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THE CALCULATION OF THE EFFECTIVE DOSE TO THE PUBLIC DUE TO THE AIR RELEASES FROM THE LHC FACILITIES

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Summary

In the present report a summary is given of calculations of the effective dose to the public in the vicinity of the LHC due to the the release of radioactive air from the LHC facilities. The calculational methods are based on the Swiss Directive HSK-R-41. Both the atmospheric and water pathways of exposure in the LHC environment have been considered. The program RELEASE has been written to calculate effective doses from airborne and liquid radioactive radionuclides rejected from the LHC facilities. The effective doses have been calculated for the long term releases taking into account the the LHC ventilation scheme, the topological altitudes, roughness of terrain and the distribution of the critical groups of the populations in the LHC area. Data for 39 radionuclides produced in the air are given. Some comparisons with the previous calculations are also presented.

Keywords: LHC, release, plume, radioactivity, dose

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1 Introduction

Predictive models for estimating effective dose due atmospheric releases play important roles in the design and operation of the accelerator facilities. In the design, they can be used in the dose estimations for both operations and emergency situations and allow to minimize dose up to reasonably achievable, to determine dose limits. When accelerators are working these models can be used to estimate potential impacts of any release during emergency situations and to determine special measures to overcame their.

The dose calculation from radioactive plumes requires consideration of both meteorological and radiological processes. At this moment there is not complete methods such as for nuclear power stations to calculate effective dose to the public due releases from accelerator installations.

L.Moritz [Mo96a] has been implemented the Draft Swiss Standard HSK-R-41/d to calculate off-site doses and dose rate due to radioactive emission from CERN, has been identified a critical group and has been determined new derived release limits for the CERN site.

Later P.Vojtyla [Voj98] has been implemented new version of Swiss directive HSK-R-41 and defined the models and scenarios for calculations of doses due releases of the radioactivity from the CERN Meyrin site. New values of some dose limits have been obtained for main critical groups of the CERN Meyrin site population and on base of high-quality meteorological data from weather station at Geneva-Cointrin airport.

The some radiological implications of the release of air from the LHC experimental regions were carried out by M.Huhtinen et al. [Huh96]. An estimation of the release of radioactivity in the air produced in the ATLAS and CMS experiments have shown that the activities release for one year are less than one per mil of the CERN Design constraints.

Above mentioned results shown that effective doses to critical groups of populations are below so-called reference dose limit for public [Hof95].

Note that for an individual member of the public outside CERN, the appropriate reference value is 0.3 mSv per year. The maximum exposure via the atmospheric or water pathways is limited to 0.2 mSv per year and the sum of the both pathway must not exceed 0.3 mSv per year.

In contrast to works [Mo96a, Voj98] that have been used a model for single point release, in case of the LHC multiple release points are distributed on the complex and lengthy site.

The problem of the calculation of the effective doses to the public due to the multiple point air release from the accelerator facilities has many methodological and technical difficulties. Here can be only marked some of them:

- Some changes in experimental conditions may lead to changes in the level, composition and spatial distribution of releases.
- Multiple release points can be distributed on the accelerator site. For each release point must be identified a critical group, doses and dose rates calculate and some dose limits determined.
- Large area and complex terrain require the use of the various weather statistics for each release point and a some inclusion of the topological correction at each receptor point.
- In contrast to nuclear power stations, the population may live near the boundary of some accelerator facilities. At these points a contribution to effective dose from the plume exposure can be significant. Therefore the realistic model of the radioactive cloud must be used instead of semi-infinite cloud model or spherical cloud model.
- It requires fast and power computers with big memory as the dose calculation are connected with both the data proceeding and the multidimensional integration.

The basis and implementation to calculate the effective doses to the public due to the multiple point air release from the LHC facilities on area 20x20 km^2 are given in the present work.

2 Methodological basis

The Swiss Directive HSK-R-41 / d [HSK41], IAEA Safety Guide No. 50-GS-S3 [50-SG-S3] and ICRP Publication 72 [ICRP72] are the methodological basis to calculate off-site doses and doses rates from release of the radioactive material to the atmosphere or to the local streams during operation of the LHC facilities.
Those documents define the main pathways for the transport of the radionuclides and exposures, scenarios of releases and the critical group for which dose calculations are carried out.
Following the Swiss Directive HSK-R-41 / d [HSK41] and ICRP Publication 72 [ICRP72] the critical group is defined as the relevant group of people which is irradiated via some pathways of the exposure in the environment and the dose rate from this exposure can be significant. Besides, both adults and infants of the age 1 year are members of the critical group. Certainly, the devision of the public into the critical group is enough relatively as one depends on many statistical factors. The definition of the critical group at the LHC site will be given in the section 8.
Two scenarios for the calculation of the effective doses are considered here. The Figure 1 shows the time scale for two scenarios. The first time scenario is a short-term release which takes place over period less than 24 hours and during which atmospheric conditions are constant. The dose calculated includes the dose for the 50 following years from radioactivity in material deposited in the environment. The second scenario is a calculation of dose rate due to chronic constant long term release with the averaged atmospheric dispersion condition. The dose is calculated for one year after 50 years of continuous operation at the same level of the emission to take into account an accumulation of the long lived radionuclides.

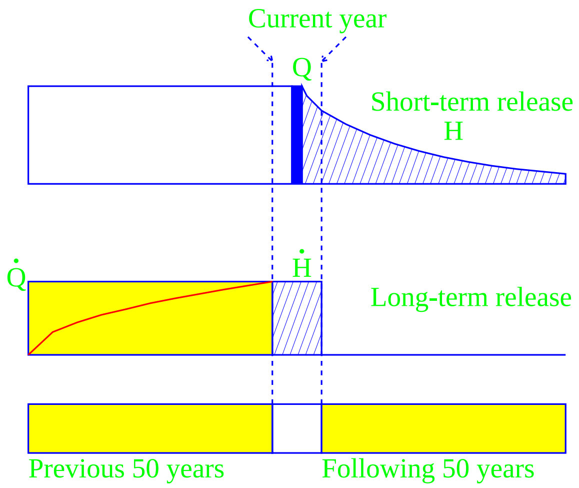

Figure 1: Time scale for short term and long term release dose calculations

In according to Directive HSK-R-41 [HSK41] there are the atmospheric and water pathways for transport of radioactive materials. The atmospheric pathway of the exposure at the LHC site include external and internal exposures. The external exposure is a sum of the immersion or submersion in the radioactive cloud and the irradiation from radioactive materials deposited on the ground. The internal exposure is due to

- inhalation of the radioactive air
- ingestion of the vegetables produced in the area of concern
- ingestion of meat and milk produced in the area of concern
- ingestion of meat and milk from animals which feed water from the local stream, lake or rivers
- ingestion of drinking water from the local stream, lake or rivers
- ingestion of fish taken from the local stream, lake or rivers

The dose calculation model on base of the Swiss Directive HSK-R-41 (without C^{14} and Tritium) is shown in the Figure 2. For the atmospheric pathway as can be seen from Figure 2, the radioactive air emission is affected by two processes: dispersion and deposition. The dispersion is a process of the mixing, dilution and transport of the ambient air on-site and off-site. The second process is the displacement of the radionuclides from the air to the ground and on the surface of plants.

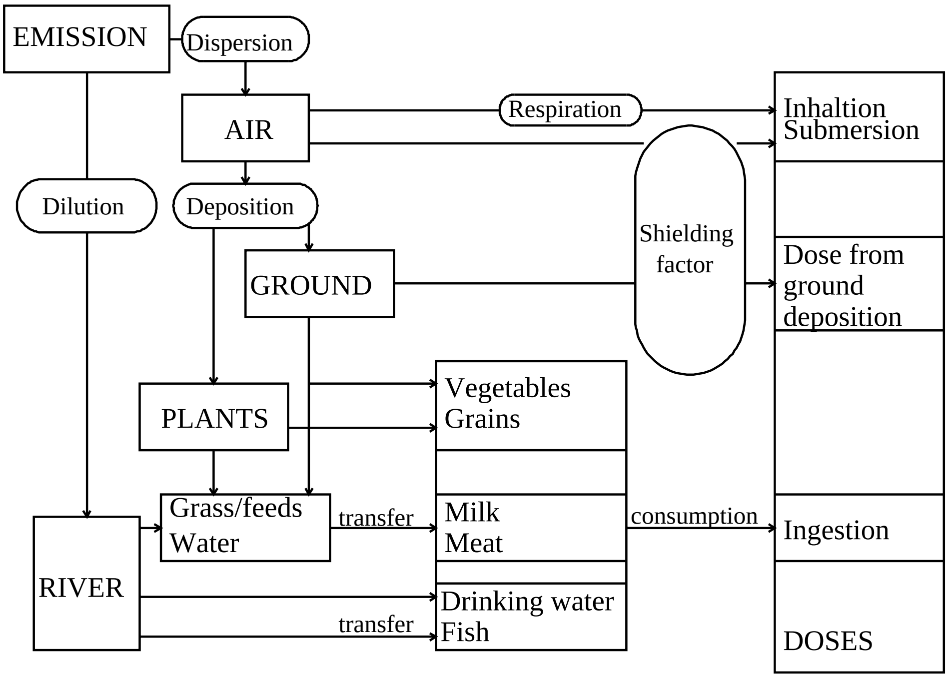

Figure 2: The HSK-R-41 dose calculation model (without C^{14} and Tritium).

2.1 Atmospheric Dispersion

In models recommended by the Swiss Directive HSK-R-41/d [HSK41] and IAEA Safety Guide No.50-GS-S3 [50-SG-S3] the local concentration of the radioactivity in air $C(x, y, z, t)$ is proportional to the release rate $\dot{Q}$ and the dispersion factor $\chi(x,y,z,t)$:

$$C(x,y,z,t) = \dot{Q} \cdot \chi(x,y,z,t), \tag{1}$$

where χ is a function of the time and coordinates of the receptor point.

2.1.1 Short and long term releases

Following the height-corrected Gaussian plume model [50-SG-S3] that takes into account the down-wash by the entrainment factor and the reflection from the ground, neglecting the variation of the wind speed and dispersion parameters with the height, the dispersion factor in the case of the short term release is:

$$\chi_s(x,y,z) = \frac{1}{2\pi\sigma_y\sigma_z u} \cdot F(h_{eff},\sigma_z,z) \cdot exp(-\frac{y^2}{2\sigma_y^2}) \tag{2}$$

$$F(h_{eff},\sigma_z,z) = (1-E) \cdot \left(exp(-\frac{(h_{eff}-z)^2}{2\sigma_z^2}) + exp(-\frac{(h_{eff}+z)^2}{2\sigma_z^2}) \right) + 2 \cdot E \cdot exp(-\frac{z^2}{2\sigma_z^2}), \tag{3}$$

where

χ_s $= the\ short\ term\ dispersion\ factor\ (s \cdot m^{-3})$
C_s $= the\ average\ short\ term\ radioactivity\ at\ point(x,y,z)\ (Bq \cdot m^{-3})$
$\dot{Q}$ $= the\ source\ release\ rate(Bq \cdot s^{-1})$
x $= downwind\ distance\ (m)$
y $= lateral\ distance\ of\ the\ receptor\ from\ the\ plume\ axis\ (m)$
z $= height\ of\ the\ receptor\ (m)$
E $= the\ entrainment\ factor$
h_{eff} $= effective\ height\ of\ the\ release\ (m)$
σ_z $= vertical\ dispersion\ coefficient\ (m)$
σ_y $= horizontal\ dispersion\ coefficient\ (m)$
u $= mean\ wind\ speed\ during\ the\ release\ (m \cdot s^{-1})$

The dispersion factor must be multiplied by the decay factor $exp(-\lambda \cdot \frac{x}{u})$ to account the decay of the short lived radionuclides in flight.

Here is not considered buoyancy effects of the plume rise as all radioactive air is exhausted near ambient temperature.

In according to IAEA Safety Guide No.50-GS-S3 all stacks is divided into three types: tall, short and ground. The stack is assumed as tall if its height greater than 2-2.5 times the height of adjacent buildings. For description of short stacks model introduces the the entrainment factor E as a fraction of the plume which is caught by down-wash in the lee of the stack or building and which can effectively be considered a ground level release. The entrainment factor E is a function of ratio of the air exhaust velocity to the wind speed:

$$E = 1.0\ ; \qquad for\ \frac{W}{u} < 1.0 \tag{4}$$

$$E = 2.58 - 1.58 \cdot \frac{W}{u}\ ; \qquad for\ 1.0 \le \frac{W}{u} < 1.5 \tag{5}$$

$$E = 0.30 - 0.06 \cdot \frac{W}{u}\ ; \qquad for\ 1.5 \le \frac{W}{u} < 5.0 \tag{6}$$

$$E = 0.0\ ; \qquad for\ \frac{W}{u} \ge 5.0 \tag{7}$$

The effective height of release is defined as a function of the height of the stack, plume rise and the topological altitude difference between the source and receptor and can be presented as follows:

$$h_{eff} = h_{st} + \Delta h + \Delta A_{sr}, \tag{8}$$

where

$$\begin{aligned} h_{st} &= height\ of\ the\ stack\ (m) \\ \Delta h &= plume\ rise\ (m) \\ \Delta A_{sr} &= the\ topological\ altitude\ diffrence\ between\ the\ source\ and\ receptor\ (m) \end{aligned}$$

For the neutral or unstable weather conditions IAEA Safety Guide No.50-GS-S3 [50-SG-S3] uses the next expression for the plume rise:

$$\Delta h = min\left(1.44D\left(\frac{W}{u}\right)^{2/3}\left(\frac{x}{D}\right)^{1/3} - C,\ 3\frac{W}{u}D\right), \tag{9}$$

where D is the internal stack diameter (m), C is a down-wash correction factor that is only determined for $W < 1.5u$ as:

$$C = 3\left(1.5 - \frac{W}{u}\right)D$$

For unstable weather conditions the minimum of the expression in Eq.(9) and two equations mentioned below is taken [50-SG-S3]:

$$\Delta h = 4\left(\frac{F_m}{S}\right)^{1/4} \tag{10}$$

$$\Delta h = 1.56S^{-1/6}\left(\frac{F_m}{u}\right)^{1/3}, \tag{11}$$

F_m is a momentum flux parameter and S is a stability parameters, defined as

$$F_m = W^2\left(\frac{D}{2}\right)^2 \tag{12}$$

$$S = 8.70 \cdot 10^{-4} \qquad for\ stability\ class\ E \tag{13}$$

$$S = 1.75 \cdot 10^{-3} \qquad for\ stability\ class\ F \tag{14}$$

The dispersion parameters σ_z and σ_y depend on the downwind distance x, the atmospheric stability class, source height and terrain roughness length z_0. The well-known scheme by Pasquill and Gifford has six atmospheric stability categories, being variable from A (extremely unstable) to F (moderate stable). The vertical dispersion parameters σ_z are calculated by using formulas by Briggs [Brig74]. The terrain roughness length z_0 for various terrain types were evaluated at the LHC site as a function of the receptor coordinates and the detail map was included in the program package RELEASE. The horizontal dispersion parameters σ_y have been interpolated from tabulated values [Mo96a].

The "sector-average" model recommended by IAEA Safety Guide No.50-GS-S3 [50-SG-S3] was used for the calculations of the long term dispersion factors. The space around the source is divided into 16 sectors with an equal angular width $\theta = \pi/8$. The centre of Sector 1 is north direction and Sector 9 is south. Within a sector the values of dispersion factor is independent of the lateral distance from the axis of the sector y. Therefore the horizontal Gaussian distribution may be replaced by an average value over the width of the sector. The sector average dispersion factor is obtained by integrating Eq. 2 over the width of the plume (effectively from $-\infty$ to ∞ and dividing by the arc length at down-distance x :

$$\chi_{L,j}(x,z) \quad = \quad \frac{1}{\sqrt{2\pi}\theta x}\sum_{i,k} P_{ijk}\frac{1}{\sigma_{z,i}u_k}\cdot F(h_{eff},\sigma_{z,i},z)\cdot exp(-\lambda\frac{x}{u_k}), \tag{15}$$

where

$\chi_{L,j}$ $= the\ long\ term\ dispersion\ factor\ (s\cdot m^{-3})$
i $= index\ of\ the\ stability\ class\ (1-6)$
j $= index\ of\ the\ sector\ (1-6)$
k $= index\ of\ the\ wind\ speed\ bin\ (1-20)$
θ $= sector\ width$
u_k $= average\ wind\ speed\ in\ the\ wind\ speed\ bin\ k\ (m\cdot s^{-1})$
P_{ijk} $= joint\ probability\ matrix\ element$

The function $F(h_{eff},\sigma_{z,i},z)$ is taken from Eq. 3. The joint probability matrix element P_{ijk} is a probability that the wind will blow from sector j with average wind speed u_k during the atmospheric conditions have the stability class i and it is given by the following equation:

$$P_{ijk} \quad = \quad T_{ijk}/T_{tot}, \tag{16}$$

where

T_{tot} $= total\ time\ of\ observation$
T_{ijk} $= time\ during\ that\ the\ wind\ blows\ from\ sector\ j$ $with\ average\ wind\ speed\ u_k\ at\ the\ stability\ class\ i$

2.1.2 Determination of the weather statistics

The calculation of the short-term and the long-term dispersion factors needs information about the weather parameters such as the mean wind speed, the wind direction, the atmospheric class stability and the precipitation rate. As a role all parameters(except for the weather class stability) can be obtained on base of a meteorological observations data.

The modified method by Pasquill and Gifford [50-SG-S3] was chosen for the determination of the atmospheric class stability as well in Ref. [Voj98]. According to the IAEA Safety Guide No. 50-SG-S3 [50-SG-S3] a method is based on the measurements of the hourly average wind speed at a 10 m level, insolation during the whole day and observations of cloud cover during the night.

The assignment of the stability class during day was obtained using the Table 1. For conservative estimation of dose more stability is taken for some intermediate cases of the dispersion conditions. In the Table 2. the assignment of the stability class during the night are given. The Safety Guide[50-SG-S3] determines the night as the period from 1 hour before sunset to 1 hour after sunrise. As in Ref. [Voj98], the night begins when the insolation drops below value 10 W$\cdot$m^{-2}.

To obtain the joint probability matrixes P$_{i,j,k}$ for the LHC facilities data of the weather observations at some points of LEP (Meyrin, Crozet, Echenevex, Cessy and Matignin) during 1984-1989 and high-quality meteorological observations from the weather station at Geneva-Cointrin airport during 1984-1989 and 1994-1997 were used. The methods of the joint probability matrix P$_{i,j,k}$ calculation for the Meyrin site is given in detail in Ref. [Voj98]. The methods uses a sector-average model recommended by IAEA Safety Guide No.50-SG-S3[50-SG-S3]. According to the model the complete range of horizontal wind direction from 0° to 360° is divided into 16 of the equal angular sectors. The angular width is equal to π/8 or 22.5°. With the 22.5° sectors the centrelines of the sector point in the direction N, NNE, NE and so on clockwise to NNW. Direction NE does not

Table 1: Assignment of the stability class during the day

Wind speed u ($m\ s^{-1}$)	Solar radiation R_d (langley·h^{-1})			
	$R_d \geq 50$	$50 > R_d \geq 25$	$25 > R_d \geq 12.5$	$12.5 > R_d$
$u < 2$	A	B	B	D
$2 \leq u < 3$	B	B	C	D
$3 \leq u < 4$	B	C	C	D
$4 \leq u < 6$	C	D	D	D
$u \leq 6$	C	D	D	D

Table 2: Assignment of the stability class during the night

Wind speed u ($m\ s^{-1}$)	Overcast (octal)	
	$\geq 4/8$ cloud cover	$\leq 3/8$ cloud cover
$u < 2$	F	F
$2 \leq u < 3$	E	F
$3 \leq u < 5$	D	E
$5 \leq u < 6$	D	D
$u \leq 6$	D	D

mean that wind direction is exactly but only implies, that it belongs to this angular sector. Note that a NNE wind affects a receptor to the SSW of a source. The number of the wind speed bins is chosen 20 as in Ref.[Voj98]. The first bin is from 0.0 $m \cdot s^{-1}$ to 1.0 $m \cdot s^{-1}$, then 18 bins with step size 0.5 $m \cdot s^{-1}$ up to 10 $m \cdot s^{-1}$. Last bin covers all situations with speeds greater than 10 $m \cdot s^{-1}$.

In the Figures 3, 4 wind rose of the Cointrin weather station for all stability classes and for years 1984-1989 and 1994-1997 are given. As it can be seen from the Figures the preferred wind directions are south-west and north-east for both cases. The distinction of the wind roses is negligible and the meteorological observation data from the Cointrin weather station for years 1984-1989 can help to determine the atmospheric stability classes at the LHC site as the weather data at the LEP site have only informations about the average wind speed and the wind direction. The data of the insolation and the overcast observations are interpolated at the same time points as the data of the LEP measurements.

It can be seen from Figures 5-9 that the wind rose at the LHC site differs from the data of the Cointrin weather station although values of the frequency of the stability class (see Table 3) show that the most frequent stability classes are B, D and F for all type of the meteorological observations data.

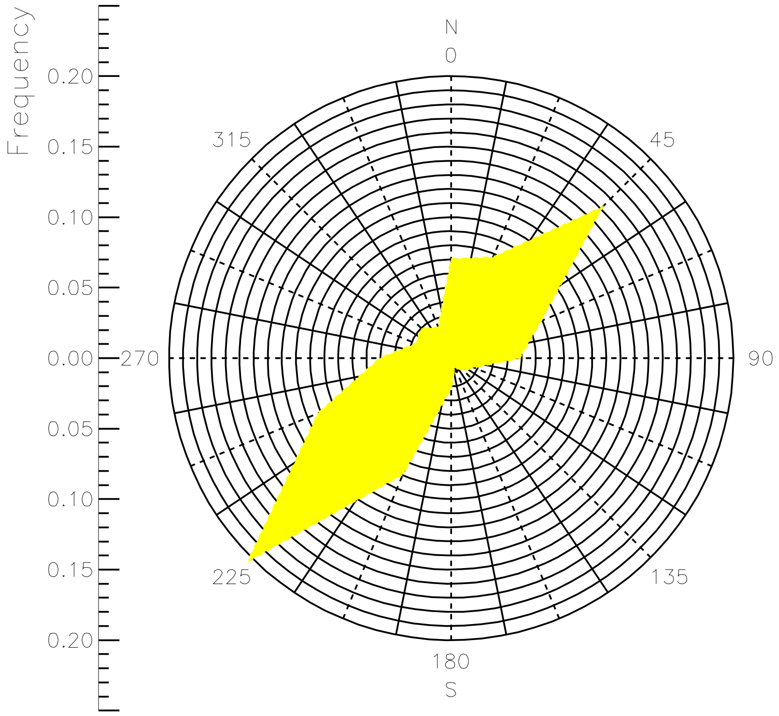

Figure 3: Wind rose of the Cointrin weather station - all stability clases 1984-1989.

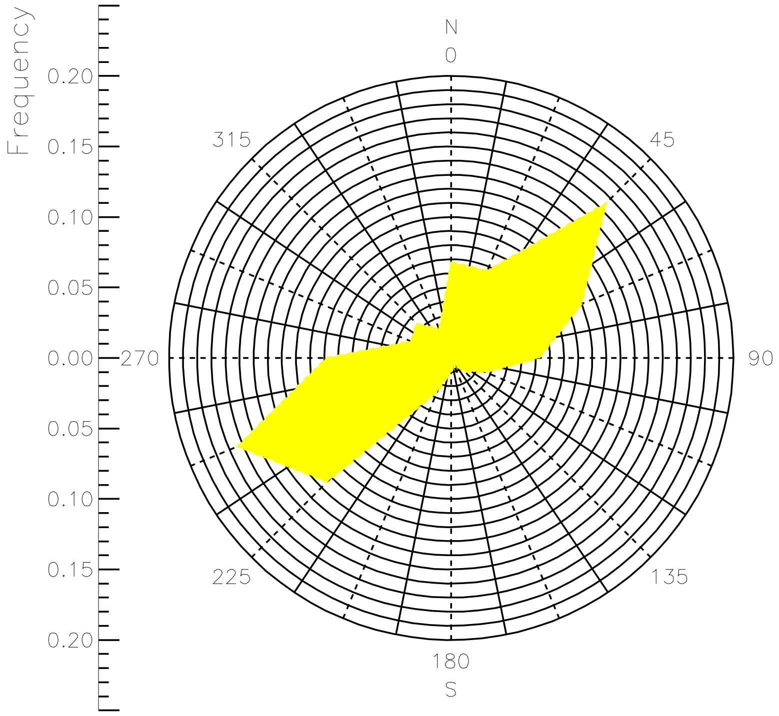

Figure 4: Wind rose of the Cointrin weather station - all stability classes 1994-1997.

The causes of such behavior can be the following:

- a considerable change of the topological altitude at the LHC site from 372 m (Lac Leman) up to 1700 m(Jura), altitude of the Cointrin weather station is 420 m;
- influence of the Jura mountain ridges;
- influence of the lake Lac Lemac;
- an insufficiency of the statistical data of the weather observation at the LEP site (the measurements is carried out each 6 hours)

Table 3: Frequency of the stability class

Stability Class	Frequency							
	Cointrin [Mo96b]	Cointrin 1984-89	Cointrin 1994-97	Cessy 1984-89	Crozet 1984-87	Echenevex 1985-89	Martignin 1984-89	Meyrin 1984-89
A	0.058	0.062	0.056	0.103	0.104	0.070	0.081	0.100
B	0.194	0.118	0.121	0.125	0.133	0.126	0.124	0.127
C	0.059	0.061	0.064	0.013	0.017	0.028	0.031	0.015
D	0.279	0.336	0.333	0.260	0.281	0.316	0.280	0.263
E	0.040	0.050	0.053	0.019	0.025	0.054	0.034	0.016
F	0.368	0.373	0.373	0.480	0.440	0.406	0.450	0.479

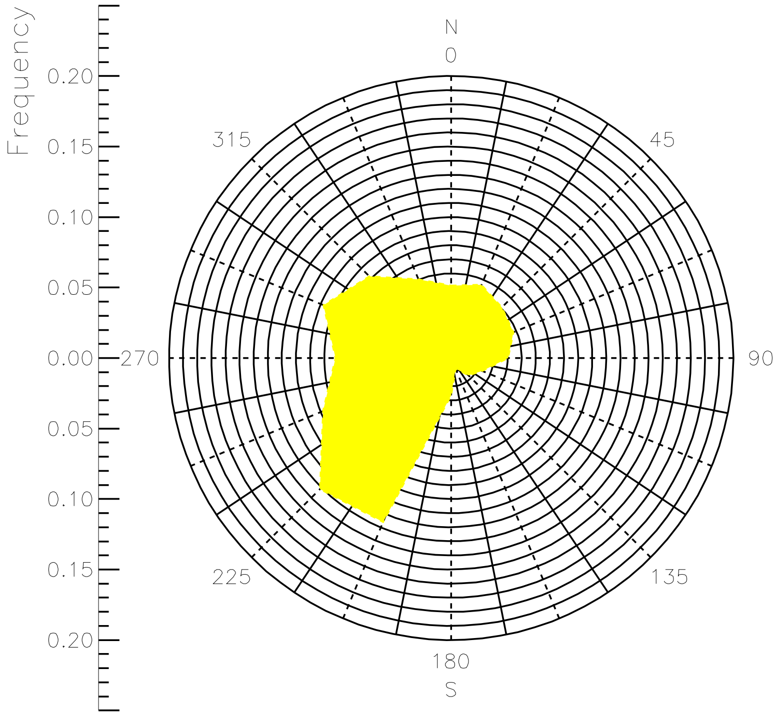

Figure 5: Wind rose of the Echenevex LEP weather station - all stability classes 1985-1989.

Wind and air temperature are affected by terrain irregularities (mountains, ridges and valleys) and the presence of the large water bodies (lakes). Therefore it is recommended by IAEA Safety

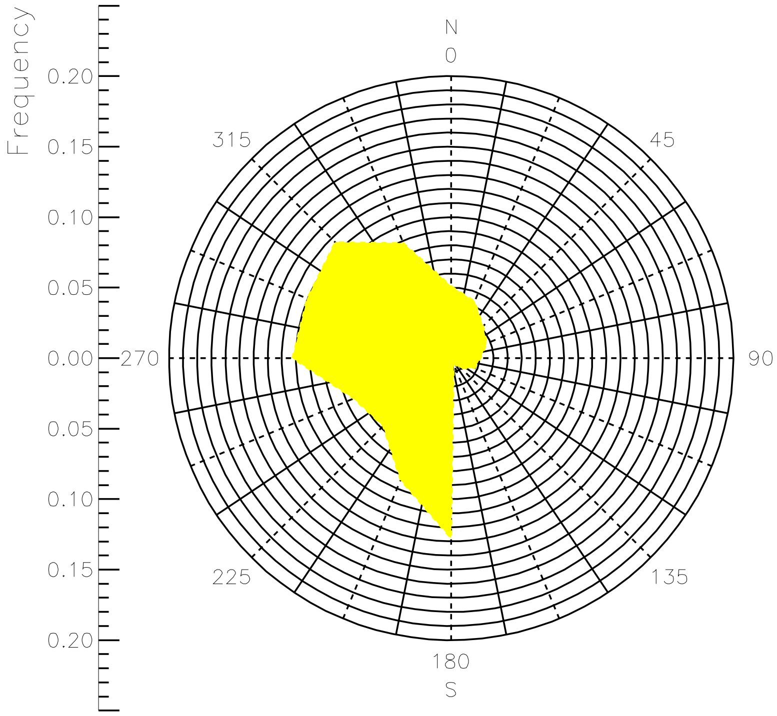

Figure 6: Wind rose of the Cessy LEP weather station - all stability classes 1984-1989.

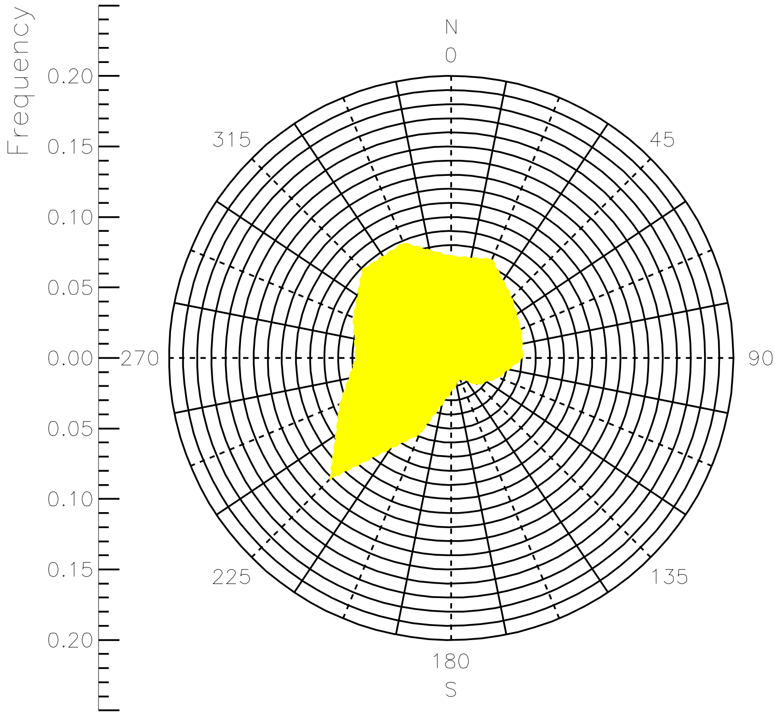

Figure 7: Wind rose of the Crozet LEP weather station - all stability classes 1984-1987.

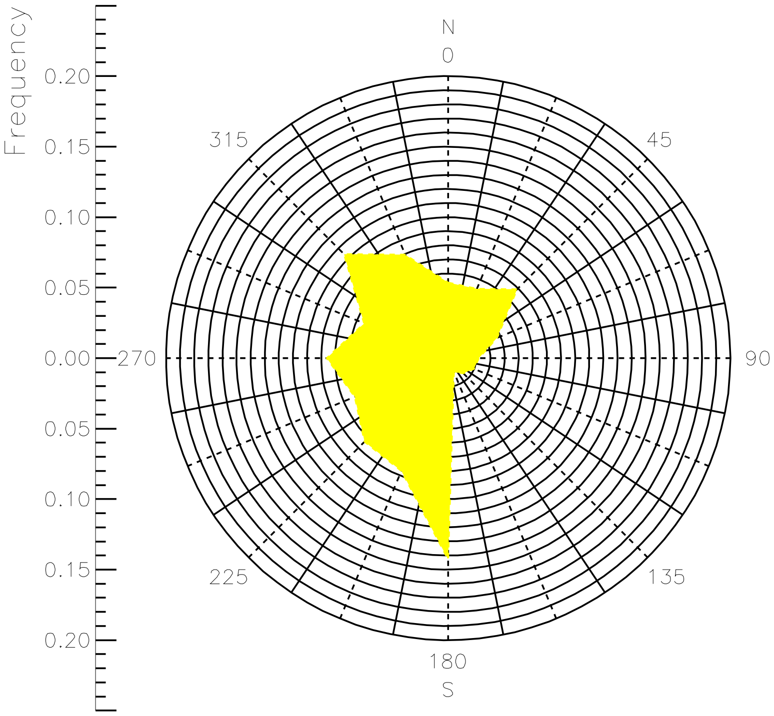

Figure 8: Wind rose of the Mategnin LEP weather station - all stability classes 1984-1989.

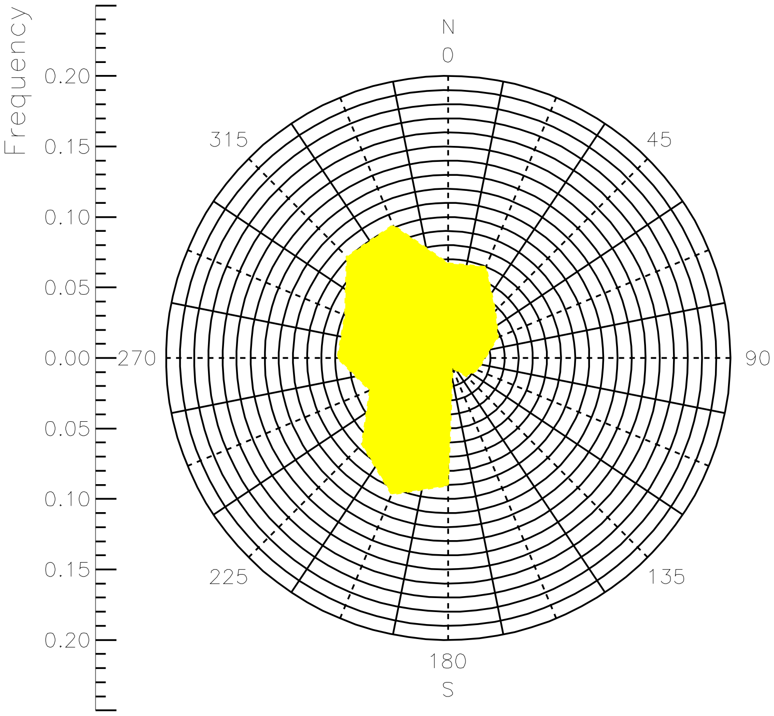

Figure 9: Wind rose of the Meyrin LEP weather station - all stability classes 1984-1989.

Guide No.50-SG-S3[50-SG-S3] to divide a site of complex terrain into two types: uneven terrain, e.g. ridges and valleys and area near a large water body. In uneven terrain, the mean atmospheric flow comprises two regimes. On the one hand, a low regime where winds are affected by structure, ridges, valleys and other objects. On the other hand, an upper regime where winds are not so affected. The stability conditions will usually be different in the two regime. The dispersion of pollutants will differ in the rate and direction in each regime. Sites near large water bodies are subject to distinct local wind system. In fair weather, wind has typical daily variation; the wind direction depends on the position of the sun, mainly being towards land during the day and towards water during the night.
Therefore for the dispersion factors calculations it is reasonable to use the joint probability matrixes $P_{i,j,k}$ obtained from data of the weather observations at Crozet and Cessy (as for uneven terrain) for the release points of P3 and P5 and data from the weather station at Geneva-Cointrin airport during 1994-1997 (as area near lake) for release points of P1, P7 and CERN site.

2.2 Ground Deposition

The radioactive materials from release deposit on the ground or on plants due to two mechanisms. The first one is a settling out due to gravitational effects, called fallout or dry deposition which affects aerosols and iodine. Another process is washout or wet deposition. It is scavenging of the radioactive materials by precipitation falling through the plume and one affects not only aerosol and iodine nut tritium in the form of water vapor. Following the Swiss Directive HSK-R-41/d [HSK41] and IAEA Safety Guide No.50-GS-S3 [50-SG-S3] let introduce the deposition factor(the deposited fraction of the radioactive material) for short term releases :

$$\xi_s = \chi_s \cdot \nu_g + \frac{\Lambda}{2\pi\sigma_y u} \cdot exp(-\frac{y^2}{2\sigma_y^2}) \cdot exp(-\lambda \cdot \frac{x}{u}), \tag{17}$$

where

ξ_s = $the\ short\ term\ deposition\ factor\ on\ the\ ground\ (m^{-2})$
ν_g = $deposition\ velocity\ (m \cdot s^{-1})$
Λ = $washout\ factor\ (s^{-1})$

The first term in Eq. 17 describes the dry deposition. The deposition velocity values of $1.5 \cdot 10^{-3}$ for aerosol and $1.0 \cdot 10^{-2}$ for elementary iodine were taken in accordance to the Swiss Directive HSK-R-41/d [HSK41]. The second term in Eq. 17 is the wet deposition. The washout factor is determined from a reference washout factor Λ_0 by the equation

$$\Lambda = \Lambda_0 \left(\frac{I_N}{I_0}\right)^k, \tag{18}$$

where

Λ_0 = $reference\ washout\ factor$
k = $correction\ coefficient$
I_N = $the\ precipitation\ rate\ (mm \cdot h^{-1})$
I_0 = $the\ reference\ precipitation\ rate\ of\ 1\ mm \cdot h^{-1}$

The values of the reference washout factor, the correction coefficient for aerosol, iodine and tritium are given in the Table 19 (see Appendix A). Following the Swiss Directive HSK-R-41/d [HSK41] the precipitation rate during the short term release is assumed to be 2 mm·h^{-1}.

For the calculation of the short term deposition factor on vegetation ξ'_s is used the same equation as for the deposition factor on the ground:

$$\xi'_s = \chi_s \cdot \nu_g + f_d \cdot \frac{\Lambda}{2\pi\sigma_y u} \cdot exp(-\frac{y^2}{2\sigma_y^2}) \cdot exp(-\lambda \cdot \frac{x}{u}), \tag{19}$$

where the factor f_d is the fraction of direct wet deposition on the plant surface and has a value of 0.3 for aerosol and 1.0 for iodine, respectively.

For calculation of the long term deposition factors is taken a simplified conservative model using an enlarged deposition velocity ν'_g = 1.7·10^{-2} m·s^{-1} because of difficulties of a four-dimensional joint probability matrix use [HSK41]. This model gives a simple relation for the long term deposition factor on the ground:

$$\xi_L = \chi_L \cdot \nu'_g \tag{20}$$

The long term deposition factor on the vegetation in the case is

$$\xi'_L = f_d \cdot \chi_L \cdot \nu'_g \tag{21}$$

3 Dose calculation

In general, recommended by the Swiss Directive HSK-R-41/d [HSK41] formulae for the calculation of the effective doses to the critical group of the population per unit release of radioactivity are valid only for the single point release. In the case of multiple point air release the release quantity Q and the release rate $\dot{Q}$ enter directly in the expression for the total effective dose. With the feature of additivity we can define the total effective dose due to the multiple point releases at a some receptor point as:

$$D(X,Y) = \sum_{l,m} \dot{Q}_{lm} \sum_k max\left(D_{lmk}(X,Y,a), D_{lmk}(X,Y,i)\right), \tag{22}$$

where

X, Y $= global\ coordinates\ of\ the\ receptor\ point\ in\ the\ coordinate\ systeme\ of\ the\ LHC\ ring\ centre$
l $= index\ of\ release\ point$
m $= index\ of\ radionuclide$
k $= index\ of\ pathways$
$\dot{Q}_{lm}$ $= release\ rate$
$D_{lmk}(X,Y,i)$ $= effective\ dose\ per\ unit\ release\ for\ infants$
$D_{lmk}(X,Y,a)$ $= effective\ dose\ per\ unit\ release\ for\ adults$

The transition from the release coordinate system into the LHC ring coordinate system was carried out with the transformation relations [HSK41]:

$$X = X_s + cos(90^\circ - \alpha) \cdot x - sin(90^\circ - \alpha) \cdot y \tag{23}$$

$$Y = Y_s + sin(90^\circ - \alpha) \cdot x + cos(90^\circ - \alpha) \cdot y \tag{24}$$

where α - angle between North and the wind direction, X_s , Y_s - global coordinates of the source point

3.1 Dose via atmospheric pathway

The total dose via the atmospheric pathway for both one-year-old infants (index i) and adults (index a) is a sum of components mentioned above:

$$D_{atm}(a,i) \;=\; max\left(D_{sic}(a,i), D_{gpl}(a,i)\right) + D_{inh}(a,i) + D_{gnd}(a,i) + D_{ing}(a,i) \tag{25}$$

where

$$\begin{array}{ll} D_{sic} & = external\ dose\ from\ the\ radioactive\ semi-infinite\ cloud \\ D_{gpl} & = external\ dose\ from\ the\ radioactive\ cloud\ (Gaussian\ model) \\ D_{inh} & = internal\ dose\ due\ to\ inhalation\ of\ the\ radioactive\ air \\ D_{gnd} & = external\ dose\ due\ to\ iradiation\ from\ ground \\ D_{ing} & = internal\ dose\ due\ to\ ingestion\ of\ food\ produced\ at\ LHC\ site \end{array}$$

For calculation of the external dose from the radioactive cloud two models were taken. The Gaussian plume model of the radioactive cloud is used only for γ - emitters and for the precise calculation dose at the receptor point especially near the source point. The semi-infinite cloud model allows to calculate the external dose from the radioactive cloud for pure β^- or α emitters as well. Below the dose calculated with the semi-infinite cloud model will be called immersion dose and the dose calculated with the Gaussian plume model will be called submersion dose.

3.1.1 Immersion dose

Following the Swiss Directive HSK-R-41 / d [HSK41] the immersion dose for both short term and long term release are given by simple relations:

$$D_{S,sic}(a,i) \;=\; \frac{1}{\alpha}\cdot k_s\cdot\chi_S\cdot e_{imm}(a,i) \tag{26}$$

$$D_{L,sic}(a,i) \;=\; \frac{1}{\alpha}\cdot f_{oc}\cdot k_s\cdot\chi_L\cdot e_{imm}(a,i), \tag{27}$$

where

$$\begin{array}{ll} \alpha & = aconversion\ factor\ from\ year\ to\ seconds \\ f_{oc} & = occupancy\ factor\ (1.0\ for\ full\ time\ presence\ at\ LHC\ site) \\ k_s & = shielding\ factor \\ \chi_S & = short\ term\ dispersion\ factor \\ \chi_L & = long\ term\ dispersion\ factor \\ e_{imm} & = dose\ conversion\ factor\ (Sv\cdot yr^{-1})/(Bq\cdot m^{-3}) \end{array}$$

In accordance to directive [HSK41] the shielding factor accounts the time spent in buildings during that the exposure is reduced. The recommended values of the shielding factor are of 0.4 and 1.0 for long-term and short-term releases, respectively. The dose conversion factors have the same values for infants and adults and they are given in section 7 (see table 11).

3.1.2 Submersion dose

It is well known that the semi-infinite model of cloud gives a conservative estimation of the dose rate for ground level releases at large downwind distances. Besides for elevated release points and short downwind distance this model may underestimate the dose near the stack point because of the contribution to the dose from overhead plume is ignored. Therefore the precise finite cloud model with the numerical integration of the dose kernel was used to calculate the dose from the external radioactive cloud [Over83, Mo96a, Voj98].

In general the short-term and the long-term doses per unit release at a distance r from a source element in the plume are given by three-dimensional space integrals:

$$D_{S,gpl}(\overrightarrow{r}') = 1.239 \cdot 10^{-13} k_s \mu_a \overline{E}_d \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{0}^{\infty} \frac{B(\overline{E}_\gamma, \mu r)e^{-\mu r}\chi_S(x,y,z)}{4\pi r^2} dxdydz \tag{28}$$

$$D_{L,gpl}(\overrightarrow{r}') = 1.239 \cdot 10^{-13} f_{oc} k_s \mu_a \overline{E}_d \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{0}^{\infty} \frac{B(\overline{E}_\gamma, \mu r)e^{-\mu r}\chi_L(x,y,z)}{4\pi r^2} dxdydz, \tag{29}$$

where $1.239 \cdot 10^{-13}$ Gy·m^3· MeV^{-1} is a conversion factor, and

$\mu_a \quad = linear\ gamma\ energy\ absorption\ coefficient\ for\ air\ (m^{-1})$
$\mu \quad = linear\ total\ amma\ attenuation\ coefficient\ for\ air\ (m^{-1})$
$\overline{E}_d \quad = average\ total\ gamma\ energy\ emitted\ per\ decay\ (MeV)$
$\overline{E}_\gamma \quad = average\ photon\ energy\ (MeV)$
$B(\overline{E}_\gamma, \mu r) \quad = build\ up\ factor$
$f_{oc} \quad = occupancy\ factor$
$k_s \quad = shielding\ factor$
$r \quad = distance\ from\ the\ plume\ element\ dxdydz\ to\ the\ receptor\ (m)$
$\chi_S \quad = short\ term\ dispersion\ factor$
$\chi_L \quad = long\ term\ dispersion\ factor$

In contrast to the original works of L.Moritz and P.Vojtyla [Mo96a, Voj98] the dose build-up factor $B(\overline{E}_\gamma, \mu r)$ by Chilton [Chi80] was used instead of linear one as the linear build-up factor overestimates dose near the point sources and underestimates the dose for distant sources. The Figure 10 shows the dose build-up factor as a function of average photon energy $\overline{E}_\gamma$ and distance μr for three various kinds of factor presentation: linear, Bergers and Chilton. For short-term release the integration of the dose kernel was performed with the same way as in [Voj98] taking into account singularity at the receptor point and integration limits were restricted by five times the gamma attenuation length $1/\mu$.

In the case of the long-term dose calculation the main computer time is spent to carry out a multidimensional integration and it rises linearly with increasing number of the receptor points. It is possible to decrease significantly the integration time using the Monte-Carlo method (special sampling) or the numerical calculation of the two-dimensional integral instead of 3-d one.

Following results of works [Over83, Mo96a] and changing the variables l and ϕ we obtain a two-dimensional integral from the dose kernel for the long-term release:

$$D_{L,gpl}(x_0, j) = 1.239 \cdot 10^{-13} f_{oc} k_s \mu_a \overline{E}_d \int_{0}^{\infty}\int_{0}^{\infty} \frac{B(\overline{E}_\gamma, \mu\sqrt{l^2+z^2})e^{-\mu\sqrt{l^2+z^2}}\chi_{L,j}(x_0,z)}{4\pi(l^2+z^2)} 2\pi l dl dz, \tag{30}$$

where

$$\begin{aligned} l &= \sqrt{r^2 - z^2} \\ \chi_{L,j}(x_0,z) &= \tfrac{1}{\sqrt{2\pi}\theta x_0}\textstyle\sum_{i,k} P_{ijk}\tfrac{1}{\sigma_{z_i} u_k} F(h_{eff}, \sigma_{z_i}, z)e^{-\lambda\frac{x_0}{u_k}} \end{aligned}$$

The comparison of results for both 3-d and 2-d integrations for more important radionuclides is presented in Figure 11. As can be seen from Figure 11 the deviations of the computed 2-d integrals from 3-d integrals do not exceed of 15-20 % for all more important radioniclides. Such methods of the dose kernel integration allows to reduce the calculation time more than 50 times.

The equation (29) is almost a classical example of the integral calculation using the Monte Carlo

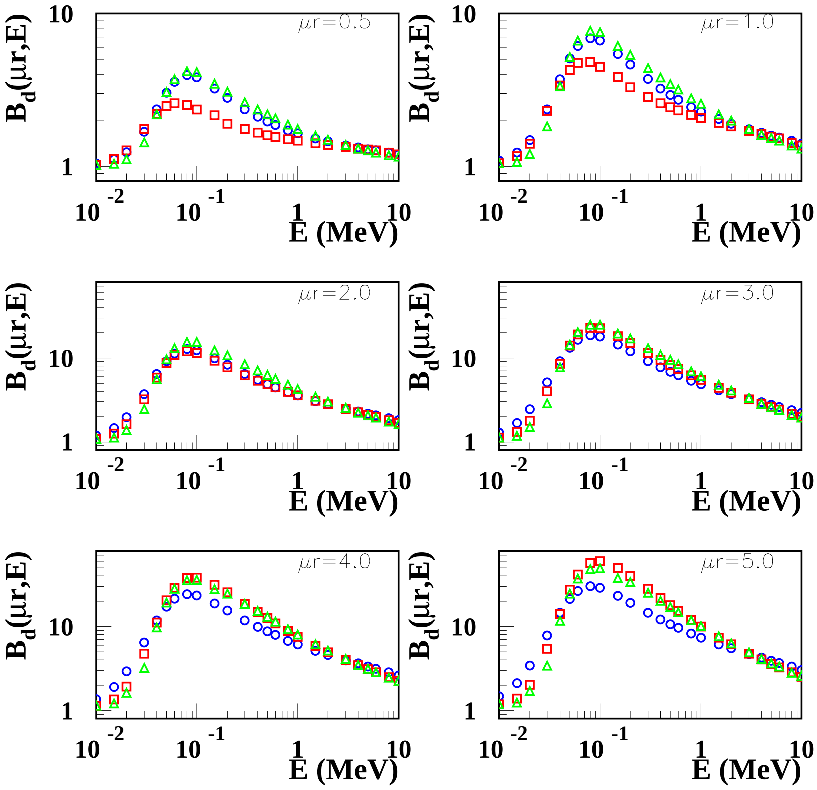

Figure 10: The dose build-up factor as a function of photon energy and distance: circle - linear build-up factor, triangular - Bergers build-up factor, square - build-up factor by Chilton.

method. The simple change of variables using the spherical coordinate transform removes a singularity in the dose kernel and the equation (29) can be written as:

$$D_{L,gpl}(\overrightarrow{r}') = 1.239 \cdot 10^{-13} f_{oc} k_s \mu_a \overline{E}_d \frac{1}{2\mu} \int_0^{\infty} \int_0^{2\pi} \int_0^{\frac{\pi}{2}} B(\overline{E}_\gamma, \mu r) \chi_L(x,y,z) p(r,\varphi,\theta) dr d\varphi d\theta, \quad (31)$$

where $p(r,\varphi,\theta)$ is a three dimensional probability density function (p.d.f.). Because of three random variables are independent the p.d.f. $p(r,\varphi,\theta)$ has the following form:

$$p(r,\varphi,\theta) = p(r) \cdot p(\varphi) \cdot p(\theta) = \mu \cdot e^{-\mu r} \cdot \frac{1}{2\pi} \cdot sin\theta \quad (32)$$

Therefore the final estimation of the integral (31) can be determined as:

$$\delta_{N_m}(\overrightarrow{r}') \approx 1.239 \cdot 10^{-13} f_{oc} k_s \mu_a \overline{E}_d \frac{1}{2\mu N_m} \sum_{m=1}^{N_m} B(\overline{E}_\gamma, \mu\xi_m) \chi_L(x(\xi_m), y(\xi_m), z(\xi_m)), \quad (33)$$

where N$_m$ is a number of independent sampling of a random value ξ_m. By using the equation (30), it is possible to construct a simple algorithm for the sampling of the mean free path (r) and angles (φ,θ):

$$r = -\mu^{-1} \cdot \ln(\gamma_1); \quad \varphi = 2\pi \cdot \gamma_2; \quad \cos\theta = \gamma_3, \quad (34)$$

where γ_i is an uniform random number in interval [0,1).
The efficiency of the integral (30) computation depends on a number of independent sampling and a singularity of the $\chi_L(x,y,z)$ function. This value corresponds to a number of nodes in case

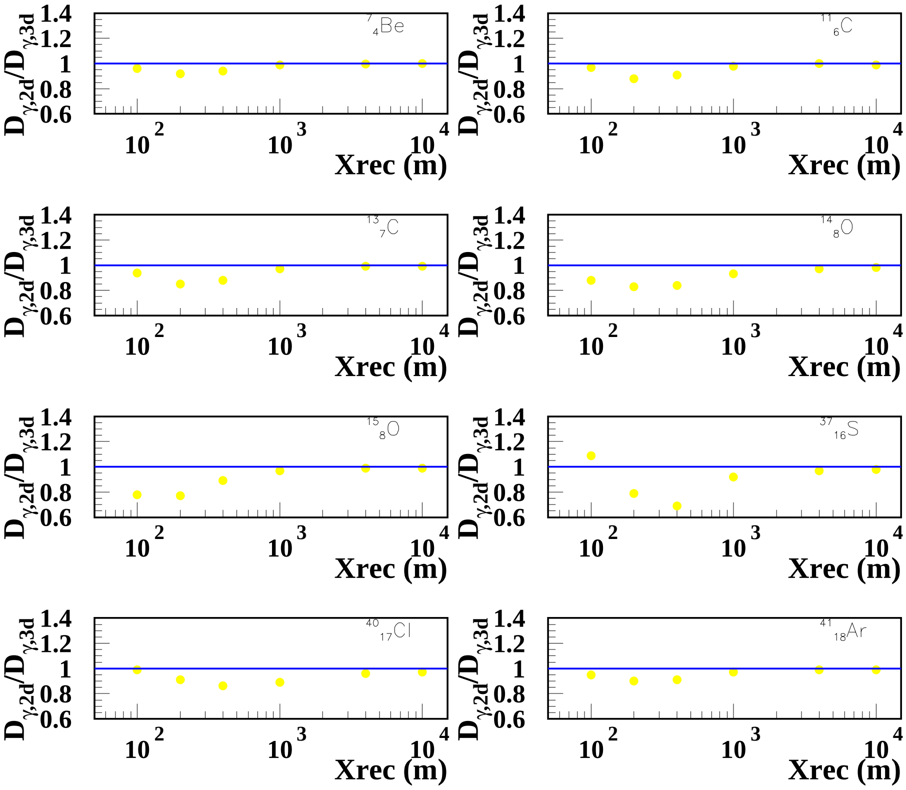

Figure 11: The ratio of two-dimensional integral to 3-dimensional one for more important radionuclides of the LHC release.

of the calculation using the equation (28), (29) The computation by using the Monte Carlo method has a some advantages in comparison with the integration (28), (29) if the number of independent sampling of the random value ξ_m will be less than a number of nodes. An estimation of dispersion can be performed on base of the central limit theorem that is:

$$| \delta_{N_m} - a | < 3\sqrt{D\delta_{N_m}/N_m}, \tag{35}$$

where δ_{N_m} is an estimation of integral (33), the a-factor is an expectation value of the $B(\overline{E}_\gamma, \mu r)\chi_L(x,y,z)$ function and $D\delta_{N_m}$ is a value of the dispersion for estimation (33). The test runs shown that the last condition is satisfied for all values of N_m greater than 1000.

3.1.3 Inhalation dose

The Swiss Directive HSK-R-41/d [HSK41] defines the inhalation doses for both short-term and long-term releases as following:

$$D_{S,inh}(a,i) = \chi_S \cdot U_{inh}(a,i) \cdot e_{inh}(a,i) \tag{36}$$

$$D_{L,inh}(a,i) = f_{oc} \cdot \chi_L \cdot U_{inh}(a,i) \cdot e_{inh}(a,i), \tag{37}$$

where

f_{oc} $= occupancy\ factor$
U_{inh} $= inhalation\ rate$
e_{inh} $= inhalation\ dose\ conversion\ factor\ (Sv \cdot Bq^{-1})$

The recommended values of the average annual inhalation rate are 2.3 $\cdot 10^{-4}$ $m^3 \cdot s^{-1}$ for adults and 6.0 $\cdot 10^{-5}$ $m^3 \cdot s^{-1}$ for infants. The age-dependent dose conversion factors were taken from [ICRP72, HSK41] and their values are given in the Table 11 of section 7.

3.1.4 External dose from ground deposition

When we consider the external dose from ground deposition for the long-term release it is necessary to take into account the contribution of the long-lived radionuclides to the ground deposition from previous years of operation. For short-term release it is important only a contribution from current release.

Following the recommendation of the Swiss Directive HSK-R-41/d [HSK41], the activity of the radionuclides deposited on the ground is a sum of two component: a slow and a fast. In this case the dose rate from the ground deposition due to a short-term release is:

$$D_{S,gnd}(a,i) \quad = \quad k_s \cdot e_{gnd}(a,i) \cdot \xi_S \left(0.63 \frac{1 - e^{-(\lambda+\lambda_F)T_{exp}}}{(\lambda + \lambda_F)} + 0.37 \frac{1 - e^{-(\lambda+\lambda_S)T_{exp}}}{(\lambda + \lambda_S)} \right), \qquad (38)$$

and for long-term release we obtain more complicate expression:

$$D_{L,gnd}(a,i) = f_{oc} \cdot k_s \cdot e_{gnd}(a,i) \cdot \xi_L \cdot$$
$$\left(\left(0.63 \frac{1 - e^{-(\lambda+\lambda_F)T_{op})}}{(\lambda + \lambda_F)} + 0.37 \frac{1 - e^{-(\lambda+\lambda_S)T_{op}}}{(\lambda + \lambda_S)} \right) \frac{1 - e^{-\lambda T_{exp}}}{\lambda} + \frac{1}{\lambda} \left(T_{exp} - \frac{1 - e^{-\lambda T_{exp}}}{\lambda} \right) \right), \qquad (39)$$

where

$k_s \quad = 0.4 \ = \ indoor\ shielding\ factor$
$f_{oc} \quad = occupancy\ factor$
$e_{gnd} \quad = dose\ conversion\ factor\ ((Sv \cdot yr^{-1})/(Bq \cdot m^{-2}))\ for\ external\ exposure\ from\ ground$
$\xi_S \quad = short\ term\ deposition\ factor$
$\xi_L \quad = long\ term\ deposition\ factor$
$\lambda \quad = radioactive\ decay\ constant\ (yr^{-1})$
$\lambda_F \quad = 1.1\ yr^{-1} \ = \ non-radioactive\ decay\ constant\ for\ fast\ component$
$\lambda_S \quad = 7.5 \cdot 10^{-3}\ yr^{-1} \ = \ non-radioactive\ decay\ constant\ for\ slow\ component$
$T_{exp} \quad = 1\ year \ = \ exposure\ time$
$T_{op} \quad = 50\ years \ = \ the\ operation\ time$

In contrast to work [Voj98] a value of the indoor shielding factor for the short-term release was taken the same as for the long-term release. The dose from ground deposition is zero for gases, for iodine the doses are multiplied by factor f_{ei} = 0.5.

3.1.5 Ingestion dose

The ingestion dose is caused by the consumption of foods. As mentioned above the Swiss Directive HSK-R-41/d [HSK41](see Fig. 1) considers a few different models for the dose calculation from aerosol, tritium and ^{14}C. The ingestion dose is zero for gases. The Swiss Directive HSK-R-41/d [HSK41] takes into account three pathway of the ingestion of radioactive material released to the atmosphere:

- consumption of the vegetables and fruits
- consumption of milk and dairy products
- consumption of meat

3.1.5.1 Ingestion dose for aerosol.

The radioactivity accumulating on the vegetation consists of two components: on the one hand, one is the direct deposition due to the mechanisms of fallout and washout, on the other hand, one is the uptake from soil through the root system. The transfer of radionuclides from soil to plants is describes by element-specific biological transfer factors, values of that are recommended by the Directive HSK-R-41 / d [HSK41].

The transformation of the radioactivity on the leaves or in the ground surrounding the root system contains not only radioactive part but non-radioactive one that is defined by the effective decay constant on the leaves $\lambda_{e,lv}$ and the effective decay constant in the soil $\lambda_{e,R}$ as :

$$\begin{aligned} \lambda_{e,lv} &= \lambda + \lambda_V && (40) \\ \lambda_{e,R} &= \lambda + \lambda_R, && (41) \end{aligned}$$

where

$$\begin{aligned} &\lambda && = radioactive\ decay\ constant \\ &\lambda_V && = non - radioactive\ decay\ constant\ on\ leaves\ for\ aerosol\ and\ iodine \\ &\lambda_R && = non - radioactive\ decay\ constant\ in\ soil\ surrounding\ the\ root\ system \end{aligned}$$

The recommended values of the non-radioactive decay constant on leaves of the vegetables are 18 yr^{-1} for aerosol and 32 yr^{-1} for iodine, respectively. The values of the non-radioactive decay constant in the ground surrounding the root system were taken from [HSK41] and they are presented in Table 21 of Appendix A.

In accordance to the time scenarios recommended by [HSK41] a year is divided into harvest time, lasting from 16 April to 15 October, and winter time to take into account the consumption of the fresh products and stored products. The long-term ingestion dose for adults or infants is given by the simple formulae:

$$D_{L,ing}(a,i) = f_{veg} D_{L,veg}(a,i) + f_{mi} D_{L,mi}(a,i) + f_{mt} D_{L,mt}(a,i), \qquad (42)$$

where

$$\begin{aligned} &f_{veg} && = fraction\ of\ vegetables\ from\ reference\ site \\ &f_{mi} && = fraction\ of\ milk\ from\ reference\ site \\ &f_{mt} && = fraction\ of\ meat\ from\ reference\ site \\ &D_{L,veg} && = the\ ingestion\ dose\ due\ to\ intake\ of\ vegetables \\ &D_{L,mi} && = the\ ingestion\ dose\ due\ to\ intake\ of\ milk \\ &D_{L,mt} && = the\ ingestion\ dose\ due\ to\ intake\ of\ meat \end{aligned}$$

The partial ingestion doses can be determined as the following:

$$D_{L,veg} = \left(C^0_{veg,lv} \left(\frac{T_1}{2} + \frac{2}{T_1} \left(\frac{1 - e^{-\lambda T_1/2}}{\lambda} \right)^2 + C^0_{veg,r} e^{-\lambda_{e,R} T_h} \frac{1 - e^{-\lambda_{e,R} T_1}}{\lambda_{e,R}} \right) \right) \cdot U_{veg}(a,i) e_{ing}(a,i) \qquad (43)$$

$$D_{L,mi} = \left(C^0_{fod,lv} \left(\frac{T_1}{2} + \frac{2}{T_1} \left(\frac{1 - e^{-\lambda T_1/2}}{\lambda} \right)^2 + C^0_{fod,r} e^{-\lambda_{e,R} T_h} \frac{1 - e^{-\lambda_{e,R} T_1}}{\lambda_{e,R}} \right) \right) \cdot V_{fod} TF_{fod-mi} e^{-\lambda T_{mi}} U_{mi}(a,i) e_{ing}(a,i) \tag{44}$$

$$D_{L,mt} = \left(C^0_{fod,lv} \left(\frac{T_1}{2} + \frac{2}{T_1} \left(\frac{1 - e^{-\lambda T_1/2}}{\lambda} \right)^2 + C^0_{fod,r} e^{-\lambda_{e,R} T_h} \frac{1 - e^{-\lambda_{e,R} T_1}}{\lambda_{e,R}} \right) \right) \cdot V_{fod} TF_{fod-mt} e^{-\lambda T_{mt}} U_{mt}(a,i) e_{ing}(a,i), \tag{45}$$

where

$T_1 = 1\ year =\ time\ of\ exposure$
$T_h = 0.29\ yr =\ time\ between\ the\ beginning\ of\ calendar\ year\ and\ harvest$
$T_{mi} = 2.7 \cdot 10^{-3}\ yr\ =\ typical\ storage\ time\ of\ milk$
$T_{mt} = 5.5 \cdot 10^{-2}\ yr\ =\ typical\ storage\ time\ of\ meat$
$U_{veg} = consumption\ rate\ of\ vegetables\ (kg \cdot yr^{-1})$
$U_{mi} = consumption\ rate\ of\ milk\ (kg \cdot yr^{-1})$
$U_{mt} = consumption\ rate\ of\ meat\ (kg \cdot yr^{-1})$
$V_{fod} = 65\ kg \cdot day^{-1}\ =\ daily\ consumption\ of\ fodder\ by\ cattle$
$TF_{fod-mi} = biological\ transfer\ factors\ from\ fodder\ to\ milk\ (day \cdot kg^{-1})$
$TF_{fod-mt} = biological\ transfer\ factors\ from\ fodder\ to\ meat\ (day \cdot kg^{-1})$
$e_{ing} = ingestion\ dose\ conversion\ factor\ (Sv \cdot Bq^{-1})\ for\ adults\ and\ infants$

The values of the average annual consumption rates of vegetables, milk and meat for populations at the LHC site are recommended by the Swiss Directive HSK-R-41/d [HSK41] and they are presented in the Table 21 of Appendix A.

In Eqs.(40)-(42) the variables C^0 are normalized concentrations of radionuclides. The normalized radionuclide concentrations on leaves of vegetables and for uptake from the root system are given by expressions:

$$C^0_{veg,lv} = \frac{\xi'_L}{Y_{veg} \lambda_{e,lv}} \tag{46}$$

$$C^0_{veg,r} = \frac{\xi_L}{P_{veg}} \cdot \frac{1 - e^{-\lambda_{e,R} T_{op}}}{\lambda_{e,R}} \cdot TF_{soil-veg} \tag{47}$$

The normalized radionuclide concentrations for fodder are given by the similar equations:

$$C^0_{fod,lv} = \frac{\xi'_L}{Y_{fod} \lambda_{e,lv}} \tag{48}$$

$$C^0_{fod,r} = \frac{\xi_L}{P_{fod}} \cdot \frac{1 - e^{-\lambda_{e,R} T_{op}}}{\lambda_{e,R}} \cdot TF_{soil-fod} \tag{49}$$

where

$Y_{veg} = typical\ areal\ density\ of\ vegetables$
$Y_{fod} = typical\ areal\ density\ of\ fodder$
$P_{veg} = typical\ areal\ density\ of\ the\ soil\ within\ the\ reach\ of\ roots\ for\ vegetables$
$P_{fod} = typical\ areal\ density\ of\ the\ soil\ within\ the\ reach\ of\ roots\ for\ fodder$
$TF_{soil-veg} = biological\ transfer\ factors\ for\ uptake\ from\ soil\ to\ vetetables\ ((Bq \cdot kg^{-1})/(Bq \cdot kg^{-1}))$
$TF_{soil-fod} = biological\ transfer\ factors\ for\ uptake\ from\ soil\ to\ fodder((Bq/kg)/(Bq/kg))$

The values of the typical area density for vegetables, fodder and soil recommended by the Swiss Directive HSK-R-41/d [HSK41] are given in the Table 21 of Appendix A.

The formulae for the calculation of the short-term ingestion dose has the same shape as for the long-term release:

$$D_{S,ing}(a,i) \quad = \quad f_{veg}D_{S,veg}(a,i) + f_{mi}D_{S,mi}(a,i) + f_{mt}D_{S,mt}(a,i) \tag{50}$$

In this case, the production time of food T_p plays a important role to calculate the partial ingestion doses as the time is a period between release and the next end of the harvest. For the dose calculation at the fixing short-term release limits, T_p has a value of 8.3 $\cdot 10^{-2}$ yr.

Following the directive [HSK41] the partial ingestion doses in case of release during the harvest time ($T_p < 0.5\ yr$) can be determined as:

$$\begin{aligned} D_{S,veg} = C^0_{veg,lv} \left(\frac{1}{\lambda_{e,lv}} + e^{-\lambda T_p} \cdot \frac{2}{\lambda_V T_1} \cdot \frac{1-e^{-\lambda T_1/2}}{\lambda} \right) \cdot U_{veg}(a,i) \cdot e_{ing}(a,i) + \\ C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p+T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot U_{veg}(a) \cdot e_{ing}(a) \end{aligned} \tag{51}$$

$$\begin{aligned} D_{S,mi} = \Bigg(C^0_{veg,lv} \left(\frac{1}{\lambda_{e,lv}} + e^{-\lambda T_p} \cdot \frac{2}{\lambda_V T_1} \cdot \frac{1-e^{-\lambda T_1/2}}{\lambda} \right) \cdot U_{mi}(a,i) \cdot e_{ing}(a,i) + \\ C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p+T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot U_{mi}(a) \cdot e_{ing}(a) \Bigg) \cdot V_{fod} TF_{fod-mi} e^{-\lambda T_{mi}} \end{aligned} \tag{52}$$

$$\begin{aligned} D_{S,mt} = \Bigg(C^0_{veg,lv} \left(\frac{1}{\lambda_{e,lv}} + e^{-\lambda T_p} \cdot \frac{2}{\lambda_V T_1} \cdot \frac{1-e^{-\lambda T_1/2}}{\lambda} \right) \cdot U_{mt}(a,i) \cdot e_{ing}(a,i) + \\ C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p+T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot U_{mt}(a) \cdot e_{ing}(a) \Bigg) \cdot V_{fod} TF_{fod-mt} e^{-\lambda T_{mt}} \end{aligned} \tag{53}$$

The partial ingestion doses in case of release during the winter time ($T_p > 0.5\ yr$) are given by expressions:

$$D_{S,veg} = C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p-T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot U_{veg}(a) \cdot e_{ing}(a) \tag{54}$$

$$D_{S,mi} = C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p-T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot V_{fod} \cdot TF_{fod-mi} \cdot e^{-\lambda T_{mi}} \cdot U_{mi}(a) \cdot e_{ing}(a) \tag{55}$$

$$D_{S,mt} = C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p-T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot V_{fod} \cdot TF_{fod-mt} \cdot e^{-\lambda T_{mt}} \cdot U_{mt}(a) \cdot e_{ing}(a) \tag{56}$$

$$D_{S,mi} = C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p-T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot V_{fod} \cdot TF_{fod-mi} \cdot e^{-\lambda T_{mi}} \cdot U_{mi}(a) \cdot e_{ing}(a) \tag{57}$$

$$D_{S,mt} = C^0_{veg,r} \cdot \frac{e^{-\lambda_{e,R}(T_p-T_1/2)} - e^{-\lambda_{e,R}T_{inc}}}{\lambda_{e,R}} \cdot V_{fod} \cdot TF_{fod-mt} \cdot e^{-\lambda T_{mt}} \cdot U_{mt}(a) \cdot e_{ing}(a) \tag{58}$$

The normalized radionuclide concentrations C^0 (kg^{-1}) for all pathway of ingestion can be written in the form:

$$C^0_{veg,lv} \quad = \quad \frac{\xi'_S}{Y_{veg}} \tag{59}$$

$$C^0_{veg,r} = \frac{\xi_S}{P_{veg}} \cdot TF_{soil-veg} \quad (60)$$

$$C^0_{fod,lv} = \frac{\xi'_S}{Y_{fod}} \quad (61)$$

$$C^0_{fod,r} = \frac{\xi_S}{P_{fod}} \cdot TF_{soil-fod} \quad (62)$$

3.1.5.2 Ingestion dose for tritium.

An equilibrium model is used for the transport of tritium in the form of HTO. According to the model it is assumed that the specific tritium activity in plants is equal to that of the water content in the air. Under assumption that factors of $f_{Lu} = 1$ and $f_N = 0$ [HSK41] for the long term and short term releases we obtain an formulae for the ingestion doses calculation:

$$D_{HTO,S} = \frac{\chi_S}{\phi \cdot \alpha} f_{wa} \left(f_{veg} U_{veg}(a,i) + f_F \left(f_{mi} U_{mi}(a,i) + f_{mt} U_{mt}(a,i) \right) \right) \cdot e_{ing}(a,i) \quad (63)$$

$$D_{HTO,L} = \frac{\chi_L}{\phi \cdot \alpha} f_{wa} \left(f_{veg} U_{veg}(a,i) + f_F \left(f_{mi} U_{mi}(a,i) + f_{mt} U_{mt}(a,i) \right) \right) \cdot e_{ing}(a,i) \quad (64)$$

where

$\phi = 9 \cdot 10^{-3}\ kg \cdot m^{-3} = average\ humidity\ of\ air$
$\alpha = conversion\ factor\ from\ year\ to\ seconds$
$f_{wa} = 0.75 = average\ water\ content\ of\ foodstuff$
$f_F = 0.4 = fraction\ of\ water\ in\ milk\ and\ meat$

3.1.5.3 Ingestion dose for ^{14}C.

A photo-synthesis model is used for the transport of ^{14}C. It is assumed that the uptake by plants is entirely through photo-synthesis, therefore it is important only the concentration in air of ^{14}C in the form of CO_2. The formulae for the calculation of the ingestion doses from ^{14}C are the same shape as in the case for tritium:

$$D_{C-14,S} = \frac{\chi_S}{\Psi \cdot \alpha} f_C \left(f_{veg} U_{veg}(a,i) + f_{mi} U_{mi}(a,i) + f_{mt} U_{mt}(a,i) \right) \cdot e_{ing}(a,i) \quad (65)$$

$$D_{C-14,L} = \frac{\chi_L}{\Psi \cdot \alpha} f_C \left(f_{veg} U_{veg}(a,i) + f_{mi} U_{mi}(a,i) + f_{mt} U_{mt}(a,i) \right) \cdot e_{ing}(a,i), \quad (66)$$

where

$\Psi = 1.8 \cdot 10^{-4}\ kg \cdot m^{-3} = carbon\ content\ of\ air$
$f_C = 0.125 = mass\ fraction\ of\ carbon\ in\ foodstuff$

3.2 Dose via water pathway

It is assumed that the public can be exposed as well due the radioactivity dissolved in effluent water. The transport and dispersion radionuclides discharged into water are calculated only for the long term releases. The model of the directive HSK-41-R [HSK41] considers two processes of decrease of the radionuclides concentration in water: dilution and radioactive decay. The total effective dose per unit release to the critical group of the population via the water pathway $D_{W,tot}$ is a sum of the ingestion dose $D_{W,ing}$ and the immersion dose $D_{W,imm}$:

$$D_{W,tot}(a,i) = D_{W,ing}(a,i) + D_{W,imm}(a,i) \tag{67}$$

3.2.1 Ingestion dose

For ingestion via the water pathway both drinking water and fish consumption are considered as well as ingestion of milk and meat from animals that have been watered with river water. There are different models for the calculation of the ingestion doses from aerosol and tritium. Besides, it is assumed that the ingestion doses from gases are equal to 0. The ingestion dose for aerosol from the long term release is then:

$$\begin{aligned}D_{W,ing} = \frac{1}{J}e^{-\lambda\frac{x}{\nu}}\left(f_W U_W(a,i) + f_{fi}TF_{wa-fi}U_{fi}(a,i)e^{-\lambda T_{fi}}\right)\cdot e_{ing}(a,i) + \\ \frac{1}{J}e^{-\lambda\frac{x}{\nu}}\cdot V_W\left(f_{miw}TF_{fod-mi}U_{mi}(a,i)e^{-\lambda T_{mi}} + f_{mtw}TF_{fod-mt}U_{mt}(a,i)e^{-\lambda T_{mi}}\right)\cdot e_{ing}(a,i),\end{aligned} \tag{68}$$

where

J $= the\ average\ flow\ rate\ of\ the\ receiving\ water\ (m^3\cdot yr^{-1})$
λ $= radioactive\ decay\ constant\ of\ radionuclide\ (s^{-1})$
ν $= velosity\ of\ the\ flow\ of\ the\ receiving\ river\ (m\cdot s^{-1})$
f_w $= fraction\ of\ drinking\ water\ from\ river$
U_w $= average\ annual\ drinking\ water\ consumption\ (m^3\cdot yr^{-1})$
f_{fi} $= fraction\ of\ fish\ from\ river$
U_{fi} $= average\ annual\ fish\ consumption\ (kg\cdot yr^{-1})$
TF_{wa-fi} $= biological\ transfer\ factor\ from\ water\ to\ fish\ (m^3\cdot kg)$
T_{fi} $= 2.7\cdot 10^{-3}\ yr\ =\ typical\ storage\ time\ for\ fish$
V_W $= 0.075\ m^3\cdot day^{-1}\ =\ average\ annual\ water\ consumption\ of\ animals$
f_{miw} $= fraction\ of\ milk\ from\ animals\ watered\ with\ river\ water$
f_{mtw} $= fraction\ of\ meat\ from\ animals\ watered\ with\ river\ water$

The same pathways are considered for tritium as HTO as for other radioactivities. But a model is used which assumes that the specific activity in the water content of plants and animals is in equilibrium with that of the receiving waters. Only a fraction $(1 - f_F)$ of the water content of animals is due to drinking water. The ingestion dose for tritium is given by:

$$D_{HTO,ing} = \frac{1}{J}\left(f_W U_W(a,i) + \frac{f_{wa}}{\rho}\left(f_{fi}U_{fi}(a,i) + (1-f_F)\left(f_{miw}U_{mi} + f_{mtw}U_{mt}\right)\right)\right)\cdot e_{ing}(a,i), \tag{69}$$

where

ρ $= 1000\ kg\cdot m^{-3}\ =\ water\ density$
f_{wa} $= 0.75\ =\ average\ water\ content\ of\ foodstuff$

The average consumption rates of water and fish for populations at the LHC site are recommended by the Swiss Directive HSK-R-41 / d [HSK41] and they are presented in Table 21 (Appendix A).

3.2.2 Immersion dose

The external exposure due to immersion in the water is important only for the short lived radionuclides and immersion dose is given a simple formulae:

$$D_{W,imm} = \frac{1}{J}e^{-\lambda\frac{x}{\nu}}\cdot f_{W,oc}\cdot e_{imm}(a), \tag{70}$$

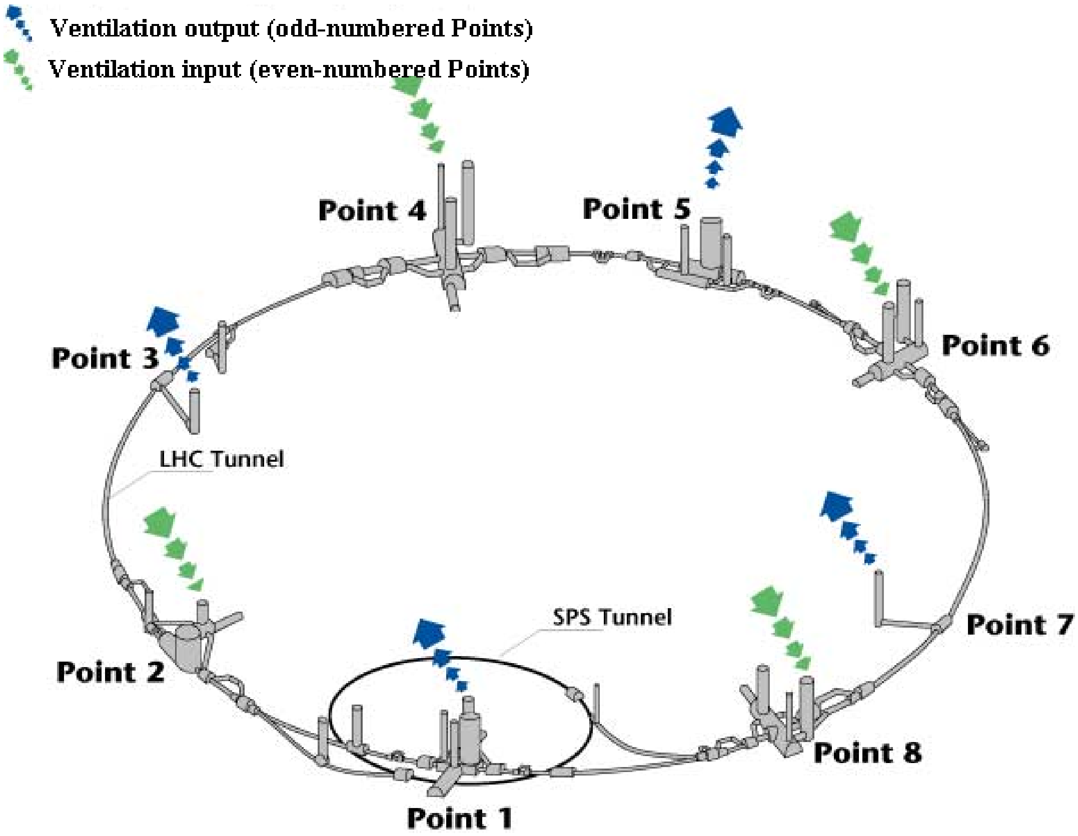

Figure 12: The conceptual scheme of the LHC ventilation system.

and where

$$\begin{aligned} f_{W,oc} &= fraction\ of\ time\ spent\ immersed\ in\ the\ river\ water \\ e_{W,imm} &= dose\ conversion\ factor\ for\ immersion\ in\ water\ ((Sv \cdot yr^{-1})/(Bq \cdot m^{-3})) \end{aligned}$$

4 The LHC ventilation system

The conceptual scheme of the LHC ventilation is shown in the Figure 12. The LHC ventilation system will draw air at the even-numbered tunnel points (P2, P4, P6, P8) and extract it via the odd-numbered points(P1, P3, P5, P7, TI2 and TI8) and at P2(the ALICE experiment) partially. The new ventilation system will have the underground and surface facilities. All system will operate with 100% renewal of the fresh air. It can be marked three different ventilation types of the underground areas in which are involved: the machine tunnel, accessible technical ares and experimental areas.
Typical rate of the air treatment in the various zones are presented in Table 4 [Roch99]. The values of the air treatment rate are not a final and they can be changed due to the LHC project changing. The Figure 13 explains the conceptual scheme of the ventilation taking in consideration the LHC ground buildings. The ventilation scheme corresponds to the current working version from May, 12, 1999.
The longitudinal ventilation will be used for each octant of the main ring. The ventilation system will provide two normal modes of operation: low speed(there is an access to tunnel) and high speed(no access to tunnel). In the case of emergency, a third mode of ventilation will be realized which will provide maximal rate of the air treatment. The normal ventilation rate will be 22500

m^3/h in each octant of the main ring.
The technical areas(labyrinths and technical caverns) will be ventilated in a different way. The experimental areas will be completely separated from the technical areas and the machine tunnel because of the use of various gases in the experimental installations.

Table 4: The air ventilation parameters of the LHC facilities

Point of LHC	Source of extracted air	Abbreviation	Building No.	Altitude (m a.s.l.)	Height Build. (m)	Height stack (m)	Ventilation rate (m^3/h)
1	Sector 8-1	SU1	2180	440.25	9.15	9.15	22500
	Sector 2-1	SU1	2180	440.25	9.15	9.15	22500
	Argon sys.	SUX1	3182	440.25	12.20	17.70	21000
	Gas sys.USA15	SUX1	3182	440.25	12.20	12.20	5000
2	ALICE	SUX2	2282	448.75	12.05	12.05	6000
3	Sector 2-32	SU32	2380	488.00	8.90	8.90	22500
	Sector 4-32	SU32	2380	488.00	8.90	8.90	22500
5	Sector 4-5	SU51	3580	508.50	8.90	23.50	22500
	Sector 6-5	SU51	3580	508.50	8.90	23.50	22500
	Argon sys.	SX5	3585	508.50	23.50	23.50	6000
	Gas sys.	SUX5	3582	508.50	13.40	13.40	5000
7	Sector 6-7	SU7	2780	430.75	8.50	8.50	22500
	Sector 8-7	SU7	2780	430.75	8.50	8.50	22500
TI2	Tunnel TI2	SUI2	296	450.00	6.50	6.50	22500
TI8	Tunnel TI8	SUI8	BA4	457.50	15.20	15.20	22500
NCGS	Target cavern	SUI8	BA4	457.50	15.20	15.50	500

5 The parameters of the LHC air releases

All parameters of the LHC air releases are given in the Table 5. As can be seen from Figure 12, the fresh air drawn through the PM85 (point 8) and the PM25(point 2) reach pit PM15(point 1). At the point P1 the radioactive air from each of the LHC tunnel are released through two ventilation exhausts which are situated on top of the building 2180. The height of this building is 9.15 m. The stack height is 9.15 m as well. At this point the air will be not only extracted from the LHC tunnel but also from the ATLAS experimental area. Note that only 5% of air from the ATLAS experimental cavern will be ventilated directly, however 21000 m^3/h will be ventilated via the argon extraction system. The air from the ATLAS experimental area will be released via four ventilation exhausts situated on top of building 3182. The height of building is 12.2 m, the height of reject is 17.7 m.
The ventilation rate at point 3 is 22500 m^3/h and the same for both tunnel sectors 2-32 and 4-32. Two ventilation exhausts is situated on top of building 2380. The height of building and stack is 8.9 m.
At point 5 the nominal ventilation rate is 22500 m^3/h from each of the adjacent tunnel sectors. The ventilation exhausts for the LHC machine are situated on top the building 3580. The height of this building is 8.9 m and the height of release is 23.50 m. As well in the case of the experimental area at point 1 only 5 % of air from the CMS experimental cavern will be ventilated directly via exhausts situated on top of building 3585.The height of this building is 23.50 m, the height of release will be at the roof level.
The ventilation rate at point 7 from each of the adjacent tunnel sectors is the same as for point 3. Two ventilation exhausts situated on top of building 2380 extract air. The height of building and stack is 8.5 m.
One-half of fresh air drawn through PM25 and pass along the tunnel sector 2-1 and tunnel TI2 will be released at the Meyrin site via the ventilation exhaust of building SUI2. The nominal ventilation rate for this part is 22500 m^3/h. The height of building SUI2 and stack is 6.5 m.
The last point of the release at the LHC site is situated at Prevessin (SPS point 4). One-half of fresh air drawn through PM85 and pass along the tunnel sector 8-1 and tunnel TI8 will be released via the ventilation exhaust of building SUI8. The nominal ventilation rate for this part is 22500 m^3/h as well. The facade height of building SUI8 is 15.2 m and the stack height is 15.2 m. Note that the CNGS ventilation system [Kou00] will released air at the same point during neutrino run. The nominal ventilation rate has been set to 500 m^3/h, during operation the radioactive air will be release through a 10 cm diameter pipe installed inside the main stack. The stack height is 15.5 m, the vertical linear air speed is 17.7 m s^{-1}. As be can seen from Table 5 the vertical linear air speed is 6.34 m s^{-1} for all the LHC release points from the machine tunnel. The transition from CERN's coordinate system into the LHC ring coordinate system was carried out by means of the transformation:

$$X_{LHC} = (X_C - 560)\cdot cos35^\circ + (Y_C - 6600)\cdot sin35^\circ \quad (71)$$

$$Y_{LHC} = -(X_C - 560)\cdot sin35^\circ + (Y_C - 6600)\cdot cos35^\circ \quad (72)$$

6 The air radioactivity at the LHC releases points

The interaction of the secondary hadron with nitrogen, oxygen and argon nuclei in the air of the LHC underground facilities will initiate a generation of the radioactive nuclei during the accelerator operation. As a role the radioactivity in the air is calculated on base of the flux and

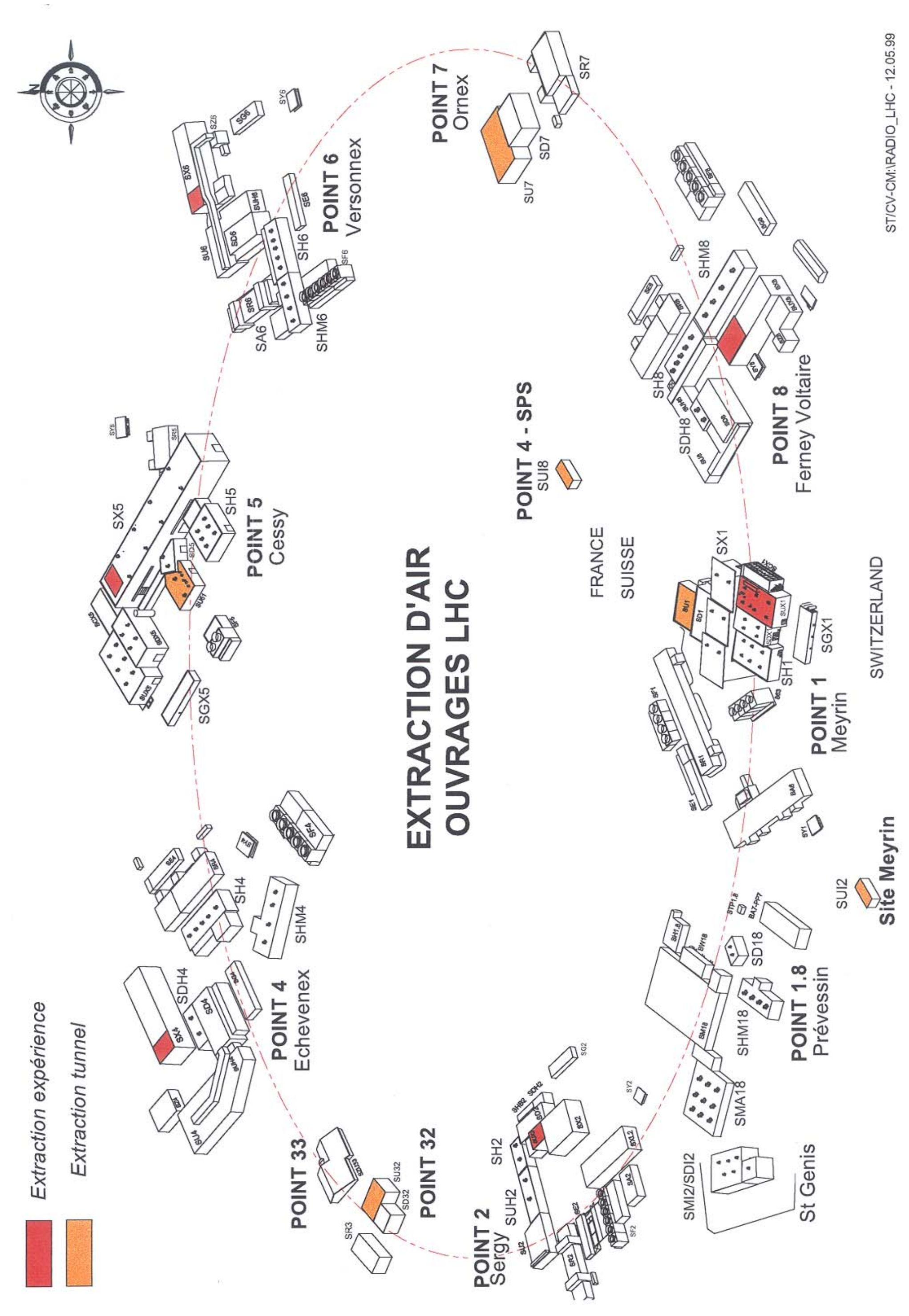

Figure 13: The ground scheme of the LHC ventilation system.

Table 5: The parameters of the LHC air releases

Release point	Source of extracted air	Coordinates		Altitude (m a.s.l.)	Height		Stack diameter (m)	Vertical speed (m/s)
		X_C (m)	Y_C (m)		Building (m)	Stack (m)		
1	Sector 8-1	2168.5	2745.5	440.25	9.15	9.15	1.12	6.34
	Sector 2-1	2168.5	2745.5	440.25	9.15	9.15	1.12	6.34
	Argon sys.	2253.3	2675.0	440.25	12.20	17.70	0.80	11.61
	USA15	2253.3	2675.0	440.25	12.20	12.20	0.40	11.05
2	ALICE	-1012.0	2702.0	448.75	12.05	12.05	0.45	10.48
3	Sector 2-32	-2120.0	4090.0	488.00	8.90	8.90	1.12	6.34
	Sector 4-32	-2120.0	4090.0	488.00	8.90	8.90	1.12	6.34
5	Sector 4-5	-1000.0	10440.0	508.50	8.90	23.50	1.12	6.34
	Sector 6-5	-1000.0	10440.0	508.50	8.90	23.50	1.12	6.34
	Argon sys.	-992.0	10489.0	508.50	23.50	23.50	0.55	7.02
	Gas sys.	-992.0	10489.0	508.50	13.40	13.40	0.40	11.05
7	Sector 6-7	4103.5	8077.5	430.75	8.50	8.50	1.12	6.34
	Sector 8-7	4103.5	8077.5	430.75	8.50	8.50	1.12	6.34
	Tunnel TI2	1330.0	2250.0	450.00	6.50	6.50	1.12	6.34
	Tunnel TI8	2305.0	4480.0	457.50	15.20	15.20	1.12	6.34
	CNGS	2305.0	4480.0	457.50	15.20	15.50	0.1	17.7

energy spectrum of hadrons in the various air volumes of the LHC underground facilities and cross-section of the production of 39 radioactive isotopes in the air [Huh96]. The calculations of the radioactivity in the air of the LHC ventilation system were carried out by various authors [Hof95, Azh99] using different Monte Carlo codes FLUKA[Fas97, Fer97] and MARS[Azh96]. The results of these calculation are given in the Table 6.

The radioactive air will be released by the LHC ventilation system via points: P1, P3, P5, P7, TI2 and TI8 during the accelerator operation. The total radioactivity of the air at a some point of the release can be calculated by the following relations:

$$\dot{Q}_i = 0.25 \cdot \dot{Q}_i^{MR} + 2.0 \cdot \dot{Q}_i^{LBR} + \dot{Q}_i^{AC}, \quad \text{for point P1} \tag{73}$$

$$\dot{Q}_i = 0.25 \cdot \dot{Q}_i^{MR} + \dot{Q}_i^{BC}, \quad \text{for point P3} \tag{74}$$

$$\dot{Q}_i = 0.25 \cdot \dot{Q}_i^{MR} + 2.0 \cdot \dot{Q}_i^{LBR} + \dot{Q}_i^{CC} + \dot{Q}_i^{DC}, \quad \text{for point P5} \tag{75}$$

$$\dot{Q}_i = 0.25 \cdot \dot{Q}_i^{MR} + \dot{Q}_i^{BC} + \dot{Q}_i^{DC}, \quad \text{for point P7} \tag{76}$$

$$\dot{Q}_i = 0.125 \cdot \dot{Q}^{MR}, \quad \text{for point SUI2} \tag{77}$$

$$\dot{Q}_i = 0.125 \cdot \dot{Q}^{MR} + \dot{Q}_i^{CNGS}, \quad \text{for point SUI8} \tag{78}$$

where i is index corresponding to i-th radionuclide of a some air release, indexes of MR, LBR, AC, BC, CC, DC and CNGS correspond to a contribution to total radioactivity from Main Ring, Low-beta Regions, ATLAS cavern, betatron cleaning, CMS cavern, DUMP cavern and CNGS facility, respectively (See Table 6).

At present moment there is not the complete data concerning with the momentum cleaning of the LHC(Point 3). The expected beam losses in the momentum cleaning will be the almost same as for the betatron one [Azh99, LHC263]. Taking into account a some scaling between beam losses in the momentum cleaning and the betatron cleaning, data of the radioactivity in the air for the insertion IR7 can be used for the insertion IR3 as a conservative estimation.

For points TI2 and TI8 the contribution to radioactivity is estimated as 1/8 from the Main Ring radioactivity. As mentioned above the air from the CNGS ventilation system will be released via exhausts situated on top of new building BA4 at point 4 of the SPS. Three separate operational runs of 67 days are assumed when the radioactive air will extracted from the target cavern. The estimations carried out in work [Kou00] have shown a high level of the expected effective dose from this source and the main contribution to total effective dose gives ^{7}Be. Therefore it is necessary to take into account this source of the air release to obtain a realistic map of the effective dose distribution at the LHC site. Data of the release of the radioactivity in MBq per year via the LHC and CNGS ventilation systems are presented in the Table 7 and in the Figures 14- 18.

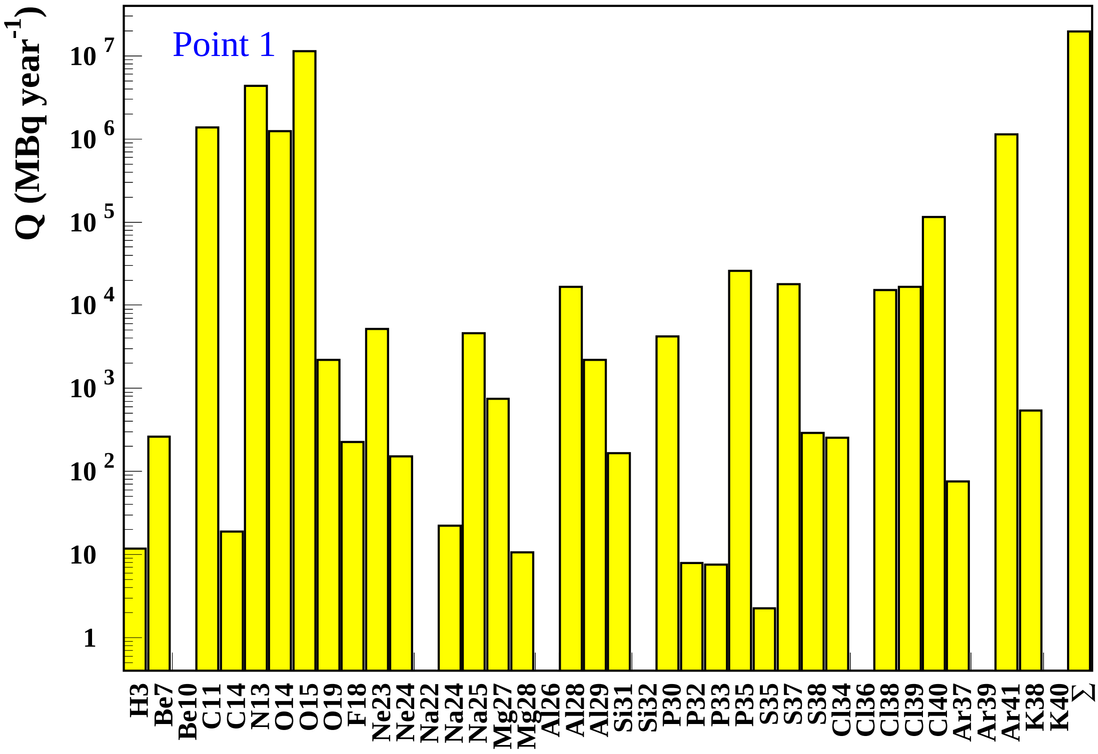

Figure 14: Release of radioactivity in MBq per year via the Point 1 of the LHC ventilation system.

7 Nuclear and element specific data

The knowledge of half-time, average photon energy emitted per decay, average photon energy of emitted photons, dose conversion factors and biological transfer factor for each radionuclide that generated in air of the LHC tunnel are needed for calculation of annual doses equivalent from the radioactive air releases.

The nuclear data for some radionuclides were taken from original work by P.Vojtyla [Voj98], another part were obtained on base of Lund Nuclear Data [Lund99].

For selected radionuclides the dose conversion factors for immersion e_{imm} and ground deposition e_{gnd} of the directive HSK-R-41 [HSK41] were used. The dose conversion factors e_{gnd} for all radionuclides generated on argon were taken from the EPA Report 402-R-93-081 [Eck93]. For other radionuclides the dose conversion factors e_{imm} and e_{gnd} from EPA Report 402-R-93-081 were used as well. The dose conversion factors for immersion in water $e_{W,imm}$ were taken from report by Eckerman [Eck93] and work by Kocher [Koc83].

The age-dependent inhalation dose conversion factors $e_{inh}(a, i)$ and the age-dependent ingestion

Table 6: Release of radioactivity in MBq per year of operation

Radionuclide	Main Ring [Ste92a]	Scrapers in Point 7 [Azh99]	Low-beta region [Hoe96]	ATLAS cavern [Huh96a]	CMS cavern [Huh96a]	Dump cavern [Daw98]
^{3}H	15	10	3.3	1.4	3.1	0.44
^{7}Be	300	200	76	35	83	7.0
^{10}Be		0.00004	0.00001	0.000002	0.000006	0.000002
^{11}C	610000	1500000	610000	9800	26000	4900
^{14}C	0.76	52	9.2	0.22	0.47	5.8
^{13}N	630000	6000000	2100000	9900	29000	3100
^{14}O	34000	1500000	620000	470	1 400	–
^{15}O	330000	14000000	5600000	6400	19000	0.006
^{19}O		3300	1100	0.86	1.6	–
^{18}F	37	290	100	17	34	1.4
^{23}Ne		7600	2600	1.8	3.6	–
^{24}Ne		230	76	0.60	1.2	0.000007
^{22}Na	0.0059	0.0087	0.0032	0.0023	0.0048	0.00012
^{24}Na	18	1.9	7.3	3.1	6.7	0.29
^{25}Na		6500	2300	3.6	7.3	–
^{27}Mg	250	910	340	4.2	9.2	0.12
^{28}Mg	32	3.0	1.1	0.38	0.89	0.071
^{26}Al		–	–	–	–	–
^{28}Al		21000	8300	25	55	0.000015
^{29}Al		2900	1100	7.9	18	0.086
^{31}Si		190	77	11	27	3.1
^{32}Si		0.00008	0.00003	0.00002	0.00004	0.000002
^{30}P		5200	2100	7.6	17	0.000014
^{32}P		8.1	3.2	1.5	3.5	0.24
^{33}P		7.9	3.2	1.2	3.0	0.31
^{35}P		34000	13000	5.7	15	–
^{35}S		2.8	1.0	0.26	0.71	0.14
^{37}S	4600	27000	8400	17	49	0.32
^{38}S		350	140	9.4	27	13
^{34m}Cl	130	260	110	3.1	7.9	1.7
^{36}Cl		0.000005	0.000002	–	0.000001	–
^{38}Cl	1100	21000	7400	110	340	290
^{39}Cl	850	23000	8100	200	570	470
^{40}Cl	4 000	180000	57 000	21	67	–
^{37}Ar		190	37	1.6	4.4	21
^{39}Ar		0.047	0.013	0.0020	0.0058	0.0024
^{41}Ar	27000	3200000	560000	2600	5800	210000
^{38}K		610	270	2.1	5.6	0.045
^{40}K		–	–	–	–	–
^{3}H	15	10	3.3	1.4	3.1	0.44
^{7}Be	300	200	76	35	83	7.0
$T_{1/2} < 1$ day	1600000	27000000	9500000	30000	82000	220000
$T_{1/2} > 1$ day	0.76	260	53	4.8	12	27

Table 7: Release of radioactivity in MBq per year via the LHC and CNGS ventilation systems

Radionuclide	Point 1	Point 3	Point 5	Point 7	SUI2	SUI8	CNGS
^{3}H	.1175E+02	.1375E+02	.1389E+02	.1419E+02	.1875E+01	.1875E+01	.5633E+04
^{7}Be	.2620E+03	.2750E+03	.3170E+03	.2820E+03	.3750E+02	.3750E+02	.1516E+06
^{10}Be	.2200E-04	.4000E-04	.2800E-04	.4200E-04	.0000E+00	.0000E+00	.7453E-02
^{11}C	.1382E+07	.1652E+07	.1403E+07	.1657E+07	.7625E+05	.7625E+05	.5243E-03
^{14}C	.1881E+02	.5219E+02	.2486E+02	.5799E+02	.9500E-01	.9500E-01	.1459E+04
^{13}N	.4367E+07	.6158E+07	.4390E+07	.6161E+07	.7875E+05	.7875E+05	.1846E-14
^{14}O	.1249E+07	.1508E+07	.1250E+07	.1508E+07	.4250E+04	.4250E+04	.0000E+00
^{15}O	.1129E+08	.1408E+08	.1130E+08	.1408E+08	.4125E+05	.4125E+05	.0000E+00
^{19}O	.2201E+04	.3300E+04	.2202E+04	.3300E+04	.0000E+00	.0000E+00	.0000E+00
^{18}F	.2262E+03	.2992E+03	.2446E+03	.3006E+03	.4625E+01	.4625E+01	.7279E+03
^{23}Ne	.5202E+04	.7600E+04	.5204E+04	.7600E+04	.0000E+00	.0000E+00	.0000E+00
^{24}Ne	.1526E+03	.2300E+03	.1532E+03	.2300E+03	.0000E+00	.0000E+00	.0000E+00
^{22}Na	.1017E-01	.1017E-01	.1280E-01	.1029E-01	.7375E-03	.7375E-03	.1041E+02
^{24}Na	.2220E+02	.6400E+01	.2609E+02	.6690E+01	.2250E+01	.2250E+01	.8240E+04
^{25}Na	.4604E+04	.6500E+04	.4607E+04	.6500E+04	.0000E+00	.0000E+00	.0000E+00
^{27}Mg	.7467E+03	.9725E+03	.7518E+03	.9726E+03	.3125E+02	.3125E+02	.6770E-18
^{28}Mg	.1058E+02	.1100E+02	.1116E+02	.1107E+02	.4000E+01	.4000E+01	.1207E+04
^{26}Al	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.5419E-04
^{28}Al	.1662E+05	.2100E+05	.1666E+05	.2100E+05	.0000E+00	.0000E+00	.0000E+00
^{29}Al	.2208E+04	.2900E+04	.2218E+04	.2900E+04	.0000E+00	.0000E+00	.5332E-29
^{31}Si	.1650E+03	.1900E+03	.1841E+03	.1931E+03	.0000E+00	.0000E+00	.1831E+04
^{32}Si	.8000E-04	.8000E-04	.1020E-03	.8200E-04	.0000E+00	.0000E+00	.6318E-01
^{30}P	.4208E+04	.5200E+04	.4217E+04	.5200E+04	.0000E+00	.0000E+00	.0000E+00
^{32}P	.7900E+01	.8100E+01	.1014E+02	.8340E+01	.0000E+00	.0000E+00	.6004E+04
^{33}P	.7600E+01	.7900E+01	.9710E+01	.8210E+01	.0000E+00	.0000E+00	.4944E+04
^{35}P	.2601E+05	.3400E+05	.2602E+05	.3400E+05	.0000E+00	.0000E+00	.0000E+00
^{35}S	.2260E+01	.2800E+01	.2850E+01	.2940E+01	.0000E+00	.0000E+00	.1074E+04
^{37}S	.1797E+05	.2815E+05	.1800E+05	.2815E+05	.5750E+03	.5750E+03	.0000E+00
^{38}S	.2894E+03	.3500E+03	.3200E+03	.3630E+03	.0000E+00	.0000E+00	.2056E+04
^{34m}Cl	.2556E+03	.2925E+03	.2621E+03	.2942E+03	.1625E+02	.1625E+02	.1448E-02
^{36}Cl	.4000E-05	.5000E-05	.5000E-05	.5000E-05	.0000E+00	.0000E+00	.1895E-02
^{38}Cl	.1518E+05	.2128E+05	.1570E+05	.2156E+05	.1375E+03	.1375E+03	.4743E+00
^{39}Cl	.1661E+05	.2321E+05	.1745E+05	.2368E+05	.1062E+03	.1062E+03	.8306E+02
^{40}Cl	.1150E+06	.1810E+06	.1151E+06	.1810E+06	.5000E+03	.5000E+03	.0000E+00
^{37}Ar	.7560E+02	.1900E+03	.9940E+02	.2110E+03	.0000E+00	.0000E+00	.8865E+04
^{39}Ar	.2800E-01	.4700E-01	.3420E-01	.4940E-01	.0000E+00	.0000E+00	.8455E+01
^{41}Ar	.1129E+07	.3207E+07	.1343E+07	.3417E+07	.3375E+04	.3375E+04	.1701E+06
^{38}K	.5421E+03	.6100E+03	.5456E+03	.6100E+03	.0000E+00	.0000E+00	.6244E-25
^{40}K	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.2561E-07
$T_{1/2} < 1$ day	.1965E+08	.2694E+08	.1992E+08	.2716E+08	.2053E+06	.2053E+06	.1842E+06
$T_{1/2} > 1$ day	.1122E+03	.2610E+03	.1470E+03	.2885E+03	.9574E-01	.9574E-01	.2237E+05
Total	.1965E+08	.2695E+08	.1992E+08	.2716E+08	.2053E+06	.2053E+06	.3638E+06

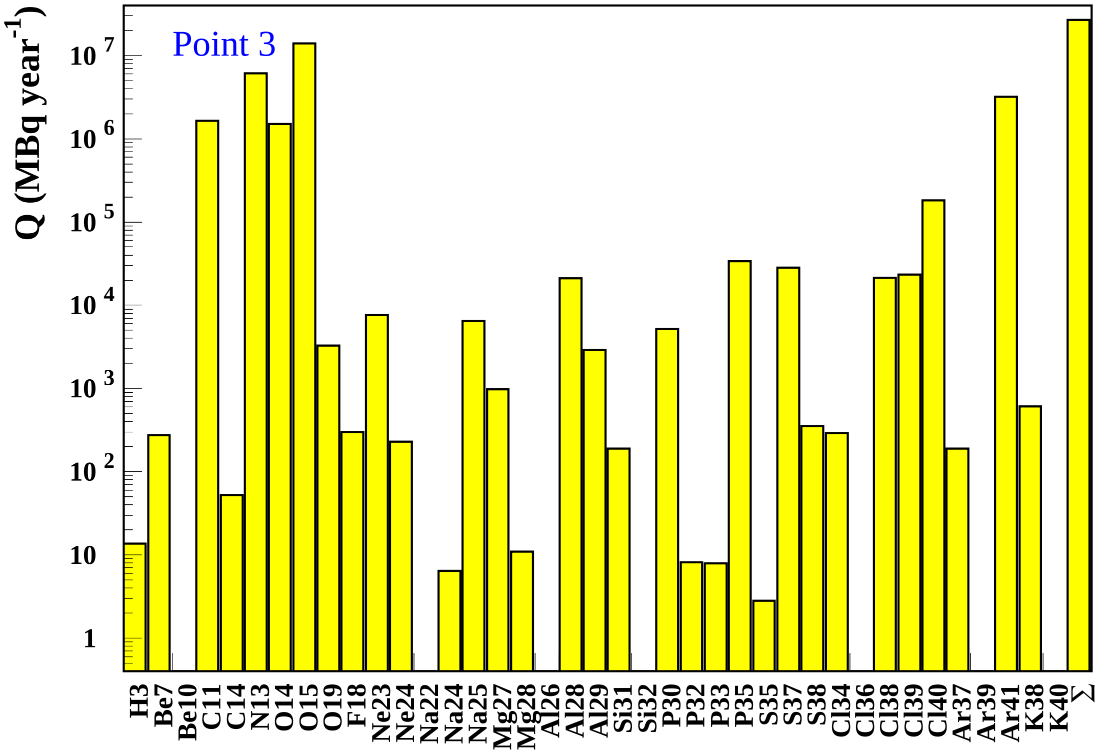

Figure 15: Release of radioactivity in MBq per year via the Point 3 of the LHC ventilation system.

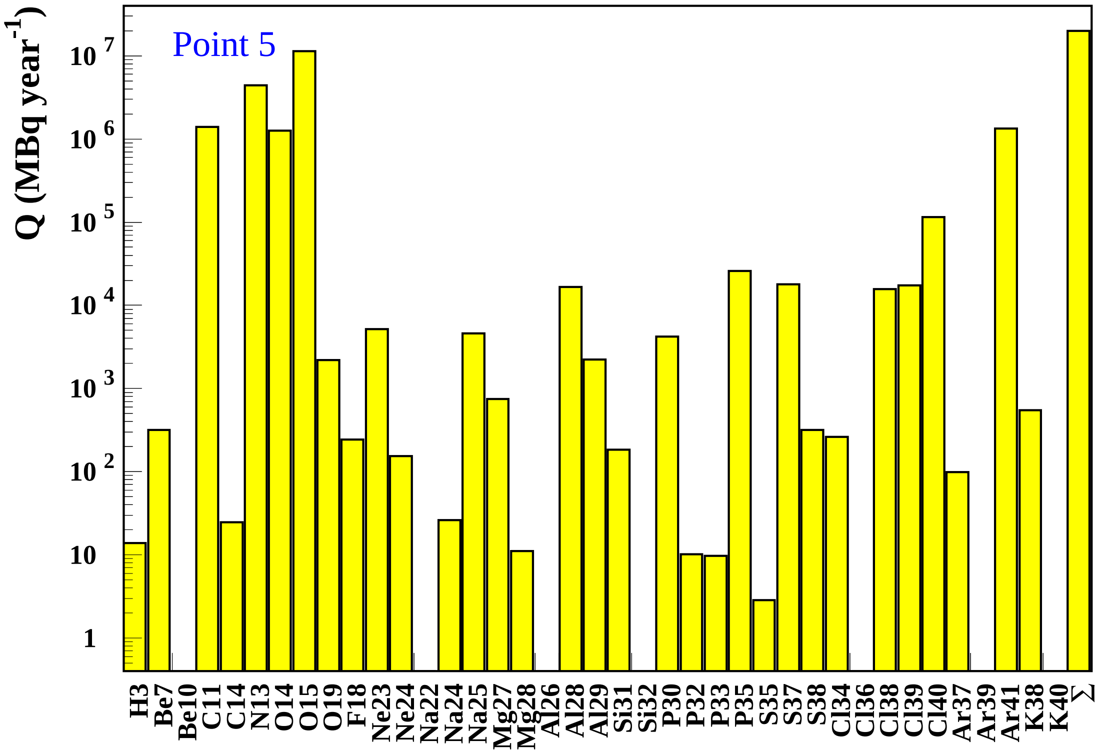

Figure 16: Release of radioactivity in MBq per year via the Point 5 of the LHC ventilation system.

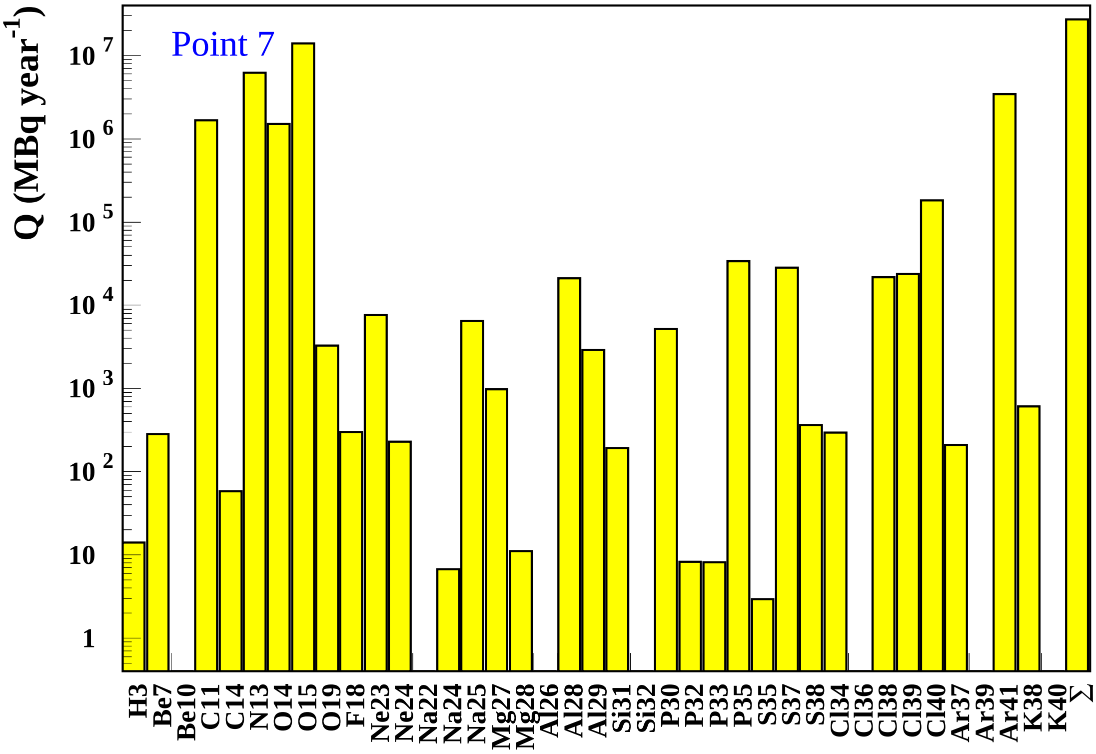

Figure 17: Release of radioactivity in MBq per year via the Point 7 of the LHC ventilation system.

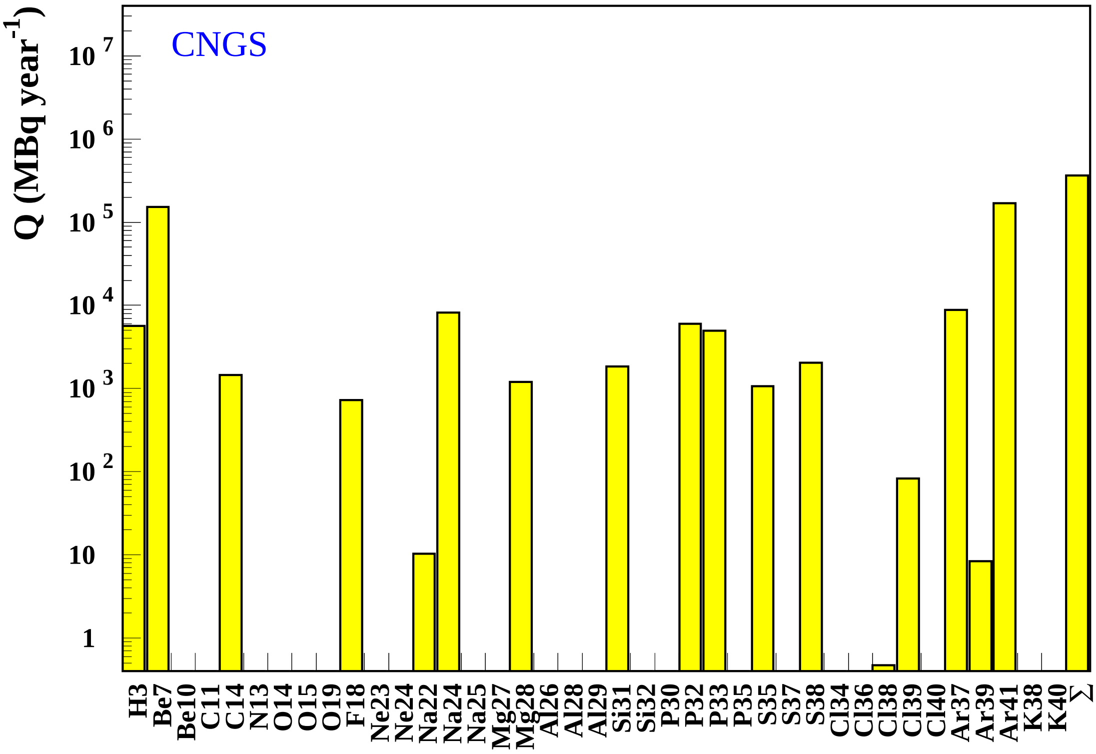

Figure 18: Release of radioactivity in MBq per year via the CNGS ventilation system.

dose conversion factors $e_{ing}(a, i)$ were taken from ICRP Publication 72 [ICRP72]. Full list of the radionuclide-specific data used in the LHC releases calculation is given in Table 8. The element-specific biological transfer factors data are taken from the directive HSK-R-41 [HSK41] and list of the biological transfer factors from H up to Ca is presented in Table 9.

Table 8: List of the radionuclide-specific data used in the LHC releases calculation

Nucl.	S	$T_{1/2}$	$\overline{E}_d$	$\overline{E}_\gamma$	e_{imm}	e_{gnd}	$e_{W,imm}$	e_{inh}(i)	e_{inh}(a)	e_{ing}(i)	e_{ing}(a)
^{3}H	T	12.33 y	0.000	0.000	0.0E+00	0.0E+00	0.0E+00	4.8E-11	1.8E-11	4.8E-11	1.8E-11
^{7}Be	A	53.3 d	0.050	0.478	6.0E-08	1.2E-09	1.6E-10	2.4E-10	5.5E-11	1.3E-10	2.8E-11
^{10}Be	A	1.51E6 y	0.000	0.000	2.9E-09	1.3E-11	6.8E-13	9.1E-08	3.5E-08	8.0E-09	1.1E-09
^{11}C	G	20.39 m	1.020	0.511	1.2E-06	2.6E-08	3.3E-09	1.1E-10	1.8E-11	1.5E-10	2.4E-11
^{14}C	C	5730 y	0.000	0.000	5.9E-11	0.0E+00	1.4E-14	6.6E-09	2.0E-09	1.6E-09	5.8E-10
^{13}N	G	9.965 m	1.020	0.511	1.3E-06	2.7E-08	3.4E-09	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{14}O	G	70.6 s	3.321	1.109	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{15}O	G	122.2 s	1.020	0.511	1.3E-06	2.8E-08	3.4E-09	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{19}O	G	26.9 s	0.940	0.614	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{18}F	A	109.2 m	0.989	0.511	1.2E-06	2.5E-08	3.4E-09	3.1E-10	5.9E-11	3.0E-10	4.9E-11
^{23}Ne	G	37.2 s	0.166	0.485	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{24}Ne	G	3.38 m	0.542	0.502	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{22}Na	A	2.609 y	2.192	0.784	2.7E-06	5.1E-08	7.4E-09	7.3E-09	1.3E-09	1.5E-08	3.2E-09
^{24}Na	A	14.96 h	4.121	2.061	5.9E-06	8.9E-08	1.5E-08	1.8E-09	2.9E-10	2.3E-09	4.3E-10
^{25}Na	A	59.1 s	0.436	0.857	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{27}Mg	A	9.49 m	0.891	0.886	1.3E-06	2.7E-08	2.8E-09	8.2E-10	8.2E-10	1.5E-09	1.5E-09
^{28}Mg	A	20.91 h	1.370	0.676	2.1E-06	4.1E-08	4.6E-09	7.2E-09	1.2E-09	1.4E-08	2.2E-09
^{26}Al	A	7.16E5 y	2.675	1.006	4.3E-06	7.7E-08	9.3E-09	7.4E-08	2.0E-08	2.1E-08	3.5E-09
^{28}Al	A	2.24 m	1.780	1.779	2.7E-06	5.1E-08	6.3E-09	8.0E-09	1.2E-09	3.0E-09	2.2E-09
^{29}Al	A	6.56 m	1.380	1.360	2.1E-06	3.7E-08	0.0E+00	6.2E-09	6.2E-09	2.3E-09	2.3E-09
^{31}Si	A	157.3 m	0.001	1.266	1.3E-08	9.5E-11	7.4E-12	4.7E-10	7.9E-11	1.0E-09	1.6E-10
^{32}Si	A	172 y	0.000	0.000	1.7E-11	9.8E-13	3.2E-14	2.7E-07	1.1E-07	4.1E-09	5.6E-10
^{30}P	A	2.5 m	1.020	0.511	1.6E-06	3.2E-08	3.4E-09	6.0E-11	6.0E-11	4.9E-11	4.9E-11
^{32}P	A	14.26 d	0.000	0.000	3.1E-09	9.2E-11	6.0E-12	1.5E-08	3.4E-09	1.9E-08	2.4E-09
^{33}P	A	25.34 d	0.000	0.000	2.6E-11	1.4E-12	5.0E-14	4.6E-09	1.5E-09	1.8E-09	2.4E-10
^{35}P	A	47.3 s	1.778	1.788	2.7E-06	4.6E-08	0.0E+00	7.3E-09	7.3E-09	2.3E-09	2.3E-09
^{35}S	A	87.51 d	0.000	0.000	7.7E-12	5.3E-13	1.5E-14	4.5E-09	1.4E-09	8.7E-10	1.3E-10
^{37}S	A	5.05 m	2.931	3.104	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{38}S	A	170.3 m	1.695	1.947	2.5E-06	3.9E-08	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{34m}Cl	G	32.0 m	1.558	1.414	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{36}Cl	G	3.01E5 y	0.000	0.511	7.0E-10	2.1E-11	1.4E-12	2.6E-08	7.3E-09	6.3E-09	9.3E-10
^{38}Cl	G	37.24 m	1.443	1.942	2.2E-06	3.7E-08	5.4E-09	3.0E-10	4.5E-11	7.7E-10	1.2E-10
^{39}Cl	G	55.6 m	1.456	1.003	1.9E-06	3.5E-08	5.0E-09	2.8E-10	4.6E-11	5.5E-10	8.5E-11
^{40}Cl	G	1.35 m	4.016	2.085	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{37}Ar	G	35.02 d	0.000	0.003	8.7E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{39}Ar	G	269 y	0.000	0.000	3.3E-09	1.1E-11	5.6E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{41}Ar	G	1.822 h	1.282	1.294	1.6E-06	3.8E-08	4.2E-09	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{38}K	A	7.636 m	3.190	1.067	5.2E-06	9.2E-08	1.1E-08	2.4E-10	2.4E-10	3.6E-10	3.6E-10
^{40}K	A	1.277E9 y	0.161	1.461	2.5E-07	4.6E-09	5.5E-10	1.7E-08	2.1E-09	4.2E-08	6.2E-09

8 Definition of the critical groups at the LHC site

A critical group of the population can be defined as a group of members of the general public who are most affected by releases. They are persons who spend a considerable fraction of time close to

Table 9: List of the biological transfer factors used for the dose calculation at the LHC site

Element	TF$_{soil-fod}$ (Bq / kg) / (Bq / kg)	TF$_{soil-veg}$ Bq / kg) / (Bq / kg)	TF$_{fod-mi}$ day / kg	TF$_{fod-mt}$ day / kg	TF$_{wat-fi}$ m^3 / kg
H	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
He	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Li	1.0E+00	1.0E+00	6.0E-03	2.0E-02	5.0E-01
Be	5.0E-04	5.0E-04	1.0E-04	1.0E-03	1.0E-01
B	1.0E-03	1.0E-03	2.0E-04	2.0E-03	1.0E+00
C	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00
N	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
O	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
F	3.0E-02	2.0E-03	2.0E-03	2.0E-01	5.0E-02
Ne	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na	4.0E-01	4.0E-01	4.0E-02	8.0E-02	1.0E-01
Mg	2.0E-01	6.0E-02	2.0E-02	1.0E-03	3.0E-02
Al	1.0E-03	1.0E-03	2.0E-04	2.0E-03	1.0E+00
Si	2.0E-04	2.0E-04	1.0E-04	4.0E-05	1.0E+00
P	5.0E-01	3.0E+00	3.0E-02	6.0E-02	2.0E+00
S	9.0E-01	9.0E-01	2.0E-02	1.0E-01	1.0E+00
Cl	5.0E+00	5.0E+00	2.0E-02	8.0E-02	5.0E-02
Ar	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
K	1.0E+00	1.0E+00	6.0E-03	2.0E-02	5.0E-01
Ca	2.0E-01	6.0E-02	2.0E-02	1.0E-03	3.0E-02

release points in one of the prevailing wind direction and who intake significant fraction of food produced from these areas.

8.1 Atmospheric pathway

Two critical group for the CERN Meryrin site have been indentified by L.Moritz [Mo96a]. The first group is the border guards and their family, they live in houses adjecent to border crossing near the entrance B to the CERN Meryrin. The occupancy factor for them is about 100 %. It is assumed that they intake 10 % of fruits and vegetables from their gardens and they produce neither meat nor milk in the area. The second group is the gardeners who work the series of the vegetables plots outside the south-east boundary of the CERN Meyrin site. In the case it is supposed that they obtain almost 100 % of their fruit and vegetable intake from their gardens and about 10 % of meat and dairy products can come from this area. The occupancy factor for this group is only about 10 %.

For the calculation of the detail dose map at the LHC site it is necessary to define all critical groups of the population who live and work in this area. Seven extra critical groups of the public are added to the classification by L.Moritz [Mo96a]. The Table 10 shows the occupancy factors and the consumption factors for all critical groups at the LHC site. Certainly, such identification is enough conventionally and conservative but it covers all population at the LHC. Moreover, the parameters for the atmospheric pathway can be revised on base of more detail statistical data and analysis of the population in this area. The distribution of the critical groups as a function of coordinates is illustrated in the Figure 19. Each colour corresponds to a critical group identified in the Table 10.

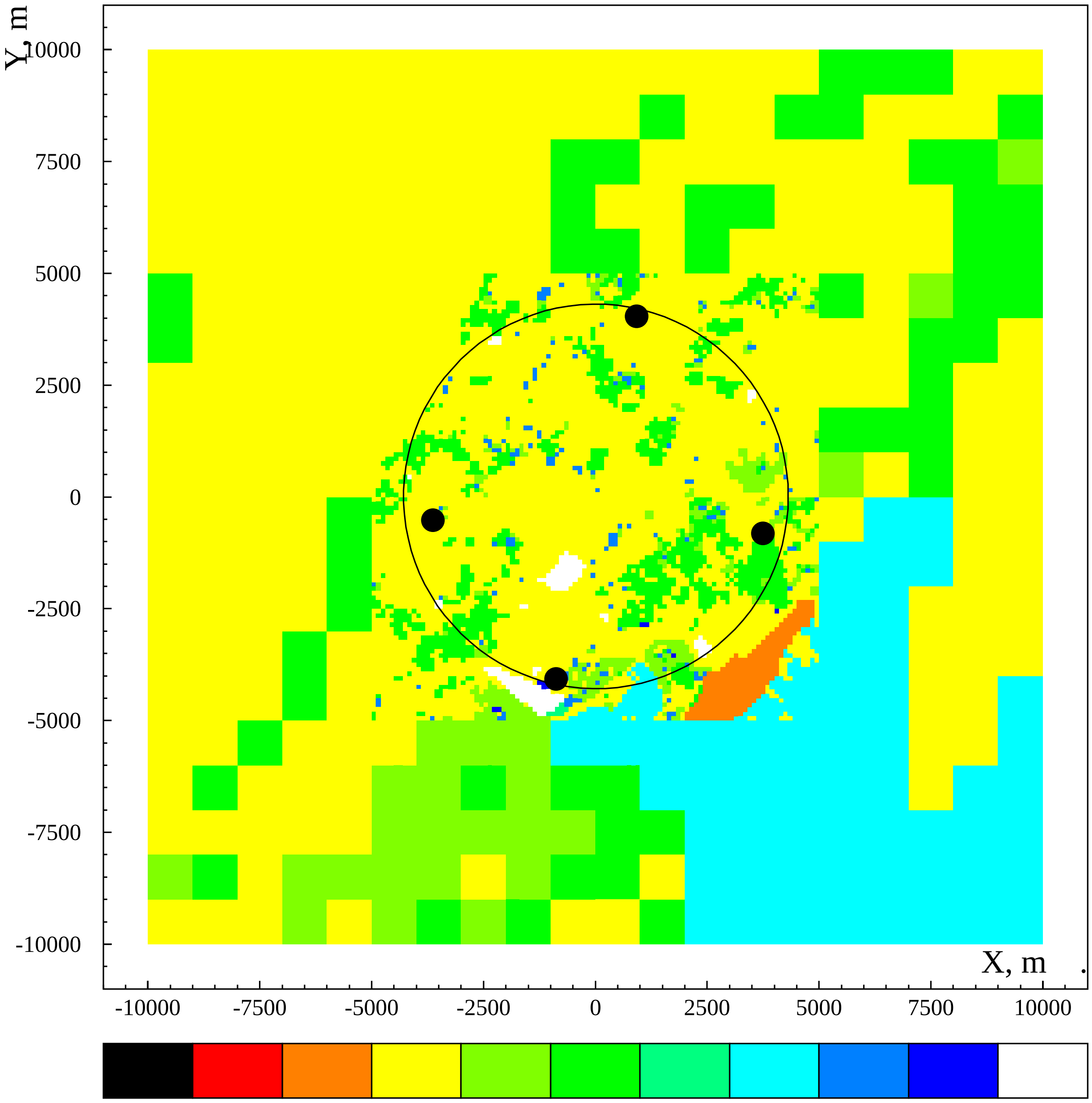

Figure 19: Distribution of the critical groups at the LHC site. Each colour correspons to a some critical group of population: white colour is CERN staff, dark blue is border guards et. al. (see Table 10 for details)

Table 10: The parameters for the atmospheric pathway

Critical group	Occupancy factor	Fraction of vegetables	Fraction of meat	Fraction of milk
CERN staff	0.5	0.0	0.0	0.0
Border guards	1.0	0.1	0.0	0.0
Farmers	1.0	0.1	0.1	0.0
City inhabitants	1.0	0.0	0.0	0.0
Gardeners	0.1	1.0	0.1	0.0
Town inhabitants	0.5	0.1	0.0	0.0
Farmers fields	0.2	0.1	0.0	0.0
Forests, fields	0.01	0.0	0.0	0.0
Airport of Geneva	0.02	0.0	0.0	0.0

Table 11: The parameters for the atmospheric pathway

Critical group	Occupancy factor	Fraction of vegetables	Fraction of meat	Fraction of milk
CERN staff	0.5	0.0	0.0	0.0
Border guards	1.0	0.1	0.0	0.0
Farmers	1.0	0.1	0.1	0.0
City inhabitants	1.0	0.0	0.0	0.0
Gardeners	0.1	1.0	0.1	0.0
Town inhabitants	0.5	0.1	0.0	0.0
Farmers fields	0.2	0.1	0.0	0.0
Forests, fields	0.01	0.0	0.0	0.0
Airport of Geneva	0.02	0.0	0.0	0.0

8.2 Water pathway

It is well known that the drinking water for the Geneva area is taken from the lake Lac Lemac at three treatment located close where the lake drains into the River Rhone. Outside Geneva area, drinking water is taken from wells. No drinking water is taken from the small rivers. As a role the water from the small rivers is used for farming and pasture. However, the people can swim and catch fish in the small rivers. A lot of the small rivers cross the LHC area. The parameters of the main water origins located at the LHC site are presented in Table 12

For the water pathway the occupancy factors and the consumption factors were defined on base of the model by L.Moritz [Mo96a] implemented to the CERN Meyrin site. In this case the critical groups have been identified as so called “near” group and “far” group. The “near” group is a group for whom all of the fish intake comes from small rivers and about 10 % of the dairy and meat products are derived from animals watered from small river. This group lives about 1

Table 12: The parameters of the water origins near the boundary of the LHC

Water origin	Annual water flow(m^3 y^{-1})	Water flow velocity(m s^{-1})
Lac Leman		
Rhone River	$2 \cdot 10^{10}$	1.0
Nant d'Avril	$5 \cdot 10^6$	1.0
Le Lion	$5 \cdot 10^6$	1.0
Allondon	$5 \cdot 10^6$	1.0
Versoix	$5 \cdot 10^6$	1.0
Journans	$5 \cdot 10^6$	1.0
Ouduar	$5 \cdot 10^6$	1.0

km downstream of discharge point. The "far" group consists of persons who live about 10 km downstream of discharge point and it is assumed that 100 % of the water and fish consumption is from the River Rhone.

In the case of the multi points releases, the large area and many water origins it is very difficult to identify strongly the critical groups. The LHC site model identifies "near" groups and "far" groups as well and it sets a correspondence between critical groups for the atmospheric and water pathways. The "near" groups consist of border guards and farmers with their fields and they are located at the distance less than 250 m from discharge point All other groups are considered as "far" group. The parameters for the critical group in the case of the water pathway are given in Table 13.

Table 13: The parameters of the water path

Critical group	Water origin	Occupancy factor	Fraction of fish	Fraction of meat	Fraction of milk	Fraction drinking water
CERN staff	Rhone river	0.01	1.0	1.0	1.0	1.0
Border guards	Local river	0.01	1.0	0.1	0.1	0.0
Farmers	Local river	0.01	1.0	0.1	0.1	0.0
City inhabitants	Rhone river	0.01	1.0	1.0	1.0	1.0
Gardeners	Rhone river	0.01	1.0	1.0	1.0	1.0
Town inhabitants	Rhone river	0.01	1.0	1.0	1.0	1.0
Farmers fields	Local river	0.01	1.0	0.1	0.1	0.0
Forests, fields	Rhone river	0.01	1.0	1.0	1.0	1.0
Airport of Geneva	Rhone river	0.01	1.0	1.0	1.0	1.0

9 The RELEASE program package

All approaches and methods mentioned above were realised in the computer code RELEASE to calculate annual doses to the public due to the radioactive air release from multi-points sources.

The program package was written in FORTRAN 77 and it has a modular and flexible structure. The general bookkeeping scheme of the RELEASE program package is shown in Figure 20. A some routines and COMMON blocks of the HSK-CERN program written by P.Vojtyla [Voj98] for the calculation of the effective doses per unit release have been implemented for the RELEASE code. In contrast to all previous codes for calculation of annual doses due air releases the RELEASE program has the most significant features:

- the code allows to calculate annual dose to the public due to multiple points releases on complex sites (20x20 km^2)
- intermediate results of calculation write in DMP file for each source
- the code allows to use 5 types of various grids for definition of the receptor location (up to 10000 points)
- a few models for topological correction of the receptor points are used.
- the maps of the LHC site topological altitudes, roughness length and critical group of the population are included in the program package
- the dose buildup factors by A.B.Chilton and some integration approaches are used for the calculation of the submersion dose
- there are data processing for all DMP-files and graphical interface for PAW

As can be seen from Figure 20 the code has three main program units. The first unit so-called “Input” is the initialization of the variables and nuclear data common to all radionuclides. There are five input files for the problem processing: problem.inp, trfs.inp, weatherXX.inp, nuclides.inp and activatXX.inp - radioactivity production data in air. First file describes the current problem (definition of the source and receptor points), tuning parameters and limits, one from five types of coordinates grids for the receptor location is loaded. A some examples of problem.inp files are presented in Appendix A.

The current version of the code are realized for the following types of grid: a polar grid (coordinate system of single release), Cartesian coordinate grid (up to 25 sub-grids), superposition (polar+Cartesian) coordinate grid, an arbitrary grid for the LHC site and an arbitrary grid for the arbitrary site. The first four grids are used only for the dose calculation at the LHC site, last one can be used for a some arbitrary sites. The Figures 21, 22 illustrate a some types of grids. The trfs.inp file contains biological conversion factors for 103 radionuclides.

The “weatherXX.inp” file describes the average wind speeds in 20 wind-speed bins and the elements of the joint probability weather matrix P$_{i,j,k}$ for each point of the release. The weather statistics at the LHC site were defined above (see section 2.1.2).

The “nuclides.inp” is a file containing the radionuclide-specific data for 39 or 100 radionuclides. Each line of the gives us the radionuclide name, its physical state (aerosol, iodine gas, tritium, ^{14}C), the half-time, the average and total energies of gammas rays and X-rays, the dose conversion factors for all of the exposure pathways (see Table reftab-nucdata in section 7).

The “activatXX.inp” file gives the radioactivity rate (Bq·yr^{-1}) released in air at each point of the release.

The second main program unit performs the calculation of the effective dose per unit release for radionuclides and some receptor points. During the code processing it copies intermediate results in DMP-file at the end of loop over radionuclides.

The last program unit so-called ’Output’ carries out data processing from DMP files for each release point, prepares tables with the dose components and the total doses. Besides, at this step

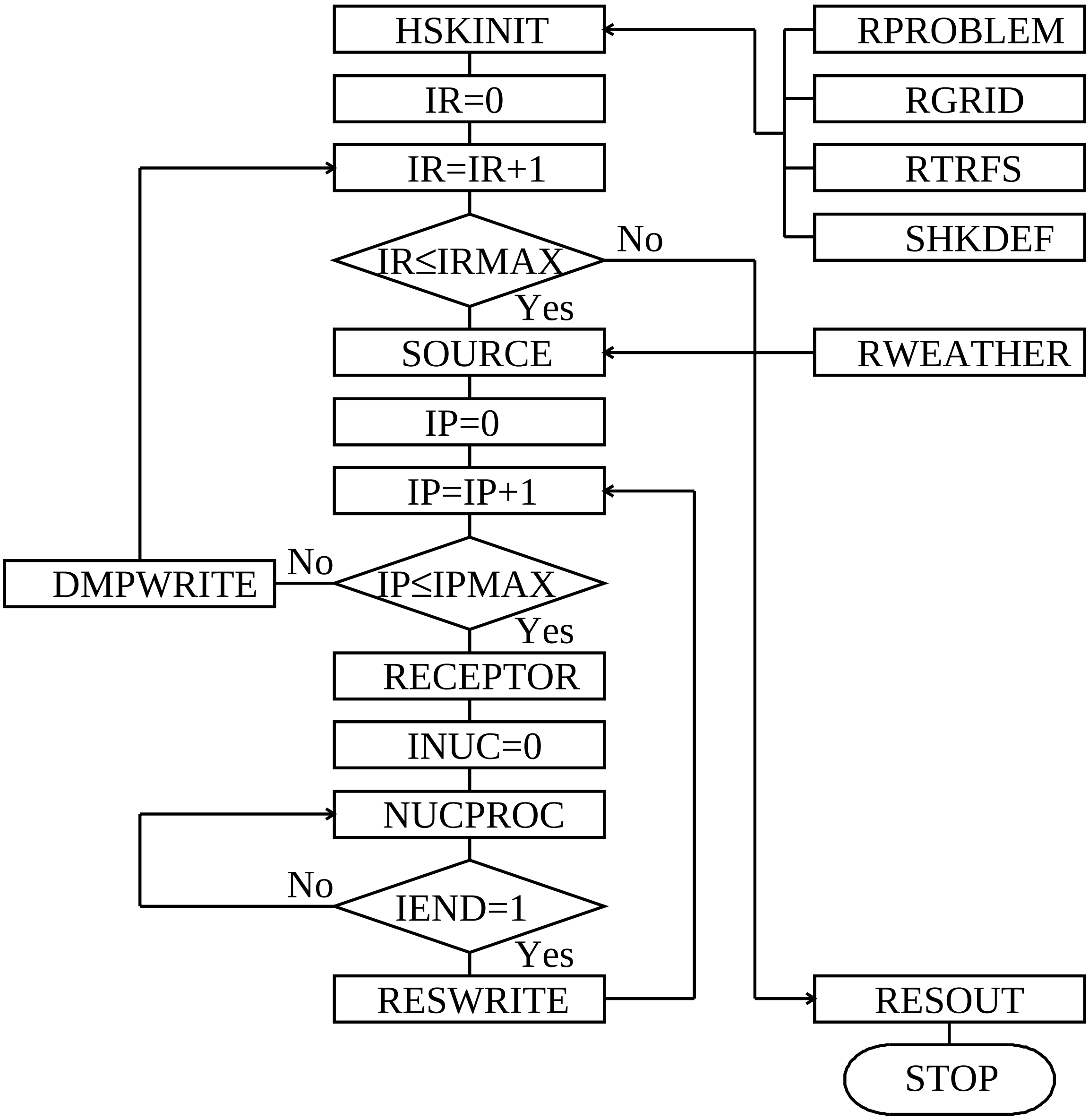

Figure 20: General bookkeeping scheme of the RELEASE code for calculation of the annual doses to public due to the multi-point air releases from the LHC facilities.

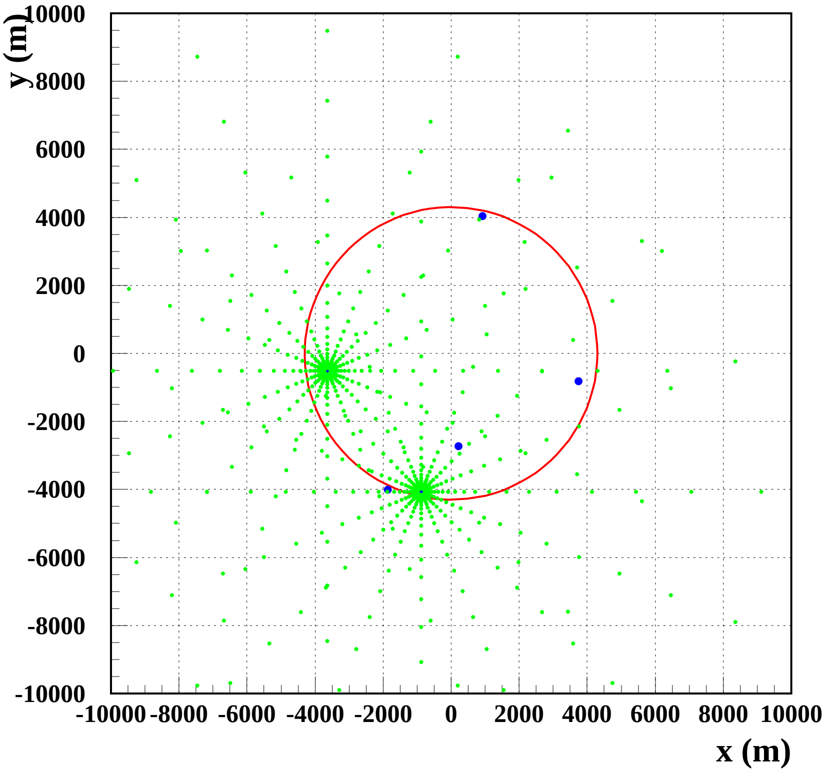

Figure 21: A grid for the dose map calculation in the polar coordinate.

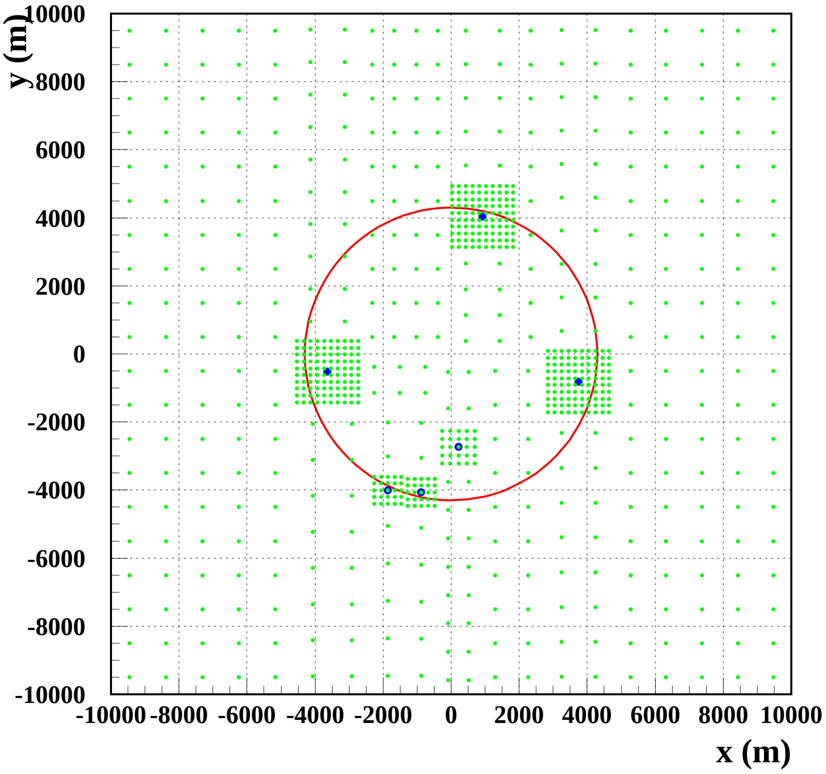

Figure 22: A grid for the dose map calculation in the Cartesian coordinate.

data for graphical interface are produced. The control for current state of the problem and possible errors is effected via “log” and “errors” files during running time.

10 Results

The code testing and its validation is an important step to develop reliable software.

10.1 Comparisons with previous calculations

The dose calculation results obtained with the RELEASE code were compared with the dose calculations by L.Moritz [Mo96b] and P.Vojtyla [Voj98] as some routines of the RELEASE code were developed on base of their original programs.
For a comparison we were chosen the calculation of the effective dose to the critical group of the population - douaniers due the radioactive air release from the ISOLDE facility. The parameters for the calculation of the effective dose per the unit release via the atmospheric and water pathway for the douaniers are presented in Table 14.

Table 14: The parameters for the calculation the radioactive air release from ISOLDE at the CERN Meyrin cite

Parameter	Value
Stack height (m)	10.1
Stack base altitude (m)	442.0
Stack diameter (m)	1.156
Exhaust speed ($m\cdot s^{-1}$)	3.17
Wind speed ($m\cdot s^{-1}$)	1.51
Wind vector azimuth	52.
Stability class (A-F)	B
Roughness length (cm)	100.0
Flow rate of receiving water (m^3/y)	$5\cdot 10^6$
Speed of receiving water ($m\cdot s^{-1}$)	1.0
Downwind distance (m)	250.0
Azimuth of the receptor (deg. from N)	52.0
Receptor altitude (m)	435.0
Precipitation rate($mm\cdot h^{-1}$)	2.0
Air: Occupancy factor	1.0
Air: Fraction of vegetables from area	0.1
Air: Fraction of milk from area	0.0
Air: Fraction of meat from area	0.0
Downstream distance - water (m)	1000.0
Water: Fraction drinking water from rivers	0.0
Water: Fraction of fish from rivers	1.0
Water: Fraction of milk from watered animals	0.1
Water: Fraction of meat from watered animals	0.1
Water: Fraction time spent in rivers	0.01

10.1.1 Comparisons: a short-term release

The effective dose from the short-term air release at the CERN Meyrin site were calculated for douaners exposed only via the atmospheric pathway during the weather stability class B and prevalent wind direction.

Comparison of the total effective dose per unit release for short-term release and for some important radionuclides calculated in the work and in previous work by L.Moritz and P.Vojtyla douaniers are shown in Table 15. A small difference between our results and calculation by L.Moritz for tritium(HTO) can be explained that new breathing rates for general population are 1.5 times less than the old value for adults.

Table 15: The short-term effective dose per unit release for douaniers, Sv/Bq

Radionuclide	[Mo96b]	[Voj98]	Present work
Tritium(as HTO, adults)	$9.1 \cdot 10^{-19}$	$6.6 \cdot 10^{-19}$	$6.6 \cdot 10^{-19}$
^{7}Be(as an aerosol, infants)	$1.5 \cdot 10^{-16}$	$2.5 \cdot 10^{-16}$	$1.0 \cdot 10^{-16}$
^{11}C(β/γ emitters with $T_{1/2}$ <1 day, infants)	$4.1 \cdot 10^{-18}$	$5.1 \cdot 10^{-18}$	$5.1 \cdot 10^{-18}$
^{22}Na(β/γ emitters with $T_{1/2}$ >1 day, infants)	$5.7 \cdot 10^{-14}$	$3.8 \cdot 10^{-14}$	$1.6 \cdot 10^{-14}$
^{60}Co(β/γ emitters with $T_{1/2}$ >1 day, infants)	$1.1 \cdot 10^{-13}$	$4.6 \cdot 10^{-14}$	$2.0 \cdot 10^{-14}$
^{131}I(radioactive iodine, infants)	$3.8 \cdot 10^{-15}$	$8.4 \cdot 10^{-15}$	$8.2 \cdot 10^{-15}$
^{210}Po(α emitters as an aerosol, infants)	$5.4 \cdot 10^{-13}$	$8.0 \cdot 10^{-13}$	$8.0 \cdot 10^{-13}$

The effective dose value for ^{7}Be is 1.5 times less than value calculated by L.Moritz and it is 2.5 times less than value calculated by P.Vojtyla. On the one hand, the cause of this fact is the use of the new dose conversion factors for beryllium. On the other hand, it is probably, in work [Voj98] the value of the indoor shielding factor was taken 1.0 instead of the recommended value of 0.4 for short-term release and for the dose calculation from the ground deposition [HSK41].

The main contribution to the total effective dose for ^{11}C gives the external exposure from the radioactive cloud therefore the the negligible distinction in the dose values are caused by more detail Gaussian plume model [50-SG-S3] and more precise algorithm of the dose kernel integration.

As can be seen from Table 14, there is a significant difference of results for radionuclides ^{22}Na and ^{60}Co, that effective dose is determined by the external exposure from the ground deposition. For ^{22}Na and ^{60}Co the dose values calculated in [Mo96b] exceed in 3.5 and 5.5 times the corresponding values obtained in present work. It seems, such discrepancy is caused by the use of various time of exposure during the short term release. In our case the doses were calculated for 12 months of exposure following the short-term release. In the model by L.Moritz the dose was calculated for 50 years following the short-term release.

10.1.2 Comparisons: a long-term release

The long-term effective dose per unit release for douaniers and for most important radionuclides are shown in Table 16.

As in case of the short-term release, the difference between the results of the dose calculation carried out by L.Moritz and present results is significant, it changes from factor of 1.4 for ^{210}Po up to 6.8 for ^{131}I. It can mark a few causes of such discrepancy. On the one hand, the Gaussian plume model [50-SG-S3] taking into account a reflection from the ground and more precise algorithms of the dose kernel integration were used in work [Voj98] and in present work. On the another hand, the detail weather joint probability matrix obtained on base of the high-quality meteorological

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[†] The Monte Carlo integration of the dose kernel.

Table 16: The long-term effective dose per unit release for douaniers, Sv / Bq

Radionuclide	[Mo96b]	[Voj98]	Present work
Atmospheric pathway			
Tritium(as HTO, adults)	$2.0 \cdot 10^{-20}$	$5.7 \cdot 10^{-20}$	$5.7 \cdot 10^{-20}$
^{7}Be(as an aerosol, infants)	$6.7 \cdot 10^{-18}$	$1.9 \cdot 10^{-17}$	$1.9 \cdot 10^{-17}$
^{11}C(β/γ emitters with $T_{1/2}$ <1 day, infants)	$5.3 \cdot 10^{-20}$	$3.4 \cdot 10^{-19}$	$2.7 \cdot 10^{-19}$ ($3.8 \cdot 10^{-19\dagger}$)
^{60}Co(β/γ emitters with $T_{1/2}$ >1 day, infants)	$5.0 \cdot 10^{-15}$	$1.5 \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$
^{131}I(radioactive iodine, infants)	$5.7 \cdot 10^{-17}$	$3.9 \cdot 10^{-16}$	$3.9 \cdot 10^{-16}$
^{210}Po(α emitters as an aerosol, infants)	$3.6 \cdot 10^{-14}$	$5.1 \cdot 10^{-14}$	$5.1 \cdot 10^{-14}$
Water pathway			
Tritium(as HTO, adults)	$1.7 \cdot 10^{-19}$	$9.5 \cdot 10^{-20}$	$9.5 \cdot 10^{-20}$
^{7}Be(as an aerosol, infants)	$5.6 \cdot 10^{-17}$	$5.9 \cdot 10^{-18}$	$5.9 \cdot 10^{-18}$
^{11}C(β/γ emitters with $T_{1/2}$ <1 day, infants)	$3.5 \cdot 10^{-18}$	$3.8 \cdot 10^{-18}$	$3.8 \cdot 10^{-18}$
^{22}Na(β/γ emitters with $T_{1/2}$ >1 day, infants)	$7.1 \cdot 10^{-16}$	$7.1 \cdot 10^{-16}$	$7.1 \cdot 10^{-16}$
^{210}Po(α emitters as an aerosol, infants)	$7.2 \cdot 10^{-13}$	$7.2 \cdot 10^{-13}$	$7.2 \cdot 10^{-13}$

observations data and new dose conversion factors recommended by [HSK41] were used in our calculations. All of these result in that the value of the dispersion factor is 3 times greater than a value calculated in [Mo96b]. The value of the dispersion factor determines the value of dose from ground deposition which gives the main contribution to the total effective dose for ^{7}Be, ^{22}Na and ^{60}Co.

As mentioned above the dose for ^{11}C is determined by the external exposure from the radioactive cloud. This value is very sensitively to a model of the dispersion factor calculation and to a integration methods. In particular, the precise integration using the Monte Carlo methods which removes a singularity in the dose kernel gives a value of $3.8 \cdot 10^{-19}$ Sv·Bq^{-1} for the total effective dose instead of $2.7 \cdot 10^{-19}$ Sv·Bq^{-1} in case of the 2-dimensional numerical integration. The values of the total effective dose for ^{11}C calculated by various authors are distinguished insignificant, the difference does not exceed 20-25%.

For the long-term release the effective dose is calculated not only for the atmospheric pathway way but also for the water pathway. The “near” group was considered by us as a critical group of the population, the parameters of this group was identified by L.Moritz [Mo96b] and can be found in Table 14. For the water pathway, the most significant difference (see Table 16) deals with the value of the effective dose for tritium and ^{7}Be. The enlargement of the value of the dose for tritium in 1.8 times is concerned with the use of the new average consumption rates of milk and meat for the Swiss population [HSK41]. The Swiss Directive uses the new value of the biological transfer factor for beryllium from water to fish which is less by 10 times than old value. Namely, therefore the value of the dose for ^{7}Be is 10 times less than the dose obtained in [Mo96b].

10.2 Dose calculation at the LHC site

As mentioned above all parameters for the calculation of the effective dose at a complex terrains can be shared into two main groups. The parameters of the first group are a function of coordinates of the release points and the receptor points at the LHC site. These parameters are determined by the LHC ventilation system, the weather statistics, the map of topological altitudes and roughness, the identification of the critical group of populations at the LHC site. The parameters of the second group such as the nuclear data and transfer factors depend on a type of radionuclide. Seven points of the radioactive releases were identified at the LHC site. The radioactivity rate in

Bq per year and the weather joint probability matrix were calculated for each point of the release (see section 6 and 2.1.2). The parameters of the ventilation and stacks for the each point the release of the radioactive air were determined in sections 4 and 5. In present work the effective doses for the atmospheric pathway at the LHC were calculated for a critical group of the population such as douaniers. For the calculation of doses via the water pathway was used the same approach as in [Kou00], the "far" groups of the population at the LHC site are considered. The full list of parameters for the calculation of the dose to the public due the radioactive release at LHC site is presented in Table 17. The Figure 23 illustrates the spatial distribution of the total effective dose in Sv per year to the public only from the LHC facilities without the air release from CNGS. The maximum values of doses are determined by the shirt lived radionuclides of releases, they reach their peak values of 17 μSv·yr^{-1} and 16 μSv·yr^{-1} along the prevalent wind direction for points P3 and P5, respectively (see Table 18). The results presented in Table 18 that the contribution of the long lived radionuclides to the maximum total effective dose is less than 0.2 % and the total dose does not exceed 5-8% from annual dose limit. There is another situation in case of the air release from CNGS facility, the detail studies of which was carried out in work [Kou00]. Assuming that 100% of aerosols remain in the air released, the spatial distribution of the total effective dose in Sv per year to the public from the CNGS facility is presented in Figure 24 In this case, the long lived radionuclides give the main contribution to the total effective dose. Moreover,^{7}Be determines about 90% of the total dose. The special regime of the air ventilation and the installation of so-called "absolute" aerosol filters allow to reduce initial high radioactivity of the long lived

Table 17: The parameters for the dose calculation at the LHC cite

Parameters	Value
Roughness length (cm)	100.0
Air: Occupancy factor	1.0
Air: Fraction of vegetables from area	0.1
Air: Fraction of milk from area	0.0
Air: Fraction of meat from area	0.0
Downstream distance - water (m)	10000.0
Flow rate of receiving water (m^3/y)	$2\cdot10^{10}$
Speed of receiving water (m· s^{-1})	1.0
Water: Fraction drinking water from rivers	1.0
Water: Fraction of fish from rivers	1.0
Water: Fraction of milk from watered animals	1.0
Water: Fraction of meat from watered animals	1.0
Water: Fraction time spent in rivers	0.01

Table 18: The maximum total effective dose to the public at the LHC site ($\mu Sv \cdot y^{-1}$)

Radionuclide	Site						
	P1	P3	P5	P7	CNGS	LHC	LHC+CNGS
^{3}H(as HTO)	$1.8\cdot10^{-6}$	$3.0\cdot10^{-6}$	$2.2\cdot10^{-6}$	$1.6\cdot10^{-6}$	$5.1\cdot10^{-4}$	$4.3\cdot10^{-6}$	$5.1\cdot10^{-4}$
^{7}Be(as an aerosol)	0.01	0.02	0.02	0.01	0.45	0.03	0.46
$T_{1/2}$ <1 day	10.13	16.93	9.44	16.01	0.44	16.94	16.94
$T_{1/2}$ >1 day	$1.7\cdot10^{-3}$	$3.2\cdot10^{-3}$	$1.9\cdot10^{-3}$	$2.0\cdot10^{-3}$	0.61	$4.2\cdot10^{-3}$	0.61
Total	10.15	16.95	9.46	16.02	1.5	16.95	17.00
D_t/D_{an}	0.05	0.085	0.047	0.08	0.008	0.085	0.085

radionuclides more than 10 times. However, the contribution of the long lived radionuclides to the total effective dose will remain significant.

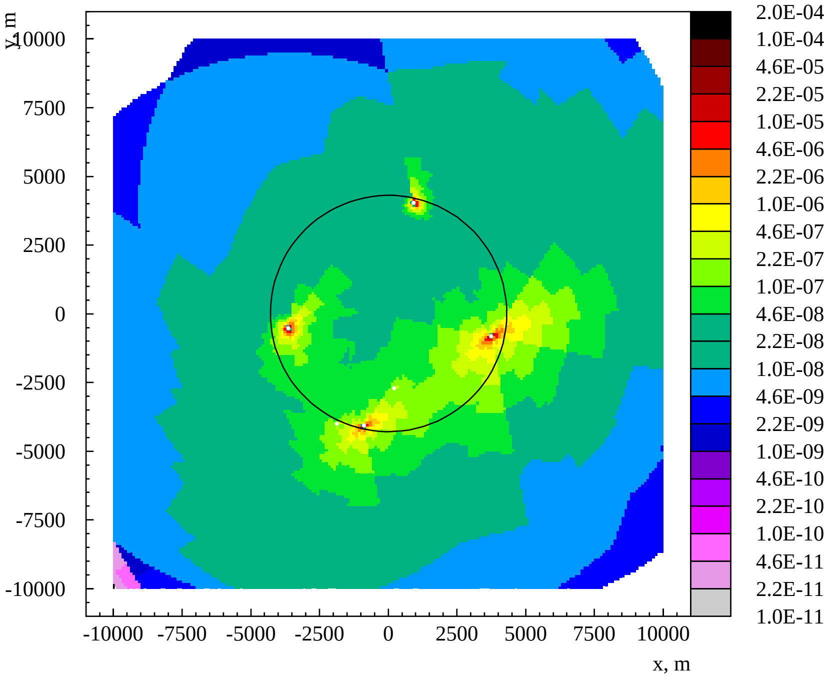

Figure 23: The total effective dose in Sv per year to the public from the LHC facilities.

The Figure 25 shows the spatial distribution of the total effective dose in Sv per year to the public from the LHC and CNGS facilities assuming that the “absolute” filters were installed in the CNGS. As before the values of the effective doses reach the maximum value near the release points P3 and P7 from the momentum and betatron cleaning systems, they do not exceed 1/10 of the annual dose limit. The dose drops more strongly with distance from the release point P5 (area near Gex) than from other points at the LHC site because of tall stack and more difficult weather joint probability matrix.

The the spatial distribution of the effective dose to the public from the short lived radionuclides at the LHC site is presented in the Figure 26. The dose distributions presented in the Figures 25,26 are very similar since near the release points the dose is determined by the short lived radionuclides. The contribution of the short lived radionuclides to the total effective dose gives a major part at distances up to 1 km from the release point. At the distance of 1-1.5 km the release point the contributions of the short lived and long lived radionuclides to the total effective dose are the same. The long lived radionuclides gives the prevailing contribution to the total effective dose beginning with the distance of 1.5 km from the release point. The Figures 27- 29 show the the the spatial distributions of the effective dose to the public from tritium, ^{7}Be and lived radionuclides at the LHC site. As can be seen from the Figures 27- 29 the contribution of the long lived radionuclides to the dose is almost everywhere determined by the air release from the CNGS facility, besides the distant regions in North at the LHC site. The high content of tritium and ^{7}Be in the air release from the CNGS facility defines the radiation situation with tritium and ^{7}Be everywhere at the LHC site.

Thus one can mark the following general features of the dose distributions for the public at the LHC site:

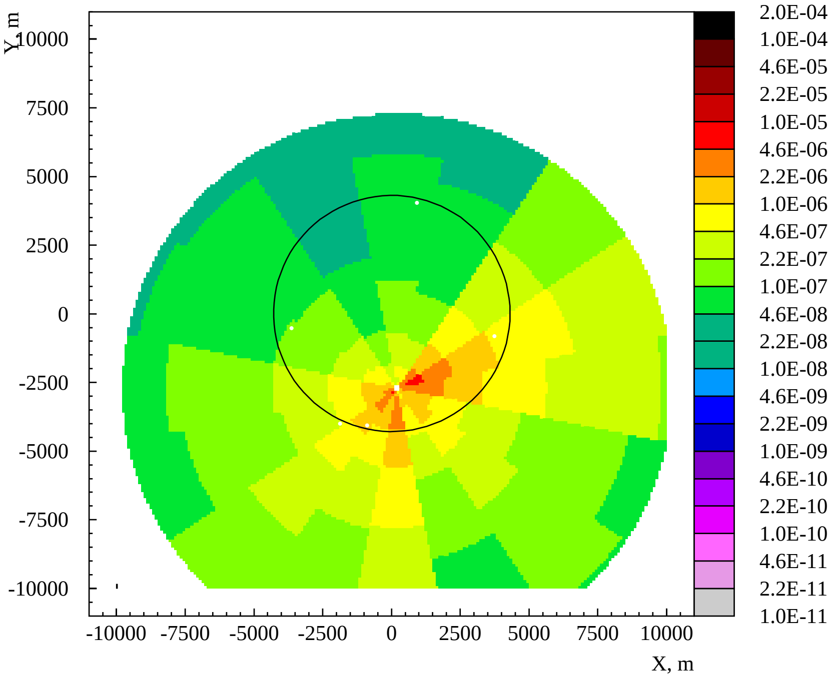

Figure 24: The total effective dose in Sv per year to the public from the CNGS facility for the case without some aerosol filters (100% of ^{7}Be).

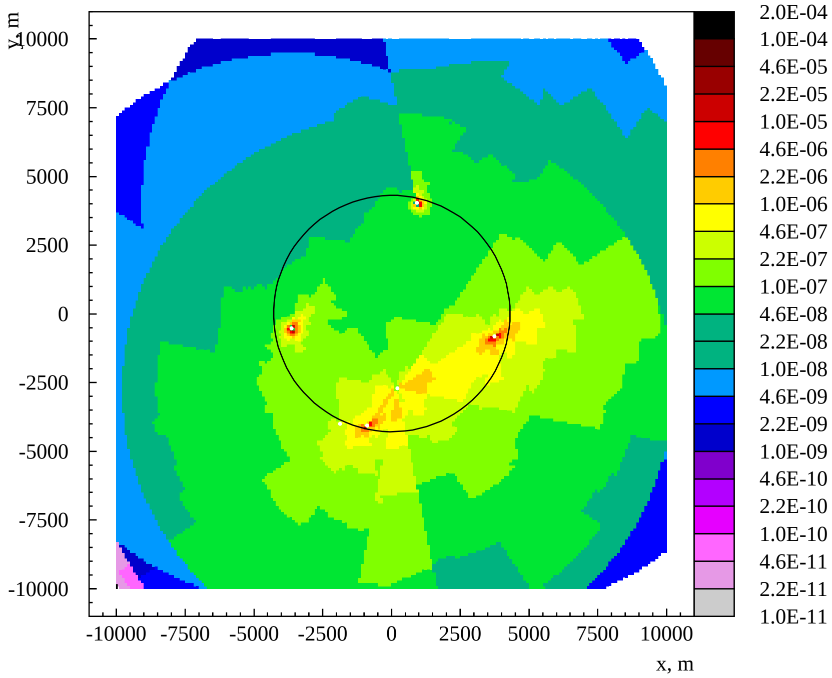

Figure 25: The total effective dose in Sv per year to the public from the LHC and CNGS facilities for the case of so-called “absolute” aerosol filters (10% of ^{7}Be).

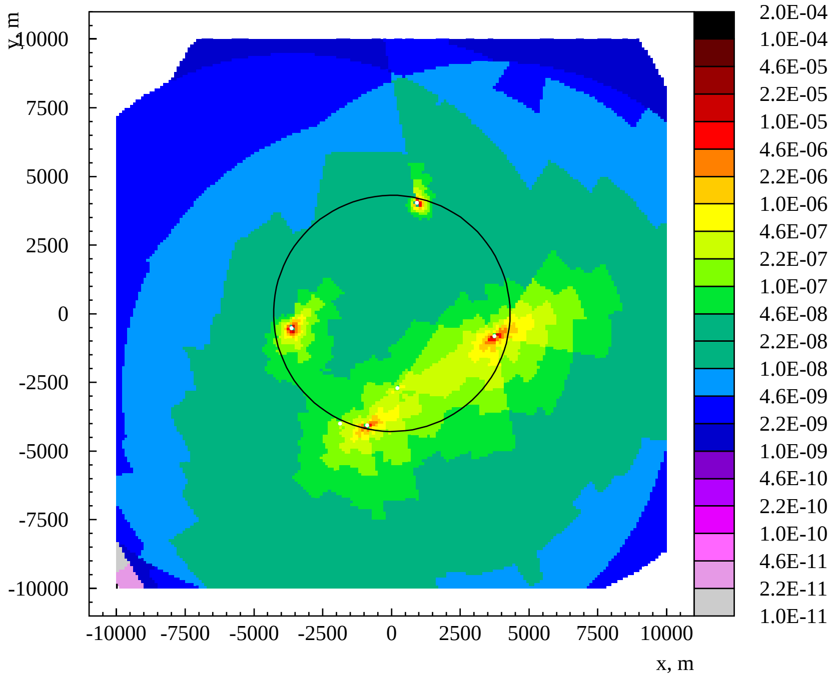

Figure 26: The effective dose (Sv·yr^{-1}) from the short-lived radionuclides to the public from the LHC and CNGS facilities.

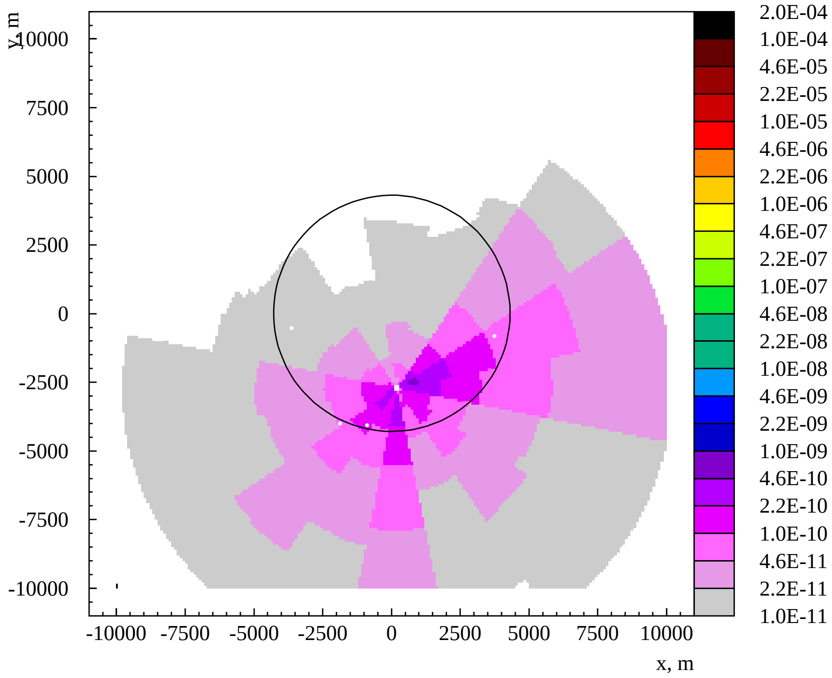

Figure 27: The effective dose (Sv·yr^{-1}) of ^{3}H to the public from the LHC and CNGS facilities.

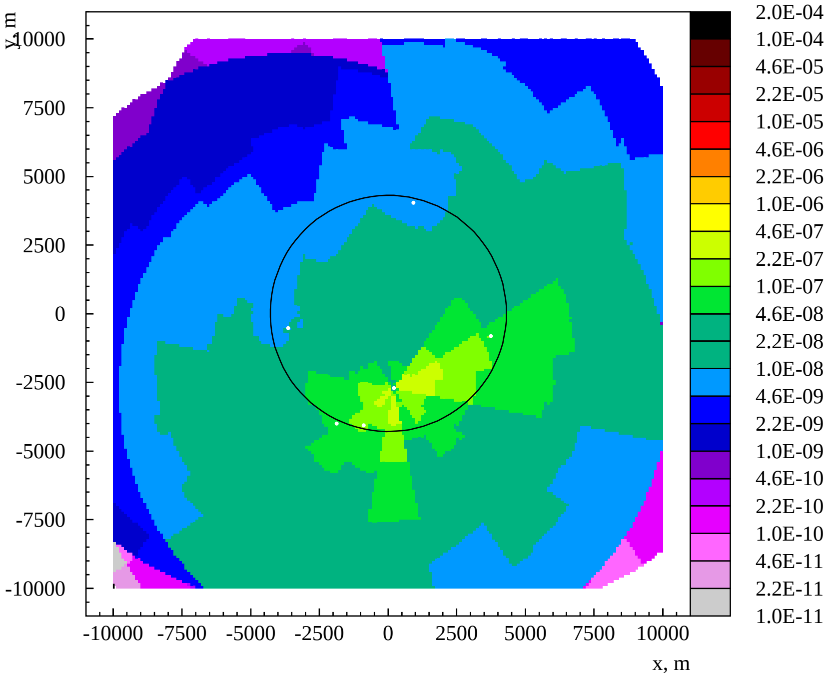

Figure 28: The effective dose (Sv·yr^{-1}) of ^{7}Be to the public from the LHC and CNGS facilities.

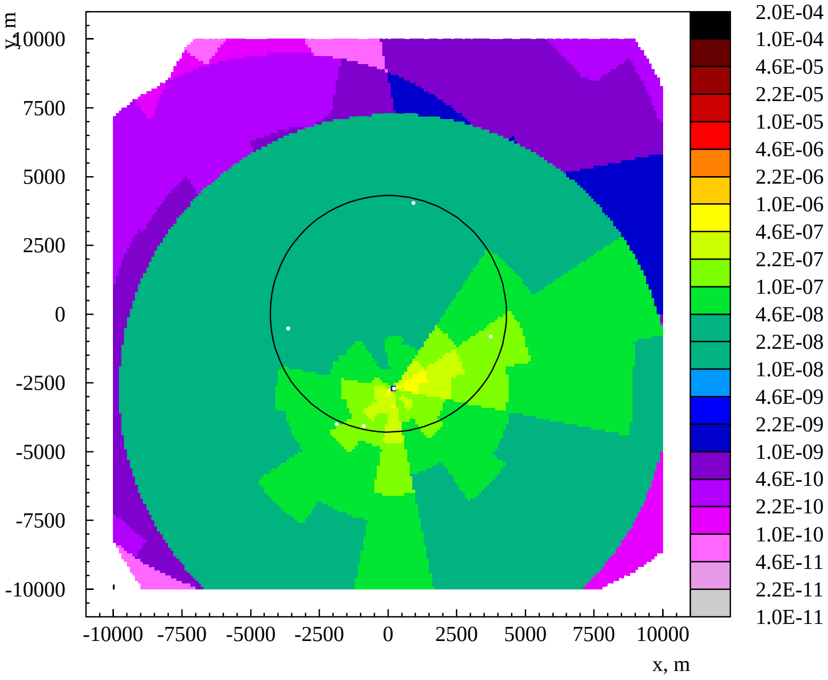

Figure 29: The effective dose (Sv·yr^{-1}) from the long-lived radionuclides to the public from the LHC and CNGS facilities.

- Near the release point the maximum values of the total effective dose are determined by the short lived radionuclides with exception of the air released from the CNGS facility.
- The air releases at points P3 and P5 can be considered as the single point release because of the large distances between the release points and different weather statistics. In this case, the influence of the air releases each other is negligible. In order to calculate accuracy the total effective dose at the sites near points P3 or P5, it is enough to take into account a dose from a single point release at this and a contribution from the CNGS facility.
- To calculate the effective doses at the sites near points P1, P7 and CNGS, all of points must be considered together because they are situated on the one line with the prevalent wind direction for the same weather statistics.

Conclusions

In frame of the present work the methods for calculation of the effective dose to the public due to multiple points release of the air radioactivity from the LHC facilities was developed on base of a implementation of the Swiss directive HSK-R-41 of July 1997 [HSK41], IAEA Safety Guide No. 50-GS-S3 [50-SG-S3] and ICRP Publication 72 [ICRP72]. The main results of the study can be summarised as follows:

- Two algorithms were proposed in order to accelerate a process of the dose kernel integration for the submersion dose calculation from the Gaussian plume.
- The main weather statistics have been defined at the LHC site
- On base of existing data have been determined release rates for 39 radionuclides and for all possible release points
- A map of the topological altitudes at the LHC site was included in consideration.
- The main critical groups of the population have been defined at the LHC site
- A map of the total effective dose to the public was calculated from all LHC facilities.
- The total effective dose reaches maximal values of 16 μSv/y and 17 μSv/y near the Point 7 and Point 3. The short-lived radionuclides give the main contribution to the total effective dose near Point 1, Point 3, Point 5 and Point 7.
- The tritium, ^{7}Be and long–lived radionuclides from CNGS facility determine completely the effective dose from long–lived radionuclides at the LHC site.
- The maximal value of the total effective dose does not exceed 1/10 of the annual dose limit
- A some approach is proposed for a fast estimation of the total effective dose near points P3 or P5.

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A Parameters used in the RELEASE program package

Table 19: Symbols and definition of the parameters for the effective dose calculation

Symbol	Definition	Unit	Value	
			Short-term	Long-term
$C(x, y, z, t)$	concentration	Bq·m^{-3}		
$C^0_{fod,lv}$	concentration on leaves of fodder	Bq·kg^{-1}		
$C^0_{fod,r}$	concentration on leaves in the root system	Bq·kg^{-1}		
$C^0_{veg,lv}$	concentration on leaves of vegetables	Bq·kg^{-1}		
$C^0_{veg,r}$	concentration in the root system of vegetables	Bq·kg^{-1}		
$D_{L,gnd}$	dose from ground deposition	Sv		
$D_{L,gpl}$	submersion dose	Sv		
$D_{L,sic}$	immersion dose	Sv		
$D_{L,ing}$	ingestion dose via atmospheric pathway	Sv		
$D_{L,HTO}$	ingestion dose for tritium	Sv		
$D_{L,C-14}$	ingestion dose for ^{14}C	Sv		
$D_{L,inh}$	inhalation dose	Sv		
$D_{W,imm}$	immersion dose via water pathway	Sv		
$D_{W,ing}$	ingestion dose via water pathway	Sv		
E	the entrainment factor			
e_{gnd}	dose conversion factor for ground deposition	(Sv·yr^{-1})/(Bq·m^{-2})		
e_{imm}	immersion dose conversion factor	(Sv·yr^{-1})/(Bq·m^{-3})		
e_{ing}	ingestion dose conversion factor	Sv·Bq^{-1}		
e_{inh}	inhalation dose conversion factor	Sv·Bq^{-1}		
f_C	mass fraction of carbon in foodstuff		0.125	0.125
f_d	fraction of direct wet deposition iodine		0.3 1.0	0.3 1.0
f_F	fraction of in milk and meat		0.4	0.4
f_{ei}	fraction of iodine		0.5	0.5
f_{fi}	fraction of fish from river			
f_{mi}	fraction of milk			
f_{mt}	fraction of meat			
f_w	fraction of drinking water			
f_{wa}	average water content in foodstuff		0.75	0.75
f_{oc}	occupancy factor			
h_{eff}	effective height of the release	m		
I_N	precipitation rate	mm· h^{-1}	-	2
I_0	referance precipitation rate	mm· h^{-1}	1	1
J	average flow rate	m^3· yr^{-1}		

Table 19-continued: Symbols and definition of the parameters for the effective dose calculation

Symbol	Definition	Unit	Value	
			Short-term	Long-term
k	correction coefficient			
	aerosol, iodine		0.8	0.8
	tritium		1.0	1.0
k_s	indoor shielding factor for immersion		0.4	1.0
k_s	indoor shielding factor for deposition		0.4	0.4
P_{ijk}	element of joint probability matrix			
P_{fod}	soil density near roots for fodder	kg·m^{-2}	120	120
P_{veg}	soil density near roots for vegetables	kg·m^{-2}	280	280
Q	radioactivity	Bq		
$\dot{Q}$	radioactivity rate	Bq·yr^{-1}		
T_1	exposure time	yr	1	1
T_{exp}	exposure time	yr	1	1
T_{fi}	storage time of fish	yr	2.7·10^{-3}	2.7·10^{-3}
T_h	time between the beginning of calendar year and harvest (April 16)	yr	0.29	0.29
T_{mi}	storage time of milk	yr	2.5·10^{-3}	2.5·10^{-3}
T_{mt}	storage time of meat	yr	5.5·10^{-2}	5.5·10^{-2}
T_{op}	operation time	yr	50	-
T_p	production time	yr		
	vegetables		0.16	0.16
	fodder		8.2 ·10^{-2}	8.2 ·10^{-2}
TF_{fod-mi}	biological transfer factors fodder-milk	day kg^{-1}		
TF_{fod-mt}	biological transfer factors fodder-meat	day kg^{-1}		
$TF_{soil-veg}$	biological transfer factors soil-vegetable	(Bq · kg^{-1})/(Bq ·kg^{-1})		
$TF_{soil-fod}$	biological transfer factors soil-fodder	(Bq · kg^{-1})/(Bq ·kg^{-1})		
TF_{wa-fi}	biological transfer factors water-fish	m^3·kg^{-1}		
u	mean wind speed during release	m·s^{-1}		
U_{fi}	average annual fish consumption	kg·yr^{-1}		
	adults		10	-
	infants		0	-
U_{inh}	average inhalation rate	m^3·s^{-1}		
	adults		2.3 ·10^{-4}	2.3 ·10^{-4}
	infants		6.0 ·10^{-5}	6.0 ·10^{-5}
U_{mi}	average annual milk consumption	kg·yr^{-1}		
	adults		160	160
	infants		200	200
U_{mt}	average annual meat consumption	kg·yr^{-1}		
	adults		75	75
	infants		20	20
U_{veg}	average annual vegetable consumption	kg·yr^{-1}		
	adults		225	225
	infants		60	60
U_W	average annual water consumption	m^3·yr^{-1}		
	adults		0.6	-
	infants		0.25	-

Table 19-continued: Symbols and definition of the parameters for the effective dose calculation

Symbol	Definition	Unit	Value	
			Short-term	Long-term
V_{fod}	dayly consumption of fodder by cattle	$kg \cdot day^{-1}$	65	65
V_{wa-fi}	average dayly water consumption	$m^3 \cdot day^{-1}$	0.075	0.075
Y_{fod}	areal density of fodder	$kg \cdot m^{-2}$	0.85	0.85
Y_{veg}	areal density of vegetables	$kg \cdot m^{-2}$	2.4	2.4
α	conversion factor from year to seconds	$s \cdot yr^{-1}$	$3.156 \cdot 10^7$	$3.156 \cdot 10^7$
Λ	washout factor	s^{-1}		
Λ_0	reference washout factor			
	aerosol, iodine	s^{-1}	$7.0 \cdot 10^{-5}$	$7.0 \cdot 10^{-5}$
	tritium	s^{-1}	$3.5 \cdot 10^{-5}$	$3.5 \cdot 10^{-5}$
λ	radioactive decay constant	yr^{-1}		
λ_F	non-radioactive decay constant for fast component	yr^{-1}	$7.5 \cdot 10^{-3}$	$7.5 \cdot 10^{-3}$
λ_S	non-radioactive decay constant for slow component	yr^{-1}	1.1	1.1
λ_R	non-radioactive decay constant near the root system of plants	yr^{-1}		
	Tc,Sr,Sc		$7.0 \cdot 10^{-2}$	$7.0 \cdot 10^{-2}$
	Ca,Br,Ba,Mn,Zn		$3.5 \cdot 10^{-2}$	$3.5 \cdot 10^{-2}$
	I,Te		$1.7 \cdot 10^{-2}$	$1.7 \cdot 10^{-2}$
	others		0.0	0.0
λ_V	non-radioactive decay constant on leaves l	yr^{-1}		
	aerosol		18	18
	iodine		32	32
ν_g	deposition velocity	$m \cdot s^{-1}$		
	aerosol		-	0.0015
	elemantary iodine		-	0.01
ν'_g	enlarged deposition velocity	$m \cdot s^{-1}$	0.017	-
χ_L	long-term dispersion factor	$s \cdot m^{-3}$		
ξ_L	long-term deposition factor on ground	m^{-2}		
ξ'_L	deposition factor on leaves	m^{-2}		
σ_y	horizontal dispersion coefficient	m		
σ_z	vertical dispersion coefficient	m		
ϕ	average humidity of air	$kg \cdot m^{-3}$	$9.0 \cdot 10^{-3}$	$9.0 \cdot 10^{-3}$
Ψ	carbon content of air	$kg \cdot m^{-3}$	$1.8 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$

B Examples of “Input” for the RELEASE code

All calculations mentioned above have been carried out with the RELEASE program package. So-called “Input” of the program requires a few files which contains general and tuning parameters of problem (*problem.inp*), the list radionuclides, their half-lives, conditions and dose conversion factors (*nuclides.inp*), the list of biological transfer factors for all elements (*trfs.inp*) and data of the joint probability matrixes $P_{i,j,k}$ (*weathermer.inp*). In fact, the paremeters containing in the *problem.inp* file are change only.

A few examples of the *problem.inp* file are given below. First one is a “Input” which uses a calculational grid in the coordinate system of a single point release (the polar coordinate system) at the LHC site:

```
Problem title                              :LHC area - POINT P1

—– Task description                        :
Actual release ? (Y/N)                     :N
Flag of writting in log file(T/F)          :F
Flag of writting in dmp file(T/F)          :T
Flag of long or short record(T/F)          :T
Flag of unfolding of dmp files(T/F)        :F
Number of release point in task            :6
Number of nuclides in run                  :2
Model type for topological correction      :1
—– Release description                     :
- Parameters for first release             :
X- coordinates of release point (m)        : -877.
Y- coordinates of release point (m)        :-4068.
Physical stack height (m)                  :9.15
Physical building height (m)               :9.15
Stack base altitude (m)                    :440.25
Stack diameter (m)                         :1.12
Exhaust speed (m/s)                        :6.34
Name of weather file                       :weatherme
Name of dmp file for Point 1               :dumpfilme
File name with integral radioactivity      :activmeP1
—– Grid description                        :
Type of grid (polar)                       :1
Number of internal grids                   :1
Number of external grids                   :0
Number of angular bins                     :16
Number of radial bins(max=51)              :51
Minimum radius along X(min = 100 m)        :100.
Maximum radius along X(max = 10000 m)      :10000.
```

Next example illustrates a “Input” for the calculation of the effective doses with a use of a superposition model of calculational grid at the LHC site (see details in section 9):

```
Problem title                          :LHC area - P1,P3,P5,P7,SI2,SI8

—— Task description                    :
Actual release ? (Y/N)                 :N
Flag of writting in log file(T/F)      :F
Flag of writting in dmp file(T/F)      :T
Flag of long or short record(T/F)      :T
Flag of unfolding of dmp files(T/F)    :F
Number of release point in task        :6
Number of nuclides in run              :39
Model type for topological correction  :1
—— Release description                 :
- Parameters for first release         :
X- coordinates of release point (m)    : -877.
Y- coordinates of release point (m)    :-4068.
Physical stack height (m)              :9.15
Physical building height (m)           :9.15
Stack base altitude (m)                :440.25
Stack diameter (m)                     :1.12
Exhaust speed (m/s)                    :6.34
Name of weather file                   :weatherme
Name of dmp file for Point 1           :dumpfilme
File name with integral radioactivity  :activmeP1
- Parameters for second release        :
X- coordinates of release point (m)    :-3635.
Y- coordinates of release point (m)    : -519.
Physical stack height (m)              :8.9
Physical building height (m)           :8.9
Stack base altitude (m)                :488.0
Stack diameter (m)                     :1.12
Exhaust speed (m/s)                    :6.34
Name of weather file                   :weathercr
Name of dmp file for Point 3           :dumpfilcr
File name with integral radioactivity  :activcrP3
- Parameters for third release         :
X- coordinates of release point (m)    : 925.
Y- coordinates of release point (m)    :4040.
Physical stack height (m)              :23.5
Physical building height (m)           :8.90
Stack base altitude (m)                :508.50
Stack diameter (m)                     :1.12
Exhaust speed (m/s)                    :6.34
Name of weather file                   :weatherce
Name of dmp file for Point 5           :dumpfilce
File name with integral radioactivity  :activceP5
```

- Parameters for fourth release :
X- coordinates of release point (m) : 3745.
Y- coordinates of release point (m) : -815.
Physical stack height (m) :8.50
Physical building height (m) :8.50
Stack base altitude (m) :430.75
Stack diameter (m) :1.12
Exhaust speed (m/s) :6.34
Name of weather file :weatherme
Name of dmp file for Point 7 :dumpfilma
File name with integral radioactivity :activmaP7
- Parameters for fivth release :
X- coordinates of release point (m) :-1864.
Y- coordinates of release point (m) :-4005.
Physical stack height (m) :6.50
Physical building height (m) :6.50
Stack base altitude (m) :450.0
Stack diameter (m) :1.12
Exhaust speed (m/s) :6.34
Name of weather file :weatherme
Name of dmp file for SI2 :dmpfilsi2
File name with integral radioactivity :activsui2
- Parameters for sixth release :
X- coordinates of release point (m) : 213.
Y- coordinates of release point (m) :-2713.
Physical stack height (m) :15.2
Physical building height (m) :6.50
Stack base altitude (m) :457.5
Stack diameter (m) :1.12
Exhaust speed (m/s) :6.34
Name of weather file :weatherme
Name of dmp file for SI8 :dmpfilsi8
File name with integral radioactivity :activsui8
—— Grid description :
Type of grid (superposition) :3
Number of internal grids :6
Number of external grids :18
Number of angular bins :16
Number of radial bins for first grid : 5
Minimum radius along X(min = 100 m) :100.
Maximum radius along Y(max = 10000 m) :490.
Number of radial bins for second grid : 5
Minimum radius along X(min = 100 m) :100.
Maximum radius along Y(max = 10000 m) :490.

Number of radial bins for third grid :11
Minimum radius along X(min = 100 m) :100.
Maximum radius along Y(max = 10000 m) :1000.
Number of radial bins for fourth grid :11
Minimum radius along X(min = 100 m) :100.
Maximum radius along Y(max = 10000 m) :1000.
Number of radial bins for fivth grid :11
Minimum radius along X(min = 100 m) :100.
Maximum radius along Y(max = 10000 m) :1000.
Number of radial bins for sixth grid : 5
Minimum radius along X(min = 100 m) :100.
Maximum radius along Y(max = 10000 m) :590.
Mix and Max X-values for first grid : -1370.5 -383.5
Mix and Max Y-values for first grid : -4568. -3568.
Size of bins for X,Y coordinates : 98.7 100.
Mix and Max X-values for second grid : -2357.5 -1370.5
Mix and Max Y-values for second grid : -4505. -3505.
Size of bins for X,Y coordinates : 98.7 100.
Mix and Max X-values for third grid : -4635. -2635.
Mix and Max Y-values for third grid : -1519. 481.
Size of bins for X,Y coordinates : 100. 100.
Mix and Max X-values for fourth grid : -75. 1925.
Mix and Max Y-values for fourth grid : 3040. 5040.
Size of bins for X,Y coordinates : 100. 100.
Mix and Max X-values for 5-th grid : 2745. 4745.
Mix and Max Y-values for 5-th grid : -1815. 185.
Size of bins for X,Y coordinates : 100. 100.
Mix and Max X-values for 6-th grid : -383.5 809.5
Mix and Max Y-values for 6-th grid : -3338. -2138.
Size of bins for X,Y coordinates : 119.3 120.
Mix and Max X-values for 7-th grid :-10000. -4635.
Mix and Max Y-values for 7-th grid :-10000. 10000.
Size of bins for X,Y coordinates : 268.25 250.
Mix and Max X-values for 8-th grid : -4635. -2357.5
Mix and Max Y-values for 8-th grid :-10000. -1519.
Size of bins for X,Y coordinates : 227.75 212.025
Mix and Max X-values for 9-th grid : -4635. -2635.
Mix and Max Y-values for 9-th grid : 481. 10000.
Size of bins for X,Y coordinates : 200. 190.38
Mix and Max X-values for 10-th grid : -2357.5 -1370.5
Mix and Max Y-values for 10-th grid :-10000. -4505.
Size of bins for X,Y coordinates : 197.4 219.68
Mix and Max X-values for 11-th grid : -2357.5 -1370.5
Mix and Max Y-values for 11-th grid : -3505. -1519.
Size of bins for X,Y coordinates : 197.4 198.6

Mix and Max X-values for 12-th grid : -1370.5 -383.5
Mix and Max Y-values for 12-th grid :-10000. -4568.
Size of bins for X,Y coordinates : 197.4 217.28
Mix and Max X-values for 13-th grid : -1370.5 -383.5
Mix and Max Y-values for 13-th grid : -3568. -1519.
Size of bins for X,Y coordinates : 197.4 204.90
Mix and Max X-values for 14-th grid : -2635. -383.5
Mix and Max Y-values for 14-th grid : -1519. 0.
Size of bins for X,Y coordinates : 150.10 151.90
Mix and Max X-values for 15-th grid : -2635. -75.
Mix and Max y-values for 15-th grid : 0. 10000.
Size of bins for X,Y coordinates : 128. 200.
Mix and Max X-values for 16-th grid : -383.5 809.5
Mix and Max Y-values for 16-th grid :-10000. -3338.
Size of bins for X,Y coordinates : 119.30 166.550
Mix and Max X-values for 17-th grid : -383.5 809.5
Mix and Max Y-values for 17-th grid : -2138. 0.
Size of bins for X,Y coordinates : 119.30 106.9
Mix and Max X-values for 18-th grid : 809.5 2745.
Mix and Max Y-values for 18-th grid :-10000. 0.
Size of bins for X,Y coordinates : 193.55 200.
Mix and Max X-values for 19-th grid : -75. 1925.
Mix and Max Y-values for 19-th grid : 0. 3040.
Size of bins for X,Y coordinates : 200. 152
Mix and Max X-values for 20-th grid : -75. 1925.
Mix and Max Y-values for 20-th grid : 5040. 10000.
Size of bins for X,Y coordinates : 200. 198.4
Mix and Max X-values for 21-th grid : 1925. 2745.
Mix and Max Y-values for 21-th grid : 0. 10000.
Size of bins for X,Y coordinates : 164. 200.
Mix and Max X-values for 22-th grid : 2745. 4745.
Mix and Max Y-values for 22-th grid :-10000. -1815.
Size of bins for X,Y coordinates : 200. 204.6250
Mix and Max X-values for 23-th grid : 2745. 4745.
Mix and Max Y-values for 23-th grid : 185. 10000.
Size of bins for X,Y coordinates : 200. 196.30
Mix and Max X-values for 24-th grid : 4745. 10000.
Mix and Max X-values for 24-th grid : -10000. 10000.
Size of bins for X,Y coordinates : 262.75 250.

Last sample shows a “Input” for the dose calculation at a some point of an arbitrary site (Neutrino area):

Problem title	:Neutrino area - Arbitrary manual grid
—— Task description	:
Actual release ? (Y/N)	:N
Flag of writting in log file(T/F)	:T
Flag of writting in dmp file(T/F)	:T
Flag of long or short record(T/F)	:T
Flag of unfolding of dmp files(T/F)	:T
Number of release point in task	:1
Number of nuclides in run	:1
Model type for topological correction	:1
—— Release description	:
- Parameters of release	:
X- coordinates of release point (m)	: 0.
Y- coordinates of release point (m)	: 0.
Physical stack height (m)	:16.39
Physical building height (m)	:15.0
Stack base altitude (m)	:440.25
Stack diameter (m)	:0.6
Exhaust speed (m/s)	:15.72
Name of weather file	:weathermer
Name of dmp file	:dmpfile200
File name with integral radioactivity	:activisui8
—— Grid description	:
Type of grid (manual model)	:5
Maximal number of the receptor points	:1
X, Y - coordinates of first point	:141.42 141.42
Receptor altitude (m)	:440.25
Roughness length(cm)	:40.0
Air: Occupancy factor	:1.000
Air: Fraction of vegetables from area	:0.100
Air: Fraction of milk from area	:0.000
Air: Fraction of meat from area	:0.000
Water: Occupancy factor	:0.010
Water: Fr. of fish from rivers	:1.000
Water: Fr. of milk from watered animals	:1.000
Water: Fr. of meat from watered animals	:1.000
Water: Fr. drinking water from rivers	:1.000
Flow rate of receiving water (m^3/y)	:2.0E+10
Downstream distance - water (m)	:1.0E+04
Speed of receiving water (m/s)	:1.00