from activity deposited at the outer walls and roof, respectively.

2.4. Weighted shielding factor

For a given distribution of residences, a weighted shielding factor is defined as:

$$S_{in} = \sum_i p_i \cdot S_{in,i}$$

where p_i is the fraction of a given residence type (single family, 3rd storey in a 7-storey house, etc.) having the shielding factor $S_{in,i}$.

The weighted shielding factor expresses the ratio of the average individual dose rate for the area under consideration when all individuals remain indoors, to the outdoor dose rate one meter above an infinite surface with the same activity concentration.

With an equal distribution of people in the given distribution of residences, the weighted shielding factor also expresses the ratio of the collective dose rate from indoor residence, to the collective dose rate to the population from outdoor residence on an infinite surface source.

2.5 Time-averaged shielding factor

The weighted shielding factor S_{in} is a static shielding factor for a given geographic area as far as residence in homes is concerned. However, it is necessary to consider different locations of the population during a week, i.e. out-of-doors, working place, transport, and at home. This time-averaged shielding factor is defined as:

$$\overline{S}_t = \sum_i \frac{t_i}{168} \cdot S_i$$

where t_i is the number of hours in a week during which an individual is located at a place having the shielding factor S_i (which can either be a weighted shielding factor or a single shielding factor).

The above is correct only when the different shielding factors S_i refer to areas with the same activity concentration as the reference area. This implies that the population of a certain district is employed within this district. Of course, this is a simplification, but the error is somewhat counterbalanced in the summing of the collective doses for many municipalities.

Furthermore, it should be noted that both the weighted and the time-averaged shielding factors should be used only to calculate collective doses and average individual doses for the evaluation of stochastic health effects, but not for calculating individual doses for the assessment of non-stochastic health effects. For this purpose, the area under consideration should be divided into shielding classes and a time-averaged shielding factor calculated for each.

2.6. The calculating model DEPSHIELD

The fundamental calculation method used here is based on the so-called exponential point attenuation kernel that links the radiation flux density or another measurable quantity related to the flux density at a given detector point to the point-source strength. Attenuation resulting from geometrical spreading with increasing distance from the source as well as exponential attenuation and scattering of the photons are taken into consideration. The assumptions for the point-kernel method are that both the source and shielding medium are isotropic, i.e. that the source radiates uniformly in all directions, and that the medium has the same attenuating properties in all directions. Besides, as far as scattering of photons is concerned it is assumed that both source and detector are located within an infinite homogeneous medium. For a given extended isotropic source the dose rate is found by proper integration of the point kernel over the source extension.

The indoor dose rate from deposited activity on the different surfaces can be calculated from the follwing general equation:

$$\dot{D}_{in} = \frac{k}{4\pi} \cdot \left(\frac{\mu_{en}}{\rho}\right)_{air} \cdot E \cdot \sum_i Q_i \int_{A_i} B(\Sigma\mu t) \cdot r^{-2} \cdot \exp(-\Sigma\mu t) \cdot dA$$

$\Sigma\mu t$ is here the sum of all the mean free paths in the building materials and air through which the photons will penetrate during travel from source to detector point. A_i are the areas with the activity concentration Q_i. A computer code DEPSHIELD has been developed to calculate the shielding factors from this general equation (Hedemann Jensen, P. 1982).

3. CALCULATION RESULTS

The necessary input data for the calculation of shielding factors are the mass-thickness for outer walls, roofs, floors, inner walls, partition walls, and window fraction. Calculations have been made for houses in France, Denmark and United Kingdom based on informations from Ecole Polytechnique Feminine (DAVIN, F. et. al. 1984), The Danish Building Research Institute and NRPB (CRICK, M. et. al. 1984). Furthermore, results are given also for different house types in the UK based on calculations from Home Office Scientific Advisory Branch 1981. A more comprehensive set of calculations for house types in all the CEC-countries requires a detailed classification of the buildings in each country as done in the Home Office report. The most important parameters for such a classification are the mass-thickness of outer walls, partition walls and floors. This is not done in the present study, but some information can be extracted for single-family and multistorey houses in most of the ten CEC-countries.

For the single-family houses it is assumed in the calculations that the dry deposition velocity to the surrounding ground area is a factor of ten higher than to the house surfaces, resulting in a ten-times higher activity concentration on the ground. For multistorey buildings the deposition velocity to all surfaces are assumed to be equal.

To give an impression of the importance of the different parameters some parameter variations have been made in the calculations of shielding factors for Danish houses.

3.1. Calculated shielding factors for French houses.

A study has been made (DAVIN, F. et. al.) concerning data for French houses so calculations of shielding factors can be made for both single-family and multistorey buildings in France. Based on these data shielding factors have been calculated for four different groupings of single-family houses and for three sizes of flats in modern multistorey buildings with 5 - 6 storeys. The tables below show the data used and the calculated shielding factors S. For the multistorey buildings the S-indices g, m, and t refer to the ground, middle, and top floor positions, respectively.

Table 1. Data and calculated shielding factors for French single-family houses.

Building data	Built before 1920	Built 1940 - 1950	Traditional	Prefabricated
Outer wall, kgm^{-2}	748	357	493	357
Inner walls, kgm^{-2}	595	340	340	289
Roof, kgm^{-2}	408	357	357	323
Floor to ceiling hight,cm	310	250	250	237
Length, m	13.5	13.5	13.5	13.5
Width, m	8.8	8.8	8.8	8.8
Window percentage, %	16	16	16	16
Ground width, m	40	40	40	40
Shielding factor, S	0.025	0.086	0.052	0.090

If the dry deposition velocities to all surfaces were assumed to be equal, the shielding factors in Table 1 would increase by 35 - 50%.

Table 2. Data and calculated shielding factors for French modern multistorey buildings

Building data	Size of appartment		
	74 m^2	88 m^2	101 m^2
Outer wall, kgm^{-2}	418	418	418
Inner walls, kgm^{-2}	272	272	272
Partition walls, kgm^{-2}	374	374	374
Floors, kgm^{-2}	418	418	418
Roof, kgm^{-2}	418	418	418
Floor to ceiling height, cm	250	250	250
Length, m	10.38	12.18	13.98
Width, m	8.58	8.58	8.58
Window percentage, %	16	16	16
Road width, m	40	40	40
Shielding factor, S_g	0.041	0.035	0.030
S_m	0.010	0.0075	0.0055
S_t	0.017	0.015	0.014

3.2. Shielding factors for British houses

3.2.1. Calculated shielding factors

Within the CEC-MARIA project a set of benchmark problems has been defined to compare three shielding models currently used in UK, FRG, and Denmark. The building structures chosen for this study was a typical British two-storey semi-detachted house and a British eight-storey building. The table below shows the data used and the calculated shielding factors by the DEPSHIELD-code.

Table 3. Data and calculated shielding factors for British semi-detached and multistorey buildings.

Building data	Semi-detached	Multistorey
Outer wall, kgm^{-2}	320	690
Inner walls, kgm^{-2}	230 - 396	230 - 396
Floors, kgm^{-2}	22	690
Roof, kgm^{-2}	68	460
Floor to ceiling height, cm	300	320
Length, m	16	20
Width, m	14	20
Window percentage, %	10	13
Road and ground width, m	30 - 100	>300
Shielding factor, S_g	0.073	0.031
S_m	-	0.008
S_t	0.055	0.012

If the dry deposition velocity to all surfaces were assumed to be equal for the semi-detached house, the shielding factor for the bottom storey would be increased to 0.13 and for the upper storey to 0.15.

3.2.2. Shielding factors calculated by the Home Office

Calculations of shielding factors have been made for 18 different types of British dwellings (HOME OFFICE 1981). Activity is assumed to be deposited equally on roof and ground, but not on outer walls. The table below show the data and the calculated shielding factors (central area).

Table 4. Data and calculated shielding factors for the most common British houses

Building data	Building type		
	Lightweight	Modern	Traditional
Outer wall, kgm^{-2}	60	366	513-767
Inner walls, kgm^{-2}	30	70-122	213-254
Floors, kgm^{-2}	59	59	59
Roof, kgm^{-2}	49-112	112	112
Shielding factors:			
One - storey, S_0	0.40	0.17	0.11
Two - storey, S_0	0.33	0.11-0.17	0.05-0.08
S_1	0.33	0.11-0.14	0.06-0.09
Three - storey, S_0	0.33	0.05	0.05-0.07
S_1	0.25	0.05	0.04-0.06
S_2	0.25	0.14	0.07-0.10
> Four storey, S_g	-	-	0.04
S_m	-	-	0.04
S_t	-	-	0.07

3.3. Calculated shielding factors for Danish houses

Based on building data from the Danish Building Research Institute the Danish buildings are divided into three categories: lightweight, modern, and traditional. The two tables below show the data and calculated shielding factors for single-family and multistorey buildings.

Table 5. Data and calculated shielding factors for Danish single-family houses

Building data	Building type		
	Lightweight	Modern	Traditional
Outer wall, kgm^{-2}	150	300	400
Inner walls, kgm^{-2}	100	100	200
Roof, kgm^{-2}	100	100	120
Floor to ceiling height, cm	250	250	250
Length, m	15	15	15
Width, m	8	8	8
Window percentage %	25	25	25
Ground width, m	40	40	40
Shielding factor, S	0.28	0.17	0.10

Table 6. Data and calculated shielding factors for Danish multistorey buildings.

Building data	Building type		
	Lightweight	Modern	Traditional
Outer wall, kgm^{-2}	250	400	600
Inner walls, kgm^{-2}	100	150	200
Partition walls, kgm^{-2}	250	250	250
Floors, kgm^{-2}	150	400	200
Roof, kgm^{-2}	100	350	250
Floor to ceiling height, cm	280	280	280
Length, m	9.0	9.0	9.0
Width, m	7.8	7.8	7.8
Window percentage, %	25	25	25
Road width, m	20	20	20
Shielding factor, S_g	0.10	0.06	0.03
S_m	0.05	0.02	0.01
S_t	0.10	0.03	0.04

To give an impression of the importance of the building parameters, a variation of outer wall and inner wall thickness, ground width, and window percentage have been made. The results are shown in Table 7. The parameter variations are shown in the left column. The value below the variation interval is the fixed value of the considered parameter when the others are varied.

Table 7. Shielding factor variation for Danish houses.

Parameter variation	Building type			
	Single-family	Multistorey		
	S	S_g	S_m	S_t
Outer wall, kgm^{-2} 255 → 595 s:410 m:595	.15→.043	.089→.032	.032→.011	.051→.033
Inner wall, kgm^{-2} 0 → 425 220	.10→.056	.051→.027	.018→.009	.058→.030
Ground width, m 20 → ∞ s:15 m:20	.075→.13	.032→.051	.011→.021	.033→.041
Window percentage, % 10→50 25	.051→.095	.018→.06	.006→.021	.029→.042

4. DISCUSSION OF UNCERTAINTIES

The fundamental calculation method used in this study is based on the so-called exponential point attenuation kernel that links the radiation flux density or other measurable quantities related to the flux density at a given detector point to the point-source strength. Attenuation resulting from geometrical spreading with increasing distance from the source as well as exponential attenuation and scattering of the photons are taken into consideration. The assumptions for the point-kernel method are that both the source and shielding medium are isotropic, i.e. that the source radiates uniformly in all directions and that the medium has the same attenuating properties in all directions. Besides, as far as scattering of photons is concerned, it is assumed that both source and detector are located within an infinite homogeneous medium.

These assumptions are approximately fulfilled in the calculations of the reference dose rate and the outdoor dose rate from finite surfaces as verified by transport theory calculations and experimental measurements (LAURIDSEN, B. et al.). Therefore, the outdoor dose rate can be calculated with an accuracy of perhaps 10-20%.

Otherwise, in the calculation of the indoor dose rate the assumption that the source and the detector should be located within an infinite medium is not fulfilled. As the dose build-up factors have been derived for an infinite medium, the indoor dose rate is overestimated in some cases when calculated from the point-kernel method. The infinity assumption is nearly always fulfilled for the building walls for photons penetrating the wall perpendicular or nearly perpendicular from source to detector point. All the primary photons that is scattered in the wall will arise here from a wall area within 2-3 mean free paths in the wall material around the primary photon direction, i.e. within a 10-40 cm radius, depending on the photon energy.

On the other hand, as the detector point inside an apartment is surrounded by air, the infinity assumption can never be fulfilled along the photon direction. Therefore, the photons that will be back-scattered in an homogenous medium from the semi-infinite medium behind the detector point will be absent. However, it is believed that this is somewhat counterbalanced by the back-scatter from inner walls, floor, and ceiling in the apartment. The back-scatter component that is contained in the dose build-up factor is of importance only for lower photon energies and can be neglected for energies above 1 MeV (JAEGER, R.G. et al.).

The skyshine component from photon scattering in air is indirectly included in the model, as the build-up factor is calculated from the sum of all the mean free paths in building structures <u>and</u> an infinite air slab with a thickness equal to the distance between the detector point and each infinitesimal area source.

As far as basements are concerned the main radiation contribution here may come from radiation scattering in the walls of the ground storey and penetrating downwards (SMOKE, M.A.). This "in-and-down" effect cannot be handled by the DEPSHIELD model, and shielding factors for basements cannot be calculated from the present model.

A similar problem exists for the detector points at the upper stories in high buildings. Here the main component may be the primary and air-scattered photons having penetrated air only and reaching the outer wall right outside the detector storey. The photons may then be scattered in the wall and emerge from the inner side of the wall to reach the detector point. Therefore, the ground radiation component at upper stories could be seriously underestimated.

Another important source of uncertainty is the deposition velocities for the different surfaces such as roads, gardens, walls, and roofs. In this study it is assumed that the deposition velocities to all surfaces apart from gardens are equal, and for gardens a factor of ten higher (ROED, J.).

If, for instance, the deposition velocity to roofs and walls is equal to that of the garden, then the shielding factor for a normal single-family house would be doubled. Additionally, if the deposition velocity to outer walls is neglected, as is done in several studies (SPENCER, L.V. et al., DEFENCE CIVIL PREPARADNESS AGENCY, HOME OFFICE SCIENTIFIC ADVISORY BRANCH, BURZON, Z.G. et. al., STRICKLER, T. et al.), then the shielding factor for the middle floors in multistorey buildings would decrease by as much as a factor of 30. Therefore, when calculating realistic shielding factors it is very important that the ratio of the deposition velocity at one surface to another is known.

Uncertainties will also depend on geometrical simplifications of the buildings and their surroundings and the data used in the calculations for attenuation, build-up, and energy absorption. However, it is believed that these uncertainties are less important compared with those already mentioned.

It is concluded that shielding factors for simple one- and two-storey structures can be calculated fairly accurately. The same will be the case in the lower-placed residences of a multistorey compartmented building. In the upper residences of multistorey buildings with heavy outer walls the radiation from ground deposits may be dominated by photons scattered by the wall just outside the detector storey. This scatter component cannot be calculated by the point-kernel method, and therefore the ground radiation dose rate at the upper storeys may be underestimated in some cases. However, the deposited activity on roof and outer walls may be the dominant sources at these residences. This will therefore tend to make the underestimate of the ground dose rate insignificant.

5. SURVEY OF RELEVANT STUDIES

Attempts to develop satisfactory methods for estimating shielding factors for ordinary buildings against gamma radiation from radioactive fallout began in the early 1950's. Intensive research of many kinds was carried out in the decade from the mid-fifties to the mid-sixties. In the period following there has been a steady decline in new research on these problems. The sections below survey studies on shielding factor estimates based on experiments or calculations.

5.1. Calculations

One of the earliest calculating procedures is the "DCPA Standard Method for Fallout Gamma Radiation Shielding Analysis" (DEFENCE CIVIL PREPAREDNESS AGENCY) that is based on the basic data and primary calculations made by SPENCER (1962). The Standard Method includes the radiation contribution from activity deposited on the roof and the surrounding ground area, but not the contribution from activity deposited on outer wall surfaces. Much experimental effort has gone into verifying the shielding factors calculated by the Standard Method, and the method is still widely used today for civil defence applications.

The Standard Method calculates the ground radiation contribution to the shielding factor as the product of a geometry factor, an exterior wall barrier factor, an interior wall attenuation factor, and floor and ceiling attenuation factors. The total ground geometry factor includes geometrical factors for direct radiation through that portion of a wall lying below the detector plane, for skyshine radiation through that portion of a wall lying above the detector plane and for scatter radiation through the walls lying above and below the detector plane. The primary overhead radiation contribution to the shielding factor depends on the solid angle fraction subtending the roof source and the mass-thickness of the roof. Modifying attenuation factors for the presence of inner walls, ceilings and floors are multiplied to the primary overhead contribution. The presence of wall apertures, such as windows and doors affects the ground radiation contribution both as direct radiation and ceiling-shine radiation. The effect of an aperture is generally to increase the contribution and to decrease the protection, particularly if apertures exist below the detector plane, so that direct radiation may reach the detector point without passing any barriers. The Standard Method determines the direct aperture and ceiling-shine radiation components by modifying the total ground geometry factor and by adding a ceiling-shine geometrical factor. A detailed desciption of the Standard Method is given in (SPENCER, L.V. et al., DEFENCE CIVIL PREPAREDNESS AGENCY).

Two computer codes CAPS-2 (DURST, J.L.) and PF-COMP (LYDAY, R.O. et al.), which have the Standard Method as basis, were produced for use by the US Office of Civil Defense. These two computer programs perform the numerical equivalent of the reading of charts and graphs in the manual TR-20 (DEFENCE CIVIL PREPAREDNESS AGENCY) and do the many calculation sequences that would be involved in a hand calculation. A comparison between these two codes has been made (GRITZNER, M.L. et al.), and it is concluded that the PF-COMP code is better than CAPS-2; the latter should be restricted to calculating structures with low protection factors (about 20 or less) and/or of only limited complexity.

A three-dimensional Monte Carlo code TERF (COHEN, M.O.) has been developed to treat complex structures and non-uniform terrain. Calculational results obtained using the TERF code are in generally good agreement with the experimental results obtained at Kansas State University for a blockhouse erected for the experiments (SPENCER, L.V. et al.). Also calculations of the dose rate in the basement of a typical shielding structure both with and without basement ceiling are in generally good agreement with the results obtained from the Standard Method using the empirical revised ceiling attenuation factor given by Eisenhauer (SPENCER, L.V. et al.). Other important conclusions have been reached from studies with TERF. It has been shown, for a particular geometry, that the dose rate in the building is completely insensitive to the slope of the surrounding ground surface source, for slopes less than 15 degrees. Besides, the "half-height flat roof" approximation that also is used in the DEPSHIELD code should be used with some reservation.

Another Monte Carlo code, COHORT (FRENCH, R.L. et al.) was used to calculate shielding factors for an upright cylindrical concrete barrier with a 10-ft radius exposed to gamma rays from infinite and finite-plane ^{60}Co sources. Comparisons with shielding factors calculated by the Standard Method showed that the two methods agreed within 10 pct. for the infinite-plane source. For the finite sources the COHORT factors were from 45 pct. higher to 30 pct. lower than corresponding Standard Method factors for small and large solid angle fractions, respectively. One of the conclusions from this study is that the importance of wall scatter radiation increases sharply with increased wall thickness; it is 24 pct. of the indoor dose for a mass-thickness of 98 kg m^{-2}, 39 pct. for 195 kg m^{-2}, and 55 pct. for 390 kg m^{-2}. Corresponding percentages for wall scattering computed with the Standard Method are higher by 95, 65, and 55 pct., respectively. The Monte Carlo data indicated that separate directional response functions should be used for radiation coming from above and from below the detector plane. It was concluded that any errors in the Standard Method data and assumptions must tend to compensate one another, and that similar Monte Carlo studies must be made of other aspects of the Standard Method in order to fully understand these implications.

In (CLARKE, E.T. et al.) and (BURSON, Z.G. et al.) calculated shielding factors from the Standard Method are shown for simple and more complex structures. For 10 x 10 meter simple block houses the shielding factor for fallout activity on roof and ground surfaces is of the magnitude 0.06 - 0.15 for wall mass-thicknesses in the range 300-500 kg m^{-2}.

In the manual TR-20 (DEFENCE CIVIL PREPAREDNESS AGENCY) several illustrative problems are presented to emphasize the methods used to calculate shielding factors from the Standard Method. Four of these problems have been calculated by DEPSHIELD to make a comparison with the Standard Method. Case 1 (Problem 4-4 in TR-20) is a simple one-storey blockhouse without windows, placed on an infinite ground surface. Case 2 (Problem 4-19) is also a simple windowless one-storey blockhouse placed on a surface with finite dimensions. The ground area is quadratic with a size of 1176 m^2. Case 3 (Problem 4-15) is a simple one-storey blockhouse with windows, placed on an infinite ground surface. The window areas cover approximately 55% of the outer wall area of the building. Finally, case 4 (Problem 4-13) is a multistorey building with interior walls, placed on an infinite ground surface. The detector point is placed at the ninth storey.

The following table shows the shielding factors for the four cases calculated by DEPSHIELD for 1 MeV photons and by the Standard Method. It is assumed that no activity has been deposited on the outer wall surfaces.

Table 8. Shielding factors calculated by the Standard Method and the DEPSHIELD-code for selected problems in the Manual TR-20.

Case No.	Shielding Factor	
	Standard Method	DEPSHIELD
1	0.061	0.069
2	0.035	0.031
3	0.21	0.26
4	0.0075	0.0050

A recent British study (HOME OFFICE SCIENTIFIC ADVISORY BRANCH) gives protection factors (PF) for typical British buildings. The protection factors have been calculated by a computer code for fallout activity on roofs and ground areas. Where available the PF was worked out for several kinds of buildings of the same type and the average value of these was taken. The PF's are given separately according to the degree of shielding by other buildings, i.e. in "central" and "suburban" areas. PF's are also given separately according to whether or not windows are blocked. This distinction applies only to the blocking of the windows in the shelter room, not of any others in the building. For six of the buildings the dimensions of outer walls, inner walls, and roofs are very similar to those of a typical Danish single-family house. Therefore, a comparison has been made between these buildings. The table below shows the shielding factors (1/PF) for the ground storey given in (HOME OFFICE SCIENTIFIC ADVISORY BRANCH) and the value for the single-family house calculated by DEPSHIELD for identical fall-out activity concentration on the roof and surrounding ground area. No deposition on outer walls is included.

Table 9. Shielding factors for typical British houses and for a typical Danish single-family house.

House type	Shielding factor	
	Home Office (suburban area)	DEPSHIELD
1 storey modern	0.20	0.12
1 storey traditional	0.13	0.12
2 storey modern, detached	0.20	0.12
2 storey modern, other	0.13	0.12
2 storey traditional	0.11	0.12
2 storey traditional, other	0.06	0.12

In a newer Swedish study (FINK, R. et al.) shielding factors have been determined for the area around the Barsebäck nuclear power plant. For the cities Lund and Malmö, both of which are similar to Copenhagen as far as building types are concerned, it is found that approximately 45 pct. of the day population has a shielding factor of 0.02, approximately 45 pct. a shielding factor of 0.05, and approximately 10 pct. a shielding factor of 0.2. This gives a weighted shielding factor for the day population in the two cities of approximately 0.05.

In (KOCHER, D.C., 1980) and (KOCHER, D.C, 1979) the point-kernel integration method has been used to estimate shielding factors for external gamma radiation from both airborne and surface-deposited nuclides. For surface-deposited activity, contributions from sources on the ground outside the building, the floor inside the building, the inside walls and ceiling, and the outside walls and ceiling are considered. It is assumed that the building is a hemispherical shell ("igloo"-shaped) with uniform wall thickness. For a thick-walled building the indoor dose rate is determined almost entirely by the contributions from sources inside the building, and the shielding factors are independent on the wall thickness as long as the thick-walled condition (wall thickness greater then ~5 mean free paths for the photons) is maintained. Here the indoor dose rate is determined by the indoor deposition velocity that is assumed to be 10% of the outdoor deposition velocity. The shielding factors for thick-walled buildings vary over a wide range from 0.0001 - 0.2. For thin-walled buildings (wall thickness less then ~2 mean paths) the shielding factors are typically in the range 0.5 - 1. In (KOCHER, D.C., 1980) a shielding factor of 0.29 is found for a wall-thickness of 329 kg m^{-2} using a source term for routine releases from a hypothetical fuel reprocessing plant.

At present a set of benchmark problems are calculated at KFK, NRPB, and Risø. The KFK - and NRPB - codes both use the point-kernel method to calculate shielding factors. At the beginning of 1985 a report will be published containing an analysis of the reason for eventual divergent results (CRICK, M. et. al.).

5.2. Experiments

In the late 1950's and early 1960's a series of shielding experiments with simple blockhouses and complex structures were made in the U.S. (REXROAD, R.E. et al., AUXIER, J.A. et al., BURSON, Z.G. 1966, BURSON, Z.G. 1970, STRICKLER, T. et al., BORELLA, H. et al., BATTER, J. et al., ROBINSON, M.J. et al.). The fall-out source on the roof was normally simulated by a grid of point sources and the plane ground source by pumping a source through a length of tubing placed around the house. The system consisted of a remotely controlled hydraulic pumping unit which pumped the radioactive source through the tubing. High intensity sources of the nuclides ^{60}Co and ^{137}Cs were used. The calculations by the Standard Method and the experiments agree in most cases to better than 20% for both the simple block houses and complex structures over a range of shielding factors down to ≈ 0.01. Experiments on multistorey buildings with interior walls showed that the measured shielding factor was practically insensitive to the placement of the interior walls either close to the detector point in the middle of the house or close to the outer wall. This confirms the validity of the method used in DEPSHIELD, where the interior wall thickness is added to the outer wall thickness.

DEPSHIELD has been used to calculate the shielding factors measured in one of the Kansas State University experiments (SPENCER, L.V. et al.). One of the structures erected for the experimental programme was a concrete blockhouse 20 ft x 20 ft with a first-storey height of 8 ft and a basement height of 8 ft. The walls had a mass-thickness of 34 $g \cdot cm^{-2}$ and the roof and basement ceiling a thickness of 27 $g \cdot cm^{-2}$. The blockhouse contained a door and a window. A plane source on the roof of the blockhouse was simulated by 4.6 mCi point sources of ^{60}Co placed at two-foot intervals. A plane source on the ground around the blockhouse was simulated by a tube source laid out in three areas covering a quarter-circular area of 160 ft radius from the center of the block house. The estimated contribution from the ground source beyond 160 ft accounted for 20-40% of the total exposure on the first (ground) storey. The instrumentation included 20R and 200 mR pocket dosimeters, Landsverk 2R dosimeters, and Victoreen 1R and 10 mR ion chambers. The measured shielding factors on the vertical centerline of the first storey agreed with calculations by the Standard Method within a few percent.

The table below shows the measured shielding factors and the calculated shielding factors for the ground storey by the code DEPSHIELD, without deposition on the outer walls.

Table 10. Measured and calculated shielding factors for the Kansas State University blockhouse.

Source	Experiment	DEPSHIELD
Ground contribution	0.18-0.25	0.22
Roof contribution	0.05	0.051

Other experiments with one- and two-storey houses (BURSON, Z.G. 1966) gave shielding factors of 0.1-0.2 measured in outer rooms and 0.05-0.1 measured in inner rooms. These figures agree reasonable well with the calculated shielding factors for Danish one- and two-storey houses of the range 0.04-0.28, where the contribution from deposited activity on outer walls is included.

6. ACKNOWLEDGMENT

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Calculated Shielding Factors for Selected European Houses

Per Hedemann Jensen

33 pages + 10 tables + illustrations

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Health Physics

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Abstract

Shielding factors for gamma radiation from activity deposited on structures and ground surfaces have been calculated with the computer model DEPSHIELD for single-family and multi-storey buildings in France, United Kingdom and Denmark. For all three countries it was found that the shielding factors for single-family houses are approximately a factor of 2 - 10 higher than those for buildings with five or more storeys. Away from doors and windows the shielding factors for French, British, and Danish single-family houses are in the range 0.03 -0.1, 0.06-0.4, and 0.07-0.3, respectively. The uncertainties of the calculations are discussed and DEPSHIELD-results are compared with other methods as well as with experimental results.

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