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Calculation Method for Gamma Dose Rates From Gaussian Puffs

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Risø National Laboratory, Roskilde, Denmark
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Abstract The Lagrangian puff models are widely used for calculation of the dispersion of releases to the atmosphere. Basic output from such models is concentration of material in the air and on the ground. The most simple method for calculation of the gamma dose from the concentration of airborne activity is based on the semi-infinite cloud model. This method is however only applicable for puffs with large dispersion parameters, i.e. for receptors far away from the release point. The exact calculation of the cloud dose using volume integral requires large computer time usually exceeding what is available for real time calculations.

The volume integral for gamma doses could be approximated by using the semi-infinite cloud model combined with correction factors. This type of calculation procedure is very fast, but usually the accuracy is poor because only a few of the relevant parameters are considered.

A multi-parameter method for calculation of gamma doses is described here. This method uses precalculated values of the gamma dose rates as a function of E_γ,σ_y, the asymmetry factor – σ_y/σ_z, the height of puff center – H and the distance from puff center R_{xy}. To accelerate the calculations the release energy, for each significant radionuclide in each energy group, has been calculated and tabulated. Based on the precalculated values and suitable interpolation procedure the calculation of gamma doses needs only short computing time and it is almost independent of the number of radionuclides considered.

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1 Introduction

The mesoscale dispersion model RIMPUFF (Thykier-Nielsen and Mikkelsen, 1987) is a fast and operational computer code suitable for real-time simulation of releases of environmentally hazardous materials and gases to the atmosphere. Suitable as a real-time model for emergency preparedness, it has recently been selected for inclusion in the EU RODOS, real time decision support system under development at KfK (Ehrhardt et. al.,1993).

RIMPUFF includes models for calculating external gamma doses from airborne and deposited radioactivity. To improve these, very simple, models KFKI AERI and Risø have started a joint project supported by the EU. The first results for spherical approximations were reported earlier (Thykier-Nielsen et al., 1993). The achievements for asymmetrical (real) puffs are given below.

2 Risø Puff Diffusion Model

The mesoscale dispersion model RIMPUFF applies to nonhomogeneous terrain and moderate topography on a horizontal scale of 0 to 50 km, and responds to changing (instationary) meteorological conditions. The Lagrangian puff-model simulates time changing continuous releases by sequentially releasing a series of Gaussian shaped puffs at fixed release rate on a specified grid. The amount of radioactive material allocated to individual puffs equals the release rate times the time elapsed between puff releases.

RIMPUFF is equipped with computer time effective features for terrain and stability-dependent dispersion parametrization, plume rise formulas, inversion and ground-level reflection capabilities and wet/dry (source) depletion. In addition, the code optionally provides local relative diffusion parametrization and scheme for horizontal/vertical shear diffusion.

When applied to orographically influenced dispersion scenarios, RIMPUFF is advantageously interfaced with a high resolution mean flow-model such as LINCOM. This enables the model to treat plume bifurcation in complex terrain by use of the puff pentafurcation scheme.

3 Initial Gamma Dose Model

The first gamma dose model used in RIMPUFF was based on the semi-infinite cloud model with correction factors given in (Slade, 1968). This model starts by calculating the concentration X-puff (0,0,0) in the center of each puff and the distance R from the puff-center to each grid point. The gamma dose rate in a grid point is then calculated using the formula:

$$d_\gamma = \sum_E f(E_\gamma)\, E_\gamma)\, 0.2292 GKOR(\sigma, R/\sigma)\, GKOR1\,(\sigma, E_\gamma)\, \mathrm{X}_{\mathrm{puff}}\,(0,0,0) \quad (1)$$

where

$f(E_\gamma)$	frequency of photons in energy group
E_γ	mean energy of gamma radiation in energy group [MeV]
$GKOR(\sigma, R/\sigma)$	correction factor for variation of doses with distance and dispersion parameter from Fig. 7.14 in (Slade, 1968)
$GKOR1\,(\sigma, E_\gamma)$	correction factor for variation of doses with photon energy from Fig. 7.16 in (Slade, 1968). This factor is > 1 for $E_\gamma < 0.7$ MeV and < 1 for $E_\gamma > 0.7$ MeV.
σ	dispersion parameter, where $\sigma = \sqrt{\sigma_{xy}\sigma_z}$
$X_{\mathrm{puff}}\ (0,0,0)$	activity concentration in puff center [Ci/m^3].

4 Calculation Method for Gamma Dose Rates from Gaussian Puffs

The calculation method for gamma dose rates described above is based on the cylindrical plume model. For a puff model the use of a semi-infinite cloud model may lead to large errors. Therefore, a method for calculation of gamma dose rates based on a Gaussian puff model has been implemented. This method is described in detail below.

The gamma dose rate for a Gaussian puff using the volume integral at point R is equal to

$$d(Q, E_\gamma, \sigma_y, \sigma_z, H, R_{xy}) = 2K\sigma_{en}E_\gamma \int_{x=-\infty}^{\infty}\int_{y=0}^{\infty}\int_{z=-\infty}^{\infty} \frac{B(\mu r)}{4\pi r^2} e^{-\mu r} \mathrm{X}(x,y,z)\,dx\,dy\,dz \quad \text{Gy/sec} \qquad (2)$$

where

Q	activity in one puff [Bq] with 1 photon/disintegration
E_γ	energy of gamma radiation [MeV]
σ_y	crosswind puff dispersion parameter [m] ($\sigma_x = \sigma_y$)
σ_z	vertical puff dispersion parameter [m]
H	height of the puff center [m]
R_{xy}	distance of the puff center base point ($x = y = 0, z = -H$) from the receptor point [m]
K	constant, $1.6 \cdot 10^{-13}$ [Gy/sec/MeV/kg]
σ_{en}	energy absorption coefficient for air [m^2/kg]
B	build up factor
μ	linear attenuation factor for air [m^{-1}]
r	distance of the volume $dxdydz$ from the receptor point located at the distance R_{xy} from the puff center base point
$\mathrm{X}(x,y,z)$	the concentration in point x, y, z [Bq/m^3]

$$\mathrm{X}(x,y,z) = \frac{Q}{(2\pi)^{3/2}\sigma_y^2\sigma_z} \exp\left(-\frac{x^2}{2\sigma_y^2}\right) \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{z^2}{2\sigma_z^2}\right). \qquad (3)$$

Calculations were made using the following set of numerical data:

Q	1 Bq MeV/E_γ where E_γ is given in MeV (for the present case $Q = 5$; 2; 1 and 0.5 Bq, respectively)
E_γ	0.2; 0.5; 1 and 2 MeV
B	Capo polynomials and Risø data for energy 0.2 MeV, from (Jensen and Thykier-Nielsen, 1980)
σ_y	range from 10 - to 2000 m (8 values)
σ_z	given as a function of σ_y for a range of σ_y/σ_z from 0.4 to 40 (11 values)
H	range from 10 to 500 m (8 values)
R_{xy}	up to a distance where the dose rate decreases below 1% of dose rate at $R_{xy} = 0$
σ_{en}	data by Storm 1967 reproduced in (Lauridsen, 1982)
μ	for air data interpolated from (Thykier, 1978). The numerical values are: 0.2 MeV - $1.60 \cdot 10^{-2}\ \mathrm{m}^{-1}$ 0.5 MeV - $1.14 \cdot 10^{-2}\ \mathrm{m}^{-1}$ 1.0 MeV - $8.30 \cdot 10^{-3}\ \mathrm{m}^{-1}$ 2.0 MeV - $5.70 \cdot 10^{-3}\ \mathrm{m}^{-1}$

The other values were so chosen that the total error of the calculations is minimized. Special attention was paid to the values of the volume integral close to the receptor point r. For B outside the range of approximation, the last acceptable value has been used in each case. The infinite cloud model was used for large σ_y (above 2000 m) where it gives more reliable data than the numerical integration.

The steps in the numerical integration were specified as follows:

$$\Delta x = \Delta y = \sigma_y/10 \text{ and } \Delta z = \sigma_z/10 \text{ up to } \pm 5\sigma_y \text{ and } \pm 5\sigma_z$$

except around the receptor point where integration steps of $\sigma_y/40$ and $\sigma_z/40$ were used for a volume of $\pm\sigma_y$ and $\pm\sigma_z$.

It is assumed that the ground surface is totally reflecting. This is taken in to account by modeling the puff as a perfect Gaussian one, which is "folded" at the ground surface as shown in Fig. 1. The implication of this model is that due to symmetry both the semi-infinite (with reflection) and the infinite (without ground reflection) puff gamma dose model give the same gamma dose at ground level.

The results of calculations (i.e. gamma dose rates due to 1 MeV/s energy release) are given for energies 0.2, 0.5 1 and 2 MeV. (These data are available on a floppy diskette from the authors.) Using the numerical data base the gamma dose rate can be calculated. When the activity of different radionuclides in a puff is known, then the simplest method is to divide the gamma energies of different gamma-radiation lines into several groups.

The following division is suggested:

Group	E nominal (MeV)	Energy range (MeV)
1	0.2	≤ 0.35
2	0.5	$> 0.35 \ldots\ 0.75$
3	1.0	$> 0.75 \ldots\ 1.5$
4	2.0	> 1.5

For each radionuclide the library must contain the energy release rate (MeV/s) for unit activity in each energy group. Using the library, the puff inventory, the dispersion parameters and the height of the puff center the dose rate for each energy group can be calculated for a given distance R_{xy} from the puff center

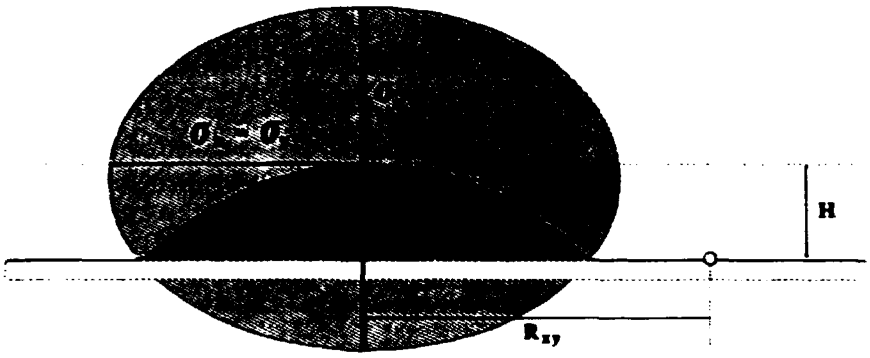

Figure 1. Reflection of the puff at ground surface.

basepoint using a suitable interpolation. For values not given in the calculated results it is recommended to use the semi-infinite model.

The energy emission data for 28 nuclides (mainly fission products) typically released into the atmosphere are given in table 1.

5 Range of Parameters Used for Calculation of Gamma Doses from Asymmetrical Puffs

Besides the photon energy dependence of doses there are 4 independent parameters in dose estimation: the puff-center height (H), the distance from the puff base point R_{xy}, the horizontal dispersion parameter (σ_y) and the asymmetry factor (σ_y/σ_z).

For these parameters, calculations are made for the ranges described below: a height interval of $10 \leq H \leq 500$ m (divided into 8 points). For R_{xy} the distance is increased so that the dose rate is less than 1% of the maximum, i.e. the dose rate for $R_{xy} = 0$ m. This results in a varying number of points (between 8 and 40) for the different cases.

It is more complicated to determine the possible ranges of σ_y and of the asymmetry factor. If the height-dependent dispersion parameters of the Karlsruhe/Jülich system (Bundesminister, 1983) are used, a range of $13 \leq \sigma_y \leq 67000$ and $0.07 \leq \sigma_y/\sigma_y \leq 100$ can be found at a distance from the source between 100 and 20 000 m. The extremely high values of σ_y/σ_z occur in stable categories and at large distances (Fig. 2, series 1). It should be noted that the Karlsruhe/Jülich dispersion parameters refer to a 1 hour averaging time. If the meteorological parameters are to be updated every 10 minutes as it is the intention for RODOS at short distances, much lower σ_y values should be used in stable categories. This would result in maximum values of σ_y/σ_z that are much lower.

Table 1. Energy emission data for 28 nuclides typically released into the atmosphere.

Nuclide	Energy in MeV/decay for group				
	1	2	3	4	5
^{41}Ar	0	0	1.283	0	1.283
^{85m}Kr	1.561E-1	0	0	0	1.561E-1
^{87}Kr	0	2.140E-1	9.364E-2	4.632E-1	7.709E-1
^{88}Kr	5.704E-2	1.572E-2	2.166E-1	1.619	1.908
^{88}Rb	0	0	1.373E-1	4.846E-1	6.220E-1
^{89}Rb	0	0	1.145	7.430E-1	1.888
^{95}Nb	0	0	7.658E-1	0	7.658E-1
^{105}Rh	7.741E-2	0	0	0	7.741E-2
^{106}Rh	0	1.707E-1	2.340E-2	2.343E-3	1.964E-1
^{110m}Ag	0	9.302E-1	1.593	2.157E-1	2.739
^{131}I	2.060E-2	3.585E-1	0	0	3.791E-1
^{132}I	0	1.013	1.152	5.639E-2	2.222
^{133}I	0	4.848E-1	1.096E-1	0	5.944E-1
^{134}I	1.466E-2	3.320E-1	1.896	0	2.243
^{135}I	0	6.645E-2	9.910E-1	4.743E-1	1.532
^{131m}Xe	2.000E-2	0	0	0	2.000E-2
^{133}Xe	4.600E-2	0	0	0	4.600E-2
^{133m}Xe	4.070E-2	0	0	0	4.070E-2
^{135}Xe	2.256E-1	1.990E-2	0	0	2.455E-1
^{135m}Xe	0	4.276E-1	0	0	4.276E-1
^{137}Xe	0	1.367E-1	7.227E-3	6.955E-3	1.508E-1
^{138}Xe	1.002E-1	1.286E-1	5.060E-2	7.991E-1	1.079
^{132}Te	2.313E-1	0	0	0	2.313E-1
^{134}Cs	0	7.322E-1	8.226E-1	0	1.555
^{137}Cs	0	5.627E-1	0	0	5.627E-1
^{140}Ba	2.347E-2	1.535E-1	0	0	1.770E-1
^{140}La	7.139E-2	2.365E-1	63.695E-1	1.629E-1	2.307
^{144}Ce	1.671E-1	0	0	0	1.671E-2

group 1: $E \leq 0.35$ MeV
group 2: $0.35 \text{ MeV} < E \leq 0.75$ MeV
group 3: $0.75 \text{ MeV} < E \leq 1.5$ MeV
group 4: $1.5 \text{ MeV} < E$
group 5: total energy emission

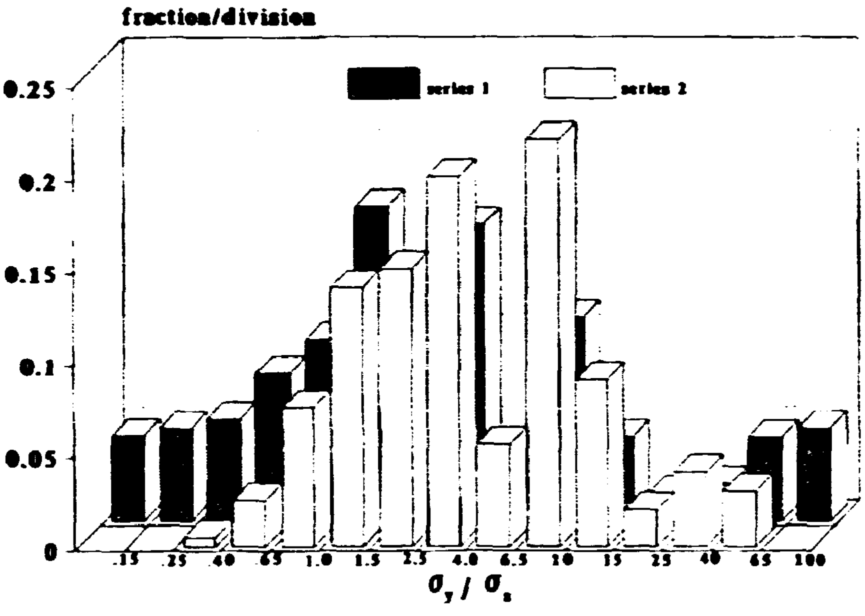

Figure 2. The range and distribution of the asymmetry factor without limitations (series 1) and with limitations (series 2) up to the maximum values of σ_y and σ_z used in numerical integrations.

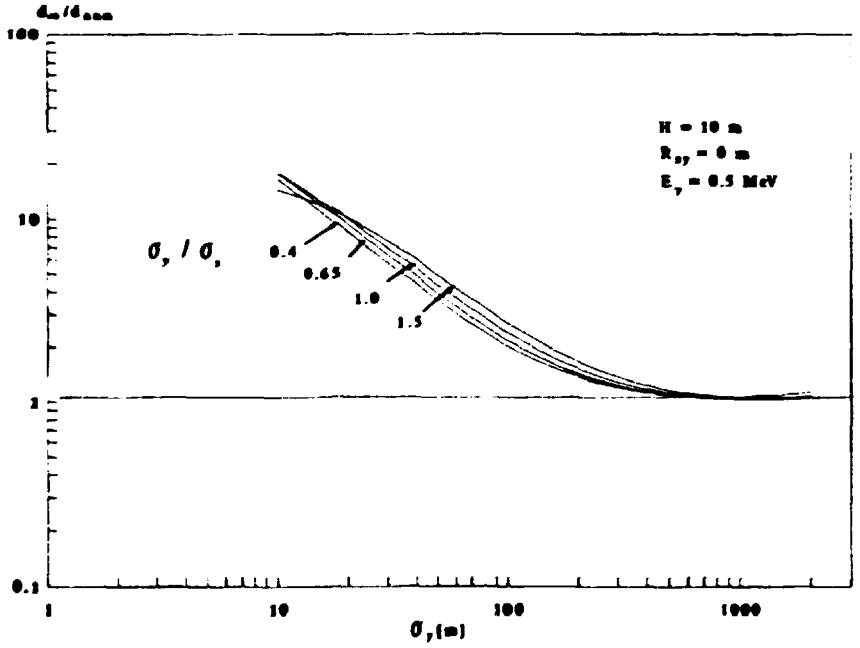

Figure 3. The ratio of dose rates calculated by the semi-infinite and numerical integration methods as a function of σ_y for values of $\sigma_y/\sigma_z \leq 1.5$.

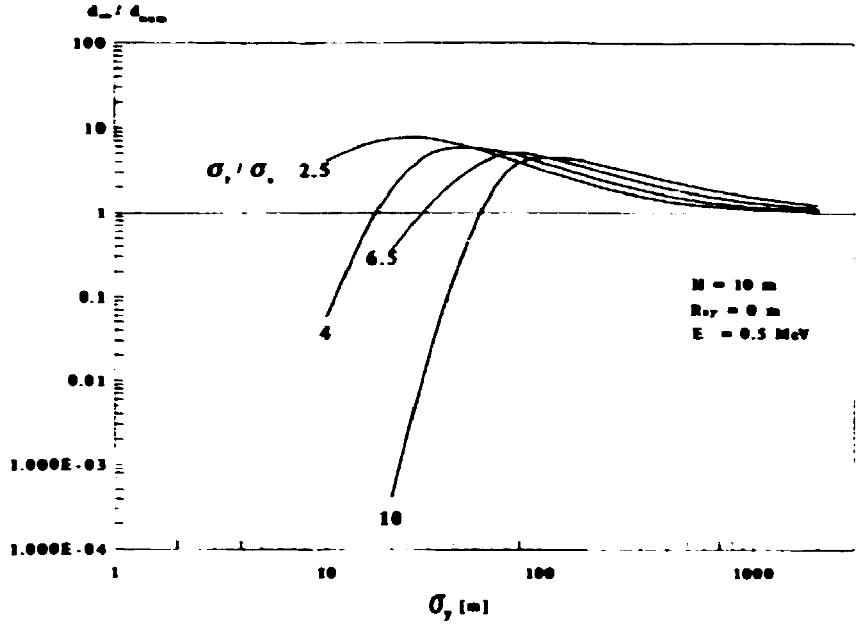

Figure 4. The ratio of dose rates calculated by the semi-infinite and numerical integration methods as a function of σ_y for values of $\sigma_y/\sigma_z > 1.5$.

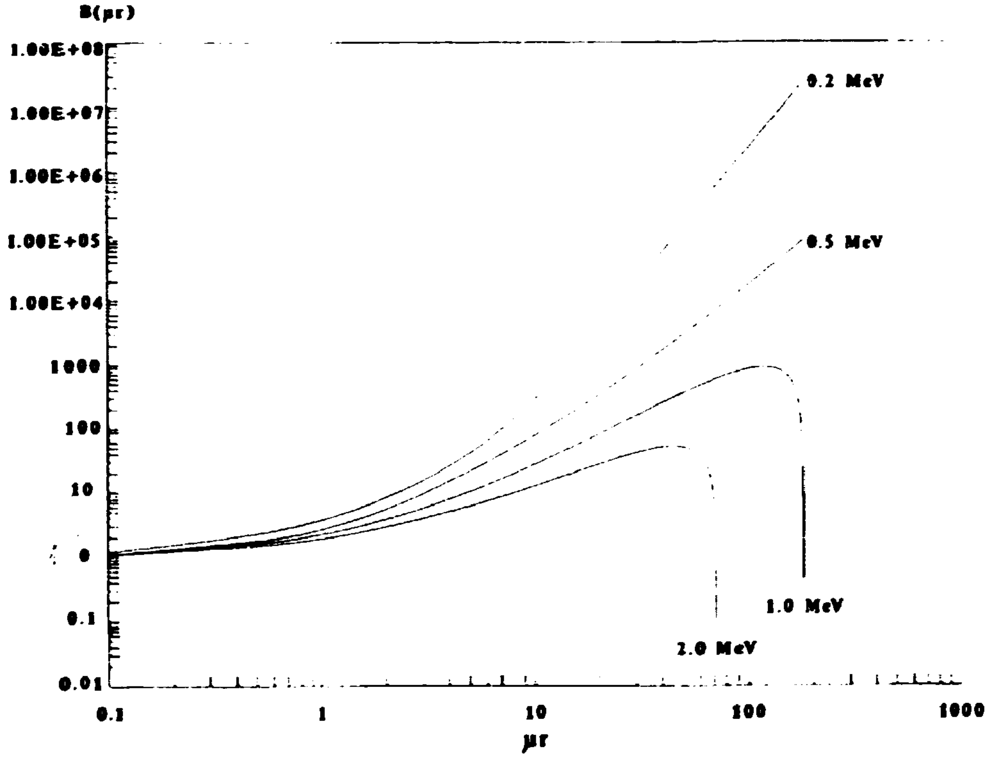

Figure 5. Buildup factors for different gamma-radiation energies as a function of distance in μr units.

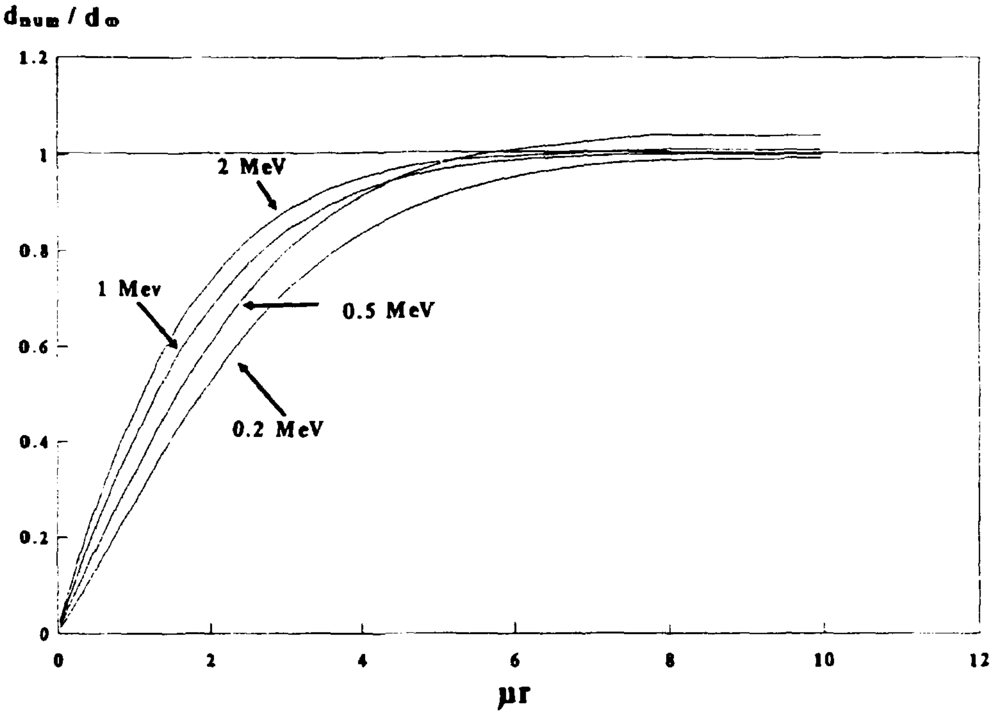

Figure 6. Ratio of dose rates calculated by numerical integral and semi-infinite model as a function of the distance used for integration in μr units.

Moreover, based on investigations on the applicability of the infinite cloud model, it seems likely that when σ_y is of the order 2000 m the infinite cloud model can be applied for any values of R_{xy} and H. This is illustrated in Figs. 3 and 4 for cases of $H = 10$ m, $R_{xy} = 0$ and $E = 0.5$ MeV. In some cases these figures suggest a slight increase in the rate of $d_\infty/d_{\mathrm{num}}$ (ratio of dose rates calculated by a semi-infinite model to numerical integration method) above $\sigma_y = 1000$ m. It was proved by investigations that this virtual increase is due to the relatively coarse integration steps and it disappears using finer steps, for example $\sigma/100$. As the calculation program uses the semi-infinite cloud model if $\sigma_y \geq 1000$ m and $\sigma_y/\sigma_z \leq 4$ and in all other cases when $\sigma_y \geq 2000$ m, these less accurate results from the numerical integration are not used in the program. In the calculations the interval of σ_y values is taken from 10 to 2000 m. This interval is covered by 8 values of σ_y.

It should be noted that large errors may arise when applying numeric integration for large σ-values and/or for large distances. This is due to the limited range of validity for the buildup factors. Using the Capo-polynomials for $E_\gamma > 0.2$ MeV and the Risø values for $E_\gamma = 0.2$ MeV the validity range of build up factors is determined as follows:

$0 \leq \mu r \leq 20$ for $E_\gamma > 0.2$ MeV
$0 \leq \mu r \leq 7$ for $E_\gamma = 0.2$ MeV

In Fig. 5 the values of the buildup factor are shown both within and outside their range of validity. In Fig. 5 a very sharp breaking point can be seen for $E = 1$ MeV and $E = 2$ MeV at $\mu r \geq 120$ and $\mu r \geq 45$, respectively. Distances corresponding to these μr values are about 14000 m and 8000 m. Taking the $\pm 5\sigma$ volume integral, an elementary volume may extend much longer from the receptor point than these distances. Therefore, the calculation program uses the last acceptable value for B outside the range of approximation.

To test the correctness of the buildup factors used, the numerical integral and semi-infinite model have been compared for the case of uniformly distributed activity. It has been found that in the case of a sufficiently large volume both methods give the same results with a systematic error less than 5% (Fig. 6). As here the dose rate values calculated by numerical integration reach their saturation value inside validity range, this control can serve only for checking the buildup factors inside the validity range and not for extrapolated values.

Another problem arises in the application of numerical integration in connection with inversion conditions at large distances from the release point. Here, the dispersed material undergoes multiple reflections between the ground surface and the inversion layer resulting in a homogeneous vertical distribution of the material. For such an activity concentration the application of the semi-infinite model should give more reliable results than the results obtained by numerical integration. Consequently, for dose rate calculation the infinite cloud model is applicable from distances where the numeric values of σ_z are equal or higher than the height of the inversion layer.

Using the assumptions made above (i.e. $\sigma_y \leq 2000$ m, $\sigma_z \leq A$ (the height of inversion layer), a smaller range for the asymmetry factor can be estimated. In Fig. 2 the range and distribution of the asymmetry factor are shown for cases both without and with limitations for σ_y and σ_z. (It is noticeable that in the latter case values of $\sigma_y/\sigma_z > 15$ occur only in the F category, where the horizontal dispersion parameter given in (Bundesminister, 1983) is extremely large for averaging times much lower than one hour. When the release height is 180 m, it is in fact the same for A and F categories.)

6 Parameter Dependence of Dose Rates from Asymmetrical Puffs

If as a first approximation the energy dependence is neglected (i.e. $E_\gamma = 0.5$ MeV for Figs. 7 to 10), the new parameters compared to the case of spherical puffs are the horizontal distance and the asymmetry factor. In Figs. 7 and 8 the dose rate on the ground surface just below the puff center is shown as a function of the asymmetry factor. The volume of the puff determined by $\sigma_{\text{eff}} = (\sigma_y^2\sigma_z)^{1/3}$ is kept constant, only its shape is changing. For small puffs (Fig. 7) the shape of the puff actually does not affect the values of dose rate if the puff distance from the ground is large enough compared to σ_{eff}. For large puffs the situation is the opposite. The farther the puff is from the ground, the more significant is the dependence of dose rates on the asymmetry factor. Figures 9 and 10 illustrate the dose rate as a function of distance from the puff center in the $x-y$ plane. The second independent variable is the asymmetry factor. The height of the puff from the ground is 10 m here. Conclusions from these figures can be paralleled with those from Figs. 7 and 8. For small puffs, the asymmetry factor affects the dose rate significantly only at small distances from the puff center. For large puffs the differences in dose rates are large at large distances from the puff center due to the shape of the puff.

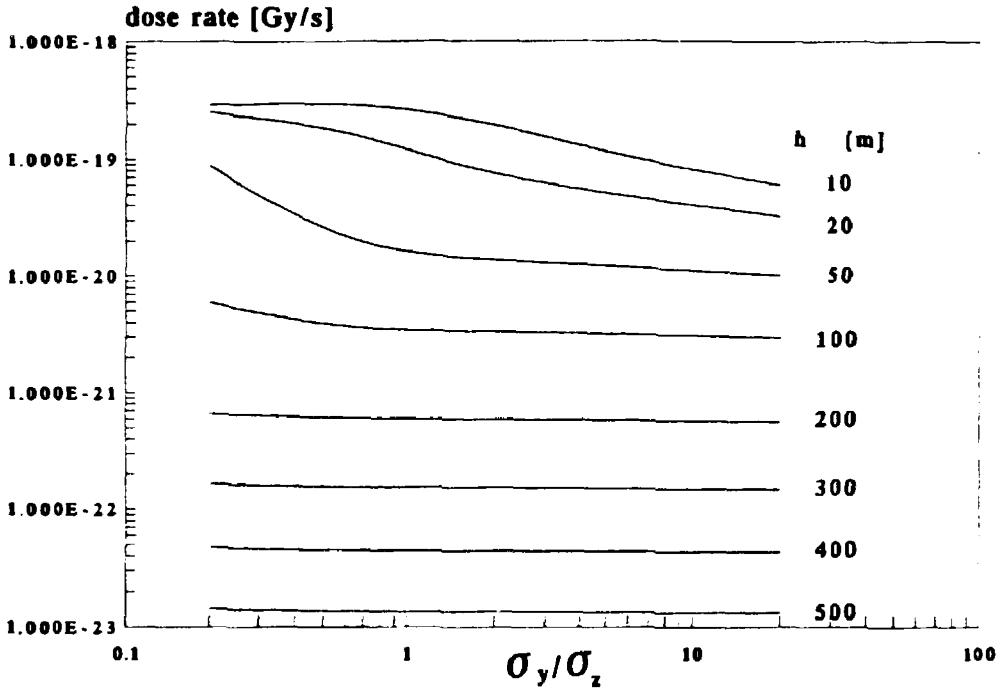

Figure 7. Dose rate as a function of asymmetry factor for different puff heights (σ_{eff} = 10 m, E_γ = 0.5 MeV)

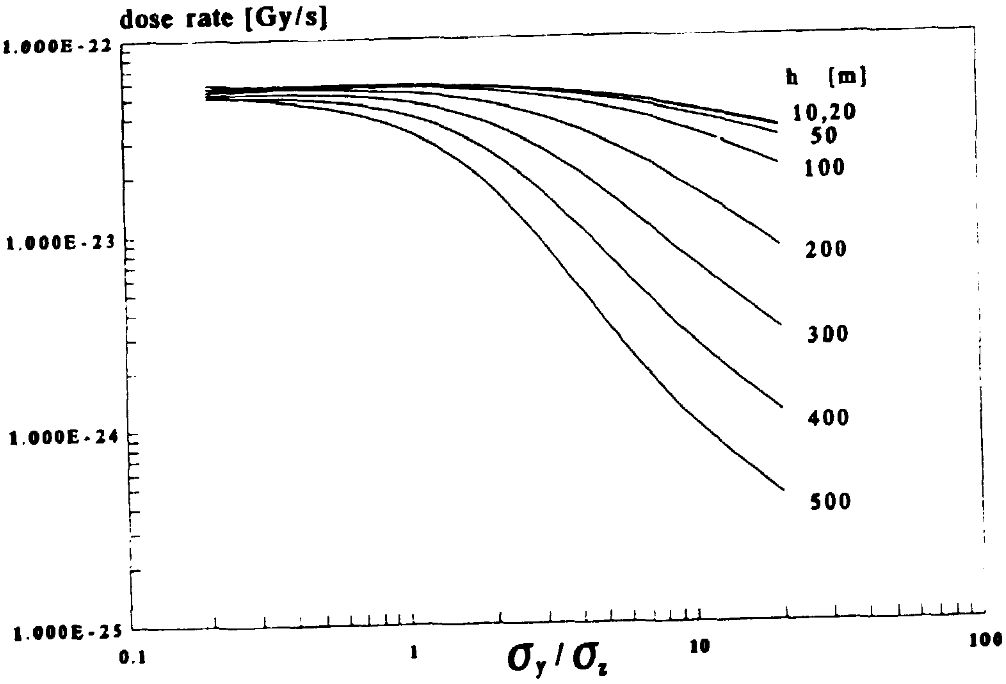

Figure 8. Dose rate as a function of asymmetry factor for different puff heights (σ_{eff} = 500 m, E_γ = 0.5 MeV).

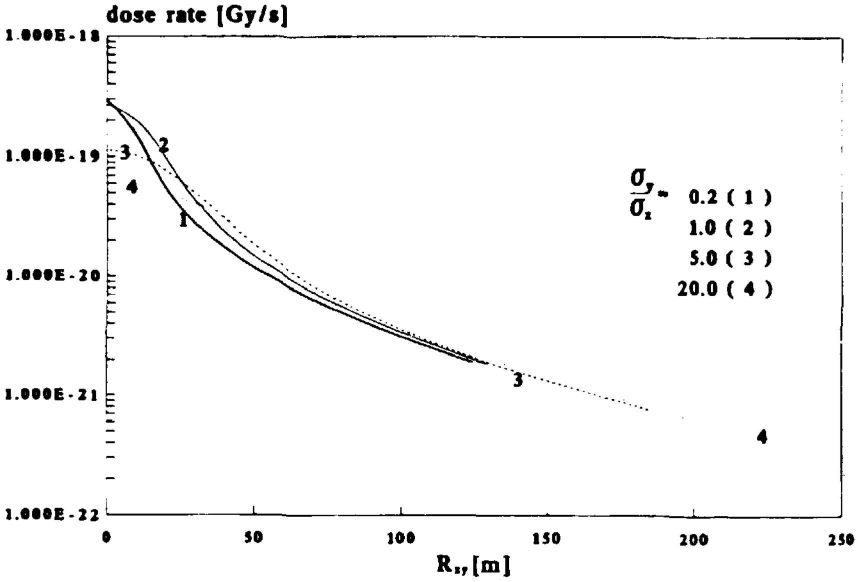

Figure 9. Dose rate as a function of horizontal distance from the puff center in the case of different asymmetry factors (σ_{eff} = 10 m, E_γ = 0.5 MeV).

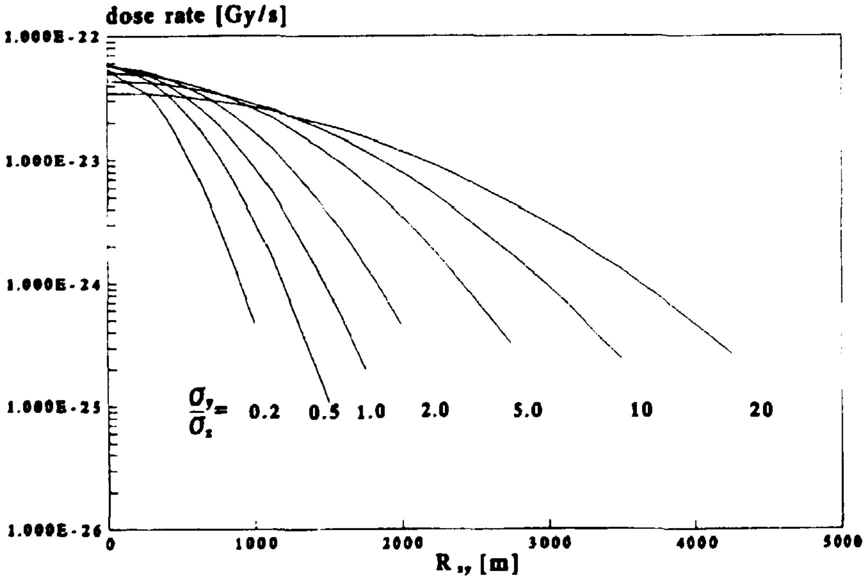

Figure 10. Dose rate as a function of horizontal distance from the puff center in the case of different asymmetry factors (σ_{eff} = 500 m, E_γ = 0.5 MeV).

7 Simplified Calculation Procedure for Accidental Releases

Because of limitations on computer time for real time calculations, it is important to have a fast procedure for calculation of gamma dose rates from Gaussian puffs. As the computing time is proportional to the number of gamma energy groups it is reasonable to decrease the number of groups, provided the additional computation error does not increase significantly. Therefore, the use of a single energy group has been investigated for use in the early phase of atmospheric releases during a reactor accident.

7.1 Mean photon energy of released radionuclides

To estimate the mean photon energy of radionuclides released to the atmosphere a limited set of radionuclides has been chosen. Only the nuclides which are the most important during a reactor accident have been selected according to the default data in COSYMA and RODOS programs (see table 2). The Sr isotopes are negligible from the point of view of gamma dose, so they were omitted while the gamma radiating daughter elements of ^{140}Ba and ^{106}Ru (i.e. ^{140}La and ^{106}Rh) were included in our list. Activity values were taken from COSYMA (CEC, 1990) and, in some cases, from (Kelly, 1982).

Values of "time before release", "duration of release" and the "fraction of core inventory released to environment" were taken from (Kelly, 1982) for three accident release categories, namely UK1A, UK5A and UK11. A constant rate of emission was assumed during the time of release. The original core inventory after shutdown was corrected for decay and daughter element production.

In Figs. 11 and 12 the time dependence of the mean photon energy is shown for short-term and long-term releases. For comparison, the mean energy calculated for a long-term release of the Paks Nuclear Power Plant (Hungary) is also shown (Safety, 1980). For short releases (Fig. 11 for $T \leq 1$ hour) the mean photon energy is estimated between 0.7-0.8 MeV, while in case of long releases (Fig. 12 for $T \geq$ 10 hour) it decreases from 0.7 MeV to 0.1-0.2 MeV.

7.2 Application of the mean photon energy for estimating of gamma dose

The order of magnitude of the errors made in the dose calculations by using a mean photon energy instead of the actual energies was investigated. These calculations are based on data given in the earlier report (Thykier-Nielsen, 1993) for symmetrical puffs i.e. $\sigma_y/\sigma_z = 1$.

The dose rate was calculated using the mean energy of a given photon composition as well as the individual photon energies. Results were compared for several cases as shown in Figs. 13 and 14.

The figures show that in receptor points near the puff center there is good agreement between the results of the two calculation methods. These are the cases where the dose rates from a given puff are high. Here the use of the mean energy results in an overestimation of 6-8% compared to the real dose rates. At larger distances from the puff center the use of the mean energy leads to underestimation of the dose rates. Though this error may be an order of magnitude, note that the dose rates are very low in such distances from the center of the puff.

The agreement in centerline doses (instead of dose rates) calculated by the mean and the individual photon energies are even better. The total dose originating from a puff that passes over a receptor point leads to a difference less than 6-7% between a puff that passes over a receptor point leads to a difference less than 6-7% between the doses calculated by the two methods mentioned above. This does not apply to points far away from the puff center line. In such cases the use of the mean energy leads to underestimation of the relatively low dose rates.

Concerning the calculation of dose rates in consecutive advection time steps the following has to be noted. If the meteorological parameters are averaged for every 10 minutes, then it is sufficient to follow only one puff trajectory in the 10 minute intervals. This will give a large reduction in calculation time. But in this case, the temporary dose rates calculated in time steps are only intermediate calculation results without real physical meaning. (Note, that the actual release is continuous and not divided in discrete puffs.) The puffs are only a mathematical representation of a 10 minute release. They may be used for calculating the 10 minute dose. From this dose the dose rate may be calculated by division with time. This dose rate may be compared with actual measurements. Based on these considerations the use of the mean photon energy is an acceptable approximation in the dose calculations.

Table 2. Significant radionuclides of core inventory after shut down.

Nuclide	Core inventory (Bq)	COSYMA	KODOS	Recently used
^{88}Kr	2.83E+18	+	+	+
^{88}Rb	5.36E+18	+		+
^{89}Sr	3.37E+18		+	
^{90}Sr	1.75E+17	+		
^{105}Rh	3.44E+18	+		+
^{106}Rh	1.50E+18			+
^{106}Ru	1.47E+18	+		+
^{131}I	3.85E+18	+	+	+
^{132}I	5.55E+18	+	+	+
^{133}I	7.47E+18	+	+	+
^{134}I	7.84E+18		+	
^{135}I	6.70E+18	+	+	+
^{132}Te	5.36E+18	+	+	+
^{133}Xe	7.36E+18	+	+	+
^{135}Xe	1.51E+18	+	+	+
^{134}Cs	5.11E+17	+	+	+
^{137}Cs	2.61E+17	+	+	+
^{140}Ba	6.80E+18		+	+
^{140}La	7.00E+18			+
^{144}Ce	4.03E+18	+		+
^{241}Pu	2.23E+17	+		

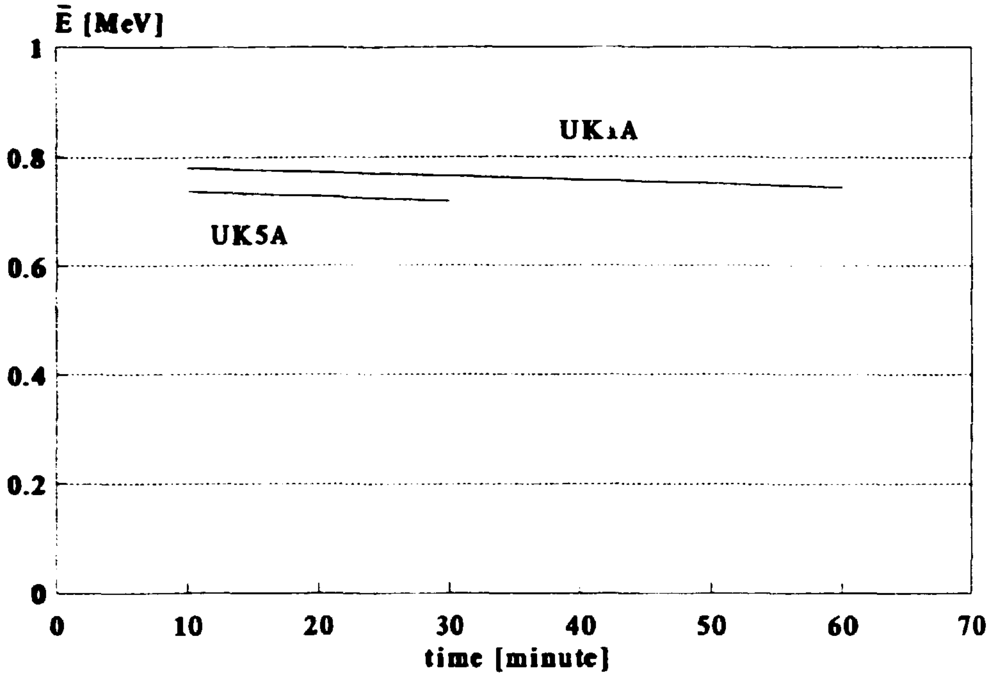

Figure 11. Mean photon energy of radionuclides due to short-term accidental releases.

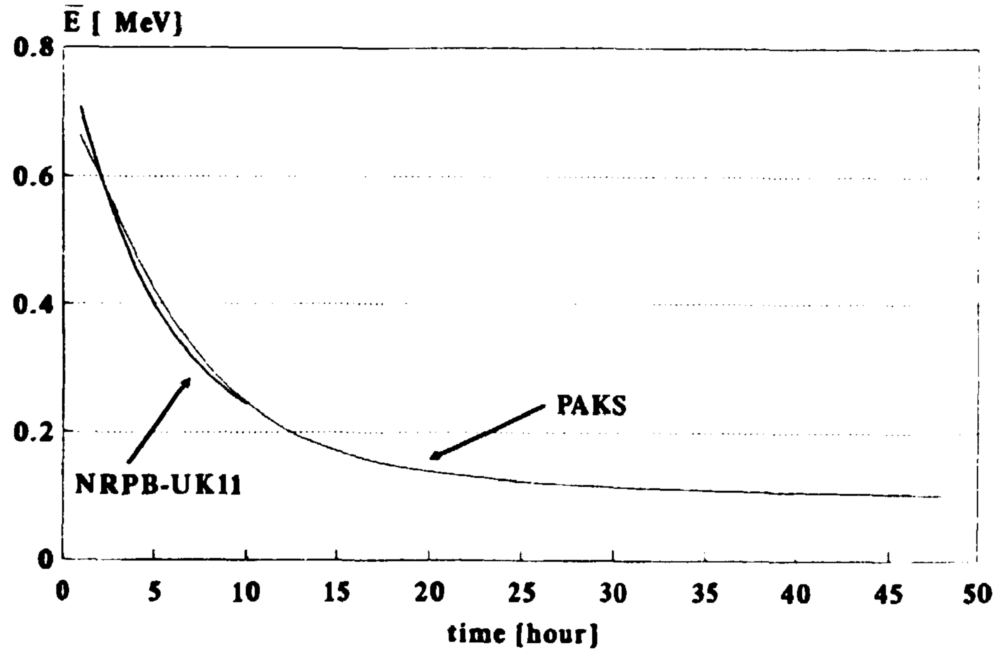

Figure 12. Mean photon energy of radionuclides due to long-term accidental releases.

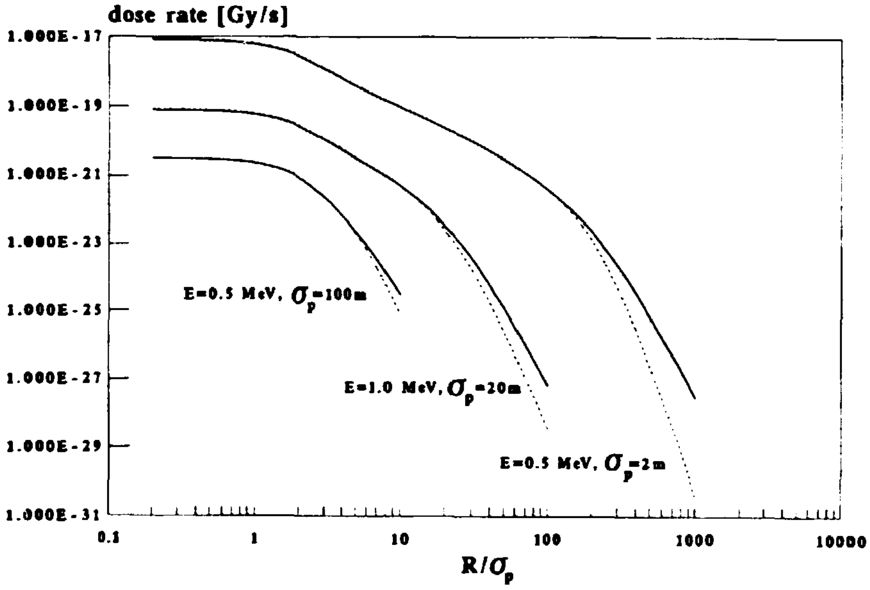

Figure 13. Dose rates calculated by the mean (dotted line) and the actual photon energies.

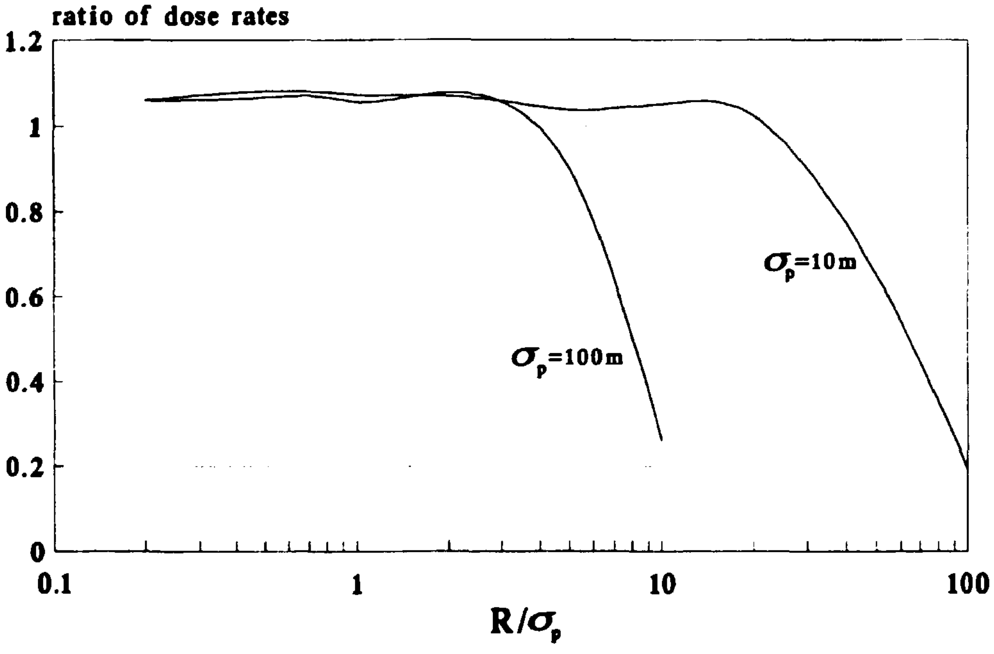

Figure 14. Ratio of dose rates calculated by the mean and the actual photon energies.

7.3 Photon energy dependence of dose calculations for puffs

Calculational tests described briefly in paragraph 7.1 are based on the fact that the mean photon energy of radionuclides released to the environment in a reactor accident varies within the range of 0.2-0.8 MeV as a function of time. It was shown in paragraph 7.2 that the use of the mean energy instead of the individual ones of a given photon result in acceptable agreement in dose(rate) calculations.

In this chapter an estimate the errors due to application a medium photon energy, i.e. 0.5 MeV, instead of the different values within the range of 0.2-0.8 MeV is given. According to Fig. 15, a mean photon energy which is higher or lower than the one applied (0.8, 0.2, 0.5 MeV, respectively) results in underestimation or overestimation in dose rates near the puff center. The size of these differences does not exceed ± 5-15%. Farther from the puff center, i.e. at relatively low dose rates the sign of the differences is the opposite and they are one order of magnitude. These calculation tests resulted in differences of ± 4-10% when applying them for doses instead of dose rates. It can be concluded from the tests described in paragraph 7 that the actual photon energies of a given radionuclide composition due to an accidental release can be neglected, i.e. a photon energy of 0.5 MeV can be used as a mean energy for gamma dose calculations. This procedure is especially acceptable when estimating the overall consequences of a reactor accident, where the most important is to find total dose instead of the temporary dose rates.

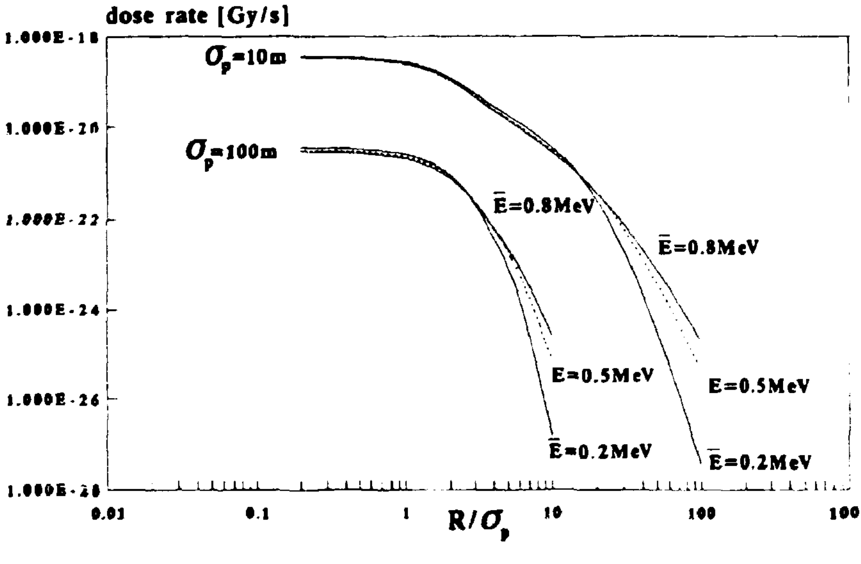

Figure 15. Energy dependence of dose rate in the range of 0.2 - 0.8 MeV.

8 Conclusions

The method described will significantly improve the procedure for calculation of the gamma radiation doses from puffs. The tabulated dose rate values can be used for fast real time calculations in case of an accident.

A simplified method has been given for the early phase (the first hours) of atmospheric releases in case of a reactor accident.

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Abstract (Max. 2000 char.)

The Lagrangian puff models are widely used for calculation of the dispersion of releases to the atmosphere. Basic output from such models is concentration of material in the air and on the ground. The most simple method for calculation of the gamma dose from the concentration of airborne activity is based on the semi-infinite cloud model. This method is however only applicable for puffs with large dispersion parameters, i.e. for receptors far away from the release point. The exact calculation of the cloud dose using volume integral requires large computer time usually exceeding what is available for real time calculations.

The volume integral for gamma doses could be approximated by using the semi-infinite cloud model combined with correction factors. This type of calculation procedure is very fast, but usually the accuracy is poor because only a few of the relevant parameters are considered.

A multi-parameter method for calculation of gamma doses is described here. This method uses precalculated values of the gamma dose rates as a function of E_γ,σ_y, the asymmetry factor – σ_y/σ_z, the height of puff center – H and the distance from puff center R_{xy}. To accelerate the calculations the release energy, for each significant radionuclide in each energy group, has been calculated and tabulated. Based on the precalculated values and suitable interpolation procedure the calculation of gamma doses needs only short computing time and it is almost independent of the number of radionuclides considered.

Descriptors INIS/EDB

ATMOSPHERIC CIRCULATION; CONTAMINATION; FISSION PRODUCT RELEASE; GAMMA RADIATION; GAUSS FUNCTION; MATHEMATICAL MODELS; METEOROLOGY; MULTI-PARAMETER ANALYSIS; PLUMES; RADIATION DOSES

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