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Description of NORMTRI: a Computer Program for Assessing the Off-Site Consequences from Air-Borne Releases of Tritium During Normal Operation of Nuclear Facilities

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Abstract

The computer program NORMTRI has been developed to calculate the behaviour of tritium in the environment released into the atmosphere under normal operation of nuclear facilities. It is possible to investigate the two chemical forms tritium gas and tritiated water vapour. The conversion of tritium gas into tritiated water followed by its reemission back to the atmosphere as well as the conversion into organically bound tritium is considered.

NORMTRI is based on the statistical Gaussian dispersion model ISOLA, which calculates the activity concentration in air near the ground and the ground contamination due to dry and wet deposition at specified locations in a polar grid system. ISOLA requires a four-parametric meteorological statistics derived from one or more years synoptic recordings of 1-hour-averages of wind speed, wind direction, stability class and precipitation intensity.

Additional features of NORMTRI are the possibility to choose several dose calculation procedures, ranging from the equations of the German regulatory guidelines to a pure specific equilibrium approach.

Beschreibung von NORMTRI: Ein Rechenprogramm zur Abschätzung der radiologischen Konsequenzen von Tritiumfreisetzungen während des Normalbetriebs kerntechnischer Anlagen

Zusammenfassung

Das Computerprogramm NORMTRI dient zur Berechnung des Verhaltens von Tritium in der Umwelt, das während des Normalbetriebs einer Anlage emittiert wurde. Es ermöglicht das Verhalten von Tritiumgas und tritiierten Wasserdampf modellmäßig zu beschreiben. NORMTRI enthält die wichtigsten Prozesse wie die Umwandlung von Tritiumgas in tritiierten Wasserdampf, die Reemission von tritiiertem Wasserdampf wieder zurück in die Atmosphäre sowie die Umwandlung in das organisch gebundene Tritium.

NORMTRI basiert auf dem statistischen gaußartigen Ausbreitungsmodell ISOLA. ISOLA berechnet die bodennahe Aktivitätskonzentration in der Luft und die Bodenkontamination durch trockene und nasse Ablagerung an Gitterpunkten, die in einem Polarkoordinatensystem durch die Schnittpunkte von Winkel und Radius festgelegt werden. Es benötigt eine 4-parametrige Ausbreitungsstatistik über mehrere Jahre, die aus stündlichen Mittelwerten der Windgeschwindigkeit und -richtung, der Ausbreitungskategorie und Niederschlagsintensität abgeleitet wird.

Außerdem ist es in NORMTRI möglich, verschiedene Berechnungsweisen der Individual- und Kollektivdosen zu wählen. Es werden sowohl Ansätze, die auf den deutschen Genehmigungsrichtlinen basieren, vorgestellt, und auch solche, die auf spezifischen Gleichgewichtsbedingungen beruhen.

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1. Introduction

This report describes the computer code NORMTRI, developed for dose assessments of tritium emissions during normal operations of nuclear facilities. The releases of tritium may appear as a gas (HT), see Figure 1, or as tritiated water (HTO), see Figure 2.

The radionuclide tritium may occur in the environment in three chemical forms as HT, HTO and organically bound tritium (OBT). The behaviour of tritium in the environment after chronic HTO releases seems to be well understood (see e.g. [23]. [1], [26] and [17]). Tritium, released as HTO, may be deposited on soil and vegetation via dry and wet deposition processes. In soil, HTO is rapidly connected to the residual soil water.

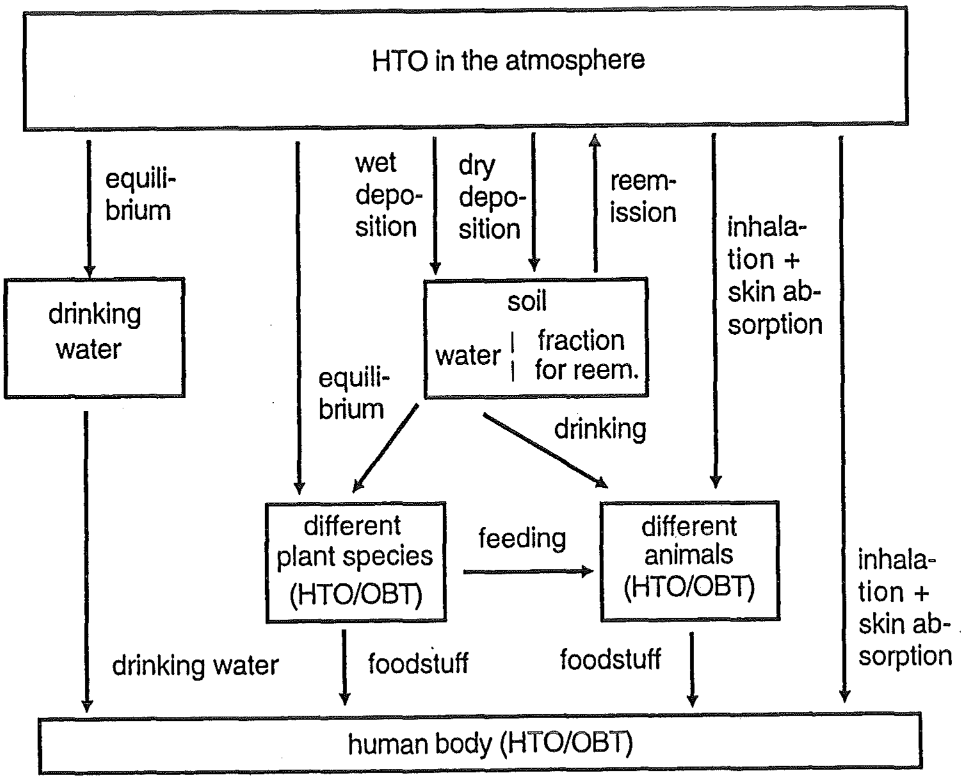

Figure 1. Structure of NORMTRI (HTO part)

Tritium concentrations in plants are strongly correlated to the HTO concentrations in air humidity and precipitation water. Theoretical considerations and experimental work evaluated in the above mentioned articles, indicate that the tritium in the plants has its source in both, the air-water and the soil-water compartment. The relative humidity of the atmospheric water is hereby the steering factor. If the air humidity is very high, most of the tritium originates from the atmosphere. If the air humidity is very low, most of the tritium enters the plant via the root system.

Data from Savannah River show [18], that the specific tritium concentrations in foodstuffs reach about 50 to 80% of the specific tritium concentration in atmospheric moisture. Measured specific tritium concentrations in rainwater at the same locations have values close to the tritium content in air moisture [18]. Measurements [2] as well as the experience gained from applications of the accidental tritium model UFOTRI [24] show that most of the dry deposited tritium evaporates back into the atmosphere very rapidly, before it became available to the plants. Therefore it is assumed in NORMTRI that all the HTO from dry deposition will be released back into the atmosphere. Only the HTO from the wet deposition process is used for the calculation of the specific tritium concentration in the soil water, which can be taken up by the plant via the root system.

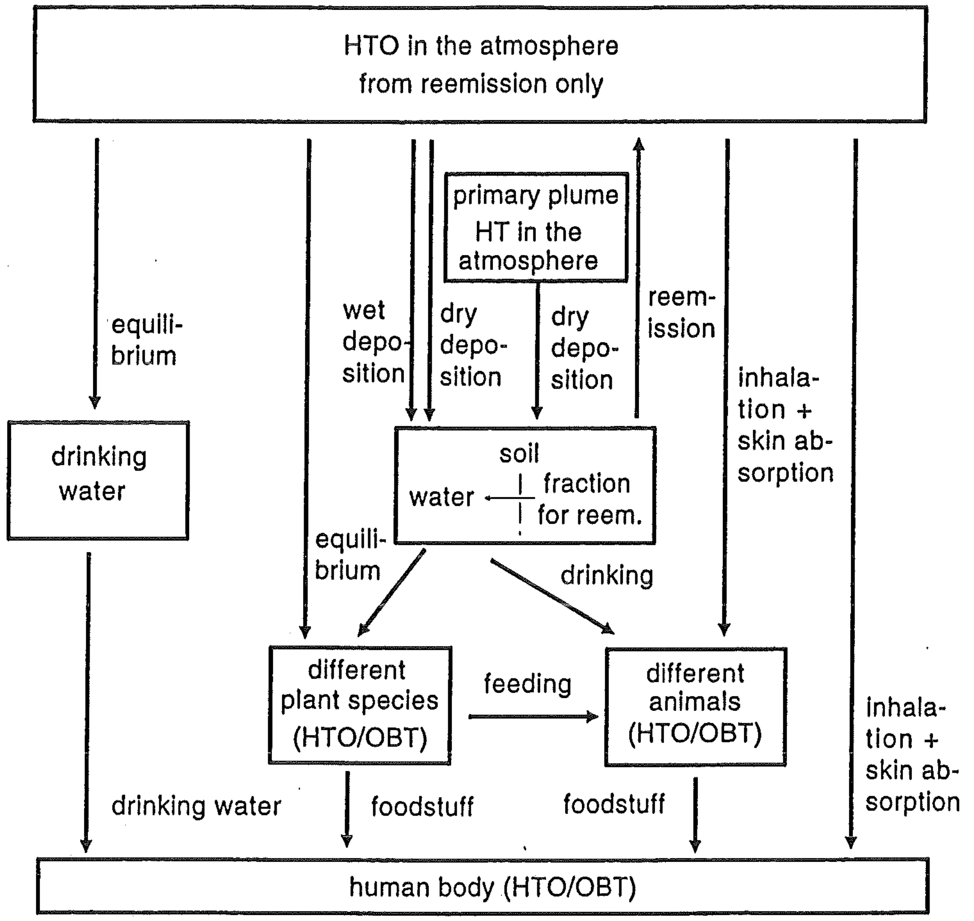

Figure 2. Structure of NORMTRI (HT part)

The behaviour of tritium in its chemical form of HT is slightly different, however, the doses are much lower compared to a release of HTO. Tritium gas, released into the atmosphere will be deposited to the soil only via the dry deposition process [8]. Conversion of HT into HTO during the atmospheric transport as well as the direct uptake by the leaves of the plants is negligibly small [8]. Once deposited, HT converts rapidly into

HTO, which will be then reemitted again into the atmosphere. Therefore, the tritium concentration in foodstuffs is determined solely by the converted HTO.

To avoid high effort for programming and computing time for a dynamic modelling of the behaviour of the reemitted HTO following a chronic HT emission, the ratio of the activity concentration in air between HT and the reemitted HTO in the equilibrium state has to be defined. Applying this equilibrium factor, it is possible to calculate the HTO concentrations in the foodchains. As until now no long-term controlled experimental results are available, data from short-term HT-release experiments performed in France [7] and Canada [2] are often used to derive such equilibrium factors (see for example [20]). To close this gap of knowledge, a chronic HT release experiment is planned for Summer 1994 [6].

A second method has been applied in the TRITMOD model [17]. The model combines a compartimental approach for calculating the mass balance at every distance point with an atmospheric dispersion module under steady state conditions. The code includes processes such as deposition to soil and plants, reemission from soil and plant to the atmosphere and transport to deeper soil layers. The straight line Gaussian atmospheric dispersion module calculates the tritium concentration stepwise - from one distance point to the next - starting close to the source. For each step the compartimental module is been called and determines the mass balance at this grid point under steady state conditions. The new tritium concentration in the air at this point, which results from the compartment module, is then the new tritium concentration for the atmospheric dispersion module which transports the tritium to the next gridpoint. Simplified one can say that the reemitted HTO from one grid point will be added to the tritium from the primary plume during the tranport process. A disadvantage of this model is the fact that the atmospheric transport is only directed straight forward. This implies that the windrose has to be nearly uniform distributed within the year.

Another method, which has been applied in NORMTRI, is to describe the transport and dispersion process of the reemitted HTO explicitely by a dispersion model. Hereto a statistical atmospheric dispersion model has been applied, which calculates the dispersion process within one year for all emissions from the relevant area sources located in the area under investigation. This approach has the advantage, that one can use the knowledge about the behaviour of HTO in the environment also for releases of HT-gas, because the tritium concentration in air humidity and soil water based on the reemitted HTO from the area sources determines the tritium concentration in the foodstuffs.

Here it has to be mentioned, that the weather data from one year, which is the standard application period, will be subdivided into two winter periods (from January 1. to March 31. and from October 16. to December 31.) and one vegetation period (from April 1. to October 15.).

2. Atmospheric dispersion submodule

The atmospheric dispersion process is subdivided into two steps. Primarily, one has to calculate - within a certain time period (e.g. 1 year) - the dispersion of the released tritium from the site and the subsequent deposition onto the ground. In a second step, the reemission of tritium from the ground has to be taken into account - also for the same time period as before. For both, the computer code ISOLA V has been applied. A detailed description of the dispersion module used in NORMTRI can be found in Appendix A. A short overview ot its principles can be found in this chapter.

2.1 Primary plume module

The computer code ISOLA V calculates the air and ground concentration patterns around nuclear installations for long-term quasy stationary release situations. ISOLA V is a so-called 'statistical Gaussian dispersion model'. This means, for all different dispersion situations during the considered time period, a double Gaussian distribution of the released radionuclides is assumed throughout the plume.

ISOLA V uses hourly meteorological data of a station near the source. Therefrom a four-parameter statistics will be prepared [28]. It includes meteorological parameters such as wind speed, wind direction, stability classes and rain intensities. A frequency distribution will be calculated for each of the different dispersion conditions which have been identified to occur during the investigation period. Thereafter, for all the sampled dispersion conditions, the activity concentrations of the air near the ground and the ground contamination will be calculated. The activity concentrations calculated for these dispersion situations around the nuclear installation will be summarized, whereby their frequency of occurrence is taken into account. This leads to a mean contamination during the considered time period.

The source is assumed to be cold (that means, no thermal plume rise). The plume inventory is depleted during the passage by dry and wet deposition. The plume extends into one, two or more sectors, depending on its width and the position of the axis relative to the wind direction sectors. The calculation matrix is a polar r - ϕ coordinate system with an angular resolution of 5^0 (72 sectors) and a maximum number of 20 radii. The weather statistics and dispersion modules use an azimuthal resolution of 15^0 or 30^0.

2.2 Area source module

ISOLA V has been also applied for the calculation of the transport and dispersion of the secondary plumes which originate from the area sources. The area source for the polar coordinate system will be defined as follows. Starting from the north clockwise, 7 grid points of two neighboured radii (= 14 grid points) will define one area source. These 14 values will be used to calculate the mean tritium concentration in soil by simple arithmetic averaging. The centre of each area will be the point where the plume for the reemission process starts. Assuming that the total area under investigation will be subdivided into 20 radii and 72 sectors, 240 different area sources can be defined (12 per distance band x up to 20 distances). To save computing time - the results are also not very sensitive to a second reemission phase - the newly deposited tritium will not be considered for a second reemission step, which may slightly underestimate the influence of the reemitted HTO.

Every area source will release its tritium content under the identical weather conditions of the primary dispersion process. Thus the program ISOLA will be applied up to 240 times during one weather period, with different locations of the release point.

There exist a lot of possibilities to replace the exact but complicate solution of a double integral for the area source by other, nearly accurately but simplified, assumptions [9]. One of them which has been successfully used within the accidental tritium dispersion code UFOTRI [24]replaces the area source by a single source point in the centre of the area, with a given initial widening of the plume. This method presents the least difficulties in programming combined with an acceptable accuracy (see [24]). The source point in the center of the area source is assigned an initial sigma value σ_{y0} whose square is added to sigma σ_y

$$\sigma_{yg} = \sqrt{\sigma_y^2 + \sigma_{y0}^2} \qquad (1)$$

The initial sigma value σ_{y0} is defined as the width of the area source divided by 4.3, a factor resulting from the geometry of a Gaussian plume. At a distance of 2.15 x σ_{y0} from the plume axis in each lateral direction, the concentration has decreased to 1/10 of the concentration below the plume axis. This is the limiting criterion for a plume as commonly defined in the relevant literature [27]. The remaining calculational procedure for the dispersion modelling is the same as for an individual source; only σ_{yg} will be used instead of σ_y.

3. Tritium submodel

3.1 *General remarks*

In NORMTRI it is assumed that the specific tritium content (HTO) in vegetation water has its sources in both, the soil water and the atmospheric humidity. Furtheron, the relative air humidity defines the fraction of the tritium which results from the atmospheric water vapour or from the soil water. If the humidity is high, the atmosphere is dominating, if the humidity is low, the soil water is the prefered source for HTO. A discrimination factor of about 1.1, which has its origin in the differences of the molar weights of water vapour and tritiated water vapour, has to be taken into account when calculating the equilibrium between air and plant water. [25]. Therefrom the basic equation describing the HTO content in the plant water can be derived as:

$$C_{pw,HTO} = 1.1\,\rho\,C_{air,HTO} + (1.-\rho) \times C_{soil,HTO} \tag{2}$$

with:

$C_{pw,HTO}$	specific HTO concentration in plant water
$C_{air,HTO}$	specific HTO concentration in air humidity
$C_{soil,HTO}$	specific HTO concentration in soil water
ρ	relative air humidity (ranging from 0. to 1.)

The relative humidity in Europe and in most of the non-arid regions range from 70% to 80% averaged over the year [11]. The first value seems to be more applicable for summer conditions, the latter one for the winter time. However, since most of the exchange between the air and the vegetation takes place during the daytime, a further reduced value for the relative humidity may be used. Of great importance is the absolute amount of water in the air, which has to be used to calculate the specific HTO concentration in the atmosphere. The following parameter values may be used as a standard input for the vegetation period:

rel. humidity	70 %
temperature	$15\ ^0$
absolute humidity	9.2 (g/m^3)

The tritium concentration in the organic material (OBT) is assumed to be in fully equilibrium with the HTO in the plant water. Experimental results obtained for animals (rabbits) which lived for 3 years in a separated environment under equilibrium conditions, indicate this equilibrium approach of 1.0. [16]. However, new experimental work [15] shows, that the OBT may be discriminated against HTO by about 30 to 40 %. This discrimination factor can be considered in NORMTRI but the fully equilibrium is used as default value, which may be changed easily by the user. It is further assumed, that an equilibrium state is established from the beginning of the time period under investigation. This is due to the fact that in case of normal operation conditions, the tritium releases from former years tend to establish equilibrium conditions over the whole time period of many years.

As the amount and the composition (water and organic fraction) of the nutriments are important for the transfer rate of tritium into the human body, the list of foodstuffs considered in NORMTRI has been extended in comparison to the German regulatory guidelines. The typical German diet can be subdivided into 7 classes of nutriments. For each of these classes one or more foodstuffs have been considered in the model:

leafy vegetables	salad
root vegetables	potatoes
grain products	winter wheat
fruits	apples
meat and meat products	beef, pork, sheep and chicken
milk and milk products	milk from dairy cows
drinking water	drinking water

Beside the above mentioned nutriment plants, several forage crops for cows, beef, pork and chicken, are considered in NORMTRI (see Table 1).

foodstuff	water content (%)	content of organic matter (%)
winter wheat	13	87
potatoes	80	20
salad	90	10
apples	80	20
white beet	80	20
hey	14	86
grass	80	20
manjok	13	87
silage	65	35

Table 1. Plants considered in NORMTRI together with their contribution of organic and anorganic matter

Food processing is accounted for by weighting factors, however - to the authors knewledge -, values for tritium have not been reported in the open literature.

3.2 Tritium in water

In NORMTRI the user can choose two different ways to calculate specific HTO concentrations in water. First, it can be assumed that the drinking water for humans as well as the water for animals originates from deeper sources such as the ground water. The second approach treats the drinking water as surface water. The HTO concentration in surface water can be calculated by assuming equilibrium between air moisture and surface water. The concentration in ground water can be derived by applying a reduction factor, redw, to the HTO concentration obtained for the surface water. Thus the tritium concentration in water can be calculated:

$$C_{wat} = \frac{C_{ay,HTO}}{\Phi \, aky} \times redw \tag{3}$$

with:

C_{wat}	specific HTO concentration in drinking water in Bq/kg
$C_{ay,HTO}$	mean HTO concentration in air moisture during the whole year in $Bq\,s\,m_{-3}$
aky	1 year in s
Φ	average water content in air during the whole year in $kg\,m^{-3}$
redw	reduction factor for ground water concentration (default = 0.001)

The difference between the HTO concentration in surface water and ground water is set to a value of 1000, which can be easily changed by the user. It should represent the dilution which occurs if the tritium from the surface travels downwards to a depth of several 10 meters and is then diluted within a large reservoir of ground water.

3.3 Tritium in plants

The calculation procedure for most of the considered plants is similar to that described in detail for leafy vegetables in the next paragraph. The HTO content in the atmospheric water and the soil water are both sources for the tritium concentration (HTO and OBT) in the crops with the relative humidity as the steering factor as described above. What differs from plant to plant is the fraction of the organic and anorganic matter. These values are listed in Table 1 for several crops and referred lateron as pf1 (water) and pf2 (organic). The root vegetables are treated in a slightly different way. There, the OBT and HTO content are derived separately. The HTO content in the tubers has solely the soil as source, whereas the OBT concentration in the tubers is calculated as for the leafy vegetables, with the soil and the atmosphere as source.

The HTO concentration in soil is calculated separately for an HT and HTO release. In case of an HTO-release, only the wet deposited tritium - resulting from the primary or from the reemission process - is used for the calculations of tritium in plants. The dry deposited tritium is assumed to evaporate totally back into the atmosphere. In case of an HT-release the dry deposited HT - wet deposition is negligible small - is converted into HTO, which is reemitted again into the atmosphere. The reemitted HTO is then the source for the tritium in plants and lifestock. The converted and reemitted HTO is treated as if it was primarily an HTO release. However, the dry deposition process from HT is different from that of HTO. Here the convertion of HT into HTO due to microbiological activities is the dominating factor for determining the dry deposition rate. From experimental results it is known that the HT-gas penetrates deeper into the soil than HTO. It is converted into HTO and the remaining HT is directly evaporated back into the atmosphere, as it is not bound to the soil or the water in soil. Due to these processes, which are different from those found for HTO, it is assumed in NORMTRI, that not all the converted HTO evaporates back into the atmosphere. This assumption is supported by results obtained within the short-term HT-release experiments performed in France [7] and Canada [2] as well as experience gained from model calculations with the tritium model UFOTRI developed for accidental release situations. Both indicate, that a noticeable amount of HTO still remains in the soil. Thus it is assumed that 20% of the primarily deposited HT, which is converted into HTO, remains in the soil and contributes to the specific tritium content in soil water together with the wet deposited HTO from the area sources.

3.3.1 Tritium concentrations in leafy vegetables (salad)

The mean specific HTO concentration in the atmospheric water vapour and the soil water during the vegetation period is the basis for the calculation of the HTO concentration in leafy vegetables. The HTO concentration in vegetables for the winter seasons (storage) has been derived from the summer value by simply considering the radioactive decay during the time difference between harvesting and consumption.

The HTO concentration in salad for the vegetation period is calculated as follows:

$$\begin{aligned} C_{lv,s,HTO} &= 1.1\,\rho\,\frac{C_{a,HTO}}{ak} \times \frac{pf1_{lv}}{\Phi} \\ &\quad + (1.0-\rho) \times C_{s,HTO} \times \frac{pf1_{lv}}{wat_s} \end{aligned} \tag{4}$$

with:

$C_{lv,s,HTO}$ specific HTO concentration during the vegetation period in leafy vegetables in Bq/kg wet weight

$C_{a,HTO}$ time integrated HTO air concentration in $Bq\ s\ m^{-3}$

ak	duration of the vegetation period in s
$pf1_{lv}$	water content in 1 kg fresh weight (0.8 kg)
ρ	relative air humidity (ranging from 0. to 1.)
Φ	mean water content in air during the vegetation period in $kg\ m^{-3}$
$C_{s,HTO}$	HTO in soil within the vegetation period in $Bq\ m^{-2}$
wat_s	precipitation, fallen during the vegetation period in $kg\ m^{-2}$

For the vegetation period, the OBT concentration in salad will be obtained by multiplying the HTO equilibrium concentration with a reduction factor taking into account the lower amount of hydrogen atoms in the organic material in comparison to water, as well as a potential discrimination factor:

$$\begin{aligned} C_{lv,s,OBT} = {} & 1.1\,\rho\,\frac{C_{a,HTO}}{ak} \times \frac{pf2_{lv}}{\Phi} \times redh \times dis \\ & + (1.0-\rho) \times C_{s,HTO} \times \frac{pf2_{lv}}{wat_s} \times redh \times dis \end{aligned} \tag{5}$$

with:

$C_{lv,s,OBT}$	specific OBT concentration during the vegetation period in leafy vegetables in Bq/kg wet weight
$pf2_{lv}$	organic matter in 1 kg fresh weight (0.2 kg)
$redh$	reduction factor of hydrogen content in the organic matter to hydrogen content in water (0.73)
dis	discrimination factor of the equilibrium concentration in organic matter (1.0)

During the two winter seasons, the HTO concentration in salad is calculated by multiplying the summer concentration simply with a reduction factor which takes the radioactive decay during the two storage periods into account. The first lasts about 3 months (end of summer till end of the year) and the second lasts 5 month from the end of the vegetation season (previous year) till the vegetation period of the present year. For the latter one, striktly speaking, the concentration of the former year has to be applied. But under the assumption, that the weather and the emission rates have not changed during the operation period, only one mean meteorological year seems to be sufficient.

$$C_{lv,w,HTO} = C_{lv,s,HTO} \times reds_w \times dis \tag{6}$$

with:

$C_{lv,w,HTO}$	specific HTO concentration during the two winter seasons (w1, w2) in leafy vegetables in Bq/kg wet weight
$reds_w$	radioactive decay for storage from summer to winter (two times: period prior to the summer, period following summer)

The OBT concentration in salad for the winter seasons is calculated as mentioned above for the OBT concentration during the summer season.

$$C_{lv,w,OBT} = C_{lv,s,OBT} \times reds_w \tag{7}$$

with:

$C_{lv,w,OBT}$ specific OBT concentration during the two winter periods (w1, w2) in leafy vegetables in Bq/kg wet weight

3.3.2 HTO concentrations in root vegetables (potatoes)

It is assumed that the tritium in soil dominates the HTO concentrations in the edible parts (tubers) of the root vegetables. For the HTO concentration in the water compartment of the tubers it is therefore assumed that it originates solely from the HTO in the soil water. The OBT concentration in the organic parts of the tubers will be calculated according to the standard procedure described above, with the two sources of tritium such as the air moisture and the soil water. The reason for this treatment can be found in the growing process of the organic material, which takes place in the photosynthetic active parts of the plants which are located above the ground. During the production of the dry matter, the specific tritium concentration in plant water will be the source for the permanently incorporated tritium into the organic fraction. The organic material will then be translocated downwards and stored into the tubers. Thus, the specific OBT concentration in tubers is linked to the specific HTO concentration in plant water.

For the vegetation period, the HTO concentration in the tubers will be calculated:

$$C_{po,s,HTO} = C_{s,HTO} \times \frac{pf1_{po}}{wat_s} \tag{8}$$

with:

$C_{lv,s,HTO}$ specific HTO concentration during the vegetation period in tubers in Bq/kg wet weight

$C_{s,HTO}$ HTO in soil within the vegetation period in $Bq\ m^{-2}$

$pf1_{po}$ water content in 1 kg fresh weight of potato tuber (0.8 kg)

The OBT concentration in potato tubers for the vegetation period is calculated according to the procedure described for leafy vegetables:

$$\begin{aligned} C_{po,s,OBT} = {} & 1.1\,\rho\ \frac{C_{a,HTO}}{ak} \times \frac{pf2_{po}}{\Phi} \times redh \times dis \\ & + (1.0-\rho) \times C_{s,HTO} \times \frac{pf2_{po}}{wat_s} \times redh \times dis \end{aligned} \tag{9}$$

with:

$C_{po,s,OBT}$ specific OBT concentration during the vegetation period

	in tuber in Bq/kg
$pf2_{po}$	organic matter in 1 kg fresh weight of potato tuber (0.2 kg)

The tritium concentrations for both winter periods can be determined by multiplying the summer concentrations with the reduction factor, reds, taking into account the delay time between harvesting and consumption or feeding. This has been demonstrated for salad and will not be repeated here again.

3.4 Tritium in meat from beef, pork, sheep and chicken

It is assumed that the water compartment as well as the organic compartment of the animals is in equilibrium with the incoming tritium originating from inhalation, skin absorption and the feeding material. The animal's feed consists mainly of forage crops and water as listed below. Its combination differs from winter to summer, as shown exemplarily in Table 2 and 3. The tritium concentration in drinking water for animals may be reduced by a diluting factor (deep source from uncontaminated ground water) or it can be in equilibrium with the concentration in air moisture (surface water). Uptake of HTO via inhalation and skin absorption is an additional pathway for the uptake of air moisture. The breathing rates of the five animal species are listed in Table 4. Skin absorption is taken into account by multiplying the breathing rate with a factor of 1.5, which is well established for humans [21], but may overestimate the real values for animals with a thick coat. The HTO concentration in animal meat can be calculated by adding all the incoming tritium connected to each pathway (feeding or inhalation + skin absorption), weighted by its relative fraction of the total uptake of water. In case of feeding water intake, the specific concentration of soil water or of drinking water will be applied.

$$\begin{aligned} C_{ms,HTO} &= 0.9 \times \left(\sum_{n=1}^{N} C_{as,n,HTO} \frac{FO_{m,n}}{FOT_m} + C_{a,HTO} \frac{BRS_m}{FOT_m} \right) \\ &\quad + 0.9 \times \left(\sum_{n=1}^{N} C_{as,n,OBT} \frac{FO_{m,n}}{FOT_m} \right) \end{aligned} \qquad (10)$$

with:

$C_{ms,HTO}$	HTO concentration in meat of animal m during the vegetation period in Bq/kg wet weight
$C_{as,n,HTO}$	HTO concentration in feeding foodstuff n of animal m during the vegetation period in Bq per kg wet weight
$C_{a,s,n,OBT}$	OBT concentration in feeding foodstuff n of animal m during the vegetation period in Bq per kg wet weight
$FO_{m,n}$	intake of forage plant n and animal m in kg/day wet weight
BRS_m	water intake from inhalation + skin absorption per animal m in kg/day

FOT_m $\quad BRS_m + \sum_{n=1}^{N} FO_{m,n}$ total amount of forage + atm. humidity intake per animal m in kg/day wet weight

The OBT concentration in animal meat will be calculated similar to the procedure above. Only a reduction factor, redh, will account for the difference in the number of hydrogen atoms between the organic and anorganic fractions.

$$\begin{aligned} C_{ms,OBT} &= 0.1 \times redh \times \left(\sum_{n=1}^{N} C_{a,s,n,HTO} \frac{FO_{m,n}}{FOT_m} + C_{a,HTO} \frac{BRS_m}{FOT_m} \right) \\ &+ 0.1 \times \left(\sum_{n=1}^{N} C_{as,n,OBT} \frac{FO_{m,n}}{FOT_m} \right) \end{aligned} \tag{11}$$

with:

$C_{ms,OBT}$ OBT concentration in meat of animal m during the vegetation period in Bq/kg

The amount of feedstuff for the five animals within the vegetation period is listed in Table 2. During the winter period the feeding habits change for most of the animals (see Tables 2 and 3). This implies new values for $FO_{m,n}$ and FOT_m. Additionally, the reduction due to the radioactive decay, $reds_w$, has to be considered. Thus Equation 9 and Equation 10 have to be multiplied by $reds_w$ and the values for $FO_{m,n}$ and FOT_m have to be taken from Table 3.

	cereal	potatoes	white beet	hey	grass	manjoc	silage	water
cow	0.0	0.0	0.0	4.0	65.0	0.0	0.0	30.0
beef	0.0	0.0	0.0	3.0	0.0	0.0	13.0	30.0
pork	2.55	0.1	0.0	0.0	0.0	0.25	0.0	12.0
sheep	0.0	0.0	0.0	0.0	8.0	0.0	0.0	3.0
chicken	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Table 2. Animal forage (FO) during the summer period in kg/day wet weight

	cereal	potatoes	white beet	hey	grass	manjoc	silage	water
cow	0.0	0.0	0.0	3.0	0.0	3.6	3.2	70.0
beef	0.0	0.0	0.0	3.0	0.0	0.0	13.0	30.0
pork	2.55	0.1	0.0	0.0	0.0	0.25	0.0	12.0
sheep	0.3	0.0	0.0	0.5	0.0	0.0	2.0	9.0
chicken	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Table 3. Animal forage (FO) during the winter period in kg/day wet weight

	breathing rate in m^3/day	skin absorption rate in m^3/day	total water uptake (BRS) in kg / day
cow	130.0	65.0	1.75
beef	75.0	37.5	1.01
pork	25.0	12.5	0.34
sheep	17.0	8.5	0.23
chicken	0.4	0.2	0.004

Table 4. Water uptake of 5 animals via inhalation and skin absorption: (water content of 9 g per m^3 air)

3.5 Tritium in milk from dairy cows

As for the tritium in meat, it is assumed that the milk is in equilibrium with the incoming tritium from inhalation, skin absorption and fodder. The general approach is in accordance with the formalism used for animal's meat, thus one can use Equation 9 and Equation 10 by modifying simply the fraction of the water taken up via feeding (FO) and inhalation + skin absorption (BRS). The HTO concentration in milk will be calculated:

$$\begin{aligned} C_{mi,s,HTO} &= 0.91 \times \left(\sum_{n=1}^{N} C_{a,s,n,HTO} \frac{FO_{c,n}}{FOT_c} + C_{a,HTO} \frac{BRS_c}{FOT_c} \right) \\ &+ 0.91 \times \left(\sum_{n=1}^{N} C_{a,s,n,OBT} \frac{FO_c}{FOT_c} \right) \end{aligned} \tag{12}$$

with:

$C_{mi,s,HTO}$	HTO concentration in milk of the dairy cow for the vegetation period in Bq/kg wet weight
$C_{a,s,n,HTO}$	HTO concentration in feeding foodstuff n of the cow during the vegetation period in Bq per kg wet weight
$C_{a,s,n,OBT}$	OBT concentration in feeding foodstuff n of the cow c during the vegetation period in Bq per kg wet weight
$FO_{c,n}$	amount of feeded material per plant n and cow c in kg
BRS_c	water intake from inhalation + skin absorption for the dairy cow in kg/day
FOT_c	$BRS_c + \sum_{n=1}^{N} FO_{c,n}$ total amount of forage + atm. humidity intake per dairy cow in kg/day

The OBT concentration in milk of a dairy cow can be obtained:

$$\begin{aligned} C_{c,s,OBT} &= 0.09\,redh \times \left(\sum_{n=1}^{N} C_{a,s,n,HTO} \frac{FO_{c,n}}{FOT_c} + C_{a,HTO} \frac{BRS_c}{FOT_c} \right) \\ &+ 0.09 \times \left(\sum_{n=1}^{N} C_{a,s,n,OBT} \frac{FO_c}{FOT_c} \right) \end{aligned} \tag{13}$$

with:

$C_{mi,s,OBT}$	OBT concentration in milk of a dairy cow during the vegetation period in Bq/kg wet weight

During the winter season, the feeding habits change according to Table 2. The Equations 11 and 12 will be modified with new $FO_{c,n}$ and FOT_c values and multiplied with the reduction from radioactive decay as explained for animal's meat.

3.6 Dose calculations

NORMTRI offers 3 options to calculate the dose to the public from tritium releases during normal operations. First and recommended is the approach as described in the following chapter. A further possibility is to assume that the whole body of an individual is always in equilibrium with the air humidity, independent of the foodstuffs consumed (see chapter 3.7.2). As a third option one can calculate the dose according to the set of equations proposed in the German regulatory guidelines [3] (see chapter 3.6.3).

3.6.1 Standard approach

The inhalation dose is the result of the incorporation of both, the HT/HTO during plume passage and the reemitted HTO after HT/HTO deposition. The impact from inhalation of HT is about 4 orders of magnitude lower than from HTO. Thus the primary HT plume is in principle negligible for the dose assessment. The incorporation of HTO via inhalation is calculated by using a breathing rate, averaged over the daily normal activities of an adult and assuming that all tritium is uniformely distributed in the body. The different behaviour of HT is described by a reduced dose conversion factor of about four orders of magnitude. Skin absorption is taken into account by an additional absorption rate of HTO from the air. The dose is the result of the summed fractions of incorporated tritium multiplied by the dose conversion factors:

$$D_{ih} = \sum_{i=1}^{N} (\mathrm{BR} + \mathrm{SKR}) \times \mathrm{DCF}_i \times C_{a,i} \qquad (14)$$

with:

D_{ih}	dose from inhalation and skin absorption in Sv
BR	breathing rate in $m^3\,s^{-1}$
SKR	skin absorption rate (only HTO) in $m^3\,s^{-1}$
DCF_i	dose-conversion factor in Sv/Bq for the two chemical forms i: HT and HTO
$C_{a,i}$	time-integrated air concentration in Bq s m^{-3} for the two chemical forms i: HT and HTO

For estimating the individual intake from the ingestion pathways, the conservative assumption is made that all food consumed is produced locally. However, it is possible to use two reduction factors which allow for taking into account the reduction from food processing and food importation. The ingestion dose is obtained by multiplying the tritium intake by dose conversion factors.

The two chemical forms of the incorporated tritium, HTO and OBT, are treated separately in NORMTRI. Thus, two different dose-conversion factors, one for the anorganic fraction (HTO) and the other one for the organic fraction (OBT) of the human body are considered. The ingestion dose is calculated by summing up the incorporated activity of all relevant foodstuffs.

$$D_{in} = \sum_{ls=1}^{YS} \sum_{f=1}^{2} \mathrm{DCF}_f \times \sum_{n=1}^{N} IG_n \times C_{fn} \qquad (15)$$

with:

D_{in}	dose from ingestion
YS	time periods of the year with different vegetation characteristics (2 winter- and 1 vegetation period)
n	foodstuffs: milk, meat from pork, beef, sheep and chicken, leafy vegetables, root crops, grain products
f	chemical form of tritium (HTO of OBT)
DCF_F	dose-conversion factor (HTO, OBT) in SV/Bq
IG_N	consumption rate of foodstuff n per season in $kg\ d^{-1}$
C_{fn}	time-integrated specific concentration in the foodstuff n for each season in Bq dkg^{-1}

The collective dose is obtained by multiplying the individual dose value by the population living in the area represented by a single grid point.

3.6.2 Specific equilibrium approach

Under the assumption, that the tritium concentrations in the environment such as all foodstuffs, the human body and the air humidity are in equilibrium, a so-called "specific equilibrium dose" may be calculated. Based on experimental work from [16] about equilibrium concentration in rabbits, the ratio between organic and anorganic tritium in tissues of human bodies can be set to 1. If one assumes, that the mean specific tritium concentration in the body water and in the organic fraction is equal to the specific HTO concentration in air humidity, the following relationship can be established:

$$C_{hb,HTO} = 1.1\ \frac{C_{a,HTO}}{ay} \times \frac{M_w}{\Phi} \qquad (16)$$

$$C_{hb,OBT} = 1.1\ \frac{C_{a,HTO}}{ay} \times \frac{M_o}{\Phi} \times redh \qquad (17)$$

with:

$C_{hb,HTO}$	mean HTO concentration in the body water in Bq
$C_{hb,OBT}$	mean OBT concentration in the body water in Bq
$C_{a,HTO}$	time integrated HTO air concentration in $Bq\ s\ m^{-3}$
ay	duration of the year in s
M_w	weight of body water in kg (45)

M_o	weight of body organic material in kg (25)

In the basic approach for calculating the committed effective dose equivalent H the assumption of a single intake of tritium into the human body is made. This leads to the following formula [14]:

$$\begin{aligned} H &= \frac{7.890 \times 10^{-11}}{M} \int_{f=0}^{\infty} A_0 \, e^{-\lambda_e t} \, dt \\ &= 7.890 \times 10^{-11} \, \frac{A_0}{M \, \lambda_e} \end{aligned} \qquad (18)$$

with:

H	committed effective dose equivalent in Sv
A_0	total activity in the body at time zero in Bq
M	total weight of human body (70 kg)
t	time after intake in d
λ_e	effective elimination constant in d^{-1} $= ln2/T_{eff}$
T_{eff}	effective half-life in d

A_0 will be calculated by adding both tritium concentrations $C_{hb,HTO}$ and $C_{hb,OBT}$ from Equations 16 and 17, respectively. But in case of the above described equilibrium conditions, Equation 18 has to be modified to become valid for a continuous intake of tritium. One procedure is to convert the time integrated tritium concentration resulting from a single input into an equivalent average tritium concentration ranging over a certain period. Therefore the integral in Equation 18 has to be solved from time zero till infinity. Assuming a half-life T_{eff} of 10 days for HTO in human body water together with a single intake A_0 of 1 Bq, the integral in Equation 18 gives a value of 14.4. Thus a single intake of 1 Bq, integrated till infinity, can be interpreted as an average load of 1 Bq lasting for only 14.4 days. The extrapolation of this result up to the period of one year, $A_0/\lambda_e = 365$ leads to a multiplication factor of about 25. This value of 25 has to be multiplied by the mean tritium concentration in the water and organic fraction of the human body, to obtain the committed effective dose equivalent under the assumption of a continuous intake during one year. Additionally, one has to take into account, that under equilibrium conditions, the dose conversion factors of OBT and HTO are identical. The difference in the dose conversion factors results only from different turn-over times when assuming a single intake, which is not the case under equilibrium conditions. Thus, the committed effective dose H_{tot} under the 'specific equilibrium conditions' will be calculated according to:

$$H_{tot} = 7.890 \times 10^{-11} \times \frac{C_{hb,HTO} \times 25}{M_w} + 7.890 \times 10^{-11} \times \frac{C_{hb,OBT} \times 25}{M_o} \qquad (19)$$

where

H_{tot} = committed effective dose under equilibrium conditions in Sv

3.6.3 German regulatory guidelines from 1990

As a third possibility the dose can be calculated according to the set of equations proposed within the German regulatory guidelines [3]. Tritium is always released in HTO form. It is assumed that the HTO concentration in plants originates to 30% from the air humidity and to 70% from precipitation water. The tritium concentration in soil depends only on the wet deposition process. Dry deposition is neglected, which may compensate the missing reemission process in the guidelines. The dose from ingestion is calculated by multiplying the specific concentrations in foodstuffs with the yearly consumption rates and the dose conversion factor for HTO. OBT is not taken into account. These assumptions lead to the following set of basic equations for the dose from ingestion:

$$H_{reg} = A_j \left(K_{g1} X_s + K_{g2} W_s\right) \times DOSF \qquad (20)$$

with

H_{reg}	committed effective dose (Sv) from ingestion based on the equations of [3]
A_j	yearly source term in Bq/yr
K_{g1}	tritium concentration which contributes from air moisture to the total HTO concentration in plants in s/m^3
K_{g2}	tritium concentration which contributes from soil water to the total HTO concentration in plants in $1/m^2$
X_s	long-term dispersion coefficient for the vegetation period in s/m^3
W_s	long-term washout factor for the vegetation period in m^2
DOSF	dose conversion factor for HTO in Sv/Bq ($1.6\ 10^{-11}$)

The transfers from the grass to the animals and the milk will be calculated by using transfer factors (T-milk = 0.02 d/l; T-meat = 0.02 d/kg) together with a feeding rate for a cow/beef of 65 kg wet weight of grass per day. The fraction of the HTO concentration in foodstuffs originating from the atmosphere K_{g1} will be calculated:

$$K_{g1} = a_p \frac{f_l f_{wat}}{\Phi_s} \left(U_{pf} + U_{bl} + U_{mi} M T_{mi} + U_{fl} M T_{fl} \exp\left(-lam\, t_v\right) \right) \qquad (21)$$

with:

K_{g1}	tritium concentration which contributes from air moisture to the total HTO concentration in foodstuffs in s/m^3
a_p	factor year to seconds ($3.2\ 10^{-8} yr/s$)
f_l	fraction of tritium from air moisture (0.3)

f_{wat}	fraction of water content in plants (0.8)
Φ_s	mean air moisture for the vegetation period in $kg\ m^{-3}$ (0.009)
U_{pf}	consumption rate of vegetable products in kg / yr (460)
U_{bl}	consumption rate of leafy vegetable in kg / yr (40)
U_{fl}	consumption rate of meat and meat products in kg / yr (150)
T_{fl}	transfer rate grass to meat in d/kg (0.02)
U_{mi}	consumption rate of milk and milk products in kg / yr (330)
T_{mi}	transfer rate grass to milk in d/l (0.02)
M	fodder of a cow/beef in kg/d (65)
lam	radioactive decay constant of tritium
T_v	time between slaughter and consumption in d (20)

The fraction of the HTO concentration in foodstuffs which is based on the tritium concentration in precipitation water K_{g2} will be calculated:

$$K_{g2} = \frac{f_n f_{wat}}{\rho_w J_s} \left(U_{pf} + U_{bl} + U_{mi} M T_{mi} + U_{fl} M T_{fl} \exp(-lam\ t_v) \right) \tag{22}$$

with:

K_{g2}	tritium concentration which contributes from precipitation water to the total HTO concentration in foodstuffs in s/m^2
f_n	fraction of tritium from precipitation (0.7)
ρ_w	density of water in kg/l (1.0)
J_s	precipitation during the vegetation period in mm

The dose from inhalation will be obtained by multiplying the time integrated activity in air near ground with the breathing rate and the dose conversion factor for HTO (see Equation 14). Two differences to Equation 14 are significant: the uptake via the skin is neglected and tritium is always present as HTO.

3.7 Results obtained with NORMTRI

In the following, some results of calculations for releases of tritium as HTO and HT are presented. The effective dose equivalent (EDE) is split into the contribution of the different exposure pathways: external irradiation from ground (GR), external irradiation from the passing cloud (CL), internal irradiation from inhalation + skin absorption during the plume passage (IH), internal irradiation from inhalation + skin absorption during the re-emission phase (IHR) and internal irradiation from contaminated foodstuffs (IG). The two exposure pathways GR and CL are neglectable, because tritium is a β emitter only.

The release conditions are characterized in Table 5.

chemical form	HTO / HT
release height	100 m
release duration	1 year
released quantity	1 TBq/year
dispersion parameter set	MOL
met. statistics (1 year)	Karlsruhe
relative humidity	70 %
air humidity	9 g/m**3
dry deposition velocity HTO	0.5 cm
dry deposition velocity HT	0.05 cm
washout coefficient (w)	w = A*I**B
coefficient A	9.0 E-05
coefficient B	0.6
breathing rate	2.66 E-4 m**3/s
skin absorption rate	1.60 E-4 m**3/s
ingestion rate vegetables	45 kg/year
ingestion rate root vegetables	85 kg/year
ingestion rate grain products	95 kg/year
ingestion rate meat	75 kg/year
ingestion rate milk	110 kg/year
drinking water (ground water)	500 kg/year
dose conversion factor inhalation HT	6.8 E-16 Sv/Bq
dose conversion factor inhalation HTO	1.6 E-11 Sv/Bq
dose conversion factor ingestion HTO	4.0 E-11 Sv/Bq
dose conversion factor ingestion OBT	1.6 E-11 Sv/Bq

Table 5. Release conditions for comparison calculations

3.7.1 HTO-releases

In case of releases of HTO, the ingestion pathways (IG) contribute by more than 70% to the individual effective dose equivalent as shown in Table 6 for various distances. The direct inhalation pathway (IH) has its maximum in the near range (more than 20% at 1 to 3 km) and decreases in the very near and farther ranges. The small values in the near range are the result of the release from the stack. At farther distances the contribution from reemission (IHR) is increased.

DISTANCE (M)	CL%	GR%	IH%	IG%	IHR%	EDE (SV)
145.0	0.00	0.00	2.27	96.20	1.52	1.88E-08
210.0	0.00	0.00	5.48	92.22	2.30	1.61E-08
320.0	0.00	0.00	10.45	87.74	1.82	1.42E-08
500.0	0.00	0.00	15.30	82.89	1.80	1.30E-08
680.0	0.00	0.00	17.83	80.36	1.81	1.19E-08
1000.0	0.00	0.00	19.80	77.26	2.94	9.94E-09
1500.0	0.00	0.00	20.37	76.19	3.44	7.72E-09
2000.0	0.00	0.00	21.48	75.36	3.16	5.99E-09
3200.0	0.00	0.00	20.69	75.70	3.61	3.59E-09
5000.0	0.00	0.00	19.08	76.45	4.47	2.05E-09
6800.0	0.00	0.00	17.82	77.15	5.03	1.36E-09
10000.0	0.00	0.00	16.25	78.09	5.66	8.00E-10
15000.0	0.00	0.00	14.87	78.64	6.48	4.81E-10
20000.0	0.00	0.00	14.42	78.68	6.91	3.40E-10
32000.0	0.00	0.00	14.24	77.91	7.85	2.02E-10
46000.0	0.00	0.00	12.57	78.13	9.30	1.34E-10
68000.0	0.00	0.00	12.46	77.27	10.27	8.31E-11
100000.0	0.00	0.00	12.90	76.59	10.50	4.79E-11

Table 6. Distance dependent EDE (Sv) of the MEI from routine releases of HTO (meteorological station Karlsruhe, typical, Mol, 100 m),: release rate of 1.0 E+12 Bq (HTO), release duration of 1 year, percentage contribution of pathways

3.7.2 HT-releases

In case of releases of HT, the ingestion pathways contribute by more than 80% to the individual effective dose equivalent as shown in Table 7 for various distances. The direct inhalation pathway (IH) is negligibly small which is due to the very low dose conversion factor of HT. The contribution from the reemission process (IHR) can reach in the farther range up to 20 % of the total dose.

DISTANCE (M)	CL%	GR%	IH%	IG%	IHR%	EDE (SV)
145.0	0.00	0.00	0.02	86.86	13.12	9.55E-11
210.0	0.00	0.00	0.02	90.03	9.95	1.44E-10
320.0	0.00	0.00	0.03	92.04	7.93	1.92E-10
500.0	0.00	0.00	0.03	91.31	8.66	2.23E-10
680.0	0.00	0.00	0.04	91.19	8.78	2.29E-10
1000.0	0.00	0.00	0.04	91.35	8.61	2.09E-10
1500.0	0.00	0.00	0.04	90.28	9.68	1.76E-10
2000.0	0.00	0.00	0.03	89.89	10.07	1.41E-10
3200.0	0.00	0.00	0.03	89.24	10.73	8.67E-11
5000.0	0.00	0.00	0.03	85.73	14.24	5.43E-11
6800.0	0.00	0.00	0.03	84.43	15.54	3.77E-11
10000.0	0.00	0.00	0.03	83.57	16.40	2.33E-11
15000.0	0.00	0.00	0.02	82.56	17.41	1.60E-11
20000.0	0.00	0.00	0.02	82.11	17.87	1.20E-11
32000.0	0.00	0.00	0.02	81.63	18.34	7.97E-12
46000.0	0.00	0.00	0.02	80.75	19.23	5.84E-12
68000.0	0.00	0.00	0.02	80.29	19.69	3.94E-12
100000.0	0.00	0.00	0.02	83.08	16.91	2.45E-12

Table 7. Distance dependent EDE (Sv) of the MEI from routine releases of HT (meteorological station Karlsruhe, typical, Mol, 100 m),: release rate of 1.0 E+12 Bq (HT), release duration of 1 year, percentage contribution of pathways

3.7.3 Comparison of HT- and HTO-release

The EDE values from HT-releases are about 20 to 100 times lower than for the HTO-releases. The reason can be found in the lower deposition velocity of HT (about a factor of 10 lower than HTO), the fact that plants do not take up HT directly and the very low dose conversion factor of HT.

4. Description of the input data defined by the user

4.1 General remarks

The standard input data for a NORMTRI run is closely adapted to the structure used for the UFOTRI, a computer program for assessing the off-site consequences from accidental releases of tritium [24]. Some of the input parameters which are necessary for UFOTRI will not be supported by NORMTRI. However, to have a higher flexibility by using the same Job control data set, also unused parameters are still in the input list but will not be considered by NORMTRI. Parameters not considered in NORMTRI but still in the list are marked with the sign **not used in NORMTRI** .

For most of the steering parameters defining the run and adapting the models to the user's needs, default values are given in NORMTRI. The input data are subdivided in several groups, identified by a title card. Only the input group ISODAT has no title card. The group title cards have to be left justified. One part of the groups must always appear in the input data (obligatory input groups), the other part only if changes in the default values are wanted (optional input groups). The obligatory groups are entered in strict format, as described below. The optional groups are input using a FORTRAN NAMELIST.

The GROUP and NAMELIST names are:

	GROUP	NAMELIST
Obligatory		
	METEOZON	-----
	SOURCE	-----
	END	-----
Optional		
	PRINTOUT	OUTPAR
	POLGRID	GRDPAR
	ISOTOPE	ISOPAR
	METEOROL	METPAR
	-----	ISODAT

Obligatory input groups

- **METEOZON**	data for the meteorological zone considered for the atmospheric dispersion calculation, the sampling of the weather sequences and the sites with their population data
- **SOURCE**	data defining the release (thermal energy, release height, timing, etc.)
- **END**	card at the end of the NORMTRI specific input data

Optional input groups

- **PRINTOUT**	options defining the paper output to be produced
- **POLGRID**	definition of the polar grid
- **ISOTOPE**	specifications of the nuclides considered, washout coefficient, deposition parameters
- **METEOROL**	parameters for the atmospheric dispersion module (mixing layer height, wind profile, σ-parameters etc.) and the conditions for one single weather sequence chosen by the user (if METIN $\neq$ 0)
- **ISODAT**	Tritium-specific input data for the statistical atmospheric dispersion module and the dose module

For the order of the input groups the following rules must be considered:

1. The group ISOTOPE must precede the group SOURCE.
2. The group POLGRID must precede the group METEOZON.
3. The group PRINTOUT must precede the group POLGRID.
4. The last group of the NORMTRI-specific input must be END.
5. If the NAMELIST ISODAT is used, this card must appear after the group END.

The program unit INDAT gives a printout of the options and input data used for the run. In the following the input parameters of the NAMELIST groups are described. K means one or more input cards; S is a label for branching.

The type of the variables and arrays is given by the implicit FORTRAN type declaration; otherwise it is mentioned below.

Most of the arrays used have a dimension declarator defined by the PARAMETER statement. The maximum dimensions currently used in NORMTRI are shown in the table below. The statements are given in the member PARAM and are input to the code by the INCLUDE statement.

```
  PARAMETER (NSITMX =  1,  LWMAX  =   3,  NPHSMX = 1)
  PARAMETER (NTYPMX =  2,  NUCMAX =   2)
  PARAMETER (NRMAX  = 20,  NPHIMX =  72)
**************************************************************
*                                                            *
*   NSITMX    : MAX. NO. OF SITES             : =   1       *
*   LWMAX     : MAX. NO. OF WEATHER SEQUENCES  : =   3       *
*   NPHSMX    : MAX. NO. OF RELEASE PHASES     : =   1       *
*   NRMAX     : MAX. NO. OF RADIAL DISTANCES   : =  20       *
*   NPHIMX    : MAX. NO. OF ANGULAR SEGMENTS   : =  72       *
*   NTYPMX    : MAX. NO. OF TYPE OF NUCLIDES   : =   2       *
*               WITH DIFFERENT DEPOSITION                    *
*               CHARACTERISTICS                              *
*   NUCMAX    : MAX. NO. OF NUCLIDES           : =   2       *
*                                                            *
**************************************************************
```

4.2 *Obligatory input groups*

4.2.1 Input group METEOZON

The input group METEOZON specifies the selected meteorological zone and defines the data of the sites and of the weather sequences chosen for this zone.

The user can use his own site-specific population grid (read from NUNITS(31), or he can use the default option, a uniform population distribution.

****

* If the grid differs from the default values the input
* group POLGRID must precede the input of METEOZON

****

K1.1 title card METEOZON
(FORMAT A8)

METEOZON	name of identification (left-justified)

K1.2 Card of the selected meteorological zone
(FORMAT 1x, A8, 1X, 2I10, 4I5)

ZONNAM	name of the meteorological zone
NSTMAX	number of sites (= 1, fixed)
LMAX	number of weather sequences (max. LWMAX)
LPOPT	option for specifying the probabilities PWET of the weather sequences = 0 uniform distribution, i.e. PWET = 1/LMAX ≠ 0 PWET is defined by = 1 the input list K1.4 = 2 the weather sequence data file (NUNITS(13))
LWOPT	option for specifying the starting times LWET of the weather sequences = 1 the input list K1.3 = 2 the weather sequence data file (NUNITS(13))

IRAU	index of surface roughness for the choice of the dispersion parameters (not for special sets see group METEOROL) = 2 mean roughnesslength (low plants, rural areas, length of roughness Z < 10 cm to 1 m) = 3 great roughnesslength (forests, urban areas, length of roughness Z > 1 m)
IHOM	measurement height of wind speed (height of anemometer) in meters

If LWOPT ≠ 1 continue with S1

K1.3 Starting times of the weather sequences
(FORMAT 8I10, as many cards as needed)

LWET(L)	starting time of the weather sequences L in hours (L = 1,...LMAX)

S1 If LPOPT ≠ 1 continue with S2

K1.4 Probability distribution of the weather sequences
(FORMAT 8E10.2, as many cards as needed)

PWET(L)	probability of the weather sequences L; the sum over L must be 1 (L=1,...,LMAX)

S2 For each site NS (NS = 1,...NSTMAX) the cards K1.5 to K1.7 are required.
(not considered in NORMTRI, COSYMA relevant)

K1.5 Card of the site NS (ONLY ONE SITE IN NORMTRI)
(FORMAT I2, A8, I10, 1PE10.2)

NRST	number of identification of the site according to the population data file
STONAM(NS)	name of the site
NSTOPT(NS)	option for specifying the population data = 0 uniform population distribution POPDIC = 1 population distribution is defined by K1.7 for all distance bands = 2 population distribution is defined by K1.7 for the distance bands 1 to IEIN; outside it is uniform = 3 population distribution is defined by the site data file (NUNITS(31))

PSTO(NS)	probability of the site; in general: PSTO = number of reactor blocks at the site/ number of reactor blocks in the zone the sum over NS must be equal 1 (not considered in NORMTRI)

If NSTOPT(NS) = 1 continue with S3
If NSTOPT(NS) = 3 continue with S4

K1.6 Card of the uniform population distribution
(FORMAT E10.2, I10)

POPDIC	uniform population density in people/km^2
IEIN	index of the distance band up to which the population distribution is read from K1.7 (only required if NSTOPT(NS) = 2).

S3 For each angular segment J (J = 1,...JMAX) K1.7 is required.

K1.7 Card of the population distribution
(FORMAT 8I10, as many cards as needed)

IPOP(J,I)	population in each distance band I (I = 1,...,IMAX) for the angular segment J (see input group POLGRID). The middle of the first segment (J = 1) is 0 degree (order of the segments clockwise)

S4 End of input group METEOZON

4.2.2 Input group SOURCE

This input group defines the release and its phases. Data relating to the start and duration of the release and reactor building dimensions have to be entered in strict column format.

K2.1 title card SOURCE
(FORMAT A8)

SOURCE	name of identification (left-justified)

K2.2 Card of the source term
(FORMAT A8, 2X, 2I10)

UNFNAM	name of the source term
NPHMAX	number of release phases (set to 1) (not considered in NORMTRI)

For the release phase NP K2.3 is required.

K2.3 Card of the release parameters for phase NP
(FORMAT 2I10, 3E10.3)

IPHASE(NP)	time in whole hours between the end of the chain reactions and the start of each release phase
IHO(NP)	height of the release in meters
QH(NP)	thermal energy of the release in cal/sec
BR(NP)	width of the reactor building in meters
HOE(NP)	height of the reactor building in meters

S5 End of input group SOURCE

4.2.3 Input group END

The input group END consists only of the card K3.1 and shows the end of the input data. If there is no mistake, the following message appears:

"END OF INPUT WITHOUT ERRORS"

K3.1 title card END
(FORMAT A8)

END	name of identification (left-justified)

4.3 *Optional input groups*

4.3.1 Input group PRINTOUT

Besides the basic control output information, it is up to the user to define additional output for some control parameters. Output for tritium specific parameters and arrays will be defined in the tritium NAMELIST ISODAT. The line printer output is assigned to unit NAUS (=6) for the control output of module INDAT and to unit NUNITS(6) (=6) for the result output.

The title card of PRINTOUT is followed by the NAMELIST OUTPAR.

```
K5.1     title card PRINTOUT
         (FORMAT A8)

         PRINTOUT            name of identification (left-justified)


K5.2     DATA CARD (NAMELIST-FORMAT)
         NAMELIST OUTPAR


NAME          DEFAULT        DESCRIPTION
----          -------        -----------

IBVOUT          1            option for printout of the population distribution
                             ≠ 0 : printout for all sites
                             = 0 : no printout
```

4.3.2 Input group POLGRID

In the input group POLGRID the user defines the grid for the population data and for the calculations of concentrations and individual doses. It must precede the input group METEOZON. The title card is followed by the NAMELIST GRDPAR.

The grid consists of a polar coordinate system with the centre point at the location of the nuclear facility. The concentrations and individual doses are calculated for a grid point representing the whole grid element. If you change the default values, you have to be sure to create new distance bands which are nearly representative for a square, in view of the modelling of the re-emission part.

IMAX and JMAX are the number of radii and sectors respectively. RA is the outer radius of each radial band. IMAX, JMAX and RA must be identical to the parameters chosen when calculating the polar population distribution around the site. R is the reference point in the grid element chosen to represent the element as a whole, e.g. it could be half way between two values of RA. NORMTRI refers to each distance band by its referenced point (centre), e.g. if RA = 2000, 5000, 10000 and R = 1000, 3500 and 7500, then doses for example given at 3500 m would be representative of the doses in the band from 2 to 5 km.

K6.1 title card POLGRID
(FORMAT A8)

POLGRID	name of identification (left-justified)

K6.2 DATA CARD (NAMELIST-FORMAT)
NAMELIST GRDPAR

NAME	DEFAULT	DESCRIPTION
IMAX	20	number of radial distances (max. NRMAX)
JMAX	72	number of angular segments (max. NPHIMX)
R(I) (20 values)		radial grid; distance of the radii R(I), (I = 1,...IMAX) in meters, completed with dummy values to NRMAX values

```
   65.,   100.,   145.,   210.,   320.,
  460.,   680.,  1000.,  1500.,  2100.,
 3200.,  4600.,  6800., 10000., 15000.,
21000., 32000., 46000., 68000.,100000.
```

NAME	DEFAULT	DESCRIPTION
RA(I) (20 values)		outer radius of the distance bands I (I = 1,...IMAX) in meters, completed with dummy values to NRMAX values

```
   80.,   120.,   170.,   260.,   390.,
```

```
  570.,    840.,   1250.,   1750.,   2600.,
 3900.,   5700.,   8400.,  12500.,  17500.,
26000.,  39000.,  57000.,  84000.,125000.
```

The values of the radii RA(I) and the angular segments must be identical with those used in any preprocessing program which calculates the population distribution.

4.3.3 Input group ISOTOPE

In the input group ISOTOPE the user has to define the physical characteristics of the NTYPMX nuclide groups NN. The sequence of the nuclides is **obligatory**

- 1. nuclide HT
- 2. nuclide HTO

The title card is followed by the NAMELIST ISOPAR.

K7.1 title card ISOTOPE
(FORMAT A8)

ISOTOPE name of identification (left-justified)

K7.2 DATA CARD (NAMELIST-FORMAT)
NAMELIST ISOPAR

NAME	DEFAULT	DESCRIPTION
NABL	2	number of type of nuclides with different deposition characteristics (max. NTYPMX) NOTE had to be set to 2 NOTE: sequence is obligatory (HT before HTO)
CORRVA(NN) (2 values)	2*1.0	correction factor for deposition velocity
VA(NN) (2 values)	 0.0005 0.005	deposition velocity in m/sec for the nuclide group NN; NOTE: sequence is obligatory - NN = 1: HT-gas - NN = 2: HTO-vapour
IWASH	0	option for calculation of washout coefficient IWASH = 0: the washout coefficients and the mean relative duration of precipitation are precalculated for the nuclide groups NN and the precipitation intensity class IR IWASH = 1: the washout coefficients will be calculated according to the power law XLAM(NN) = AWASH(NN) * (I**BWASH(NN)) for the nuclide groups NN, where I denotes the precipitation intensity in mm/h; a relative duration of rainfall can also be chosen,

If IWASH = 0 the following variables will be used:

****

IREGGR(IR1) (2 values)	100,300	boundaries of the rain intensity classes IR in 0.01 mm/h - IR = 1: rain intensity IREGGR(1) - IR = 2: rain intensity between IREGGR(1) and IREGGR(2) - IR = 3: rain intensity ≥ IREGGR(2)
AMDA(NN,IR) (6 values)		washout coefficient in 1/sec for the rain intensity class IR and the nuclide group NN for IR = 1: 0.,0.00006, for IR = 2: 0.,0.00010, for IR = 3: 0.,0.00040,
REGTIM(NN,IR) (6 values)		mean duration of precipitation for the rain class IR and the nuclide group NN for IR = 1: 1., 0.5 for IR = 2: 1., 0.75 for IR = 3: 1., 0.72

If IWASH = 1 the following variables will be used:

****

AWASH(NN) (2 values)	0.0, 9.0E-5	coefficient in power law for calculation of washout coefficient;
BWASH(NN) (2 values)	0.0, 0.6,	exponent in power law for calculation of washout coefficient, dependent on the nuclide group NN
REGTIM(NN,ir) (6 values)	see above	mean duration of precipitation for the nuclide group NN, dependent of the precipitation intensity class

4.3.4 Input group METEOROL

The input group METEOROL defines the parameters for the atmospheric dispersion part of NORMTRI. If desired (KLUGSI $\neq$ 0) the user can choose a special set of dispersion parameters, which are independent on the surface rougness criteria (IRAU) and HGHT parameter. If KLUGSI > 0, also the switch (IRELT) for adjusting the original sampling time of the special sigma parameter set to the 1 hour release time should be considered.

K8.1 title card METEOROL
(FORMAT A8)

METEOROL	name of identification (left-justified)

K8.2 DATA CARD (NAMELIST-FORMAT)
NAMELIST METPAR

NAME	DEFAULT	DESCRIPTION
HGHT(IH) (IH=1,3)	50.,100.,180.	height for the σ-parameters in meters
MIXLH(ISK) (ISK=1,6)	1600,1200,800, 560, 320,200	height of the mixing layer in meters for each diffusion category ISK; (ISK = 1,...,6 represents the diffusion categories A through F)
WPE(ISK) (ISK=1,6)	0.07,0.13, 0.21,0.34, 0.44,0.44	wind profile exponent for the diffusion categories ISK (ISK = 1,...,6 represents the categories A through F)
KLUGSI	0	switch for selection of special dispersion parameter set = 0 standard parameter set = 1 parameter set from KLUG = 2 parameter set from BRIGGS
IRELT	0	switch for adjusting special dispersion parameters to the desired release duration will be used for KLUG or BRIGGS sigmas
RELTA	10	sampling time for dispersion parameter set which will be used (in minutes)
RELTN	60	meteorological time step in minutes
RELTP	0.25	power function for adjustment formula (RELTN / RELTA) ** RELTP

The horizontal and vertical dispersion parameters are calculated as a function of distance x assuming the following power law (see KfK-4332)

$$\sigma_y = PY1 \cdot x^{QY1}$$

$$\sigma_Z = \mathrm{PZ1} \bullet x^{\mathrm{QZ1}}.$$

The downwind diffusion is modelled in UFOTRI by the dispersion parameter σ_x ; as long as $\sigma_x < \sigma_y$, it is calculated due to

$$\sigma_X = \frac{2}{3}\, x \tan \mathrm{STETA1};$$

for $\sigma_x \geq \sigma_y$, it is assumed that $\sigma_x = \sigma_y$ (see KfK-4332, p. 15 - 17).

PZ1(ISK,IH,IRH) (6*3*2 values)	linear term of the formula to calculate σ_Z for: - 6 diffusion categories ISK - 3 classes of height IH - 2 classes of roughness IRH (IRH = 1 : roughness IRAU = 2 IRH = 2 : roughness IRAU = 3)

1.321,0.950,0.700,0.520,0.382,0.311,
1.321,0.950,0.700,0.520,0.382,0.311,
1.321,0.950,0.700,0.520,0.382,0.311,
0.151,0.127,0.165,0.215,0.264,0.241,
0.051,0.070,0.137,0.265,0.487,0.717,
0.025,0.033,0.104,0.307,0.546,0.485

QZ1(ISK,IH,IRH) (6*3*2 values)	exponential term of the formula to calculate σ_Z for: - 6 diffusion categories ISK - 3 classes of height IH - 2 classes of roughness IRH (IRH = 1 : roughness IRAU = 2 IRH = 2 : roughness IRAU = 3)

6*0.711,6*0.711,6*0.711,
1.219,1.108,0.996,0.885,0.774,0.662,
1.317,1.151,0.985,0.818,0.652,0.486,
1.500,1.320,0.997,0.734,0.557,0.500

PY1(ISK,IH,IRH) (6*3*2 values)	linear term of the formula to calculate σ_Y for: - 6 diffusion categories ISK - 3 classes of height IH - 2 classes of roughness IRH (IRH = 1 : roughness IRAU = 2 IRH = 2 : roughness IRAU = 3)

0.946,0.826,0.586,0.418,0.297,0.235,
0.946,0.826,0.586,0.418,0.297,0.235,
0.946,0.826,0.586,0.418,0.297,0.235,
1.503,0.876,0.659,0.640,0.801,1.294,
0.170,0.324,0.466,0.504,0.411,0.253,
0.671,0.415,0.232,0.208,0.345,0.671

QY1(ISK,IH,IRH) (6*3*2 values)	exponential term of the formula to calculate σ_Y for: - 6 diffusion categories ISK - 3 classes of height IH - 2 classes of roughness IRH (IRH = 1 : roughness IRAU = 2 IRH = 2 : roughness IRAU = 3)

```
        6*0.796,6*0.796,6*0.796,
        0.833,0.823,0.807,0.784,0.754,0.718,
        1.296,1.025,0.866,0.818,0.882,1.057,
        0.903,0.903,0.903,0.903,0.903,0.903
```

```
STETA1(ISK,IH,IRH)          horizontal standard-deviation (in degree) of wind
(6*3*2 values)              direction for:
                            - 6 diffusion categories ISK
                            - 3 classes of height IH
                            - 2 classes of roughness IRH
                                (IRH = 1 : roughness IRAU = 2
                                 IRH = 2 : roughness IRAU = 3)
        20.5,13.9,10.1,6.9,4.,2.,
        20.5,13.9,10.1,6.9,4.,2.,
        20.5,13.9,10.1,6.9,4.,2.,
        23.8,18.9,15.3,12.6,10.2,8.6,
        20.5,13.9,10.1,6.9,4.,2.,
        20.5,13.9,10.1,6.9,4.,2.
```

4.4 Tritium NAMELIST ISODAT

4.4.1 Parameters influencing the overall run

For controlling the statistics submodule and additional outlist of the dispersion submodule, the namelist **ISODAT** will assign some additional parameters. The user had to define the number of wind direction sectors and the length (in hours) of each weather sequence. Parameters which control the output printed on paper may additionally be defined.

CHIMAX = minimum value of interest of the time integrated air concentration (cut-off value)
(DEFAULT = 1.0E-12)

IDBER = number of wind direction sectors (12 or 36)
(DEFAULT = 36)

IDAUER(I) = number of hours selected for a weather sequence; I = 1,LMAX
(DEFAULT = 3 x 0)

IJAHR(2) = number of the selected year
(DEFAULT = 82 and 83)

IWRITE = 0 no output on paper of the statistics submodule
1 output of the statistics submodule for each weather sequence
(DEFAULT = 1)

IDMP = index of the first position of the concentration matrix for the printed output of the concentration data (radius)
0 < IDMP ≤ NRAD
(DEFAULT = 0)

IDMPMX = index of the last position of the concentration matrix for the printed output of the concentration data (radius)
IDMP < IDMPMX ≤ NRAD
(DEFAULT = 20)

JDMP = index of the first position of the concentration matrix for the printed output of the concentration data (sector)
0 < JDMP ≤ NPHI
(DEFAULT = 0)

JDMPMX = index of the last position of the concentration matrix for the printed output of the concentration data (sector)
JDMP < JDMPMX ≤ NPHI

(DEFAULT = 72)

IOUTR(I) = number of weather sequences to be printed, I=1,5
(DEFAULT = 5 x 0)

IOUTN = number of nuclide to be printed
(DEFAULT = 1)

TEXT(I) = text of 72 characters to define the run
(DEFAULT = 72 x ' ')

Q(I) = relative source strength of nuclide I=1,2
(DEFAULT = 1, 0)

Q1(I) = total source strength of the year in Bq will be weighted with the relative duration of one weather sequence I=1,LMAX
(DEFAULT = 3 x 0)

4.4.2 Parameters for the water content in air

PHIATM = water vapour content in air in kg/m**3
(DEFAULT = 0.009)

RELH = relative air humidity in %/100
(DEFAULT = 0.7)

4.4.3 Parameters for the ingestion module

PLANTN(I) = name of vegetable foodstuffs (char(10)) I = 1,4
(DEFAULT = 'wheat', 'potatoes', 'vegetables', 'fruits')

PFLANZ(J,I) = destination values for the 4 vegetable foodstuffs PLANTN(I)
J = 1: water content of the plant I
J = 2: organic content of the plant I
J = 3: consumption rate of foodstuff I in kg per year
J = 4: weigthing factor for the plant I
(DEFAULT = 0.13 0.87 85 1.0
0.8 0.2 90 1.0
0.9 0.1 40 1.0
0.8 0.2 0 1.0

ANIMAL(I) = name of animal foodstuffs (char(10)) I = 1,5
(DEFAULT = 'milk', 'beef', 'pork', 'sheep', ' chicken ')

AING(I) = consumption rate of animal foodstuff I in kg/year I = 1,5
(DEFAULT = 115.0, 25.0, 50.0, 0.0, 10.0)

PLANTF(I) = name of foodstuffs for animals (char(10)) I = 1,8
(DEFAULT = 'cereal', 'potatoes', 'white beet', 'hey', 'grass', 'manjok', 'silage', 'water')

FINA(J,I,K) = array containing the amount (in kg/d) of foodstuff (I) for 5 animals (K), during summer and winter seasons (J)
K = 1: dairy cow; K = 2: beef; K = 3: pork; K = 4: sheep;
K = 5: chicken
J = 1: winter; J = 2: summer
I = 1: cereal; I = 2: potato; I = 3: white beet; I = 4: hey; I = 5: grass;
I = 6: manjok; I = 7: silage; I = 8: water
(DEFAULT = 6*0.0, 4.0, 3.0, 65.0, 0., 0., 3.6, 0., 3.2, 30, 70,
6*0.0, 3.0, 3.0, 4*0.0, 13.0, 13.0, 2*40.0,
2*2.55, 2*0.1, 6*0.0, 2*0.25, 2*0.0, 2*12.,
0.0, 0.3, 5*0.0, 0.5, 8.0, 4*0.0, 2.0, 3.0, 9.0,
2*0.03, 12*0.0, 2*0.2

PROCPP(I) = fraction of plants which will be processed I = 1,4
(DEFAULT = 4 x 0.0)

AIMPP(I) = fraction of plants which will be imported I = 1,4
(DEFAULT = 4 x 0.0)

AIMM = fraction of milk which will be imported
(DEFAULT = 0.0)

PROCM = fraction of milk which will be processed
(DEFAULT = 0.0)

AIMB = fraction of beef meat which will be imported
(DEFAULT = 0.0)

PROCB = fraction of beef meat which will be processed
(DEFAULT = 0.0)

AIMP = fraction of pork meat which will be imported
(DEFAULT = 0.0)

PROCP = fraction of pork meat which will be processed
(DEFAULT = 0.0)

AIMS = fraction of sheep meat which will be imported
(DEFAULT = 0.0)

PROCS = fraction of sheep meat which will be processed
(DEFAULT = 0.0)

AIMC = fraction of chicken meat which will be imported
(DEFAULT = 0.0)

PROCC = fraction of chicken meat which will be processed
(DEFAULT = 0.0)

IWAT = 1: water has the same specific tritium concentration as air humidity
0: specific concentration of air / 1000.
(DEFAULT = 0)

UWATN = consumption rate of drinking water per year in kg
(DEFAULT = 500.)

4.4.4 Parameter for the dose module

DOSF = dose conversion factor HTO in Sv/Bq
(DEFAULT = 1.7 E-11)

DOSFHT = dose conversion factor HT in Sv/Bq
(DEFAULT = 6.7 E-15)

DOSFOB = dose conversion factor OBT in Sv/Bq
(DEFAULT = 4.5 E-11)

REDOBT = specific reduction factor OBT/HTO
(DEFAULT = 0.73)

DIS = discrimination factor OBT/HTO
(DEFAULT = 1.0)

ATEML = breathing rate in m^3/s
(DEFAULT = 2.33 E-4)

ATEMS = skin absorption rate in m^3/s
(DEFAULT = 1.6 E-4)

BRRAN(I) = breathing rate of animal I in m^3/day, I=1,5
(DEFAULT = 130.0, 75.0, 25.0, 17.0, 0.4)

4.4.5 Parameter for the module for calculating the dose according to the German regulatory guidelines

ATEMG = breathing rate in m^3/s
(DEFAULT = 2.33 E-4)

TRMI = transfer rate into milk
(DEFAULT = 0.02)

TRFL = transfer rate into beef meat
(DEFAULT = 0.02)

AIN = wet weigth of cow fodder in kg
(DEFAULT = 65.)

UPF = consumption rate of vegetables per year in kg
(DEFAULT = 460.)

UBL = consumption rate of leafy vegetables per year in kg
(DEFAULT = 40.)

UMI = consumption rate of milk per year in kg
(DEFAULT = 330.)

UFL = consumption rate of meat per year in kg
(DEFAULT = 150.)

UWAT = consumption rate of drinking water per year in kg
(DEFAULT = 880.)

CWASH = annual washout coefficient in yr/mm s
(DEFAULT = 4.0 E-9)

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Appendix A. Short description of the statistical dispersion model ISOLA

A.1 Introduction

The following comprises a description of the basic features of the statistical dispersion model ISOLA. A detailed description together with a user guide of the model version being part of the accident consequence assessment program package COSYMA can be found in [13].

The computer code ISOLA V serves to calculate atmospheric dispersion of radionuclides around nuclear installations for long term release events (several days up to several months) with release rates which are nearly constant during this time.

ISOLA V is a so-called 'statistical Gaussian dispersion model'. This means, for all different dispersion situations during the considered weather sequence, a double Gaussian distribution of the released radionuclides is assumed throughout the plume. The activity concentrations calculated for these dispersion situations at the locations of interest are summarized under due consideration of their frequency of occurrence. This leads to a mean load during the considered weather sequence.

ISOLA V is segmented into **two** parts:

1. Statistics submodule
2. Dispersion submodule

In the first part, from hourly meteorological data of a station near the source, a four-parameter statistics will be prepared [28]. It includes meteorological parameters like wind speed, wind direction, stability classes and rain intensities. In the second part, for all realized dispersion conditions, the activity concentrations of the air near the ground and the ground contamination will be calculated. Each of these single events during one weather sequence will be evaluated with respect to its frequency, to create the final result for the required period. The source is assumed to be cold (that means, no thermal plume rise). The plume inventory is depleted during the passage by dry and wet deposition. The plume extends into one, two or more sectors, depending on its width and the position of the axis relative to the wind direction sectors.

A.2 Statistics submodule of ISOLA

In the statistics submodule which is called before the dispersion subroutine, the four-parameter statistics will be created. The meteorological data of one station should be available for a period of two years with the observation interval of one hour. These two years should not be leap-years. The user can choose from these two years an interval whatever he wants to calculate the statistics. If the user selects a starting time of a weather sequence near the end of the second year, it is to be provided not to exceed the meteorological dataset. Therefore, ISOLA will rewind the meteorological dataset and start again at the beginning of the first year of the available data.

The four meteorological parameters determine the Gaussian like dispersion and its deposition on the ground. These four groups, as presented now, can be subdivided into several classes.

- Wind speed (measured at a known reference height, 7 classes)
- Wind direction (measured at a known reference height, 12 or 32 classes)
- Stability class (6 classes)
- Precipitation intensity (4 classes)

The meteorological dataset should not contain any gap. The statistical submodule samples from a predefined period greater than one hour of the hourly meteorological data all existing combinations of the four parameters. The maximum value of different dispersion situations is 36 x 7 x 6 x 4. The hourly meteorological data will be sorted into these 6048 possible classes. The probability P_C of occurrence of one class during the considered period is defined as

$$P_C = \frac{hour\ per\ class}{\sum considered\ hours} \tag{23}$$

Additionally a general statistics of all weather sequences is created for output. So the user may control the choice of weather sequences. These overall statistics include the probability of occurrence of each weather sequence too . Here the value P_{CW} of one class is summarized by the general statistics.

$$P_{CW} = P_C \times P_{WA} \tag{24}$$

with:

P_{WA} probability of one weather sequence

The sum of P_{WA} should always be equal to unity.

$$P_{WG} = \sum P_{WA} = 1 \tag{25}$$

with:

P_{WG} probability of all weather sequences

For preparing the outlist, a hierarchy of the meteorological parameters is established. First, the probabilities of the rain intensity classes is calculated. Secondly, the probabilities of wind direction sectors within one precipitation class are considered. For each combination of precipitation class and wind direction sector the occurrence of combinations of wind speed and stability class are listed. These are normalized to 100% in the outlist (Fig. 1).

An example of a weather sequence with the probability of $P_{WG} = P_{WA} = 1$ is given below.

During a time period of 4 days, there was during 72 hours or 75% of the time no measurable precipitation. Within this precipitation class the wind was blowing during 24 hours in the sector of 240° (this means 33.33%). For these selected 24 hours the combination of wind speed and stability class is listed, normalized to 100%. It is now possible to calculate the number of hours with the combination of stability class D and wind speed ranging from 4.1 m/s to 8.0 m/s characterized in the outlist by the value of 29.16%:

$$P_{WA} \times \frac{33.3}{100.} \times \frac{75}{100.} \times 29.16 = 7.3 \times N_H = 7 \text{ hours} \tag{26}$$

with:

N_H relative number of hours here $\frac{96}{100.}$

A.3 The dispersion submodule of ISOLA

A.3.1 Features of the program

The essential features of ISOLA V are described as follows:

1. up to 36 wind direction sectors;
2. assumption of a cold source (no thermal plume rise);
3. eddies behind a building are taken into account in case of low release height;
4. constant release rate during the time period covered by the meteorological data;
5. radioactive decay of the released substances during the atmospheric transport is not considered in ISOLA.
6. activity is distributed in the plume according to a double Gaussian distribution function, being reflected totally at the ground;
7. depletion of the plume by washout and dry deposition;
8. washout calculation with individual washout coefficients,
9. in the actual version, a polar grid, with the source in the centre of the system;

The washout coefficient depends not only on the material to be washed out (gas or aerosol) but also on the precipitation intensity. As the precipitation duration is not always equal to the observation period, a characteristic relative duration of the rainfall is linked to each intensity class. [29], [22].

The structure of the present ISOLA version is based on a polar coordinate grid system with the centre point at the location of the nuclear installation. The radial and azimuthal resolution can be preselected but the standard values of 20 radii and 72 azimuthal sectors are recommended. The polar system is defined in accordance with the wind rose. The polar angle is counted clockwise and is zero if it coincides with the northern direction.

A.4 Basic equations

A.4.1 Activity concentration of the atmosphere near the ground

If the pollutant concentration distribution in the plume is assumed to be a double Gaussian distribution, with total reflection at the ground plane, the averaged concentration of a nuclide q near the ground $\dot{A}_{A_q}$ is expressed as follows:

$$\dot{A}_{A_q} = \dot{A}_q \; \overline{\mathrm{X}}(r, \Phi) \tag{27}$$

in which

$\dot{A}_{A_q}$ = air concentration rate, in $Bq \; m^{-3}s^{-1}$

$\dot{A}_q$ = release rate of nuclide q, in Bq / time period

q = type of nuclide :
1. noble gas
2. aerosols
3. elemental iodine
4. organically bound iodine
5. particulate iodine

$\overline{\mathrm{X}}(r, \Phi)$ = average diffusion factor, see Equ. 7

r = distance in m

Φ = angle of the polar grid

A.4.2 Ground contamination

The ground is contaminated by dry deposition (fallout) and by wet deposition (washout).

- Dry deposition is described by v_g, v_g = deposition velocity in m/s.
- Washout is described by the washout factor $\overline{W}$ in m^{-2}.

The ground contamination rate $\dot{A}_{Fq}$ due to dry and wet deposition is calculated according to Equation 6. $\dot{A}_{F_q}$ will be handled separately for each group of nuclides listed below. $\dot{A}_{F_q}$ is a momentary contamination rate, averaged over the time period under consideration.

$$\dot{A}_{F_q} = \dot{A}_q \left[v_{g_q} \; \overline{\mathrm{X}}(r, \Phi) + \overline{W}_q(r, \Phi) \right] \tag{28}$$

in which

$\dot{A}_{F_q}$ = ground contamination rate in in $Bq\ m^{-2}s^{-1}$

$\overline{W}_q(r, \Phi)$ = average washout factor, in m^{-2}, see Equ. 8

v_{g_q} = deposition velocity of nuclide q, in $m\ s^{-1}$

The following definition formulas are used:

$$\overline{\mathrm{X}}(r_q, \Phi_q) = \frac{1}{\sqrt{2\pi}\ r_q\, \Delta\Phi} \sum_{j=1}^{6} \frac{\exp \frac{H^2}{2\,\sigma_{zj}^2}}{\sigma_{zj}(r_q)}\ B_{\mathrm{dry,j}}(r_q, \Phi_q) \qquad (29)$$

and

$$\overline{W}_q(r, \Phi) = \frac{1}{\sqrt{2\pi}\ r_q\, \delta\Phi} \sum_{j=1}^{6} B_{\mathrm{wet,j}}(r_q, \Phi_q) \qquad (30)$$

in which

$\Delta\Phi$ = $\frac{2\pi}{I}$ = sector width

I = number of wind direction sectors (up to 36)

H = emission height of the q^{th} nuclide, in m

$\sigma_{zj}(r)$ = vertical diffusion parameter of the stability category j at the distance r, given in m (will be modified at low emission height, see Equ. 16 and 17 in chapter 3.2.5)

$B_{dry,j}$ = according to Equ. 12, see chapter 3.2.3 in s / m

$B_{wet,j}$ = according to Equ. 14, see chapter 3.2.3 in m^{-1}

A.4.3 Variables $B_{dry,j}$ and $B_{wet,j}$

At first the number of neighbour sectors is evaluated which has to be considered at the distance r_q and for the stability category j.

$$z_\alpha = \frac{l}{\sqrt{2\pi}} \left[\frac{2.15\,\sigma_{yj}(r_q)}{r} - \alpha \right] \tag{31}$$

and

$$z_\beta = \frac{l}{\sqrt{2\pi}} \left[\frac{2.15\,\sigma_{yj}(r_q)}{r} - \beta \right] \tag{32}$$

in which

z_α (z_β) = the number of the sectors on the left - or right - hand side if looking into direction of the transport of the plume. Each rounded up to an integer value;
minimum is zero, maximum is 2 for I = 12 and 6 for i = 36 sectors

$\sigma_{yj}(r)$ = transversal diffusion parameter of the stability category j at the distance r_q, given in m (will be modified at low emission height, see Equ. 16 and 17 in chapter 3.2.5)

α = $\Phi\,(i - \frac{1}{2})\Delta\Phi$ in rad (see Fig. 3)

β = $\Delta\Phi - \alpha$ in rad (see Fig. 3)

The following definition is beeing used in the Equ. 12 and Equ. 14.

$$\mathrm{ERF}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-v^2} dv \tag{33}$$

If $z_\alpha \geq 1$ and $z_\beta \geq 1$ then is

$$
\begin{aligned}
B_{\mathrm{dry,j}} = &\left\{ 1 - ERF\left[\frac{\alpha + (z_\alpha - 1)\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] \right\} \sum_{k=1}^{K} \frac{f_{i-z_\alpha,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right) \\
&\qquad \cdots\cdots\cdots \qquad\qquad \cdots\cdots\cdots \\
&+ \left\{ ERF\left[\frac{\alpha + 2\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] - ERF\left[\frac{\alpha + \Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] \right\} \sum_{k=1}^{K} \frac{f_{i-2,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right) \\
&+ \left\{ ERF\left[\frac{\alpha + \Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] - ERF\left[\frac{\alpha}{\sqrt{2}\,\sigma_{yj}(r)} r \right] \right\} \sum_{k=1}^{K} \frac{f_{i-1,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right) \\
&+ \left\{ \underset{C_\alpha}{ERF\left[\frac{\alpha}{\sqrt{2}\,\sigma_{yj}(r)} r \right]} - \underset{C_\beta}{ERF\left[\frac{\beta}{\sqrt{2}\,\sigma_{yj}(r)} r \right]} \right\} \sum_{k=1}^{K} \frac{f_{i,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right) \qquad (34) \\
&+ \left\{ ERF\left[\frac{\beta + \Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] - ERF\left[\frac{\beta}{\sqrt{2}\,\sigma_{yj}(r)} r \right] \right\} \sum_{k=1}^{K} \frac{f_{i+1,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right) \\
&+ \left\{ ERF\left[\frac{\beta + 2\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] - ERF\left[\frac{\beta + \Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] \right\} \sum_{k=1}^{K} \frac{f_{i+2,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right) \\
&\qquad \cdots\cdots\cdots \qquad\qquad \cdots\cdots\cdots \\
&+ \left\{ 1 - ERF\left[\frac{\beta + (z_\beta - 1)\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)} r \right] \right\} \sum_{k=1}^{K} \frac{f_{i+z_\beta,j,k}}{\bar{u}_{jk}} \exp - \left(\frac{\lambda_q r}{\bar{u}_{jk}} + d \right)
\end{aligned}
$$

If $z_\alpha = 0$ then is $C_\alpha = 1$,
if $z_\beta = 0$ then is $C_\beta = 1$,

in which

$\bar{u}_{jk}$ = vertical averaged wind velocity in $m\ s^{-1}$ (see chapter 3.2.4)

f_{ijk} = frequency of the simultaneous occurrence of wind velocity range k, stability category j and wind direction sector i,

$$\sum_{ijk} f_{ijk} = 1$$

The f_{ijk} are calculated from the four parametric statistics by the following simulation

$$f_{ijk} = \sum_{l=1}^{L} q_{ijkl}$$

for q_{ijkl} see below.

λ_q = decay constant of the q^{th} nuclide, in 1/s, set to 1

d = effects of depletion of the plume due to dry deposition

$$d = \frac{v_{g_q}}{\bar{u}_{jk}} \sqrt{\frac{2}{\pi}} \int_{j = r_0}^{r} \frac{1}{\sigma_{zj}} \exp - \frac{H^2}{2\,\sigma_{zj}^2}\, dr \tag{35}$$

v_{g_q} = deposition velocity of nuclide q, in $m\ s^{-1}$

r_0 = H, if $H \geq 10\,m$
= 10 m, if $H < 10\,m$

To integrate Equ. 13, the range from r_0 up to r is subdivided into four equal steps. Between these steps the integrand will be interpolated. By this algorithm the depletion is underestimated in unfavourable cases only, compared to other expended source depletion integration solutions.

$$
\begin{aligned}
B_{\mathrm{wet},j} = {} & \left\{ 1 \qquad - ERF\left[\frac{\alpha+(z_\alpha-1)\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i-z_\alpha,j,k,l}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right) \\
& \qquad\qquad \cdots\cdots\cdots\cdots \qquad\qquad\qquad \cdots\cdots\cdots\cdots \\
& + \left\{ ERF\left[\frac{\alpha+2\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right] - ERF\left[\frac{\alpha+\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i-2,j,k,}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right) \\
& + \left\{ ERF\left[\frac{\alpha+\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right] - ERF\left[\frac{\alpha}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i-1,j,k,l}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right) \\
& + \left\{ ERF\left[\frac{\alpha}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right] - ERF\left[\frac{\beta}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i,j,k,l}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right) \qquad (36) \\
& \qquad\qquad\qquad C_\alpha \qquad\qquad\qquad\qquad\qquad C_\beta \\
& + \left\{ ERF\left[\frac{\beta+\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right] - ERF\left[\frac{\beta}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i+1,j,k,l}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right) \\
& + \left\{ ERF\left[\frac{\beta+2\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right] - ERF\left[\frac{\beta+\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i+2,j,k,l}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right) \\
& \qquad\qquad \cdots\cdots\cdots\cdots \qquad\qquad\qquad \cdots\cdots\cdots\cdots \\
& + \left\{ 1 \qquad - ERF\left[\frac{\beta+(z_\beta-1)\Delta\Phi}{\sqrt{2}\,\sigma_{yj}(r)}\, r\right]\right\} \sum_{k=1}^{K}\sum_{l=1}^{L} \lambda_l \frac{q_{i+z_\beta,j,k,l}}{\bar{u}_{jk}} \exp-\left(\frac{\lambda_{ql}^{x}\, r}{\bar{u}_{jk}}+d\right)
\end{aligned}
$$

If $z_\alpha = 0$ then is $C_\alpha = 1$,
if $z_\beta = 0$ then is $C_\beta = 1$,

in which

$\bar{u}_{jk}$ = vertical averaged wind velocity in m / s (see chapter 3.2.4)

f_{ijkl} = frequency of the simultaneous occurrence of precipitation intensity l with the wind velocity range k, stability category j and wind direction sector i,

$\sum_{ijkl} q_{ijkl} = 1$

l = 1 means "no precipitation"

Λ_{lq} = washout coefficient for nuclide q and rain intensity l, in 1 / s

λ^{x}_{ql} = $\lambda_q + \Lambda_{lq}$ total depletion coefficient of the plume, in 1 / s

A.4.4 Wind Velocity $\bar{u}_{jk}$

The wind velocity $\bar{u}_{jk}$ is being averaged in the vertical direction from ground up to twice the emission level, separately for each stability category j and for each wind velocity range k.

$$\bar{u}_{jk} = \frac{1}{H}\int_0^{2H_q} u_{0k}\left(\frac{z}{H_0}\right)^{p_j} dz = \frac{u_o}{1+p_j}\left(\frac{2H_q}{H_0}\right)^{p_j} \qquad (37)$$

in which

H_0 = reference height of measuring the wind velocity, in m

u_{0k} = average of the wind velocity range k at the level H_0, in $m\ s^{-1}$

p_j = exponent of the vertical wind velocity profile for stability category j

The average u_{0k} is being calculated from all single measured velocities which fall into the range k. It is independent of the stability category. The wind profile exponent p_j is the average of all exponents p, which result from the least-squares-fit of an exponential function - like the integrand in Equ. 15 - to the measured vertical wind velocity profile at the stability category j. If $\bar{u}_{jk} < 0.5\ m\ s^{-1}$, calculated from Equ. 15, then $\bar{u}_{jk}$ is set equal to $0.5\ m\ s^{-1}$. Values of p_j, valid for the Karlsruhe are:

stability	A	B	C	D	E	F
p_j	0.07	0.13	0.21	0.34	0.44	0.44

A.4.5 Eddies caused by a building

If the release height $H < H_{\mathrm{thresh}}$,
then the diffusion parameters $\sigma_{yj}(r)$ and $\sigma_{zj}(r)$ are modified as follows in order to take into account the additional turbulence caused by eddies behind a building :

$$\sigma_{yj} = \sqrt{\sigma_{yj}^2 + \frac{H^2}{2\pi}} \qquad (38)$$

and

$$\sigma_{zj} = \sqrt{\sigma_{zj}^2 + \frac{H^2}{2\pi}} \qquad (39)$$

in which

H_{thresh} = height of a building, in m