DIPLOMARBEIT

Accident Scenarios with Environmental Impact of the TRIGA Mark II Reactor Vienna

Ausgeführt am
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Abstract

The safety report of the TRIGA Mark II Reactor in Vienna[12] includes three accident scenarios and their deterministic dose consequence to the environment. The destruction of the most activated fuel element, the destruction of all fuel elements and a plane crash were treated scenarios in that report. The calculations were made in 1978 with the computer program STRISK[3].

In this diploma theses, the program package PC COSYMA[1, 2] was applied on the TRIGA Mark II Reactor in Vienna and the deterministic consequences of the scenarios to the environment were updated. The fission product inventories of all fuel elements were taken from a calculation with ORIGEN2[11, 16].

To get meteorological data of the atmospheric condition around the release area, a weather station was installed. The release parameters were taken from the safety report[12] or were replaced by worst case parameters. Further on, a fourth scenario for the case of a small plane crash was added. For the sake of completeness all scenarios were calculated with different atmospheric conditions. The diploma theses started in February 2009 and was finished in August 2009 .

Kurzfassung

Der Sicherheitsbericht des TRIGA Mark II Reaktors in Wien[12] umfasst drei Unfallszenarien und deren deterministische Dosisauswirkung auf die Umgebung. Es wurden der Bruch des höchstbelasteten Brennelements, der Bruch aller Brennelemente und ein Flugzeugabsturz als mögliche Szenarien betrachtet. Die Berechnungen stammen aus dem Jahr 1978 und wurden mit dem Programm STRISK[3] durchgeführt.

Die Aufgabe dieser Diplomarbeit umfasste die Anwendung des Programmpakets PC COSYMA[1, 2] auf den TRIGA Mark II Reaktor in Wien und die Aktualisierung der deterministischen Auswirkung der Unfallszenarien auf die Umgebung. Das Inventar der Spaltprodukte aller Brennelemente wurde aus einer Berechnung mit ORIGEN2[11, 16] entnommen.

Um meteorologische Daten für das Freisetzungsareal zu bekommen, wurde eine Wetterstation installiert. Die Parameter für die Freisetzung wurden aus dem Sicherheitsbericht[12] übernommen oder durch Worst-Case Parameter ersetzt. Des Weiteren wurde ein viertes Szenario für den Fall des Absturzes eines kleinen Flugzeuges hinzugefügt. Der Vollständigkeit halber sind die Szenarien mit verschiedenen meteorologischen Bedingungen berechnet worden. Die Diplomarbeit startete im Februar 2009 und dauerte bis August 2009 .

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1 Introduction

This diploma theses is build up with four chapters. In this chapter the basics of the TRIGA Mark II reactor in Vienna[15], the structure of PC COSYMA[1, 2] and basics of plume dispersion in the atmosphere[8] are treated.
The rain rate, the solar radiation, the wind direction and the wind speed at the location around the reactor were measured with a weather station[13] and are presented in chapter two, whereas the Pasquill stability class was determined with wind speed and solar radiation[10].
In chapter three a brief description of used parameters and those values for deterministic calculation in PC COSYMA[1, 2] is presented. The release parameters were taken from the safety report[12] or were replaced by worst case parameters. The fission product inventories of all fuel elements were taken from a calculation with ORIGEN2[11, 16]
The destruction of the fuel element with highest activity content, the destruction of all fuel elements, the case of a small plane crash and the case of a large plane crash were treated scenarios in this work. The effective doses after one day and after 50 years are presented in chapter four, whereas worst atmospheric conditions were treated.
The fission product inventories (only nuclides, which are considered in PC COSYMA) of all fuel elements are presented in Appendix A. Each scenario was calculated with different atmospheric conditions and the most affected sector of every condition is presented in Appendix B.1, B.2, B.3 and B.4.

1.1 The TRIGA Mark-II Reactor[15]

The TRIGA Mark-II reactor was built by General Atomic (San Diego, California, U.S.A.) and went critical for the first time on March 7^{th} 1962. It is a research reactor of the swimming-pool type and is averaged 220 days per year under operation for training, research and isotope production purposes (**T**raining, **R**esearch, **I**sotope **P**roduction, **G**eneral **A**tomic = TRIGA). The maximum power output under continuous conditions amounts $250kW_{th}$, whereas the produced heat is released into a channel of the river Danube via a primary and secondary coolant circuit. At nominal power of $250kW_{th}$, the centre fuel temperature is about $200°C$ and the thermal flux amounts $1 \cdot 10^{13}cm^{-2}s^{-1}$ in the core centre.
The power output of the reactor is very low. Thus the burn-up of the fuel is small and most fuel elements, which were loaded in 1962, are still in operation.
The fuel consists of an uniform mixture of $8wt\%$ uranium, $1wt\%$ hydrogen and $91wt\%$ zirconium, whereas the the zirconium-hydride acts as main moderator. The special property of this moderator is a reduced moderation at high temperatures, which permits pulsed mode.
The shut-down of the reactor can proceed either manually or automatically by the safety system. The control rods require about $0.1s$ to fall completely into the core. Technical data and dimensions of the TRIGA Mark II reactor see table 1.1.

The Fuel Elements of the TRIGA Mark-II Reactor

The reactor core consists of 83 fuel elements which are arranged in an annular lattice. Three various fuel element types are used in the reactor, whereas 54 fuel elements are 102-type, 20 fuel elements are 104-type and 9 fuel elements are FLIP-type. The facts for each type are presented in table 1.2 and the type positioning in the core is presented in figure 4.7. All three types have the same overall dimensions. The substance difference lies in the Uranium enrichment, which is 20% for 102-type, 20% for 104-type and 70% for FLIP-type.
For 102-type, aluminium is used as cladding material. Steel is used in 104-type and FLIP-type fuel elements.

reactor core	
diameter of active core	max. 49.5cm
height of active core	35.56cm
fuel-moderator material	$8wt\%$ uranium
	$91wt\%$ zirconium
	$1wt\%$ hydrogen
reflector	
material	graphite with aluminium cladding
radial thickness	30.5cm
top and bottom thickness	10.2cm
construction	
reactor mounting	heavy and standard concrete
	6.55m high
	6.19m wide
	8.76m long
reactor tank diameter	1.98m
reactor tank depth	6.40m
radial shielding	
graphite	30.5cm
water	45.7cm
heavy concrete	206cm
vertical shielding above core	
water	4.90m
graphite	10.2cm
vertical shielding underneath core	
water	61.0cm
graphite	10.2cm
standard concrete	91cm

Table 1.1: Facts of the TRIGA Mark II reactor in Vienna

	Type 102	**Type 104**	**Type 110* (FLIP)**
Fuel moderator material			
H/Zr-ratio	1.0	1.65	1.65
Uranium content [wt%]	8.5	8.5	8.5
Enrichment [%]	20	20	70
Diameter [mm]	35.8	36.3	36.3
Length [mm]	356	381	381
Poisoning	SmO3-disks	none	Er with 1.6 w/o
Graphite reflector			
Porosity	20	20	20
Diameter [mm]	35.8	36.3	36.3
Length [mm]	102	87.3	88.1
Fuel cladding			
Material	Al-1100 F	304 SS	304 SS
Wall thickness [mm]	0.76	0.51	0.51
Overall dimensions			
Outer diameter [mm]	37.5	37.5	37.5
Length [mm]	720.6	720.6	720.6

Table 1.2: Fuel element types of TRIGA Mark II reactor in Vienna

1.2 Program package PC COSYMA

To assess the off-site consequences of an accidental release of radioactive material to the atmosphere, the program system COSYMA (COde SYstem from MAria) was developed by Forschungszentrum Karlsruhe (FZK in Germany) and the National Radiological Protection Board (NRPB in United Kingdom). The development of this program was an objective of the European Commission's (EC) MARIA program (Methods for Assessing the Radiological Impact or Accidents). COSYMA was based on the earlier program UFOMOD and was generally available in 1990. The first personal computer version of COSYMA was released in 1993 followed by version 2 in 1995. This sub chapter is based on [2].

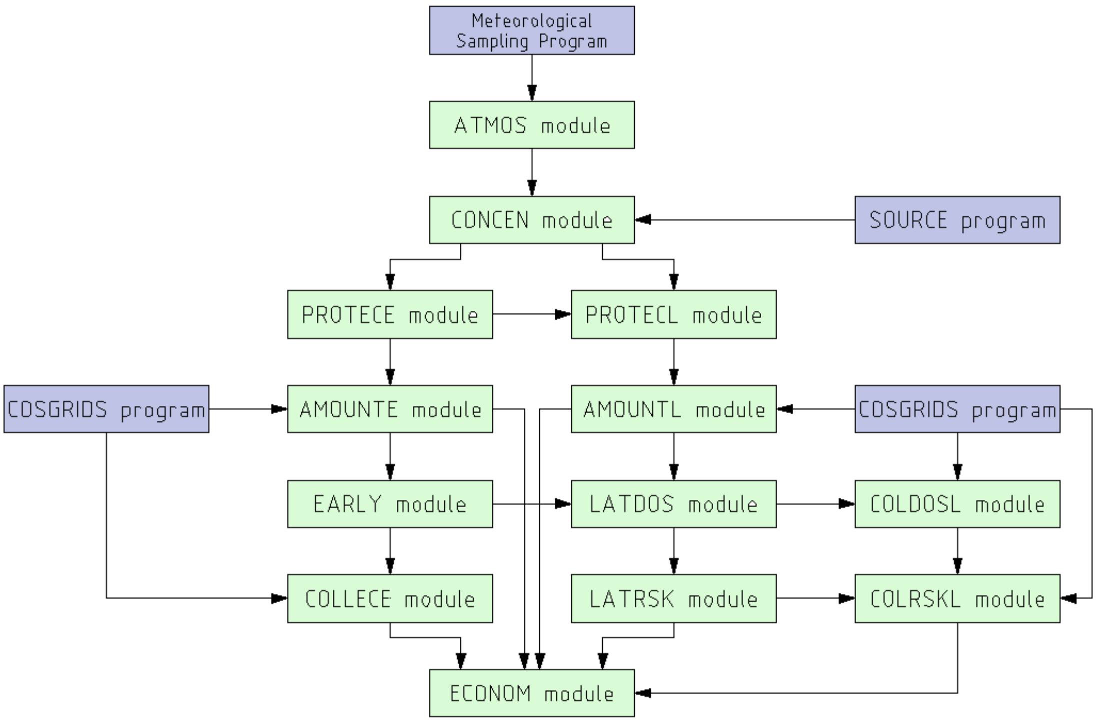
The air concentration, the deposition of particular nuclides, the received dose by members of the population, the individual and the collective risks of early health effects, the individual and the collective risks of late health effects, the risk of or extend of countermeasures and the economic costs can be calculated. This endpoints can be differed into two groups. The first group gives the conditions at particular points, the other group gives the conditions summed over the population. A variety of countermeasures as sheltering, evacuation, relocation, decontamination of land and buildings, administration of stable iodine tablets and food bans can be treated.

Health effects are differed into 2 groups, early health effects and late health effects. Early health effects occur within a few month and late health effects occur over longer periods ($\approx 50a$). The endpoint economic cost calculates the costs of the countermeasures and the health effects. PC-COSYMA can be used for deterministic and probabilistic calculations. In deterministic calculations only a single set of atmospheric conditions is considered. In probabilistic calculations a wide range of atmospheric conditions is considered.

The build-up of PC-COSYMA is partitioned into three major sections, the input interface, the calculation program and the result interface. In the input interface the user can define the endpoints and the values for the input parameters. The calculation program implements the used modules automatically and supplies the required calculations. The results can be represent within the result interface in

graphical or tabular form or can be exported for external use.
Different models, used in PC COSYMA are described in table 1.3[2]. A description of subsidiary programs is presented in table 1.4[2]. The process chart of PC COSYMA is pictured in figure 1.1[2].

Figure 1.1: Process chart of PC COSYMA



1.2.1 Hardware and operating system

PC COSYMA was written for MS-DOS© 4.0 or higher and needs an IBM compatible PC having at least 4 MByte RAM. The installation of the system requires about 12 MByte on hard disk. A deterministic run needs less than 1 MByte storage.

ATMOS	calculates time-integrals of air concentration at each point affected by the plume
	calculates time-integrals of deposition at each point affected by the plume
	unit release of 4 idealized groups of nuclides (noble gases, aerosol, elemental iodine, organic iodine) is assumed
	calculates the plume arrival time for each grid point
	calculates correction factors for determining the cloud γ-dose from air concentration
CONCEN	combines the results for unit release of the idealized nuclides with information on the amounts of each nuclides released
	calculates the air concentration of each nuclide at each grid point.
	calculates the deposition of each nuclide at each grid point
	regards radioactive decay during the period of plume travel
	regards daughter build-up during the period of plume travel
	calculates cloud γ-dose from air concentration and correction factors
PROTECE	determines the extent and duration of the protective actions for short term
PROTECL	determines the extent and duration of the protective actions for long term
AMOUNTE	calculates the number of persons or amount of produce affected by countermeasures for short term
AMOUNTL	calculates the number of persons or amount of produce affected by countermeasures for long term
LATDOS	calculates individual dose over long periods of time
LATRSK	calculates individual risks of late health effects
EARLY	calculates individual dose over short periods of time and individual risks of early health effects
COLDOSL	calculates collective dose over long periods of time
COLLECE	calculates number of early health effects in the population
COLLECL	calculates number of late health effects in the population
ECONOM	calculates off-site economic costs arising from the countermeasures and the health effects

Table 1.3: Used modules in PC COSYMA

SOURCE	selects those nuclides, which make the most important contributions to dose from each pathway
METSAM	selects sequences of atmospheric conditions for probabilistic analysis
COSGRIDS	is used to obtain information about distributions of population around the site
	is used to obtain information about distributions of agricultural production around the site

Table 1.4: Used subsidiary programs in PC COSYMA

For this work, PC COSYMA was installed on a HP Compaq nx9110 notebook with Intel® Pentium® 4 CPU 2.80GHz and 433.8 MB RAM. The installed operating system was Ubuntu 9.04 with Kernel 2.6.28-11-generic under GNOME 2.26.1. The program was emulated with DOS© EMU 1.4.0.0. The program was stable and no problems occurred during operation.

1.2.2 Dispersion model

In PC COSYMA the MUSEMET dispersion model is used. It is a segmented Gaussian plume model, where the wind speed, the wind direction, the Pasquill stability class and the rainfall rate for every hour can be given. In the MUSEMET dispersion model the release over a long time period can be defined. For this, the release is described by a series of hourly phases, where every phase is treated separately. Three different types of following the trajectory by the dispersing material can be selected. Horizontal and vertical dispersion parameters, which are functions of the atmospheric stability, are used in this model. The plume standard deviation has the form $\sigma = a \cdot x^b$, whereas a and b are coefficients and x is the distance in downwind.
It can be differed between smooth and rough underlying surface, whereas in the rough parameter set different rates of plume growth can be assumed for different

release heights. Building effects and down wash are also treated in this model. The half-life information of radioactive decay is based on information from ICRP-38.

1.2.3 Dose calculation

If radioactive material is released to the atmosphere, different paths (routes) contribute to the irradiation of persons. This paths are external γ-irradiation from material in the cloud and deposited material on the ground, external β-irradiation from deposited material on skin and clothing, internal irradiation from inhalation of cloud or re-suspended material and internal irradiation after ingestion of contaminated food.

The external γ-irradiation from material in the cloud, the external β-irradiation from deposited material on skin and clothing and the internal irradiation from inhalation of cloud material only affect to persons, who are direct deferred to the plume. The external γ-irradiation from cloud material is important as long as the plume is present, the external β-irradiation from deposited material on skin and clothing stops after removing of the material and the duration of internal irradiation from inhalation depends on the half-life of inhaled nuclides.
The external γ-irradiation from deposited material on the ground, the internal irradiation from inhaled re-suspended material and the internal irradiation after ingestion of contaminated foodstuff can be present for long time.

External exposure pathways

In external exposure pathways the γ-irradiation from material in the plume, the γ-irradiation from material on the ground and the β-irradiation from deposited material on skin and clothes are treated.
The **external γ-dose from material in the plume** is calculated by multiplying the time integrated air concentration with the cloud γ-dose per unit air concentration (library). The cloud γ-dose per unit air concentration is based under the assumption of a semi-infinite, uniform concentrated plume. In the atmospheric dispersion module, correction factors of plume shape and plume size are derived.
The **external γ-dose from deposited material** is calculated by multiplying

the amount of deposited material with the dose per unit deposition. The dose per unit deposition at a series of time includes the contribution of daughter products, which are formed after deposition, and is provided as a library with the system.
The **β-dose to skin from material deposited on skin and clothes** depends on the amount of deposited material, the length of time and the dose per unit deposit. The deposition on skin is defined with a user defined factor times the dry deposited material on the ground. The length of time can be set by the user with an effective half life. Only dose from skin which is not covered by clothing is treated.

Internal exposure pathways

Internal exposure pathways are inhalation of material in the plume, inhalation of re-suspended material and ingestion.
The dose from **inhalation of material from the plume** is calculated by multiplying the time integrated air concentration, the breathing rate and the dose per unit activity inhaled. The dose per unit activity inhaled is provided by a data library with the system.
The dose from **inhalation of re-suspended material** is calculated by multiplying the time integrated air concentration, the breathing rate and the dose per unit activity inhaled. The air concentration of re-suspended material at a specific time after deposition is calculated in PC COSYMA with a re-suspension factor $R = a \cdot e^{-b \cdot t} + c$, where a,b and c are parameters and t is the time since deposition.

1.2.4 Calculation of health effects

PC COSYMA can derive the risk of health effects from the calculated dose. It can be differed between early health effects (deterministic effects) and late health effects (stochastic effects).

Early health effects

Early health effects are distinguished between fatal effects, which causes death and non fatal effects, which lead to severe disability or require continuous medical treatment for the rest of the life. In PC-COSYMA the probability for an individual to be affected is

$$r = 1 - e^{-H}$$

where

$$H = ln2 \left(\frac{D}{D_{50}}\right)^S .$$

The parameter D is the received dose in an appropriate period, D_{50} defines the dose which will cause the effect at 50% of all persons and s is a parameter to determine the slope in the dose-risk relationship. Experience has shown, that early effects only occur if an threshold, which can be set by the user, is exceeded. High dose rates are more effective for causing early health effects, than low dose rates. For this, the ratio D/D_{50} is replaced by the sum over doses delivered in different time periods with appropriate D_{50} and reads as

$$\frac{D}{D_{50}} = \sum_i \frac{D^i}{D^i_{50}}.$$

D^i is the received dose in the considered time period and D^i_{50} is the dose which causes the effect in 50% of the persons in the appropriate time period.
The variation of D_{50} with the dose rate is given with

$$D^i_{50} = D_\infty + \frac{D_0}{DR^i},$$

where D_∞ is the value of D_{50} at high dose rate, DR^i is the averaged dose rate over a period and D_0 is a parameter for the relationship.
The sensitivity of organs for high and low LET irradiation is different. In this model the high LET dose is multiplied with the Relative Biological Effectiveness (RBE), whereas different organs have different values of RBE.
The death from irradiation of bone marrow parameters are based on studies of persons exposed to the atomic bombs in Japan, the fallout in the Marshall islands and the Chernobyl accident. The parameters for exposure of the lung are based

on animal experiments. The risk of death from exposure of the skin is calculated under the assumption that 10% (hand and face) from the total body surface is burned (the parameters are from burns, which are not caused by radiation). In PC COSYMA is assumed that a specified fraction of the population will die from this burns.

Late health effects

The late health effects can be differed between fatal and non-fatal cancers in the exposed population and hereditary effects in their descendants. These effects have a linear relationship between dose and risk and do not have a threshold.
Radiation produces a risk of cancer. If this risk of cancer is independent of the natural cancer risk and is the same in all population for the same dose, an absolute risk model is assumed. If the risk of cancer caused by radiation depends on the natural cancer risk and increases this risk with a multiplication factor and is the same in all population for the same dose, a relative risk model is assumed.
Each model has advantages to describe some cancers and so both models are used in PC-COSYMA. The exposed population consists of persons with different age. Late effects may not appear for tens of years after exposure. So persons may die of other causes before the radiation effect occurs.
PC COSYMA calculates the risk of late health effects as dose multiplied with a risk coefficient.

Collective risks

The risk of an individual suffering a health effect is calculated at each grid point. The number of effects in the population at a grid point is the risk at the grid point multiplied with the population at that grid point. The total number of effects in the population is the sum up over all grid points. In this diploma theses only individual risks are treated.

1.3 Gaussian plume dispersion

This sub chapter is based on the dispersion theory of substances in the atmosphere in [8]. The atmospheric flow transports exhausted gases, radioactive nuclides or other pollutant with the mean wind field and through turbulence. It is possible to transport this contaminates perpendicular to the mean wind field, which is known as diffusion.
The diffusion equation to describe the spreading of a pollution with the concentration $\bar{c}$ in the atmosphere reads as

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}\frac{\partial \bar{c}}{\partial x} + \bar{v}\frac{\partial \bar{c}}{\partial y} + \bar{w}\frac{\partial \bar{c}}{\partial z} = \frac{\partial}{\partial x}K_x\frac{\partial \bar{c}}{\partial x} + \frac{\partial}{\partial y}K_y\frac{\partial \bar{c}}{\partial y} + \frac{\partial}{\partial z}K_z\frac{\partial \bar{c}}{\partial z} + \bar{P}_c, \qquad (1.1)$$

whereas $\bar{u}$, $\bar{v}$, $\bar{w}$ are wind speeds in x, y or z direction. The first term on the left side has the value 0 for steady state models and the remaining terms on the left side describe the transport by the mean wind (advection). The first three terms on the right side include the effect of turbulent diffusion and P_c is a source or a drain of the pollutant concentration. K is the "eddy diffusivity" and represents the intensity of turbulent motions and varies with stability of the atmosphere.

Continuous source point

At a continuous source point, a constant amount of material is released in time. If no transport from the source appears, the concentration will increase with time. A stationary state only appears, if material is transported from the source through a mean wind field and through turbulence. Some assumptions were made for a solution of the diffusion equation. A steady state concentration with $\frac{\partial c}{\partial t} = 0$ is assumed. The wind speed in x-axis is constant and the wind speed in y and z-axis is 0. Further is assumed that the turbulent diffusion coefficients are constant in space, which means $\frac{\partial K_x}{\partial x} = \frac{\partial K_y}{\partial y} = \frac{\partial K_z}{\partial z} = 0$. During the spread no pollutant is produced or annihilated. With this assumptions, formula 1.1 reads as

$$\bar{u}\frac{\partial \bar{c}}{\partial x} = K_x\frac{\partial^2 \bar{c}}{\partial x^2} + K_y\frac{\partial^2 \bar{c}}{\partial y^2} + K_z\frac{\partial^2 \bar{c}}{\partial z^2}. \qquad (1.2)$$

To get a solution of this equation, it is assumed, that

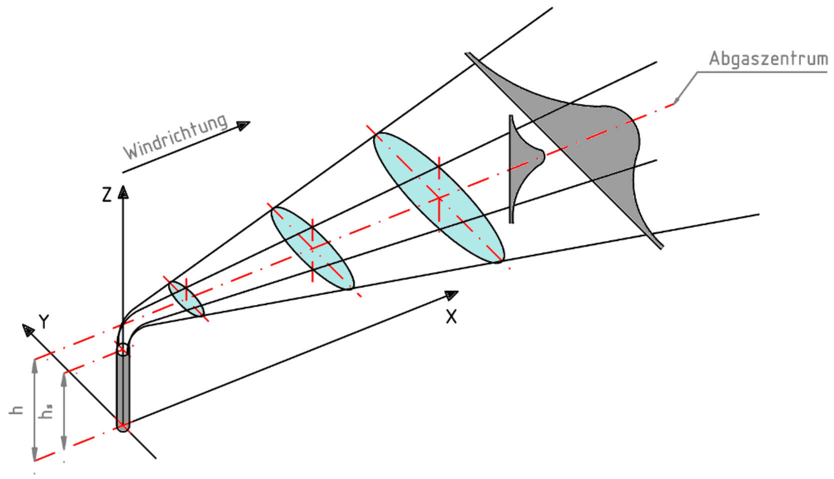
$$\left|K_x\tfrac{\partial^2 \bar{c}}{\partial x^2}\right| \ll \left|\bar{u}\tfrac{\partial \bar{c}}{\partial x}\right| \qquad (1.3)$$

which means, the advection of the concentration with the flux is much bigger than the diffusion in flux direction. With this assumption a diffusion only occurs in y and z-axis and the dispersion in x-axis only occurs from advection with the mean velocity $\bar{u}$.
The solution of the formula 1.2 with assumption 1.3 reads as

$$\bar{c}(x, y, z) = \frac{Q}{4\pi x\sqrt{K_y K_z}} e^{-\frac{\bar{u}}{4x}\left(\frac{y^2}{K_y}+\frac{(z-h)^2}{K_z}\right)}. \tag{1.4}$$

In this equation the position of the source lies at $x = 0$, $y = 0$ and $z = h$. Q is the source in kg/s and gives the amount of released pollutant in time.
The concentration has a two dimensional Gaussian curve distribution in y-z-plane for every distance x from the release point. At height $z = h$, the concentration decreases with distance from the release point. The plume spreads with x because of diffusion in y and z-direction. This behaviour is presented in figure 1.2.

Figure 1.2: Gaussian plume dispersion



In this figure the wind direction is along x-axis and the height of the stack is h_s.
If the exhaust gas has thermal energy, buoyancy occurs and a virtual stack height h, which is higher than the height of the chimney is used for evaluation.

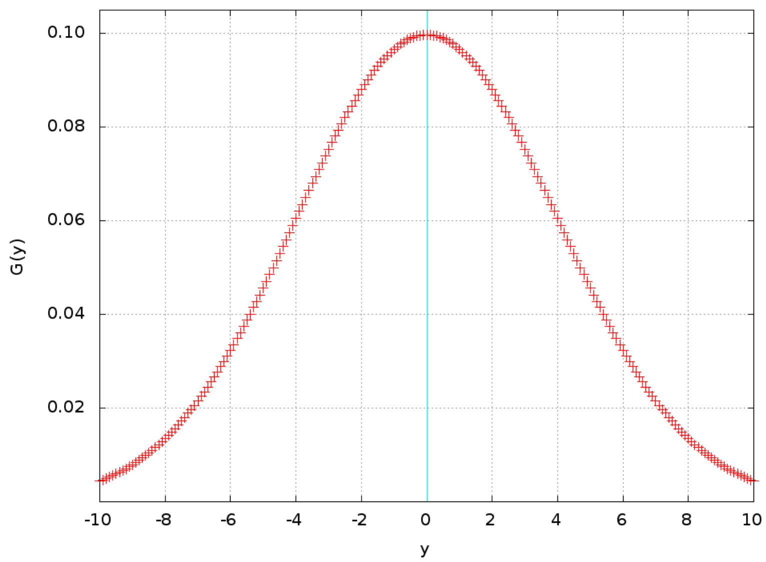
Gaussian curve

The Gaussian curve reads as

$$G(y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(y-y_0)^2}{2\sigma^2}}. \tag{1.5}$$

The fraction $\frac{1}{\sqrt{2\pi\sigma}}$ norms the Integral of $G(y)$ from $-\infty$ to $+\infty$ to a value of 1. If the integral boundary is taken from $-\sigma$ to σ a value of 0.683 is obtained, which means that 68.3% of the whole pollutant material is within a distance of $\pm\sigma$ from the plume dispersion axis. The concentration at $y = \pm\sigma$ has the factor $\frac{1}{\sqrt{e}}$ of the maximum concentration at y_0. A presentation of a Gaussian curve with $\sigma = 4$ see figure 1.3.

Figure 1.3: Standardized Gaussian curve with $\sigma = 4$



In case of a continuous point source, a two dimensional Gaussian curve appears, with different σ values in y and z-axis. After insertion of the transformation $K_y = \frac{1}{2}\sigma_y^2 \frac{u}{x}$ and $K_z = \frac{1}{2}\sigma_z^2 \frac{u}{x}$ into formula 1.4 , the new concentration formula reads as

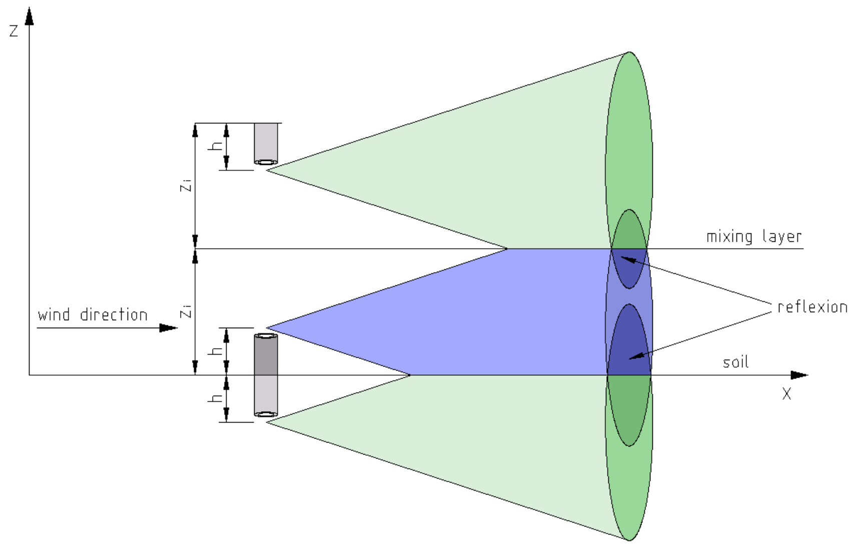
$$\bar{c}(x, y, z) = \frac{Q}{2\pi\bar{u}\sigma_y(x)\sigma_z(x)} e^{-\frac{y^2}{2\sigma_y^2(x)}} e^{-\frac{(z-h)^2}{2\sigma_z^2(x)}} \tag{1.6}$$

and is used in practice.

Consideration of soil and mixing layer

Equation 1.6 is valid for diffusion in 3-dimensional infinity space. To treat the dispersion in the real atmosphere, the soil and the mixing layer must be considered. The height of the release source is assumed with $z = h$. On ground ($z = 0$) and mixing layer ($z = z_i$) a reflection of the plume occurs (see figure 1.4).

Figure 1.4: Plume reflection on ground and mixing layer



For reflection on the ground a virtual mirror release at height $-h$ is used and for reflection at the mixing layer height a virtual mirror release at height $2 \cdot z_i - h$ is used (see figure 1.4). If this two virtual stacks are inserted in equation 1.6, it reads as

$$\bar{c}(x,y,z) = \frac{Q}{2\pi\bar{u}\sigma_y\sigma_z} e^{\left(-\frac{y^2}{2\sigma_y^2}\right)} \cdot \left(e^{-\frac{(z-h)^2}{2\cdot\sigma_z^2}} + e^{-\frac{(z+h)^2}{2\cdot\sigma_z^2}} + e^{-\frac{(z-2\cdot z_i+h)^2}{2\cdot\sigma_z^2}} \right). \tag{1.7}$$

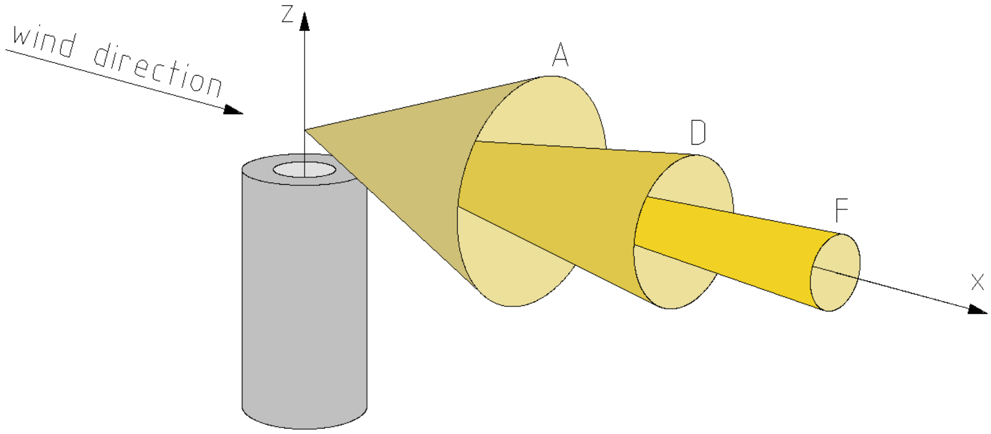
Practical use

Equation 1.7 has a few assumptions:

- the dispersion is temporal invariant (only one atmospheric condition)
- the dispersion is spatial invariant
- homogeneous rough of the surface on the earth
- no chemical or physical change of the pollutant
- horizontal transport of pollutant by advection
- reflection of the plume on soil and mixing layer

The inhomogeneity of the atmosphere is respect with experimentally determined dispersion parameters at different heights.

Figure 1.5: Plume behaviour with different atmospheric stabilities



As said before, σ_y and σ_z are dispersion coefficients in y-axis and z-axis. They depend on the behaviour of the atmosphere and are correlated to six Pasquill stability classes. The behaviour of Pasquill stability classes is presented in figure 1.5 (for better presentation only three classes are drawn). Pasquill stability class F describes a very stable atmosphere (night) and the spread of the plume is small. Pasquill stability class A describes a very unstable atmosphere (day) and the spread of the plume is large.

Example of Gaussian plume dispersion

To demonstrate the Gaussian plume dispersion, a release rate Q with $10g/s$, a release height at $20m$, a mixing layer height at $320m$, a wind speed of $1m/s$ and dispersions coefficients σ_y and σ_z for Pasquill stability class E (see table 3.6) were assumed. The wind direction lies in x-axis. The concentration of the pollutant was evaluated on a lattice in x-y-plane for different heights (z-axis). The lattice points were interpolated and presented in 3-dimensional form with gnuplot.
In figure 1.6 the pollutant concentration of the ground is presented. In figure 1.7, 1.8, 1.9, 1.10 and 1.11 the pollutant concentration in a height of 5m, 10m, 15m, 20m and 30m is presented. The treated size in every figure is 100m times 100m. The highest concentration occurs in a height of 20m, which corresponds the release height.

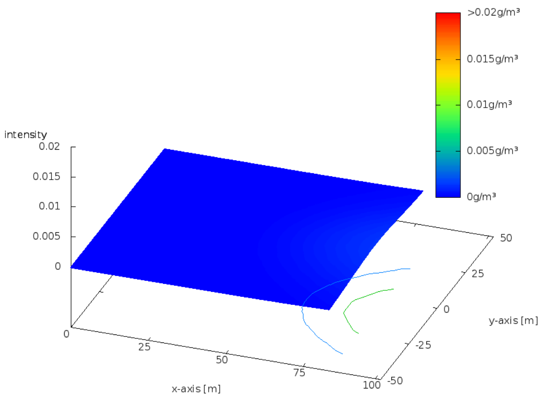


Figure 1.6: Pollutant concentration on the ground

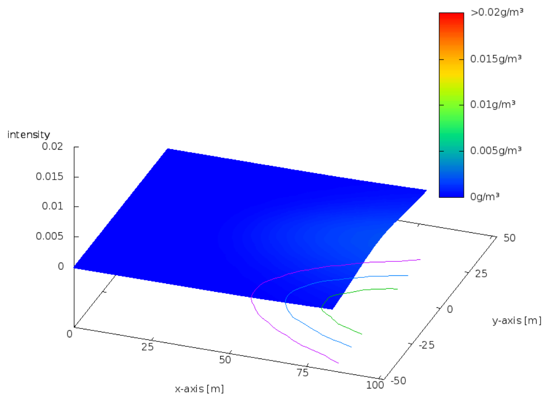


Figure 1.7: Pollutant concentration at $5m$

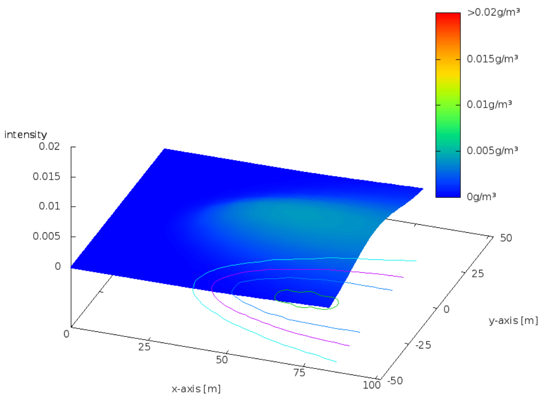


Figure 1.8: Pollutant concentration at $10m$

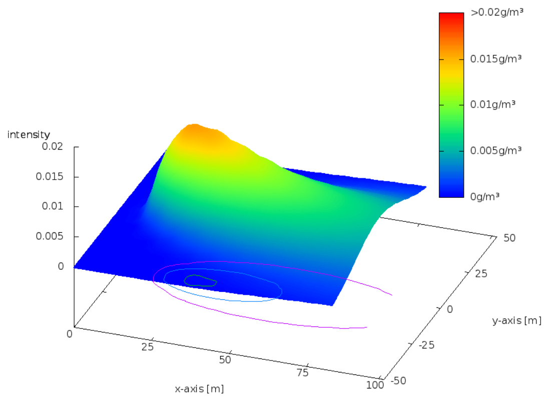


Figure 1.9: Pollutant concentration at $15m$

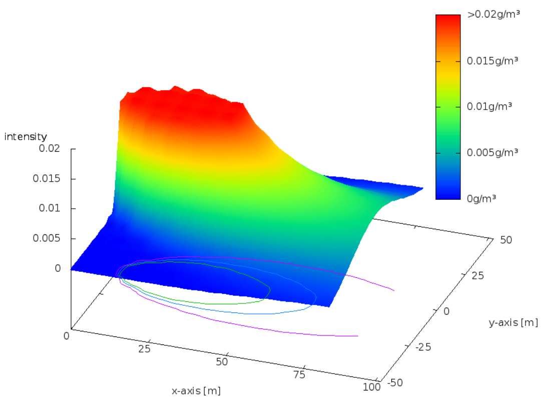


Figure 1.10: Pollutant concentration at $20m$

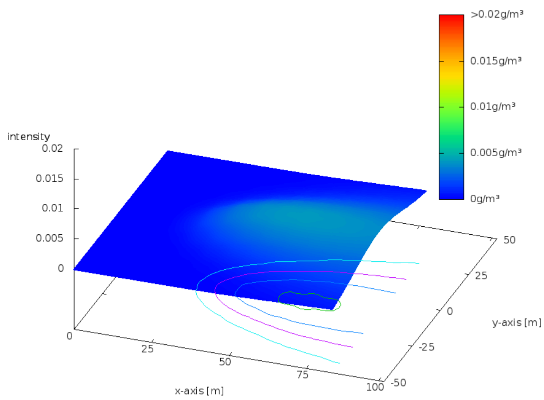


Figure 1.11: Pollutant concentration at $30m$

2 Weather data at the location

To get more information about the weather condition at the location, a weather station was installed. This was the Vantage Pro2 PlusTM Station model, manufactured by Davis Instruments[13]. The station was installed in a height of 13m above ground with sensors to determine the wind direction, wind speed, rain rate, solar radiation etc.
The measurement of wind direction, wind speed and rain rate started on April 3^{rd} at 03:00:00 PM and the measurement of solar radiation started on May 13^{th} at 12:40:00 PM, because the solar radiation detector was additionally installed. For analysis of the weather data, all measurements till June 15^{th} 09:50:00 AM were used.

2.1 Wind direction

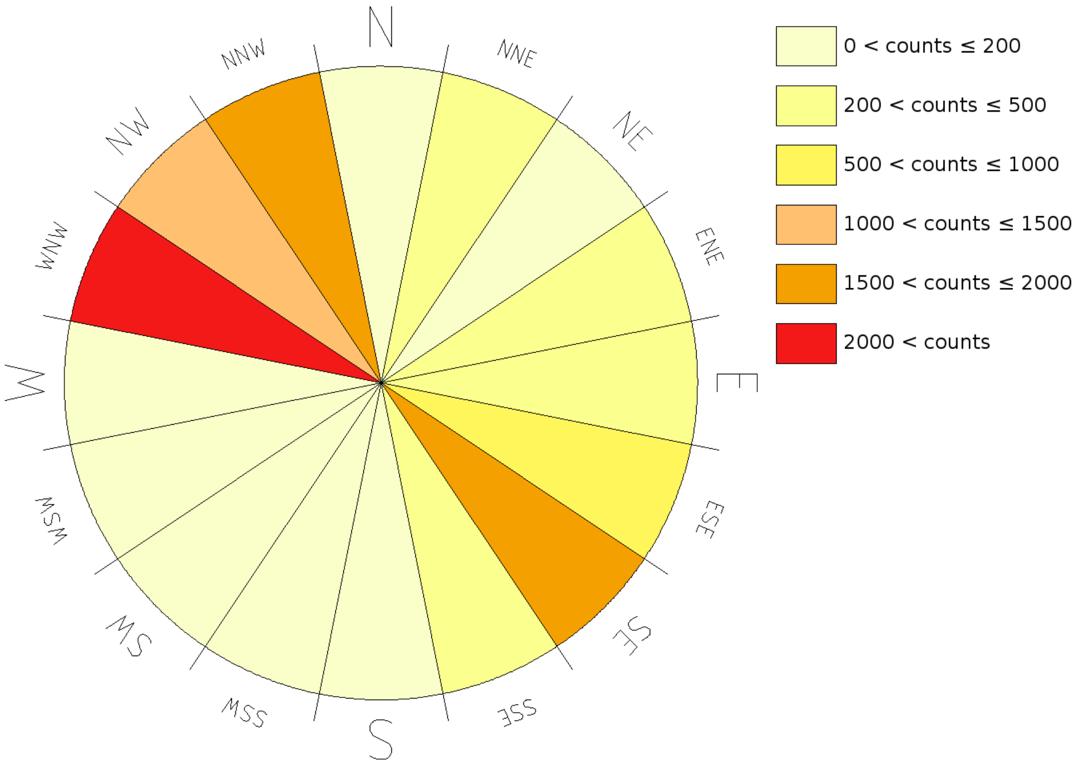
The wind direction was measured with an anemometer, which is part of the Integrated Sensor Suite of the weather station. The presentation of the direction occurs with a compass rose, whose resolution amounts 22.5 deg. The range of the compass rose amounts 16 compass pts with a nominal accuracy of ± 0.3 compass pts.[13] A 10 minute dominant wind direction was determined by the console. In table 2.1, the distribution of 10170 wind direction measurements is presented. For better presentation the counts are illustrated in figure 2.1. In 576 issues no mean value was presentable because the direction of the wind was to turbulent. The most occurred wind direction was WNW and this direction was used for deterministic scenarios.

wind direction	counts	wind direction	counts
N	127	S	109
NNE	379	SSW	36
NE	165	SW	39
ENE	405	WSW	48
E	438	W	129
ESE	892	WNW	2016
SE	1618	NW	1271
SSE	382	NNW	1540

no readout	576

Table 2.1: Distribution of 10170 wind direction measurements at the location

Figure 2.1: Distribution of 10170 wind direction measurements at the location



2.2 Wind speed

The wind speed was measured with an anemometer, which is part of the Integrated Sensor Suite of the weather station. The resolution of the wind speed amounts $0.5m/s$ with a range from $1m/s$ to $68m/s$ and nominal accuracy of $\pm 1m/s$[13]. A 10 minute average wind speed was calculated by the console. In table 2.2, the distribution of 10170 wind speed measurements is presented. Most measurements have a value between $1m/s$ and $2m/s$. For better presentation a distribution of integral round up measurement values is presented in figure 2.2.

wind velocity v [m/s]	**counts**	**wind velocity v [m/s]**	**counts**
$v = 0$	1353	$5 < v \leq 6$	530
$0 < v \leq 1$	1556	$6 < v \leq 7$	381
$1 < v \leq 2$	1787	$7 < v \leq 8$	196
$2 < v \leq 3$	1728	$8 < v \leq 9$	112
$3 < v \leq 4$	1250	$9 < v \leq 10$	12
$4 < v \leq 5$	1264	$10 < v \leq 11$	1

Table 2.2: Distribution of 10170 wind speed measurements at the location

2.3 Solar radiation

The solar radiation was measured with a solar radiation sensor, which was additionally installed on the weather station. The sensor measures the intensity of the sun's radiation, which reaches the horizontal surface. This irradiation can be differed between direct irradiation from the sun and reflected irradiation from the rest of the sky. The resolution of the solar radiation sensor amounts $1W/m^2$ with a range from $0W/m^2$ to $1800W/m^2$ and has nominal accuracy of $\pm 5\%$ of full scale.[13] A 10 minute average solar radiation was calculated by the console. In

Figure 2.2: Distribution of 10170 wind speed measurements at the location

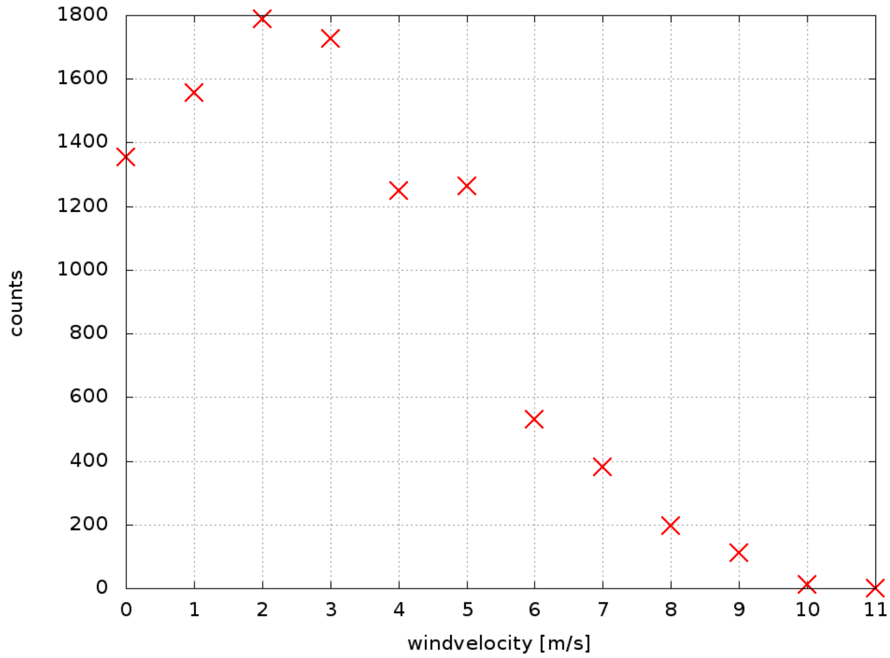


table 2.3 the distribution of 4424 solar radiation measurements is presented. 1580 values had $0W/m^2$ and appropriate night-time. Most of the counts were measured between $0W/m^2$ and $100W/m^2$. For better presentation the values were round up to the next 10^2-number and are distributed in figure 2.3.

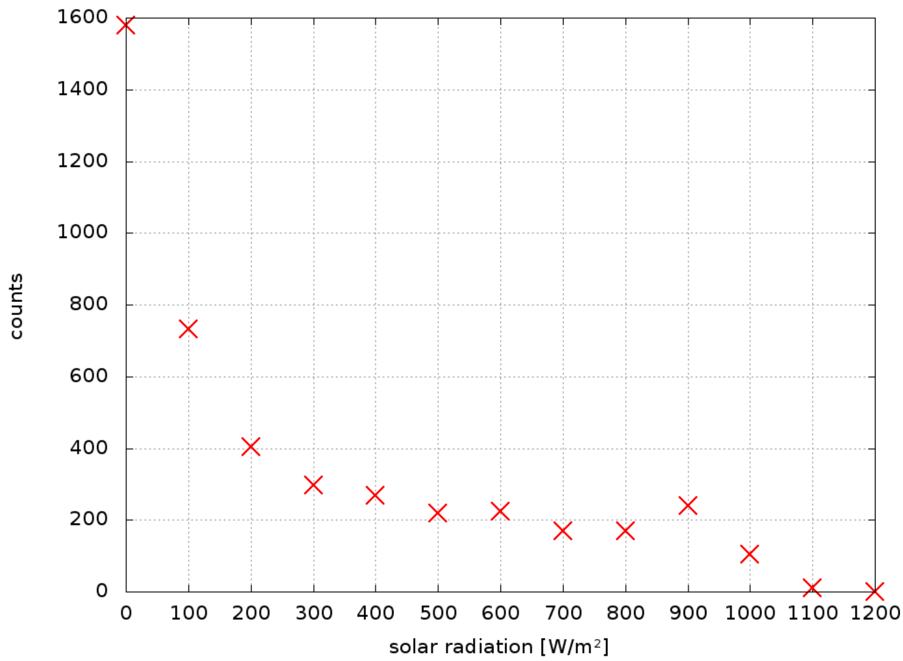
2.4 Pasquill stability classes

The Pasquill stability classes were determined for 4424 measurements. For that assignment, the wind speed and the solar radiation were used.[10] As said before, the solar radiation sensor only measures the irradiation in the daytime and cannot measure the irradiation by night. 2844 measurements of the solar radiation had a value higher than $0W/m^2$ (daytime). For that measurements it is no problem to correlate them to the corresponding Pasquill stability class A, B, C or D. In table 2.4 the distribution of the Pasquill stability classes A, B, C and D for different

solar radiation R $[W/m^2]$	**counts**	**solar radiation R** $[W/m^2]$	**counts**
$R = 0$	1580	$600 < R \leq 700$	170
$0 < R \leq 100$	731	$700 < R \leq 800$	170
$100 < R \leq 200$	403	$800 < R \leq 900$	241
$200 < R \leq 300$	298	$900 < R \leq 1000$	105
$300 < R \leq 400$	269	$1000 < R \leq 1100$	11
$400 < R \leq 500$	220	$1100 < R \leq 1200$	1
$500 < R \leq 600$	225		

Table 2.3: Distribution of 4424 solar radiation measurements at the location

Figure 2.3: Distribution of 4424 solar radiation measurements at the location



wind speeds is given (daytime).
1580 measured values had a solar radiation of $0W/m^2$. Measurements with $0W/m^2$ can be referred to Pasquill stability class D, if they have a wind speed higher than $5m/s$. This condition was fulfilled by 53 measurements. Measurements with $0W/m^2$ and a wind speed lower than $5m/s$ belong to Pasquill stability class E or F. This condition was fulfilled by 1527 measurements. It is not possible to differ them with the installed sensors. In table 2.5 the distribution of the Pasquill stability classes D, E or F for different wind speeds is given (night-time).

wind velocity v	**counts**				
$[m/s]$	**A**	**B**	**C**	**D**	
$v = 0$	7	11	21	42	
$0 < v \leq 1$	103	19	43	87	
$1 < v \leq 2$	254	51	71	94	
$2 < v \leq 3$	318	104	99	100	
$3 < v \leq 4$	253	83	141	98	
$4 < v \leq 5$	194	82	182	70	
$5 < v \leq 6$	0	102	54	16	
$6 < v \leq 7$	0	49	32	13	
$7 < v \leq 8$	0	0	28	5	
$8 < v \leq 9$	0	0	16	2	
$9 < v \leq 10$	0	0	0	0	
$v \geq 10$	0	0	0	0	
	$\sum 1129$	$\sum 501$	$\sum 687$	$\sum 527$	$\sum 2844$

Table 2.4: Pasquill stability class distribution of 4424 measurements at the location (daytime)

wind velocity v	**counts**		
$[m/s]$	**D**	**E or F**	
$v = 0$	0	389	
$0 < v \leq 1$	0	350	
$1 < v \leq 2$	0	263	
$2 < v \leq 3$	0	287	
$3 < v \leq 4$	0	151	
$4 < v \leq 5$	0	87	
$5 < v \leq 6$	23	0	
$6 < v \leq 7$	18	0	
$7 < v \leq 8$	5	0	
$8 < v \leq 9$	6	0	
$9 < v \leq 10$	1	0	
$v \geq 10$	0	0	
	$\sum 53$	$\sum 1527$	$\sum 1580$

Table 2.5: Pasquill stability class distribution of 4424 measurements at the location (at night)

2.5 Rain rate

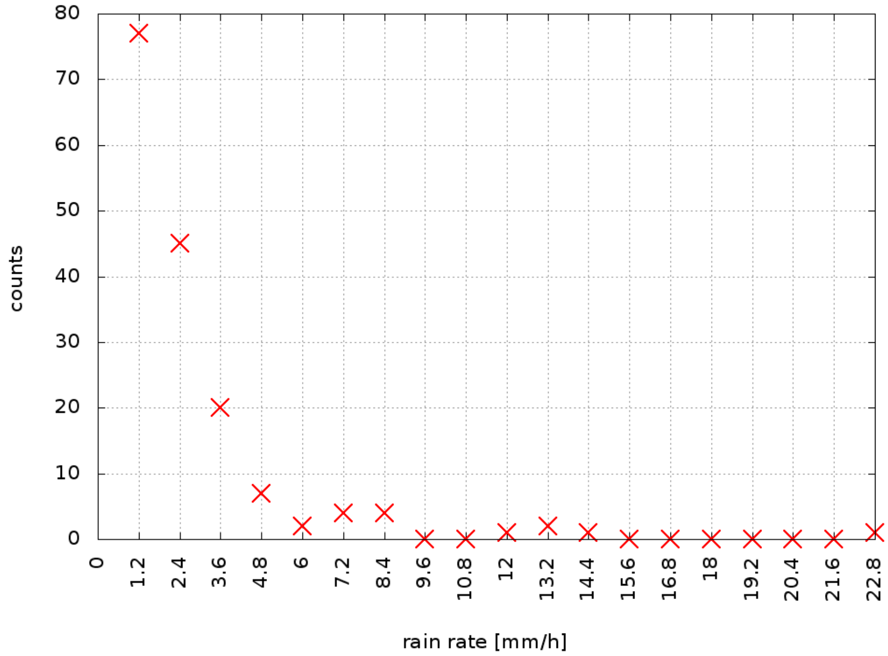
The rain rate was measured with a tipping-bucket rain collector, which is part of the Integrated Sensor Suite of the weather station. The resolution of the rain rate amounts $0.2mm$ (metric adapter) with a range up to $1999.9mm/h$ and has nominal accuracy of $\pm 1mm/h$.[13] In table 2.6 the distribution of the rain rate is presented for 10170 measurements. For 10006 measurements no rain was detected, which means no rain occurred or the rain rate was under the resolution of the sensor. This was by far the most performed behaviour. An other presentation of the rain

rain rate [mm/10min]	**rain rate [mm/h]**	**counts**	**rain rate [mm/10min]**	**rain rate [mm/h]**	**counts**
0	0	10006	1.2	7.2	4
0.2	1.2	77	1.4	8.4	4
0.4	2.4	45	2	12	1
0.6	3.6	20	2.2	13.2	2
0.8	4.8	7	2.4	14.4	1
1	6	2	3.8	22.8	1

Table 2.6: Distribution of 10170 rain rate measurements at the location

rate distribution is given in diagram 2.4 (for better presentation only rain rates higher than $0mm/h$ were treated).

Figure 2.4: Distribution of 10170 rain rate measurements at the location (for better presentation only rain rates higher than $0mm/h$ were treated)



3 Used parameters for deterministic scenarios

In this section all parameters are listed, which are equal for all scenarios. The parameters which are specific for appropriate scenarios are listed in the result chapter of each scenario.

3.1 Basic parameters

In this work, only radionuclide concentrations, individual dose and individual risks are treated. A list of used endpoints is presented in table 3.1[1]. The short term individual dose is calculated after one day. Countermeasures and ingestion are not treated in the scenarios.

3.2 Temporary change of atmospheric conditions

The time resolution of atmospheric conditions in PC COSYMA is one hour. It is possible to save the wind direction, the wind speed, the Pasquill stability class, the rain rate and the mixing layer height of every hour for one or two years in a file.
A temporal change of atmospheric conditions is only used in probabilistic consideration. In deterministic consideration, only one atmospheric condition occurs.[1]

radionuclide concentrations	yes
short term individual dose (after 1 day)	yes
long term individual dose	yes
short term individual risks	yes
long term individual risks	yes
short term collective health effects	no
long term collective dose	no
long term collective health effects	no
economic consequences	no

Table 3.1: Used endpoints for deterministic consideration

3.3 Plume Dispersion

The program PC COSYMA is constructed by the Gaussian plume model and the most important factor of plume dispersion is the behaviour of the atmosphere. This behaviour can be defined with lots of different models. PC COSYMA uses

	A	**B**	**C**	**D**	**E**	**F**
behaviour of the atmosphere	very labile	labile	neutral till light labile	neutral till light stable	stable	very stable

Table 3.2: Classification of the Pasquill stability classes

the model of Pasquill stability classes, which differs six stabilities of the atmosphere between very labile (A) and very stable (F). The classification of them see table 3.2[10].

There are three different options to determine the Pasquill stability class. The first option depends on cloudiness and wind speed. If the wind speed is measured and the cloudiness is determined, the belonging Pasquill stability class can picked out from table 3.3[10]. A high solar radiation (few clouds) leads to a labile Pasquill

wind speed $[\frac{m}{s}]$	**day**			**night**	
	solar radiation			**radiation**	
	strong	**middle**	**light**	**light**	**strong**
				cloudiness	
				greater than $\frac{3}{8}$	**less than** $\frac{3}{8}$
$0 \leq \bar{u} < 2$	A	A-B	B	(E-F)	(F)
$2 \leq \bar{u} < 3$	A-B	B	C	E	F
$3 \leq \bar{u} < 5$	B	B-C	C	D	E
$5 \leq \bar{u} < 6$	C	C-D	D	D	D
$6 \leq \bar{u}$	C	D	D	D	D

Table 3.3: Definition of the Pasquill stability class from wind speed and cloudiness

stability class. A low solar radiation (many clouds) leads to a stable Pasquill stability class. In the night, the stability class is predominantly stable because of the absence of solar radiation.

The second option to determine the Pasquill stability class is to pick it out of a diagram with wind speed in x-axis and solar radiation in y-axis.[10] This is the option, which is used in this work after measuring the wind speed and the solar radiation with the weather station.

A further option to determine the Pasquill stability class is to pick it out of a diagram with wind speed in x-axis and temperature gradient in y-axis.[10] The problem in this case is the difficulty to determine the temperature gradient of the atmosphere for every hour.

If the plume reaches the ground or the height of the mixing layer, it will be

	A	**B**	**C**	**D**	**E**	**F**
height of the mixing layer in m	1600	1200	800	560	320	200

Table 3.4: Heights of the mixing layer for each stability class

reflected. Every atmosphere condition has its own mixing layer height. For the location at the Atomic Institute, no data of mixing layer heights were available and it is difficult to determine them, on top of that for every hour. So the standard mixing layer heights from PC COSYMA were taken for each stability class (see table 3.4[1]). This is no problem, because the influence of the mixing layer height to the dose is negligible for the four scenarios.

In PC COSYMA it is possible to choose the roughness of the surface between

	A	**B**	**C**	**D**	**E**	**F**
wind profile exponent p	0.07	0.13	0.21	0.34	0.44	0.44

Table 3.5: Wind profile exponent for each stability class

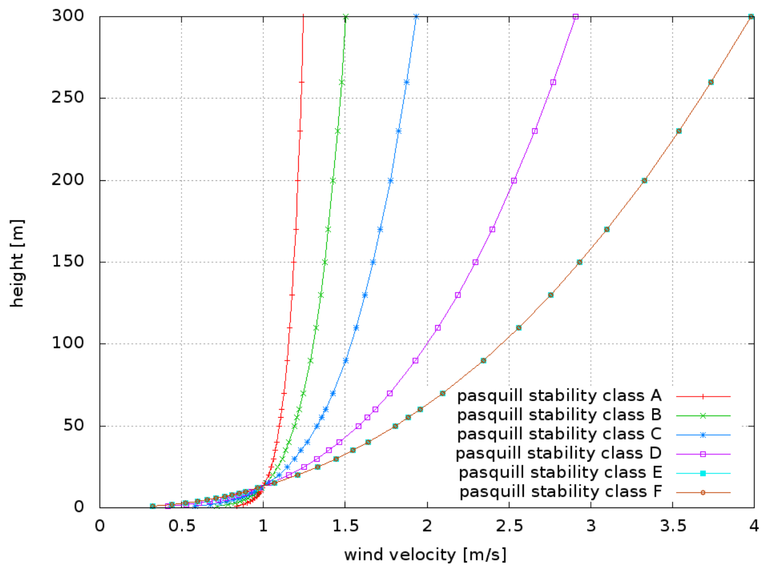
rough terrain and smooth terrain.[1] This are two different models included in the software package. The rough terrain was developed for throatiness greater than one meter. In this work the rough terrain model was taken, because of the area around the reactor.

Each Pasquill stability class has its own wind profile, which is defined as

$$u_{(z)} = u_{(z=z_0)} \cdot \left(\frac{z}{z_0}\right)^p .$$

With this formula the wind speed in an arbitrarily height z can be calculated, if the wind speed in a height z_0 is known. In this work z_0, which is the height of the installed weather station, has a value of $13m$. The only parameter in the wind profile formula, which depends on the Pasquill stability class, is the wind profile exponent p. In this work the standard values from PC COSYMA were used, because no better values for the Atomic Institute were available and it is not expected to change the values by the user.[1] In table 3.5[1], a list of used wind profile exponents for each Pasquill stability class is presented. The wind speed profiles (of each Pasquill stability class) with a wind speed of $1m/s$ in $13m$ height are presented in diagram 3.1.

Figure 3.1: Wind profile for different Pasquill stability classes



For further calculation, the Pasquill stability classes must be converted into mathematical dispersion coefficients. For this, the Pasquill stability classes are expressed with σ parameters. Every Pasquill stability class consists of two σ parameters, one for height (plume dispersion in z-axis) and one for lateral spread (plume dispersion in y-axis), if the downwind direction lies in x-axis. The formula for σ_y reads as

$$\sigma_y = a \cdot x^b.$$

It consists of a linear coefficient, an exponential coefficient and depends on downwind distance (the downwind direction lies in x-axis). The formula for σ_z has the same form (different parameters) and reads as

$$\sigma_z = a \cdot x^b.$$

In table 3.6[1, 6] the linear and the exponential coefficients of the σ_y and σ_z parameters are presented for all Pasquill stability classes at heights of 50m, 100m and 180m. This are the standard values of PC COSYMA and were used in this work. In figure 3.2 and 3.3 the behaviour of σ_y and σ_z in $50m$ height is presented. Figure 3.4 and 3.5 shows the behaviour of σ_y and σ_z in $100m$ height, figure 3.6

		50m	**100m**	**180m**
A	linear σ_z coefficient	0.15	0.05	0.03
	exponential σ_z coefficient	1.22	1.32	1.5
	linear σ_y coefficient	1.5	0.17	0.67
	exponential σ_y coefficient	0.83	1.3	0.9
B	linear σ_z coefficient	0.13	0.07	0.03
	exponential σ_z coefficient	1.11	1.15	1.32
	linear σ_y coefficient	0.88	0.32	0.42
	exponential σ_y coefficient	0.82	1.03	0.9
C	linear σ_z coefficient	0.17	0.14	0.1
	exponential σ_z coefficient	1	0.99	1
	linear σ_y coefficient	0.66	0.47	0.23
	exponential σ_y coefficient	0.81	0.87	0.9
D	linear σ_z coefficient	0.22	0.27	0.31
	exponential σ_z coefficient	0.89	0.82	0.73
	linear σ_y coefficient	0.64	0.5	0.21
	exponential σ_y coefficient	0.78	0.82	0.9
E	linear σ_z coefficient	0.26	0.49	0.55
	exponential σ_z coefficient	0.77	0.65	0.56
	linear σ_y coefficient	0.8	0.41	0.35
	exponential σ_y coefficient	0.75	0.88	0.9
F	linear σ_z coefficient	0.24	0.72	0.49
	exponential σ_z coefficient	0.66	0.49	0.5
	linear σ_y coefficient	1.29	0.25	0.67
	exponential σ_y coefficient	0.72	1.06	0.9

Table 3.6: Linear coefficient and exponential coefficient for σ_y and σ_z of all Pasquill stability classes at 50m, 100m and 180m height

Figure 3.2: Behaviour of σ_y for each Pasquill stability class at 50m height

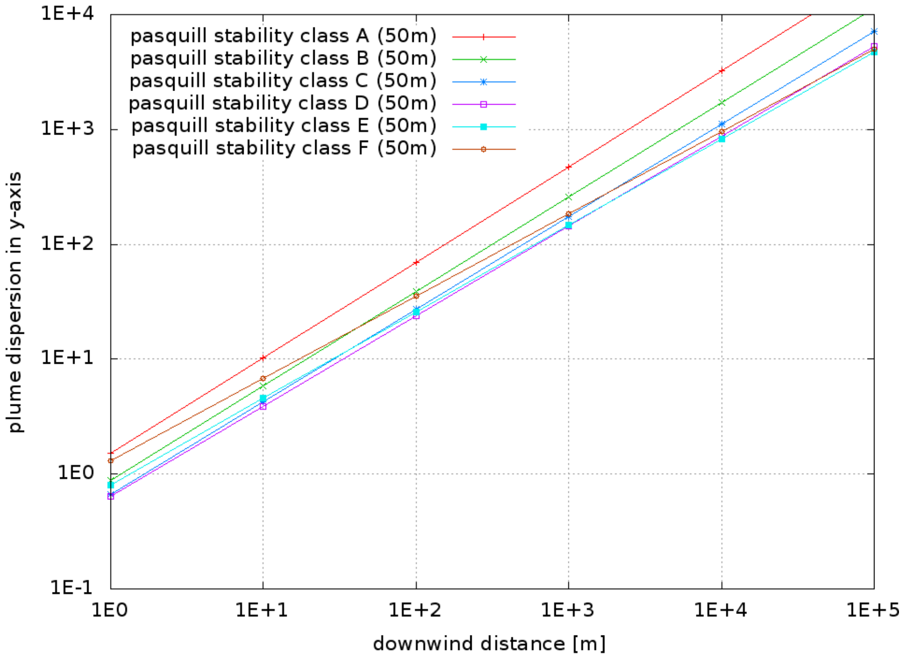


Figure 3.3: Behaviour of σ_z for each Pasquill stability class at 50m height

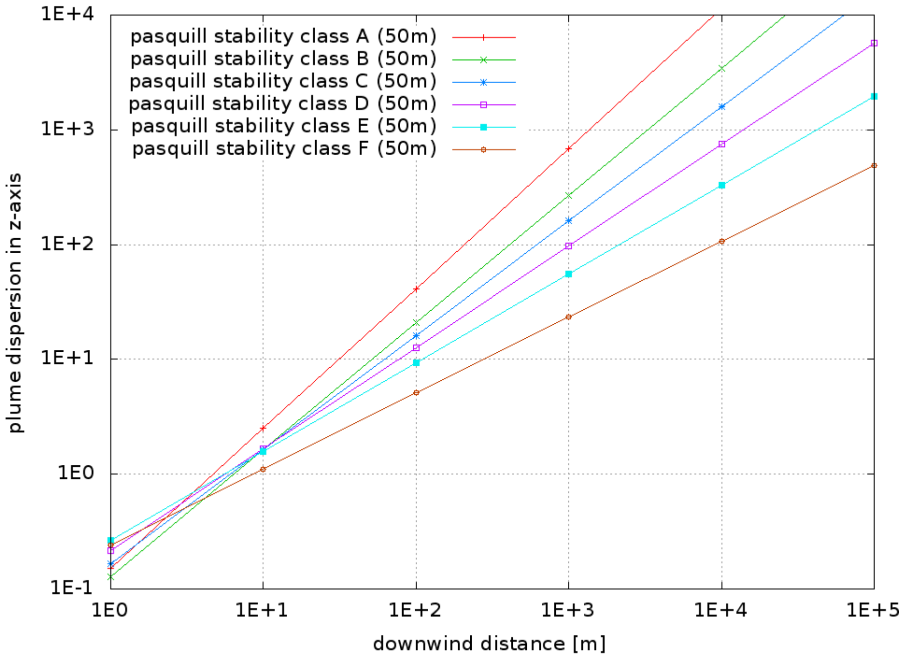


Figure 3.4: Behaviour of σ_y for each Pasquill stability class at 100m height

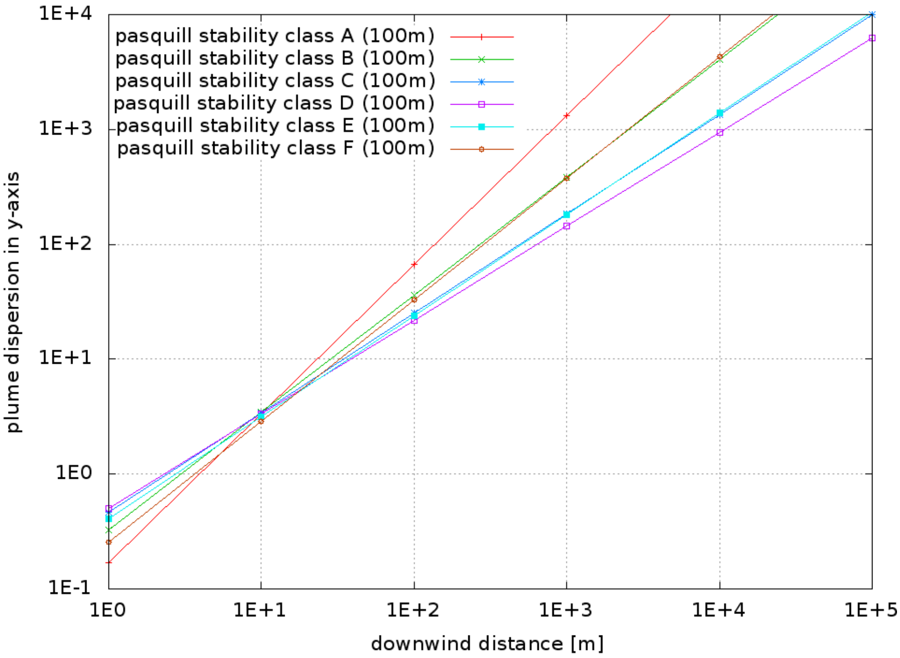


Figure 3.5: Behaviour of σ_z for each Pasquill stability class at 100m height

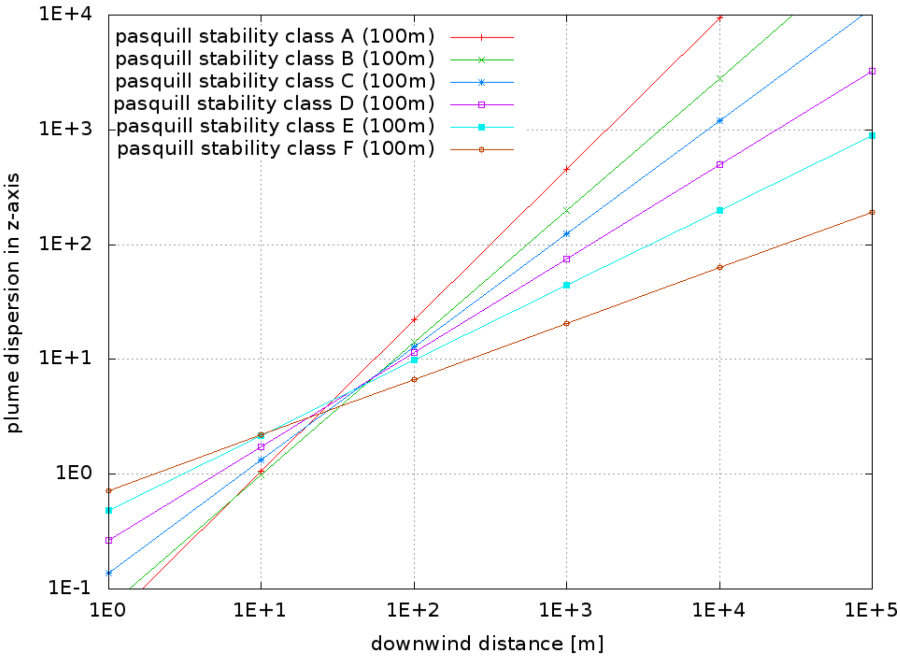


Figure 3.6: Behaviour of σ_y for each Pasquill stability class at 180m height

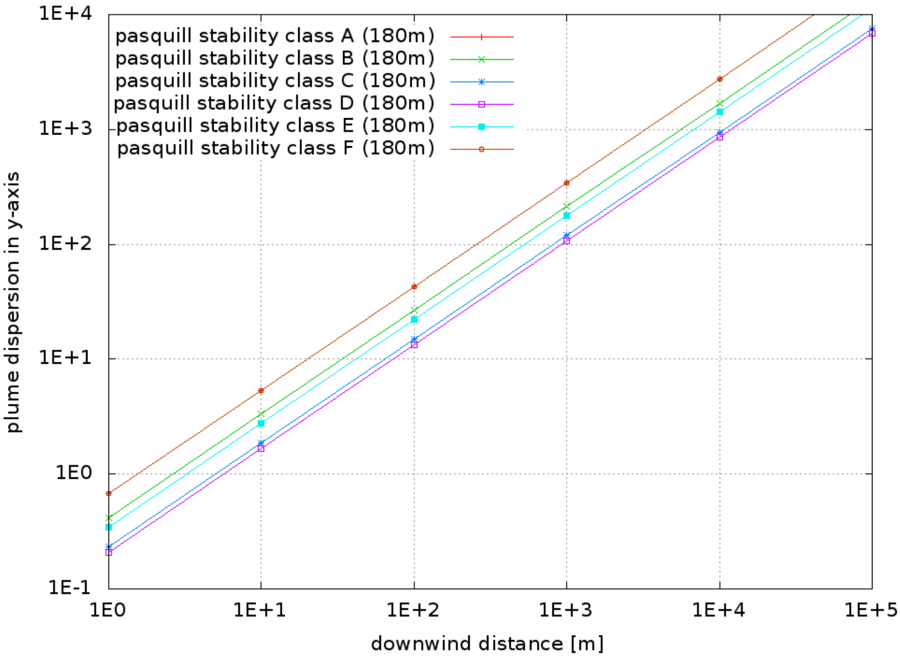
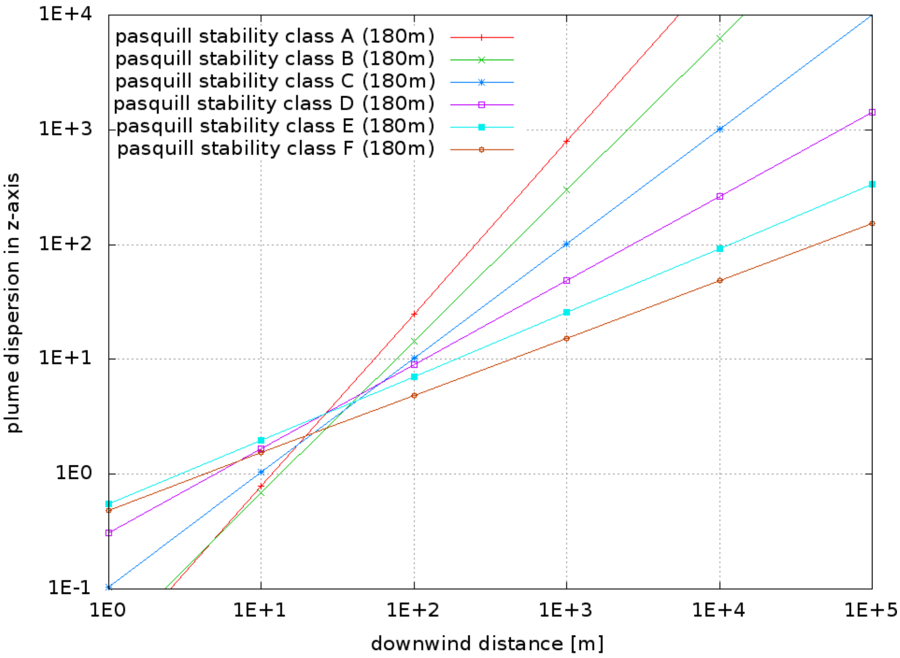


Figure 3.7: Behaviour of σ_z for each Pasquill stability class at 180m height



and 3.7 presents the behaviour of σ_y and σ_z in $180m$ height.
The PC COSYMA standard values of horizontal standard deviation are presented in table 3.7[1]. These parameters are not relevant for deterministic treatment, because these parameters are used to determine the amount of along-wind plume spread at points, where the plume trajectory changes its direction.

	50m	**100m**	**180m**
A	23.8°	20.5°	20.5°
B	18.9°	13.9°	13.9°
C	15.3°	10.1°	10.1°
D	12.6°	6.9°	6.9°
E	10.2°	4°	4°
F	8.6°	2°	2°

Table 3.7: Horizontal standard deviation in degrees

3.4 Deposition of radioactive nuclides

The deposition of atmospheric pollution is the most important factor to clean the atmosphere.[7] It will be differed between dry and wet deposition according as rain is included or not.

Dry deposition theory

This sub chapter is based on dry deposition theory in [7]. In the free atmosphere, tracers will be transported vertically to the soil, plants or artificial surfaces. This transportation can be described in the same way as the Ohmic law. A resistance R can be defined, which reads as

$$R = R_a + R_b + R_c,$$

whereas R_a defines the resistance of the near-ground free atmosphere, which depends on wind speed, rough of the soil and thermic stability. R_b defines the re-

sistance against the vertical transport through molecular diffusion of the laminar air, which has thickness of about $1mm$, over surfaces. R_c depends on the chemical and physical properties of the surface (structure of the surface, pH-value etc.).
Driving force of air agitation is the gradient wind. By friction on surfaces, the air agitation get smaller and a vertical wind profile arises. Thus turbulences occur and a vertical exchange of particles appear. The aero dynamical turbulence is superimposed with the thermic turbulence which origins from convective motion of the air.
Further on deposit processes by sedimentation through the gravity for particles bigger than $10\mu m$ and the impaction caused by inertial force for particles bigger than $1\mu m$ occur. An other form of deposition is the interception of tracers by horizontal flowing air through vegetation or buildings.
The formula for the deposition flux reads as

$$F = \frac{c(z)}{R},$$

where $c(z)$ is the concentration in the reference height of the free atmosphere over the surface. It is very different to determine the resistance, whereas the deposition velocity, which reads as

$$v_D = \frac{1}{R},$$

is used. The deposition velocity depends on atmospheric stability, rough of the surface etc.

Wet deposition theory

This sub chapter is based on wet deposition theory in [7]. Wet deposition is the amount of atmospheric tracers, which are deposited with rain on the surface per time and area with a rain intensity greater than $0,1mm/h$. Humid deposition is the deposition for slight rain (smaller than $0,1mm/h$), dew, dewdrops or overlying clouds. Wet deposition differs between rain out (in-cloud-scavenging) and wash out (below-cloud-scavenging). Rain out consists of all processes in the cloud from condensing of the droplet till rain out from the cloud. Wash out consists of the apposition of tracers on the droplet during its fall. Under assumption that wet deposition removes tracers non-reversible, a wash out coefficient λ can be introduced and a formula for the concentration reads as

$$c_g = c_{g(t=0)} e^{-\lambda t}, \tag{3.1}$$

which is comparable with the radioactive decay law. c_g defines the concentration of the tracer in gaseous phases. The wash out coefficient λ depends on the distribution of the droplet size, the fall velocity of the droplets and the capture of the cross section. For aerosols, it also depends on the size distribution of them.

Used parameters

The released nuclides are differed in PC COSYMA into four idealized groups.[1] These four groups are noble gases, aerosols, elemental bound iodine and organic bound iodine, whereas noble gases only spread with the plume. For the three other groups, the parameters for dry deposition as well as wet deposition can be set by the user. In this work the default values of PC COSYMA were used because no better values for the location exist. That is no problem, because the influence on a change of the parameters is very small respectively negligible in the calculated scenarios. The default values of PC COSYMA were derived from empiric measurements of different releases in the past. In table 3.8[1] all deposition parameters for aerosols, elemental bound iodine and organic bound iodine are listed.

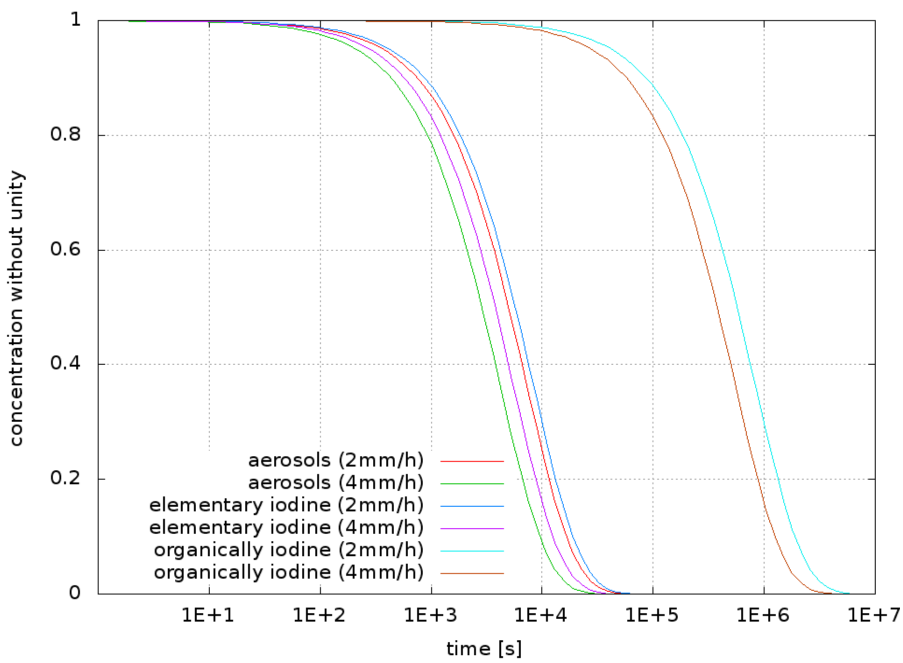
The formula for dry deposition in PC COSYMA reads as $F = c \cdot v$, where F is the flux density, c is the concentration and v is the deposition velocity of the respective group of nuclides.[1] With a correction factor, the default deposition velocity can be scaled. The formula for the washout coefficient in PC COSYMA reads as $\lambda = a \cdot R^b$, where R is the rain rate, a is a constant coefficient and b is an exponential coefficient.[1]

In figure 3.8, the change of concentration with time for aerosols, elementary bound iodine and organically bound iodine with different rain rates (2mm/h and 4mm/h)

aerosols	dry deposition velocity [m/s]	0.001
	dry deposition correction factor	1
	wet deposition coefficient a	8.0E-05
	wet deposition coefficient b	0.8
elementary bound iodine	dry deposition velocity [m/s]	0.01
	dry deposition correction factor	1
	wet deposition coefficient a	8.0E-05
	wet deposition coefficient b	0.6
organically bound iodine	dry deposition velocity [m/s]	5.0E-004
	dry deposition correction factor	1
	wet deposition coefficient a	8.0E-07
	wet deposition coefficient b	0.6

Table 3.8: Used deposition parameters for aerosols, elementary iodine and organically bound iodine

Figure 3.8: Decrease of concentration by wet deposition with time



is presented. For this diagram the wash out coefficients of each group (different rain rates) were inserted in formula 3.1.
In the safety report[12], all scenarios were evaluated without rain and thus no wet deposition is needed for them. Wet deposition parameters were used for evaluations in the Appendix with rain rates greater than $0mm/h$.

3.5 Definition of the source

The fission products of each fuel element were evaluated with ORIGEN[16]. For the calculation in the safety report[12] scenarios, only noble gases and halogens were considered, because these nuclides are volatile enough (noble gases are more volatile than halogens) to release from the fuel to the ventilation system and further on into the atmosphere. The noble gases are primarily for the gamma submission dose and the halogens are primarily for the thyroids dose responsible.[12] In this work only radioactive nuclides with a half live greater than 14.1 minutes were considered. The noble gases helium, neon, argon and radon were not evaluated in ORIGEN[16]. This means, the only considered noble gases were krypton and xenon. The halogens fluorine, chlorine and astatine were not evaluated in ORIGEN[16]. Bromine is not considered in PC COSYMA. This means, the only treated halogen was iodine. In table 3.9[20], the half life and the decay constants are presented for all treated nuclides. To demonstrate the decay of different nuclides, the whole core inventory from table 4.5 was taken. In figure 3.9, 3.10 and 3.11 the decay of the krypton, xenon and iodine core inventory is presented with time.

If a fuel element bursts, only a fraction of the whole fission product inventory is released. To define the fraction of the released halogens and noble gases the formula[17]

$$w_i = e_i \cdot f_i \cdot g_i$$

was used, where e_i defines the fraction of fission products, which migrate into the gap between fuel and fuel element cladding. f_i defines the fraction of fission products, which migrate from the gap between fuel and fuel element cladding into

	half-life	**half-life [s]**	**decay constant**
Kr-83m	1.83 h	$6.59 \cdot 10^3$	$1.05 \cdot 10^{-4}$
Kr-85m	4.48 h	$1.61 \cdot 10^4$	$4.30 \cdot 10^{-5}$
Kr-85	10.76 a	$3.39 \cdot 10^8$	$2.04 \cdot 10^{-9}$
Kr-87	76.3 m	$4.58 \cdot 10^3$	$1.51 \cdot 10^{-4}$
Kr-88	2.84 h	$1.02 \cdot 10^4$	$6.78 \cdot 10^{-5}$
I-129	15700000 a	$4.95 \cdot 10^{14}$	$1.40 \cdot 10^{-15}$
I-130	12.36 h	$4.45 \cdot 10^4$	$1.56 \cdot 10^{-5}$
I-131	8.02 d	$6.93 \cdot 10^5$	$1.00 \cdot 10^{-6}$
I-132	2.3 h	$8.28 \cdot 10^3$	$8.37 \cdot 10^{-5}$
I-133	20.8 h	$7.49 \cdot 10^4$	$9.26 \cdot 10^{-6}$
I-134	52 m	$3.12 \cdot 10^3$	$2.22 \cdot 10^{-4}$
I-135	6.61 h	$2.38 \cdot 10^4$	$2.91 \cdot 10^{-5}$
Xe-131m	11.9 d	$1.03 \cdot 10^6$	$6.74 \cdot 10^{-7}$
Xe-133m	2.19 d	$1.89 \cdot 10^5$	$3.66 \cdot 10^{-6}$
Xe-133	5.25 d	$4.54 \cdot 10^5$	$1.53 \cdot 10^{-6}$
Xe-135m	15.3 m	$9.18 \cdot 10^2$	$7.55 \cdot 10^{-4}$
Xe-135	9.1 h	$3.28 \cdot 10^4$	$2.12 \cdot 10^{-5}$
Xe-138	14.1 m	$8.46 \cdot 10^2$	$8.19 \cdot 10^{-4}$

Table 3.9: Half life and decay constant of used Kr, I and Xe nuclides

the water tank. g_i defines the fraction of fission products, which are released from the water tank to the reactor hall respective to the atmosphere.
The parameter e_i was experimentally verified by General Atomic with a value of $0,0015\%$.[12] This value is valid for fuel temperatures under 300 °C.[12] In this temperature range the release from the fuel-moderator-mixture to the gap between fuel element and fuel element cladding occurs only by fission fragment repulsion.[12] If the temperatures are higher, this effect will be superimposed by a temperature depended diffusion.[12]
PC COSYMA allows the user to define 14 groups of nuclides, whereas each group has its own release fraction.[1] For the scenarios in this work, two groups were defined, one for noble gases (krypton and xenon) and one for halogens (iodine).
The release of nuclides can proceed in different phases (PC COSYMA allows a maximum of six[1]). For this, the release fraction factor can be split and each split part allocates to sequenced phases. In the safety report[12], the release was partitioned into three phases in three sequenced hours. In this work only one release phase is used with a release duration of one hour. This is the worst case for deterministic treatment, because the whole release fraction is released within one hour.
If the released plume has any thermal energy, the plume experiences buoyancy and the release height will increase. In the safety report[12] and in the present, no thermal energy was assumed (0 MW).

Calculation with ORIGEN 2[16]

ORIGEN 2.2[11] was developed at the Oak Ridge National Laboratory (ORNL). It is a one-group depletion and radioactive decay computer code. It was used to calculate the activity and the isotopic composition of the spent fuel. For this calculation, the initial compositions, the one-group microscopic cross-sections for each isotope, the length of the irradiation periods and the flux or power of irradiation were required. The fission cross section and the fission product yield libraries for TRIGA fuel either has not been developed or it is not known if any one exists.[16] Thus libraries for 102-type TRIGA fuel elements were modelled. It was assumed, that an average power for each fuel element was applied for whole period of irradiation.[16] The calculation of the isotopic composition of TRIGA fuel elements was confirmed with gamma spectroscopic measurements of Cs-137 (six spent fuel elements were verified). The model still needs confirmation for short lived isotopes. The TRIGA current core has three types of fuel elements with loading of 83 fuel elements, whereas the ORIGEN 2 model was developed for 102-type fuel and was modified for 104-type fuel elements and FLIP fuel elements. The inventory of each fuel element was evaluated for a reactor operation from March 9^{th} 1962 to June 30^{th} 2009.

Figure 3.9: Decay of the whole krypton core inventory with time

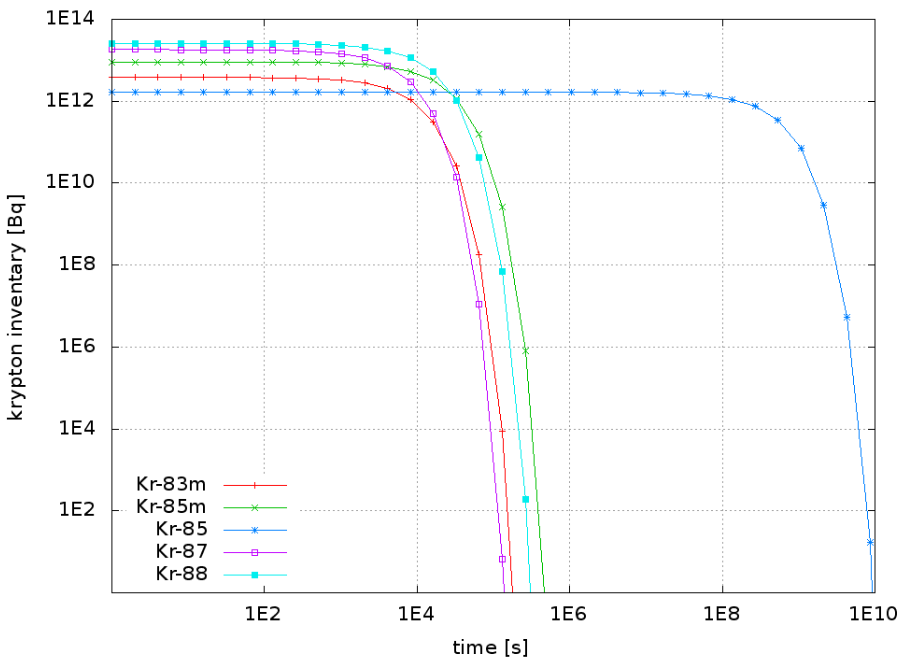


Figure 3.10: Decay of the whole xenon core inventory with time

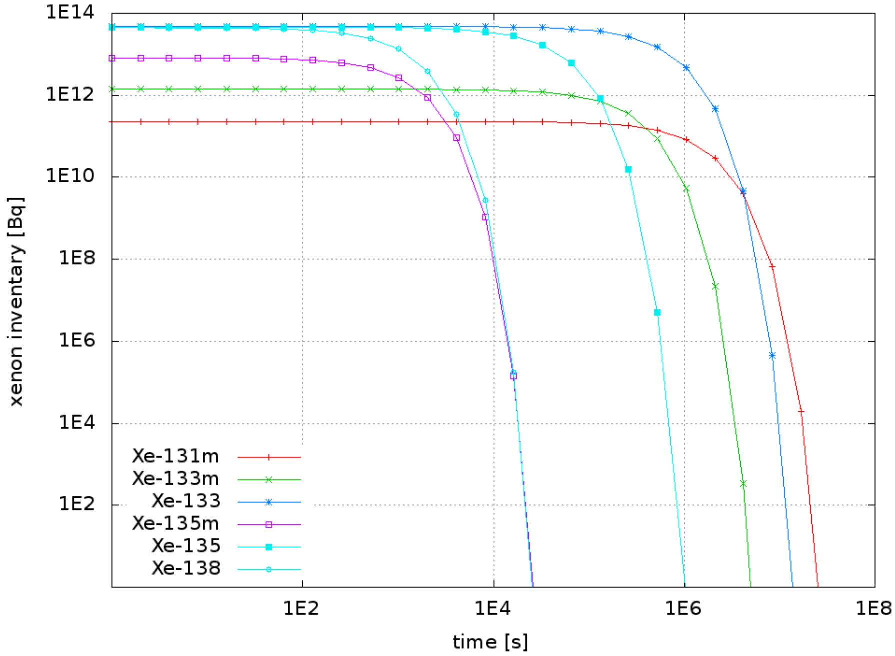
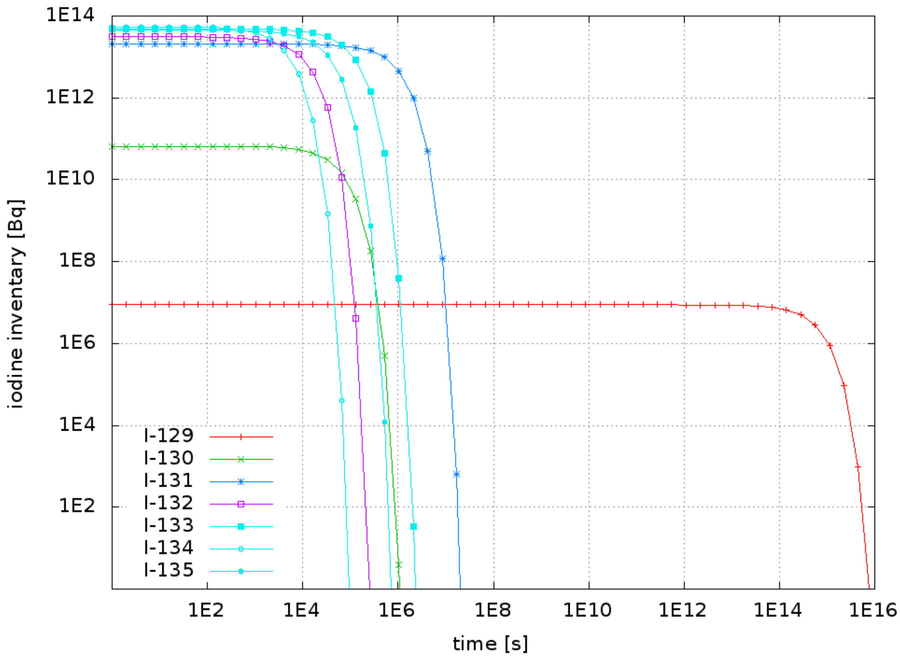


Figure 3.11: Decay of the whole iodine core inventory with time



3.6 Spatial partitioning around the location

The spatial partitioning around the location is done with a lattice. In this work the calculation for all scenarios are within 5km from the release point. The lattice is partitioned into 64 sectors (each sector has $5,625^\circ$) and 25 circles. The maximum resolution in PC COSYMA has 72 sectors and 25 circles.[1] For this work 64 sectors were used, because the weather station uses a wind rose. This means the weather station differs 16 directions and every wind direction belongs to a full sector of the lattice. In table 3.10, the radii of used circles are listed and in figure 3.12, a sketch of the defined lattice around the release point is presented. Sector 1 shows in N,

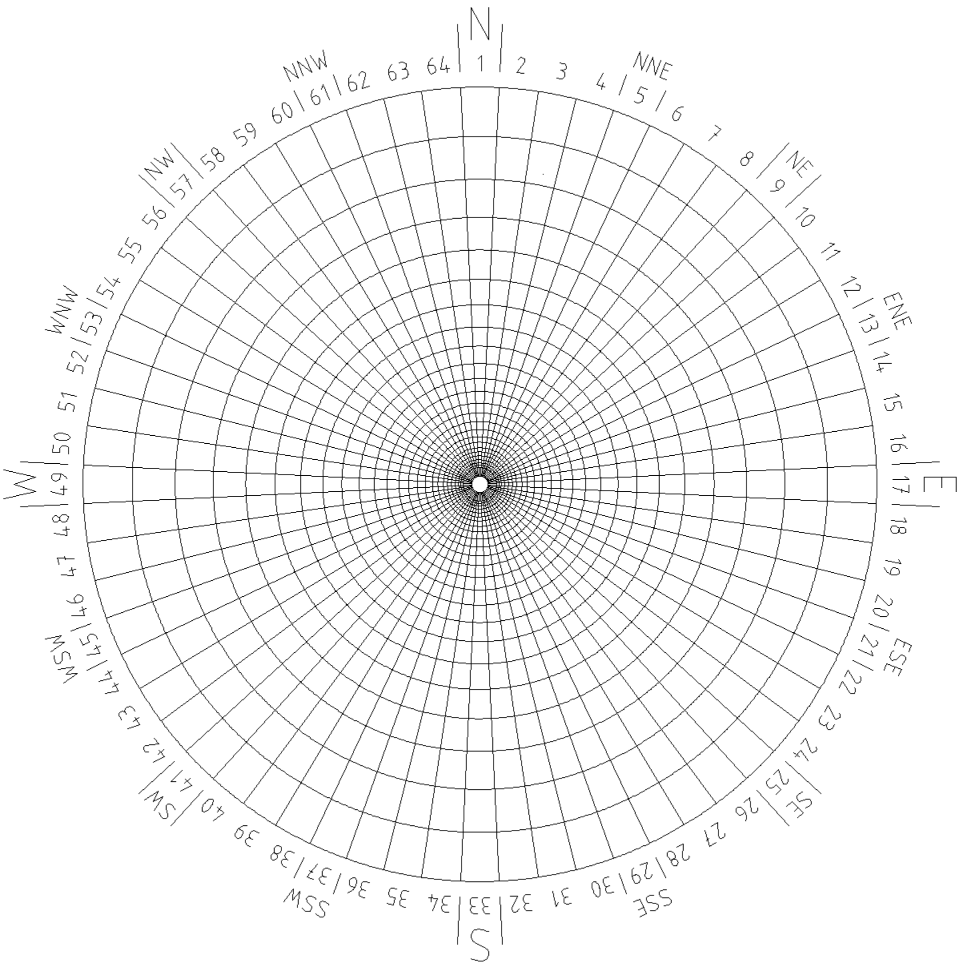
	[km]		**[km]**		**[km]**
1	0.21	**11**	0.79	**21**	2.95
2	0.24	**12**	0.90	**22**	3.36
3	0.27	**13**	1.02	**23**	3.84
4	0.31	**14**	1.17	**24**	4.38
5	0.36	**15**	1.33	**25**	5.00
6	0.41	**16**	1.52		
7	0.46	**17**	1.74		
8	0.53	**18**	1.98		
9	0.60	**19**	2.26		
10	0.69	**20**	2.58		

Table 3.10: Radii of the lattice

sector 17 shows in E, sector 33 shows in S and sector 49 shows in W. The most counted wind direction with the weather station was WNW (see section 2.1). In deterministic calculations with wind direction from WNW (sector 53), the dose is symmetrically distributed around sector 21.

PC COSYMA calculates the mean value of the dose for each lattice-element. To calculate the collective doses or the collective risks to persons, a library-lattice with the population of Europe is available in PC COSYMA. Each lattice element of the library has a size of 10km times 10km. If better population data at the location is available, the lattice segment of the library can be replaced by a finer lattice. This is not relevant for this work, because in this work only individual doses or individual risks are presented.[1]

Figure 3.12: Graphical illustration of the lattice around the release point



3.7 Shielding parameter

The received dose outdoors is higher than the received dose in a protected location, because shielding effects occur.[1] Thus the user must set shielding parameters, which define the ratio between outdoors and the protected location and characterize this location. These location factors have to be established for cloud gamma exposure, deposit gamma exposure, inhalation of cloud, re-suspended material and dose from skin contamination.

The **γ-cloud dose** in PC COSYMA is calculated for rural areas.[1] This means no shielding effects from buildings are treated. If the person is located in a residential area, the location factor outdoors is about 0.7 because shielding of the nearby buildings.[1] The location factor indoors is smaller, because the buildings can have a shielding factor up to 0.01.[1] In table 3.11[1] a list of shielding factors for different environment or building conditions with appropriate location factors are presented for indoors and outdoors. Persons stay both outdoors and indoors for a certain time, thus a mixing location factor must be defined. For example a rural environment with an outdoor location factor of 1 and an indoor location factor of 0.5 is taken. With the assumption that persons spend 90% of their time in buildings, the mixing location factor has a value of 0.905 ($0.9 \cdot 1.0 + 0.1 \cdot 0.5 = 0.905$). In this work the worst case was used, this means that persons stay 100% of their time outdoors in rural area.

The **deposit γ exposure** in PC COSYMA is appropriate for outdoor location in urban areas and can rise up to a factor of 1.2 for rural areas.[1] The indoor location factor depends on the type of the building (construction of walls and roof), the size and the number of floors. In table 3.12[1] a list of shielding factors for different environment or building conditions with appropriate location factors for indoors and outdoors is presented. Persons stay outdoors and indoors for time, thus a mixing location factor must be defined. In this work the worst case was used, this means that persons stay 100% of their time outdoors in urban areas.

If the **inhalation dose** and the **deposition to skin** is calculated, a difference between the air concentration indoors and outdoors must be considered. This origins of filtering effects of buildings and different deposition pattern between in-

Environment/building type	**outdoor**	**indoor**
Default[1]	0.7	0.1
Rural[1]	1.0	0.5
Residential[1]	0.7	0.7
City[1]	0.7	0.05
Low shielded	-	1.0
Medium shielded	-	0.3
High shielded	-	0.01
Cellars	-	0.05
Cars	-	1.0

[1] must be weighted for indoor and outdoor occupancy

Table 3.11: Shielding factors for cloud gamma exposure

Environment/building type	**outdoor**	**indoor**
Default[1]	1.0	0.04
Rural[1]	1.0	0.2
Residential[1]	1.0	0.1
City[1]	1.0	0.02
Low shielded	-	0.5
Medium shielded	-	0.1
High shielded	-	0.01
Cellars (with windows)	-	0.02
Cellars (without windows)	-	0.0005
Cars	-	0.7

[1] must be weighted for indoor and outdoor occupancy

Table 3.12: Shielding factors for deposit gamma exposure

doors and outdoors. The outdoor location factor is 1.0 for urban and rural areas.[1] The indoor location factor depends on the ventilation rate of the building and on the degree of furnishing and is assumed for northern European buildings with 0.45.[1] Since the Chernobyl accident, location factors have been estimated from experimental work and Chernobyl measurements. In this work the worst case was used (no influence of buildings).

A summery of used location factors in this work see table 3.13.

	location factor
cloud radiation	1
ground radiation	1
inhalation	1
re suspension	1
deposition on skin and clothes	1

Table 3.13: Used shielding parameters (worst case)

3.8 Dose and health effects

PC COSYMA differs between early dose/health effects and late dose/health effects. In this work all pathways for early as well as late dose and health effects were considered (see table 3.14).

Early dose and health effects

Early dose and health effects distinguish between morbidity effects and mortality effects. In this work the standard values from PC COSYMA were used. A list of the morbidity effect parameters see table 3.15[2]. A list of the mortality effect parameters see table 3.16[2]. The standard risk threshold parameter for early health

cloud shine	yes
ground shine	yes
inhalation	yes
re suspension	yes
skin and clothing	yes

Table 3.14: Dose-risk pathways

effects has a value of 0.01, which assumes a limit below that no early health effects occur.[1] The fraction of population, for which skin burns are fatal, was assumed with the standard value of 0.05[1].

	$D_0[\frac{Gy^2}{h}]$	D_∞	**shape parameter**
lung function impairment	15	5	7
hypothyroidism	30	60	1.3
cataracts	0.01	3	5
mental retardation	0	1.5	3
skin burns	5	20	5

Table 3.15: Dose response morbidity

Late dose and health effects

For late dose and health effects the cancer risk factors for different organs of the body must be defined. One set is derived by GSF (National Research Center for Environment and Health Neuherberg, Germany)[18] and the other set is based on those given in ICRP-60 (International Commission on Radiological Protection)[19]. In this work the GSF cancer risk factors were used, because these values are recommended[1]. A list of the GSF cancer risk factors for different organs are listed in table 3.17[2]. Different kinds of cancer have different cancer mortality fractions. The standard values of PC COSYMA are presented in table 3.17[2].

	$D_0[\frac{Gy^2}{h}]$	D_∞	shape parameter
pulmonary syndrome	30	10	7
haematopoietic syndrome	0.1	4.5	6
gastro-intestinal syndrome	0	15	10
pre- or neo- natal death	0	1.5	3
skin burns	5	20	5

Table 3.16: Dose response mortality

		GSF cancer risk factors [risk/Sv]	**cancer mortality fractions [risk/Sv]**
bone marrow	leukaemia	$5.16 \cdot 10^{-3}$	1
bone surface	cancer	$1.33 \cdot 10^{-4}$	1
breast	cancer	$8.00 \cdot 10^{-3}$	0.4
lung	cancer	$9.00 \cdot 10^{-3}$	0.75
stomach	cancer	$9.05 \cdot 10^{-3}$	0.85
colon	cancer	$3.43 \cdot 10^{-3}$	0.55
liver	cancer	$4.67 \cdot 10^{-3}$	1
pancreas	cancer	$5.26 \cdot 10^{-3}$	0.9
thyroid	cancer	$1.77 \cdot 10^{-3}$	0.1
remainder	cancer	$3.86 \cdot 10^{-3}$	0.6
skin	cancer	$1.38 \cdot 10^{-4}$	0.01
total		$5.05 \cdot 10^{-2}$	—
gonads	hereditary	$2.00 \cdot 10^{-2}$	—

Table 3.17: GSF cancer risk factors and cancer mortality fractions for late dose and health effects

Miscellaneous Parameter

In PC COSYMA it is possible to choose between effective dose equivalent (ICRP-26) and effective dose (ICRP-60), whereas in this work the effective dose (ICRP-60) was used.
A breathing rate is used to calculate the inhalation dose. The standard breathing rate in PC COSYMA has a value of $2.67 \cdot 10^{-4} m^3/s$ and is guilty for adults.[1]
The half life of activity on skin is assumed with 30 days, whereas the activity on skin has the same value as the dry deposited activity on the ground.[1]
The relationship between the amount of deposited material and the re suspended air concentration after a specific time towards deposition is described with the re suspension factor R. The formula reads as

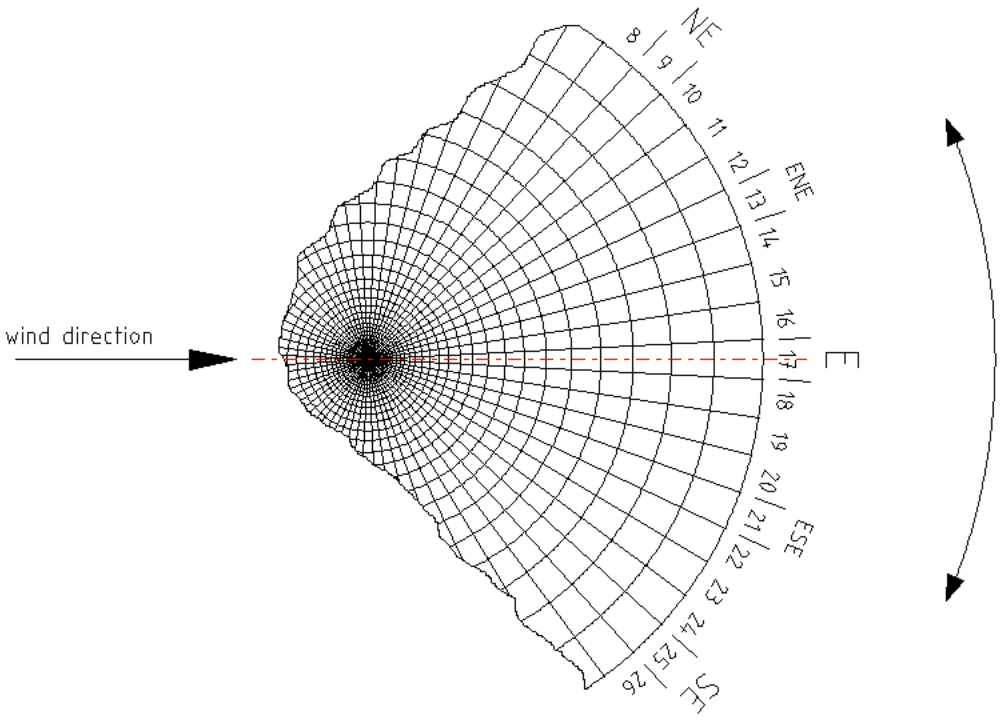
$$R = 5 \cdot 10^{-8} \cdot e^{-3.5 \cdot 10^{-8} \cdot t} + 1 \cdot 10^{-9},$$

whereas the standard values of PC COSYMA are already inserted. R is the ratio of air concentration to deposition in $[1/m]$ and t is the time since deposition.[1]

4 Analysis

In deterministic calculations, only one weather condition is assumed, which is stable in time. This means, only one wind direction occurs. The effective dose distribution is symmetric and the most polluted sector lies in down wind direction. If the wind direction is W, the most polluted sector lies in E (see figure 4.1).

Figure 4.1: Symmetric distribution of the effective dose in deterministic runs

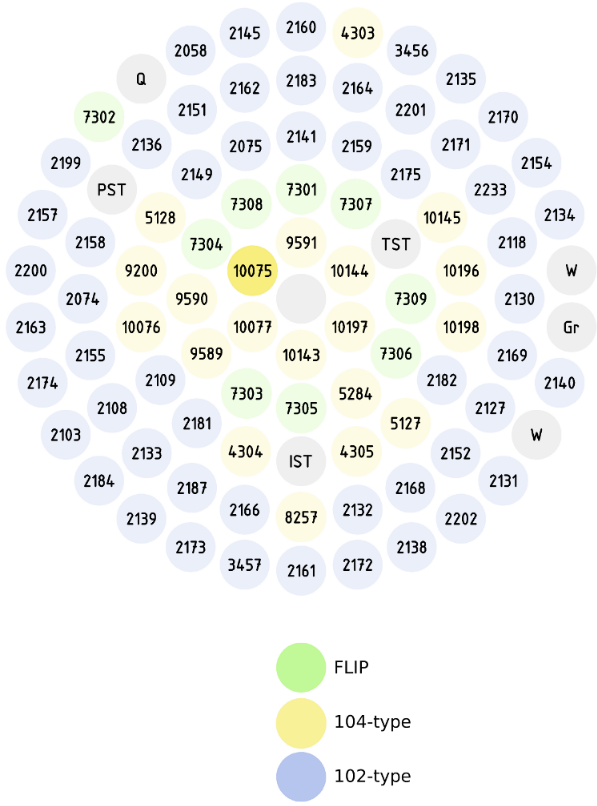


This chapter treats four different scenarios. The first scenario describes the consequence after destruction of the fuel element with highest activity content of krypton, xenon and iodine. The second scenario describes the consequence after destruction of all fuel elements. The third scenario treats the consequence after a small air crash and the fourth scenario treats the consequence after a big air crash. Scenario one, two and four were considered in the safety report[12] of 1978, whereas scenario three was not considered.
Instead of Pasquill stability class F in the safety report[12], Pasquill stability class E was used in this work. The wind speed was taken from the safety report[12] with 1m/s. The rain rate was taken from the safety report[12] with 0mm/h. The effective dose (ICRP-60) after one day and after 50 years was calculated. In the Appendix, the most polluted sector is presented with different atmospheric conditions for all scenarios.
The effective dose (ICRP-60) distribution after one day and after 50 years was transferred on a map. This was made with application QCad 2.0.5.0, gimp 2.6.6 and a digital map of Vienna[14].

4.1 Worst case Scenario 1 - Destruction of the fuel element with highest activity content

In Scenario 1 the destruction of the fuel element with highest activity content was regarded. It was assumed, that the building is alright. The **height of the building** was assumed with **20m**, the **width of the building** was assumed with **20m** and the **release height** was assumed with **20m**. The fission product inventory of all fuel elements in the reactor core was evaluated with ORIGEN[16] and is tabulated (only nuclides, which were considered in PC COSYMA) in Appendix A. The **most activated fuel element** was a 104-type fuel element with the number **10075** in the B ring (inner ring) of the reactor core (see figure 4.2).

Figure 4.2: Position of the most activated fuel element in the reactor core



The fission product inventory of fuel element number 10075 is presented in table 4.1 (only nuclides, which were considered in PC COSYMA). After destruction of the

	inventory [Bq]
Kr-83m	$5.91 \cdot 10^{10}$
Kr-85m	$1.39 \cdot 10^{11}$
Kr-85	$2.22 \cdot 10^{10}$
Kr-87	$2.81 \cdot 10^{11}$
Kr-88	$3.97 \cdot 10^{11}$
I-129	$7.47 \cdot 10^{4}$
I-130	$7.16 \cdot 10^{8}$
I-131	$3.21 \cdot 10^{11}$
I-132	$4.77 \cdot 10^{11}$
I-133	$7.44 \cdot 10^{11}$
I-134	$8.40 \cdot 10^{11}$
I-135	$6.93 \cdot 10^{11}$
Xe-131m	$3.56 \cdot 10^{9}$
Xe-133m	$2.18 \cdot 10^{10}$
Xe-133	$7.45 \cdot 10^{11}$
Xe-135m	$1.26 \cdot 10^{11}$
Xe-135	$7.03 \cdot 10^{11}$
Xe-138	$6.87 \cdot 10^{11}$

Table 4.1: Fission product inventory of fuel element number 10075 (only nuclides, which were considered in PC COSYMA)

fuel element with highest activity content, only a fraction of the whole inventory is released. To define the fraction of the released noble gases and halogens, the formula

$$w_i = e_i \cdot f_i \cdot g_i,$$

was used, where e_i defines the fraction of fission products, which migrate into the gap between fuel and fuel element cladding. f_i defines the fraction of the fission products, which migrate from the gap between fuel and fuel element cladding into the water tank. g_i defines the fraction of the fission products, which are released from the water tank to the ventilation system. The index N is used for noble gases and the index H is used for halogens.

Noble gases

For e_N, f_N and g_N the same assumptions were used as in the safety report[12]. e_N is the empirically found parameter from General Atomic and describes the amount of noble gases, which reach the gap between fuel and fuel element cladding. It was assumed, that 100% of all noble gases were released from the gap between fuel and fuel element cladding into the water tank. Further was assumed that all noble gases from the water tank were released to the ventilation system. In table 4.2 a list of used parameters and the total release fraction w_N of noble gases is presented.

	noble gases
e_N	$1.5 \cdot 10^{-5}$
f_N	1
g_N	1
w_N	$1.5 \cdot 10^{-5}$

Table 4.2: Scenario 1 - release fraction of noble gases

Halogens

For e_H, f_H and g_H the same assumptions were used as in the safety report[12]. e_H is the empirically found parameter from General Atomic and describes the amount of halogens, which reach the gap between fuel and fuel element cladding. The safety report[12] partitioned halogens into two classes, organic halogens and other halogens. In this report was assumed that 50% of all halogens were released from the gap between fuel and fuel element cladding into the water tank. It was assumed that 10% of all halogens in the water tank were in organic form and were released to the ventilation system. Further was assumed that 1% of the leftover halogens in the water tank (which had an other chemical form) were released to the ventilation system. In table 4.3 a list of the release fractions for organically bound halogens, halogens in other chemical form and the total release fraction of halogens is presented. The only halogen, which was used in the calculation was iodine.

	organic halogens	**other halogens**	
e_H	$1.5 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	
f_H	0.5	0.5	
g_H	0.1	0.009	
w_H	$7.5 \cdot 10^{-7}$	$6.75 \cdot 10^{-8}$	$\sum \ldots 8.17 \cdot 10^{-7}$

Table 4.3: Scenario 1 - release fraction of organic halogens and other halogens

organically bound iodine	92 %
elementary bound Iodine	4 %
aerosol Iodine	4 %

Table 4.4: Scenario 1 - chemical form of released iodine

In PC COSYMA, isotopes of iodine are partitioned into three chemical forms. These are organically bound iodine, elementary bound iodine and aerosol iodine. Each chemical form has different deposition parameters, which were explained in section 3.4. In the safety report[12] was assumed that 92% of the released iodine was organically bound and 8% was in other chemical form. For the calculation in this work was assumed, that the other iodine was partitioned into 50% of elementary bound iodine and 50% of iodine in aerosol form. In table 4.4 the distribution of the chemical form of the released iodine, which was used in the calculation, is presented.

Analysis of Scenario 1

A Pasquill stability class F, a wind speed of 1m/s and no rain were assumed in the safety report[12]. Instead of Pasquill stability class F, Pasquill stability class E was used in this calculation, because the effective dose (ICRP-60) in this condition is higher. The wind direction in the safety report[12] was assumed with W, which was changed to WNW in this calculation, because of measurements with the weather station.
In figure 4.3 and 4.4 the **effective dose (ICRP-60) in Sv after one day** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.31km the dose is less than $1 \cdot 10^{-10}$Sv and exterior a radius of 1.98km the dose is less than $1 \cdot 10^{-11}$Sv.
In figure 4.5 and 4.6 the **effective dose (ICRP-60) in Sv after 50 years** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.60km the dose is less than $1 \cdot 10^{-10}$Sv and exterior a radius of 3.36km the dose is less than $1 \cdot 10^{-11}$Sv.
The effective dose (ICRP-60) after one day with **different Pasquill stability classes**, a wind speed of $1m/s$ and a rain rate of $0mm/h$ see figure B.1, the effective dose (ICRP-60) after 50 years see figure B.2.
The effective dose (ICRP-60) after one day with **different wind speeds**, Pasquill stability class E and a rain rate of $0mm/h$ see figure B.3, the effective dose (ICRP-60) after 50 years see figure B.4.
The effective dose (ICRP-60) after one day with **different rain rates**, Pasquill stability class E and a wind speed of $1m/s$ see figure B.5, the effective dose (ICRP-60) after 50 years see figure B.6.

Figure 4.3: Scenario 1 - effective dose (ICRP-60) after 1 day

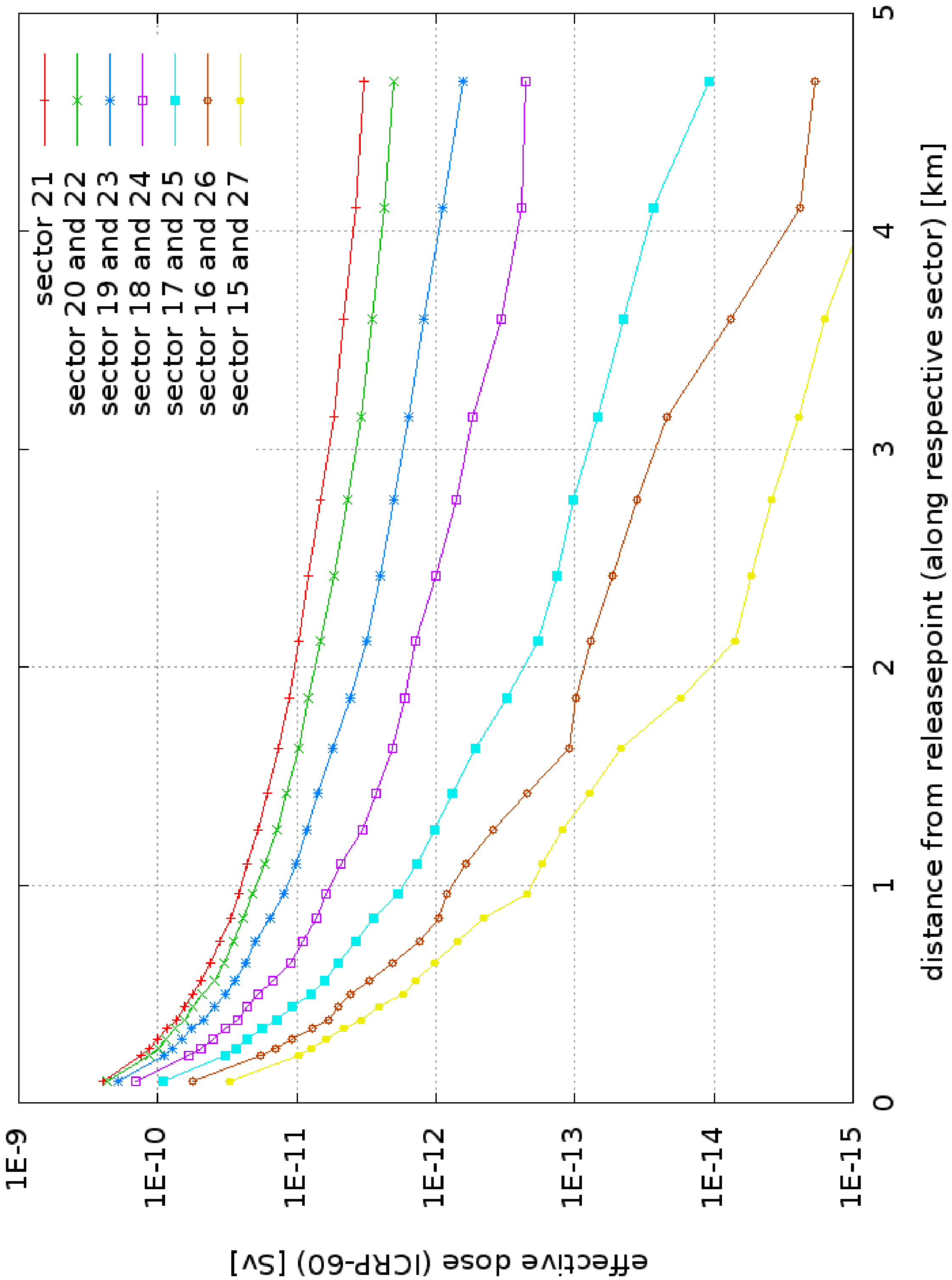


Figure 4.4: Scenario 1 - effective dose (ICRP-60) after 1 day

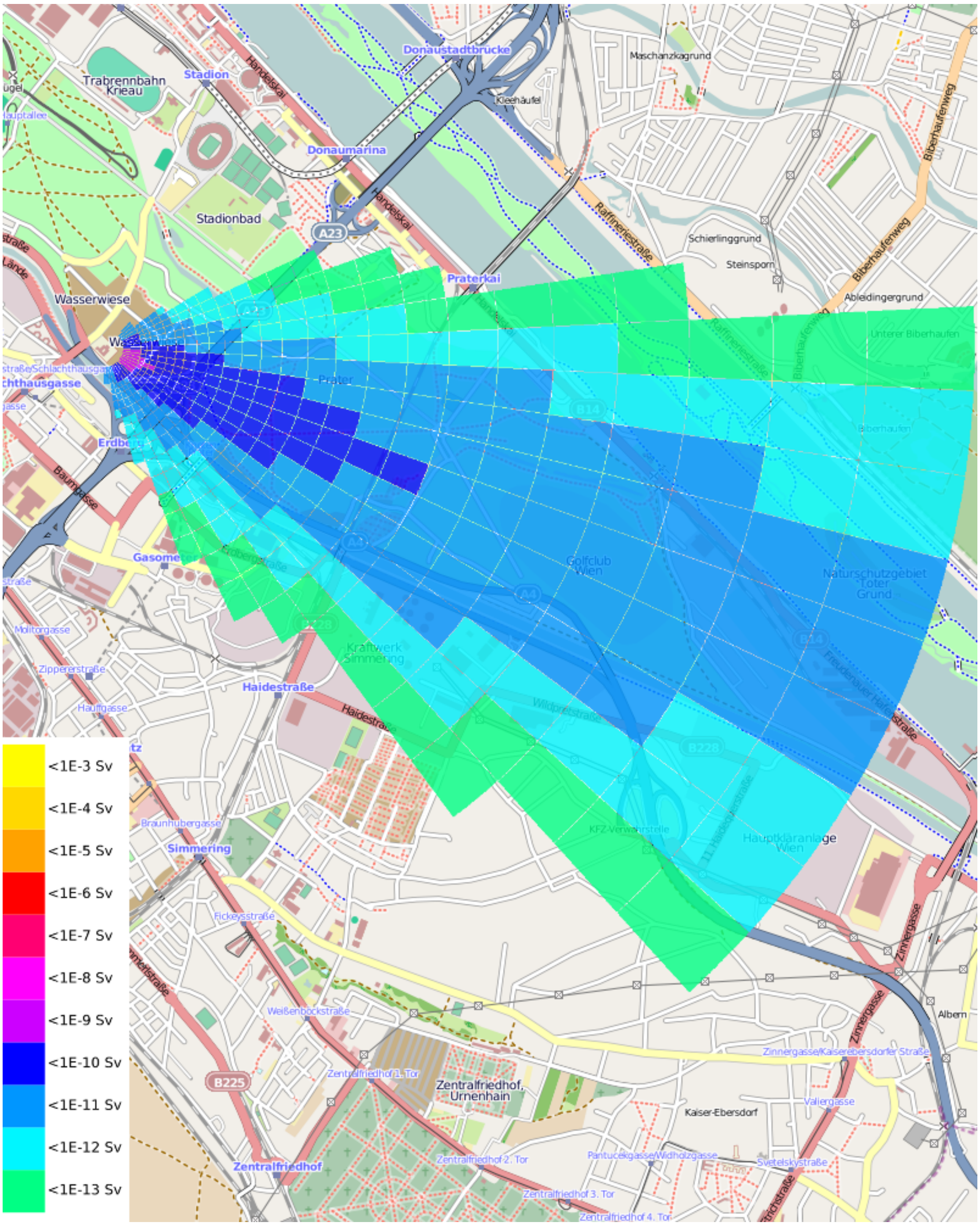


Figure 4.5: Scenario 1 - effective dose (ICRP-60) after 50 years

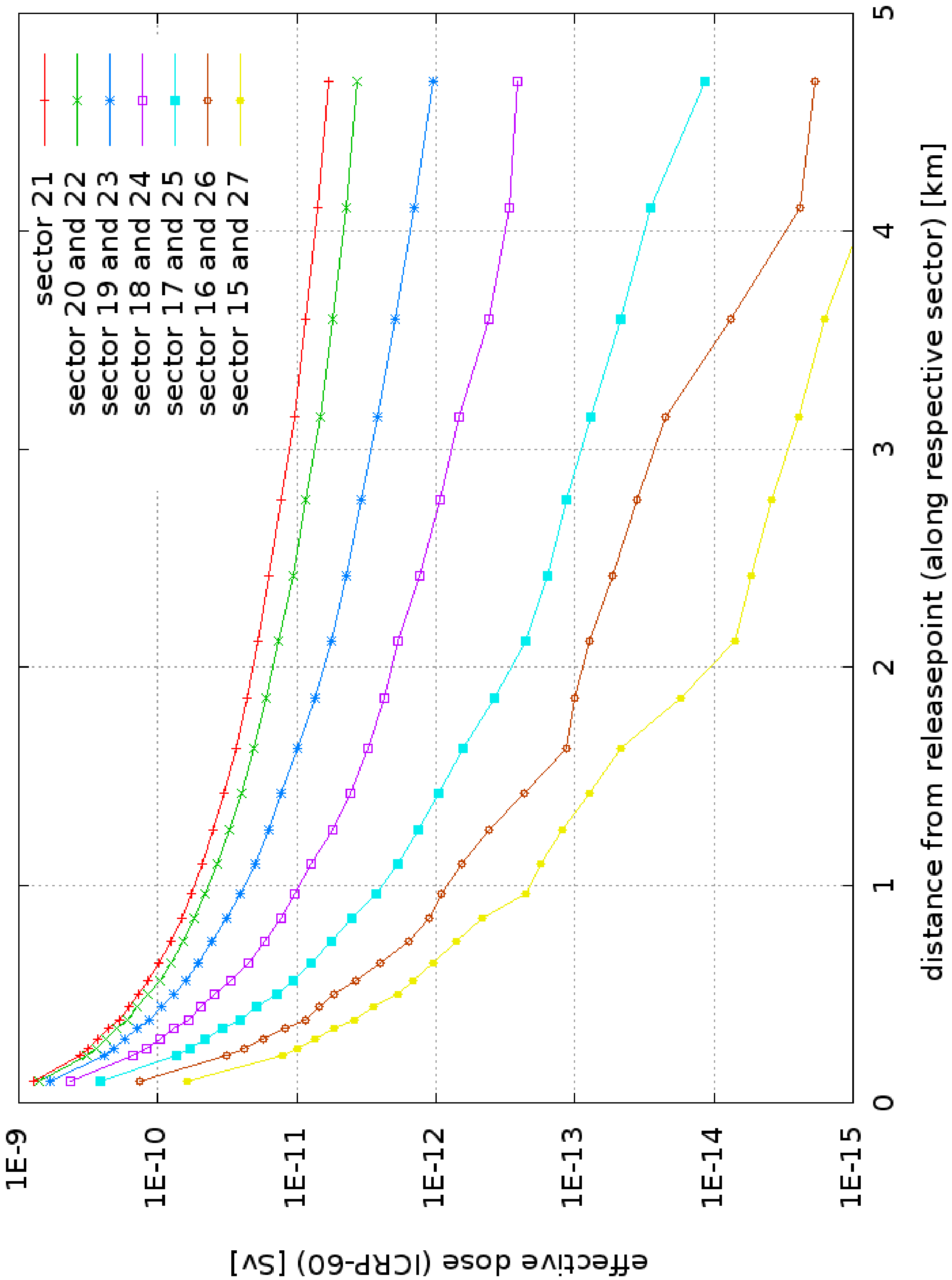
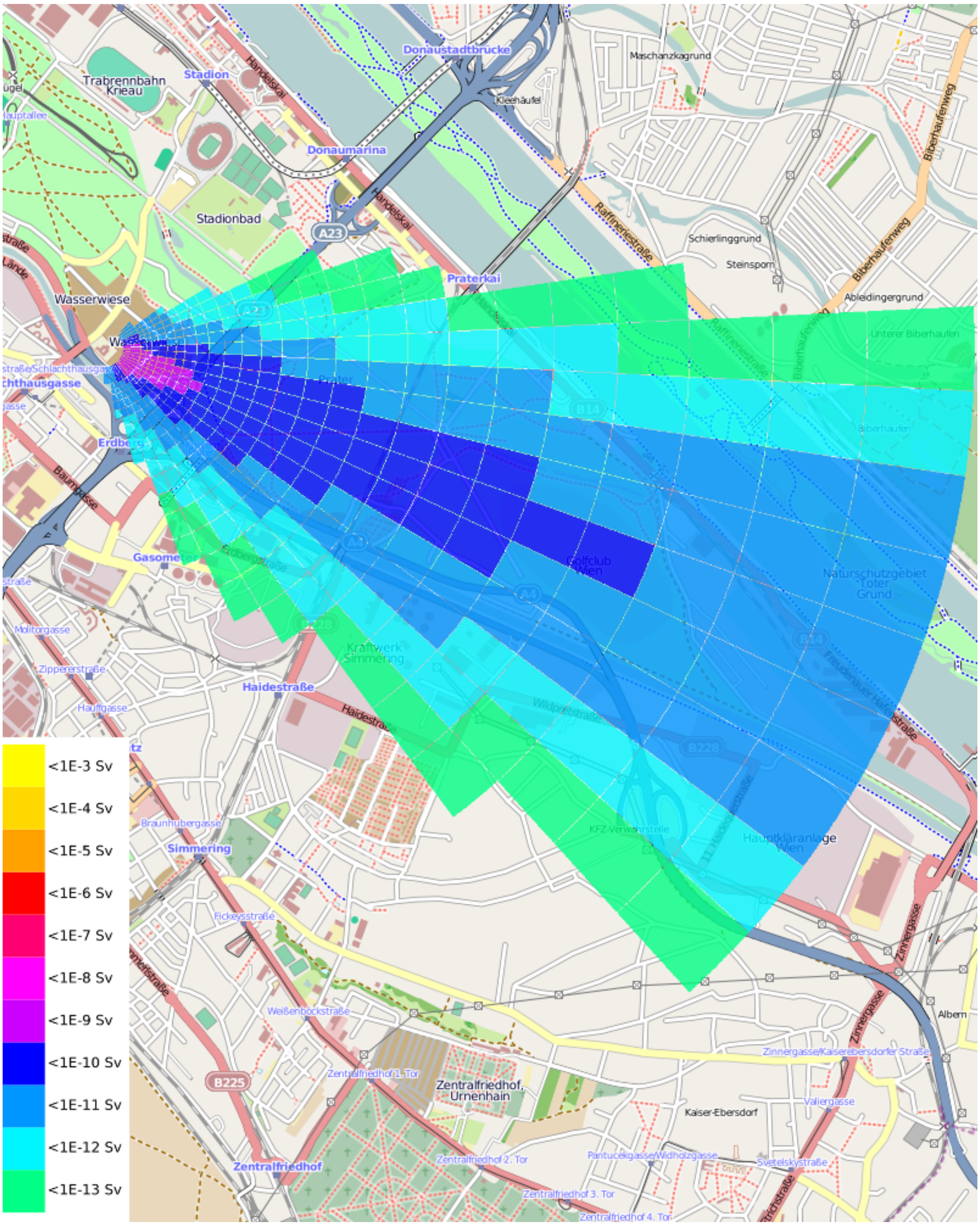


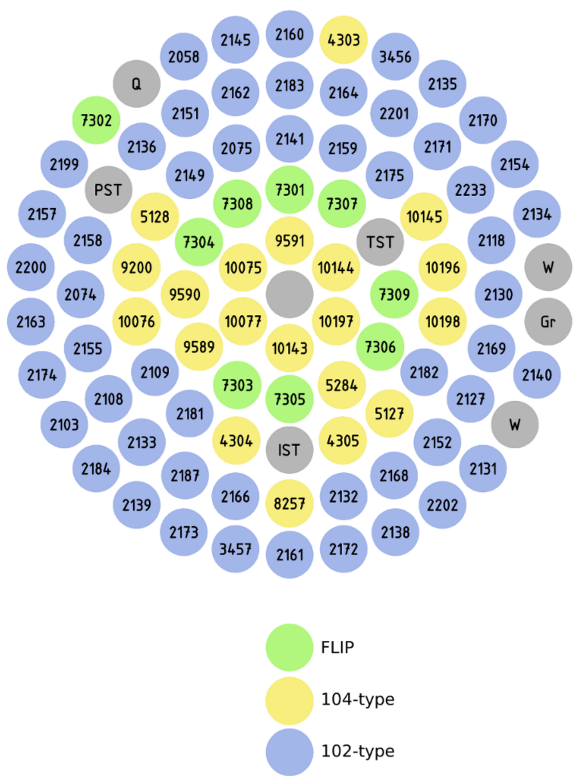
Figure 4.6: Scenario 1 - effective dose (ICRP-60) after 50 years



4.2 Worst case Scenario 2 - Destruction of all fuel elements

In Scenario 2 the destruction of all fuel elements was regarded. It was assumed, that the building is alright. The **height of the building** was assumed with **20m**, the **width of the building** was assumed **with 20m** and the **release height** was assumed with **20m**. The fission product inventory of all fuel elements in the reactor core was evaluated with ORIGEN[16] and is tabulated (only nuclides, which were considered in PC COSYMA) in Appendix A. The position of all fuel elements in the reactor core see figure 4.7.

Figure 4.7: Position of the fuel elements in the reactor core



The fission product inventory of the whole reactor core (summed over all fuel elements) is presented in table 4.5 (only nuclides, which were considered in PC COSYMA). After destruction of all fuel elements, only a fraction of the whole in-

	full core inventory [Bq]
Kr-83m	$3.82 \cdot 10^{12}$
Kr-85m	$9.00 \cdot 10^{12}$
Kr-85	$1.67 \cdot 10^{12}$
Kr-87	$1.82 \cdot 10^{13}$
Kr-88	$2.57 \cdot 10^{13}$
I-129	$8.78 \cdot 10^{6}$
I-130	$6.57 \cdot 10^{10}$
I-131	$2.08 \cdot 10^{13}$
I-132	$3.10 \cdot 10^{13}$
I-133	$4.83 \cdot 10^{13}$
I-134	$5.45 \cdot 10^{13}$
I-135	$4.49 \cdot 10^{13}$
Xe-131m	$2.30 \cdot 10^{11}$
Xe-133m	$1.41 \cdot 10^{12}$
Xe-133	$4.83 \cdot 10^{13}$
Xe-135m	$8.19 \cdot 10^{12}$
Xe-135	$4.59 \cdot 10^{13}$
Xe-138	$4.45 \cdot 10^{13}$

Table 4.5: Fission product inventory of all fuel elements (only nuclides, which were considered in PC COSYMA)

ventory is released. To define the fraction of the released noble gases and halogens, the formula

$$w_i = e_i \cdot f_i \cdot g_i,$$

was used, whereas e_i defines the fraction of fission products, which migrate into the gap between fuel and fuel element cladding. f_i defines the fraction of the fission products, which migrate from the gap between fuel and fuel element cladding into the water tank. g_i defines the fraction of the fission products, which are released from the water tank to the reactor hall. The index N is used for noble gases and the index H is used for halogens.

Noble gases

For e_N, f_N and g_N the same assumptions were used as in the safety report[12]. e_N is the empirically found parameter from General Atomic and describes the amount of noble gases, which reach the gap between fuel and fuel element cladding. It was assumed, that 100% of all noble gases were released from the gap between fuel and fuel element cladding into the water tank. Further was assumed that all noble gases from the water tank were released to the ventilation system. In table 4.6 a list of this parameters and the total release fraction w_N of noble gases is presented.

	noble gases
e_E	$1.5 \cdot 10^{-5}$
f_E	1
g_E	1
w_E	$1.5 \cdot 10^{-5}$

Table 4.6: Scenario 2 - release fraction of noble gases

Halogens

For e_H, f_H and g_H the same assumptions were used as in the safety report[12]. e_H is the empirically found parameter from General Atomic and describes the amount of halogens, which reach the gap between fuel and fuel element cladding. The safety report[12] partitioned halogens into two classes, organic halogens and other halogens. In this report was assumed that 50% of all halogens were released from the gap between fuel and fuel element cladding into the water tank. It was assumed that 10% of all halogens in the water tank were in organic form and were released to the ventilation system. Further was assumed that 1% of the leftover halogens in the water tank (which had an other chemical form) were released to the ventilation system. In table 4.7 a list of the release fractions for organically bound halogens, halogens in other chemical form and the total release fraction of halogens is presented. The only halogen, which was used in the calculation was iodine.

	organically bound halogens	**other halogens**	
e_H	$1.5 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	
f_H	0.5	0.5	
g_H	0.1	0.009	
w_H	$7.5 \cdot 10^{-7}$	$6.75 \cdot 10^{-8}$	$\sum \ldots 8.17 \cdot 10^{-7}$

Table 4.7: Scenario 2 - release fraction of organic halogens and other halogens

organically bound iodine	92 %
elementary bound iodine	4 %
aerosol iodine	4 %

Table 4.8: Scenario 2 - chemical form of released iodine

In PC COSYMA, isotopes of iodine are partitioned into three chemical forms. These are organically bound iodine, elementary bound iodine and aerosol iodine. Each chemical form has different deposition parameters, which were explained in section 3.4. In the safety report[12] was assumed that 92% of the released iodine was organically bound and 8% was in other chemical form. For the calculation in this work was assumed, that 50% of the other iodine was elementary bound iodine and 50% was in aerosol form. In table 4.8 the distribution of the chemical form of the released iodine, which was used in the calculation, is presented.

Analysis of Scenario 2

A Pasquill stability class F, a wind speed of 1m/s and no rain were assumed in the safety report[12]. Instead of Pasquill stability class F, Pasquill stability class E was used in this calculation, because the effective dose (ICRP-60) in this condition is higher. The wind direction in the safety report[12] was assumed with W, which was changed to WNW in this evaluation, because of measurements with the weather station.

In figure 4.8 and 4.9 the **effective dose (ICRP-60) in Sv after one day** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.21km the dose is less than $1 \cdot 10^{-8}$ Sv and exterior a radius of 1.52km the dose is less than $1 \cdot 10^{-9}$ Sv.

In figure 4.10 and 4.11 the **effective dose (ICRP-60) in Sv after 50 years** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.46km the dose is less than $1 \cdot 10^{-8}$ Sv and exterior a radius of 2.58km the dose is less than $1 \cdot 10^{-9}$ Sv.

The effective dose (ICRP-60) after one day with **different Pasquill stability classes**, a wind speed of $1m/s$ and a rain rate of $0mm/h$ see figure B.7, the effective dose (ICRP-60) after 50 years see figure B.8.

The effective dose (ICRP-60) after one day with **different wind speeds**, Pasquill stability class E and a rain rate of $0mm/h$ see figure B.9, the effective dose (ICRP-60) after 50 years see figure B.10.

The effective dose (ICRP-60) after one day with **different rain rates**, Pasquill stability class E and a wind speed of $1m/s$ see figure B.11, the effective dose (ICRP-60) after 50 years see figure B.12.

Figure 4.8: Scenario 2 - effective dose (ICRP-60) after 1 day

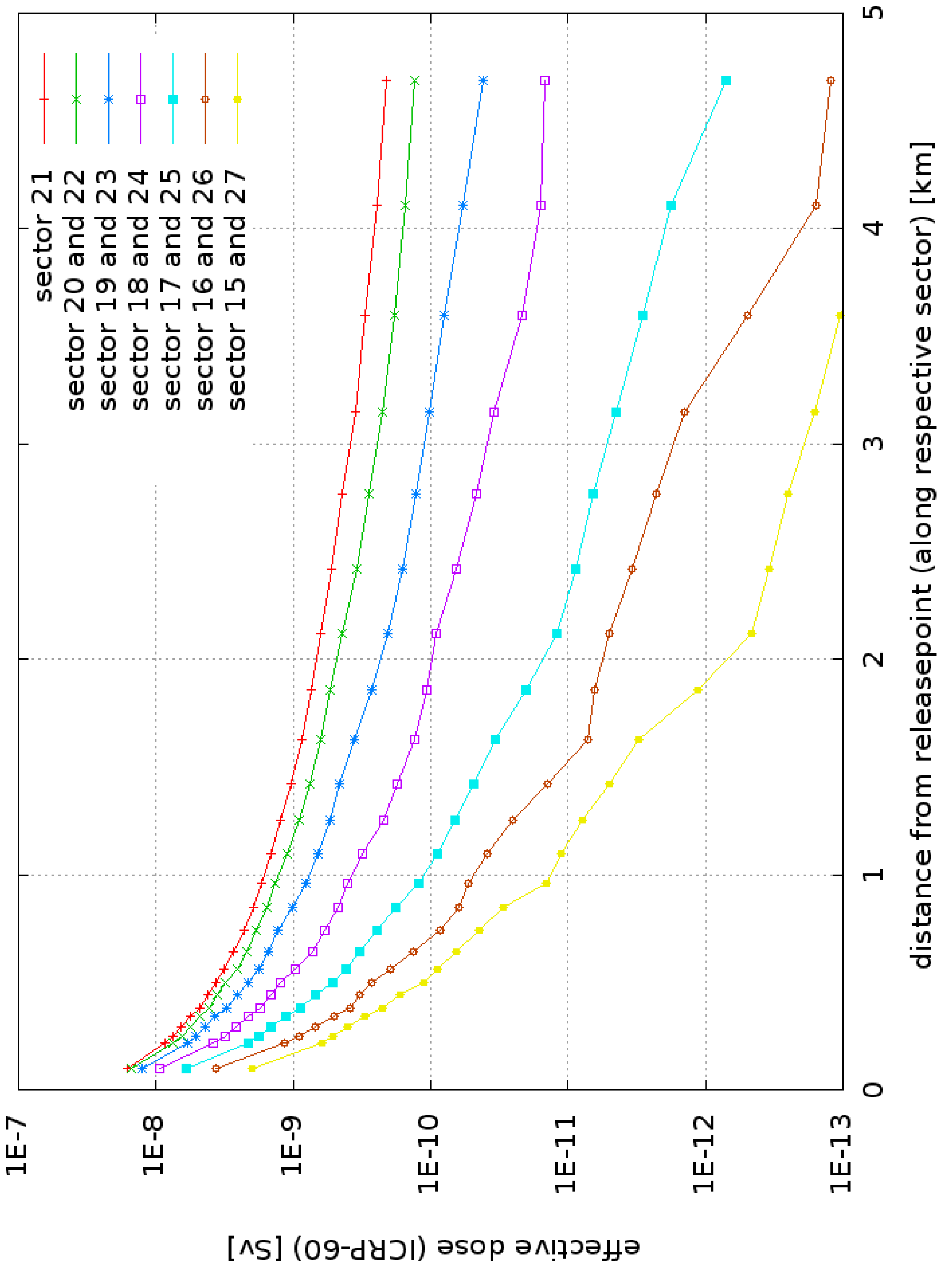


Figure 4.9: Scenario 2 - effective dose (ICRP-60) after 1 day

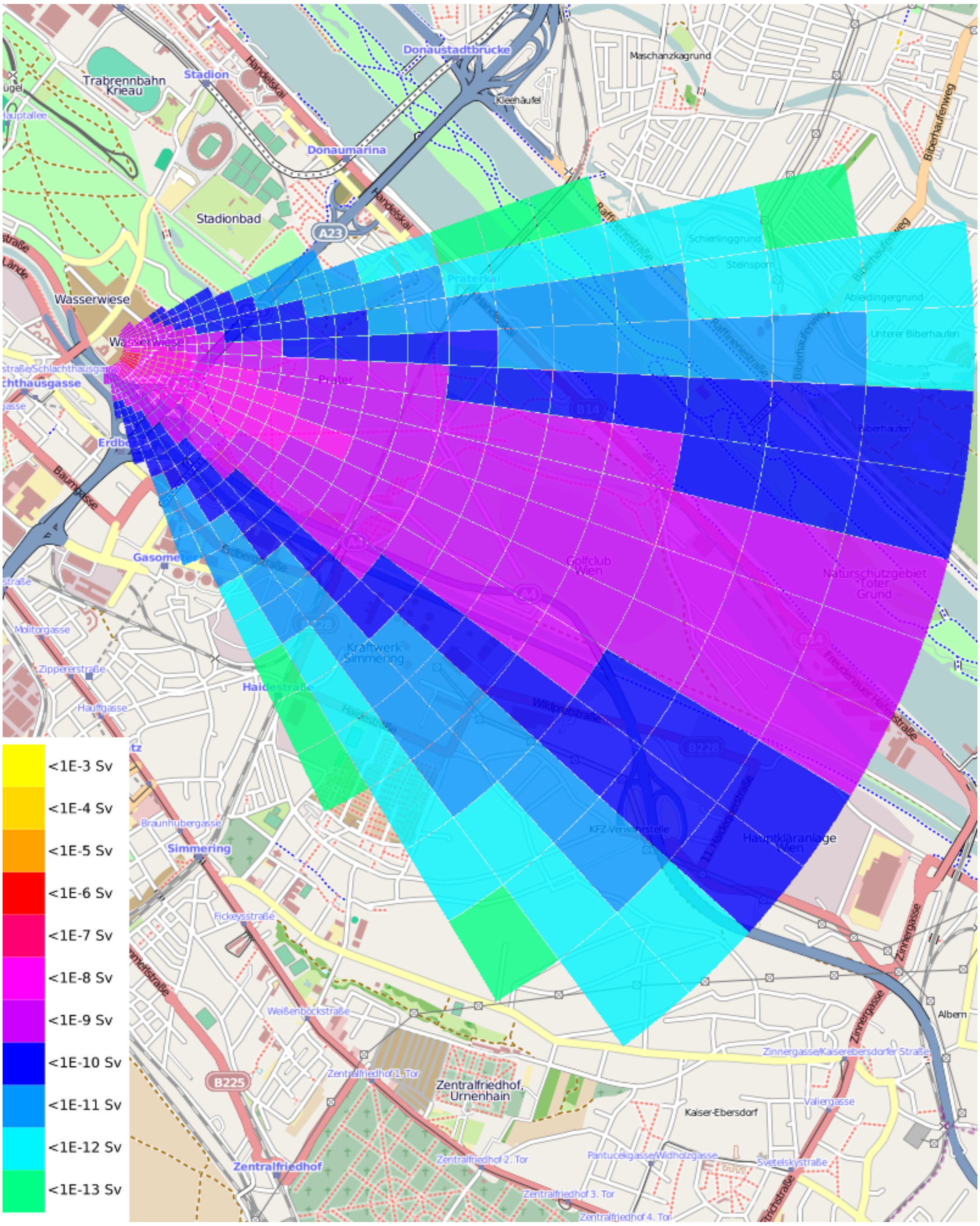


Figure 4.10: Scenario 2 - effective dose (ICRP-60) after 50 years

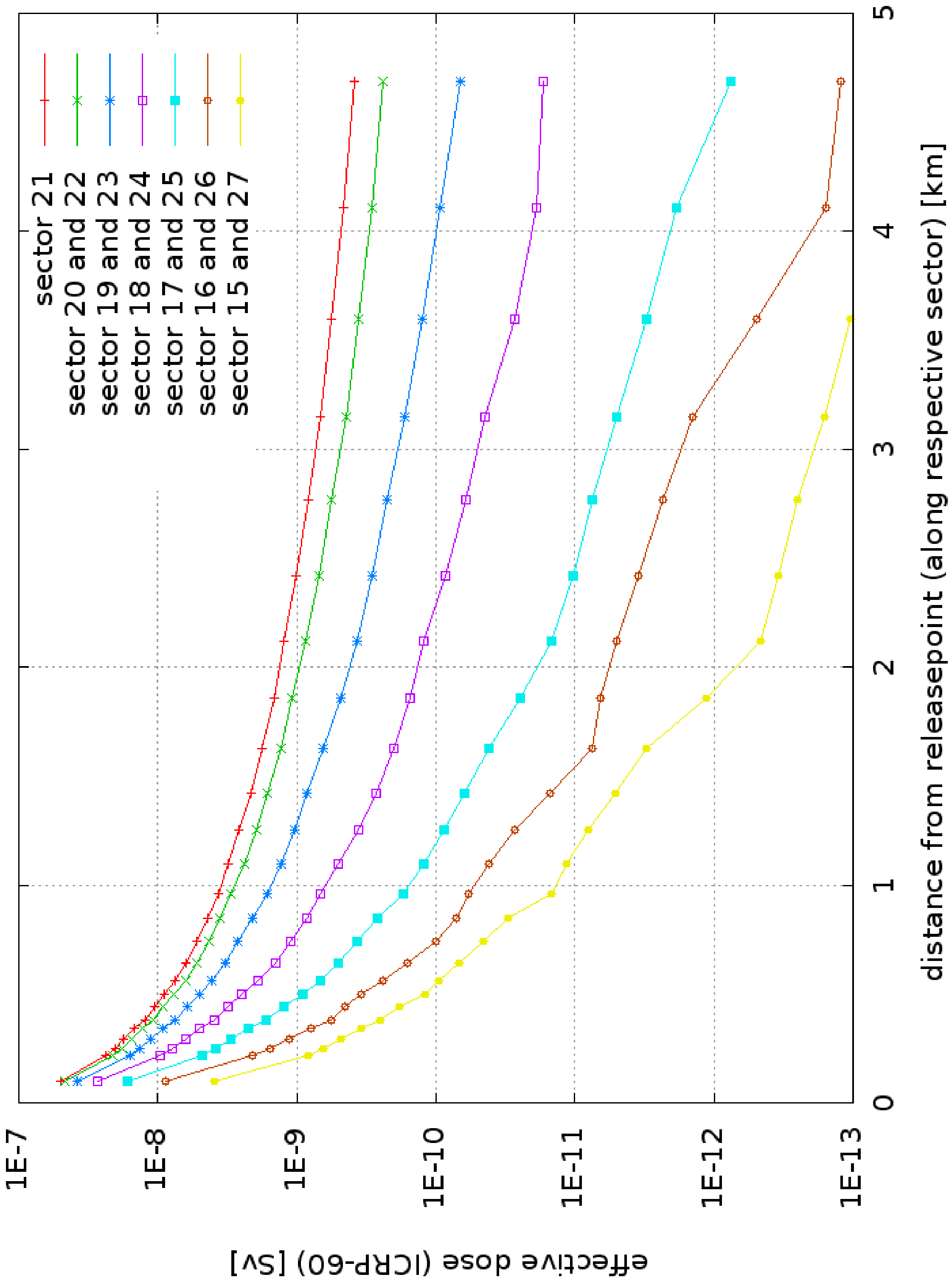
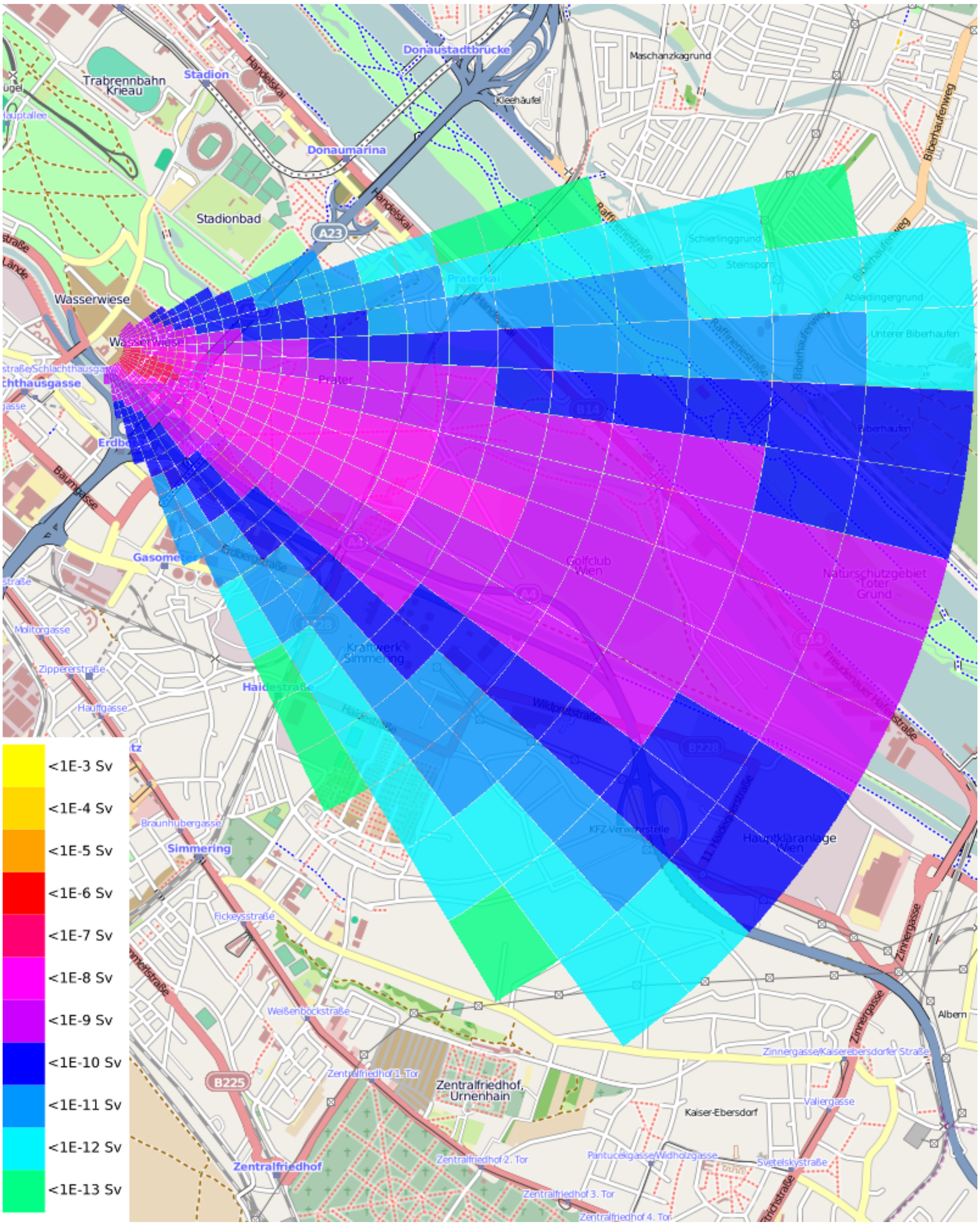


Figure 4.11: Scenario 2 - effective dose (ICRP-60) after 50 years



4.3 Worst case Scenario 3 - Case of a small plane crash

In Scenario 3 the case of a small plane crash was regarded. This scenario was not treated in the safety report[12]. It was assumed, that the building and the water tank were damaged and all fuel elements were destructed. The **height of the building** was assumed with **6m**, the **width of the building** was assumed with **20m** and the **release height** was assumed with **6m**. The fission product inventory of all fuel elements in the reactor core was evaluated with ORIGEN[16] and is tabulated (only nuclides, which were considered in PC COSYMA) in Appendix A. The position of all fuel elements in the reactor core see 4.7 and the fission product inventory of the whole reactor core (summed over all fuel elements) is presented in table 4.5 (only nuclides, which were considered in PC COSYMA).
After a small plane crash, only a fraction of the whole inventory is released. To define the fraction of the released noble gases and halogens, the formula

$$w_i = e_i \cdot f_i \cdot g_i,$$

was used, where e_i defines the fraction of fission products, which migrate into the gap between fuel and fuel element cladding. f_i defines the fraction of the fission products, which migrate from the gap between fuel and fuel element cladding into the water tank. g_i defines the fraction of the fission products, which are released from the water tank into the atmosphere. The index N is used for noble gases and the index H is used for halogens.

Noble gases

For e_N the empirically found parameter from General Atomic was taken[12]. It was assumed, that 100% of all noble gases were released from the gap between fuel and fuel element cladding into the atmosphere. In table 4.9 a list of the used parameters and the total release fraction w_N of noble gases is presented.

	noble gases
e_N	$1.5 \cdot 10^{-5}$
f_N	1
g_N	1
w_N	$1.5 \cdot 10^{-5}$

Table 4.9: Scenario 3 - release fraction of noble gases

Halogens

For e_H the empirically found parameter from General Atomic was used[12]. It was assumed that 50% of all halogens were released from the gap between fuel and fuel element cladding into the water tank. Further was assumed that all halogens in the water tank were released into the atmosphere, whereas 10% of all halogens were in organic form. In table 4.13 a list of the release fractions for organically bound halogens, halogens in other chemical form and the total release fraction of halogens is presented. The only halogen, which was used in the calculation was iodine. In

	organically bound halogens	other halogens	
e_H	$1.5 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	
f_H	0.5	0.5	
g_H	0.1	0.9	
w_H	$7.5 \cdot 10^{-7}$	$6.75 \cdot 10^{-6}$	$\sum \ldots 7.5 \cdot 10^{-6}$

Table 4.10: Scenario 3 - release fraction of organic halogens and other halogens

PC COSYMA, isotopes of iodine are partitioned into three chemical forms. These are organically bound iodine, elementary bound iodine and aerosol iodine. Each chemical form has different deposition parameters, which were explained in section 3.4. It was assumed, that 10% of the released iodine was organically bound and the rest was in an other chemical form. It was assumed, that the rest is partitioned into 50% elementary bound iodine and 50% aerosol iodine. In table 4.8 the distribution

organically bound iodine	10 %
elementary bound iodine	45 %
aerosol iodine	45 %

Table 4.11: Scenario 3 - chemical form of released iodine

of the chemical form of the released iodine, which was used in the calculation is presented.

Analysis of Scenario 3

A wind speed of 1m/s, Pasquill stability class E, a rain rate of 0mm/h and a wind direction from WNW were used in this scenario.

In figure 4.12 and 4.13 the **effective dose (ICRP-60) in Sv after one day** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.21km the dose is less than $1 \cdot 10^{-7}$ Sv, exterior a radius of 1.02km the dose is less than $1 \cdot 10^{-8}$ and exterior a radius of 4.38km the dose is less than $1 \cdot 10^{-9}$ Sv.

In figure 4.14 and 4.15 the **effective dose (ICRP-60) in Sv after 50 years** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.53km the dose is less than $1 \cdot 10^{-7}$ Sv and exterior a radius of 2.26km the dose is less than $1 \cdot 10^{-8}$ Sv.

The effective dose (ICRP-60) after one day with **different Pasquill stability classes**, a wind speed of $1m/s$ and a rain rate of $0mm/h$ see figure B.13, the effective dose (ICRP-60) after 50 years see figure B.14.

The effective dose (ICRP-60) after one day with **different wind speeds**, Pasquill stability class E and a rain rate of $0mm/h$ see figure B.15, the effective dose (ICRP-60) after 50 years see figure B.16.

The effective dose (ICRP-60) after one day with **different rain rates**, Pasquill stability class E and a wind speed of $1m/s$ see figure B.17, the effective dose

(ICRP-60) after 50 years see figure B.18.

Figure 4.12: Scenario 3 - effective dose (ICRP-60) after 1 day

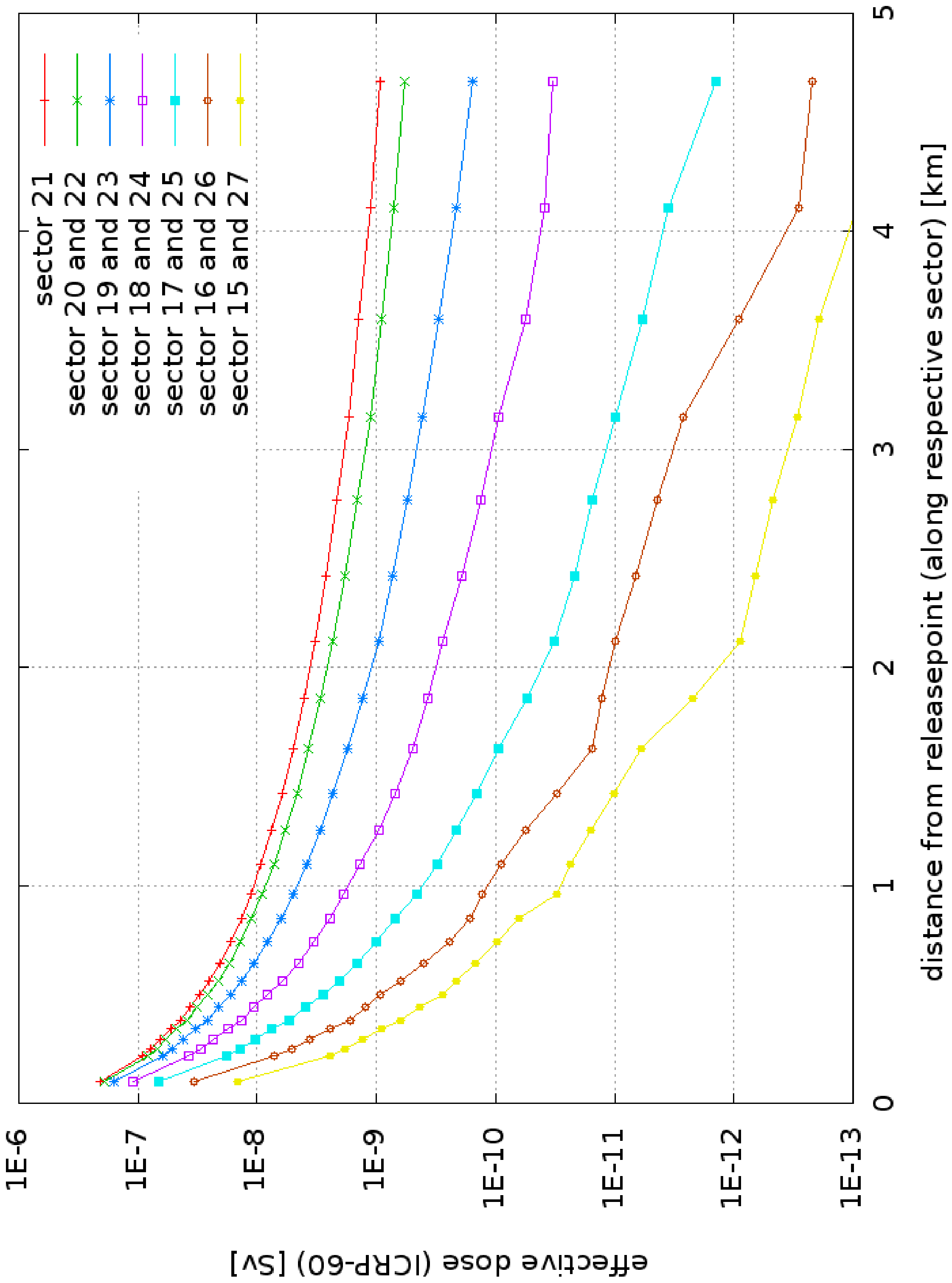


Figure 4.13: Scenario 3 - effective dose (ICRP-60) after 1 day

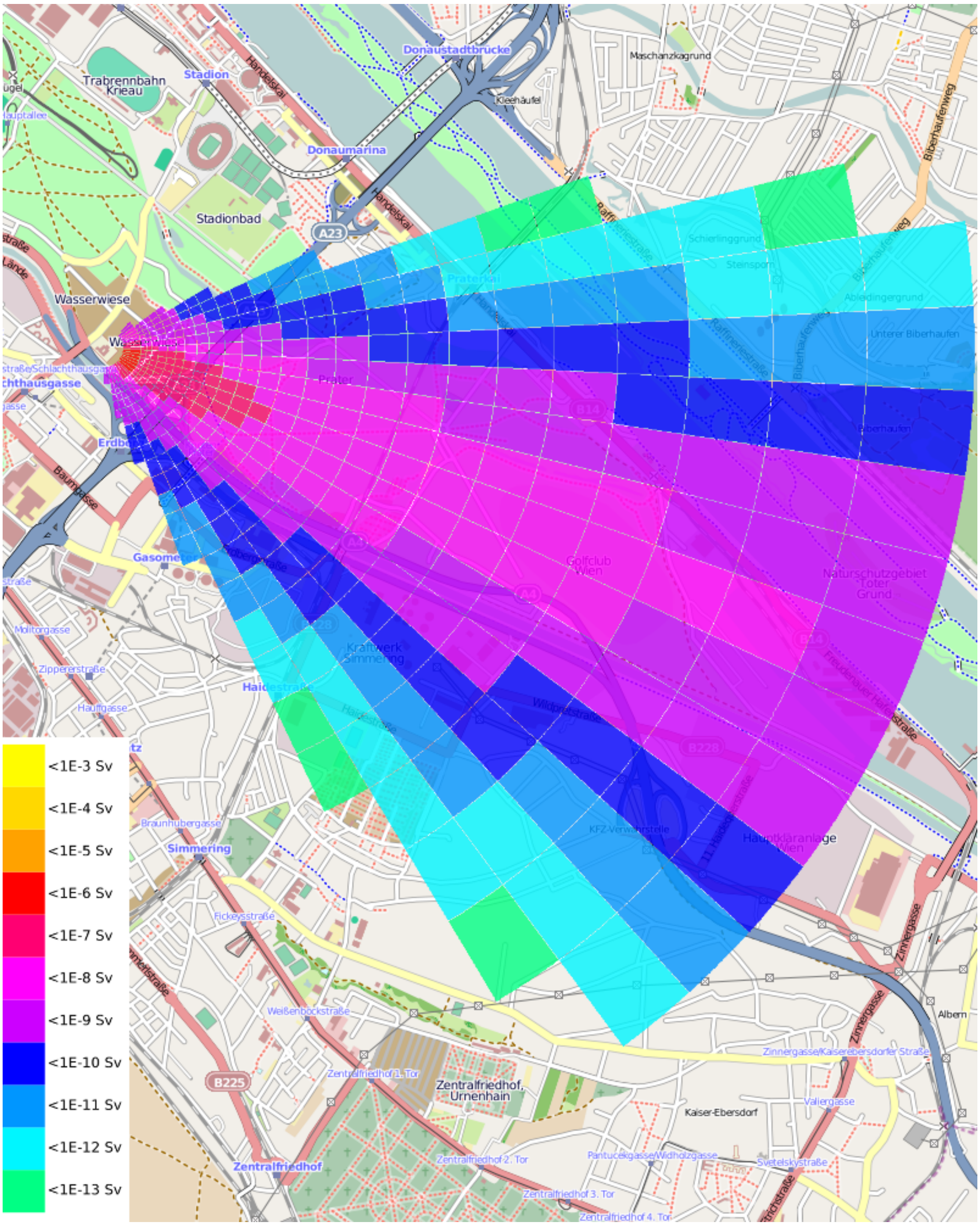


Figure 4.14: Scenario 3 - effective dose after (ICRP-60) 50 years

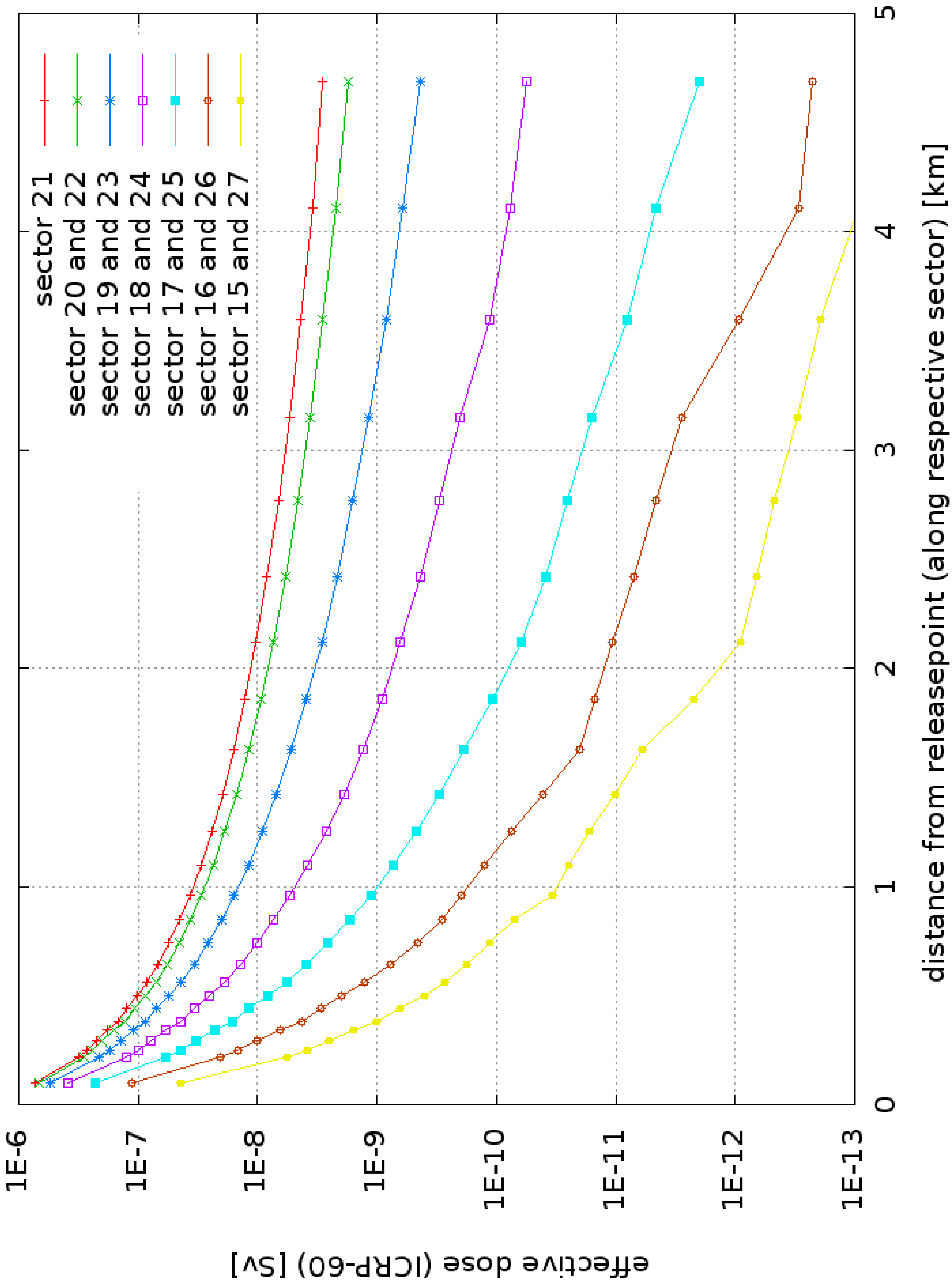
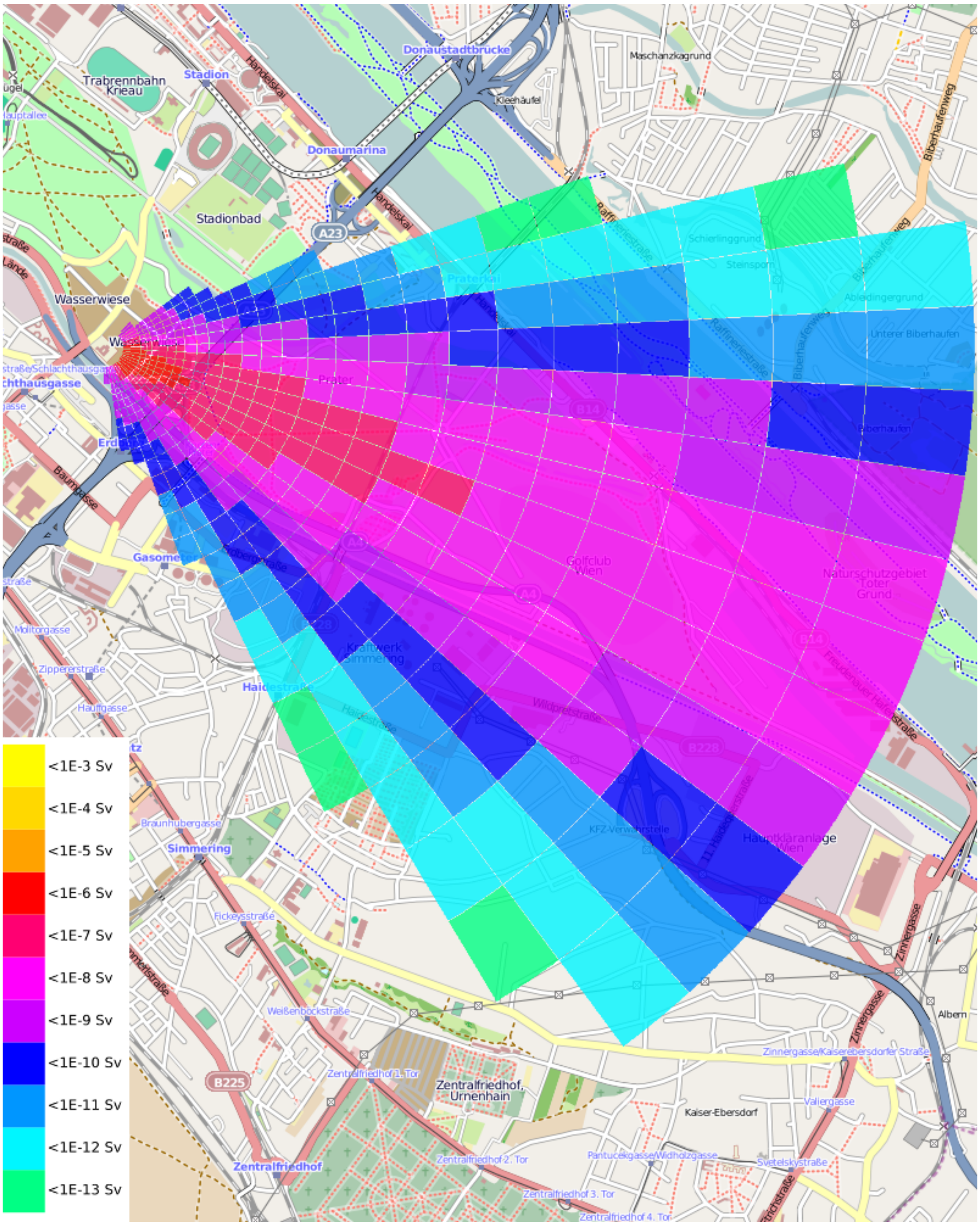


Figure 4.15: Scenario 3 - effective dose (ICRP-60) after 50 years



4.4 Worst case Scenario 4 - Case of a large plane crash

In Scenario 4 the case of a large plane crash was regarded. It was assumed, that the **building was fully damaged**. The **height of the building** was assumed with **1m**, the **width of the building** was assumed with **20m** and the **release height** was assumed with **1m**. In the safety report[12], the height of the building and the release height were assumed with 0.5m, which is not possible in PC COSYMA, because only integral numbers are allowed. The fission product inventory of all fuel elements in the reactor core was evaluated with ORIGEN[16] and is tabulated (only nuclides, which were considered in PC COSYMA) in Appendix A. The position of all fuel elements in the reactor core see 4.7. The fission product inventory of the whole reactor core (summed over all fuel elements) is presented in table 4.5 (only nuclides which were considered in the calculation).
After a large plane crash, only a fraction of the whole inventory is released. To define the fraction of the released noble gases and halogens, the formula

$$w_i = e_i \cdot f_i \cdot g_i,$$

was used, whereas e_i defines the fraction of fission products, which migrate into the gap between fuel and fuel element cladding. f_i defines the fraction of the fission products, which migrate from the gap between fuel and fuel element cladding into the water tank. g_i defines the fraction of the fission products, which are released from the water tank into the atmosphere. The index N is used for noble gases and the index H is used for halogens.

Noble gases

For e_N, f_N and g_N the same assumptions were used as in the safety report[12]. e_N describes the amount of noble gases, which reach the gap between fuel and fuel element cladding and has the value 1. This means all noble gases reach the gap between fuel and fuel element cladding. Further was assumed, that 100% of all noble gases were released from the gap between fuel and fuel element cladding into the water tank and all noble gases from the water tank were released into the atmosphere. In table 4.12 a list of all release fractions and the total release fraction w_N of noble gases is presented.

	noble gases
e_E	1
f_E	1
g_E	1
w_E	1

Table 4.12: Scenario 4 - release fraction of noble gases

Halogens

For e_H, f_H and g_H the same assumptions were used as in the safety report[12]. e_H is the empirically found parameter from General Atomic and describes the amount of halogens, which reach the gap between fuel and fuel element cladding. The safety report[12] partitioned halogens into two classes, organic halogens and other halogens. In this report was assumed that 100% of all halogens were released from the gap between fuel and fuel element cladding into the water tank. It was assumed that 100% of all halogens in the water tank were released into the atmosphere. Further was assumed, that 10% of all halogens were in organic form and the rest was in other form. In table 4.13 a list of release fractions for organically bound halogens, halogens in other chemical form and the total release fraction of halogens is presented. The only halogen, which was used in the calculation was iodine. In PC COSYMA, isotopes of iodine are partitioned into three chemical forms. These are organically bound iodine, elementary bound iodine and aerosol iodine. Each chemical form has different deposition parameters, which were explained in section 3.4. In the safety report[12] was assumed that 10% of the released iodine was organically bound and 90% was in other form. For the calculations was assumed that 50% of the other iodine was elementary bound iodine and 50% was in aerosol

	organically bound halogens	other halogens	
e_H	$1.5 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	
f_H	1	1	
g_H	0.1	0.9	
w_H	$1.5 \cdot 10^{-6}$	$1.35 \cdot 10^{-5}$	$\sum \ldots 1.5 \cdot 10^{-5}$

Table 4.13: Scenario 4 - release fraction of organic halogens and other halogens

organically bound iodine	10 %
elementary bound iodine	45 %
aerosol iodine	45 %

Table 4.14: Scenario 4 - chemical form of released iodine

form. In table 4.14 the distribution of the chemical form (of the released iodine), which was used in the calculation, is presented.

Analysis of Scenario 4

A Pasquill stability class F, a wind speed of 1m/s and no rain were assumed in the safety report[12]. Instead of Pasquill stability class F, Pasquill stability class E was used in this calculation, because the effective dose (ICRP-60) in this case is higher. The wind direction in the safety report[12] was assumed with W, which was changed to WNW in this calculation, because of measurements with the weather station.
In figure 4.16 and 4.17 the **effective dose (ICRP-60) in Sv after one day** is presented for the most affected sectors. The release point is the Atomic Institute and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.60km the dose is less than $1 \cdot 10^{-4}$ Sv and exterior a radius of 4.38km the dose is less than $1 \cdot 10^{-5}$ Sv.
In figure 4.18 and 4.19 the **effective dose (ICRP-60) in Sv after 50 years** is presented for the most affected sectors. The release point is the Atomic Institute

and the wind direction is WNW. The dose is evaluated in an area within 5km distance from the release point. Exterior a radius of 0.60km the dose is less than $1 \cdot 10^{-4}$ Sv and exterior a radius of 4.38km the dose is less than $1 \cdot 10^{-5}$ Sv.
The effective dose (ICRP-60) after one day with **different Pasquill stability classes**, a wind speed of $1m/s$ and a rain rate of $0mm/h$ see figure B.19, the effective dose (ICRP-60) after 50 years see figure B.20.
The effective dose (ICRP-60) after one day with **different wind speeds**, Pasquill stability class E and a rain rate of $0mm/h$ see figure B.21, the effective dose (ICRP-60) after 50 years see figure B.22.
The effective dose (ICRP-60) after one day with **different rain rates**, Pasquill stability class E and a wind speed of $1m/s$ see figure B.23, the effective dose (ICRP-60) after 50 years see figure B.24.

Figure 4.16: Scenario 4 - effective dose (ICRP-60) after 1 day

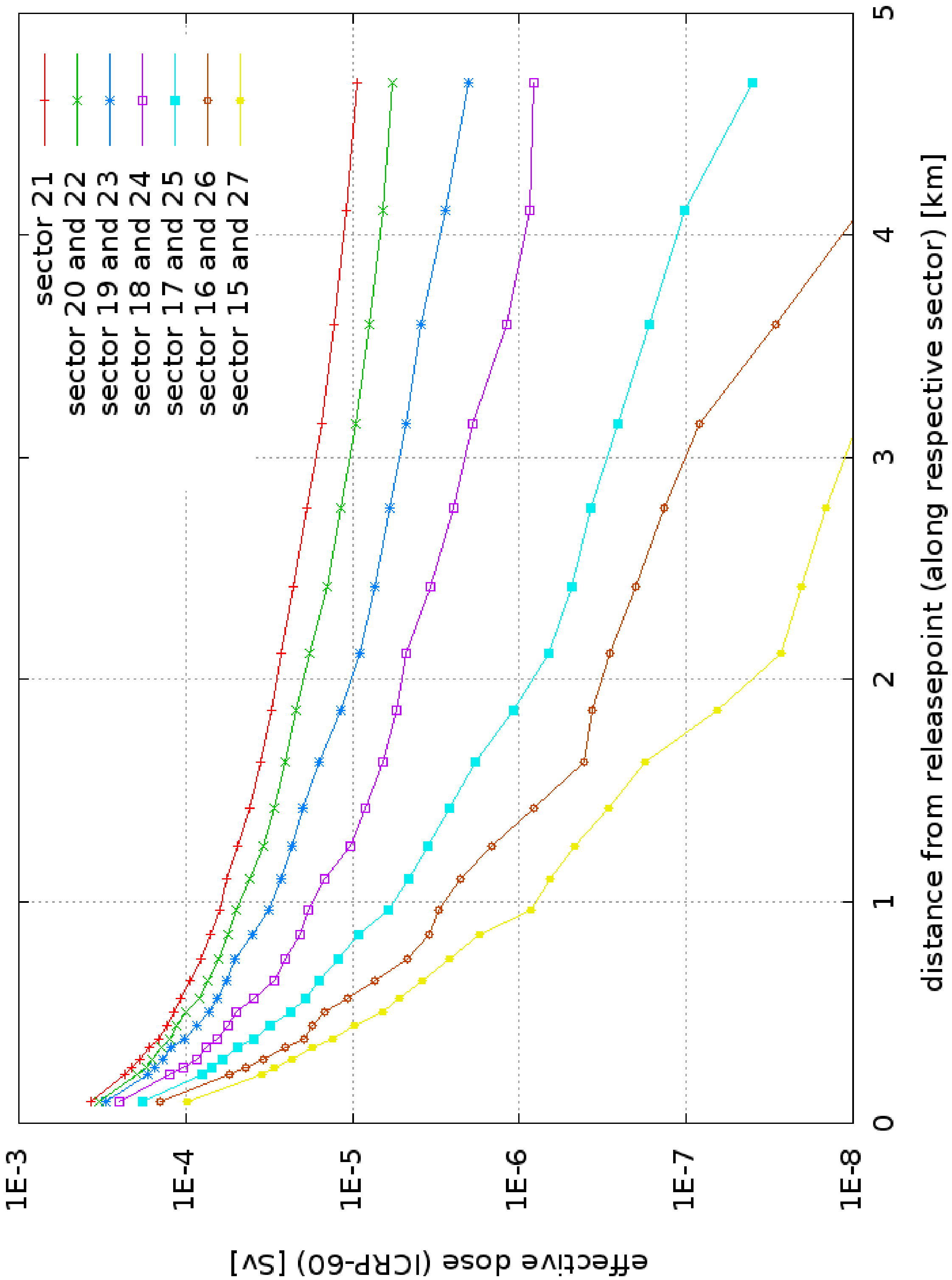


Figure 4.17: Scenario 4 - effective dose (ICRP-60) after 1 day

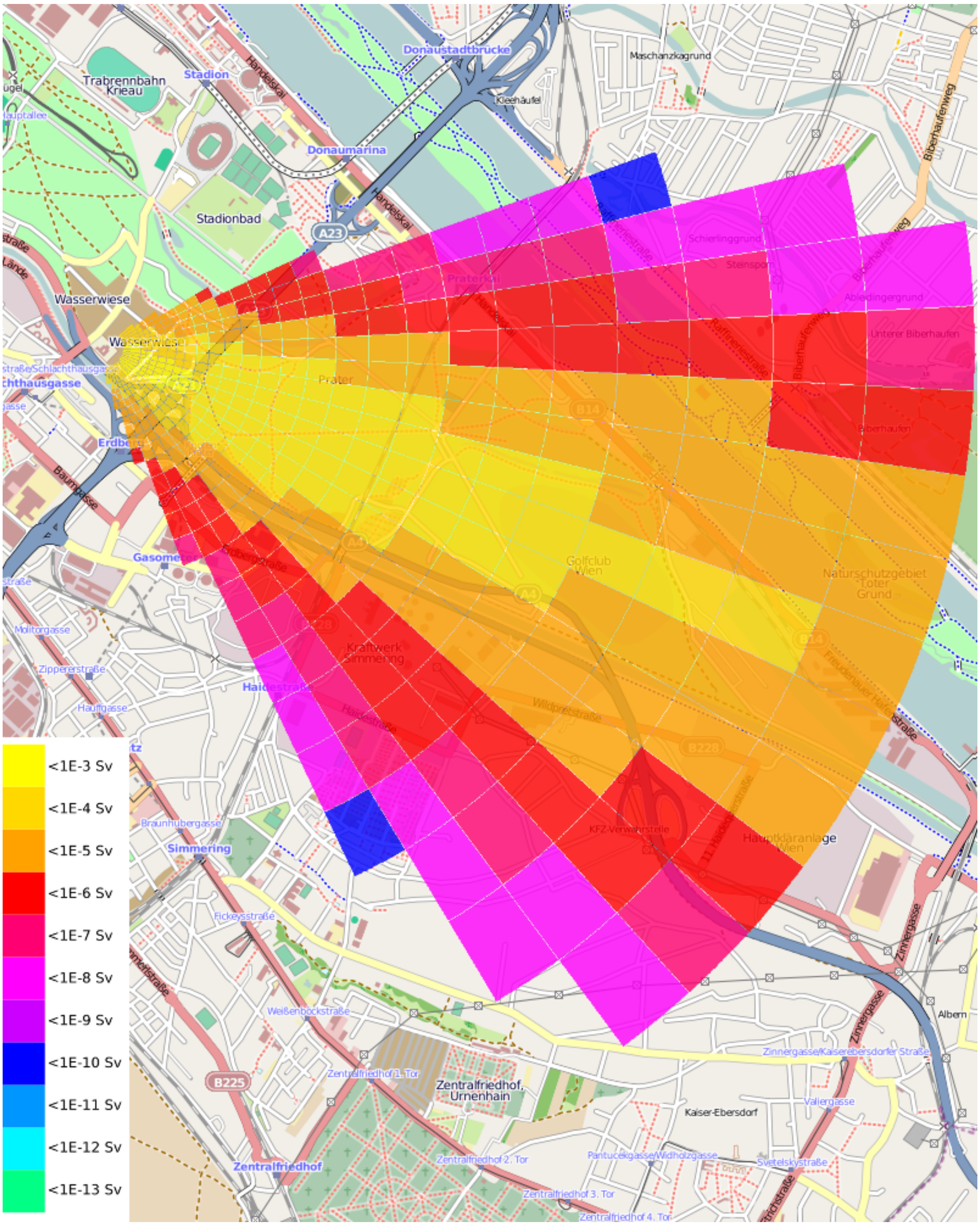


Figure 4.18: Scenario 4 - effective dose (ICRP-60) after 50 years

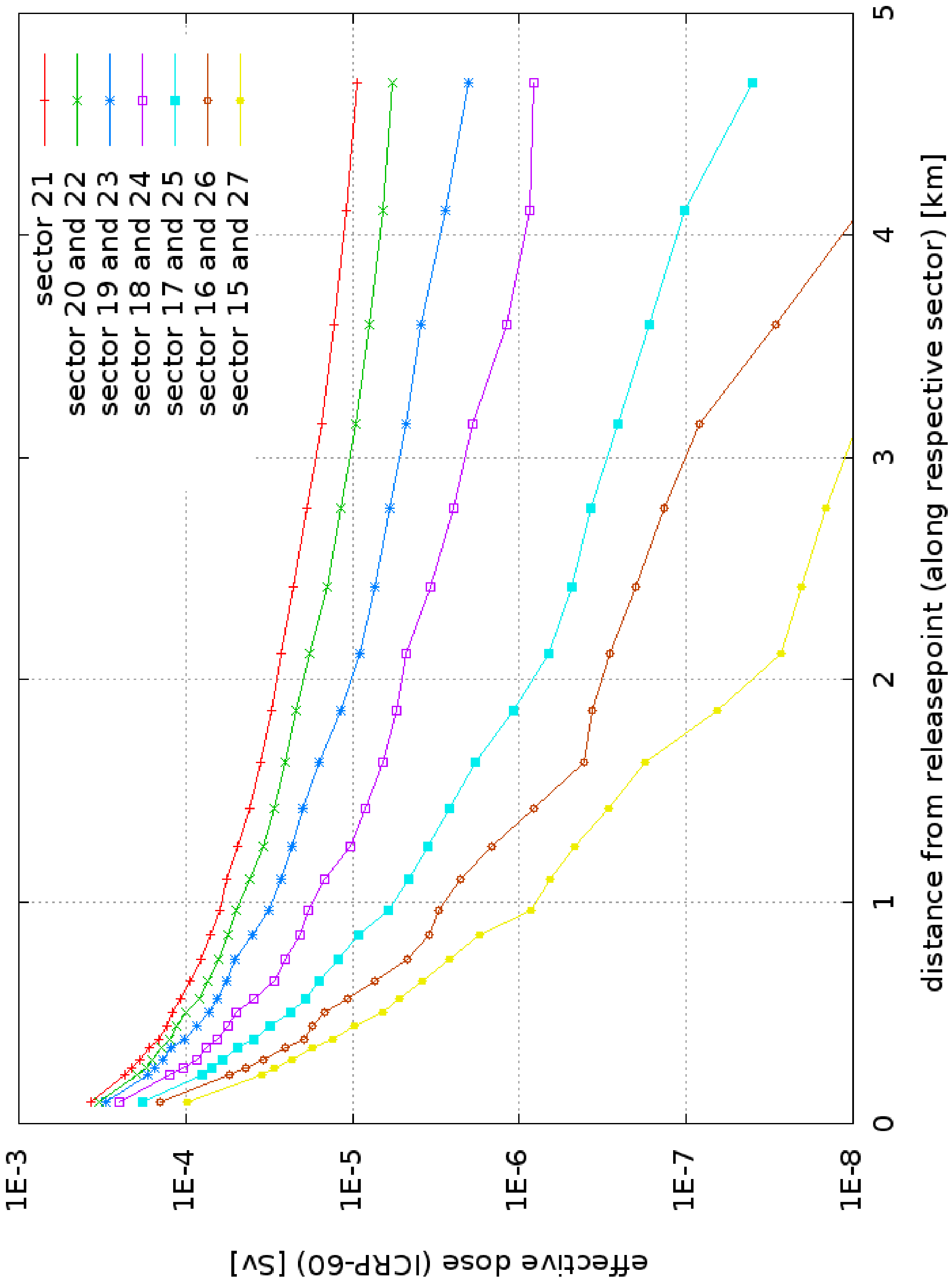
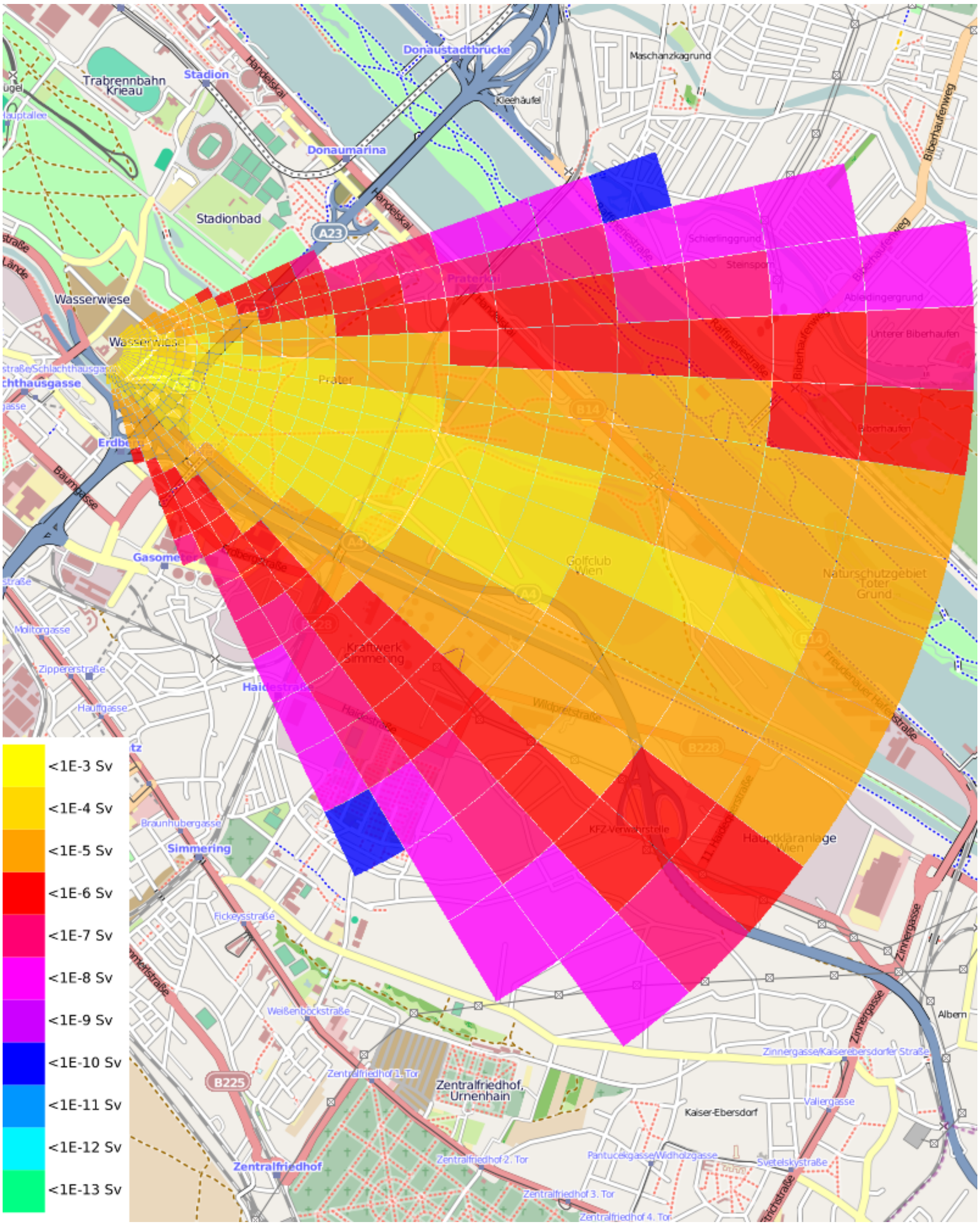


Figure 4.19: Scenario 4 - effective dose (ICRP-60) after 50 years



A Fission Product Inventory of each fuel element

(reactor operation from March 9^{th} 1962 to June 30^{th} 2009)

	2058 inventory [Bq]	2074 inventory [Bq]	2075 inventory [Bq]	2103 inventory [Bq]	2108 inventory [Bq]
Kr-83m	$4.11 \cdot 10^{10}$	$4.57 \cdot 10^{10}$	$4.67 \cdot 10^{10}$	$4.24 \cdot 10^{10}$	$4.37 \cdot 10^{10}$
Kr-85m	$9.66 \cdot 10^{10}$	$1.07 \cdot 10^{11}$	$1.10 \cdot 10^{11}$	$9.98 \cdot 10^{10}$	$1.03 \cdot 10^{11}$
Kr-85	$1.97 \cdot 10^{10}$	$2.19 \cdot 10^{10}$	$2.24 \cdot 10^{10}$	$2.03 \cdot 10^{10}$	$2.10 \cdot 10^{10}$
Kr-87	$1.95 \cdot 10^{11}$	$2.17 \cdot 10^{11}$	$2.22 \cdot 10^{11}$	$2.01 \cdot 10^{11}$	$2.07 \cdot 10^{11}$
Kr-88	$2.75 \cdot 10^{11}$	$3.06 \cdot 10^{11}$	$3.13 \cdot 10^{11}$	$2.84 \cdot 10^{11}$	$2.93 \cdot 10^{11}$
I-129	$1.17 \cdot 10^{5}$	$1.31 \cdot 10^{5}$	$1.34 \cdot 10^{5}$	$1.19 \cdot 10^{5}$	$1.25 \cdot 10^{5}$
I-130	$8.43 \cdot 10^{8}$	$1.07 \cdot 10^{9}$	$1.12 \cdot 10^{9}$	$8.86 \cdot 10^{8}$	$9.63 \cdot 10^{8}$
I-131	$2.24 \cdot 10^{11}$	$2.50 \cdot 10^{11}$	$2.55 \cdot 10^{11}$	$2.32 \cdot 10^{11}$	$2.39 \cdot 10^{11}$
I-132	$3.34 \cdot 10^{11}$	$3.72 \cdot 10^{11}$	$3.80 \cdot 10^{11}$	$3.45 \cdot 10^{11}$	$3.55 \cdot 10^{11}$
I-133	$5.19 \cdot 10^{11}$	$5.79 \cdot 10^{11}$	$5.91 \cdot 10^{11}$	$5.37 \cdot 10^{11}$	$5.53 \cdot 10^{11}$
I-134	$5.86 \cdot 10^{11}$	$6.53 \cdot 10^{11}$	$6.67 \cdot 10^{11}$	$6.05 \cdot 10^{11}$	$6.23 \cdot 10^{11}$
I-135	$4.84 \cdot 10^{11}$	$5.39 \cdot 10^{11}$	$5.51 \cdot 10^{11}$	$5.00 \cdot 10^{11}$	$5.15 \cdot 10^{11}$
Xe-131m	$2.49 \cdot 10^{9}$	$2.78 \cdot 10^{9}$	$2.84 \cdot 10^{9}$	$2.57 \cdot 10^{9}$	$2.65 \cdot 10^{9}$
Xe-133m	$1.52 \cdot 10^{10}$	$1.70 \cdot 10^{10}$	$1.74 \cdot 10^{10}$	$1.57 \cdot 10^{10}$	$1.62 \cdot 10^{10}$
Xe-133	$5.20 \cdot 10^{11}$	$5.79 \cdot 10^{11}$	$5.92 \cdot 10^{11}$	$5.37 \cdot 10^{11}$	$5.53 \cdot 10^{11}$
Xe-135m	$8.83 \cdot 10^{10}$	$9.85 \cdot 10^{10}$	$1.01 \cdot 10^{11}$	$9.12 \cdot 10^{10}$	$9.40 \cdot 10^{10}$
Xe-135	$4.94 \cdot 10^{11}$	$5.49 \cdot 10^{11}$	$5.61 \cdot 10^{11}$	$5.10 \cdot 10^{11}$	$5.25 \cdot 10^{11}$
Xe-138	$4.78 \cdot 10^{11}$	$5.33 \cdot 10^{11}$	$5.44 \cdot 10^{11}$	$4.94 \cdot 10^{11}$	$5.09 \cdot 10^{11}$

	2109 inventory [Bq]	2118 inventory [Bq]	2127 inventory [Bq]	2130 inventory [Bq]	2131 inventory [Bq]
Kr-83m	$4.69 \cdot 10^{10}$	$4.47 \cdot 10^{10}$	$3.71 \cdot 10^{10}$	$4.57 \cdot 10^{10}$	$4.55 \cdot 10^{10}$
Kr-85m	$1.10 \cdot 10^{11}$	$1.05 \cdot 10^{11}$	$8.74 \cdot 10^{10}$	$1.07 \cdot 10^{11}$	$1.07 \cdot 10^{11}$
Kr-85	$2.25 \cdot 10^{10}$	$2.14 \cdot 10^{10}$	$1.78 \cdot 10^{10}$	$2.19 \cdot 10^{10}$	$2.18 \cdot 10^{10}$
Kr-87	$2.23 \cdot 10^{11}$	$2.12 \cdot 10^{11}$	$1.76 \cdot 10^{11}$	$2.17 \cdot 10^{11}$	$2.16 \cdot 10^{11}$
Kr-88	$3.15 \cdot 10^{11}$	$3.00 \cdot 10^{11}$	$2.49 \cdot 10^{11}$	$3.06 \cdot 10^{11}$	$3.05 \cdot 10^{11}$
I-129	$1.34 \cdot 10^{5}$	$1.28 \cdot 10^{5}$	$1.06 \cdot 10^{5}$	$1.31 \cdot 10^{5}$	$1.30 \cdot 10^{5}$
I-130	$1.13 \cdot 10^{9}$	$1.02 \cdot 10^{9}$	$7.05 \cdot 10^{8}$	$1.07 \cdot 10^{9}$	$1.06 \cdot 10^{9}$
I-131	$2.57 \cdot 10^{11}$	$2.44 \cdot 10^{11}$	$2.03 \cdot 10^{11}$	$2.50 \cdot 10^{11}$	$2.49 \cdot 10^{11}$
I-132	$3.82 \cdot 10^{11}$	$3.63 \cdot 10^{11}$	$3.01 \cdot 10^{11}$	$3.72 \cdot 10^{11}$	$3.70 \cdot 10^{11}$
I-133	$5.94 \cdot 10^{11}$	$5.66 \cdot 10^{11}$	$4.70 \cdot 10^{11}$	$5.79 \cdot 10^{11}$	$5.76 \cdot 10^{11}$
I-134	$6.70 \cdot 10^{11}$	$6.38 \cdot 10^{11}$	$5.29 \cdot 10^{11}$	$6.53 \cdot 10^{11}$	$6.49 \cdot 10^{11}$
I-135	$5.54 \cdot 10^{11}$	$5.27 \cdot 10^{11}$	$4.37 \cdot 10^{11}$	$5.39 \cdot 10^{11}$	$5.36 \cdot 10^{11}$
Xe-131m	$2.85 \cdot 10^{9}$	$2.71 \cdot 10^{9}$	$2.25 \cdot 10^{9}$	$2.78 \cdot 10^{9}$	$2.76 \cdot 10^{9}$
Xe-133m	$1.74 \cdot 10^{10}$	$1.66 \cdot 10^{10}$	$1.38 \cdot 10^{10}$	$1.70 \cdot 10^{10}$	$1.69 \cdot 10^{10}$
Xe-133	$5.95 \cdot 10^{11}$	$5.66 \cdot 10^{11}$	$4.70 \cdot 10^{11}$	$5.79 \cdot 10^{11}$	$5.76 \cdot 10^{11}$
Xe-135m	$1.01 \cdot 10^{11}$	$9.62 \cdot 10^{10}$	$7.98 \cdot 10^{10}$	$9.85 \cdot 10^{10}$	$9.80 \cdot 10^{10}$
Xe-135	$5.64 \cdot 10^{11}$	$5.37 \cdot 10^{11}$	$4.47 \cdot 10^{11}$	$5.49 \cdot 10^{11}$	$5.46 \cdot 10^{11}$
Xe-138	$5.47 \cdot 10^{11}$	$5.21 \cdot 10^{11}$	$4.33 \cdot 10^{11}$	$5.33 \cdot 10^{11}$	$5.30 \cdot 10^{11}$

Table A.1: Inventory of 102-type fuel elements 2058, 2074, 2075, 2103, 2108, 2109, 2118, 2127, 2130 and 2131 in Bq (only nuclides, which were considered in PC COSYMA)

	2132 inventory [Bq]	2133 inventory [Bq]	2134 inventory [Bq]	2135 inventory [Bq]	2136 inventory [Bq]
Kr-83m	$4.32\cdot10^{10}$	$4.14\cdot10^{10}$	$4.43\cdot10^{10}$	$3.96\cdot10^{10}$	$3.66\cdot10^{10}$
Kr-85m	$1.02\cdot10^{11}$	$9.75\cdot10^{10}$	$1.04\cdot10^{11}$	$9.32\cdot10^{10}$	$8.62\cdot10^{10}$
Kr-85	$2.07\cdot10^{10}$	$1.99\cdot10^{10}$	$2.12\cdot10^{10}$	$1.90\cdot10^{10}$	$1.76\cdot10^{10}$
Kr-87	$2.05\cdot10^{11}$	$1.97\cdot10^{11}$	$2.10\cdot10^{11}$	$1.88\cdot10^{11}$	$1.74\cdot10^{11}$
Kr-88	$2.89\cdot10^{11}$	$2.78\cdot10^{11}$	$2.97\cdot10^{11}$	$2.66\cdot10^{11}$	$2.46\cdot10^{11}$
I-129	$1.22\cdot10^{5}$	$1.19\cdot10^{5}$	$1.27\cdot10^{5}$	$1.13\cdot10^{5}$	$1.05\cdot10^{5}$
I-130	$9.29\cdot10^{8}$	$8.61\cdot10^{8}$	$9.98\cdot10^{8}$	$8.10\cdot10^{8}$	$6.85\cdot10^{8}$
I-131	$2.36\cdot10^{11}$	$2.26\cdot10^{11}$	$2.42\cdot10^{11}$	$2.16\cdot10^{11}$	$2.00\cdot10^{11}$
I-132	$3.51\cdot10^{11}$	$3.37\cdot10^{11}$	$3.60\cdot10^{11}$	$3.22\cdot10^{11}$	$2.97\cdot10^{11}$
I-133	$5.46\cdot10^{11}$	$5.24\cdot10^{11}$	$5.61\cdot10^{11}$	$5.01\cdot10^{11}$	$4.63\cdot10^{11}$
I-134	$6.16\cdot10^{11}$	$5.92\cdot10^{11}$	$6.32\cdot10^{11}$	$5.65\cdot10^{11}$	$5.22\cdot10^{11}$
I-135	$5.09\cdot10^{11}$	$4.88\cdot10^{11}$	$5.22\cdot10^{11}$	$4.67\cdot10^{11}$	$4.31\cdot10^{11}$
Xe-131m	$2.62\cdot10^{9}$	$2.52\cdot10^{9}$	$2.69\cdot10^{9}$	$2.40\cdot10^{9}$	$2.22\cdot10^{9}$
Xe-133m	$1.60\cdot10^{10}$	$1.54\cdot10^{10}$	$1.64\cdot10^{10}$	$1.47\cdot10^{10}$	$1.36\cdot10^{10}$
Xe-133	$5.47\cdot10^{11}$	$5.25\cdot10^{11}$	$5.61\cdot10^{11}$	$5.02\cdot10^{11}$	$4.63\cdot10^{11}$
Xe-135m	$9.29\cdot10^{10}$	$8.92\cdot10^{10}$	$9.53\cdot10^{10}$	$8.52\cdot10^{10}$	$7.87\cdot10^{10}$
Xe-135	$5.19\cdot10^{11}$	$4.99\cdot10^{11}$	$5.32\cdot10^{11}$	$4.77\cdot10^{11}$	$4.41\cdot10^{11}$
Xe-138	$5.03\cdot10^{11}$	$4.83\cdot10^{11}$	$5.16\cdot10^{11}$	$4.61\cdot10^{11}$	$4.27\cdot10^{11}$

	2138 inventory [Bq]	2139 inventory [Bq]	2140 inventory [Bq]	2141 inventory [Bq]	2145 inventory [Bq]
Kr-83m	$3.69\cdot10^{10}$	$3.87\cdot10^{10}$	$4.00\cdot10^{10}$	$4.85\cdot10^{10}$	$4.31\cdot10^{10}$
Kr-85m	$8.68\cdot10^{10}$	$9.10\cdot10^{10}$	$9.41\cdot10^{10}$	$1.14\cdot10^{11}$	$1.01\cdot10^{11}$
Kr-85	$1.77\cdot10^{10}$	$1.86\cdot10^{10}$	$1.92\cdot10^{10}$	$2.33\cdot10^{10}$	$2.06\cdot10^{10}$
Kr-87	$1.75\cdot10^{11}$	$1.84\cdot10^{11}$	$1.90\cdot10^{11}$	$2.30\cdot10^{11}$	$2.05\cdot10^{11}$
Kr-88	$2.47\cdot10^{11}$	$2.60\cdot10^{11}$	$2.68\cdot10^{11}$	$3.25\cdot10^{11}$	$2.89\cdot10^{11}$
I-129	$1.05\cdot10^{5}$	$1.11\cdot10^{5}$	$1.14\cdot10^{5}$	$1.39\cdot10^{5}$	$1.21\cdot10^{5}$
I-130	$6.95\cdot10^{8}$	$7.70\cdot10^{8}$	$8.23\cdot10^{8}$	$1.22\cdot10^{9}$	$9.18\cdot10^{8}$
I-131	$2.01\cdot10^{11}$	$2.11\cdot10^{11}$	$2.18\cdot10^{11}$	$2.66\cdot10^{11}$	$2.35\cdot10^{11}$
I-132	$2.99\cdot10^{11}$	$3.14\cdot10^{11}$	$3.25\cdot10^{11}$	$3.95\cdot10^{11}$	$3.50\cdot10^{11}$
I-133	$4.66\cdot10^{11}$	$4.89\cdot10^{11}$	$5.06\cdot10^{11}$	$6.14\cdot10^{11}$	$5.45\cdot10^{11}$
I-134	$5.26\cdot10^{11}$	$5.52\cdot10^{11}$	$5.71\cdot10^{11}$	$6.93\cdot10^{11}$	$6.15\cdot10^{11}$
I-135	$4.34\cdot10^{11}$	$4.55\cdot10^{11}$	$4.71\cdot10^{11}$	$5.72\cdot10^{11}$	$5.08\cdot10^{11}$
Xe-131m	$2.24\cdot10^{9}$	$2.35\cdot10^{9}$	$2.42\cdot10^{9}$	$2.95\cdot10^{9}$	$2.61\cdot10^{9}$
Xe-133m	$1.37\cdot10^{10}$	$1.43\cdot10^{10}$	$1.48\cdot10^{10}$	$1.80\cdot10^{10}$	$1.60\cdot10^{10}$
Xe-133	$4.67\cdot10^{11}$	$4.90\cdot10^{11}$	$5.07\cdot10^{11}$	$6.15\cdot10^{11}$	$5.45\cdot10^{11}$
Xe-135m	$7.92\cdot10^{10}$	$8.32\cdot10^{10}$	$8.60\cdot10^{10}$	$1.05\cdot10^{11}$	$9.27\cdot10^{10}$
Xe-135	$4.44\cdot10^{11}$	$4.66\cdot10^{11}$	$4.81\cdot10^{11}$	$5.82\cdot10^{11}$	$5.18\cdot10^{11}$
Xe-138	$4.30\cdot10^{11}$	$4.51\cdot10^{11}$	$4.66\cdot10^{11}$	$5.65\cdot10^{11}$	$5.02\cdot10^{11}$

Table A.2: Inventory of 102-type fuel elements 2132, 2133, 2134, 2135, 2136, 2138, 2139, 2140, 2141 and 2145 in Bq (only nuclides, which were considered in PC COSYMA)

	2149 inventory [Bq]	2151 inventory [Bq]	2152 inventory [Bq]	2154 inventory [Bq]	2155 inventory [Bq]
Kr-83m	$4.53{\cdot}10^{10}$	$4.57{\cdot}10^{10}$	$4.37{\cdot}10^{10}$	$4.18{\cdot}10^{10}$	$4.57{\cdot}10^{10}$
Kr-85m	$1.06{\cdot}10^{11}$	$1.07{\cdot}10^{11}$	$1.03{\cdot}10^{11}$	$9.82{\cdot}10^{10}$	$1.07{\cdot}10^{11}$
Kr-85	$2.17{\cdot}10^{10}$	$2.19{\cdot}10^{10}$	$2.10{\cdot}10^{10}$	$2.00{\cdot}10^{10}$	$2.19{\cdot}10^{10}$
Kr-87	$2.15{\cdot}10^{11}$	$2.17{\cdot}10^{11}$	$2.07{\cdot}10^{11}$	$1.98{\cdot}10^{11}$	$2.17{\cdot}10^{11}$
Kr-88	$3.03{\cdot}10^{11}$	$3.06{\cdot}10^{11}$	$2.93{\cdot}10^{11}$	$2.80{\cdot}10^{11}$	$3.06{\cdot}10^{11}$
I-129	$1.30{\cdot}10^{5}$	$1.31{\cdot}10^{5}$	$1.25{\cdot}10^{5}$	$1.19{\cdot}10^{5}$	$1.31{\cdot}10^{5}$
I-130	$1.05{\cdot}10^{9}$	$1.07{\cdot}10^{9}$	$9.63{\cdot}10^{8}$	$8.74{\cdot}10^{8}$	$1.07{\cdot}10^{9}$
I-131	$2.48{\cdot}10^{11}$	$2.50{\cdot}10^{11}$	$2.39{\cdot}10^{11}$	$2.28{\cdot}10^{11}$	$2.50{\cdot}10^{11}$
I-132	$3.68{\cdot}10^{11}$	$3.72{\cdot}10^{11}$	$3.55{\cdot}10^{11}$	$3.39{\cdot}10^{11}$	$3.72{\cdot}10^{11}$
I-133	$5.73{\cdot}10^{11}$	$5.79{\cdot}10^{11}$	$5.53{\cdot}10^{11}$	$5.28{\cdot}10^{11}$	$5.79{\cdot}10^{11}$
I-134	$6.46{\cdot}10^{11}$	$6.53{\cdot}10^{11}$	$6.23{\cdot}10^{11}$	$5.96{\cdot}10^{11}$	$6.53{\cdot}10^{11}$
I-135	$5.34{\cdot}10^{11}$	$5.39{\cdot}10^{11}$	$5.15{\cdot}10^{11}$	$4.92{\cdot}10^{11}$	$5.39{\cdot}10^{11}$
Xe-131m	$2.75{\cdot}10^{9}$	$2.78{\cdot}10^{9}$	$2.65{\cdot}10^{9}$	$2.53{\cdot}10^{9}$	$2.78{\cdot}10^{9}$
Xe-133m	$1.68{\cdot}10^{10}$	$1.70{\cdot}10^{10}$	$1.62{\cdot}10^{10}$	$1.55{\cdot}10^{10}$	$1.70{\cdot}10^{10}$
Xe-133	$5.74{\cdot}10^{11}$	$5.79{\cdot}10^{11}$	$5.53{\cdot}10^{11}$	$5.29{\cdot}10^{11}$	$5.79{\cdot}10^{11}$
Xe-135m	$9.75{\cdot}10^{10}$	$9.85{\cdot}10^{10}$	$9.40{\cdot}10^{10}$	$8.98{\cdot}10^{10}$	$9.85{\cdot}10^{10}$
Xe-135	$5.44{\cdot}10^{11}$	$5.49{\cdot}10^{11}$	$5.25{\cdot}10^{11}$	$5.02{\cdot}10^{11}$	$5.49{\cdot}10^{11}$
Xe-138	$5.28{\cdot}10^{11}$	$5.33{\cdot}10^{11}$	$5.09{\cdot}10^{11}$	$4.87{\cdot}10^{11}$	$5.33{\cdot}10^{11}$

	2157 inventory [Bq]	2158 inventory [Bq]	2159 inventory [Bq]	2160 inventory [Bq]	2161 inventory [Bq]
Kr-83m	$4.13{\cdot}10^{10}$	$4.37{\cdot}10^{10}$	$4.36{\cdot}10^{10}$	$4.57{\cdot}10^{10}$	$4.28{\cdot}10^{10}$
Kr-85m	$9.71{\cdot}10^{10}$	$1.03{\cdot}10^{11}$	$1.03{\cdot}10^{11}$	$1.07{\cdot}10^{11}$	$1.01{\cdot}10^{11}$
Kr-85	$1.98{\cdot}10^{10}$	$2.10{\cdot}10^{10}$	$2.09{\cdot}10^{10}$	$2.19{\cdot}10^{10}$	$2.05{\cdot}10^{10}$
Kr-87	$1.96{\cdot}10^{11}$	$2.07{\cdot}10^{11}$	$2.07{\cdot}10^{11}$	$2.17{\cdot}10^{11}$	$2.03{\cdot}10^{11}$
Kr-88	$2.77{\cdot}10^{11}$	$2.93{\cdot}10^{11}$	$2.92{\cdot}10^{11}$	$3.06{\cdot}10^{11}$	$2.87{\cdot}10^{11}$
I-129	$1.18{\cdot}10^{5}$	$1.25{\cdot}10^{5}$	$1.25{\cdot}10^{5}$	$1.31{\cdot}10^{5}$	$1.22{\cdot}10^{5}$
I-130	$8.53{\cdot}10^{8}$	$9.63{\cdot}10^{8}$	$9.61{\cdot}10^{8}$	$1.07{\cdot}10^{9}$	$9.21{\cdot}10^{8}$
I-131	$2.25{\cdot}10^{11}$	$2.39{\cdot}10^{11}$	$2.38{\cdot}10^{11}$	$2.50{\cdot}10^{11}$	$2.34{\cdot}10^{11}$
I-132	$3.35{\cdot}10^{11}$	$3.55{\cdot}10^{11}$	$3.55{\cdot}10^{11}$	$3.72{\cdot}10^{11}$	$3.48{\cdot}10^{11}$
I-133	$5.22{\cdot}10^{11}$	$5.53{\cdot}10^{11}$	$5.52{\cdot}10^{11}$	$5.79{\cdot}10^{11}$	$5.41{\cdot}10^{11}$
I-134	$5.89{\cdot}10^{11}$	$6.23{\cdot}10^{11}$	$6.23{\cdot}10^{11}$	$6.53{\cdot}10^{11}$	$6.11{\cdot}10^{11}$
I-135	$4.86{\cdot}10^{11}$	$5.15{\cdot}10^{11}$	$5.14{\cdot}10^{11}$	$5.39{\cdot}10^{11}$	$5.04{\cdot}10^{11}$
Xe-131m	$2.50{\cdot}10^{9}$	$2.65{\cdot}10^{9}$	$2.65{\cdot}10^{9}$	$2.78{\cdot}10^{9}$	$2.60{\cdot}10^{9}$
Xe-133m	$1.53{\cdot}10^{10}$	$1.62{\cdot}10^{10}$	$1.62{\cdot}10^{10}$	$1.70{\cdot}10^{10}$	$1.59{\cdot}10^{10}$
Xe-133	$5.22{\cdot}10^{11}$	$5.53{\cdot}10^{11}$	$5.52{\cdot}10^{11}$	$5.79{\cdot}10^{11}$	$5.42{\cdot}10^{11}$
Xe-135m	$8.88{\cdot}10^{10}$	$9.40{\cdot}10^{10}$	$9.39{\cdot}10^{10}$	$9.85{\cdot}10^{10}$	$9.21{\cdot}10^{10}$
Xe-135	$4.97{\cdot}10^{11}$	$5.25{\cdot}10^{11}$	$5.25{\cdot}10^{11}$	$5.49{\cdot}10^{11}$	$5.15{\cdot}10^{11}$
Xe-138	$4.81{\cdot}10^{11}$	$5.09{\cdot}10^{11}$	$5.08{\cdot}10^{11}$	$5.33{\cdot}10^{11}$	$4.98{\cdot}10^{11}$

Table A.3: Inventory of 102-type fuel elements 2149, 2151, 2152, 2154, 2155, 2157, 2158, 2159, 2160 and 2161 in Bq (only nuclides, which were considered in PC COSYMA)

	2162 inventory [Bq]	2163 inventory [Bq]	2164 inventory [Bq]	2166 inventory [Bq]	2168 inventory [Bq]
Kr-83m	$4.37\cdot10^{10}$	$3.94\cdot10^{10}$	$4.53\cdot10^{10}$	$4.37\cdot10^{10}$	$4.28\cdot10^{10}$
Kr-85m	$1.03\cdot10^{11}$	$9.26\cdot10^{10}$	$1.06\cdot10^{11}$	$1.03\cdot10^{11}$	$1.01\cdot10^{11}$
Kr-85	$2.10\cdot10^{10}$	$1.89\cdot10^{10}$	$2.17\cdot10^{10}$	$2.10\cdot10^{10}$	$2.05\cdot10^{10}$
Kr-87	$2.07\cdot10^{11}$	$1.87\cdot10^{11}$	$2.15\cdot10^{11}$	$2.07\cdot10^{11}$	$2.03\cdot10^{11}$
Kr-88	$2.93\cdot10^{11}$	$2.64\cdot10^{11}$	$3.03\cdot10^{11}$	$2.93\cdot10^{11}$	$2.87\cdot10^{11}$
I-129	$1.25\cdot10^{5}$	$1.13\cdot10^{5}$	$1.30\cdot10^{5}$	$1.25\cdot10^{5}$	$1.23\cdot10^{5}$
I-130	$9.63\cdot10^{8}$	$8.00\cdot10^{8}$	$1.04\cdot10^{9}$	$9.63\cdot10^{8}$	$9.24\cdot10^{8}$
I-131	$2.39\cdot10^{11}$	$2.15\cdot10^{11}$	$2.47\cdot10^{11}$	$2.39\cdot10^{11}$	$2.34\cdot10^{11}$
I-132	$3.55\cdot10^{11}$	$3.20\cdot10^{11}$	$3.68\cdot10^{11}$	$3.55\cdot10^{11}$	$3.48\cdot10^{11}$
I-133	$5.53\cdot10^{11}$	$4.98\cdot10^{11}$	$5.73\cdot10^{11}$	$5.53\cdot10^{11}$	$5.42\cdot10^{11}$
I-134	$6.23\cdot10^{11}$	$5.62\cdot10^{11}$	$6.46\cdot10^{11}$	$6.23\cdot10^{11}$	$6.11\cdot10^{11}$
I-135	$5.15\cdot10^{11}$	$4.64\cdot10^{11}$	$5.33\cdot10^{11}$	$5.15\cdot10^{11}$	$5.05\cdot10^{11}$
Xe-131m	$2.65\cdot10^{9}$	$2.39\cdot10^{9}$	$2.75\cdot10^{9}$	$2.65\cdot10^{9}$	$2.60\cdot10^{9}$
Xe-133m	$1.62\cdot10^{10}$	$1.46\cdot10^{10}$	$1.68\cdot10^{10}$	$1.62\cdot10^{10}$	$1.59\cdot10^{10}$
Xe-133	$5.53\cdot10^{11}$	$4.99\cdot10^{11}$	$5.73\cdot10^{11}$	$5.53\cdot10^{11}$	$5.42\cdot10^{11}$
Xe-135m	$9.40\cdot10^{10}$	$8.47\cdot10^{10}$	$9.75\cdot10^{10}$	$9.40\cdot10^{10}$	$9.22\cdot10^{10}$
Xe-135	$5.25\cdot10^{11}$	$4.74\cdot10^{11}$	$5.44\cdot10^{11}$	$5.25\cdot10^{11}$	$5.15\cdot10^{11}$
Xe-138	$5.09\cdot10^{11}$	$4.59\cdot10^{11}$	$5.27\cdot10^{11}$	$5.09\cdot10^{11}$	$4.99\cdot10^{11}$

	2169 inventory [Bq]	2170 inventory [Bq]	2171 inventory [Bq]	2172 inventory [Bq]	2173 inventory [Bq]
Kr-83m	$4.37\cdot10^{10}$	$4.25\cdot10^{10}$	$4.57\cdot10^{10}$	$3.54\cdot10^{10}$	$3.83\cdot10^{10}$
Kr-85m	$1.03\cdot10^{11}$	$1.00\cdot10^{11}$	$1.07\cdot10^{11}$	$8.33\cdot10^{10}$	$9.01\cdot10^{10}$
Kr-85	$2.10\cdot10^{10}$	$2.04\cdot10^{10}$	$2.19\cdot10^{10}$	$1.68\cdot10^{10}$	$1.84\cdot10^{10}$
Kr-87	$2.07\cdot10^{11}$	$2.02\cdot10^{11}$	$2.17\cdot10^{11}$	$1.68\cdot10^{11}$	$1.82\cdot10^{11}$
Kr-88	$2.93\cdot10^{11}$	$2.85\cdot10^{11}$	$3.06\cdot10^{11}$	$2.38\cdot10^{11}$	$2.57\cdot10^{11}$
I-129	$1.25\cdot10^{5}$	$1.22\cdot10^{5}$	$1.31\cdot10^{5}$	$9.31\cdot10^{4}$	$1.09\cdot10^{5}$
I-130	$9.63\cdot10^{8}$	$9.08\cdot10^{8}$	$1.07\cdot10^{9}$	$5.81\cdot10^{8}$	$7.53\cdot10^{8}$
I-131	$2.39\cdot10^{11}$	$2.32\cdot10^{11}$	$2.50\cdot10^{11}$	$1.93\cdot10^{11}$	$2.09\cdot10^{11}$
I-132	$3.55\cdot10^{11}$	$3.45\cdot10^{11}$	$3.72\cdot10^{11}$	$2.87\cdot10^{11}$	$3.11\cdot10^{11}$
I-133	$5.53\cdot10^{11}$	$5.38\cdot10^{11}$	$5.79\cdot10^{11}$	$4.47\cdot10^{11}$	$4.84\cdot10^{11}$
I-134	$6.23\cdot10^{11}$	$6.07\cdot10^{11}$	$6.53\cdot10^{11}$	$5.04\cdot10^{11}$	$5.46\cdot10^{11}$
I-135	$5.15\cdot10^{11}$	$5.01\cdot10^{11}$	$5.39\cdot10^{11}$	$4.16\cdot10^{11}$	$4.51\cdot10^{11}$
Xe-131m	$2.65\cdot10^{9}$	$2.58\cdot10^{9}$	$2.78\cdot10^{9}$	$2.14\cdot10^{9}$	$2.32\cdot10^{9}$
Xe-133m	$1.62\cdot10^{10}$	$1.58\cdot10^{10}$	$1.70\cdot10^{10}$	$1.31\cdot10^{10}$	$1.42\cdot10^{10}$
Xe-133	$5.53\cdot10^{11}$	$5.38\cdot10^{11}$	$5.79\cdot10^{11}$	$4.47\cdot10^{11}$	$4.85\cdot10^{11}$
Xe-135m	$9.40\cdot10^{10}$	$9.15\cdot10^{10}$	$9.85\cdot10^{10}$	$7.59\cdot10^{10}$	$8.23\cdot10^{10}$
Xe-135	$5.25\cdot10^{11}$	$5.11\cdot10^{11}$	$5.49\cdot10^{11}$	$4.27\cdot10^{11}$	$4.61\cdot10^{11}$
Xe-138	$5.09\cdot10^{11}$	$4.95\cdot10^{11}$	$5.33\cdot10^{11}$	$4.12\cdot10^{11}$	$4.46\cdot10^{11}$

Table A.4: Inventory of 102-type fuel elements 2162, 2163, 2164, 2166, 2168, 2169, 2170, 2171, 2172 and 2173 in Bq (only nuclides, which were considered in PC COSYMA)

	2174 inventory [Bq]	**2175** inventory [Bq]	**2181** inventory [Bq]	**2182** inventory [Bq]	**2183** inventory [Bq]
Kr-83m	$4.43{\cdot}10^{10}$	$4.64{\cdot}10^{10}$	$4.67{\cdot}10^{10}$	$4.85{\cdot}10^{10}$	$4.53{\cdot}10^{10}$
Kr-85m	$1.04{\cdot}10^{11}$	$1.09{\cdot}10^{11}$	$1.10{\cdot}10^{11}$	$1.14{\cdot}10^{11}$	$1.06{\cdot}10^{11}$
Kr-85	$2.12{\cdot}10^{10}$	$2.23{\cdot}10^{10}$	$2.24{\cdot}10^{10}$	$2.33{\cdot}10^{10}$	$2.17{\cdot}10^{10}$
Kr-87	$2.10{\cdot}10^{11}$	$2.20{\cdot}10^{11}$	$2.22{\cdot}10^{11}$	$2.30{\cdot}10^{11}$	$2.15{\cdot}10^{11}$
Kr-88	$2.97{\cdot}10^{11}$	$3.11{\cdot}10^{11}$	$3.13{\cdot}10^{11}$	$3.25{\cdot}10^{11}$	$3.03{\cdot}10^{11}$
I-129	$1.27{\cdot}10^{5}$	$1.33{\cdot}10^{5}$	$1.34{\cdot}10^{5}$	$1.39{\cdot}10^{5}$	$1.30{\cdot}10^{5}$
I-130	$9.98{\cdot}10^{8}$	$1.11{\cdot}10^{9}$	$1.12{\cdot}10^{9}$	$1.22{\cdot}10^{9}$	$1.05{\cdot}10^{9}$
I-131	$2.42{\cdot}10^{11}$	$2.54{\cdot}10^{11}$	$2.55{\cdot}10^{11}$	$2.66{\cdot}10^{11}$	$2.48{\cdot}10^{11}$
I-132	$3.60{\cdot}10^{11}$	$3.78{\cdot}10^{11}$	$3.80{\cdot}10^{11}$	$3.95{\cdot}10^{11}$	$3.68{\cdot}10^{11}$
I-133	$5.61{\cdot}10^{11}$	$5.88{\cdot}10^{11}$	$5.91{\cdot}10^{11}$	$6.14{\cdot}10^{11}$	$5.73{\cdot}10^{11}$
I-134	$6.32{\cdot}10^{11}$	$6.63{\cdot}10^{11}$	$6.67{\cdot}10^{11}$	$6.93{\cdot}10^{11}$	$6.46{\cdot}10^{11}$
I-135	$5.22{\cdot}10^{11}$	$5.48{\cdot}10^{11}$	$5.51{\cdot}10^{11}$	$5.72{\cdot}10^{11}$	$5.34{\cdot}10^{11}$
Xe-131m	$2.69{\cdot}10^{9}$	$2.82{\cdot}10^{9}$	$2.84{\cdot}10^{9}$	$2.95{\cdot}10^{9}$	$2.75{\cdot}10^{9}$
Xe-133m	$1.64{\cdot}10^{10}$	$1.73{\cdot}10^{10}$	$1.74{\cdot}10^{10}$	$1.80{\cdot}10^{10}$	$1.68{\cdot}10^{10}$
Xe-133	$5.61{\cdot}10^{11}$	$5.89{\cdot}10^{11}$	$5.92{\cdot}10^{11}$	$6.15{\cdot}10^{11}$	$5.74{\cdot}10^{11}$
Xe-135m	$9.53{\cdot}10^{10}$	$1.00{\cdot}10^{11}$	$1.01{\cdot}10^{11}$	$1.05{\cdot}10^{11}$	$9.75{\cdot}10^{10}$
Xe-135	$5.32{\cdot}10^{11}$	$5.58{\cdot}10^{11}$	$5.61{\cdot}10^{11}$	$5.82{\cdot}10^{11}$	$5.44{\cdot}10^{11}$
Xe-138	$5.16{\cdot}10^{11}$	$5.41{\cdot}10^{11}$	$5.44{\cdot}10^{11}$	$5.65{\cdot}10^{11}$	$5.28{\cdot}10^{11}$

	2184 inventory [Bq]	**2187** inventory [Bq]	**2199** inventory [Bq]	**2200** inventory [Bq]	**2201** inventory [Bq]
Kr-83m	$4.85{\cdot}10^{10}$	$4.37{\cdot}10^{10}$	$4.63{\cdot}10^{10}$	$3.46{\cdot}10^{10}$	$4.37{\cdot}10^{10}$
Kr-85m	$1.14{\cdot}10^{11}$	$1.03{\cdot}10^{11}$	$1.09{\cdot}10^{11}$	$8.15{\cdot}10^{10}$	$1.03{\cdot}10^{11}$
Kr-85	$2.19{\cdot}10^{10}$	$2.10{\cdot}10^{10}$	$2.21{\cdot}10^{10}$	$1.66{\cdot}10^{10}$	$2.10{\cdot}10^{10}$
Kr-87	$2.30{\cdot}10^{11}$	$2.07{\cdot}10^{11}$	$2.20{\cdot}10^{11}$	$1.65{\cdot}10^{11}$	$2.07{\cdot}10^{11}$
Kr-88	$3.25{\cdot}10^{11}$	$2.93{\cdot}10^{11}$	$3.11{\cdot}10^{11}$	$2.32{\cdot}10^{11}$	$2.93{\cdot}10^{11}$
I-129	$1.04{\cdot}10^{5}$	$1.25{\cdot}10^{5}$	$1.26{\cdot}10^{5}$	$9.68{\cdot}10^{4}$	$1.25{\cdot}10^{5}$
I-130	$8.96{\cdot}10^{8}$	$9.63{\cdot}10^{8}$	$1.03{\cdot}10^{9}$	$5.94{\cdot}10^{8}$	$9.63{\cdot}10^{8}$
I-131	$2.64{\cdot}10^{11}$	$2.39{\cdot}10^{11}$	$2.53{\cdot}10^{11}$	$1.89{\cdot}10^{11}$	$2.39{\cdot}10^{11}$
I-132	$3.93{\cdot}10^{11}$	$3.55{\cdot}10^{11}$	$3.77{\cdot}10^{11}$	$2.81{\cdot}10^{11}$	$3.55{\cdot}10^{11}$
I-133	$6.13{\cdot}10^{11}$	$5.53{\cdot}10^{11}$	$5.86{\cdot}10^{11}$	$4.37{\cdot}10^{11}$	$5.53{\cdot}10^{11}$
I-134	$6.91{\cdot}10^{11}$	$6.23{\cdot}10^{11}$	$6.62{\cdot}10^{11}$	$4.94{\cdot}10^{11}$	$6.23{\cdot}10^{11}$
I-135	$5.71{\cdot}10^{11}$	$5.15{\cdot}10^{11}$	$5.46{\cdot}10^{11}$	$4.07{\cdot}10^{11}$	$5.15{\cdot}10^{11}$
Xe-131m	$2.94{\cdot}10^{9}$	$2.65{\cdot}10^{9}$	$2.81{\cdot}10^{9}$	$2.09{\cdot}10^{9}$	$2.65{\cdot}10^{9}$
Xe-133m	$1.80{\cdot}10^{10}$	$1.62{\cdot}10^{10}$	$1.72{\cdot}10^{10}$	$1.28{\cdot}10^{10}$	$1.62{\cdot}10^{10}$
Xe-133	$6.13{\cdot}10^{11}$	$5.53{\cdot}10^{11}$	$5.87{\cdot}10^{11}$	$4.38{\cdot}10^{11}$	$5.53{\cdot}10^{11}$
Xe-135m	$1.04{\cdot}10^{11}$	$9.40{\cdot}10^{10}$	$9.98{\cdot}10^{10}$	$7.43{\cdot}10^{10}$	$9.40{\cdot}10^{10}$
Xe-135	$5.81{\cdot}10^{11}$	$5.25{\cdot}10^{11}$	$5.56{\cdot}10^{11}$	$4.17{\cdot}10^{11}$	$5.25{\cdot}10^{11}$
Xe-138	$5.65{\cdot}10^{11}$	$5.09{\cdot}10^{11}$	$5.40{\cdot}10^{11}$	$4.03{\cdot}10^{11}$	$5.09{\cdot}10^{11}$

Table A.5: Inventory of 102-type fuel elements 2174, 2175, 2181, 2182, 2183, 2184, 2187, 2199, 2200 and 2201 in Bq (only nuclides, which were considered in PC COSYMA)

	2202 inventory [Bq]	2203 inventory [Bq]	2233 inventory [Bq]	3456 inventory [Bq]	3457 inventory [Bq]
Kr-83m	$4.40{\cdot}10^{10}$	$4.22{\cdot}10^{10}$	$4.45{\cdot}10^{10}$	$4.35{\cdot}10^{10}$	$5.10{\cdot}10^{10}$
Kr-85m	$1.03{\cdot}10^{11}$	$9.93{\cdot}10^{10}$	$1.05{\cdot}10^{11}$	$1.02{\cdot}10^{11}$	$1.20{\cdot}10^{11}$
Kr-85	$2.11{\cdot}10^{10}$	$2.02{\cdot}10^{10}$	$2.12{\cdot}10^{10}$	$2.05{\cdot}10^{10}$	$2.00{\cdot}10^{10}$
Kr-87	$2.09{\cdot}10^{11}$	$2.00{\cdot}10^{11}$	$2.11{\cdot}10^{11}$	$2.06{\cdot}10^{11}$	$2.43{\cdot}10^{11}$
Kr-88	$2.95{\cdot}10^{11}$	$2.83{\cdot}10^{11}$	$2.98{\cdot}10^{11}$	$2.92{\cdot}10^{11}$	$3.43{\cdot}10^{11}$
I-129	$1.26{\cdot}10^{5}$	$1.20{\cdot}10^{5}$	$1.21{\cdot}10^{5}$	$1.12{\cdot}10^{5}$	$7.10{\cdot}10^{4}$
I-130	$9.79{\cdot}10^{8}$	$8.87{\cdot}10^{8}$	$9.47{\cdot}10^{8}$	$8.80{\cdot}10^{8}$	$6.20{\cdot}10^{8}$
I-131	$2.40{\cdot}10^{11}$	$2.31{\cdot}10^{11}$	$2.43{\cdot}10^{11}$	$2.37{\cdot}10^{11}$	$2.77{\cdot}10^{11}$
I-132	$3.58{\cdot}10^{11}$	$3.43{\cdot}10^{11}$	$3.62{\cdot}10^{11}$	$3.53{\cdot}10^{11}$	$4.12{\cdot}10^{11}$
I-133	$5.57{\cdot}10^{11}$	$5.34{\cdot}10^{11}$	$5.63{\cdot}10^{11}$	$5.50{\cdot}10^{11}$	$6.43{\cdot}10^{11}$
I-134	$6.28{\cdot}10^{11}$	$6.02{\cdot}10^{11}$	$6.35{\cdot}10^{11}$	$6.20{\cdot}10^{11}$	$7.26{\cdot}10^{11}$
I-135	$5.18{\cdot}10^{11}$	$4.97{\cdot}10^{11}$	$5.24{\cdot}10^{11}$	$5.12{\cdot}10^{11}$	$5.98{\cdot}10^{11}$
Xe-131m	$2.67{\cdot}10^{9}$	$2.56{\cdot}10^{9}$	$2.70{\cdot}10^{9}$	$2.63{\cdot}10^{9}$	$3.07{\cdot}10^{9}$
Xe-133m	$1.63{\cdot}10^{10}$	$1.57{\cdot}10^{10}$	$1.65{\cdot}10^{10}$	$1.61{\cdot}10^{10}$	$1.88{\cdot}10^{10}$
Xe-133	$5.57{\cdot}10^{11}$	$5.34{\cdot}10^{11}$	$5.64{\cdot}10^{11}$	$5.50{\cdot}10^{11}$	$6.43{\cdot}10^{11}$
Xe-135m	$9.47{\cdot}10^{10}$	$9.08{\cdot}10^{10}$	$9.58{\cdot}10^{10}$	$9.35{\cdot}10^{10}$	$1.09{\cdot}10^{11}$
Xe-135	$5.29{\cdot}10^{11}$	$5.08{\cdot}10^{11}$	$5.35{\cdot}10^{11}$	$5.22{\cdot}10^{11}$	$6.08{\cdot}10^{11}$
Xe-138	$5.12{\cdot}10^{11}$	$4.92{\cdot}10^{11}$	$5.18{\cdot}10^{11}$	$5.07{\cdot}10^{11}$	$5.93{\cdot}10^{11}$

Table A.6: Inventory of 102-type fuel elements 2202, 2203, 2233, 3456 and 3457 in Bq (only nuclides, which were considered in PC COSYMA)

	4303 inventory [Bq]	4304 inventory [Bq]	4305 inventory [Bq]	5127 inventory [Bq]	5128 inventory [Bq]
Kr-83m	$5.62 \cdot 10^{10}$	$5.53 \cdot 10^{10}$	$5.52 \cdot 10^{10}$	$5.76 \cdot 10^{10}$	$5.09 \cdot 10^{10}$
Kr-85m	$1.32 \cdot 10^{11}$	$1.30 \cdot 10^{11}$	$1.30 \cdot 10^{11}$	$1.36 \cdot 10^{11}$	$1.20 \cdot 10^{11}$
Kr-85	$2.58 \cdot 10^{10}$	$2.61 \cdot 10^{10}$	$2.58 \cdot 10^{10}$	$2.66 \cdot 10^{10}$	$2.30 \cdot 10^{10}$
Kr-87	$2.67 \cdot 10^{11}$	$2.63 \cdot 10^{11}$	$2.62 \cdot 10^{11}$	$2.74 \cdot 10^{11}$	$2.42 \cdot 10^{11}$
Kr-88	$3.77 \cdot 10^{11}$	$3.71 \cdot 10^{11}$	$3.70 \cdot 10^{11}$	$3.87 \cdot 10^{11}$	$3.41 \cdot 10^{11}$
I-129	$1.26 \cdot 10^{5}$	$1.41 \cdot 10^{5}$	$1.36 \cdot 10^{5}$	$1.32 \cdot 10^{5}$	$1.08 \cdot 10^{5}$
I-130	$1.18 \cdot 10^{9}$	$1.33 \cdot 10^{9}$	$1.27 \cdot 10^{9}$	$1.28 \cdot 10^{9}$	$9.28 \cdot 10^{8}$
I-131	$3.07 \cdot 10^{11}$	$3.03 \cdot 10^{11}$	$3.02 \cdot 10^{11}$	$3.15 \cdot 10^{11}$	$2.77 \cdot 10^{11}$
I-132	$4.57 \cdot 10^{11}$	$4.50 \cdot 10^{11}$	$4.49 \cdot 10^{11}$	$4.69 \cdot 10^{11}$	$4.13 \cdot 10^{11}$
I-133	$7.12 \cdot 10^{11}$	$7.01 \cdot 10^{11}$	$6.99 \cdot 10^{11}$	$7.30 \cdot 10^{11}$	$6.43 \cdot 10^{11}$
I-134	$8.03 \cdot 10^{11}$	$7.90 \cdot 10^{11}$	$7.88 \cdot 10^{11}$	$8.23 \cdot 10^{11}$	$7.25 \cdot 10^{11}$
I-135	$6.63 \cdot 10^{11}$	$6.52 \cdot 10^{11}$	$6.51 \cdot 10^{11}$	$6.79 \cdot 10^{11}$	$5.99 \cdot 10^{11}$
Xe-131m	$3.41 \cdot 10^{9}$	$3.36 \cdot 10^{9}$	$3.35 \cdot 10^{9}$	$3.50 \cdot 10^{9}$	$2.76 \cdot 10^{9}$
Xe-133m	$2.09 \cdot 10^{10}$	$2.06 \cdot 10^{10}$	$2.05 \cdot 10^{10}$	$2.14 \cdot 10^{10}$	$1.88 \cdot 10^{10}$
Xe-133	$7.12 \cdot 10^{11}$	$7.01 \cdot 10^{11}$	$7.00 \cdot 10^{11}$	$7.30 \cdot 10^{11}$	$6.43 \cdot 10^{11}$
Xe-135m	$1.21 \cdot 10^{11}$	$1.19 \cdot 10^{11}$	$1.19 \cdot 10^{11}$	$1.24 \cdot 10^{11}$	$1.09 \cdot 10^{11}$
Xe-135	$6.73 \cdot 10^{11}$	$6.62 \cdot 10^{11}$	$6.61 \cdot 10^{11}$	$6.89 \cdot 10^{11}$	$6.09 \cdot 10^{11}$
Xe-138	$6.55 \cdot 10^{11}$	$6.45 \cdot 10^{11}$	$6.43 \cdot 10^{11}$	$6.72 \cdot 10^{11}$	$5.92 \cdot 10^{11}$

	5284 inventory [Bq]	8257 inventory [Bq]	9200 inventory [Bq]	9589 inventory [Bq]	9590 inventory [Bq]
Kr-83m	$5.12 \cdot 10^{10}$	$3.96 \cdot 10^{10}$	$4.27 \cdot 10^{10}$	$5.35 \cdot 10^{10}$	$5.35 \cdot 10^{10}$
Kr-85m	$1.20 \cdot 10^{11}$	$9.33 \cdot 10^{10}$	$1.01 \cdot 10^{11}$	$1.26 \cdot 10^{11}$	$1.26 \cdot 10^{11}$
Kr-85	$2.28 \cdot 10^{10}$	$1.59 \cdot 10^{10}$	$4.28 \cdot 10^{9}$	$2.11 \cdot 10^{10}$	$2.11 \cdot 10^{10}$
Kr-87	$2.43 \cdot 10^{11}$	$1.89 \cdot 10^{11}$	$2.04 \cdot 10^{11}$	$2.54 \cdot 10^{11}$	$2.54 \cdot 10^{11}$
Kr-88	$3.44 \cdot 10^{11}$	$2.66 \cdot 10^{11}$	$2.88 \cdot 10^{11}$	$3.59 \cdot 10^{11}$	$3.59 \cdot 10^{11}$
I-129	$1.03 \cdot 10^{5}$	$5.82 \cdot 10^{4}$	$8.70 \cdot 10^{3}$	$7.61 \cdot 10^{4}$	$7.61 \cdot 10^{4}$
I-130	$8.84 \cdot 10^{8}$	$3.81 \cdot 10^{8}$	$7.30 \cdot 10^{7}$	$6.61 \cdot 10^{8}$	$6.61 \cdot 10^{8}$
I-131	$2.79 \cdot 10^{11}$	$2.15 \cdot 10^{11}$	$2.29 \cdot 10^{11}$	$2.90 \cdot 10^{11}$	$2.90 \cdot 10^{11}$
I-132	$4.15 \cdot 10^{11}$	$3.20 \cdot 10^{11}$	$3.42 \cdot 10^{11}$	$4.32 \cdot 10^{11}$	$4.32 \cdot 10^{11}$
I-133	$6.47 \cdot 10^{11}$	$4.99 \cdot 10^{11}$	$5.35 \cdot 10^{11}$	$6.74 \cdot 10^{11}$	$6.74 \cdot 10^{11}$
I-134	$7.30 \cdot 10^{11}$	$5.63 \cdot 10^{11}$	$6.05 \cdot 10^{11}$	$7.61 \cdot 10^{11}$	$7.61 \cdot 10^{11}$
I-135	$6.02 \cdot 10^{11}$	$4.64 \cdot 10^{11}$	$4.98 \cdot 10^{11}$	$6.28 \cdot 10^{11}$	$6.28 \cdot 10^{11}$
Xe-131m	$3.10 \cdot 10^{9}$	$2.38 \cdot 10^{9}$	$2.54 \cdot 10^{9}$	$3.22 \cdot 10^{9}$	$3.22 \cdot 10^{9}$
Xe-133m	$1.90 \cdot 10^{10}$	$1.46 \cdot 10^{10}$	$1.56 \cdot 10^{10}$	$1.97 \cdot 10^{10}$	$1.97 \cdot 10^{10}$
Xe-133	$6.47 \cdot 10^{11}$	$4.99 \cdot 10^{11}$	$5.36 \cdot 10^{11}$	$6.75 \cdot 10^{11}$	$6.75 \cdot 10^{11}$
Xe-135m	$1.10 \cdot 10^{11}$	$8.44 \cdot 10^{10}$	$9.03 \cdot 10^{10}$	$1.14 \cdot 10^{11}$	$1.14 \cdot 10^{11}$
Xe-135	$6.13 \cdot 10^{11}$	$4.75 \cdot 10^{11}$	$5.09 \cdot 10^{11}$	$6.38 \cdot 10^{11}$	$6.38 \cdot 10^{11}$
Xe-138	$5.96 \cdot 10^{11}$	$4.60 \cdot 10^{11}$	$4.95 \cdot 10^{11}$	$6.22 \cdot 10^{11}$	$6.22 \cdot 10^{11}$

Table A.7: Inventory of 104-type fuel elements 4303, 4304, 4305, 5127, 5128, 5284, 8257, 9200, 9589 and 9590 in Bq (only nuclides, which were considered in PC COSYMA)

	9591 inventory [Bq]	10075 inventory [Bq]	10076 inventory [Bq]	10077 inventory [Bq]	10143 inventory [Bq]
Kr-83m	$5.32{\cdot}10^{10}$	$5.91{\cdot}10^{10}$	$5.83{\cdot}10^{10}$	$5.87{\cdot}10^{10}$	$5.56{\cdot}10^{10}$
Kr-85m	$1.25{\cdot}10^{11}$	$1.39{\cdot}10^{11}$	$1.37{\cdot}10^{11}$	$1.38{\cdot}10^{11}$	$1.31{\cdot}10^{11}$
Kr-85	$2.07{\cdot}10^{10}$	$2.22{\cdot}10^{10}$	$2.02{\cdot}10^{10}$	$2.01{\cdot}10^{10}$	$1.55{\cdot}10^{10}$
Kr-87	$2.53{\cdot}10^{11}$	$2.81{\cdot}10^{11}$	$2.77{\cdot}10^{11}$	$2.79{\cdot}10^{11}$	$2.65{\cdot}10^{11}$
Kr-88	$3.58{\cdot}10^{11}$	$3.97{\cdot}10^{11}$	$3.92{\cdot}10^{11}$	$3.95{\cdot}10^{11}$	$3.74{\cdot}10^{11}$
I-129	$7.33{\cdot}10^{4}$	$7.47{\cdot}10^{4}$	$6.30{\cdot}10^{4}$	$6.21{\cdot}10^{4}$	$4.13{\cdot}10^{4}$
I-130	$6.33{\cdot}10^{8}$	$7.16{\cdot}10^{8}$	$6.09{\cdot}10^{8}$	$6.04{\cdot}10^{8}$	$3.80{\cdot}10^{8}$
I-131	$2.89{\cdot}10^{11}$	$3.21{\cdot}10^{11}$	$3.16{\cdot}10^{11}$	$3.18{\cdot}10^{11}$	$3.01{\cdot}10^{11}$
I-132	$4.30{\cdot}10^{11}$	$4.77{\cdot}10^{11}$	$4.71{\cdot}10^{11}$	$4.74{\cdot}10^{11}$	$4.48{\cdot}10^{11}$
I-133	$6.71{\cdot}10^{11}$	$7.44{\cdot}10^{11}$	$7.34{\cdot}10^{11}$	$7.40{\cdot}10^{11}$	$6.99{\cdot}10^{11}$
I-134	$7.57{\cdot}10^{11}$	$8.40{\cdot}10^{11}$	$8.29{\cdot}10^{11}$	$8.35{\cdot}10^{11}$	$7.90{\cdot}10^{11}$
I-135	$6.25{\cdot}10^{11}$	$6.93{\cdot}10^{11}$	$6.84{\cdot}10^{11}$	$6.89{\cdot}10^{11}$	$6.51{\cdot}10^{11}$
Xe-131m	$3.21{\cdot}10^{9}$	$3.56{\cdot}10^{9}$	$3.51{\cdot}10^{9}$	$3.53{\cdot}10^{9}$	$3.34{\cdot}10^{9}$
Xe-133m	$1.96{\cdot}10^{10}$	$2.18{\cdot}10^{10}$	$2.15{\cdot}10^{10}$	$2.17{\cdot}10^{10}$	$2.05{\cdot}10^{10}$
Xe-133	$6.71{\cdot}10^{11}$	$7.45{\cdot}10^{11}$	$7.34{\cdot}10^{11}$	$7.40{\cdot}10^{11}$	$6.99{\cdot}10^{11}$
Xe-135m	$1.14{\cdot}10^{11}$	$1.26{\cdot}10^{11}$	$1.24{\cdot}10^{11}$	$1.25{\cdot}10^{11}$	$1.18{\cdot}10^{11}$
Xe-135	$6.35{\cdot}10^{11}$	$7.03{\cdot}10^{11}$	$6.93{\cdot}10^{11}$	$6.98{\cdot}10^{11}$	$6.61{\cdot}10^{11}$
Xe-138	$6.19{\cdot}10^{11}$	$6.87{\cdot}10^{11}$	$6.77{\cdot}10^{11}$	$6.83{\cdot}10^{11}$	$6.46{\cdot}10^{11}$

	10144 inventory [Bq]	10145 inventory [Bq]	10196 inventory [Bq]	10197 inventory [Bq]	10198 inventory [Bq]
Kr-83m	$5.66{\cdot}10^{10}$	$4.53{\cdot}10^{10}$	$4.46{\cdot}10^{10}$	$4.62{\cdot}10^{10}$	$4.63{\cdot}10^{10}$
Kr-85m	$1.33{\cdot}10^{11}$	$1.07{\cdot}10^{11}$	$1.05{\cdot}10^{11}$	$1.09{\cdot}10^{11}$	$1.09{\cdot}10^{11}$
Kr-85	$1.29{\cdot}10^{10}$	$9.74{\cdot}10^{9}$	$9.27{\cdot}10^{9}$	$7.80{\cdot}10^{9}$	$5.05{\cdot}10^{9}$
Kr-87	$2.70{\cdot}10^{11}$	$2.16{\cdot}10^{11}$	$2.13{\cdot}10^{11}$	$2.20{\cdot}10^{11}$	$2.21{\cdot}10^{11}$
Kr-88	$3.81{\cdot}10^{11}$	$3.05{\cdot}10^{11}$	$3.00{\cdot}10^{11}$	$3.11{\cdot}10^{11}$	$3.11{\cdot}10^{11}$
I-129	$3.16{\cdot}10^{4}$	$2.33{\cdot}10^{4}$	$2.19{\cdot}10^{4}$	$1.74{\cdot}10^{4}$	$1.04{\cdot}10^{4}$
I-130	$2.98{\cdot}10^{8}$	$1.78{\cdot}10^{8}$	$1.66{\cdot}10^{8}$	$1.40{\cdot}10^{8}$	$9.07{\cdot}10^{7}$
I-131	$3.05{\cdot}10^{11}$	$2.44{\cdot}10^{11}$	$2.39{\cdot}10^{11}$	$2.49{\cdot}10^{11}$	$2.49{\cdot}10^{11}$
I-132	$4.55{\cdot}10^{11}$	$3.64{\cdot}10^{11}$	$3.59{\cdot}10^{11}$	$3.71{\cdot}10^{11}$	$3.71{\cdot}10^{11}$
I-133	$7.10{\cdot}10^{11}$	$5.68{\cdot}10^{11}$	$5.60{\cdot}10^{11}$	$5.80{\cdot}10^{11}$	$5.80{\cdot}10^{11}$
I-134	$8.03{\cdot}10^{11}$	$6.42{\cdot}10^{11}$	$6.33{\cdot}10^{11}$	$6.55{\cdot}10^{11}$	$6.55{\cdot}10^{11}$
I-135	$6.62{\cdot}10^{11}$	$5.29{\cdot}10^{11}$	$5.21{\cdot}10^{11}$	$5.40{\cdot}10^{11}$	$5.40{\cdot}10^{11}$
Xe-131m	$3.39{\cdot}10^{9}$	$2.71{\cdot}10^{9}$	$2.68{\cdot}10^{9}$	$2.45{\cdot}10^{9}$	$2.76{\cdot}10^{9}$
Xe-133m	$2.08{\cdot}10^{10}$	$1.66{\cdot}10^{10}$	$1.50{\cdot}10^{10}$	$1.70{\cdot}10^{10}$	$1.69{\cdot}10^{10}$
Xe-133	$7.11{\cdot}10^{11}$	$5.69{\cdot}10^{11}$	$5.36{\cdot}10^{11}$	$5.80{\cdot}10^{11}$	$5.80{\cdot}10^{11}$
Xe-135m	$1.20{\cdot}10^{11}$	$9.60{\cdot}10^{10}$	$9.46{\cdot}10^{10}$	$9.79{\cdot}10^{10}$	$9.78{\cdot}10^{10}$
Xe-135	$6.72{\cdot}10^{11}$	$5.40{\cdot}10^{11}$	$5.32{\cdot}10^{11}$	$5.51{\cdot}10^{11}$	$5.51{\cdot}10^{11}$
Xe-138	$6.57{\cdot}10^{11}$	$5.26{\cdot}10^{11}$	$5.18{\cdot}10^{11}$	$5.37{\cdot}10^{11}$	$5.37{\cdot}10^{11}$

Table A.8: Inventory of 104-type fuel elements 9591, 10075, 10076, 10077, 10143, 10144, 10145, 10196, 10197 and 10198 in Bq (only nuclides, which were considered in PC COSYMA)

	7301 inventory [Bq]	7302 inventory [Bq]	7303 inventory [Bq]	7304 inventory [Bq]	7305 inventory [Bq]
Kr-83m	$5.48 \cdot 10^{10}$	$3.71 \cdot 10^{10}$	$5.46 \cdot 10^{10}$	$5.04 \cdot 10^{10}$	$5.05 \cdot 10^{10}$
Kr-85m	$1.30 \cdot 10^{11}$	$8.78 \cdot 10^{10}$	$1.29 \cdot 10^{11}$	$1.19 \cdot 10^{11}$	$1.19 \cdot 10^{11}$
Kr-85	$2.45 \cdot 10^{10}$	$1.62 \cdot 10^{10}$	$2.46 \cdot 10^{10}$	$2.21 \cdot 10^{10}$	$2.22 \cdot 10^{10}$
Kr-87	$2.62 \cdot 10^{11}$	$1.78 \cdot 10^{11}$	$2.61 \cdot 10^{11}$	$2.41 \cdot 10^{11}$	$2.42 \cdot 10^{11}$
Kr-88	$3.70 \cdot 10^{11}$	$2.51 \cdot 10^{11}$	$3.69 \cdot 10^{11}$	$3.41 \cdot 10^{11}$	$3.41 \cdot 10^{11}$
I-129	$1.10 \cdot 10^{5}$	$6.85 \cdot 10^{4}$	$1.12 \cdot 10^{5}$	$9.41 \cdot 10^{4}$	$9.42 \cdot 10^{4}$
I-130	$2.79 \cdot 10^{8}$	$1.21 \cdot 10^{8}$	$2.84 \cdot 10^{8}$	$2.22 \cdot 10^{8}$	$2.23 \cdot 10^{8}$
I-131	$2.94 \cdot 10^{11}$	$1.99 \cdot 10^{11}$	$2.93 \cdot 10^{11}$	$2.71 \cdot 10^{11}$	$2.71 \cdot 10^{11}$
I-132	$4.38 \cdot 10^{11}$	$2.97 \cdot 10^{11}$	$4.37 \cdot 10^{11}$	$4.04 \cdot 10^{11}$	$4.04 \cdot 10^{11}$
I-133	$6.87 \cdot 10^{11}$	$4.65 \cdot 10^{11}$	$6.85 \cdot 10^{11}$	$6.32 \cdot 10^{11}$	$6.33 \cdot 10^{11}$
I-134	$7.77 \cdot 10^{11}$	$5.26 \cdot 10^{11}$	$7.74 \cdot 10^{11}$	$7.14 \cdot 10^{11}$	$7.16 \cdot 10^{11}$
I-135	$6.40 \cdot 10^{11}$	$4.34 \cdot 10^{11}$	$6.38 \cdot 10^{11}$	$5.89 \cdot 10^{11}$	$5.90 \cdot 10^{11}$
Xe-131m	$3.27 \cdot 10^{9}$	$2.21 \cdot 10^{9}$	$3.25 \cdot 10^{9}$	$3.00 \cdot 10^{9}$	$3.01 \cdot 10^{9}$
Xe-133m	$2.01 \cdot 10^{10}$	$1.36 \cdot 10^{10}$	$2.00 \cdot 10^{10}$	$1.85 \cdot 10^{10}$	$1.85 \cdot 10^{10}$
Xe-133	$6.87 \cdot 10^{11}$	$4.66 \cdot 10^{11}$	$6.85 \cdot 10^{11}$	$6.32 \cdot 10^{11}$	$6.33 \cdot 10^{11}$
Xe-135m	$1.16 \cdot 10^{11}$	$7.85 \cdot 10^{10}$	$1.16 \cdot 10^{11}$	$1.07 \cdot 10^{11}$	$1.07 \cdot 10^{11}$
Xe-135	$6.62 \cdot 10^{11}$	$4.50 \cdot 10^{11}$	$6.60 \cdot 10^{11}$	$6.10 \cdot 10^{11}$	$6.11 \cdot 10^{11}$
Xe-138	$6.37 \cdot 10^{11}$	$4.31 \cdot 10^{11}$	$6.35 \cdot 10^{11}$	$5.86 \cdot 10^{11}$	$5.86 \cdot 10^{11}$

	7306 inventory [Bq]	7307 inventory [Bq]	7308 inventory [Bq]	7309 inventory [Bq]
Kr-83m	$4.61 \cdot 10^{10}$	$5.22 \cdot 10^{10}$	$4.47 \cdot 10^{6}$	$5.31 \cdot 10^{10}$
Kr-85m	$1.09 \cdot 10^{11}$	$1.23 \cdot 10^{11}$	$8.43 \cdot 10^{6}$	$1.26 \cdot 10^{11}$
Kr-85	$1.91 \cdot 10^{10}$	$2.22 \cdot 10^{10}$	$1.13 \cdot 10^{5}$	$2.13 \cdot 10^{10}$
Kr-87	$2.21 \cdot 10^{11}$	$2.50 \cdot 10^{11}$	$1.42 \cdot 10^{7}$	$2.54 \cdot 10^{11}$
Kr-88	$3.11 \cdot 10^{11}$	$3.53 \cdot 10^{11}$	$2.00 \cdot 10^{7}$	$3.59 \cdot 10^{11}$
I-129	$7.29 \cdot 10^{4}$	$8.82 \cdot 10^{4}$	9.01E-001	$7.66 \cdot 10^{4}$
I-130	$1.59 \cdot 10^{8}$	$2.16 \cdot 10^{8}$	$7.44 \cdot 10^{4}$	$1.92 \cdot 10^{8}$
I-131	$2.47 \cdot 10^{11}$	$2.80 \cdot 10^{11}$	$5.39 \cdot 10^{7}$	$2.85 \cdot 10^{11}$
I-132	$3.69 \cdot 10^{11}$	$4.17 \cdot 10^{11}$	$7.57 \cdot 10^{7}$	$4.25 \cdot 10^{11}$
I-133	$5.78 \cdot 10^{11}$	$6.54 \cdot 10^{11}$	$9.99 \cdot 10^{7}$	$6.66 \cdot 10^{11}$
I-134	$6.53 \cdot 10^{11}$	$7.39 \cdot 10^{11}$	$1.04 \cdot 10^{8}$	$7.53 \cdot 10^{11}$
I-135	$5.38 \cdot 10^{11}$	$6.09 \cdot 10^{11}$	$9.18 \cdot 10^{7}$	$6.20 \cdot 10^{11}$
Xe-131m	$2.74 \cdot 10^{9}$	$3.11 \cdot 10^{9}$	$5.99 \cdot 10^{5}$	$3.16 \cdot 10^{9}$
Xe-133m	$1.69 \cdot 10^{10}$	$1.91 \cdot 10^{10}$	$3.36 \cdot 10^{6}$	$1.95 \cdot 10^{10}$
Xe-133	$5.78 \cdot 10^{11}$	$6.55 \cdot 10^{11}$	$1.00 \cdot 10^{8}$	$6.66 \cdot 10^{11}$
Xe-135m	$9.74 \cdot 10^{10}$	$1.10 \cdot 10^{11}$	$2.32 \cdot 10^{7}$	$1.12 \cdot 10^{11}$
Xe-135	$5.58 \cdot 10^{11}$	$6.31 \cdot 10^{11}$	$1.07 \cdot 10^{8}$	$6.42 \cdot 10^{11}$
Xe-138	$5.35 \cdot 10^{11}$	$6.06 \cdot 10^{11}$	$7.12 \cdot 10^{7}$	$6.17 \cdot 10^{11}$

Table A.9: Inventory of FLIP fuel elements 7301, 7302, 7303, 7304, 7305, 7306, 7307, 7308 and 7309 in Bq (only nuclides, which were considered in PC COSYMA)

B Variation of atmospheric conditions

B.1 Scenario 1

Figure B.1: Scenario 1 - effective dose (ICRP-60) after 1 day for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

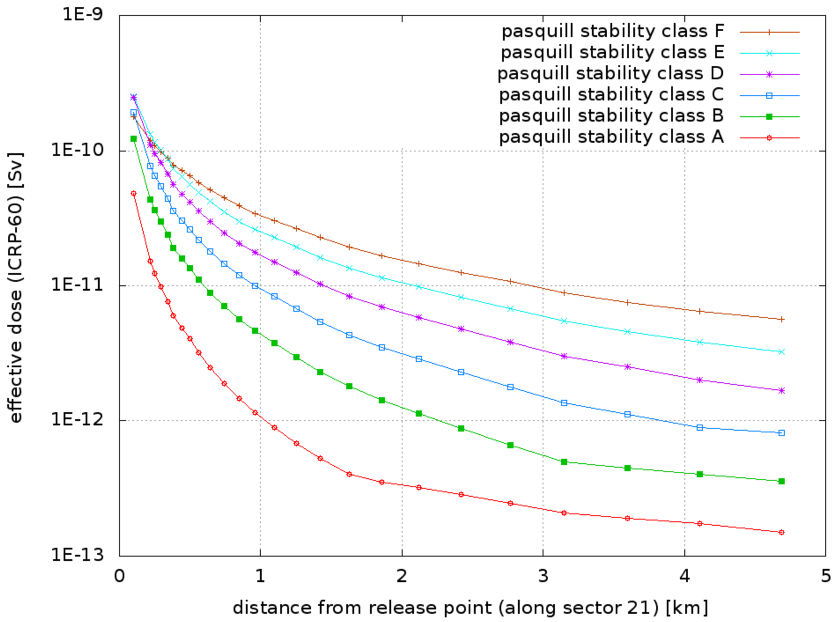


Figure B.2: Scenario 1 - effective dose (ICRP-60) after 50 years for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

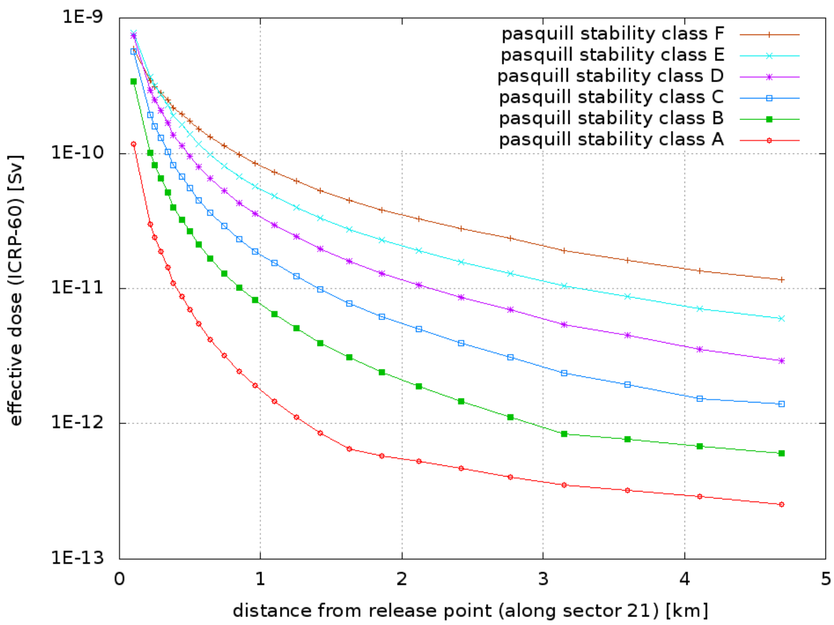


Figure B.3: Scenario 1 - effective dose (ICRP-60) after 1 day for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

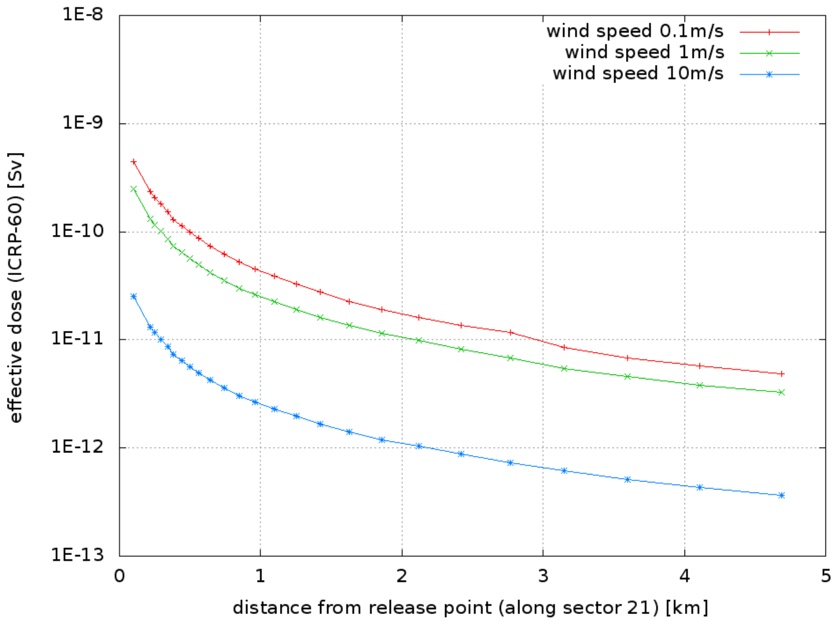


Figure B.4: Scenario 1 - effective dose (ICRP-60) after 50 years for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

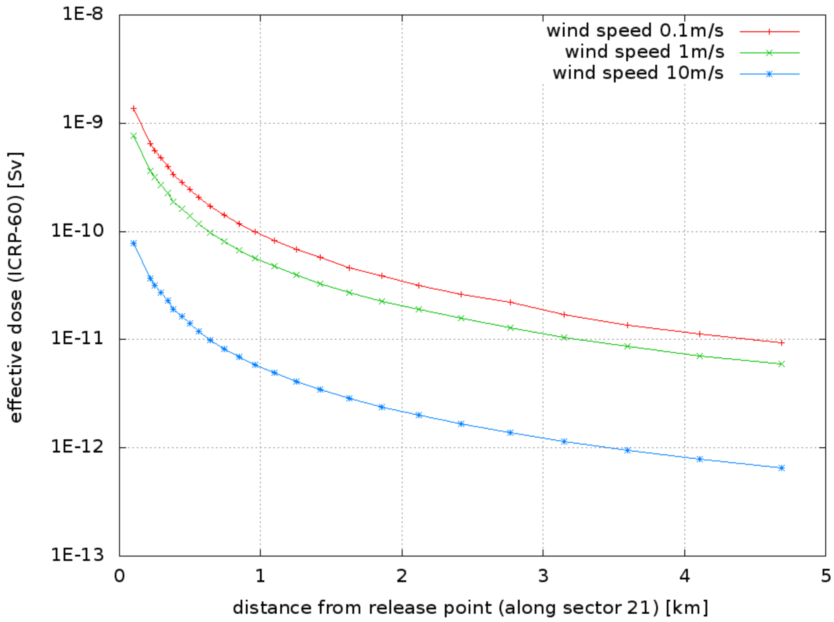


Figure B.5: Scenario 1 - effective dose (ICRP-60) after 1 day for different rain rates (Pasquill stability class E, wind speed 1m/s)

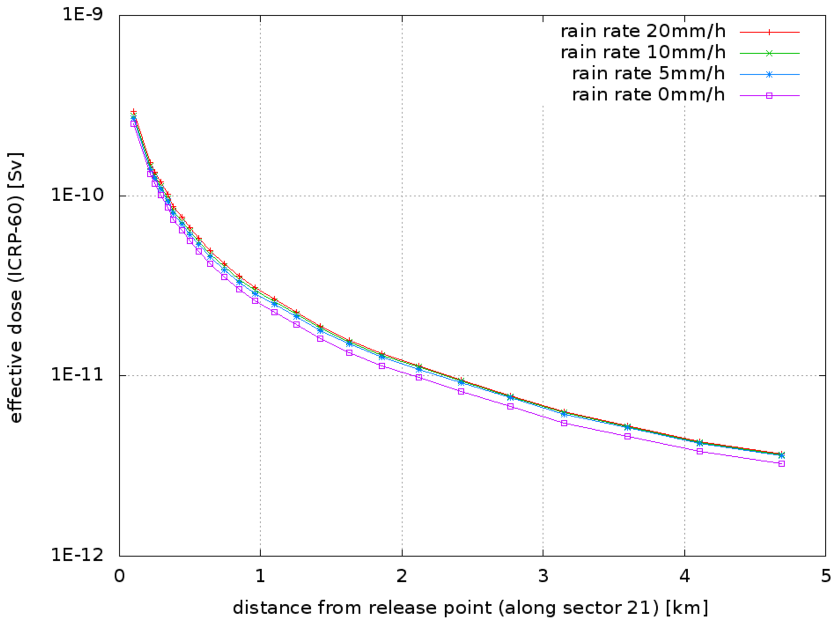
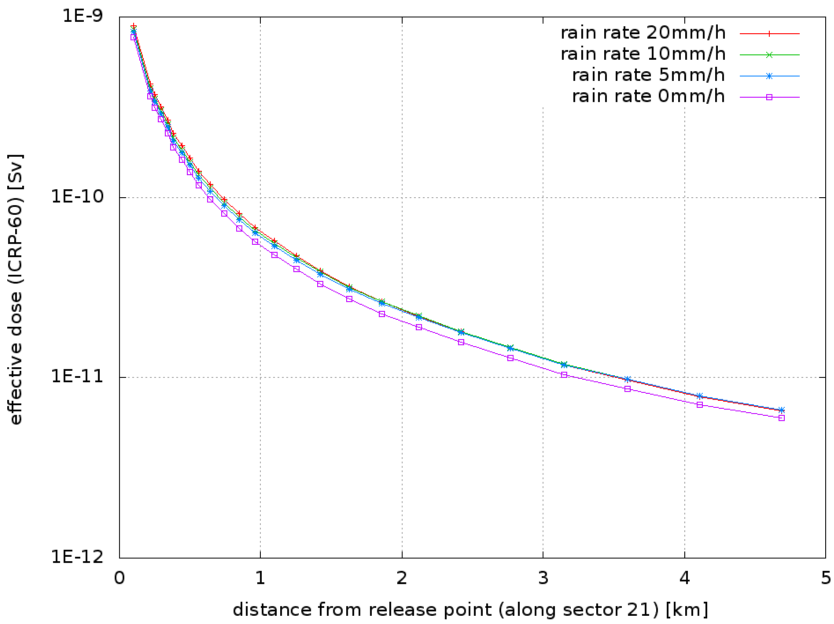


Figure B.6: Scenario 1 - effective dose (ICRP-60) after 50 years for different rain rates (Pasquill stability class E, wind speed 1m/s)



B.2 Scenario 2

Figure B.7: Scenario 2 - effective dose (ICRP-60) after 1 day for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

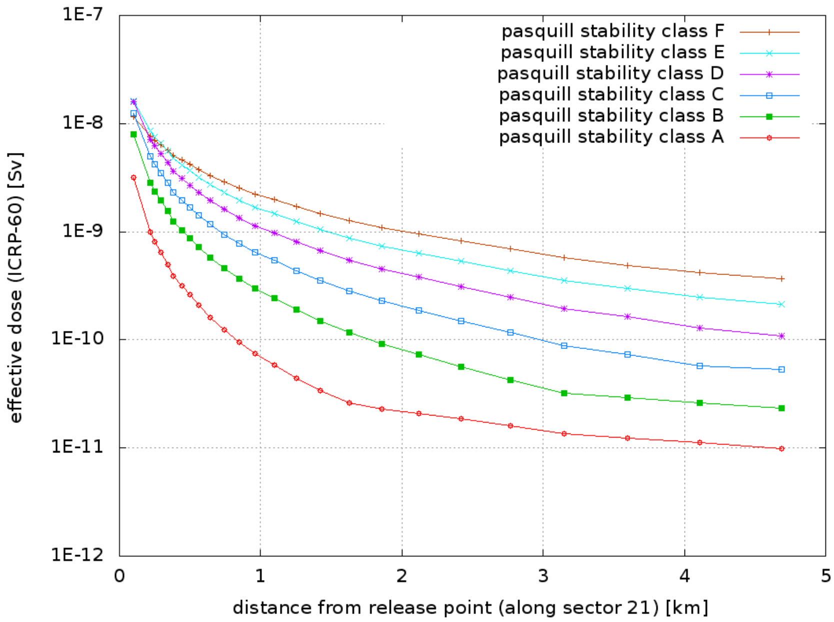


Figure B.8: Scenario 2 - effective dose (ICRP-60) after 50 years for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

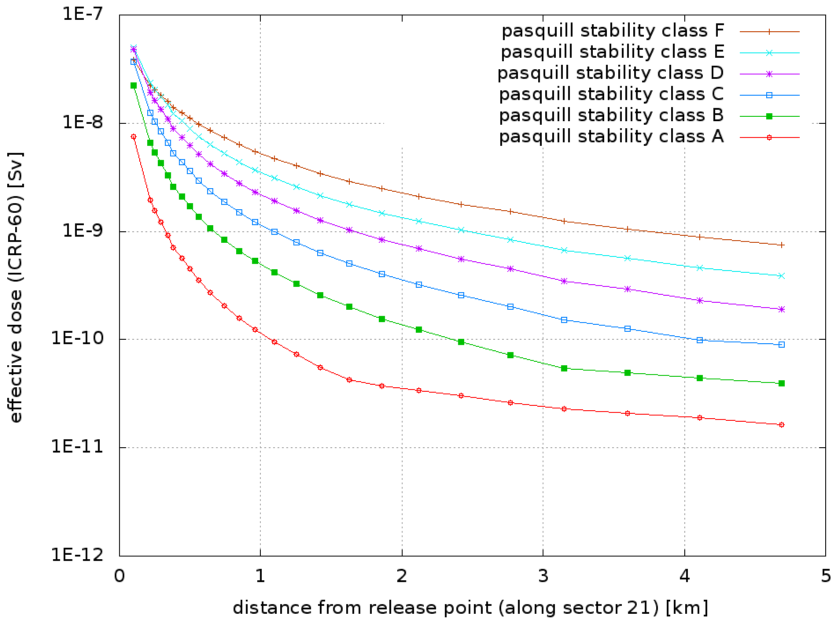


Figure B.9: Scenario 2 - effective dose (ICRP-60) after 1 day for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

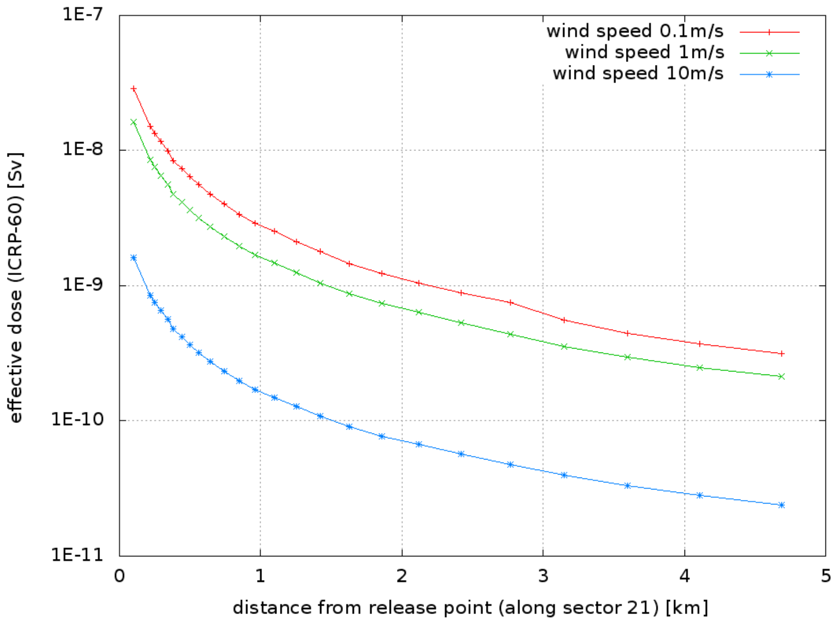


Figure B.10: Scenario 2 - effective dose (ICRP-60) after 50 years for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

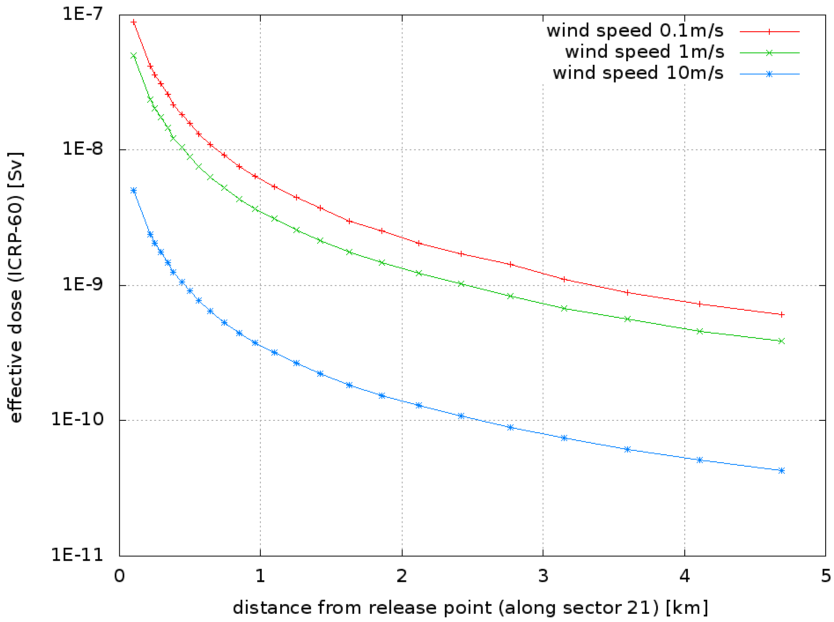


Figure B.11: Scenario 2 - effective dose (ICRP-60) after 1 day for different rain rates (Pasquill stability class E, wind speed 1m/s)

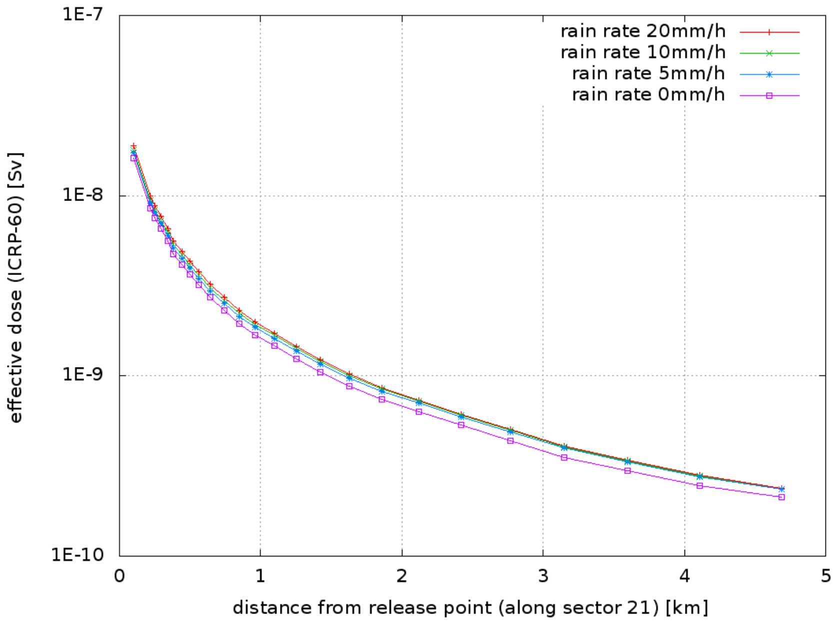
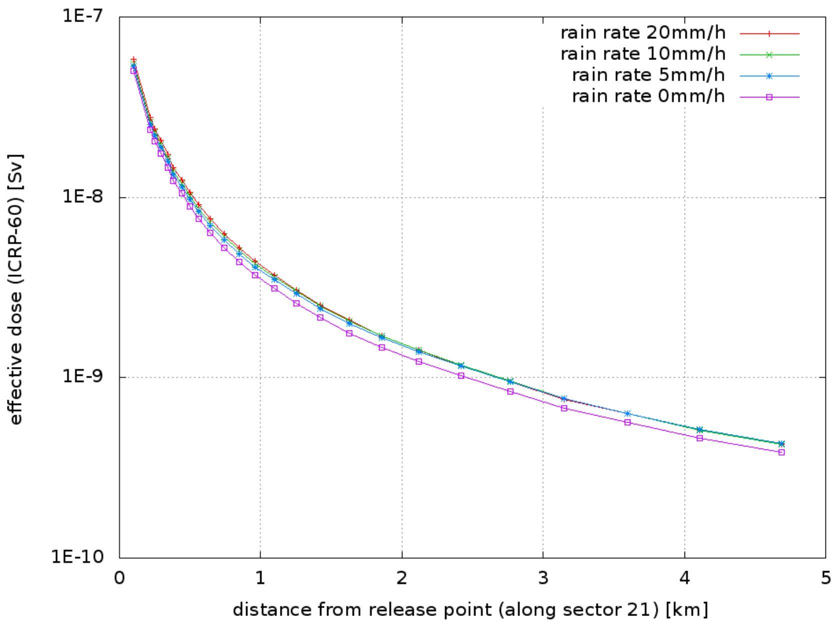


Figure B.12: Scenario 2 - effective dose (ICRP-60) after 50 years for different rain rates (Pasquill stability class E, wind speed 1m/s)



B.3 Scenario 3

Figure B.13: Scenario 3 - effective dose (ICRP-60) after 1 day for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

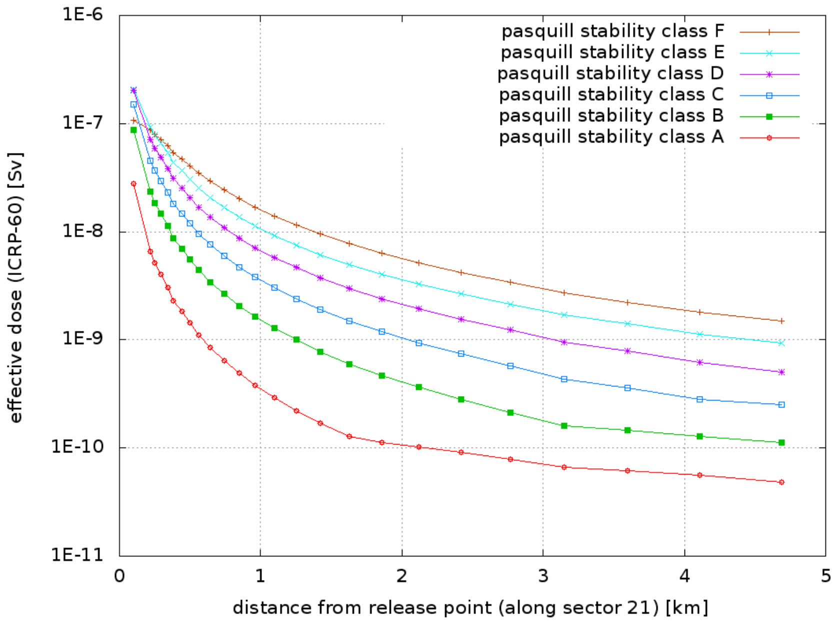


Figure B.14: Scenario 3 - effective dose (ICRP-60) after 50 years for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

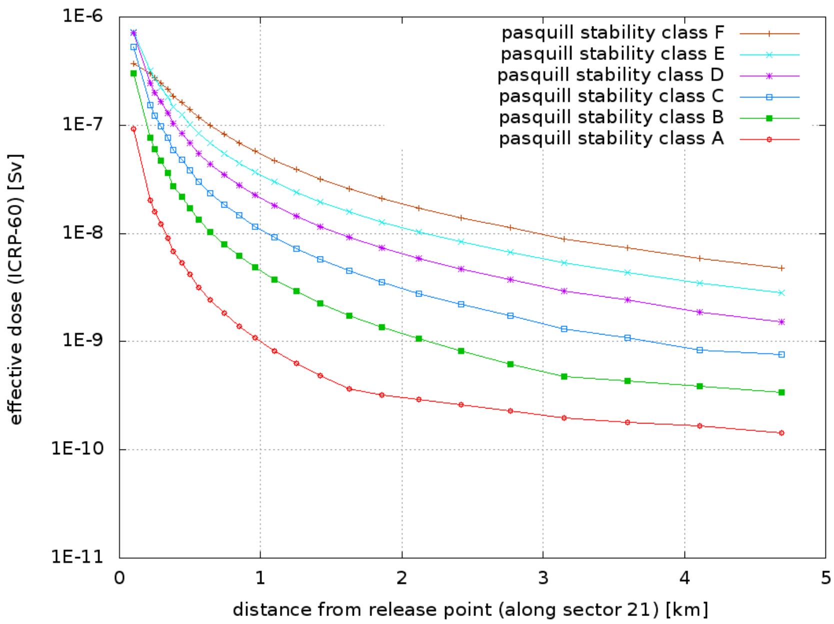


Figure B.15: Scenario 3 - effective dose (ICRP-60) after 1 day for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

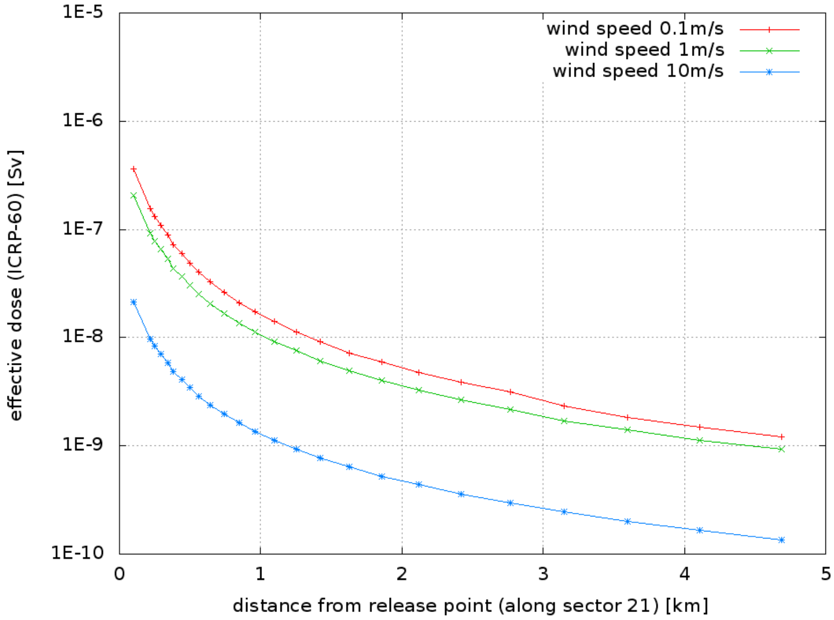


Figure B.16: Scenario 3 - effective dose (ICRP-60) after 50 years for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

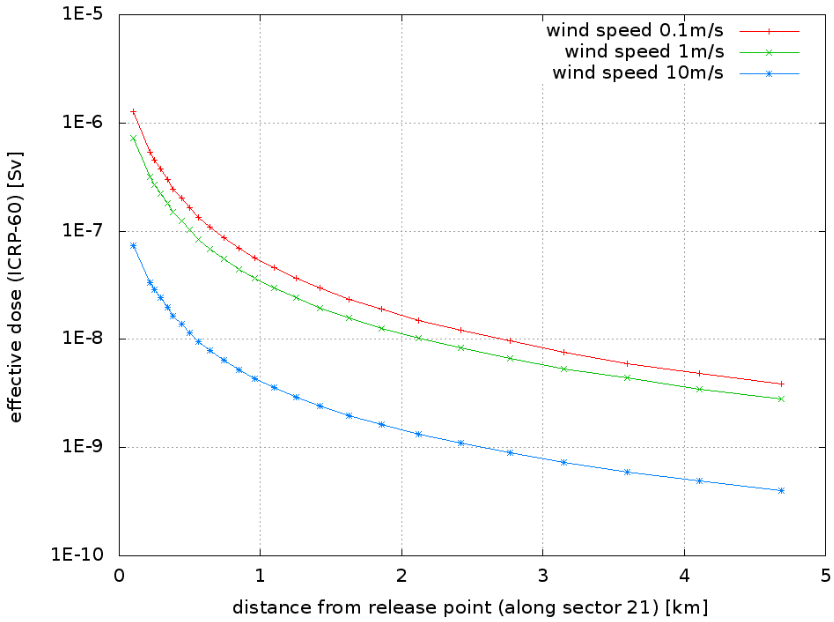


Figure B.17: Scenario 3 - effective dose (ICRP-60) after 1 day for different rain rates (Pasquill stability class E, wind speed 1m/s)

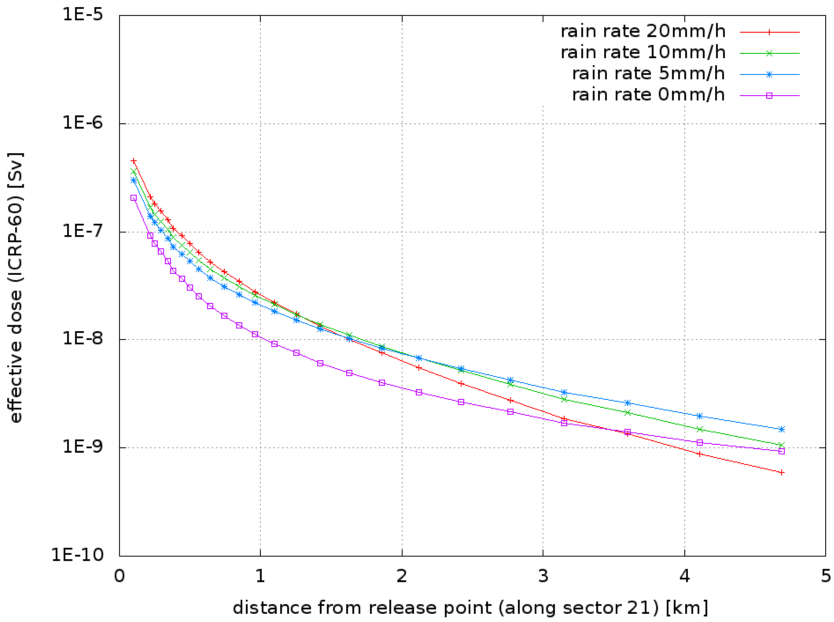
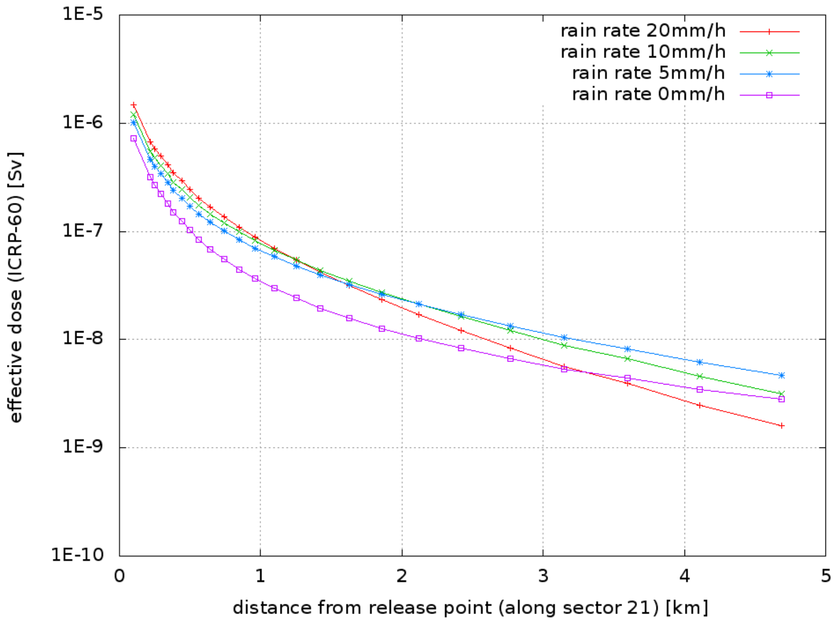


Figure B.18: Scenario 3 - effective dose (ICRP-60) after 50 years for different rain rates (Pasquill stability class E, wind speed 1m/s)



B.4 Scenario 4

Figure B.19: Scenario 4 - effective dose (ICRP-60) after 1 day for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

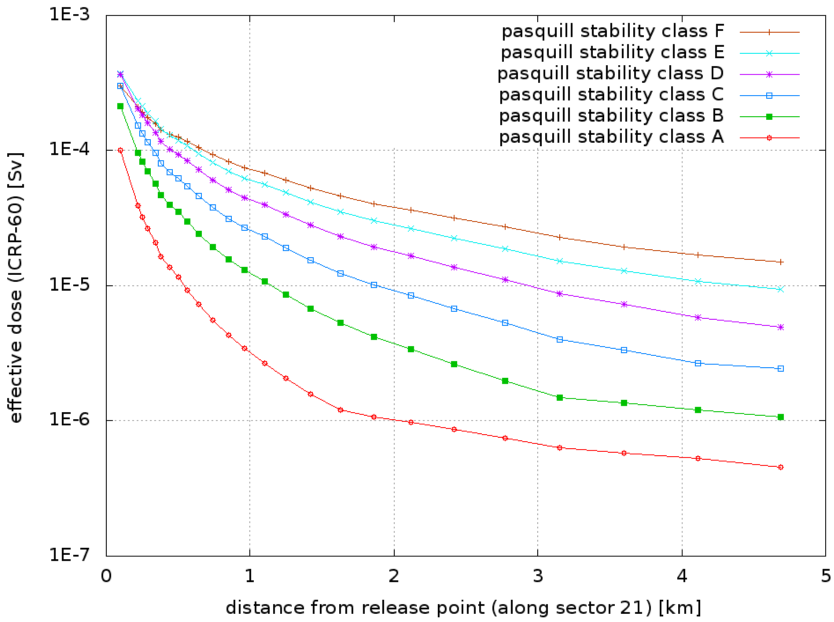


Figure B.20: Scenario 4 - effective dose (ICRP-60) after 50 years for different Pasquill stability classes (wind speed 1m/s, rain rate 0mm/h)

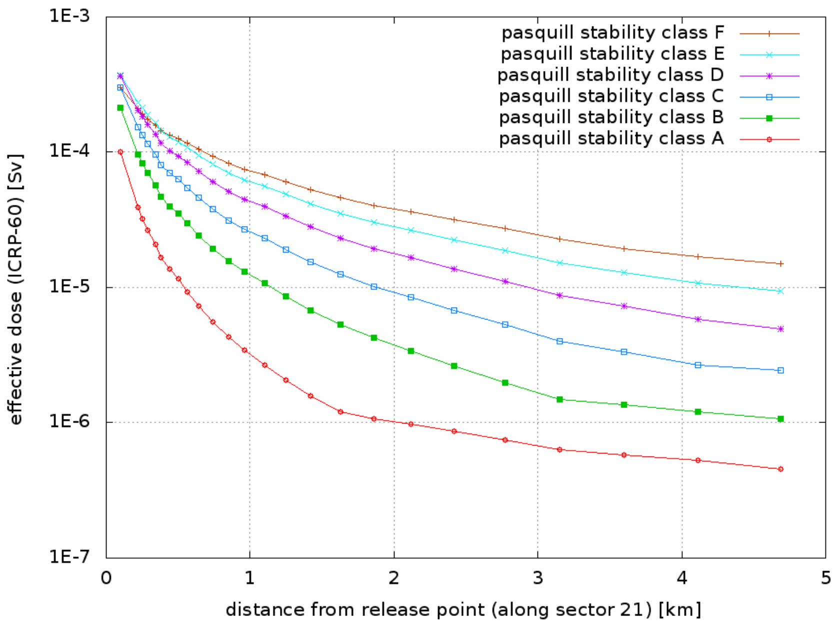


Figure B.21: Scenario 4 - effective dose (ICRP-60) after 1 day for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

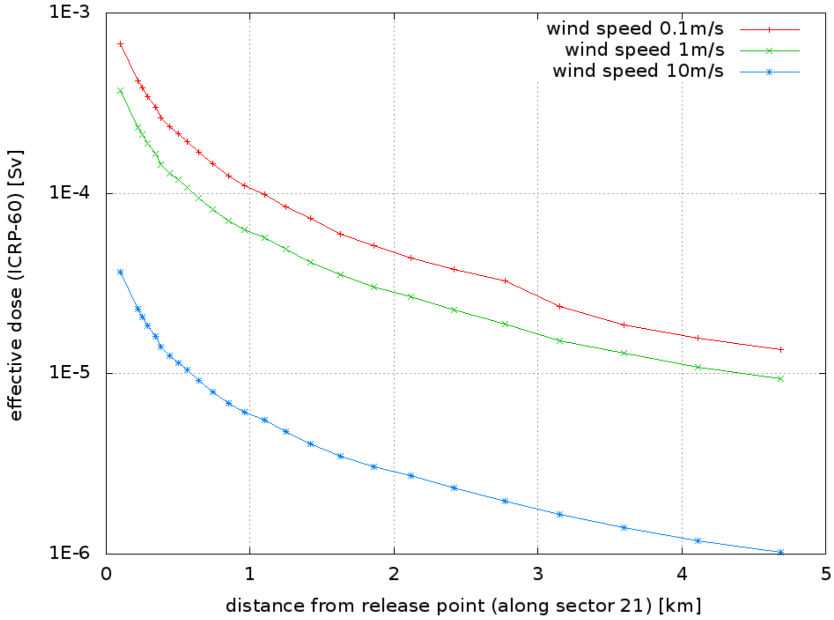


Figure B.22: Scenario 4 - effective dose (ICRP-60) after 50 years for different wind speeds (Pasquill stability class E, rain rate 0mm/h)

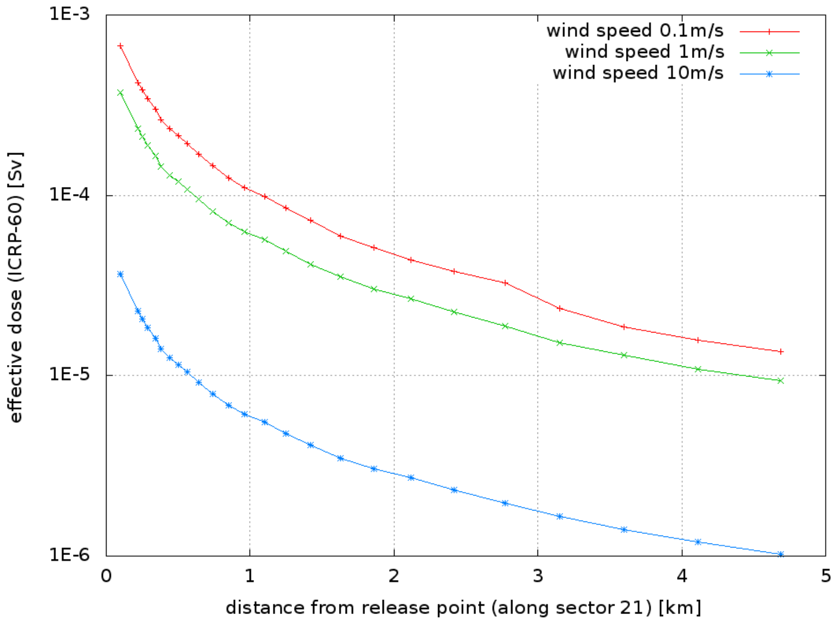


Figure B.23: Scenario 4 - effective dose (ICRP-60) after 1 day for different rain rates (Pasquill stability class E, wind speed 1m/s)

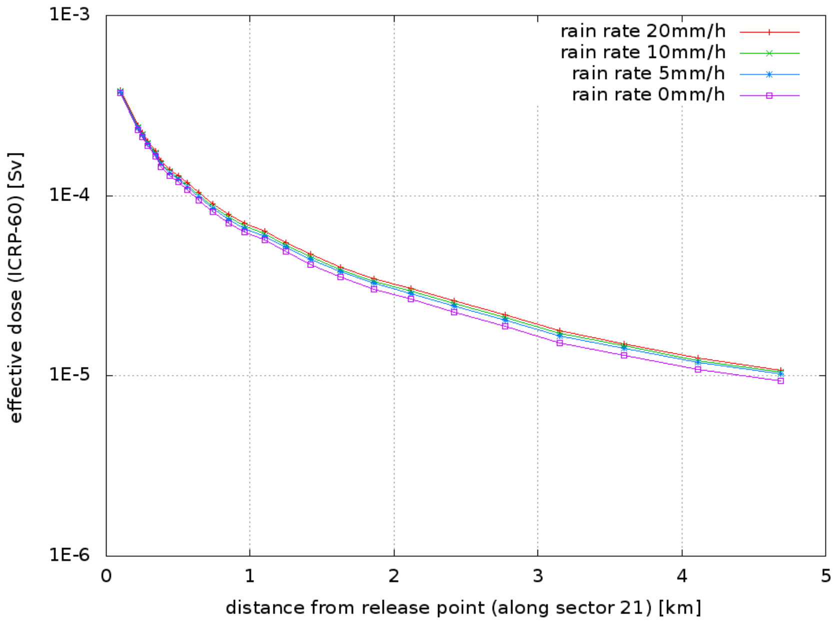
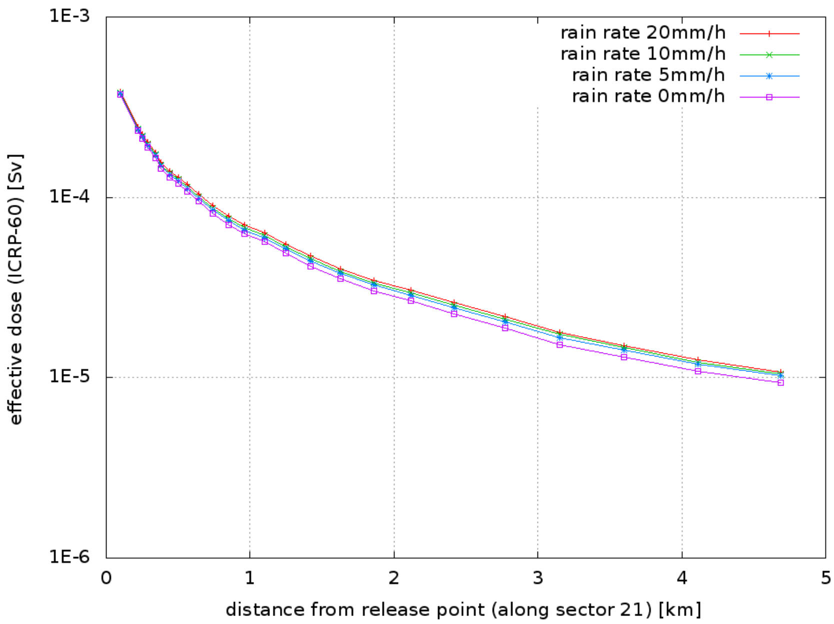


Figure B.24: Scenario 4 - effective dose (ICRP-60) after 50 years for different rain rates (Pasquill stability class E, wind speed 1m/s)



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