Safety Guidance

Guidance on the application of conservative and less conservative approaches for the analysis of radiological consequences

June 2017

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Abstract

The objective of this guidance document is to complement the existing guidance document Safety Demonstration 2013-05-15-NH-5-4-3-EN by providing views of the regulatory body on the application of a conservative and a less conservative approach for the evaluation of radiological consequences of incidents and accidents at nuclear facilities.

This guidance is focussing on radiological consequences due to atmospheric dispersion of releases.

Applicability:	All new Class 1 nuclear installations except disposal installations
Keywords:	Radiological consequences, atmospheric dispersion, representative person
Classification: Public **Distribution: Unrestricted**	
Valid until:	NA

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1 Introduction

FANC is developing, in close collaboration with Bel V, a series of guidance documents for new Class 1 installations. In the guidance on "Safety demonstration" [1] the use of a conservative and a less conservative ((more) best estimate) approach are mentioned without giving further specifications on these approaches.

2 Scope and Objective

The objective of this guidance document is to complement the existing guidance document on "Safety demonstration" [1] by providing views of the regulatory body (FANC + Bel V) on the application of a conservative and a less conservative approach for the evaluation of radiological consequences of incidents and accidents at nuclear facilities.

Providing guidance on a conservative and a less conservative approach for scenario development of incidents and accidents is out of scope of the present document. This topic will be covered (whenever the need arises) in (a) separate guidance document(s).

This guidance is focussing on radiological consequences due to atmospheric dispersion of releases. Dispersion through the aquatic system of accidental liquid releases is out of scope.

The applicant is free to propose an approach that differs from this guideline provided it is fulfilling the safety objectives and related guidance in [1]. The nuclear regulator will evaluate the proposed approach and its justification in the light of this guideline.

3 Input from the accident scenario analysis

This guidance will be written supposing that the source term released to the environment is a known input, because determined by an analysis of the incident or accident scenario in the considered installation.

- The available source term and the fraction of it released within the installation after an incident or accident, must be determined with a level of conservatism which is appropriate for the considered incident or accident.
- Retention of radioactive material within the installation is scenario and installation specific. If credited in the determination of the amount of radioactive substances released to the environment, this retention needs to be determined taking into account the appropriate level of conservatism.

The discussion of the topics determining the released source term are out of the scope of this guidance document.

The evaluation of the radiological consequences uses some parameters which depend on the scenario and the installation. Some of those parameters are addressed below, to the extent necessary for the clarity of this guidance further down on the evaluation of radiological consequences.

- Depending on the scenario and the characteristics of the installation, the release point to the environment can be different :
  - The considered release height will affect the meteorological dispersion coefficients to be taken into account. Depending on the scenario and the installation, ground releases or releases through a stack or other parts of the installation have to be considered.
  - In the case of stack release:

- plume rise due to flow velocity resulting from the scenario (e.g. flow velocity corresponding to the available ventilation flow rate) must be taken into account to determine the effective release height.
- plume rise due to temperature difference of the release and the environment must be taken into account to determine the effective release height. Temperature of the released gases is resulting from the scenario, ambient temperature is derived from meteorological data.
- the plume can't rise higher than the height of the inversion layer corresponding to the stability class of the weather conditions. The heights of the inversion layers to be considered are given in table 1a and 1b, for all weather stability classes according to Pasquill and Bultynck-Malet.

- Scenarios including fire, as an initiator or consequential event, need to be considered, where relevant[1]. In case of fire, the plume rise should be considered taken into account the heat release rate (kW/m²) representative for the fire scenario.
- It might be necessary to consider different hypotheses within a scenario leading to different release points or effective release heights. Depending on the evaluation and the criterion to be met, considering different release heights or plume rises might be necessary. Higher values will be more penalising for the size of the affected area (evacuation zone, sheltering zone), lower values will penalise the maximum dose values nearby[2].

- The duration and timing of the releases should be justified by the analysis of the scenarios considered.

Table 1a: Height of the inversion layer for Pasquill stability classes, based on [10]

Stability class	A	B	C	D	E	F
	Very unstable	Moderately unstable	Slightly unstable	Neutral	Slightly stable	Moderately stable
Height (m)	1300	900	850	800	400	100

Table 1b: Height of the inversion layer for Bultynck-Malet stability classes, based on [13]

Stability class	E1	E2	E3	E4	E5	E6	E7
	Very Stable	Stable	Neutral	Slightly unstable	Unstable	Very unstable	High wind speed
Height (m)	400	400	800	850	900	1300	800

[1] Heat release rates to be considered are scenario dependent. References such as [19] can be used to determine appropriate values for the heat release rate.
[2] For example :
- Air plane crash with or without kerosene fire;
- Release from a building with or without failure of the ventilation system ensuring stack release instead of ground release.

4 Representative person

4.1 General aspects

According to the guidance on safety demonstration, dose evaluations have to be performed for the most vulnerable and exposed individual. This representative person is the hypothetical individual receiving a dose which is representative for the most highly exposed group in the population.

The representative person is considered at a location where he is able/allowed to stay and where the person will be exposed at the highest (time integrated) concentration of radioactive releases.

The representative person belongs to the age group which is most affected by the exposure to the radioactive release. The age groups to be considered are given in the Royal Decree of 20/07/2001 annex III [3].

The representative person shall be characterised by age-depending physiological parameters (such as breathing rates), habit data (activities), dietary data and residence data.

The representative person is characterised by data which are reasonable for the most exposed population. This means that the habit data apply realistically to the individual within the range of what people encounter in day-to-day life and are consistent with their daily needs and requirements [8]. This further clarifies the statement of [1]. “The dose for the public should be evaluated for the most exposed and vulnerable individual (based on realistic parameters)…”. These habit data need to be sustainable for a longer period of time. Extreme habits of a single member of the public should not dictate the characteristics of the representative person.

4.2 Specific aspects

4.2.1 Age groups

The age groups to be considered are given in the Royal Decree of 20/07/2001 annex III [3]. The radiological safety objectives need to be met for each age group (except for thyroid dose evaluations for which the guidance on safety demonstration specifies the age groups to be considered: infant, child and adolescent).

4.2.2 Place of residence and activities

The data for the representative person on his level of activity, with related breathing rates, and time spent outdoors are based on the tables 4, 5 and 6 from the ICRP 71 [6]. ICRP71 gives breathing rate data for male persons. Other references may discriminate between male and female for certain age groups (e.g. ICRP89). It is proposed to use only the ICRP71 values for male persons since these values are bounding for both sexes.

The ICRP71 includes the daily time budget at each level of activity for all age groups. In order to simplify the calculation, following assumption could be used for all age groups:

- Light exercise within the time period up to 6 hours after the onset of the releases.
- For release periods exceeding 6 hours, an average activity level can be used for the part after 6 hours.

The numerical values for the breathing rates to be considered are given in table 2.

Table 2: Breathing rates to be considered in the evaluations of radiological consequences, based on ICRP71 [6]

Age group	0 – 1 y.o.	1 – 2 y.o.	2 – 7 y.o.	7 – 12 y.o.	12 – 17 y.o.	Adult
Breathing rate at light exercise (m^3/h)	0.19	0.35	0.57	1.12	1.38	1.50
Daily average breathing rate (m^3/h)	0.12	0.21	0.36	0.64	0.84	0.92

In any calculation of the dose for the public, the representative person should be considered to be outdoors and at ground level, also for the analyses for accidents within C4 when considering the criteria for sheltering and evacuation. However, in the evaluation of the acceptability of the obtained results from the calculation in comparison with the radiological criteria for evacuation, reduction of the dose due to sheltering could be taken into account if justified. This has to be done on a case-by-case basis.

For design basis category C2, C3a and C3b, during short lasting releases (<6h), the representative person should be located at any place outside the site boundaries where the person can stay for work, leisure or residence. For longer lasting releases, after 6h, the representative person is to be located in a location designated as residential area or working area[3]. However, reduction of time being exposed in working areas can be argumented.

For design basis category C4a, the distances to be considered are determined by establishing the sheltering and evacuation zones, as described in the guidance on safety demonstration.

4.2.3 Dietary habits

For the evaluation of the lifetime dose and, in some cases as specified in [1], for the evaluation of the consumability of agricultural products, the ingestion dose is to be considered. Doses received from ingestion of contaminated consumable products should be determined on the consumption rates defined in the table 3, according to the guidance 2012-11-19-KO-5-4-1-FR [2] which is based on US NRC Regulatory Guide RG 1.109.

To evaluate the total effective ingestion dose, a fraction of 10% of contaminated agricultural products may be considered, the remaining 90% being considered as not contaminated [17].

Table 3: Consumption rate of food stuff according to [2]

	Unit	0 – 1 y.o.	1 – 2 y.o.	2 – 7 y.o.	7 – 12 y.o.	12 – 17 y.o.	Adult
Fruits, vegetables, cereals	kg/y	0	520	520	520	630	520
Fresh leafy vegetables	kg/y	0	26	26	26	42	64
Milk	l/y	330	330	330	330	400	310
Meat	kg/y	0	41	41	41	65	110
Fish	kg/y	0	6.9	6.9	6.9	16	21

[3] It is however allowed to apply the more conservative hypotheses applicable for the first 6h hours also in the long term, for instance for reducing the complexity of the calculations.

5 Exposure pathways

The table 4 below recapitulates the exposure pathways to be considered in the evaluation of the radiological consequences for the different design basis categories, as prescribed in the guidance on safety demonstration [1].

In addition the table 4 indicates which dispersion models need to be developed or selected (according to the guidance given below in §6 and §7) in order to evaluate the contribution to the dose of each of these pathways.

Lifetime committed dose for an adult should be determined for a 50y period, for the other age groups 70y should be considered.

Dose conversion factors for irradiation doses (β and γ) should be taken from the Royal Decree of 20/07/2001 annex III [3] where available or could be derived from international references such as [5][7][15][16][18].

Dose conversion factors (Sv/Bq) for lifetime committed effective dose due to ingestion and inhalation are given in the Royal Decree of 20/07/2001 Annex III [3]. Organ weighting factors are given in the Royal Decree of 20/07/2001 Annex II. For dose coefficients which are not listed in the Royal Decree, dose conversion factors should be defined based on other recognized documents such as [5][6][7].

Isotopes can have different dose conversion factors according to the absorption type (fast, medium, slow), which depends on the form of the isotope. In general, the absorption type with the most penalising dose conversion factor should be used in the evaluation of the radiological consequences, unless it is justified that the isotope will be released in a form corresponding to another absorption type.

Table 4: The exposure pathways and dispersion models to be considered for all design basis categories and all radiological criteria to be evaluated according to [1].

	Design Basis Category	**Exposure pathways to be considered**	**Related dispersion phenomena of radioactive releases**
Effective dose assessment	C2 – anticipated operational occurrences C3a – postulated single initiating events C3b – postulated multiple failure events	• Direct exposure[4] • Cloud shine • Inhalation	• Atmospheric dispersion – cloud passage
	C4 – severe accidents	• Direct exposure • Cloud shine • Inhalation • Ground shine	• Atmospheric dispersion – cloud passage • Dry and wet deposition from atmospheric dispersion
Thyroid dose assessment	All	• Inhalation	• Atmospheric dispersion – cloud passage
Consumption of agricultural products	C3a – postulated single initiating events C3b – postulated multiple failure events C4 – severe accidents	• Activity concentration in agricultural products or ingestion dose	• Dry and wet deposition from atmospheric dispersion • Transfer in the food chain
Lifetime committed effective dose assessment	C3a – postulated single initiating events C3b – postulated multiple failure events C4 – severe accidents	• Ingestion dose • Ground shine • Inhalation[5]	• Atmospheric dispersion – cloud passage • Dry and wet deposition from atmospheric dispersion • Transfer in the food chain

[4] For the definition of direct exposure, see FANC Guideline 2013-05-15-NH-5-4-3-EN [1].

[5] For the lifetime committed effective dose, the contributions of direct exposure and cloud shine are not taken into account. Their contribution will be small in comparison to the 1Sv limit if the other dose criteria are already met.

6 Atmospheric dispersion

6.1 Atmospheric dispersion model

6.1.1 General aspects

The dispersion coefficients[6] χ/Q(s/m³), which are the concentration of activity χ (Bq/m³) in the air at a certain spot in the surroundings divided by the released activity rate Q (Bq/s) at the point of release in the installation, should be determined.

To determine these dispersion coefficients, the dispersion of the radioactive material may be described with a bi-gaussian model for a semi-infinite cloud [9][11][12][13][14]. More complex models could be used when available and considered necessary. However, in the case of safety demonstration, doses assessment is merely an estimate for which more accuracy on one particular aspect (e.g. the dispersion) might not be useful.

In a bi-gaussian model, the dispersion coefficient for a distance x in the wind direction from the point of release is depending on the Gaussian parameters $\sigma_y(x)$[7], $\sigma_z(x)$[8], the wind speed and effective release height. The Gaussian parameters $\sigma_y(x)$ and $\sigma_z(x)$ are depending on the weather stability class. These stability classes should be defined based on temperature differences (as a function of height) and wind speeds, using the Pasquill method or an equivalent method (such as Bultynck-Malet).

The actual vertical distribution of activity which is considered should take into account the reflection of the plume on the ground. At the point where the plume hits the ground, the radioactive material is considered to be dispersed back up into the air.

In case of an inversion layer (positive temperature gradients in the lower atmosphere) the plume is also reflected downwards at the height of the inversion layer. For stable weather conditions (relatively small σ_z) this has little impact on the dispersion at relatively short distances from the source. In these cases, it is acceptable not to consider the inversion.

The dispersion coefficients need to be determined for the effective release height which is relevant and justified for the evaluated scenario. Plume rise should be determined based on the temperature difference between the released gases and the mean ambient temperature derived from meteorological data relevant for the site. If the geographic relief in the surroundings of the site might significantly influence the doses at some locations compared to a flat terrain situation, the relief should be considered when modelling the atmospheric dispersion.

For scenarios with ground releases or with a point of release at low height compared to buildings adjacent to the point of release, the wind field at the point of release will be disturbed. Turbulences in the air flow due to the vicinity of buildings near the point of release, and also due to the physical dimensions of the stack in case of stack release, are bending down the plume. This reduction of the effective height of the plume due to building wake effects or stack tip down wash should be taken into account[9]. A way to calculate this reduction of the effective height is documented in Appendix A, based on [20].

The dispersion models for a certain period of time are based on the assumption that the release rate is constant during this period of time. For a release which varies substantially over time, the release should be split up in different periods for which it is convenient to consider a constant

[6] The dispersion coefficients are also sometimes referred to as dilution coefficients or relative concentration values.

[7] $\sigma_y(x)$ – horizontal dispersion parameter in the direction perpendicular to the centerline of the direction (x) in which the plume is progressing (standard deviation of the concentration distribution in the crosswind direction)

[8] $\sigma_z(x)$ – vertical dispersion parameter (standard deviation of the concentration distribution in the vertical direction)

[9] The consideration of the impact of the building wake effect is limited to the impact on the effective release height. It is not required to model the complex turbulent flow in the wake of a building.

release. The prescriptions mentioned above and below within this paragraph 6.1 of this guidance (for effective release height and dispersion coefficients to be used) should be applied to the dose calculations for each of the release periods separately. The resulting doses are the sum of the results for all release periods.

6.1.2 Determination of dispersion coefficient values to be used

Requirements regarding the site evaluation [4] include that the atmospheric dispersion coefficients should be determined using appropriate models. This should be done on the basis of relevant meteorological data [4]. At least one full year of meteorological data collected at or near the site should be available (typically with averaged sampling time max. up to one hour), together with other relevant regional data. Historical data, for instance data obtained before construction of older buildings on the site, can be used if their validity is still justified. The data collected should include wind speed and direction, air temperature, precipitation and atmospheric stability parameters [4].

From this large set of meteorological data, the dispersion coefficients are derived by statistical calculations, as described below in §6.1.2.1 (Approach 1).

In the case that the full set of required data relevant for the site is not available, actions should be started in order to collect the data. These data should be available within two years after the time of publication of this guidance and be used in the safety demonstration of new class I nuclear installations. In the meanwhile, a more pragmatic approach can be applied, using existing dispersion models, in which the dispersion coefficients are defined according to the meteorological stability classes. The use of the models and parameters to be selected in this approach are described in more detail in §6.1.2.2 (Approach 2).

6.1.2.1 Approach 1 – based on a large set of meteorological data

Based on the site-specific meteorological data (see §6.1.2), average wind speed and meteorological stability are derived (typically sampled with 10 minutes as averaged sampling time, max. up to one hour). From this wind speed and meteorological stability, for each sampling point, the dispersion coefficient values can be calculated using existing equations or models[10] taking into account an effective release height representative for the accidental scenario considered. As a consequence, for each distance of interest from the release point, a set of corresponding dispersion coefficients can be obtained.

From the statistical distribution of this set of dispersion coefficients at a certain distance, the dispersion coefficient corresponding to a certain percentile can be derived and selected for the evaluation of the doses. The evaluations of radiological consequences in the safety demonstration should use this value for all wind directions at the same distance from the release point.

It has to be remarked that the meteorological conditions corresponding to the dispersion coefficient selected as conservative value at one distance, are not always leading to dispersion coefficients with the same level of conservatism if applied to other distances.

For release periods that last longer than the averaged sampling time, a new data set can be derived applying a sliding window of time corresponding to the release period. At each distance,

[10] The analytical formulae for determining the Gaussian dispersion parameters $\sigma_y(x)$ and $\sigma_z(x)$ such as those derived by Briggs [14], Bultynck-Malet [13], Hosker... can be used.

the arithmetic mean of the consecutive[11] time interval values for the dispersion coefficient within a time window equal to the release period can be calculated. By sliding this window of time over the original data set of meteorological measurements, a new data set of averaged dispersion coefficients is obtained. From this new data set, again the dispersion coefficients corresponding to the relevant percentiles can be derived in the same way as described above.

Conservative approach
For the design basis categories C2 and C3a, during short term releases as well as during long term releases, the 95 percentile dispersion coefficients should be selected from the statistical distribution.

Less conservative approach
For the design basis categories C3b and C4a, during short term releases as well as for long term releases, median dispersion coefficients should be selected from the statistical distribution.

6.1.2.2 Approach 2 – based on predefined meteorological input data

As long as an extended set of meteorological data are not available to use as input for the approach described above, models can be used which are based on analytical formulae[12] derived for determining the Gaussian dispersion parameters $\sigma_y(x)$ and $\sigma_z(x)$. The parameters are depending on the weather conditions. The analytical formulae are defined for different weather stability classes, such as those defined by Pasquill or Bultynck-Malet.
The dispersion coefficients in these models are determined based on the input of the weather stability class and wind speed (besides effective release heights which are related to the accident scenario). Therefore, the level of conservatism in the evaluation of the radiological consequences is depending on the selected weather conditions.

Table 5 and table 6 specify the stability classes and wind speeds which should be at least considered in the evaluation of the radiological consequences, when using models based upon the stability classes of Pasquill (table 5) and Bultynck-Malet (table 6).

Table 5: Weather conditions to be considered using models with Pasquill stability classes

Design basis category	Approach	Short duration releases (0h to 6h)	Long duration releases (> 6h)
C2	Conservative	Max (A, F) with wind speed 1 m/s	Max (C, F) with wind speed 2 m/s
C3a			
C3b	Less conservative	Max (C, D) with wind speed 3 m/s	Max (C, D) with wind speed 5 m/s
C4			

[11] This means that the real sequence of the meteorological conditions is considered for the point in the grid as they occur time interval by time interval.
[12] Such as those derived by Briggs [14], Bultynck-Malet [13], Hosker,…

Table 6: Weather conditions to be considered using models with Bultynck-Malet stability classes

Design basis category	Approach	Short duration releases	Long duration releases
C2	Conservative	Max (E1, E6) with wind speed 1 m/s	E1 with wind speed 2 m/s
C3a			
C3b	Less conservative	E3 with wind speed 3 m/s	E3 with wind speed 5 m/s
C4			

All wind speeds mentioned in the tables above are to be interpreted as the wind speeds at 10m above the ground. The wind speeds at the effective height of the releases can be determined according to Appendix C.

The selection of stability classes to be considered as presented in the tables above cover accident scenarios where the effective release height is not higher than 200 m. For other scenarios, for instance fires which have higher effective release heights, additional evaluations for other stability classes (e.g. Pasquill class A for a C3b event) should be looked at to ensure that the concentrations are not underestimated. The additional stability classes to be considered could be based on the tables presented in the Appendix B.

Dispersion models are based on sampling measurements for short time periods (10 minutes up to 1 hour). For releases that have longer durations, the horizontal dispersion increases due meandering in the direction of the wind (wider spread angle). Therefore, for longer release periods, the dispersion coefficient $\chi/Q(s/m^3)$ can be corrected to take this into account using:

$\chi/Q^T{}_y(x) = \chi/Q^1{}_y(x) \,.T^{-0,33}$ [9] with:

$\chi/Q^T{}_y(x)$ the dispersion coefficient at distance x valid for a release period of T hours,

$\chi/Q^1{}_y(x)$ the dispersion coefficient at distance x valid for a release period of 1 hour.

If the corrections for longer release periods are not taken into account in the used model, the resulting doses could be corrected using the correction factors in the above mentioned equations.

Conservative approach

For class C2 and C3a events with short lasting releases (<6h, see §4.2.2), penalising meteorological stability conditions together with low wind speeds of 1 m/s should be considered. For release with a low effective height, stable weather conditions will lead to the highest concentrations at short distances. With increasing effective height, unstable weather conditions will become more penalising for the concentration at short distances. Therefore, the maximum result of the evaluations for both most stable and most unstable weather conditions should be considered.

However, for class C2 and C3a events with longer lasting releases (>6h), assuming that very low wind speeds and very unstable conditions dispersion is no longer recommended [12], still a low wind speed of 2 m/s together with neutral and unstable weather conditions is to be chosen for a conservative determination of the concentrations.

Less conservative approach

In the guidance document on safety demonstration, it is indicated that the radiological consequences of the events belonging to design basis class C3b and C4 can be analysed in a less conservative way. For class C3b accidents, effective dose has to be defined for the whole period of the releases or the duration of direct irradiation exposure based on direct exposure, cloud shine and inhalation. Thyroid dose due to inhalation has to be determined. Time periods to be considered for Class C4 accident evaluations are defined in the safety objectives given in [1].

In this less conservative approach, neutral weather stability classes could be used with less penalising (higher) wind speeds.

6.2 Phenomena impacting the airborne concentration of radionuclides

For some of the radiological criteria to be evaluated, ground shine contributions have to be taken into account (see table 4 above). In order to determine the amount of radioactive material contributing to this ground shine dose, deposition from the radioactive material in the plume has to be considered. The determination of deposition of radioactive material is also needed in the evaluation of the consumability of agricultural products.

6.2.1 Radioactive decay

The radioactive decay of radioisotopes can be taken into account. For some isotopes, in evaluations considering longer periods after the release (for instance consumability of food after a year), the public will be exposed to daughter nuclides rather than the released isotope. If the decay of an isotope leads to the ingrowth of daughter nuclides which could have a significant impact on reaching the safety objectives, the ingrowth should be taken into account[13]. Notably, this could be relevant for the evaluation of ground shine dose and consumability of agricultural products.

6.2.2 Deposition

When a radioactive cloud passes in contact with the ground, radioactive material will be deposited. In all evaluations of the radiological consequences, dry deposition can be taken into account.

Wet deposition due to rain increases the amount of deposited material in the affected area. Therefore, for evaluations in which ground shine, the consumability of agricultural products or ingestion dose are considered, wet deposition[14] should be taken into account.

The depletion of the radioactive cloud due to deposition (dry and wet) can be taken into account in the dispersion modelling.

Dry deposition could lead to contaminated areas further away from the point of release, while wet deposition will lead to higher contaminated areas where rain is considered.

For evaluations where safety objective SO2 should be met, the following hypotheses on deposition should be taken into account:

- the effective dose and thyroid dose (for which ground shine is not considered – see table 4) should be determined considering dry deposition only.

[13] Remark that the contribution to the dose from ingrowth of daughter isotopes of an inhaled or ingested isotope is already taken into account in the dose conversion factors of the mother isotope.

[14] Since the mechanism of dry deposition are still present in the case of wet deposition due to rain, the evaluation with wet deposition should consider both wet and dry deposition combined. Whenever wet deposition is mentioned in this guidance, this combination of wet and dry deposition is meant.

- lifetime dose and the consumability of agricultural products should be evaluated considering both dry and wet deposition. A uniform rain should be supposed on site and beyond the site limits.

Evaluations where safety objective SO3 should be met, are related to different zones (evacuation and sheltering zone). When the safety objective is to be met beyond a certain zone, only dry deposition is to be considered within the zone in order to maximize the amount radioactive reaching the zone boundaries. Both dry and wet deposition should be considered beyond the zone, since both situations will penalise other contributors (such as inhalation dose or ground shine dose) to the total effective dose. For the same reason, the evaluation of the lifetime dose for a person beyond the site limits should consider both dry and wet deposition.

6.2.2.1 Dry deposition

Dry deposition is characterised with a deposition velocity (m/s) which is the total activity deposition per m² (Bq/m²) per time integrated concentration at ground level (Bq.s/m³). The magnitude of the deposition velocity taken into account needs to be justified according to the chemical and physical forms of the nuclides.

The deposition velocity for particulates is depending on the particle size. However, in typical studies for the safety demonstration, the distribution of the particle size is not known. Therefore, it is reasonable to work with a single value of at least 0.001 m/s.

The deposition velocity for iodine is depending on its chemical form. For non-organic iodine, a deposition velocity of 0.01 m/s could be used. For organic iodine a lower value of 10^{-4} m/s is reasonable.

6.2.2.2 Wet deposition

Wet deposition due to rainout from a cloud loaded with radioactive material and due to washout by rain falling through the plume should be considered. When considering wet deposition, rain with a uniform intensity at all locations and in time is taken into account.

Evaluations made for wet deposition should take into account the combined contamination of the land by wet and dry deposition.

Wet deposition is characterised with a washout coefficient (s^{-1}). The value of the washout coefficient should be at least:

- 2.10^{-4} s^{-1} for non-organic iodine;
- 2.10^{-6} s^{-1} for organic iodine;
- 2.10^{-4} s^{-1} for aerosols/particulates.

7 Transport of deposited isotopes through the food chain

Radioactive material contaminates agricultural products by deposition on plants/leaves and by root uptake in plants of isotopes which entered the ground. Since agricultural products should be consumable after 1 year [1], deposition on plants and leaves should not be considered in the evaluation. Indeed, during the first year, the agricultural products on which the radioactive material has been deposited will/can be harvested and destroyed.

After one year, the contamination of agricultural products will be caused by the root uptake. Therefore, deposition on the soil (directly from the cloud and due to wash off from plants) should be considered. In determining the activity present in the top layer of the soil after one year, radioactive decay should be taken into account as well as the in-growth of daughter nuclides. In addition, reduction of the concentration due to normal agricultural actions during the first year, such as ploughing, can be credited.

The concentrations in agricultural products grown on the contaminated soil are defined by element specific transfer factors which can be found in publications such as [5].

8 References

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Appendix A – Effective height reduction due to stack tip down wash and building wake effects

The equations used below for calculating the effective release height considering stack tip down wash or building wake effects, are based on the Handbook on Atmospheric Diffusion [20].

A.1 Stack tip down wash

The reduction in effective release height Δh due to stack tip down wash is calculated as:

$$\Delta h = 2 \,.\left(\frac{w_0}{u} - 1.5\right).D \qquad \text{if } \frac{w_0}{u} \leq 1.5;$$

$$\Delta h = 0 \qquad \text{if } \frac{w_0}{u} > 1.5;$$

where:

w_0 is the efflux velocity at the stack tip;
u is the wind speed at stack height;
D is the inner diameter of the stack tip.

A.2 Impact of nearby buildings on effective release height

The impact of the nearby buildings on the effective release height is depending on the difference between the release height of the stack (including the stack tip down wash) and the size of the nearby building.

For a building with height H and width W, ζ is defined as the smaller of H and W. From the release height of the stack reduced with the tip down wash h' (= stack height + Δh), the effective release height h_e, taking into account the effect of the building, is calculated as follows:

If	$h' > H + 1.5\,\zeta$	then	$h_e = h'$;
If	$H + 1.5\,\zeta > h' > H$	then	$h_e = 2h' - (H + 1.5\,\zeta)$;
If	$H > h'$	then	$h_e = h' - 1.5\,\zeta$.

Appendix B – Relation between stability classes and wind speeds

The relation between wind speed and stability class is listed in the tables below for the Pasquill classes and for the Bultynck-Malet classes.

Pasquill (From Pasquill, F. 1961: The estimation of the dispersion of windborne material, Meteorol. Mag., 90 (1063): 33-49) :

	Insolation			Night	
Surface wind speed (at 10 m) m s^{-1}	Strong	Moderate	Slight	Thinly overcast or > 4/8 low cloud	< 3/8 cloud
< 2	A	A - B	B	—	—
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

Bultynck-Malet (From Noodplan SCK•CEN : Standaard scenario's ongevallen installaties SCK•CEN - REF.IDPBW.1570.N):

Dag					
Windsnelheid (m/s) (op 160 m)	≤ 2	2 – 3	3 - 5	5-13	> 13
Sterke zon	E6	E6	E6	E5	E7
Matige zon	E5	E5	E4	E3	E7
Weinig zon	E5	E4	E4	E3	E7
Bewolkt	E3	E3	E3	E3	E7

Nacht					
Windsnelheid (m/s) (op 160 m)	≤ 2	2 – 3	3 - 5	5-13	> 13
Helder – licht bewolkt	E1	E1	E1	E2	E7
Bewolkt	E1	E1	E2	E3	E7
Zwaar bewolkt – betrokken	E1	E2	E3	E3	E7

Appendix C – Correlation between wind speed and height

The change in wind speed as a function of height can be expressed using the following law:

$$u(h1) = u(h2) . (h1/h2)^p$$

with:

u(h1): wind speed (m/s) at height h1 (m);

u(h2): wind speed (m/s) at height h2 (m);

p: exponential factor according to the tables below.

Table B.1 – Exponential factors to be used for Pasquill stability classes [14].

A	B	C	D	E	F
Very unstable	Moderately unstable	Slightly unstable	Neutral	Slightly stable	Moderately stable
0.07	0.07	0.10	0.15	0.35	0.55

Table B.2 – Exponential factors to be used for Bultynck-Malet stability classes [13].

E1	E2	E3	E4	E5	E6	E7
Very Stable	Stable	Neutral	Slightly unstable	Unstable	Very unstable	High wind speed
0.53	0.40	0.33	0.23	0.16	0.10	0.33