RODOS-based Simulation of Potential Accident Scenarios for Emergency Response Management in the Vicinity of Nuclear Power Plants

Schriften

H. Walter

F. Gering

K. Arnold

B. Gerich

G. Heinrich

U. Welte*

*) Strahlenschutzkommission

Bundesamt für Strahlenschutz

BfS-SCHR-60/16

When quoting this document please refer to the following URN:
urn:nbn:de:0221-2016091214084

Please note:
Full versions of BfS reports and BfS documents can be downloaded from the web pages of the Federal Office for Radiation Protection at http://www.bfs.de free of charge.

Salzgitter, September 2016

RODOS-based Simulation of Potential Accident Scenarios for Emergency Response Management in the Vicinity of Nuclear Power Plants

Schriften

H. Walter

F. Gering

K. Arnold

B. Gerich

G. Heinrich

U. Welte*

*) Strahlenschutzkommission

Summary

In the wake of the Fukushima disaster in March 2011, the German Federal Office for Radiation Protection (BfS) started to investigate the potential radiological consequences of a "Fukushima-like" accident in a German nuclear power plant and conducted appropriate simulations in 2012. Between the end of 2012 and the end of 2013, the first study was followed by a much more detailed and comprehensive investigation comprising more than 5000 case studies for three nuclear power plant (NPP) sites in Germany. Based on these results the German Commission on Radiological Protection (SSK) released a new recommendation in March 2014 including an expansion of the current emergency planning zones for nuclear power plants in Germany.

The key results of this study with respect to the maximum dimensions of the affected areas where dose criteria may be exceeded are described below. The following results are based on the largest nuclear release scenario "FKA" (INES scale 7):

- Threshold levels for deterministic effects and high doses (effective doses higher than 1000 mSv) can be reached or exceeded within a distance of about 3 km on average.
- The emergency reference level for the intervention "Evacuation" can be reached or exceeded within a distance of up to 9 to 18 km (adults) and/or up to 14 to 24 km (infants) on average (the indicated interval describes the minimum and maximum levels of the median value at all three NPP sites).
- The emergency reference level for the intervention "Sheltering" can be reached or exceeded within a distance of up to 62 to 80 km (adults) and/or up to 91 to 114 km (infants) on average.
- The emergency reference level for the intervention "Stable iodine prophylaxis" can be exceeded within a distance of up to 24 to 34 km (adults) and/or up to 148 to 161 km (infants and pregnant women) on average.

Key words: Fukushima accident, RODOS, emergency preparedness, emergency response planning zones, dispersion models.

1. INTRODUCTION

1.1. Background

In the wake of the Fukushima reactor accident a number of interested parties called for appropriate consequences with respect to disaster control and emergency response management. Questions were raised about the technical, scientific and legal foundations.

Following the Fukushima disaster in March 2011, the German Federal Office for Radiation Protection (BfS) started to investigate the potential radiological consequences of a “Fukushima-like” accident in a German nuclear power plant and conducted the relevant calculations (Gering 2012). One question was of particular interest: Is emergency preparedness in Germany fit for a similar accident or does it require conceptual improvements. The results showed that the existing planning did not take into account all potential scenarios of events.

The first BfS investigation was followed by a more detailed and more comprehensive study conducted between autumn 2012 and autumn 2013. The present report describes the approach and results of the second BfS study.

At the same time when the first BfS investigations were performed, the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) requested support from the Commission on Radiological Protection (SSK). The Commission was supposed to verify – against the background of the experience made in Fukushima – whether the boundary conditions, requirements and criteria contained in the relevant rules and regulations on nuclear emergency response management correspond to the state-of-the-art of research, science and technology.

In order to use the knowledge gained from the Japanese reactor accident in Germany and to incorporate this knowledge into German rules and regulations, adapted to the local boundary conditions, it was necessary to examine closely the potential radiological consequences of this type of accidents. Simply transferring the radiological consequences observed in Japan to German sites could only be a first rough, yet insufficient approach. The consequences observed in Japan are a unique case, resulting from the amount of radioactive substances released and the course of the release, the local orography and the meteorological conditions prevailing during the release. Even in Japan, an accident involving the same course of events but under different meteorological conditions might have had a large number of potential consequences.

This is all the more true for Germany since the orography and climatic conditions differ dramatically from those at the Japanese site. It was therefore decided to use model calculations in order to investigate the potential radiological consequences of such accidents for three German NPP sites that are typical with respect to their orography and regional climate. In order to take into account the meteorological conditions it was decided to superimpose a particular year's realistic meteorological data registered at the three sites upon the accidental release of radioactive substances assumed for the purposes of this study.

The methodology and boundary conditions for the model calculations to be performed by the SSK working group were established on the basis of the findings from the first BfS study and refined in cooperation with BfS. The results were assessed in a number of joint discussions.

The results of the new BfS calculations formed the basis for a new recommendation issued by the Commission on Radiological Protection, entitled "Planning areas for emergency response management in the vicinity of nuclear power plants" (SSK 2014b), that was adopted in February 2014. These results will also be the basis for the further development of off-site emergency response measures that will be derived from the implementation of the experience gained in the reactor accident.

1.2. Overview

The target of this study is to analyse the radiation exposure to the population in the event of an accident involving a meltdown in a German NPP and to identify the areas where protective measures for the population would have to be taken. The analysis is based on different release scenarios (chapter 4) and boundary conditions (chapter 3) according to the state-of-the-art of science and technology, always bearing in mind the occurrences in Fukushima (chapter 2). On the basis of these assumptions the authors evaluated the protective measures that would be required in the event of such massive releases according to the existing and advanced emergency response management concepts (chapter 3). To this end those areas were identified where high doses and serious deterministic effects might occur (in case of the assumed release and the considered meteorological situation) and where the emergency reference levels for protective measures might be exceeded.

The radiological consequences of these releases were assessed taking three NPP sites as examples (Unterweser, Grohnde and Philippsburg; see chapter 5). The radiological consequences were determined with the help of the decision support system RODOS (chapter 6). Numerical weather forecasts issued by Germany's National Meteorological Service DWD for the period November 2011 to October 2012 were used for the dispersion calculations. For every day within the above-mentioned period a separate RODOS calculation was performed and the radiological consequences were analysed at each site and for each source term (chapter 7). The results of these calculations were evaluated with the help of different criteria, in particular with respect to the size, expansion and position of the areas where dose criteria would be exceeded and protective measures for the population would have to be taken (chapter 8). This report ends with a summary of the most important results (chapter 9).

2. RELEVANT DATA ON THE COURSE OF EVENTS IN FUKUSHIMA

2.1. Description of the accident

On 11 March 2011 the Northern part of Japan was hit by a magnitude 9.0 earthquake. The epicentre was located around 130 km off the Eastern coast of the Northern part of Japan's main island Honshu. The earthquake triggered a tsunami that ravaged the coastal areas one hour later by producing several flood waves with a height of up to 15 metres.

This natural disaster triggered a severe nuclear accident at the Fukushima Dai-ichi site where six nuclear generating units comprising light water reactors were operated. The Japanese government classified this accident subsequently as a level 7 event on the International Nuclear and Radiological Event Scale (INES 7).

The accident struck the generating units 1 to 4 of the Fukushima Dai-ichi site. The reactor cores in blocks 1, 2 and 3 were destroyed because the external power supply, the internal emergency power supply and the heat removal failed. Furthermore, the cooling water supply in the wet storage facilities was interrupted so that the integrity of the fuel elements was at risk. This was in particular true for unit 4 where the complete reactor core was intermediately stored at the time of the accident due to maintenance work.

The damage that had occurred in units 1 to 3 led to significant releases of radioactive substances into the environment that lasted more than a week. Although the meteorological conditions prevailing during the main release phase contributed to a dissipation of the radioactive substances in the direction of the sea, large-scale measures for the protection of the population were required (see also GRS 2013, BfS 2012).

2.2. Areas where protective measures were implemented in Fukushima

In the first days after the accident large areas within up to 20 km from the power plant site were evacuated. In an area with a distance of up to 30 km from the plant people were urged to remain indoors. Later on, people living even further away were requested to leave their homes in an area in north-western direction with a distance of up to 47 km from the power plant site (see Fig. 2.2 below). This decision was based on local dose rate measurements.

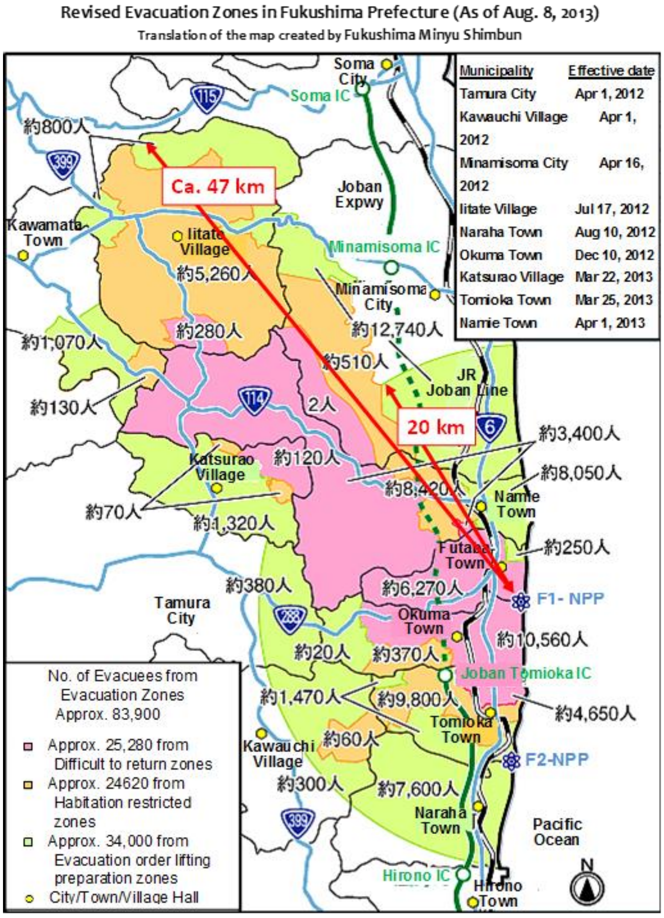


Fig. 2.2: Evacuation zones and number of people affected after the Fukushima Dai-ichi accident; this map shows the current classification of evacuation zones with respect to the future lifting of evacuation orders (Source: Fukushima Minyun Shimbun, revised by Kenji Nanba, Univ. of Fukushima).

The area where protection measures were implemented immediately after the accident is significantly larger than the corresponding evacuation zones previously envisaged both in Japan and in Germany.

3. CONCEPT FOR THE DETERMINATION OF POTENTIALLY AFFECTED AREAS

3.1. Radiological Foundations and Protection Concepts (revised in 2014)

The present study is fundamentally based on the concept previously valid for German emergency management with respect to the planning and implementation of protective measures in the case of an event involving significant releases of radioactive substances. This protection concept is described in "Radiologische Grundlagen für Entscheidungen über Maßnahmen zum Schutz der Bevölkerung bei Ereignissen mit Freisetzungen von Radionukliden" (*Radiological Foundations for decisions on measures to protect the population in case of events involving radionuclide releases*) (SSK 2014). The Radiological Foundations are based on radiobiological and radioepidemiological knowledge, in particular with respect to dose-risk and dose-effect relationships for stochastic and deterministic effects. Refinements of the protection concept could also be included in the study thanks to the cooperation of BfS and SSK.

In 2014 the Commission on Radiological Protection (SSK) concluded its revision of the Radiological Foundations (SSK 2014). In the course of this revision it was possible to include the conceptual enhancements and precisions on radiological emergency management that were made on an international level in recent years.

They are essentially based on the recommendations issued in 2007 by the International Commission on Radiological Protection ICRP 103 (ICRP 2007). The concepts for exposure situations that might result from a radiological emergency, newly introduced in the ICRP 103 publication, are more closely explained in the following publications ICRP 109 (ICRP 2009a) and ICRP 111 (ICRP 2009b), where the implementation is discussed in more detail.

ICRP recommendation 103 introduces a reference value for the residual dose that includes in particular the effective dose and takes into account dose contributions via all exposure paths (inhalation, external radiation, ingestion). In the case of serious radiological events the reference value for the effective dose within a year following the event can be fixed at a maximum of 100 mSv. The ICRP suggests that the residual dose to be stipulated for emergency planning purposes be typically between 20 mSv and 100 mSv within the first year following the event (ICRP 103). However, the reference value to be determined must take into account the gravity of the radiological consequences that has to be expected.

In the framework of the present study BfS also analysed the question if the new ICRP concept of a reference value for the residual dose in the first year following the incident matches the existing German emergency reference levels (section 8.6).

The study also includes analyses with respect to the protective measures “Temporary relocation” and “Permanent relocation” as defined by the protection concept valid up to 2014. However, the introduction of reference values according to the IRCP reduces the practical relevance of these measures.

3.2. Radiological protection goals in emergency management

BfS based its investigations presented here on the radiological protection goals set out in the Radiological Foundations (SSK 2014) and the associated assessment criteria. The Commission on Radiological Protection refined its radiological protection goals in emergency planning when revising its Radiological Foundations. All measures implemented as part of the emergency management are aimed at reducing the radiation exposure to the population, as per (SSK 2014). The objective is to avoid serious deterministic effects by taking measures to reduce individual radiation doses so that they remain below the threshold doses for these effects. According to (SSK 2014), the ICRP defines serious deterministic effects as irreversible damage that is directly attributable to the radiation exposure and leads to a significant deterioration in the quality of life.

Apart from avoiding deterministic effects, appropriate measures are envisaged in order to reduce and adequately limit the risk of individuals incurring stochastic effects.

3.3. Concept for determining potentially affected areas and the associated radiological criteria

The target of this study is to analyse the radiation exposure to the population in the event of an accident involving a meltdown in a German NPP and to identify the areas where protection measures for the population would have to be taken. The concept for determining the areas affected by protection measures is described in the SSK Recommendation "Planungsgebiete für den Notfallschutz in der Umgebung von Kernkraftwerken" (*Planning areas for emergency management in the vicinity of nuclear power plants*) (SSK 2014b). The area affected by a presumed accident is segmented according to the established goals and to the requirements for an effective and efficient implementation of protective measures. The concept for determining potentially affected areas uses a dose-related approach, based on the selection of an adequate reference accident with the associated reference source term. However, additional requirements and boundary conditions such as ensuring the implementation of protective measures in line with the priorities are also considered as weighting factors in the analysis of the calculated dose distribution.

Potentially affected areas were determined with the help of dispersion calculations based on a reference source term (chapter 4). One of the objectives of these calculations was to determine up to which distance from the source protective measures would be required in the assumed event. The emergency reference levels for the different protective measures were used as criteria to determine the areas where protective measures for the population would have to be taken.

According to (SSK 2014), emergency reference levels are dose levels that individuals will or might receive assuming certain exposure conditions. They function as radiological trigger criteria for the relevant protective measures. Emergency reference levels are planning values. The emergency reference levels for protective measures relate to the effective dose or the organ dose (in the case of the thyroid). The different emergency reference levels are dose levels that are far below the threshold doses for deterministic effects. Emergency reference levels for the protective measures listed in Table 3.3.1 are indicated in the Radiological Foundations (SSK 2014). The emergency reference levels help to determine areas where it is necessary from a radiation protection perspective to implement protective measures.

Table 3.3.1: Emergency reference levels for the interventions "Sheltering", "Stable iodine prophylaxis" and "Evacuation".

Type of intervention	**Emergency reference levels**		
	Organ dose (thyroid)	**Effective dose**	**Integration times and exposure paths**
Sheltering		10 mSv	External exposure within 7 days and committed effective dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside
Stable iodine prophylaxis	50 mSv Children and teenagers under the age of 18 and pregnant women; 250 mSv Individuals aged 18 to 45		Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside
Evacuation		100 mSv	External exposure within 7 days and committed effective dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside

Three planning areas can be determined based on the emergency reference levels stated above:

1. An area immediately connected to the NPP premises where the population should be evacuated because the “100 mSv criterion” might be exceeded.
2. An area connected to the previous one where all individuals who are scheduled for a thyroid prophylaxis should take iodine tablets because the relevant emergency reference level (thyroid dose) might be exceeded; and
3. An area connected to the previous one where children and teenagers under the age of 18 should take iodine tablets because the thyroid dose might exceed 50 mSv under the given boundary conditions.

The potential radiation exposure principally decreases with an increasing distance from the NPP premises. Thus people in the immediate vicinity of the plant would be more severely affected by the radiological consequences of an assumed accident than people further away from the plant. In order to optimise the protection of the population in line with the extent of the potential effects, the planning area for an evacuation must be further subdivided.

It must be noted that in the event of a presumed INES level 7 accident serious deterministic effects and a high risk of stochastic effects are possible in an area directly connected to the NPP premises if no protective measures are taken. It is therefore necessary to prepare protective measures for this area that can be implemented and completed very quickly with top priority and, if possible, before the release caused by the accident starts. Thus when determining the top priority planning area two aspects are of primary importance: a) avoiding serious deterministic effects and b) ensuring that the implementation of protective measures is optimised, i.e. performed in line with priorities.

In order to determine the top priority planning area the distance from the plant was analysed up to where the occurrence of serious deterministic effects would be probable if people were to remain outside permanently for 7 days. The criterion used for the potential occurrence of such effects was the threshold dose for the relevant deterministic effects. In (SSK 2014) a variety of deterministic effects and their dose thresholds are examined in detail. The threshold doses quoted there, however, are generally levels that will not provoke any effects at all in 99% of the exposed individuals.

With respect to serious deterministic effects it can be deduced from the analysis in (SSK 2014) that a short-time radiation exposure of the red bone marrow can severely impair blood cell formation. A dose threshold of 1000 mGy is quoted for this effect. Compared with the other serious deterministic effects discussed in (SSK 2014), a short-time exposure of the haematopoietic red bone marrow at a threshold dose of 1000 mGy is the most restrictive condition for adults and children. According to (SSK 2014), the increased radiation sensitivity during prenatal development calls for special threshold doses for particularly radiation-sensitive stages in the development of tissue and organs. The most restrictive conditions with respect to serious deterministic effects and the associated threshold doses result in a threshold dose of 100 mGy for short-time whole-body exposure during the foetal development stage between the 2nd and 7th week and a threshold dose of 300 mGy for the brain during the particularly radiation-sensitive stage of development between the 8th and 15th week of pregnancy.

The following table summarizes the threshold doses for the occurrence of serious deterministic effects that were taken into consideration when determining the top priority planning area. All threshold levels are cited from the Radiological Foundations (SSK 2014).

Table 3.3.2: Threshold levels for the occurrence of serious deterministic effects

Dose criterion	**Group of individuals**	**Threshold level**	**Integration times and exposure paths**
Dose to the red bone marrow	Adults, infants	1000 mGy	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside
Effective dose or uterus dose* (see below)	Foetus 2nd to 7th week	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled by the mother in this time if she were to remain permanently outside
Dose to the brain	Foetus 8th to 15th week	300 mGy	External exposure within 7 days and committed dose due to the radionuclides inhaled by the mother in this time if she were to remain permanently outside

*Since it is not possible to calculate organ doses to the foetus for the organogenesis, the inhalation dose to the mother is used as the effective dose to the foetus and the uterus dose to the mother is used for the external exposure (ICRP 2001).

Apart from the threshold levels for serious deterministic effects the SSK introduced another criterion for determining the top priority planning area with a level of 1000 mSv for the effective dose. The groups of individuals, integration times and exposure paths correspond to the boundary conditions for the emergency management levels stated in (SSK 2014). This criterion helps to determine areas where measures need to be taken with top priority and where protective measures are particularly effective. As with the threshold levels for the occurrence of serious deterministic effects this criterion is only a planning factor which helps to determine the area where protective measures must be implemented.

3.4. Other relevant criteria for the present study

The present investigations exceed the scope necessary for determining planning areas. On the basis of the previous protection concept investigations were performed to define the areas where temporary or permanent relocations might be necessary according to the assumed boundary conditions. The radiological criteria relevant for these investigations are summarized in the following Table 3.4:

Table 3.4: Emergency reference levels for the interventions Permanent relocation and Temporary relocation (as per SSK 2008)

Type of intervention	Emergency reference levels		
	Organ dose (thyroid)	Effective dose	Integration times and exposure paths
Permanent relocation		100 mSv	External exposure within 1 year due to deposited radionuclides
Temporary relocation		30 mSv	External exposure within 1 month

3.5. Methods for determining potentially affected areas

An analytical method was selected to determine the potentially affected areas. Different release scenarios were considered (see chapter 4), including a reference source term chosen by SSK for determining the planning areas. The RODOS system (Real-time Online Decision Support System) (Raskob and Gering 2010; see also http://www.rodos.fzk.de) was used to determine those areas where high doses and serious deterministic effects might occur considering the established boundary conditions and where emergency reference levels for protective measures might be exceeded. Other factors of influence for emergency management were also considered when selecting the reference source term and establishing the boundary conditions for the calculation and assessment. The method consisted of the following steps:

- Establish parameters for the assumed release of radioactive substances;
- Select reference source terms including of scenarios comparable to the Fukushima accident;
- Select representative NPP sites in Germany;
- Establish boundary conditions for the RODOS calculations;
- Establish evaluation procedures to determine potentially affected areas where protective measures are required from a radiological point of view;
- Perform RODOS calculations to determine those areas where protective measures would be necessary according to the emergency reference levels as per (SSK 2014), where the 1000 mSv criterion is reached or where serious deterministic effects might occur.

The previous planning areas are outlined in the following paragraphs for a clear presentation of the baseline situation.

The planning areas for emergency management in the vicinity of nuclear power plants are set out in the framework recommendations for disaster control in the vicinity of nuclear installations (BMU 2008), as can be seen in the table below. In 2008, the framework recommendations were last aligned with the state-of-the-art of science and technology. They apply to German nuclear installations and installations in other countries close to the German borders that require planning on German territory.

Table 3.5: Planning areas according to the framework recommendations for emergency management in the vicinity of nuclear installations (valid through February 2014; BMU 2008).

Central zone	In the central zone all alert measures type 2 must be prepared (alert measures type 2 are designed to prevent imminent risks to the lives and health of the population and include in particular interventions such as Sheltering, Stable iodine prophylaxis and Evacuation). In the case of NPP the central zone is a radius of 2 km around the plant. Measures to be taken in the central zone are particularly urgent due to the proximity to the affected plant and are generally performed independently of the direction of dispersion.
Intermediate zone	The intermediate zone is a circular planning zone where all alert measures type 2 must be prepared. In the case of NPP the intermediate zone stretches from a radius of 2 km from the plant to a radius of roughly 10 km from the plant. Measures to be taken in the intermediate zone are generally performed depending on the direction of dispersion (determined by sectors).
Exterior zone	The exterior zone is a circular planning zone where the distribution of iodine tablets to all individuals under the age of 45 must be prepared and the population must be warned not to eat freshly harvested food. In addition, measurements will be performed in the exterior zone to assess the radiological situation. In the case of NPP the intermediate zone stretches from a radius of 10 km from the plant to a radius of roughly 25 km from the plant. Measures to be taken in the exterior zone are generally performed depending on the direction of dispersion (determined by sectors).
Distant zone	The distant zone is a circular planning zone where the distribution of iodine tablets to children and teenagers under the age of 18 and to pregnant women must be prepared and the population must be warned not to eat freshly harvested food. In the case of NPP the distant zone stretches from a radius of 25 km from the plant to a radius of roughly 100 km from the plant. This zone may be divided in subsections with respect to organizing the distribution of iodine tablets. Measures to be taken in the distant zone are performed depending on the direction of dispersion (determined by sectors).

Planning areas are regions in the vicinity of the nuclear installation where particular protective measures must be prepared. In the framework recommendations these regions are called "planning zones" and are divided into central zone, intermediate zone, exterior zone and distant zone.

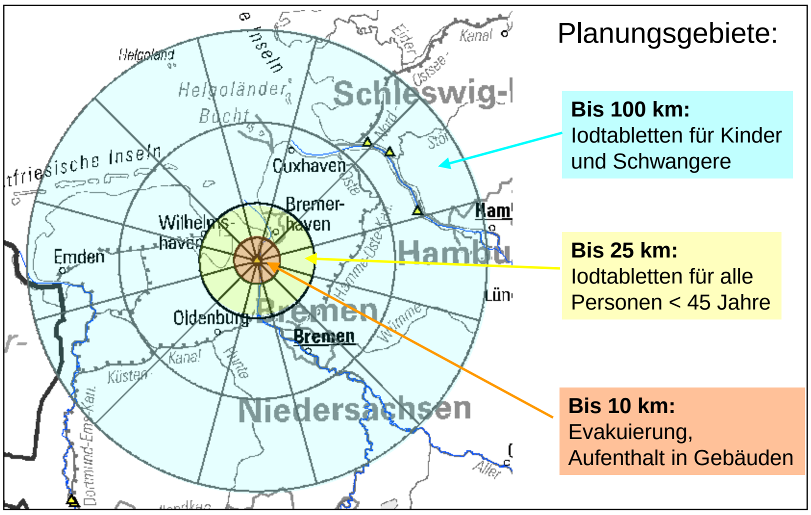


Fig. 3.1: Planning areas for disaster control (valid through February 2014), illustrated at the example of the Unterweser nuclear power plant

4. RELEASE SCENARIOS

The present study considers various release scenarios (source terms) in order to estimate the resulting radiation exposure experienced by the population and to determine the necessary protective measures.

The German Association for Plant and Reactor Safety (GRS) established representative event sequences for pressurised-water reactors and boiling-water reactors within a research project at the end of 2010. The associated source terms were added to the RODOS source term library (Löffler et al. 2010). The following table shows the developed scenarios for pressurised-water reactors.

Table 4.1: Release categories in the RODOS source term library as per (Löffler et al. 2010); for reasons of comparison the established source term for the Fukushima accident as per (GRS 2013) is indicated in italics

Name	Type	Release of iodine-131 [Bq]	Release of caesium-137 [Bq]	Beginning of main release Hours [h] after reactor shutdown	Calculated frequency [10^{-7}/year]
FKA	Uncovered steam generator tube leak	$3.1 \cdot 10^{17}$	$2.9 \cdot 10^{16}$	≈ 21	2.1
Fukushima	*Cooling failure in several reactors*	*1 to* $2 \cdot 10^{17}$	$1\text{-}2 \cdot 10^{16}$	*≈ 13*	-
FKI	Filtered pressure discharge via the chimney	$2.8 \cdot 10^{15}$	$2.8 \cdot 10^{11}$	≈ 57	8.8
FKH	Filtered pressure discharge via the roof	$2.8 \cdot 10^{15}$	$2.8 \cdot 10^{11}$	≈ 57	2.6
FKF	Unfiltered pressure discharge via the roof	$2.3 \cdot 10^{16}$	$2.8 \cdot 10^{14}$	≈ 57	2.1
FKE	Failure of the sump suction pipe	$1.8 \cdot 10^{17}$	$9.4 \cdot 10^{14}$	≈ 33	1.4

The release scenarios FKA, FKF and FKI were taken into consideration for the present study (highlighted in bold letters in the table above). These releases correspond to the highest categories, i.e. level 5 (FKI), level 6 (FKF) and level 7 (FKA) on the commonly accepted International Nuclear Event Scale (INES) used for assessing nuclear and radiological events.

A source term is characterised by the amount of radioactive substances released (release quantity), length of release and place of release. For disaster control purposes the length of the pre-release period is also of key importance (i.e. the length of time between the moment when it is recognized that a larger release of radionuclides from the plant is possible and the beginning of the release; corresponding to the "beginning of main release" in the above table).

The following figures show the development of release rates for the three considered source terms FKA, FKF and FKI.

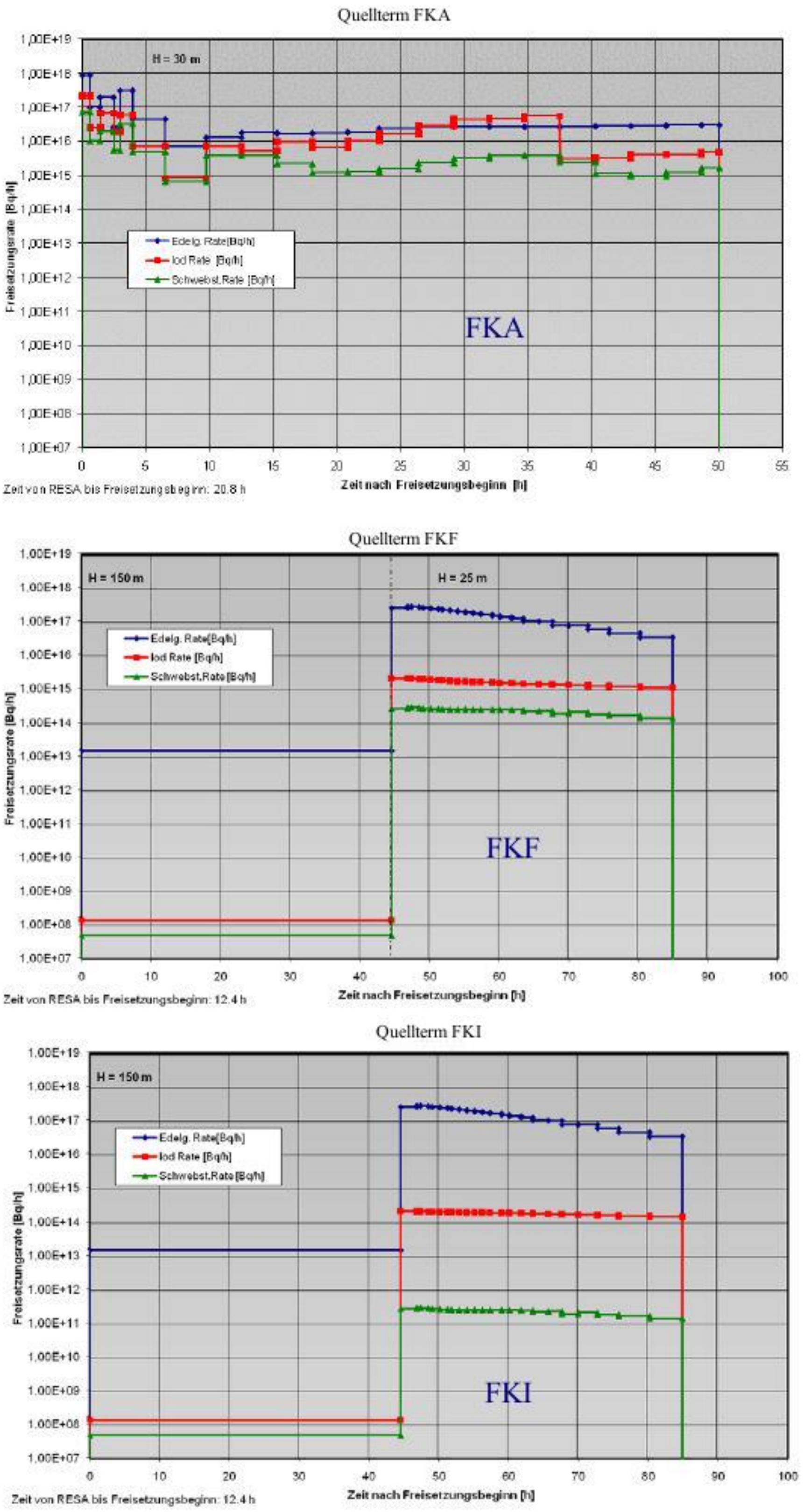


Fig. 4.1: Development of release rates over time (summed up via nuclide groups) for the considered source terms FKA, FKF and FKI. The relevant height of release (above ground) is stated in each figure in the upper left-hand corner.

5. SELECTION OF INVESTIGATED NPP SITES

5.1. Selection of investigated sites

The three areas selected for the present investigation were supposed to represent as far as possible the different climatological conditions in Germany. The selected areas are characterized by:

- Shallow orography, high wind velocity on average;
- Moderately structured orography, positioned in a valley, moderate wind velocity on average; and
- Distinctive deep valley, moderate orography, low wind velocity on average, frequent occurrence of inversions.

NPP sites within these areas were selected (Unterweser, Grohnde and Philippsburg) and the radiological consequences for accidents at these sites were calculated.

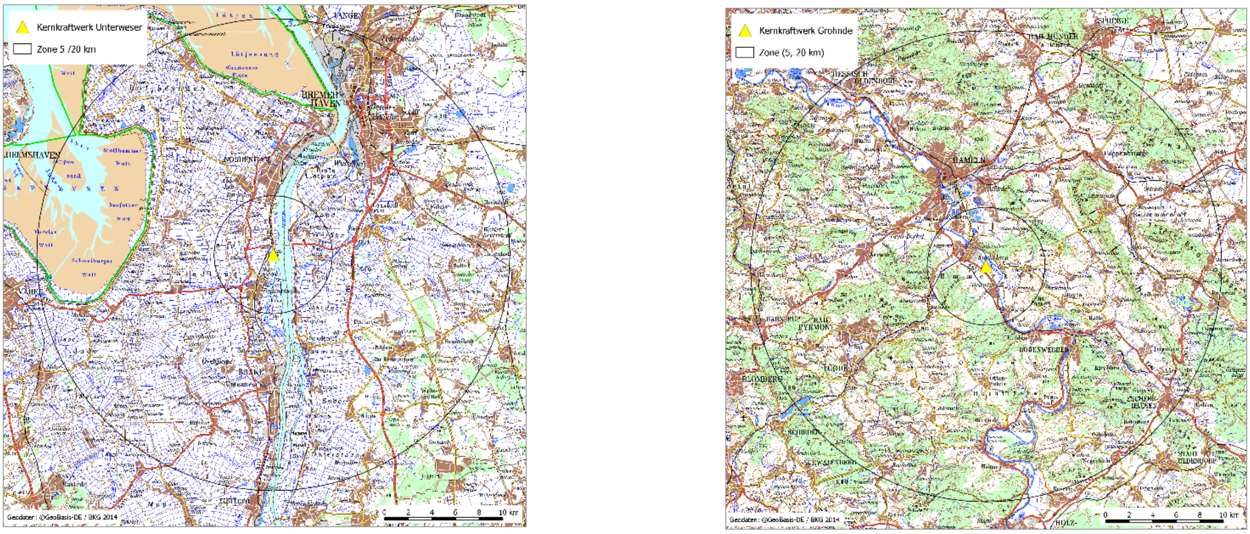


Fig. 5.1 a, b: Representation of the surroundings of Unterweser NPP (left) and Grohnde NPP (right) on a topographic map with the scale indicated in the bottom right-hand corner and circles at a distance of 5 km and 20 km from the site

Fig. 5.1 c: Representation of the surroundings of Philippsburg NPP on a topographic map with the scale indicated in the bottom right-hand corner and circles at a distance of 5 km and 20 km from the site

5.2. Meteorological comparison of individual sites

Long-term time series of meteorological measurements, established through the Remote Monitoring of Nuclear Power Plants (KFÜ), are available for the Unterweser, Grohnde and Philippsburg sites. BfS has made a statistical analysis of the monthly average of these data over several years. This analysis has shown that the period of time for which the calculations were performed, i.e. 1 November 2011 to 31 October 2012, can be considered representative for a longer period (2008 - 2012). Extraordinary meteorological conditions would have limited the validity of the results.

5.2.1. Wind velocity at the individual sites

Wind velocity is an essential parameter for dispersion. The following diagrams show the statistical distribution of wind velocity for individual wind velocity classes and different years (2008 – 2012) at the individual sites (Unterweser, Grohnde and Philippsburg).

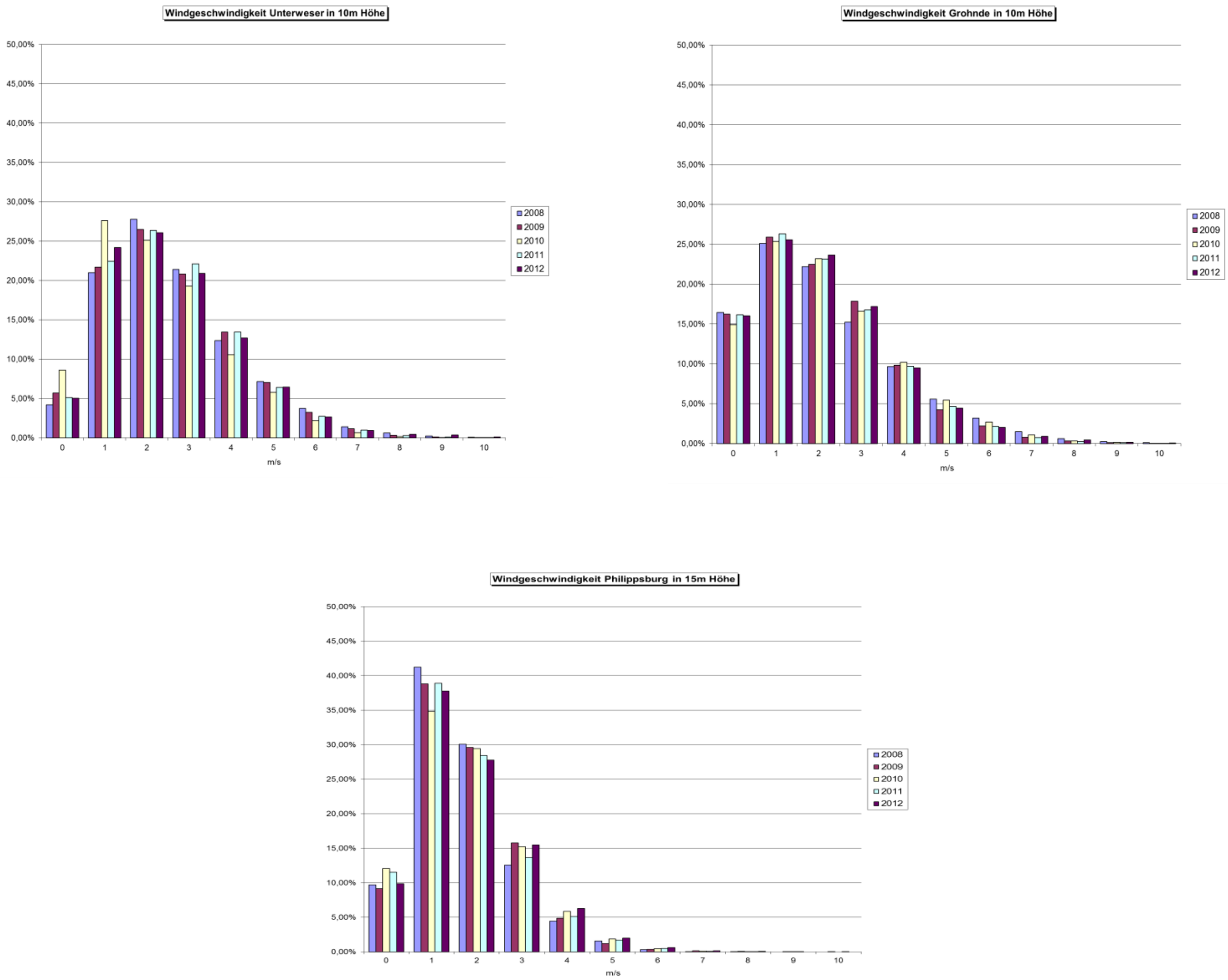


Fig. 5.2.1 a, b, c: Diagrams showing the frequency distribution of wind velocity at the Unterweser, Grohnde and Philippsburg sites in the years 2008 to 2012

The frequency distributions of wind velocity are typical representations of the different climatic regions in Germany with

- relatively high wind velocities in the north German lowlands (Unterweser),
- slightly lower wind velocities in the area of moderately structured orography (Grohnde with a distinguishable increase in frequency for lower wind velocities due to its position in a valley) and
- the shift to the area of lower wind velocities due to its position in a deep valley and frequent occurrence of inversions in the Upper Rhine Rift (Philippsburg).

The differently coloured bars each represent one year. It can be clearly seen that there are no great differences between the individual years for the set of data available (2008 – 2012). There is a slight increase in frequency for lower wind velocities (0 and 1 m/s) at Unterweser in 2010. However, this is due to statistical variations and is not relevant for the further assessments.

5.2.2. Wind direction

The wind direction is represented in the form of a frequency distribution of the wind direction as a function of time. A greater distance from the centre means that this wind direction is more frequent in the year under consideration (differently coloured lines).

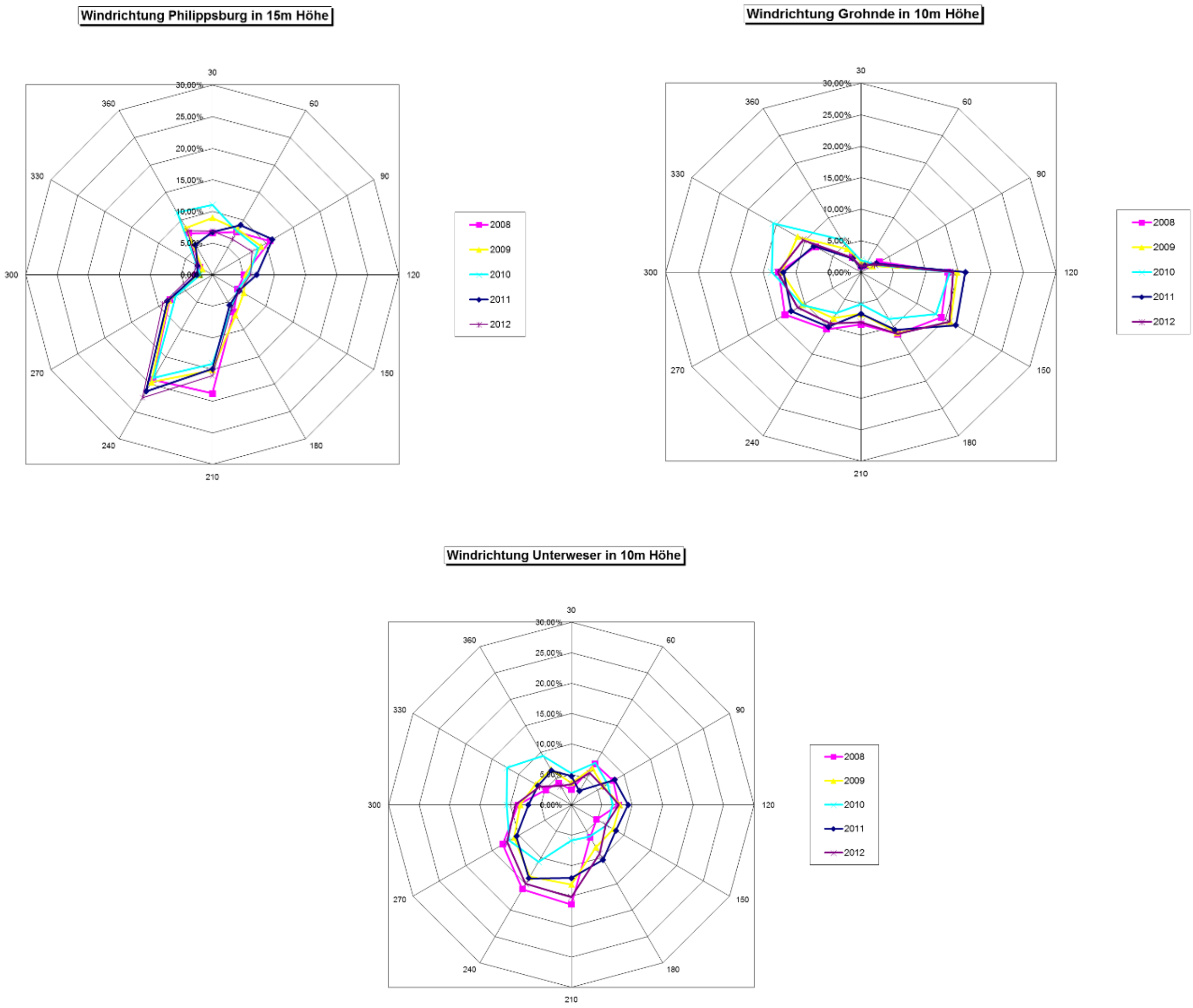


Fig. 5.2.2 a, b, c: Frequency distribution of the wind velocity at the Philippsburg, Grohnde and Unterweser sites in the years 2008 to 2012. The wind direction is combined in sectors of 30° each.

For the northern part of Germany, a broad distribution of south-western wind directions can be seen, which is typical for this region (prevailing wind direction). A dominance of certain wind directions can also be seen in the charts for Grohnde and Philippsburg. These frequent occurrences are due to the fact that the airstream is guided because of the site's position in a valley and/or the valley's orientation.

So the period of time for which the calculations were performed (1 November 2011 to 31 October 2012) can be considered representative for the meteorologically analysed years 2008 to 2012 with respect to the wind direction as well.

5.2.3. Atmospheric stability

The atmospheric stability is also of considerable relevance to the dispersion in the atmosphere. It is therefore another essential parameter for dispersion and is thus investigated in the study. The stability is represented according to the Pasquill stability classes. As per Pasquill, A means very unstable, B unstable to slightly unstable, C slightly unstable to neutral, D neutral to slightly stable, E stable and F very stable.

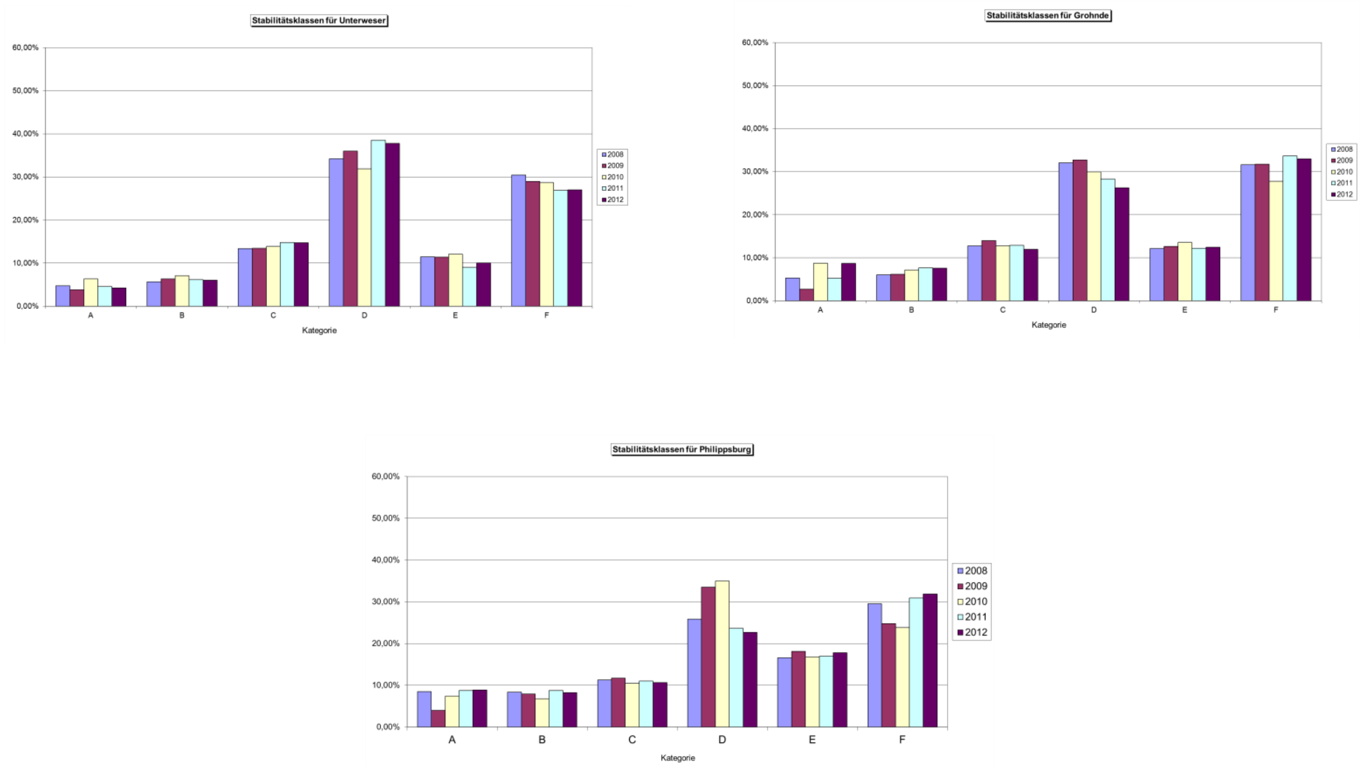


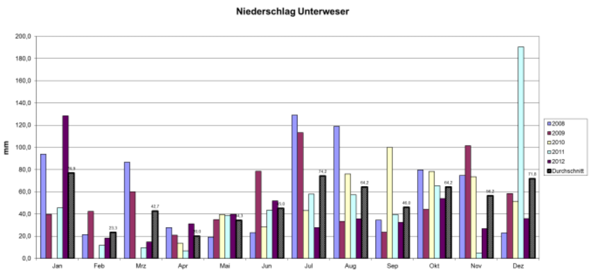
Fig. 5.2.3 a, b, c: Frequency distribution of stability (as per Pasquill) at the Unterweser, Grohnde and Philippsburg sites in the years 2008 to 2012

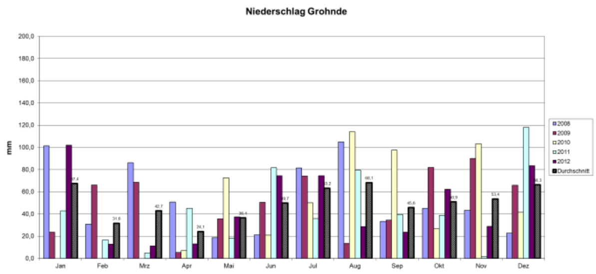
The frequency distribution of the stability classes is very similar at the different sites. Neutral to slightly stable cases (class D) and very stable cases (class F) are the most frequent occurrences. Neutral to slightly stable cases are most frequent at the Unterweser site near the German coast, while they are less often observed further away from the coast. The unstable cases (A to C) are less frequent near the German coast, while they are more often observed at the sites located in a valley (Grohnde und Philippsburg).

The frequency distribution does not present significant differences over the individual years. There are some fluctuations in class D at all sites and even less significant fluctuations in class F. Since these differences amount to less than 10% in the individual years they are not significant for the overall calculations.

5.2.4. Precipitation

Precipitation influences the dispersion of radionuclides in the atmosphere in particular due to wet deposition. This should therefore be regarded as another essential parameter for dispersion with respect to the statistical distribution in the individual years.





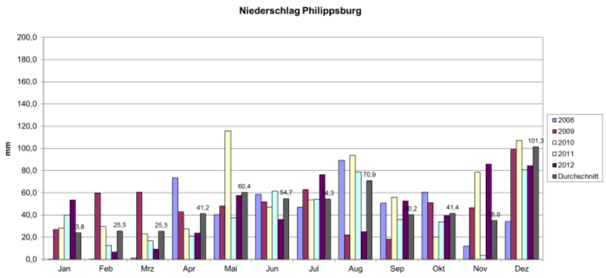


Fig. 5.2.4 a, b, c: Frequency distribution of precipitation at the Unterweser, Grohnde and Philippsburg sites in the years 2008 to 2012

Precipitation does indeed differ at the individual sites and especially over the different years. Precipitation seems to present greater differences in particular in several months of the year 2010. However, these differences are equalized by the frequency in the preceding and/or following months so that it can be assumed that these are ordinary and typical fluctuations for precipitation. It is not to be expected that these fluctuations have an impact on the wet deposition considered in RODOS calculations.

Summarizing the meteorological measurements of these essential parameters for dispersion it can be stated that the period of time chosen for the study (1 November 2011 to 31 October 2012) can be considered representative for a longer period of time (2008 – 2013).

6. THE DECISION SUPPORT SYSTEM (RODOS)

The investigations presented here and conducted by BfS on the subject of potential consequences of severe NPP accidents in Germany were performed with the help of the RODOS computer programme (Raskob und Gering 2010; http://www.rodos.fzk.de/). The Real-time Online Decision Support System (RODOS) is operated at BfS – as well as in numerous other European countries – in order to perform dispersion and dose calculations in the event of a nuclear accident (or other radionuclide releases into the environment) and to assess the potential consequences.

The Karlsruhe Institute of Technology (KIT) coordinates the development of RODOS, funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the European Commission. The project was conducted in cooperation with a working group constituted of federal government representatives and federal state representatives. For more than 10 years now the Federal Office for Radiation Protection (BfS) operates an emergency operations centre where the German RODOS is implemented and ready for operation. One of the system's special features is that the following data can be transmitted online and integrated in the calculations: real-time measuring data from the Remote Monitoring System for of Nuclear Power Plants (KFÜ) in the Federal States, meteorological forecast data from Germany's National Meteorological Service (DWD) and country-wide data from the Integrated Measurement and Information System (IMIS) used for monitoring environmental radioactivity.

RODOS comprises numerous models, e.g.

- for processing meteorological input data;
- for calculating the dispersion in the atmosphere;
- for simulating the transfer of radionuclides within the human food chain;
- for estimating the radiation exposure experienced by the population; and
- for simulating the impact of a variety of countermeasures.

6.1. Dispersion models in RODOS

A variety of dispersion models is integrated in RODOS. Due to different boundary conditions (e.g. calculation time, spatial and temporal resolution) mainly two models can be used for the extensive calculations performed with RODOS in the framework of this study. These two models will be outlined in the following paragraphs. Both models were used in the study. Since the RIMPUFF model offers a higher physical potential and the possibility to calculate consequences for greater distances from the place of release, all results presented in this study are based on calculations performed with RIMPUFF.

6.1.1. ATSTEP

ATSTEP is based on the algorithm of a Gaussian puff model and is used for distances of up to 50 km from the place of emission [http://www.rodos.fzk.de/Documents/Public/Handbook/Volume3/4_2_5_ATSTEP.pdf]. It was developed in particular for very rapid calculations in the case of a release of airborne, radioactively contaminated substances due to an accident. ATSTEP can calculate a real-time diagnosis of the radiological situation following a release and dispersion for up to 24 hours.

A radiological situation can thus be described via the following results, calculated with ATSTEP:
- Ground-level concentration (short-term or time-integrated);
- Contamination of the soil surface due to dry or wet deposition;
- Gamma radiation (from the soil, from the cloud).

These results are then edited as time-dependent, nuclide-specific fields in the entire computational domain.

The following dispersion-relevant or radiologically-relevant phenomena can be considered with the help of ATSTEP:
- Time-dependent meteorology (mast measurements, SODAR, forecast data, inhomogeneous wind fields);
- Time-dependent and nuclide-specific release rates, significance of thermal buoyancy (effective plume height).

In contrast to traditional puff models (e.g. RIMPUFF), ATSTEP does not use short-term puff releases but time-integrated, elongated puffs. The transport of each expanded puff in the atmosphere is represented by two trajectories that are each coupled to both ends of the puff. This pair of trajectories and thus the expanded puff itself follows an inhomogeneous and variable 2D-wind field so that the corresponding cloud retraces all the required changes in position, dimension and orientation, such as extending, rotating, shrinking or lateral movements.

Due to the expanded puffs the simulation of the cloud can be represented by a significantly smaller amount of puffs. The number of time steps required for simulating release and transport is therefore clearly smaller. This type of approximation thus reduces the programme's computing time so that a complete dispersion and exposure forecast for a release over several hours can be obtained in a ten-minute real-time interval.

Compared with the traditional puff model the approximation via expanded puffs requires a reduction of the spatial and temporal resolution. This higher resolution, however, is only necessary if the dispersion conditions are extremely variable and inhomogeneous.

6.1.2. RIMPUFF

The RIMPUFF model (Risø Mesoscale PUFF Model) is a Lagrangian, mesoscale, atmospheric puff dispersion model that calculates the activity and doses of airborne radioactive substances. The model can handle both non-steady and inhomogeneous meteorological situations that are particularly important with respect to estimating the short-term releases (due to an accident) of airborne radionuclides in the atmosphere.

The model can be used in homogeneous and inhomogeneous terrains with moderate orography for a range of up to several hundred kilometres from the place of emission. Time-variable releases can be represented by a series of Gaussian puffs where each puff represents the amount of release within a certain time interval.

RIMPUFF was optimised for real-time computation of activities, time-integrated activities, the deposition and the dose originating from the gamma radiation of the clouds and the soil. The RIMPUFF computation procedure comprises stability-dependent dispersion parameters, computation procedures for the effective plume height, the possibility to include inversion and reflection at the soil and the possibility to include dry and wet deposition. The model can also be used in moderately structured terrain; a puff-split procedure will be used in this case.

6.2. Dose calculations in RODOS

Dose calculations in RODOS include all relevant human exposure paths in the case of radionuclide releases. These are:

- External radiation exposure due to radionuclides in the air;
- External radiation exposure due to radionuclides deposited on the ground;
- External radiation exposure due to radionuclides deposited on the clothes or skin;
- Internal radiation exposure due to inhalation of airborne radionuclides;
- Internal radiation exposure due to ingestion of radionuclides with the food.

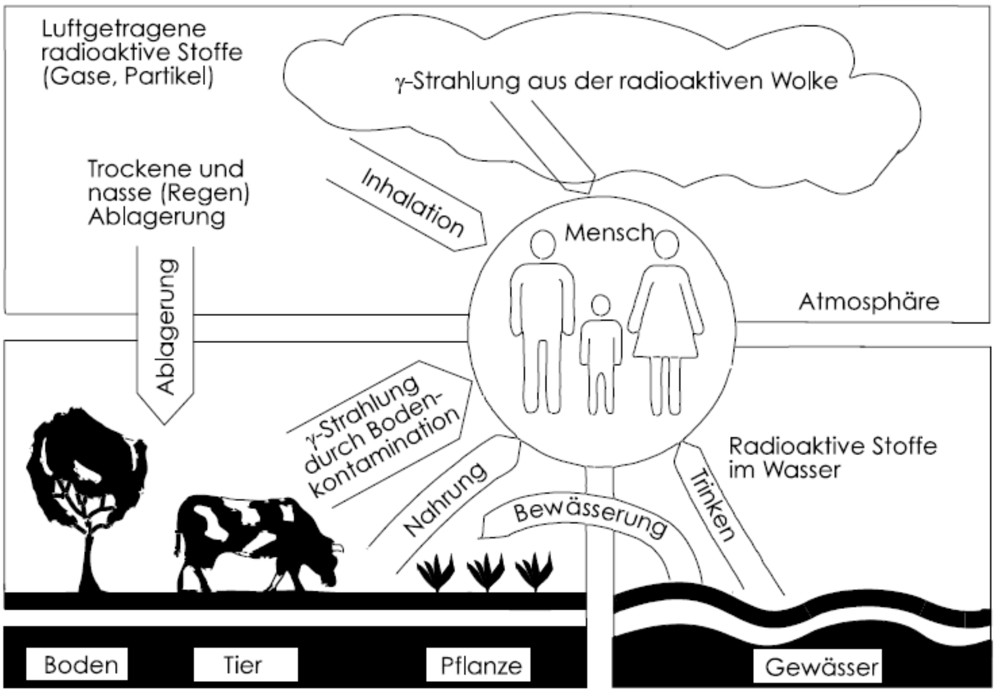


Fig. 6.2: Schematic representation of exposure paths that can lead to human radiation exposure (as per (SSK 2008)).

Dose calculations with the help of RODOS can include different factors, such as:
- Dependency of the dose on the age group considered (adults with a 50-year committed dose in case of incorporation; teenagers, children and infants with a 70-year committed dose in case of incorporation);
- Dependency of the dose on the organ considered (e.g. effective dose, thyroid dose etc.), or on inhalation rates;
- Reduction of the dose due to sheltering in buildings;
- The long-term reduction of the external dose rate due to weather-related effects;
- The influence of plant growth, harvesting, processing and storing foodstuffs and feedstuffs on the internal dose arising from the ingestion of radionuclides with the food;
- The influence of food patterns on the internal dose arising from the ingestion of radionuclides with the food.

The dose coefficients are a central element of the dose calculations – they describe the relationship of radionuclides in different environmental media (e.g. on the soil surface, in the air or in food) and the resulting human radiation exposure. RODOS uses the dose coefficients published by the International Commission on Radiological Protection (ICRP) to calculate the internal exposure (ICRP 2012, BMU 2001). The internal exposure of the foetus is also calculated with the help of dose coefficients established by the ICRP (ICRP 2001). Since no international recommendations for dose rate coefficients are available for the external exposure, RODOS uses data published by the Association for Radiation and Environmental Research (GSF) (Jacob 1990).

7. CALCULATIONS IN RODOS

7.1. Boundary conditions

The objective of this study is to analyse the consequences that an accident in a German NPP might have, including the occurrence of a meltdown. To this end those areas were identified with the help of RODOS where high doses and serious deterministic effects will occur (in case of the assumed release and the considered meteorological situation) and where the emergency reference levels for protection measures will be exceeded. The calculations in RODOS were performed on the example of three NPP sites (Unterweser, Grohnde and Philippsburg; cf. chapter 5).

Based on the releases listed in chapter 4 "Release Scenarios" and on real forecast data published by Germany's National Meteorological Service (DWD) calculations were performed in RODOS for a randomly selected period of time (1 November 2011 to 31 October 2012; 365 days with one calculation per day and a forecast period of 96 h). The large amount of computational results (obtained from more than 5000 individual calculations) constitutes a secured statistical basis for statements on the potential radiological consequences.

The selected period of time, i.e. a full year, ensures that each season with its individual meteorological conditions is sufficiently taken into consideration. An examination of the meteorological data obtained from the Remote Monitoring System of Nuclear Power Plants (KFÜ) at the individual sites over several years (see section 5.2) has shown that the period under investigation does not differ significantly from other years and can thus be considered a representative year. In order to statistically validate the data for this one-year-interval a dispersion calculation was performed in RODOS for each day and each site on the basis of the three relevant source terms (see chapter 4). Thus more than 3000 calculations were performed for 365 days and 3 sites. More than 2000 additional calculations were also performed (e.g. to investigate the impact of the dispersion model, the selected starting time and other assumptions). The individual calculations start at midnight of each day. The weather conditions at night, characterised by a stable layer, reduce the vertical exchange of contaminated air masses. Since the release is at its highest level in the beginning, the choice of midnight as starting point for the calculations generally leads to conservative results.

The data obtained from the COSMO-EM System (Consortium for Small-scale MOdeling – Model for Europe) used by Germany's National Meteorological Service (DWD) can be used as meteorological database for the flow fields. DWD routinely provides these data fields twice a day to BfS. Alternatively the meteorological data obtained from the KFÜ system of each site would have been available. The study's authors had to decide which set of data might be advantageous: more exact site data with meteorological measurements at the point of release or the DWD data that are representative for the entire simulation area. Since it was expected that the dispersion and the relevant exposure, based on the reference source term FKA, would stretch over more than 100 km in the simulation area, the DWD's data fields were considered advantageous.

Within RODOS the operator can choose between the dispersion models ATSTEP and RIMPUFF. ATSTEP is a model that is intended to provide rapidly-available calculation results so that a simple calculation algorithm was implemented. Since computing time was of minor relevance for these investigations, the authors opted for the RIMPUFF model. While RIMPUFF requires more computing time, it offers more detailed modelling (in particular for longer distances from the site of release) and thus better reproduction of the meteorological processes.

In each computation cycle the radiation exposure experienced by the population within the computational area was calculated in the form of the effective dose and the organ dose to the thyroid and bone marrow. The radiation doses were typically (i.e. unless otherwise stated) determined for an integration period of 7 days – this applies to the external doses due to radionuclides deposited on the ground – and with the conservative assumption that people would permanently remain outside without protection (i.e. shielding effects produced by buildings were not taken into consideration). The authors took account of the external exposure paths and the internal exposure due to inhalation. However, they did not take account of the internal exposure due to radionuclides in food (ingestion) since they assumed that the dose contribution caused by ingestion would be minor compared with the other exposure paths if EU maximum values for radionuclides in food were respected and use was restricted.

All calculations were performed for adults and small children (1 to 2 years of age), partly even for the embryo/foetus between the 2nd and 7th week (period during which malformations are induced by ionising radiation; SSK 2014a) and between the 8th and 15th week (main risk period for mental retardation due to ionising radiation; SSK 2014a).

The following figure shows one of the RODOS results on the example of the effective dose to adults due to inhalation, cloud and ground radiation over seven days. The interventions Sheltering and Evacuation are based on this dose value. The figure shows the result for the Grohnde site, the source term FKA and a fictitious release starting on 1 November 2011. Each of the RODOS calculations covers a square with a side length of around 320 km, the considered NPP lying in the centre of the square. This method makes it possible to calculate the radiological impact at least for a distance of 160 km from the NPP site. The red circles illustrate the previous emergency management planning areas around the NPPs (2, 10, 25 km). The circular areas at a distance of 2 to 10 km from the site and at 10 to 25 km from the site are each divided into 12 sectors. In the coloured representation of the result for this dose, the emergency reference level for the intervention Sheltering is exceeded when the colour changes from yellow to orange and the emergency reference level for the intervention Evacuation is exceeded when changing from red to magenta.

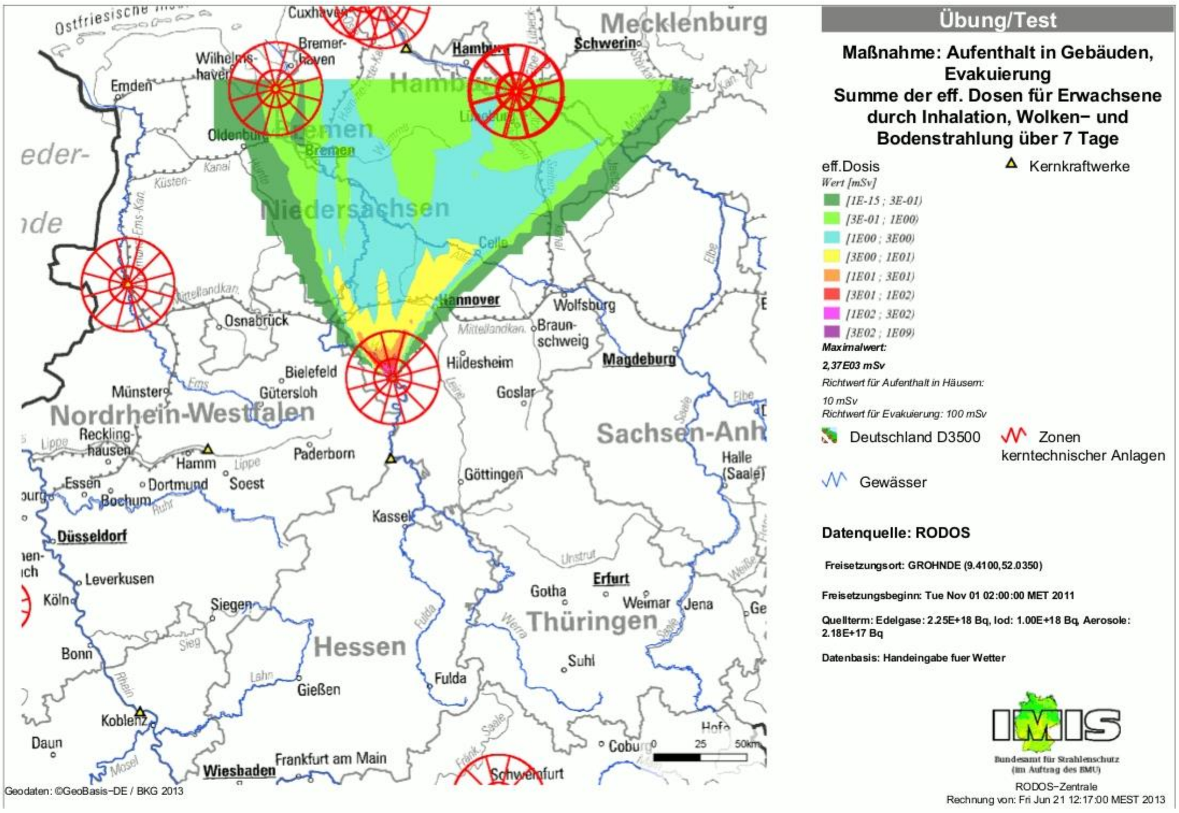


Fig. 7.1: Effective dose to adults due to inhalation, cloud and ground radiation over 7 days for the Grohnde site, the source term FKA and a fictitious release starting on 1st November 2011.

7.2. Analysis of the RODOS calculations

The results obtained from the RODOS calculations for the radiation exposure experienced by the population have been compared with different dose criteria (sections 3.3 and 3.4) and those areas have been determined where specific dose criteria were exceeded. The following dose criteria were taken into account:

1. Emergency reference levels for the interventions
   - Sheltering (effective dose of 10 mSv);
   - Evacuation (effective dose of 100 mSv);
   - Stable iodine prophylaxis (thyroid dose of 50 mSv for children, teenagers and pregnant women; thyroid dose of 250 mSv for individuals aged 18 to 45);
   - Temporary relocation (effective dose of 30 mSv in one month);
   - Permanent relocation (effective dose of 100 mSv in one year);
2. Threshold levels for the occurrence of serious deterministic effects (SSK 2914 a):
   - 1000 mGy for the dose to the red bone marrow;
   - 300 mGy for the brain dose to a foetus in 8th to 15th week;
   - 100 mSv for the effective dose to a foetus in 2nd to 7th week.
3. Dose criterion: effective dose of 1000 mSv (SSK 2014a).

The following parameters were defined for those areas where one of the dose criteria is exceeded:

- the surface area (see Fig. 7.2.1 a);
- the number of people affected (for some cases);
- the number of sectors affected at various distance ranges (see Fig. 7.2.1 b);
- the maximum distance from the NPP where each dose criterion is still exceeded (see Fig. 7.2.1 c).

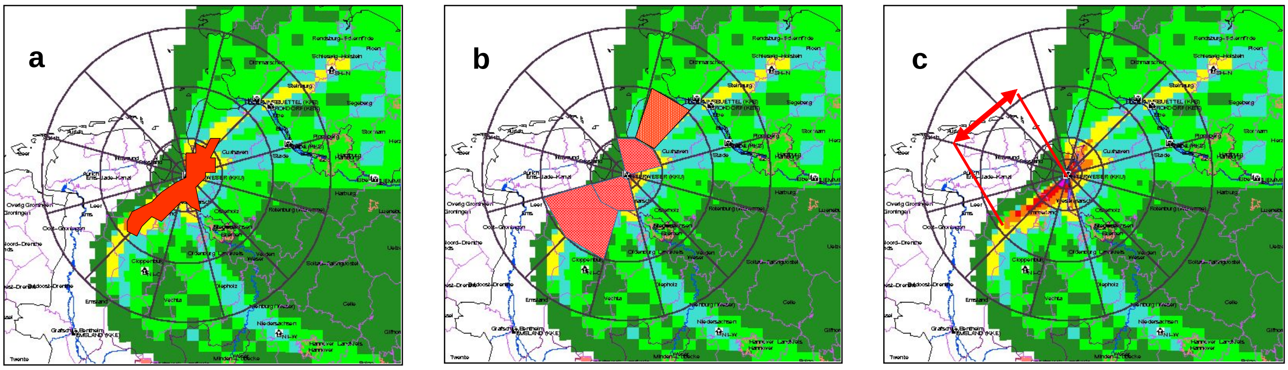


Fig. 7.2.1 a, b, c: Example of the determination of areas where one of the dose criteria is exceeded: (a) surface area, (b) number of sectors affected, (c) maximum distance from the NPP.

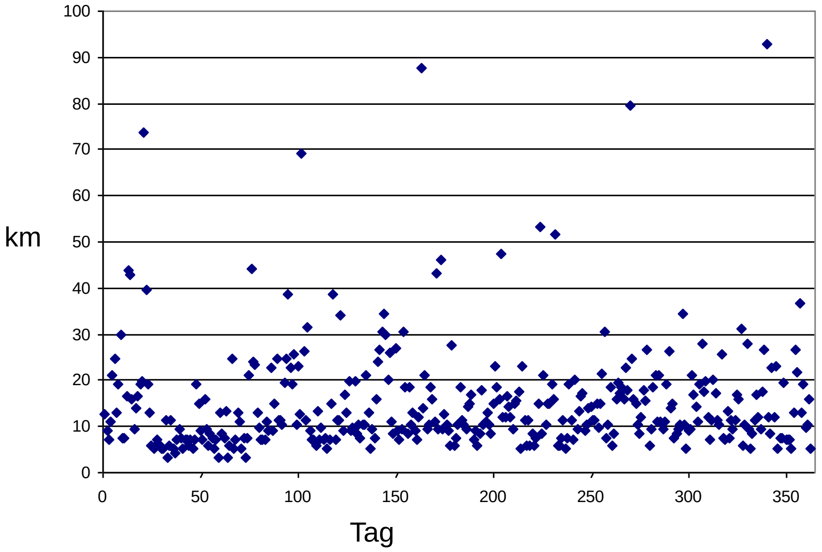
For each site, each release and each dose criterion the large number of calculations (resulting from the different weather scenarios within a year) makes it possible to determine the statistical distribution of the parameters characterising the affected areas. This distribution shows how often certain parameter values, such as a maximum distance within which an intervention needs to be implemented, can occur within one year.

Fig. 7.2.2 a below shows (by way of example) for each day within a particular year the maximum distance within which the emergency reference level for the intervention Evacuation would have been exceeded at the Unterweser site in the case of a release with the source term FKA. It can be seen that the results vary significantly. In most cases the maximum distance is between 5 km and 30 km, but larger values of up to 90 km are also reached in individual cases.

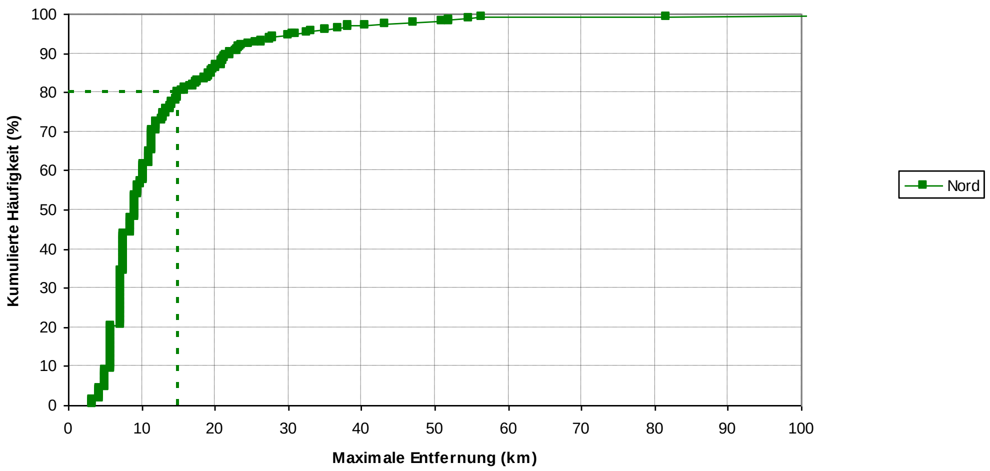
Fig. 7.2.2 b illustrates the cumulative frequency of these results. In this graphic the cumulative frequency represents the proportion of calculated weather conditions in which all areas where the relevant emergency reference value is exceeded are within the indicated distance.

Fig. 7.2.2 c shows the same results, compared for all three sites. It can be seen that the maximum distances for the intervention Evacuation tend to be longer for the "Southern" site (i.e. Philippsburg NPP) than for the other sites ("Northern" = Unterweser NPP, "Central" = Grohnde NPP).

a)



b)



c)

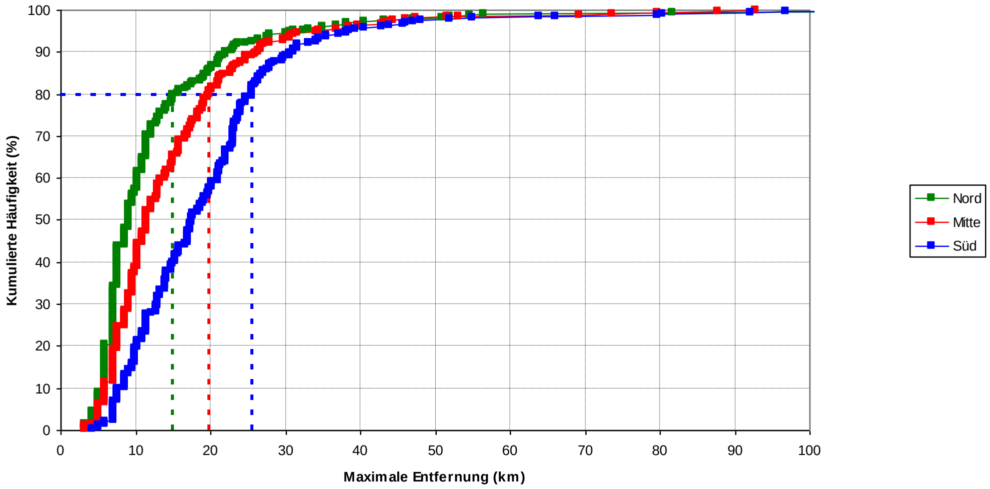


Fig. 7.2.2 a, b, c: Representation of the maximum distance within which the emergency reference level for the intervention Evacuation would have been exceeded in the case of a release with the source term FKA at the Unterweser site (a, b) and at all three sites (c).

8. RESULTS OF THE RODOS CALCULATIONS

The results of the RODOS calculations were assessed with respect to the dose criteria and the resulting protective measures for the population. The assessment focused in particular on the maximum dimensions and the total size of the affected areas, the number of affected people and the number of affected sectors (i.e. the affected angular range around the NPP).

In order to represent the results from the large number of simulations more clearly, the results of all individual calculations were summarized and statistically analysed. The data are represented via the cumulative frequency, e.g. as a function of the distance. The cumulative frequency represents the proportion of calculated weather conditions in which all areas where the relevant emergency reference value is exceeded are within the indicated distance. It can be seen from Fig. 8.1.1 a, for example, that the intervention Sheltering would have to be recommended for a distance of up to 62 km at the "Northern" site in 50% of the cases considered, while it would have to be recommended for a distance of more than 62 km in the other 50% of cases.

The statistical measure "percentile" will be used for the further assessment. "Percentile" is a measure used in statistical analyses of results, referring to the total amount (100% of simulations) of calculations performed in RODOS. The "percentile" is a value on a scale reaching from zero to one hundred, indicating the percentage of simulation calculations for which a result is equal to or lower than a previously defined value. The percentile is frequently used to estimate the extreme values in a distribution. In the context of the RODOS calculations, the 80th percentile can be used, for example, to determine the maximum distance for an intervention. Thus the 80th percentile of a distance (e.g. x km) means that an intervention will be required up to this distance of x km in 80% of the cases. In the remaining 20% of cases the intervention will be required in excess of this distance of x km.

8.1. Maximum dimensions of the affected areas

8.1.1. Intervention: Sheltering

<u>Intervention: Sheltering, adults, source term FKA</u>

Fig. 8.1.1 a: Cumulative frequency distribution of the maximum distance for the intervention Sheltering, adults, source term FKA

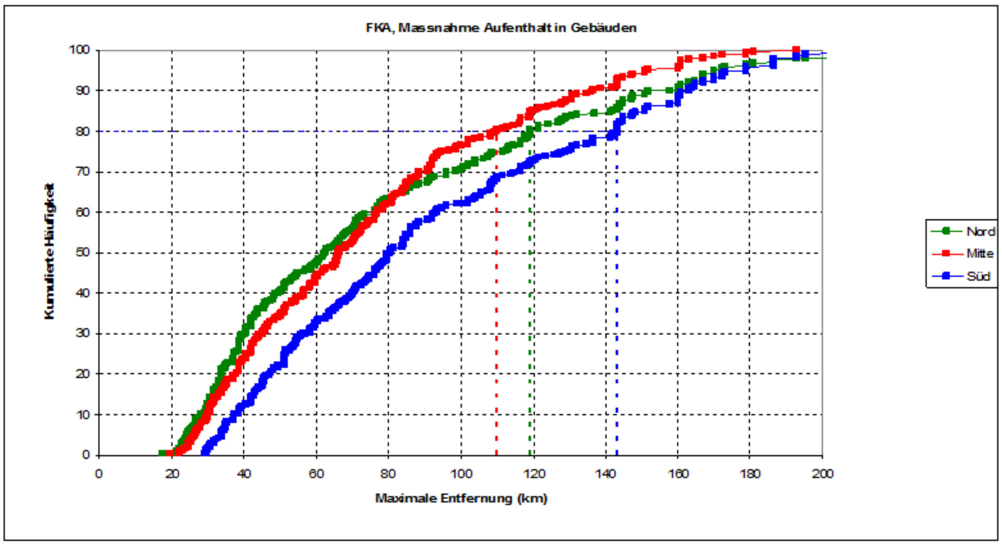


Table 8.1.1 a: Data on the cumulative frequency distribution of the maximum distance for the intervention Sheltering, adults, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Sheltering	Effective dose	Adults	10 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			62	119	152
Central site (Grohnde)			66	110	137
Southern site (Philippsburg)			80	143	163

The figure above shows the cumulative frequency of the intervention Sheltering for adults with an emergency reference level of 10 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.
Here the areas were determined where the intervention Sheltering would be necessary because the emergency reference level of 10 mSv is exceeded. The outer limit of these areas is defined as the maximum distance. In 80% of the considered cases this outer limit is at a distance of between 20 km and 110 km.

Similarly the outer limit for the Northern site would be defined as a distance of between 18 km and 119 km, and the outer limit for the Southern site would be defined as a distance of between 30 km and 143 km. Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

<u>Intervention: Sheltering, infants, source term FKA</u>

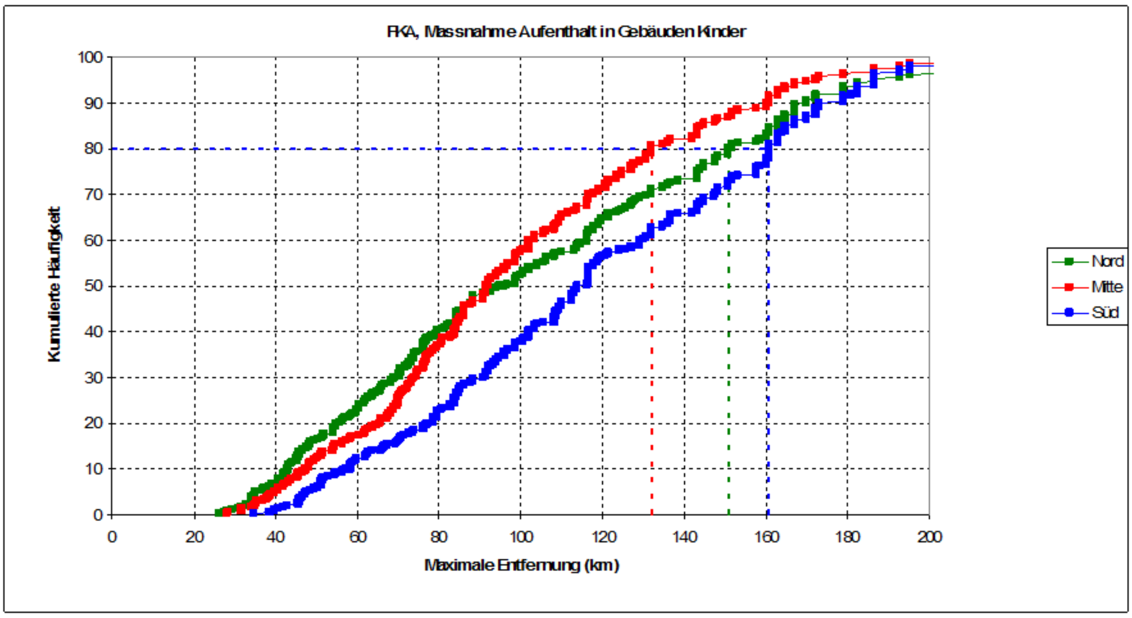


Fig. 8.1.1 b: Cumulative frequency distribution of the maximum distance for the intervention Sheltering, infants, source term FKA

Table 8.1.1 b: Data on the cumulative frequency distribution of the maximum distance for the intervention Sheltering, infants, source term FKA

<table>
<tr><td>Type of intervention</td><td>Dose criterion</td><td>Group of individuals</td><td>Emergency reference level</td><td colspan="2">Integration times and exposure paths</td></tr>
<tr><td>Sheltering</td><td>Effective dose</td><td>Infants</td><td>10 mSv</td><td colspan="2">External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside</td></tr>
<tr><td colspan="3"></td><td colspan="3">Maximum distance (km) at which the emergency reference level is exceeded.</td></tr>
<tr><td colspan="3"></td><td>50th percentile</td><td>80th percentile</td><td>90th percentile</td></tr>
<tr><td colspan="3">Northern site (Unterweser)</td><td>95</td><td>151</td><td>170</td></tr>
<tr><td colspan="3">Central site (Grohnde)</td><td>91</td><td>132</td><td>161</td></tr>
<tr><td colspan="3">Southern site (Philippsburg)</td><td>114</td><td>161</td><td>173</td></tr>
</table>

The figure above shows the cumulative frequency of the intervention Sheltering for infants with an emergency reference level of 10 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside

Based on the relevant emergency reference level of 10 mSv the intervention Sheltering should be recommended within an area with an outer limit of between 28 km and 132 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site should be defined as a distance of between 26 km and 151 km, and the outer limit for the Southern site should be defined as a distance of between 35 km and 161 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Intervention: Sheltering, adults, source term FKF

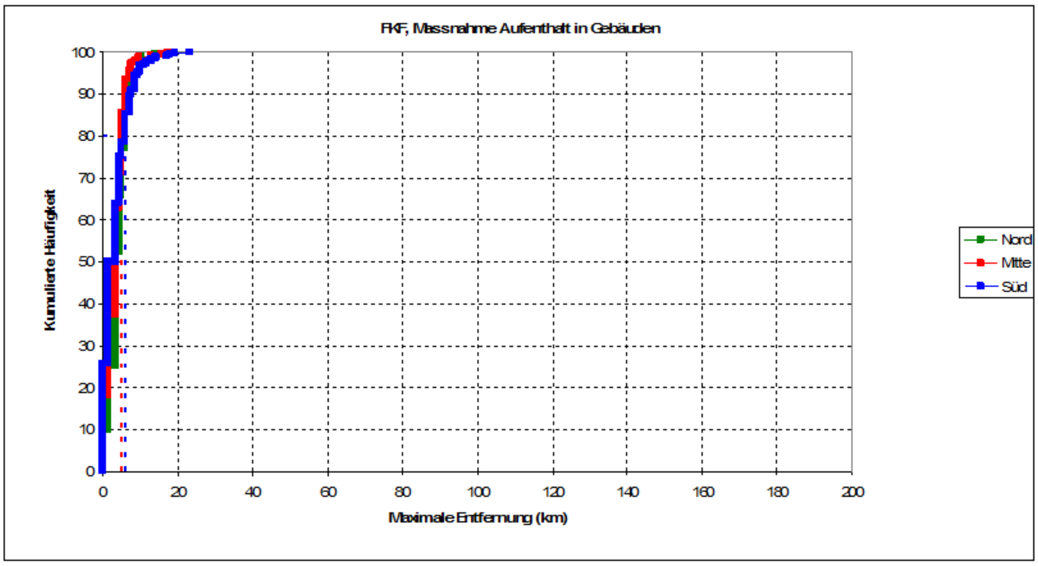


Fig. 8.1.1 c: Cumulative frequency distribution of the maximum distance for the intervention Sheltering, adults, source term FKF

Table 8.1.1 c: Data on the cumulative frequency distribution of the maximum distance for the intervention Sheltering, adults, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Sheltering	Effective dose	Adults	10 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			3	6	7
Central site (Grohnde)			3	5	6
Southern site (Philippsburg)			3	6	8

The figure above shows the cumulative frequency of the intervention Sheltering for adults with an emergency reference level of 10 mSv and the source term FKF. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 10 mSv the intervention Sheltering should be recommended within an area with an outer limit of between 0 km and 5 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 0 km and 6 km, and the outer limit for the Southern site would also be defined as a distance of between 0 km and 6 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Maximum distance for the intervention Sheltering, infants, source term FKF

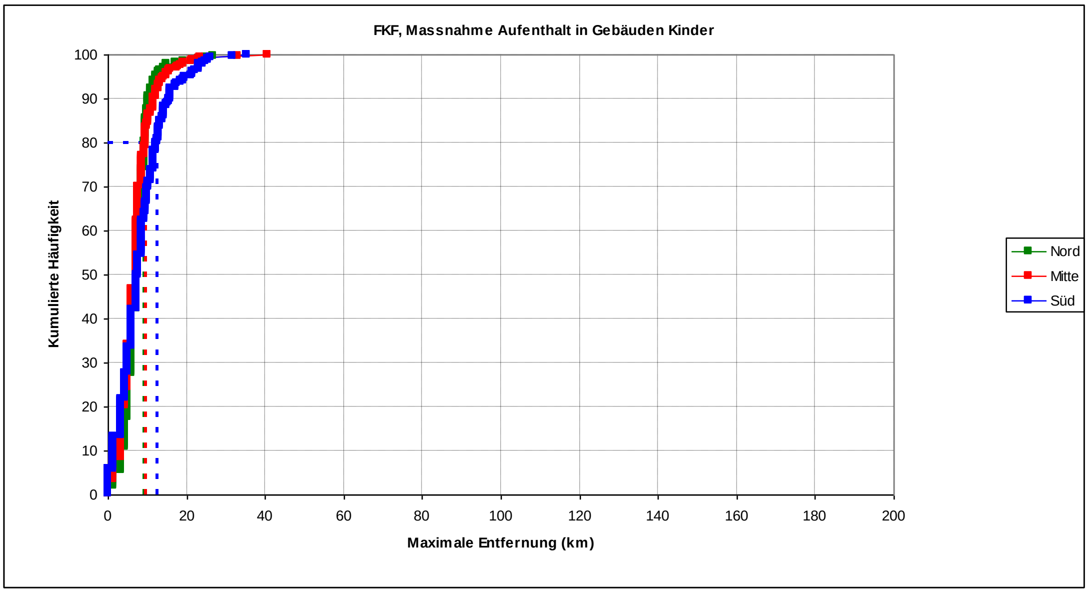


Fig. 8.1.1 d: Cumulative frequency of the maximum distance for the intervention Sheltering, infants, source term FKF

Table 8.1.1 d: Data on the cumulative frequency distribution of the maximum distance for the intervention Sheltering, infants, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Sheltering	Effective dose	Infants	10 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			7	9	10
Central site (Grohnde)			7	10	11
Southern site (Philippsburg)			8	13	16

The figure above shows the cumulative frequency of the intervention Sheltering for adults with an emergency reference level of 10 mSv and the source term FKF. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside

Based on the relevant emergency reference level of 10 mSv the intervention Sheltering should be recommended within an area with an outer limit of between 0 km and 10 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 0 km and 9 km, and the outer limit for the Southern site would be defined as a distance of between 0 km and 13 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

8.1.2. Intervention: Evacuation

Intervention: Evacuation, adults, source term FKA

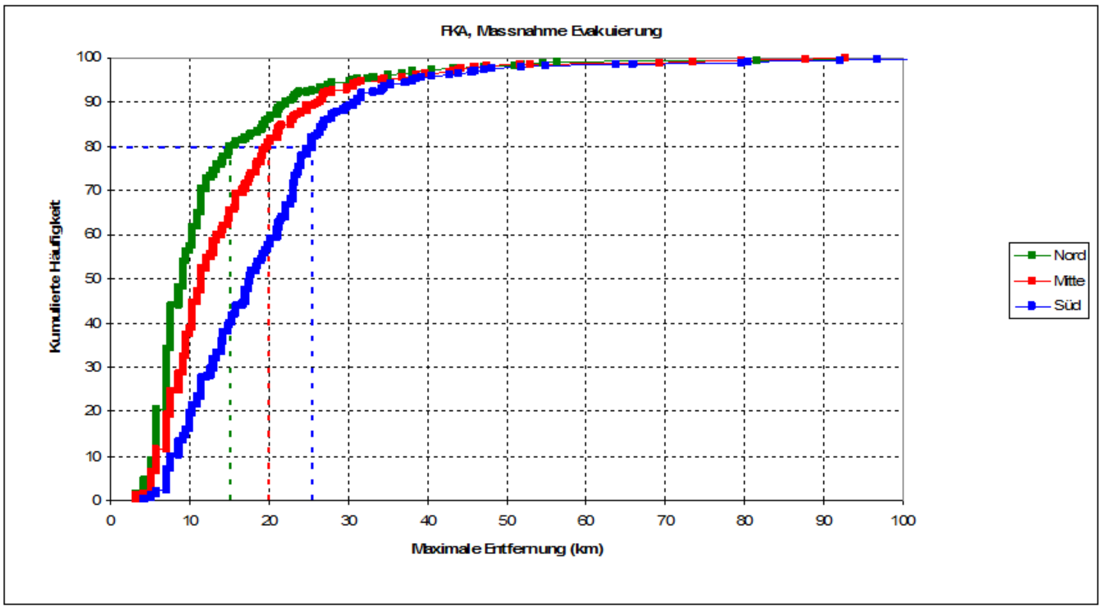


Fig. 8.1.2 a: Cumulative frequency distribution of the maximum distance for the intervention Evacuation, adults, source term FKA

Table 8.1.2 a: Data on the cumulative frequency distribution of the maximum distance for the intervention Evacuation, adults, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			9	15	22
Central site (Grohnde)			11	20	26
Southern site (Philippsburg)			18	26	31

The figure above shows the cumulative frequency of the intervention Evacuation for adults with an emergency reference level of 100 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 100 mSv the intervention Evacuation should be recommended within an area with an outer limit of between 3 km and 20 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 3 km and 15 km, and the outer limit for the Southern site would be defined as a distance of between 4 km and 26 km.
Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Intervention: Evacuation, infants, source term FKA

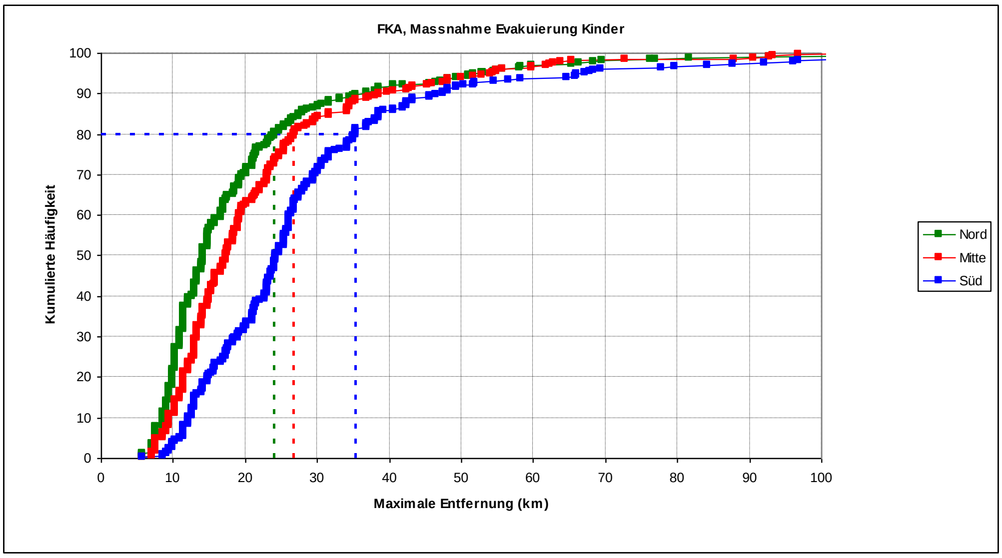


Fig. 8.1.2. b: Cumulative frequency distribution of the maximum distance for the intervention Evacuation, infants, source term FKA

Table 8.1.2. b: Data on the cumulative frequency distribution of the maximum distance for the intervention Evacuation, infants, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Infants	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			14	24	35
Central site (Grohnde)			17	27	39
Southern site (Philippsburg)			24	35	47

The figure above shows the cumulative frequency of the intervention Evacuation for infants with an emergency reference level of 100 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 100 mSv the intervention Evacuation should be recommended within an area with an outer limit of between 6 km and 27 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 6 km and 24 km, and the outer limit for the Southern site would be defined as a distance of between 6 km and 35 km.
Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Intervention: Evacuation, adults, source term FKF

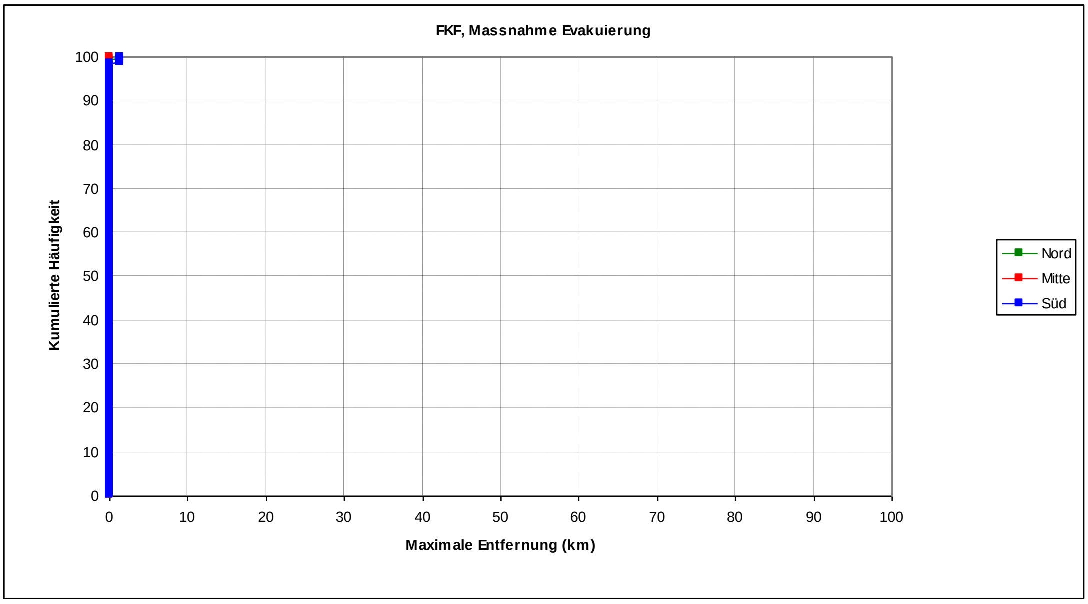


Fig. 8.1.2 c: Cumulative frequency distribution of the maximum distance for the intervention Evacuation, adults, source term FKF

Table 8.1.2 c: Data on the cumulative frequency distribution of the intervention Evacuation, adults, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	0
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	0

The figure above shows the cumulative frequency of the intervention Evacuation for adults with an emergency reference level of 100 mSv and the source term FKF. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The emergency reference level of 100 mSv is exceeded once at the Northern site, not at all at the Central site and 5 times at the Southern site; the distance for the outer limit is 1.4 km in each case. The 90th percentile is not reached.

Intervention: Evacuation, infants, source term FKF

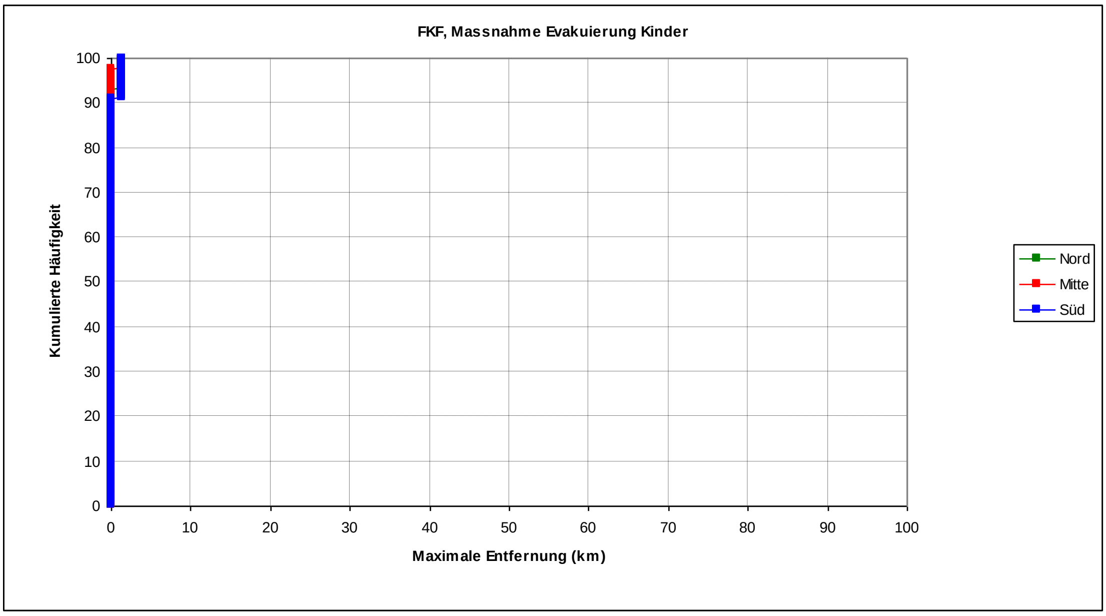


Fig. 8.1.2. d: Cumulative frequency distribution of the maximum distance for the intervention Evacuation, infants, source term FKF

Table 8.1.2 d: Data on the cumulative frequency distribution of the intervention Evacuation, infants, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Infants	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	0
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	0

The figure above shows the cumulative frequency of the intervention Evacuation for infants with an emergency reference level of 100 mSv and the source term FKF. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

In 365 individual calculations, the emergency reference level of 100 mSv is exceeded 24 times at the Northern site, 9 times at the Central site and 33 times at the Southern site; the distance for the outer limit is 1.4 km in each case. The 90th percentile is not reached.

8.1.3. Intervention: Temporary relocation

<u>Temporary relocation, adults, source term FKA</u>

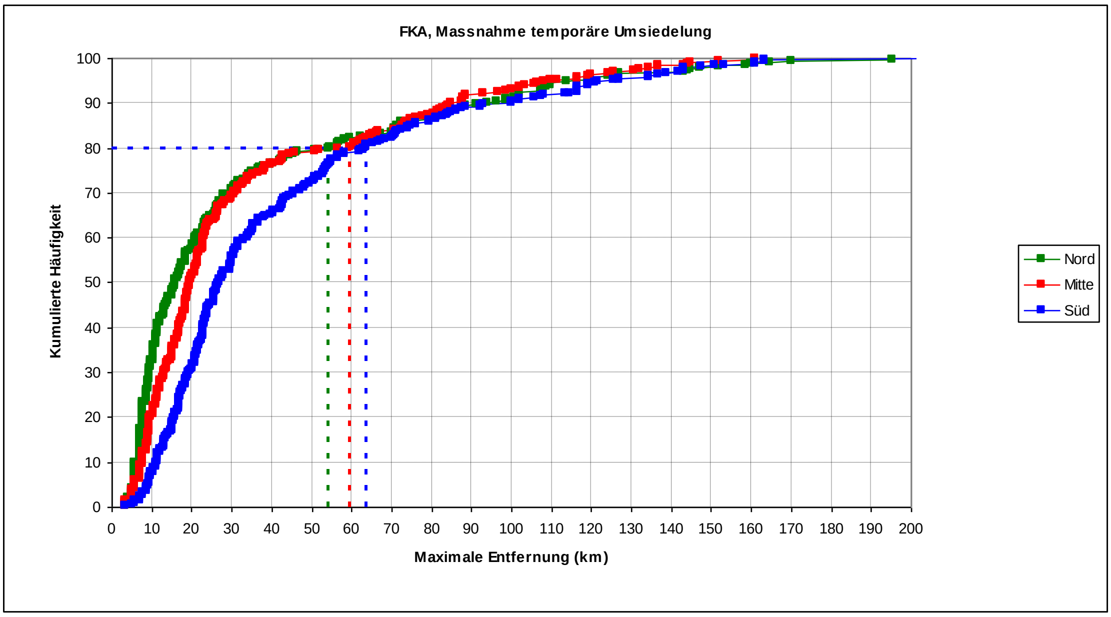


Fig. 8.1.3 a: Cumulative frequency distribution of the maximum distance for the intervention Temporary relocation, source term FKA

Table 8.1.3 a: Data on the cumulative frequency distribution of the intervention Temporary relocation, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Temporary relocation	Effective dose	Adults	30 mSv	Exterior exposure within 1 month	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			16	54	91
Central site (Grohnde)			20	60	85
Southern site (Philippsburg)			27	64	100

The figure above shows the cumulative frequency of the intervention Temporary relocation for adults with an emergency reference level of 30 mSv and the source term FKA. The integration times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 month.

Based on the previous emergency reference level of 30 mSv the intervention Temporary relocation should be recommended within an area with an outer limit of between 3 km and 60 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 3 km and 54 km, and the outer limit for the Southern site would be defined as a distance of between 3 km and 64 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Temporary relocation, infants, source term FKA

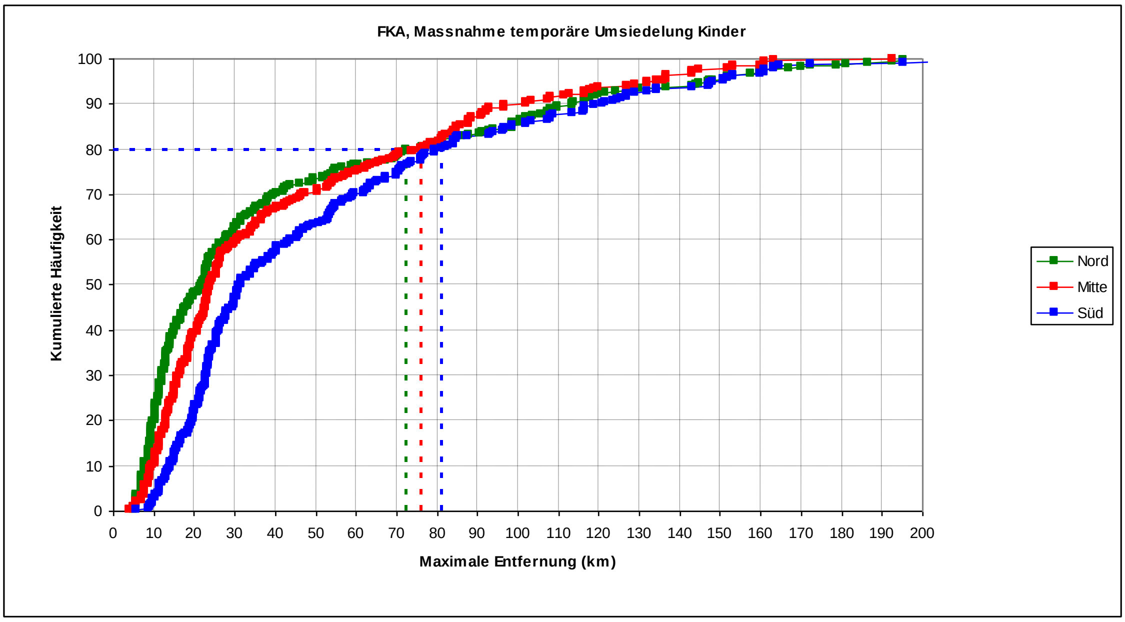


Fig. 8.1.3 b: Cumulative frequency distribution of the maximum distance for the intervention Temporary relocation, infants, source term FKA

Table 8.1.3 b: Data on the cumulative frequency distribution of the intervention Temporary relocation, infants, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Temporary relocation	Effective dose	Infants	30 mSv	Exterior exposure within 1 month	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			22	72	113
Central site (Grohnde)			24	76	102
Southern site (Philippsburg)			32	81	121

The figure above shows the cumulative frequency of the intervention Temporary relocation for infants with an emergency reference level of 30 mSv and the source term FKA. The integration times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 month.

Based on the previous emergency reference level of 30 mSv the intervention Temporary relocation should be recommended within an area with an outer limit of between 5 km and 76 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 4 km and 72 km, and the outer limit for the Southern site would be defined as a distance of between 6 km and 81 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Temporary relocation, adults, source term FKF

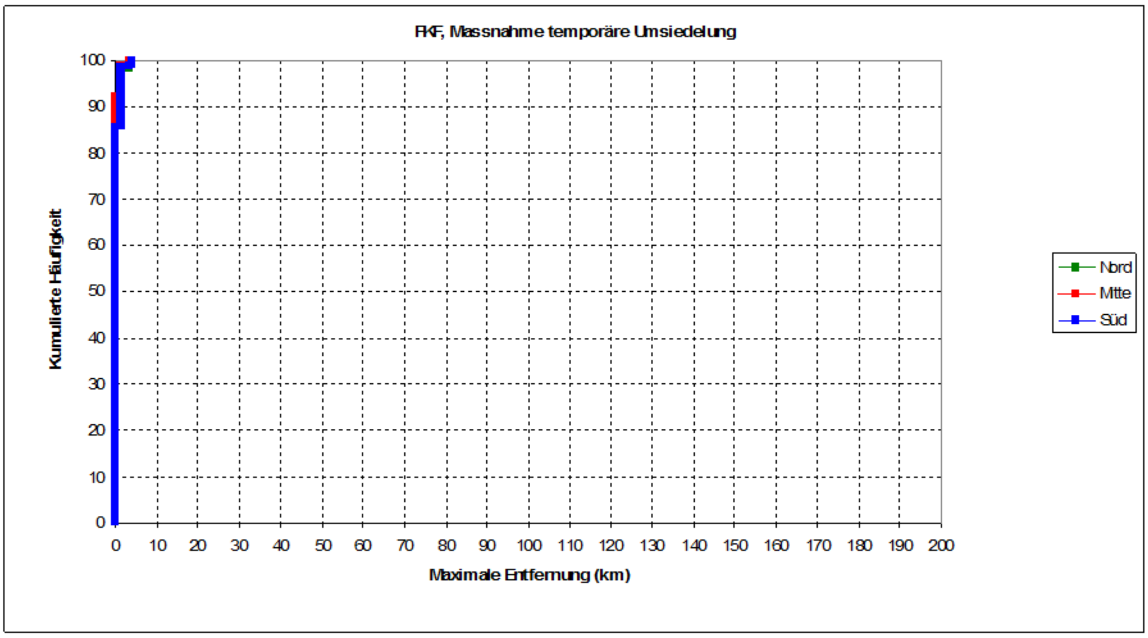


Fig. 8.1.3 c: Cumulative frequency distribution of the maximum distance for the intervention Temporary relocation, source term FKF

Table 8.1.3 c: Data on the cumulative frequency distribution of the intervention Temporary relocation, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Temporary relocation	Effective dose	Adults	30 mSv	Exterior exposure within 1 month	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	1.4
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	1.4

The figure above shows the cumulative frequency of the intervention Temporary relocation for adults with an emergency reference level of 30 mSv and the source term FKF. The integration times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 month.

In 365 individual calculations, the emergency reference level of 30 mSv is exceeded 41 times at the Northern site, 28 times at the Central site and 53 times at the Southern site; the distance for the outer limit is 4.2 km at maximum and 1.4 km in most cases. The 80th percentile is not reached.

Temporary relocation, infants, source term FKF

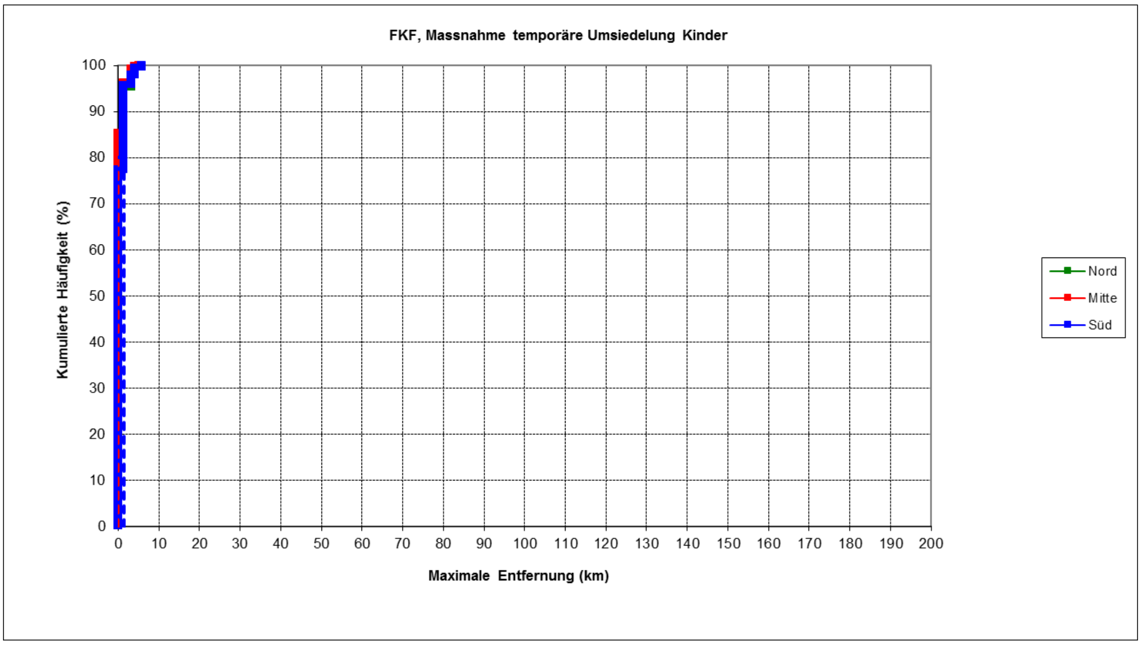


Fig. 8.1.3 d: Cumulative frequency distribution of the maximum distance for the intervention Temporary relocation, infants, source term FKF

Table 8.1.3 d: Data on the cumulative frequency distribution of the intervention Temporary relocation, infants, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Temporary relocation	Effective dose	Infants	30 mSv	Exterior exposure within 1 month	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	1.4
Central site (Grohnde)			0	0	1.4
Southern site (Philippsburg)			0	1.4	1.4

The figure above shows the cumulative frequency of the intervention Temporary relocation for infants with an emergency reference level of 30 mSv and the source term FKF. The integration times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 month.

In 365 individual calculations, the emergency reference level of 30 mSv is exceeded 68 times at the Northern site, 53 times at the Central site and 82 times at the Southern site; the distance for the outer limit is 5.1 km at maximum at the Northern and Central sites and 5.8 km at maximum at the Southern site. The 50th percentile is not reached in any case.

8.1.4. Intervention: Permanent relocation

Intervention: Permanent relocation, adults, source term FKA

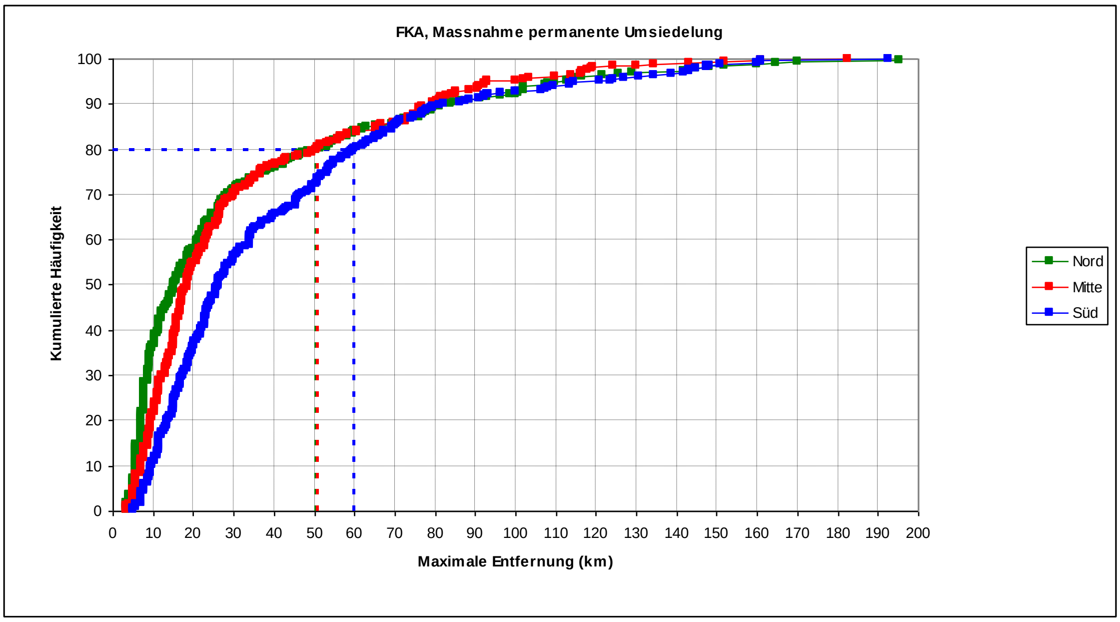


Fig. 8.1.4 a: Cumulative frequency distribution of the maximum distance for the intervention Permanent relocation, adults, source term FKA

Table 8.1.4 a: Data on the cumulative frequency distribution of the intervention Permanent relocation, adults, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Permanent relocation	Effective dose	Adults	100 mSv	Exterior exposure within 1 year due to deposited radionuclides	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			15	50	81
Central site (Grohnde)			18	51	80
Southern site (Philippsburg)			26	60	82

The figure above shows the cumulative frequency of the intervention Permanent relocation for adults with an emergency reference level of 100 mSv and the source term FKA. The integrations times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 year.

Based on the relevant emergency reference level of 100 mSv the intervention Permanent relocation should be recommended within an area with an outer limit of between 3 km and 51 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 3 km and 50 km, and the outer limit for the Southern site would be defined as a distance of between 5 km and 60 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Intervention: Permanent relocation, infants, source term FKA

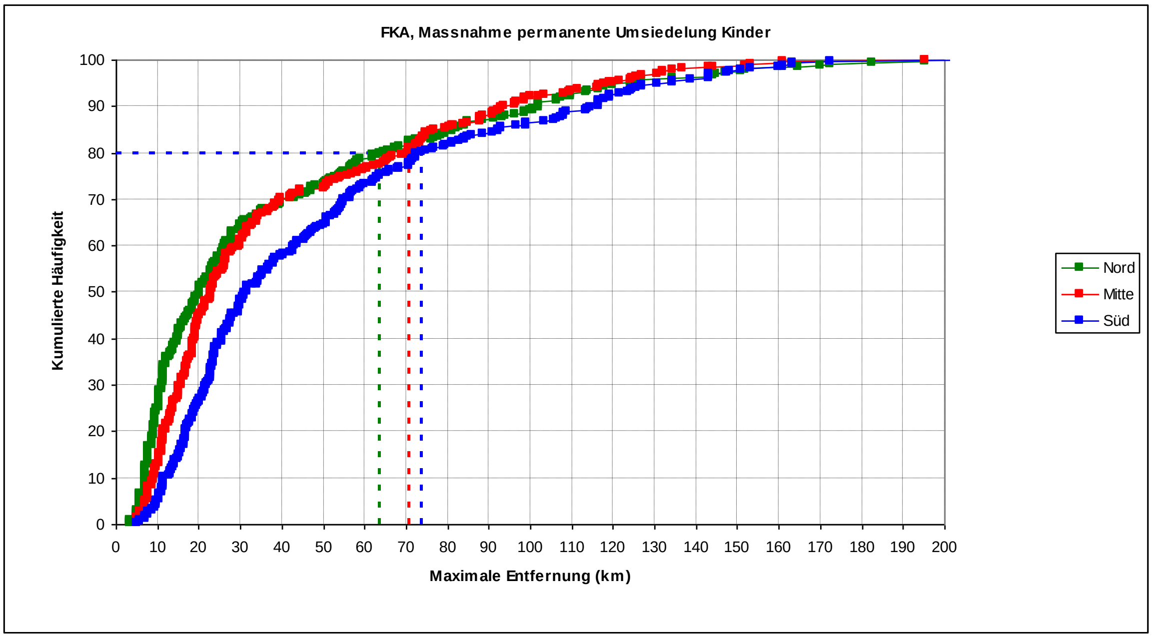


Fig. 8.1.4 b: Cumulative frequency distribution of the maximum distance for the intervention Permanent relocation, infants, source term FKA

Table 8.1.4 b: Data on the cumulative frequency distribution of the intervention Permanent relocation, infants, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Permanent relocation	Effective dose	Infants	100 mSv	Exterior exposure within 1 year due to deposited radionuclides	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			20	64	102
Central site (Grohnde)			23	71	94
Southern site (Philippsburg)			32	74	117

The figure above shows the cumulative frequency of the intervention Permanent relocation for infants with an emergency reference level of 100 mSv and the source term FKA. The integrations times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 year.

Based on the relevant emergency reference level of 100 mSv the intervention Permanent relocation should be recommended within an area with an outer limit of between 5 km and 71 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of between 3 km and 64 km, and the outer limit for the Southern site would be defined as a distance of between 5 km and 74 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Intervention: Permanent relocation, adults, source term FKF

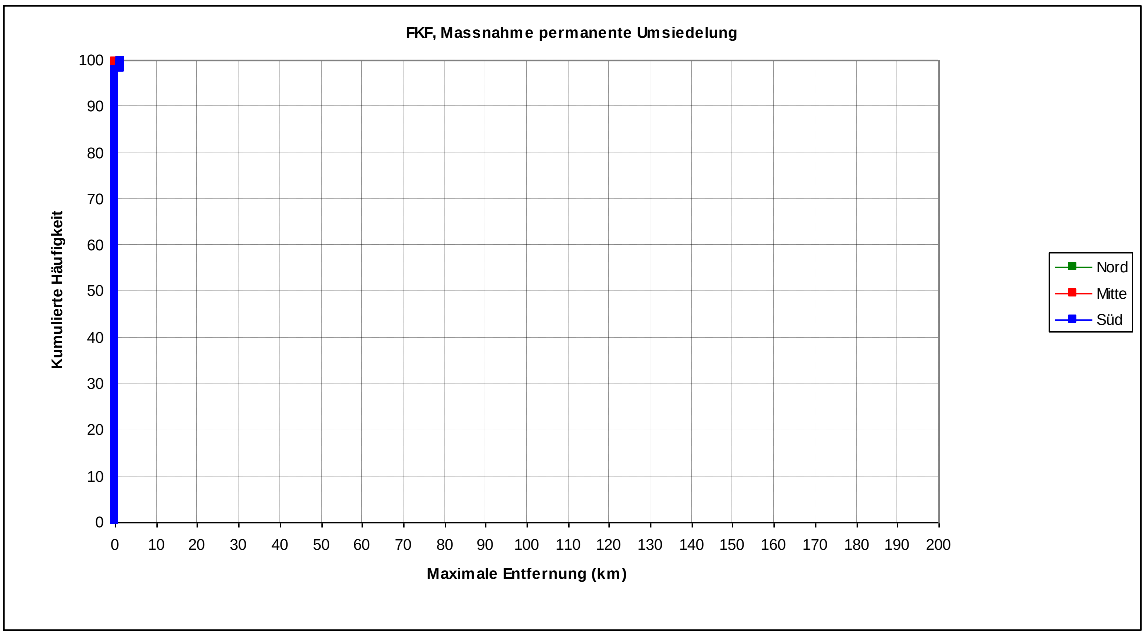


Fig. 8.1.4 c: Cumulative frequency distribution of the maximum distance for the intervention Permanent relocation, source term FKF

Table 8.1.4 c: Data on the cumulative frequency distribution of the intervention Permanent relocation, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Permanent relocation	Effective dose	Adults	100 mSv	Exterior exposure within 1 year due to deposited radionuclides	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	0
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	0

The figure above shows the cumulative frequency of the intervention Permanent relocation for adults with an emergency reference level of 100 mSv and the source term FKF. The integrations times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 year.

In 365 individual calculations, the emergency reference level of 100 mSv is exceeded 3 times at the Northern site, not at all at the Central site and 8 times at the Southern site; the distance for the outer limit is 1.4 km in each case. The 80th percentile is not reached.

Intervention: Permanent relocation, infants, source term FKF

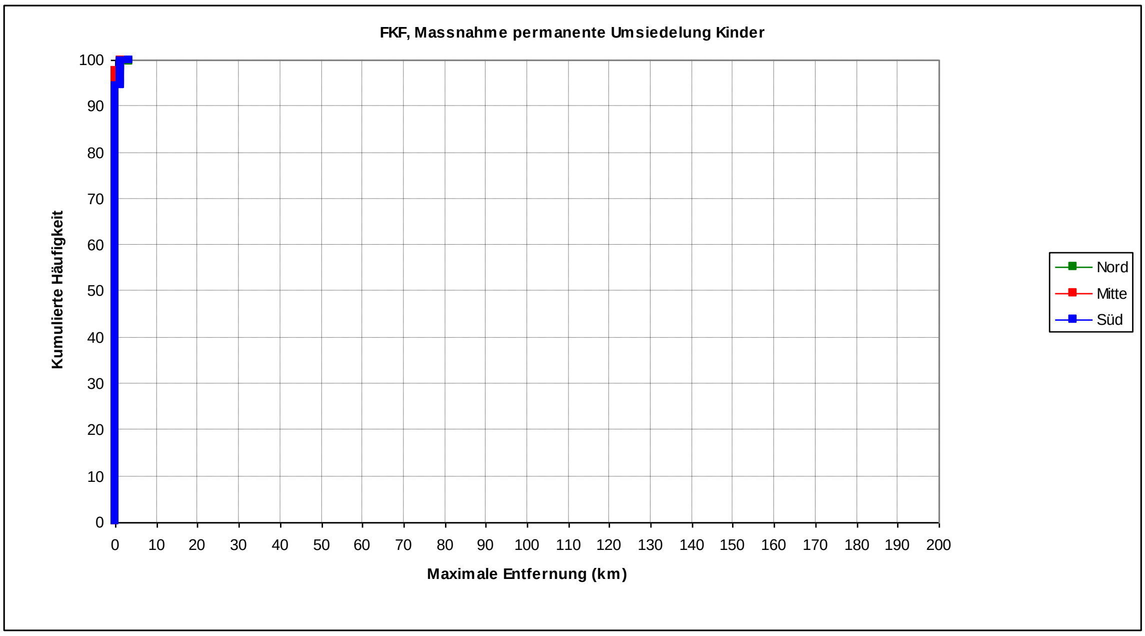


Fig. 8.1.4 d: Cumulative frequency distribution of the maximum distance for the intervention Permanent relocation, infants, source term FKF

Table 8.1.4 d: Data on the cumulative frequency distribution of the intervention Permanent relocation, infants, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Permanent relocation	Effective dose	Infants	100 mSv	Exterior exposure within 1 year due to deposited radionuclides	
			Maximum distance (km) at which the emergency reference level is exceeded.		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	0
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	0

The figure above shows the cumulative frequency of the intervention Permanent relocation for infants with an emergency reference level of 100 mSv and the source term FKF. The integrations times and exposure paths are external exposure due to radionuclides deposited on the ground within 1 year.

In 365 individual calculations, the emergency reference level of 100 mSv is exceeded 10 times at the Northern site, 9 times at the Central site and 21 times at the Southern site; the distance for the outer limit is 3.2 km at maximum and 1.4 km in most cases. The 80th percentile is not reached.

8.1.5. Intervention: Stable iodine prophylaxis

<u>Intervention: Stable iodine prophylaxis, adults, source term FKA</u>

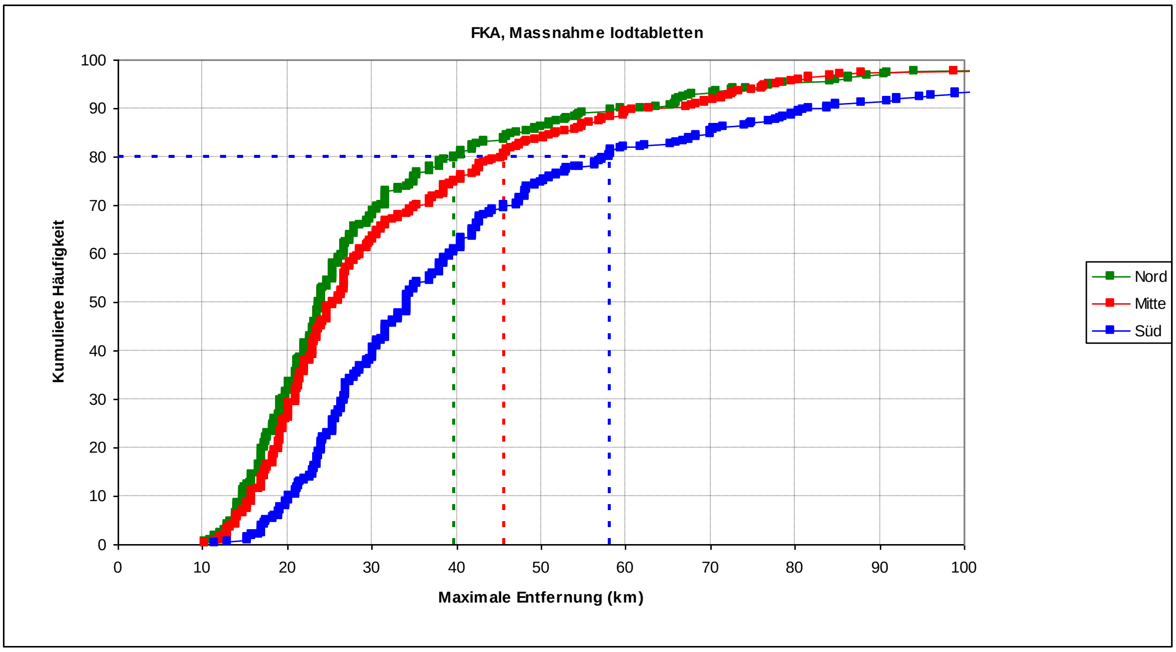


Fig. 8.1.5 a: Cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKA

Table 8.1.5 a: Data on the cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Organ dose (thyroid)	Adults (aged 18 - 45)	250 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			24	40	59
Central site (Grohnde)			26	46	63
Southern site (Philippsburg)			34	58	84

The figure above shows the cumulative frequency of the intervention Stable iodine prophylaxis for adults with an emergency reference level of 250 mSv for individuals aged 18 to 45 and the source term FKA. The integration times and exposure paths are the committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 250 mSv the intervention Stable iodine prophylaxis should be recommended within an area with an outer limit of up to 46 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of up to 40 km, and the outer limit for the Southern site would be defined as a distance of up to 58 km.
Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Intervention: Stable iodine prophylaxis, children, teenagers and pregnant women, source term FKA

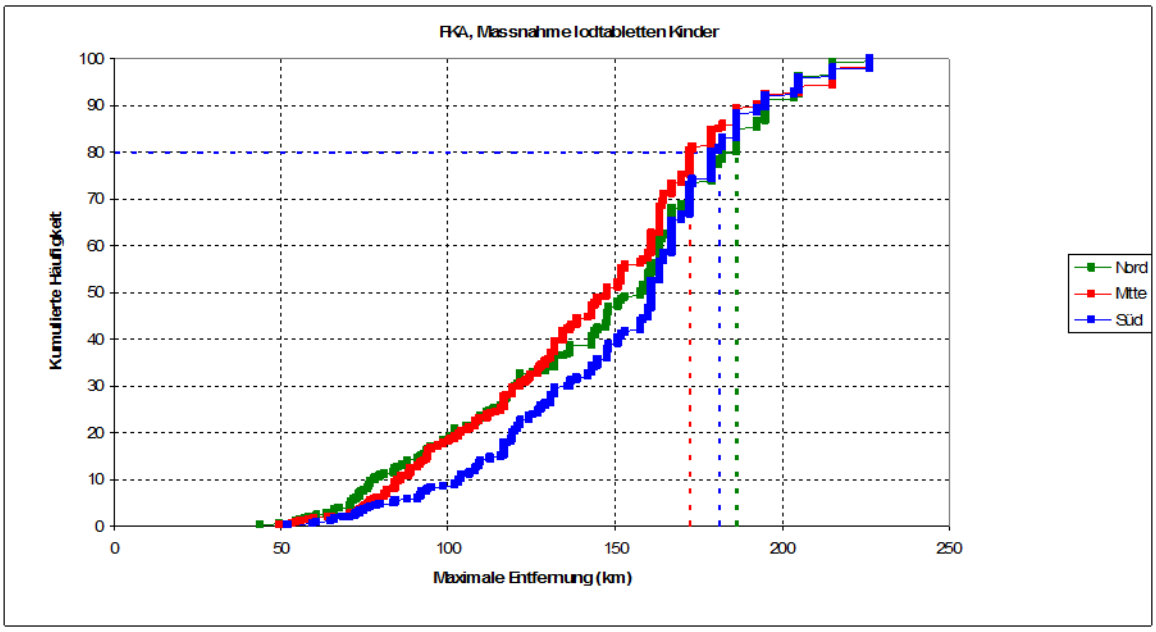


Fig. 8.1.5 b: Cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKA

Table 8.1.5 b: Data on the cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Organ dose (thyroid)	Children and teenagers under the age of 18 and pregnant women	50 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			158	187	195
Central site (Grohnde)			148	172	195
Southern site (Philippsburg)			161	181	195

The figure above shows the cumulative frequency of the intervention Stable iodine prophylaxis for children and teenagers under the age of 18 and pregnant women with an emergency reference level of 50 mSv and the source term FKA. The integration times and exposure paths are the committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 50 mSv the intervention Stable iodine prophylaxis should be recommended within an area with an outer limit of up to 172 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of up to 187 km, and the outer limit for the Southern site would be defined as a distance of up to 181 km.

Distances of more than 160-225 km (depending on the direction of dispersion) were not investigated. A value of more than 160 km thus means that the relevant dose criterion can be exceeded at least up to the distances indicated and in some cases even beyond. More expansive dispersion calculations would be required to analyse more exactly up to which distances the relevant dose criterion can indeed be exceeded; such calculations are scheduled but have not been performed yet.

Intervention: Stable iodine prophylaxis, adults, source term FKF

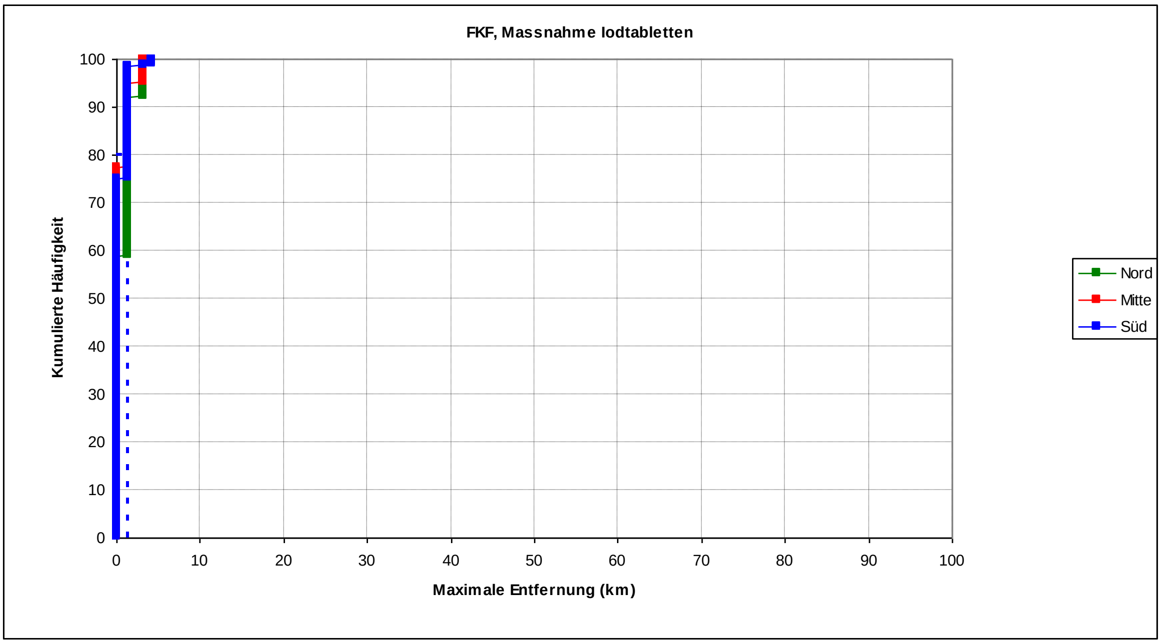


Fig. 8.1.5 c: Cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKF

Table 8.1.5 c: Data on the cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Organ dose (thyroid)	Adults (aged 18 - 45)	250 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	1.4	1.4
Central site (Grohnde)			0	1.4	1.4
Southern site (Philippsburg)			0	1.4	1.4

The figure above shows the cumulative frequency of the intervention Stable iodine prophylaxis for adults with an emergency reference level of 250 mSv for individuals aged 18 to 45 and the source term FKF. The integration times and exposure paths are the committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 250 mSv the intervention Stable iodine prophylaxis should be recommended within an area with an outer limit of up to 1.4 km from the Central site in 80% of the considered cases. The same distance applies to the Northern and the Southern site.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

Stable iodine prophylaxis, children, teenagers and pregnant women, source term FKF

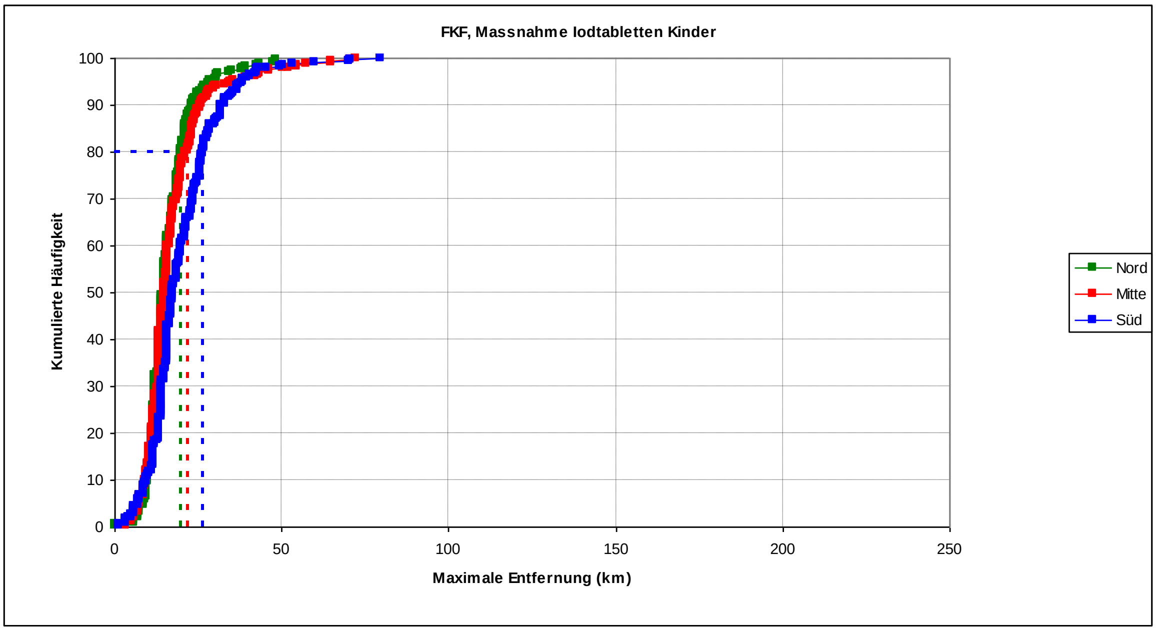


Fig. 8.1.5 d: Cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKF

Table 8.1.5 d: Data on the cumulative frequency distribution of the maximum distance for the intervention Stable iodine prophylaxis, source term FKF

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Organ dose (thyroid)	Children and teenagers under the age of 18 and pregnant women	50 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Maximum distance (km) at which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			15	20	23
Central site (Grohnde)			15	22	26
Southern site (Philippsburg)			18	26	32

The figure above shows the cumulative frequency of the intervention Stable iodine prophylaxis for children and teenagers under the age of 18 and pregnant women with an emergency reference level of 50 mSv and the source term FKF. The integration times and exposure paths are the committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 50 mSv the intervention Stable iodine prophylaxis should be recommended within an area with an outer limit of up to 22 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of up to 20 km, and the outer limit for the Southern site would be defined as a distance of up to 26 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

8.1.6. Deterministic effects and high doses

This investigation generally takes account of two different source terms, FKA and FKF (see chapter 4). In particular in the case of a release based on the source term FKA serious deterministic effects and high stochastic effects in the proximity of the plant must be expected unless protective measures are initiated or implemented. It is thus important to assess the impact for the source term FKA also with respect to the threshold doses for deterministic effects. The Commission on Radiological Protection (SSK) recently published (SSK 2014a) threshold doses for the occurrence of serious deterministic effects amounting to

- 1000 mGy for the dose to the red bone marrow in adults and infants,
- 100 mSv for the effective dose or uterus dose to the foetus (2nd – 7th week) and
- 300 mGy for the dose to the foetal brain (8th – 15th week)

In addition to these threshold doses the SSK introduced an effective dose of 1000 mSv as a further dose criterion. This criterion helped to determine the area where measures need to be taken with top priority and where protective measures are particularly effective (prioritisation of protective measures).

Calculations were performed in order to obtain the areas where the above cited threshold levels and the additional dose criterion would be reached or exceeded. The results of these calculations are described and explained in the following paragraphs.

Additional information on the dose units Gy and Sv:

In the context of radiation protection it is important to determine the absorbed doses averaged over biological tissue or over an organ. The absorbed dose is the energy imparted to a volume element, divided by the mass of this volume element. The unit used for the absorbed dose is Gray (Gy, 1 Gy = 1 J/kg).

The biological effects do not only depend on the energy but also on the type of radiation. The biological effectiveness of alpha particles and neutrons differs from that of X-rays, beta radiation or gamma radiation. In order to obtain a measure for the stochastic radiation effects which is valid for all types of radiation, the energy dose is multiplied by a dimensionless weighting factor. This factor is defined for each type of radiation and characterises the biological effectiveness in relation to that of photons. The average absorbed dose to a tissue or organ, multiplied by the weighting factor, is called the organ dose. The unit used for the organ dose is Sievert (Sv, 1 Sv = 1 J/kg).

The biological effectiveness of ionising radiation also varies between the different tissues and organs in the human body. These differences are particularly important with respect to stochastic effects since the probability of radiation-induced cancer depends on the type of tissue or organ considered. In order to express the different sensitivity to the dose, dimensionless tissue weighting factors were introduced that are defined according to ICRP 103 (ICRP 2007). The sum of the organ doses weighted in this manner is called the effective dose; it is also stated in Sievert (Sv).

The organ dose and the effective dose should not be used in the context of deterministic effects since the conversion factors used for multiplication with the absorbed dose are considerably lower than those for stochastic effects.

High doses (effective dose > 1000 mSv), adults, source term FKA

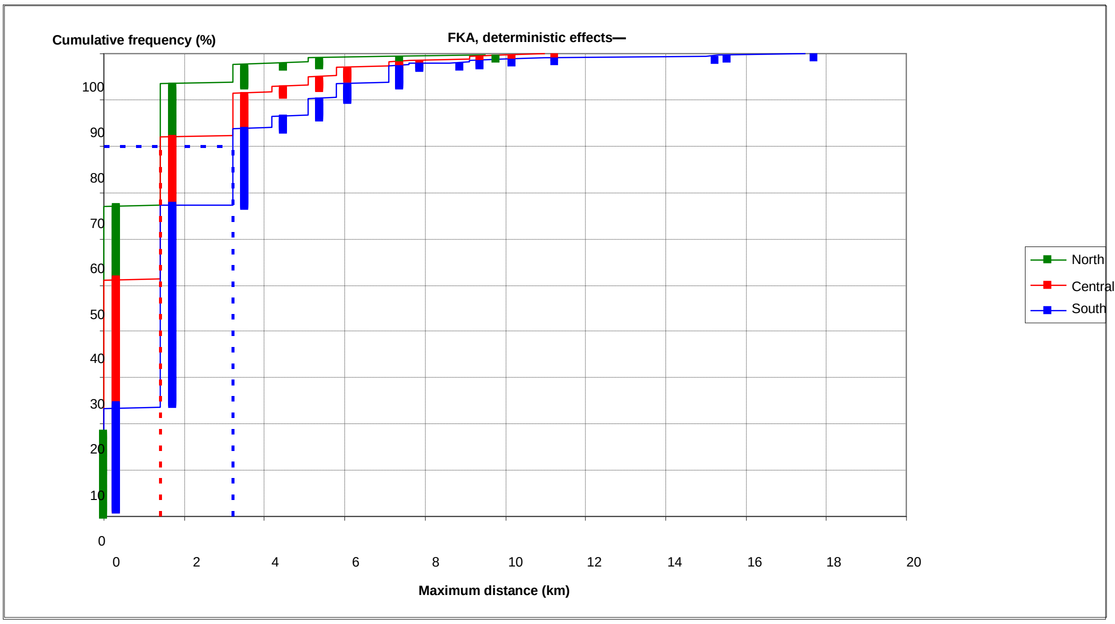


Fig. 8.1.6 a: Cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, adults, source term FKA

Table 8.1.6 a: Data on the cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, adults, source term FKA

	Dose criterion	Group of individuals	Criterion	Integration times and exposure paths	
	Effective dose	Adults	1000 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the criterion is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	1.4	1.4
Central site (Grohnde)			0	1.4	3.2
Southern site (Philippsburg)			1.4	3.2	5.1

The figure above shows the cumulative frequency of the maximum distance at which the effective dose of 1000 mSv is exceeded in adults for the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The 1000 mSv criterion is exceeded within an area whose outer limit is at a distance of up to 1.4 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of up to 1.4 km, and the outer limit for the Southern site would be defined as a distance of up to 3.2 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

High doses (effective dose > 1000 mSv), infants, source term FKA

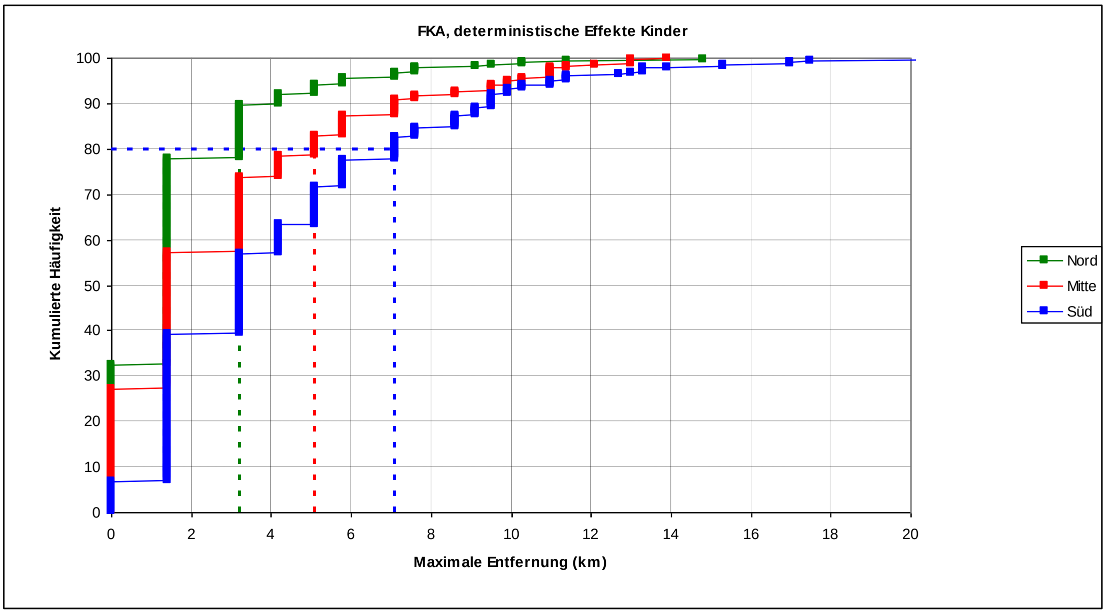


Fig. 8.1.6 b: Cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, infants, source term FKA

Table 8.1.6 b: Data on the cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, infants, source term FKA

	Dose criterion	Group of individuals	Criterion	Integration times and exposure paths	
	Effective dose	Infants	1000 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the criterion is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			1.4	3.2	4.2
Central site (Grohnde)			1.4	5.1	7.1
Southern site (Philippsburg)			3.2	7.1	9.5

The figure above shows the cumulative frequency of the maximum distance at which the effective dose of 1000 mSv is exceeded in infants for the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The 1000 mSv criterion is exceeded within an area whose outer limit is at a distance of up to 5.1 km from the Central site in 80% of the considered cases. Similarly the outer limit for the Northern site would be defined as a distance of up to 3.2 km, and the outer limit for the Southern site would be defined as a distance of 7.1 km.

Please refer to the table above in order to obtain the distances resulting for 50% or 90% of the cases.

High doses (effective dose > 1000 mSv), adults, source term FKF

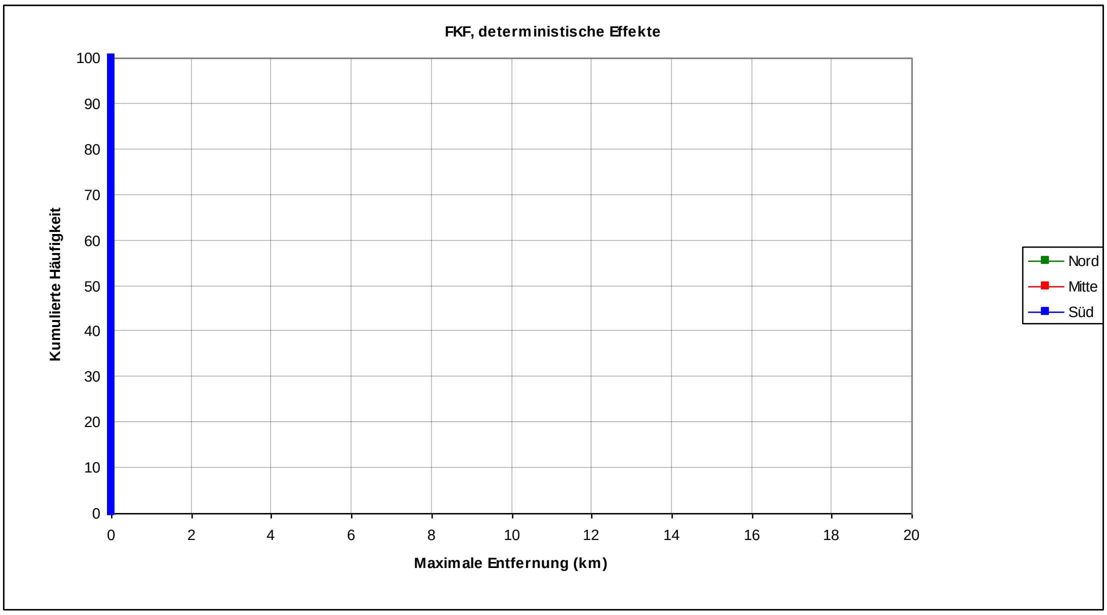


Fig. 8.1.6 c: Cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, adults, source term FKF

Table 8.1.6 c: Data on the cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, adults, source term FKF

	Dose criterion	Group of individuals	Criterion	Integration times and exposure paths	
	Effective dose	Adults	1000 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the criterion is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	0
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	0

The figure above shows the cumulative frequency of the maximum distance at which the effective dose of 1000 mSv is exceeded in adults for the source term FKF. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The calculations show that the 1000 mSv criterion is not reached in any of the cases (distances of less than 1.4 km from the plant were not investigated).

High doses (effective dose > 1000 mSv), infants, source term FKF

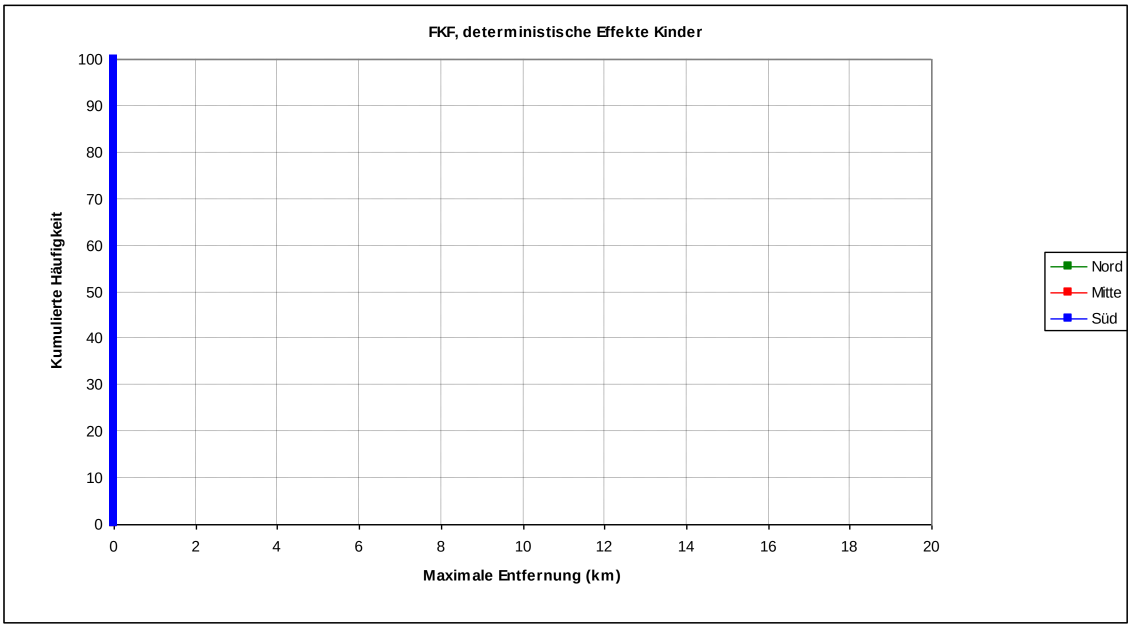


Fig. 8.1.6 d: Cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, infants, source term FKF

Table 8.1.6 d: Data on the cumulative frequency distribution of the maximum range where the effective dose exceeds 1000 mSv, infants, source term FKF

	Dose criterion	Group of individuals	Criterion	Integration times and exposure paths	
	Effective dose	Infants	1000 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Maximum distance (km) at which the criterion is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			0	0	0
Central site (Grohnde)			0	0	0
Southern site (Philippsburg)			0	0	0

The figure above shows the cumulative frequency of the maximum distance at which the effective dose of 1000 mSv is exceeded in infants for the source term FKF. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The calculations show that the 1000 mSv criterion is not reached in any of the cases (distances of less than 1.4 km from the plant were not investigated).

8.1.7. Dose to the red bone marrow

<u>Dose to the red bone marrow, adults, Grohnde, source term FKA</u>

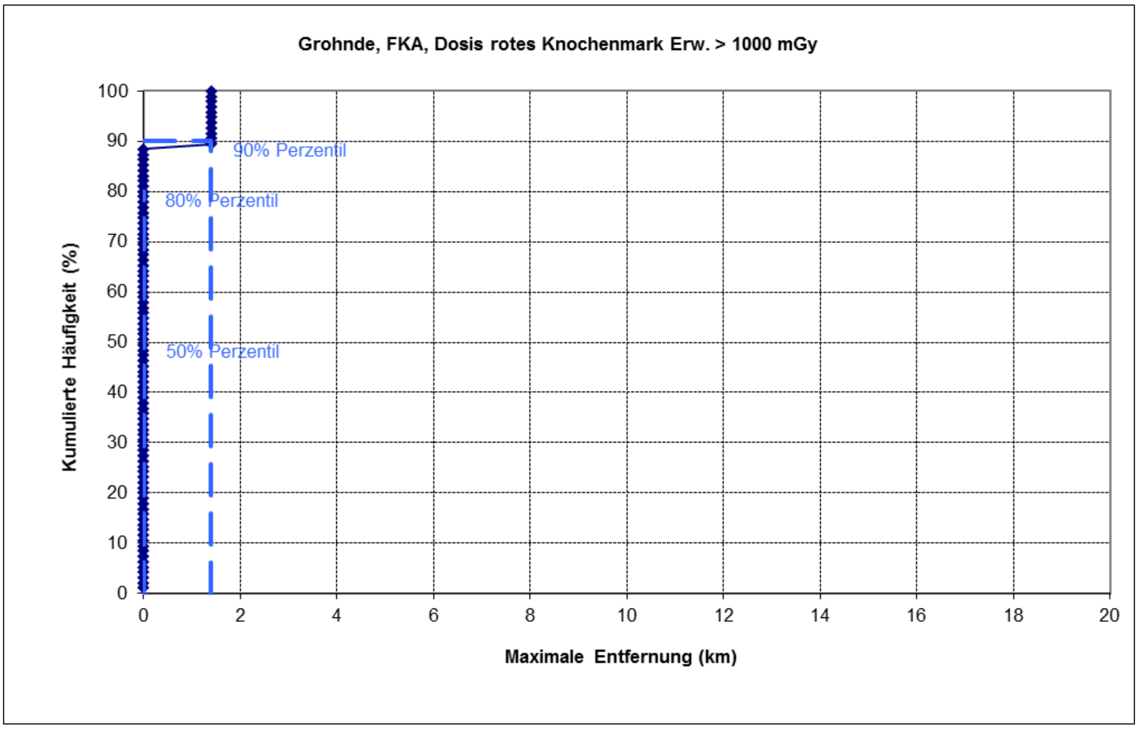


Fig. 8.1.7 a: Cumulative frequency distribution of the maximum distance at which the dose to the red bone marrow in adults exceeds 1000 mGy, source term FKA.

Table 8.1.7 a: Data on the cumulative frequency distribution of the maximum distance at which the dose to the red bone marrow in adults exceeds 1000 mGy, source term FKA.

	Dose criterion	Group of individuals	Threshold level	Integration times and exposure paths	
	Dose to red bone marrow	Adults	1000 mGy	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
Adults			Maximum distance (km) at which the threshold level is exceeded		
			50th percentile	80th percentile	90th percentile
Central site (Grohnde)			0	0	1.4

The figure above shows the cumulative frequency of the maximum distance at which the dose to the red bone marrow in adults exceeds 1000 mGy for the source term FKA. These calculations were only performed for the Grohnde site and for 95 cases within one year (i.e. roughly every 4th day). The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The calculations show that the criterion of 1000 mGy is only exceeded in 10% of the considered cases (actually in 11 cases); the distances are up to 1.4 km from the plant.

Dose to the red bone marrow, infants, Grohnde, source term FKA

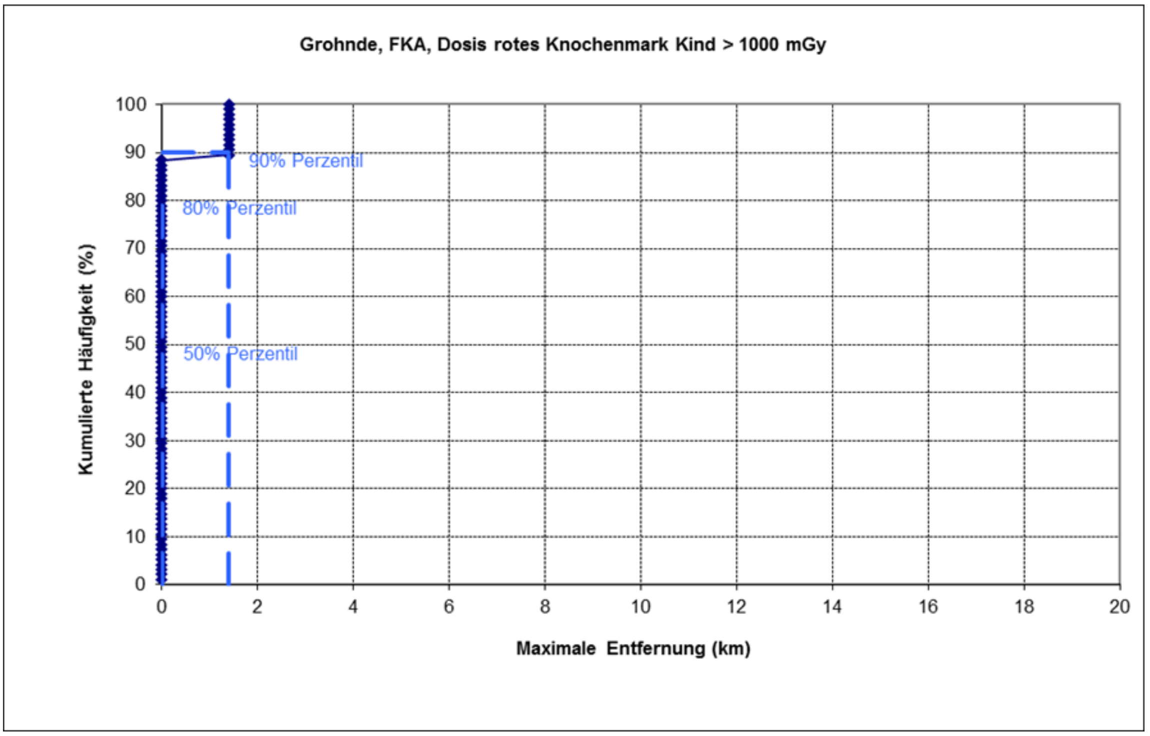


Fig. 8.1.7 b: Cumulative frequency distribution of the maximum range where the absorbed dose to the red bone marrow in infants exceeds 1000 mGy, source term FKA.

Table 8.1.7 b: Data on the cumulative frequency distribution of the maximum distance at which the absorbed dose to the red bone marrow in infants exceeds 1000 mGy, source term FKA.

	Dose criterion	Group of individuals	Threshold level	Integration times and exposure paths	
	Dose to red bone marrow	Infants	1000 mGy	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
Infants			Maximum distance (km) at which the threshold level is exceeded		
			50th percentile	80th percentile	90th percentile
Central site (Grohnde)			0	0	1.4

The figure above shows the cumulative frequency of the maximum distance at which the dose to the red bone marrow in infants exceeds 1000 mGy for the source term FKA. These calculations were only performed for the Grohnde site and for 95 cases within one year (i.e. roughly every 4th day). The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

The calculations show that the criterion of 1000 mGy is only exceeded in 90 % of the considered cases (actually in 11 cases); the distances are up to 1.4 km from the plant.

8.1.8. Dose to the foetus

Dose to the foetus, 2nd -7th week

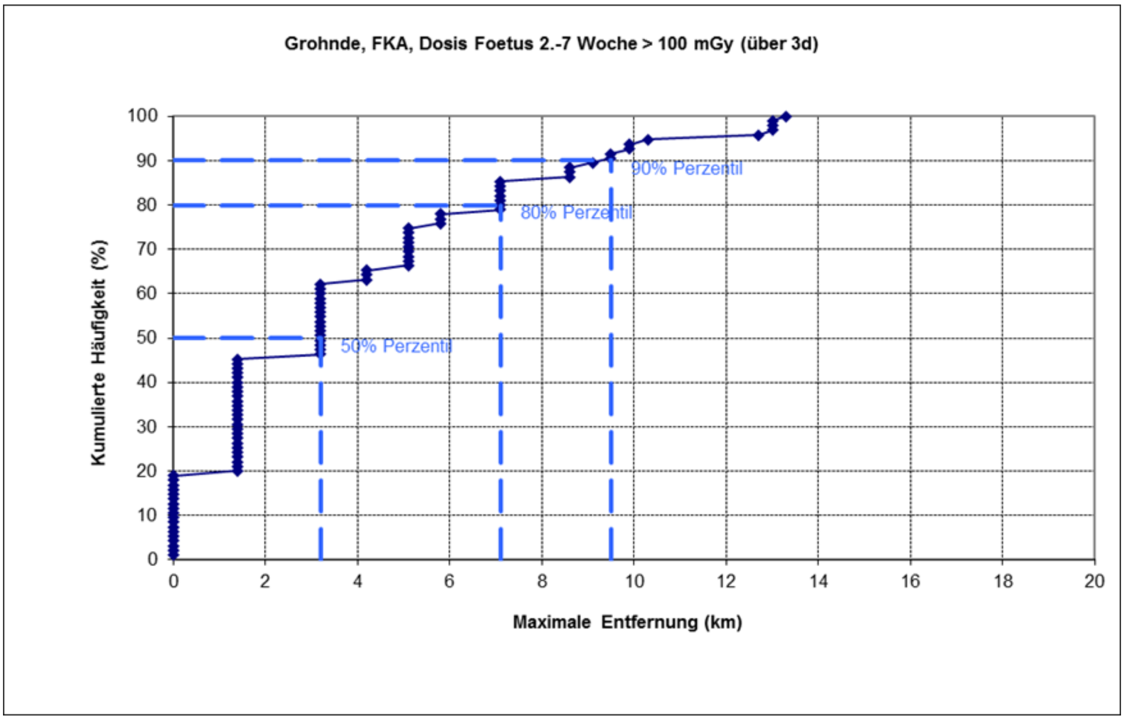


Fig. 8.1.8 a: Cumulative frequency distribution of the maximum distance at which the absorbed dose to the foetus (2nd - 7th week) exceeds 100 mGy, source term FKA.

Table 8.1.8 a: Data on the cumulative frequency distribution of the maximum distance at which the absorbed dose to the foetus (2nd - 7th week) exceeds 100 mGy, source term FKA

Effectiveness	Dose criterion	Group of individuals	Threshold level	Integration times and exposure paths	
Absorbed dose	Dose to the brain	Foetus (2nd to 7th week)	100 mGy	External exposure within 7 days and committed dose due to the radionuclides inhaled by the mother in this time if she were to remain permanently outside	
Foetus (2nd to 7th week)			Maximum distance (km) at which the threshold level is exceeded		
			50th percentile	80th percentile	90th percentile
Central site (Grohnde)			3.2	7.1	9.5

The figure above shows the cumulative frequency of the maximum distance at which the dose to the foetus (2nd to 7th week) exceeds 100 mGy for the source term FKA. These calculations were only performed for the Grohnde site and for 95 cases within one year (i.e. roughly every 4th day). The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled by the mother in this time if she were to remain permanently outside.

The calculations show that the 100 mGy criterion is exceeded at the 80th percentile up to a distance of 7.1 km from the plant. The 50th percentile is exceeded up to a distance of 3.2 km from the plant, and the 90th percentile up to a distance of 9.5 km from the plant.

Dose to the foetus, 8th - 15th week

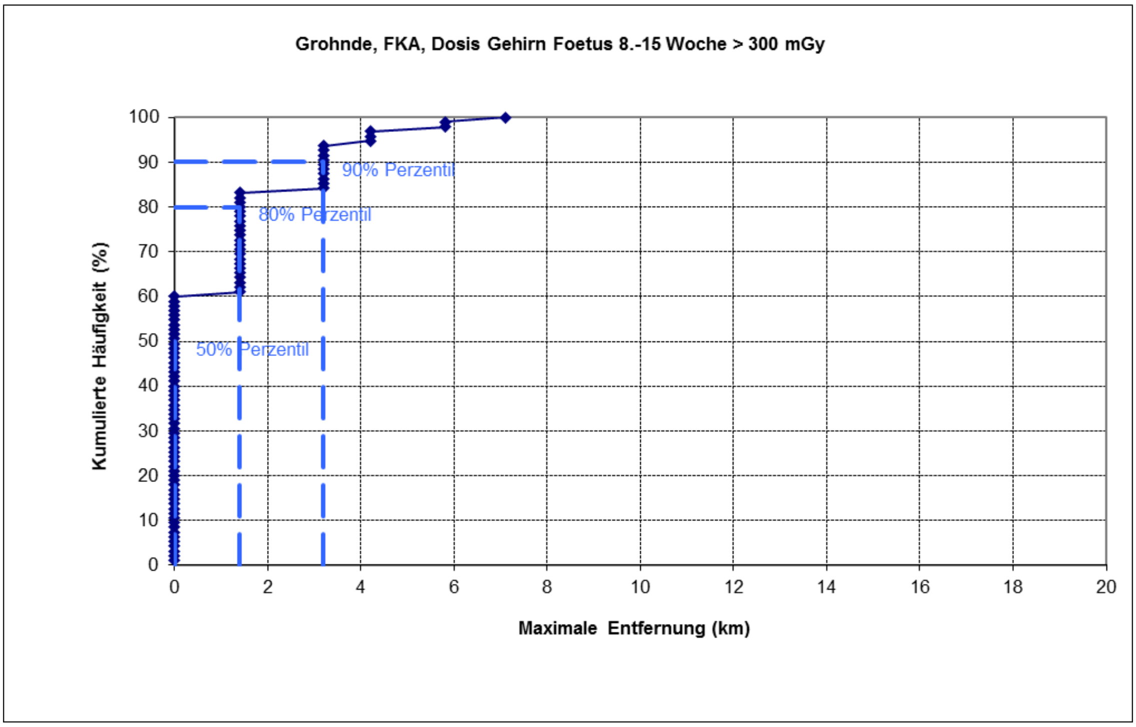


Fig. 8.1.8 b: Cumulative frequency distribution of the maximum distance at which the absorbed dose to the foetus (8th - 15th week) exceeds 300 mGy, source term FKA.

Table 8.1.8 b: Data on the cumulative frequency distribution of the maximum distance at which the absorbed dose to the foetus (8th - 15th week) exceeds 300 mGy, source term FKA

Effectiveness	Dose criterion	Group of individuals	Threshold level	Integration times and exposure paths	
Absorbed dose	Dose to the brain	Foetus (8th to 15th week)	300 mGy	External exposure within 7 days and committed dose due to the radionuclides inhaled by the mother in this time if she were to remain permanently outside	
Foetus (8th - 15th week)			Maximum distance (km) at which the threshold level is exceeded		
			50th percentile	80th percentile	90th percentile
Central site (Grohnde)			0	1.4	3.2

The figure above shows the cumulative frequency of the maximum distance at which the dose to the foetus (8th - 15th week) exceeds 300 mGy for the source term FKA. These calculations were only performed for the Grohnde site and for 95 cases within one year (i.e. roughly every 4th day). The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled by the mother in this time if she were to remain permanently outside.

The calculations show that the 300 mGy criterion is exceeded at the 80th percentile up to a distance of 1.4 km from the plant. The 50th percentile is not reached at all (distances of less than 1.4 km from the NPP were not investigated); the 90th percentile is exceeded at a distance of up to 3.2 km.

8.2. Size of the affected areas

Areas affected by the intervention Sheltering

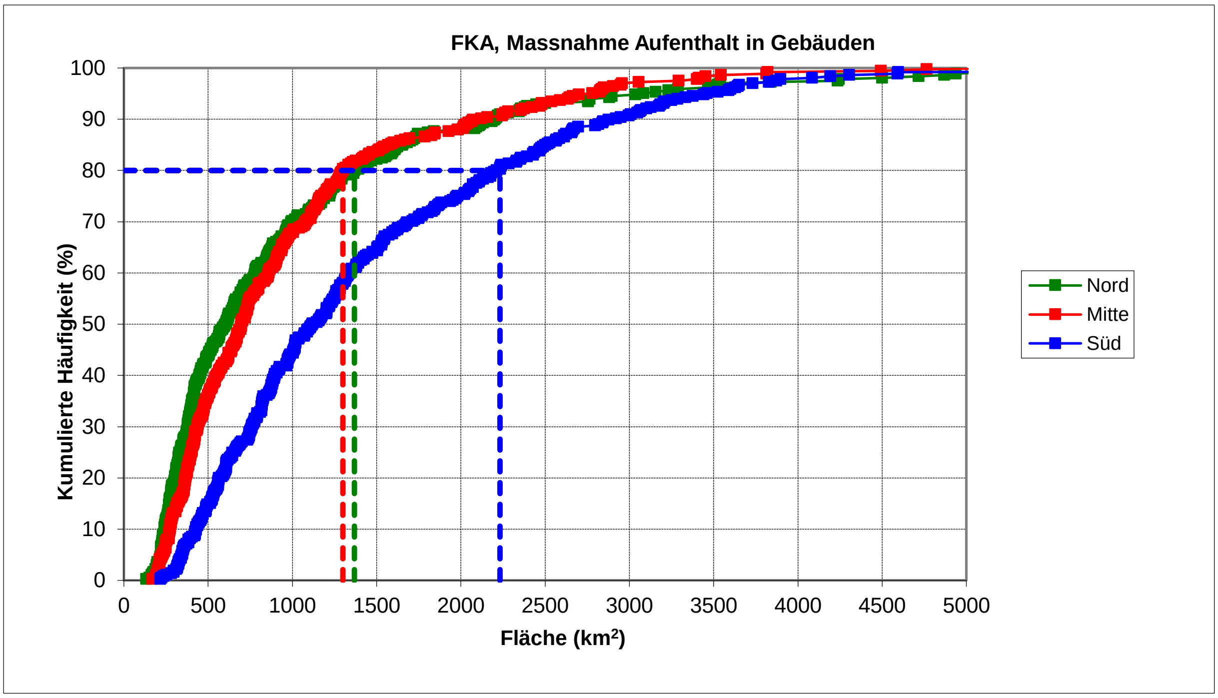


Fig. 8.2 a: Cumulative frequency distribution of the areas affected by the intervention Sheltering, adults, source term FKA

Table 8.2 a: Data on the cumulative frequency distribution of the areas affected by the intervention Sheltering, adults, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Sheltering	Effective dose	Adults	10 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Area (km^2) in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			600	1368	2196
Central site (Grohnde)			696	1300	2120
Southern site (Philippsburg)			1120	2232	2920

The figure above shows the cumulative frequency of areas affected by the intervention Sheltering for adults with an emergency reference level of 10 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 10 mSv an area of up to 1300 km^2 is affected by the intervention Sheltering at the Central site in 80% of the considered cases. Similarly an area of up to 1368 km^2 is affected at the Northern site and an area of up to 2232 km^2 at the Southern site. Please refer to the table above in order to obtain the areas resulting for 50% or 90% of the cases.

Areas affected by the intervention Evacuation

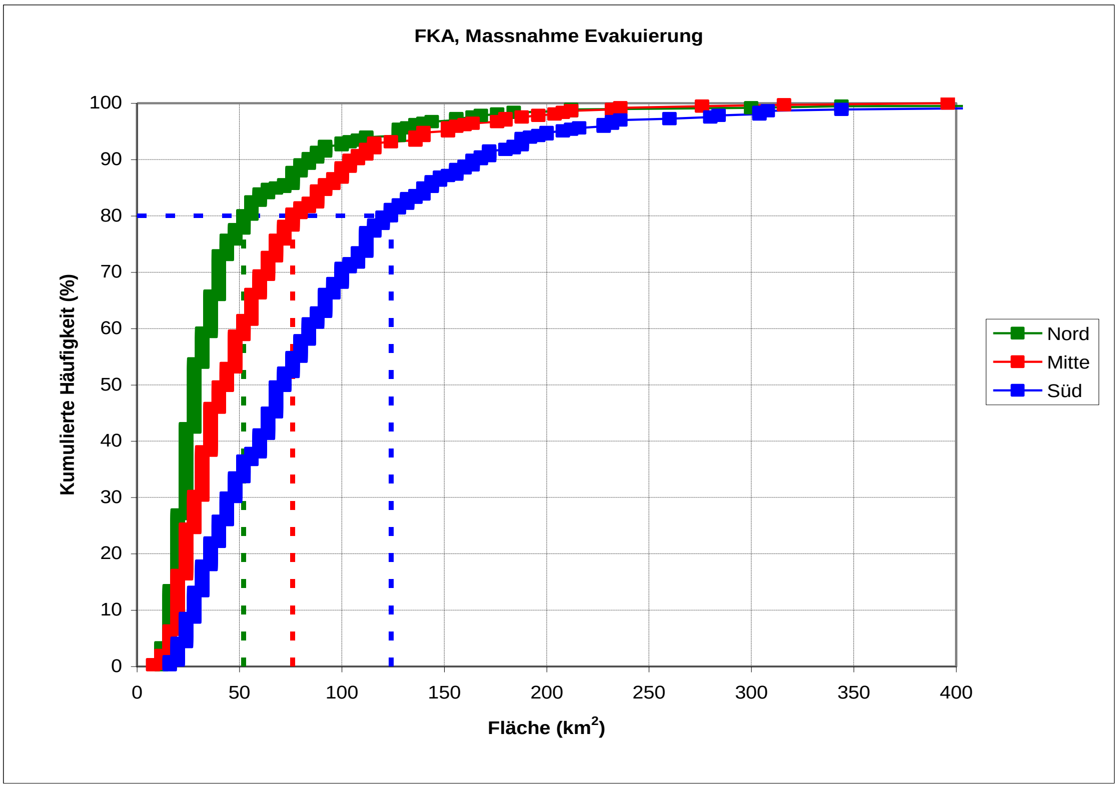


Fig. 8.2 b: Cumulative frequency distribution of the areas affected by the intervention Evacuation, adults, source term FKA

Table 8.2. b: Data on the cumulative frequency distribution of the areas affected by the intervention Evacuation, adults, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Area (km^2) in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			28	52	84
Central site (Grohnde)			44	76	108
Southern site (Philippsburg)			72	124	168

The figure above shows the cumulative frequency of areas affected by the intervention Evacuation for adults with an emergency reference level of 100 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 100 mSv an area of up to 76 km^2 is affected by the intervention Evacuation at the Central site in 80% of the considered cases. Similarly an area of up to 52 km^2 is affected at the Northern site and an area of up to 124 km^2 at the Southern site. Please refer to the table above in order to obtain the areas resulting for 50% or 90% of the cases.

Areas affected by the intervention Stable iodine prophylaxis for adults

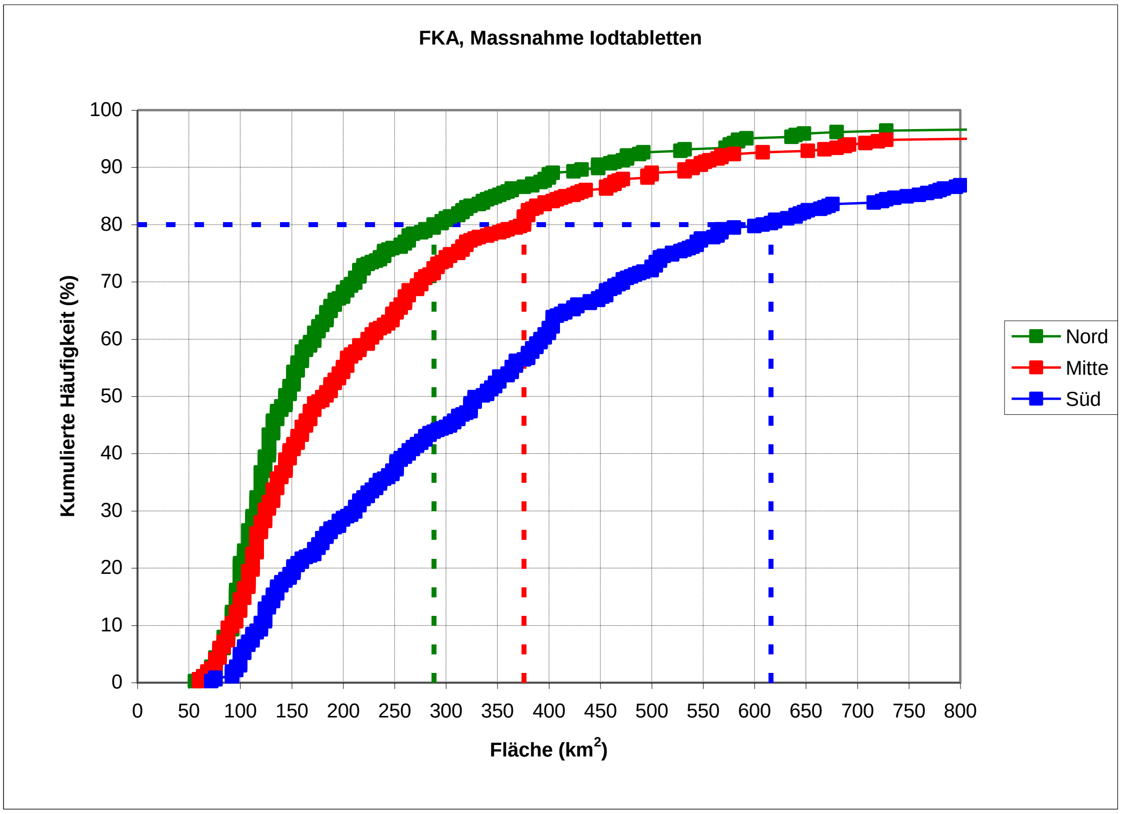


Fig. 8.2 c: Cumulative frequency distribution of the areas affected by the intervention Stable iodine prophylaxis, adults (aged 18 to 45), source term FKA

Table 8.2 c: Data on the cumulative frequency distribution of the areas affected by the intervention Stable iodine prophylaxis, adults (aged 18 to 45), source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Effective dose	Adults (aged 18 to 45)	250 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Area (km^2) in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			144	288	448
Central site (Grohnde)			184	376	540
Southern site (Philippsburg)			336	616	956

The figure above shows the cumulative frequency of areas affected by the intervention Stable iodine prophylaxis for adults (aged 18 to 45) with an emergency reference level of 250 mSv and the source term FKA. The integration times and exposure paths are the committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside.
Based on the relevant emergency reference level of 250 mSv an area of up to 376 km^2 is affected by the intervention Stable iodine prophylaxis at the Central site in 80% of the considered cases. Similarly an area of up to 288 km^2 is affected at the Northern site and an area of up to 616 km^2 at the Southern site.
Please refer to the table above in order to obtain the areas resulting for 50% or 90% of the cases.

Areas affected by the intervention Stable iodine prophylaxis for children, teenagers and pregnant women

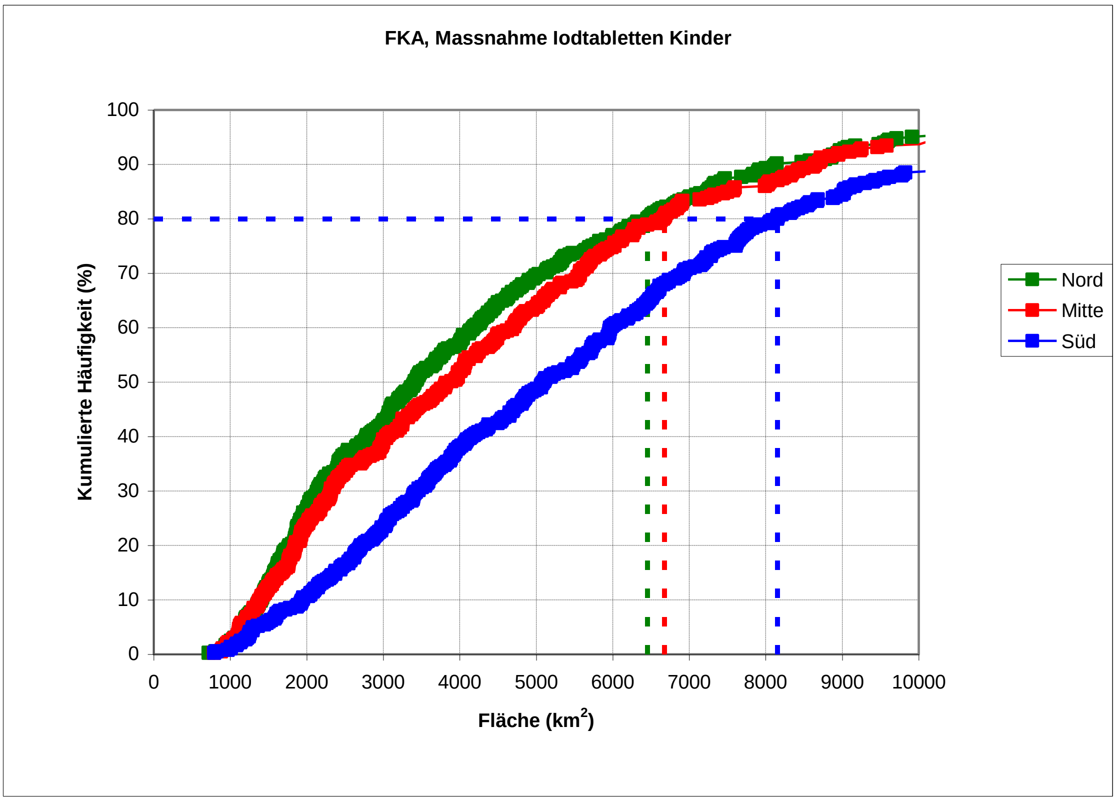


Fig. 8.2 d: Cumulative frequency distribution of the areas affected by the intervention Stable iodine prophylaxis, children, teenagers under the age of 18 and pregnant women, source term FKA

Table 8.2 d: Data on the cumulative frequency distribution of areas affected by the intervention Stable iodine prophylaxis, children, teenagers under the age of 18 and pregnant women, source term FKA

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Effective dose	Children, teenagers under the age of 18 and pregnant women	50 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Area (km^2) in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Northern site (Unterweser)			3408	6456	8124
Central site (Grohnde)			3892	6676	8648
Southern site (Philippsburg)			5104	8156	10,444

The figure above shows the cumulative frequency of areas affected by the intervention Stable iodine prophylaxis for children, teenagers under the age of 18 and pregnant women with an emergency reference level of 50 mSv and the source term FKA. The integration times and exposure paths are the committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside.
Based on the relevant emergency reference level of 50 mSv an area of up to 6676 km^2 is affected by the intervention Stable iodine prophylaxis at the Central site in 80% of the considered cases. Similarly an area of up to 6456 km^2 is affected at the Northern site and an area of up to 8156 km^2 at the Southern site. Please refer to the table above in order to obtain the areas resulting for 50% or 90% of the cases.

Areas affected by the intervention Evacuation outside a 20-km radius

Grohnde site

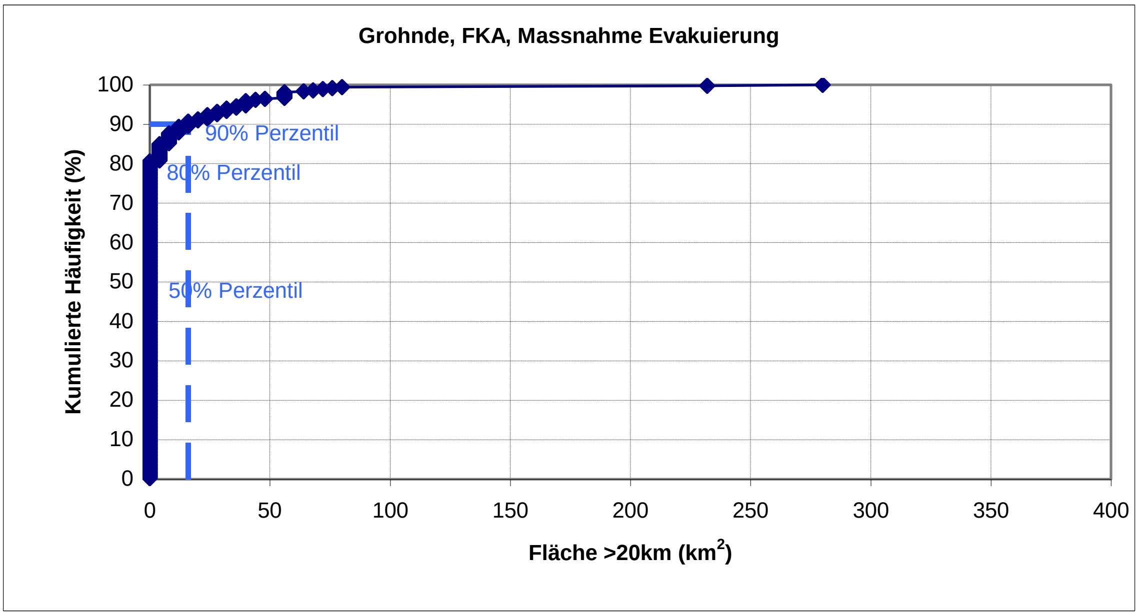


Fig. 8.2 e: Cumulative frequency distribution of the areas at a distance of more than 20 km affected by the intervention Evacuation, adults, source term FKA, Grohnde site

Table 8.2 e: Data on the cumulative frequency distribution of the areas at a distance of more than 20 km affected by the intervention Evacuation, adults, source term FKA, Grohnde site

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Area (km²) at a distance of more than 20 km in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Central site (Grohnde)			0	0	16

The figure above shows the cumulative frequency of areas (at a distance of more than 20 km) affected by the intervention Evacuation for adults with an emergency reference level of 100 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 100 mSv no area at a distance of more than 20 km is affected in 80% of the considered cases at the Central site. The same applies to the 50th percentile. Only for 90% of the considered cases an area of 16 km² is affected.

8.3. Number of individuals in affected areas

<u>Number of individuals in areas affected by the intervention Evacuation, adults, Grohnde</u>

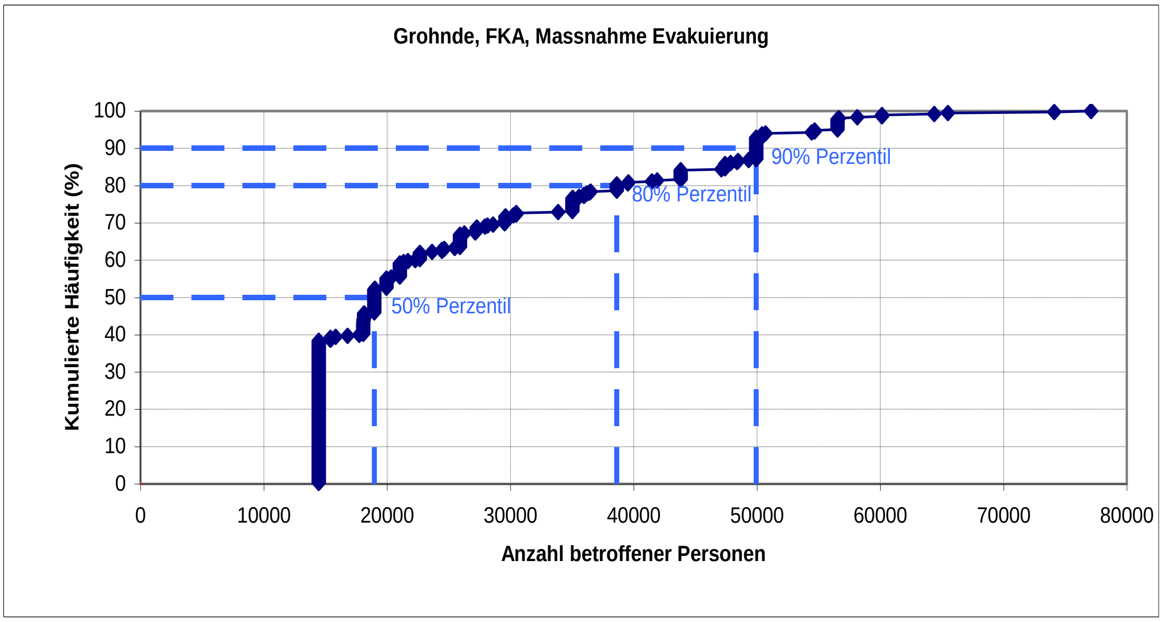


Fig. 8.3 a: Cumulative frequency distribution of the number of individuals within a 20-km radius affected by the intervention Evacuation, adults, source term FKA, Grohnde site

Table 8.3 a: Data on the cumulative frequency distribution of the number of individuals within a 20-km radius affected by the intervention Evacuation, adults, source term FKA, Grohnde site

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Number of individuals in areas within a 20-km radius where the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Central site (Grohnde)			18959	38632	49945

The figure above shows the cumulative frequency of the number of individuals within a 20-km radius from the plant for the intervention Evacuation for adults with an emergency reference level of 100 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 100 mSv up to 38632 individuals are affected by the intervention Evacuation in 80% of the considered cases. Up to 18959 individuals are affected at the 50th percentile and up to 49945 individuals are affected at the 90th percentile.

Number of individuals in the areas affected by the intervention Evacuation, adults, Philippsburg

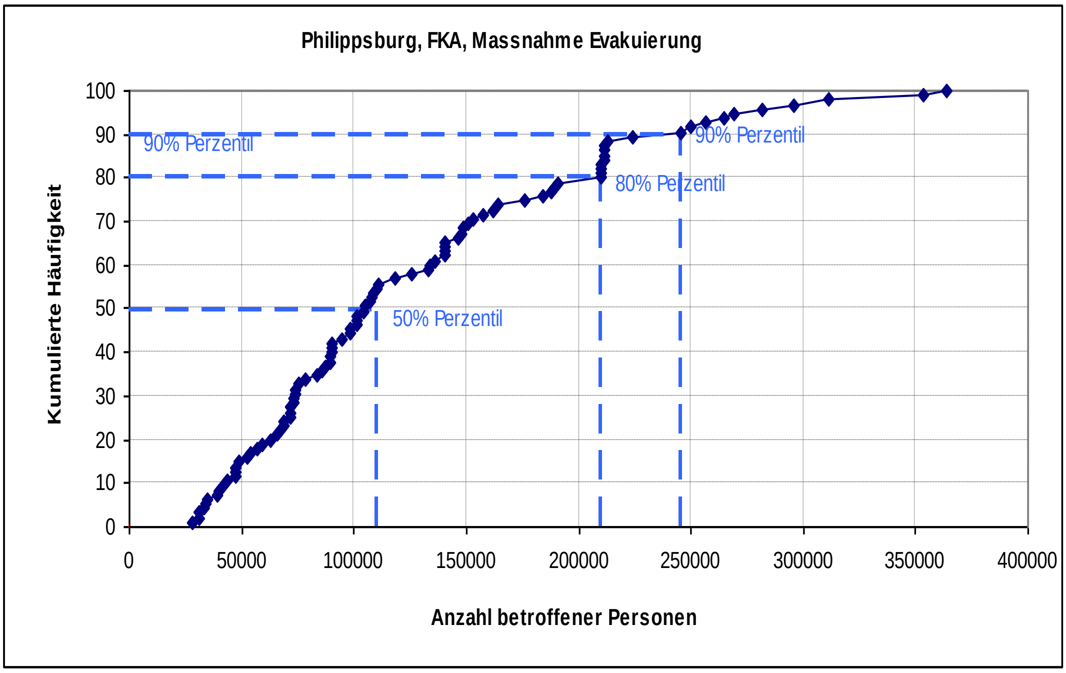


Fig. 8.3 b: Cumulative frequency distribution of the number of individuals in areas affected by the intervention Evacuation, adults, source term FKA, Philippsburg site

Table 8.3 b: Data on the cumulative frequency distribution of the number of individuals in areas affected by the intervention Evacuation, adults, source term FKA, Philippsburg site

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Number of individuals in areas within a 20-km radius where the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
Philippsburg			109881	210176	245169

The figure above shows the cumulative frequency of the number of individuals in the areas affected by the intervention Evacuation, Philippsburg site, for adults, with an emergency reference level of 100 mSv and the source term FKA. The integration times and exposure paths are external exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside.

Based on the relevant emergency reference level of 100 mSv, up to 210176 individuals are affected in 80% of the considered cases. Similarly a maximum of 109881 individuals are affected in 50% of the considered cases and a maximum of 245169 individuals are affected in 90% of the considered cases.

8.4. Number of affected sectors

Number of sectors affected by the intervention Sheltering, adults

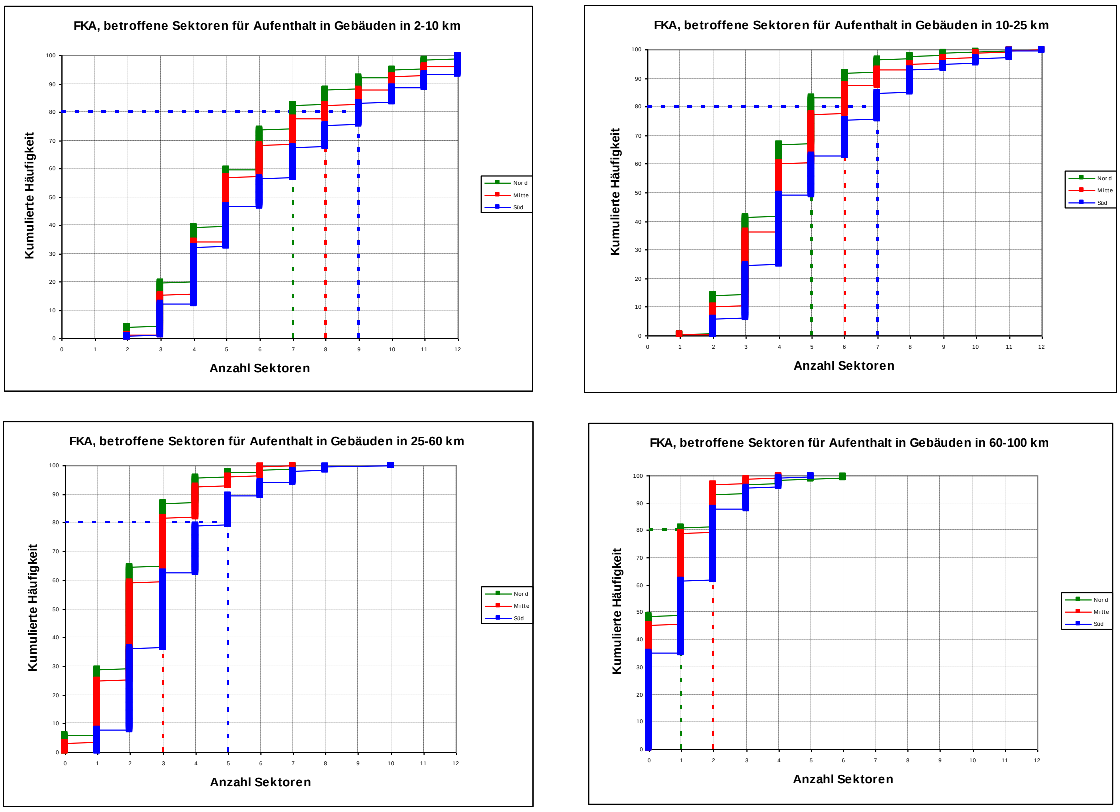


Fig. 8.4.1 a, b, c, d: Cumulative frequency distribution of the sectors affected by the intervention Sheltering for adults and the source term FKA at various distance ranges from the plant

Table 8.4.1: Data on the cumulative frequency distribution of the sectors affected by the intervention Sheltering for adults and the source term FKA at various distance ranges from the plant

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Sheltering	Effective dose	Adults	10 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
			Number of sectors in which the emergency reference level is exceeded		
Distance range from the plant (km)			50th percentile	80th percentile	90th percentile
2 - 10			5 - 6	7 - 9	9 - 11
10 - 25			4 - 5	5 - 7	6 - 8
25 - 60			2 - 3	3 - 5	4 - 6
60 - 100			0 - 1	1 - 2	2 - 3

The figure and table relating to the cumulative frequency distribution of sectors affected by the intervention Sheltering for adults and the source term FKA show that a rather high number of sectors is impacted in the near range (between 5 and 9 sectors at the 80th percentile). The affected area in the near range is thus a semi-circle or three-quarter circle around the point of emission. The number of affected sectors decreases with increasing distance so that only very few sectors (a maximum of 3 sectors) are affected at a distance of 60 to 100 km. The impact on sectors correlates with the meteorological dispersion situation.

Number of sectors affected by the intervention Evacuation, source term FKA, adults

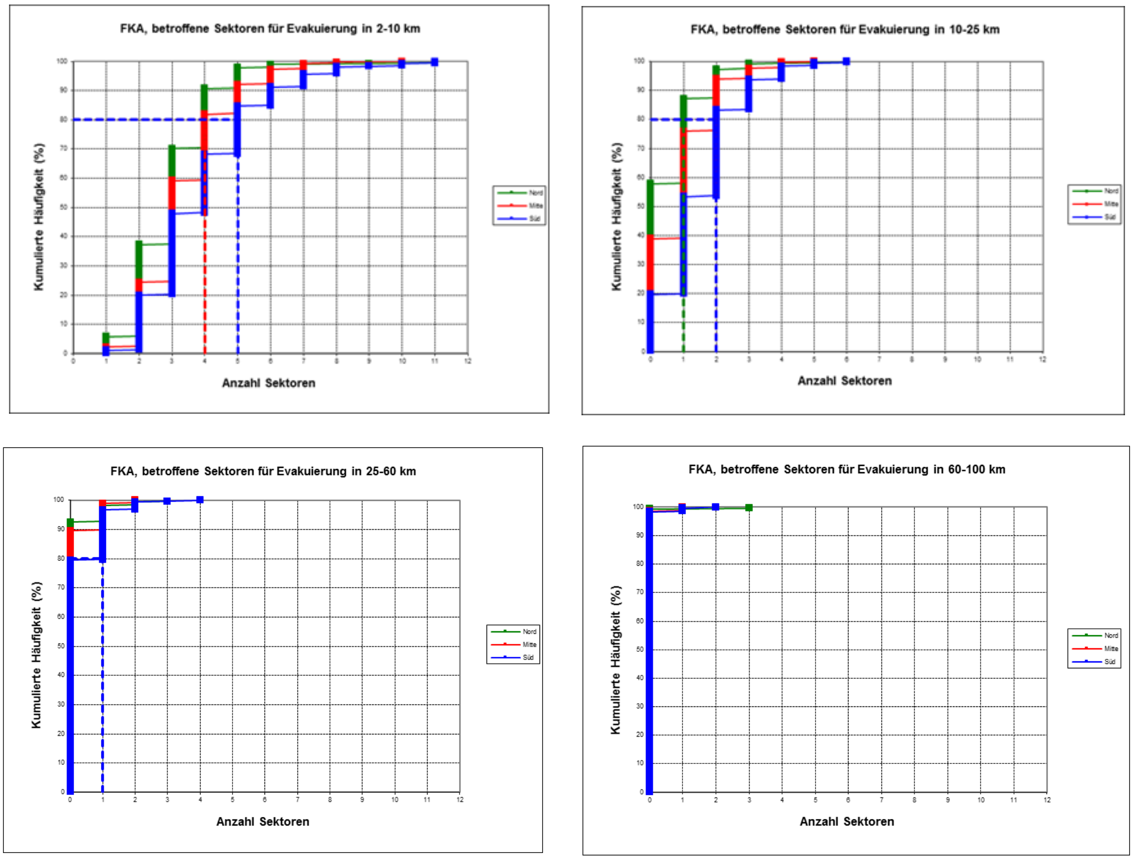


Fig. 8.4.2 a, b, c, d: Cumulative frequency distribution of the sectors affected by the intervention Evacuation for adults and the source term FKA at the Northern, Central and Southern sites.

Table 8.4.2: Data on the cumulative frequency distribution of the number of sectors affected by the intervention Evacuation, adults, source term FKA, Northern, Central and Southern sites

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Evacuation	Effective dose	Adults	100 mSv	External exposure within 7 days and committed dose due to the radionuclides inhaled in this time if the individual were to remain permanently outside	
Distance in km			Number of sectors in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
2 - 10			3 - 4	4 - 5	4 - 6
10 - 25			0 - 1	1 - 2	2 - 3
25 - 60			0	0 - 1	0 - 1
60 - 100			0	0	0

The figure and table relating to the cumulative frequency distribution of the sectors affected by the intervention Evacuation for adults and the source term FKA show that 4 to 5 sectors are impacted in the near range at the 80th percentile. The number of sectors decreases significantly with increasing distance. At a larger distance of up to 60 km the number of affected sectors is reduced to one sector. The impact on sectors correlates with the meteorological dispersion situation.

Number of sectors affected by the intervention Stable iodine prophylaxis for individuals aged 18 to 45

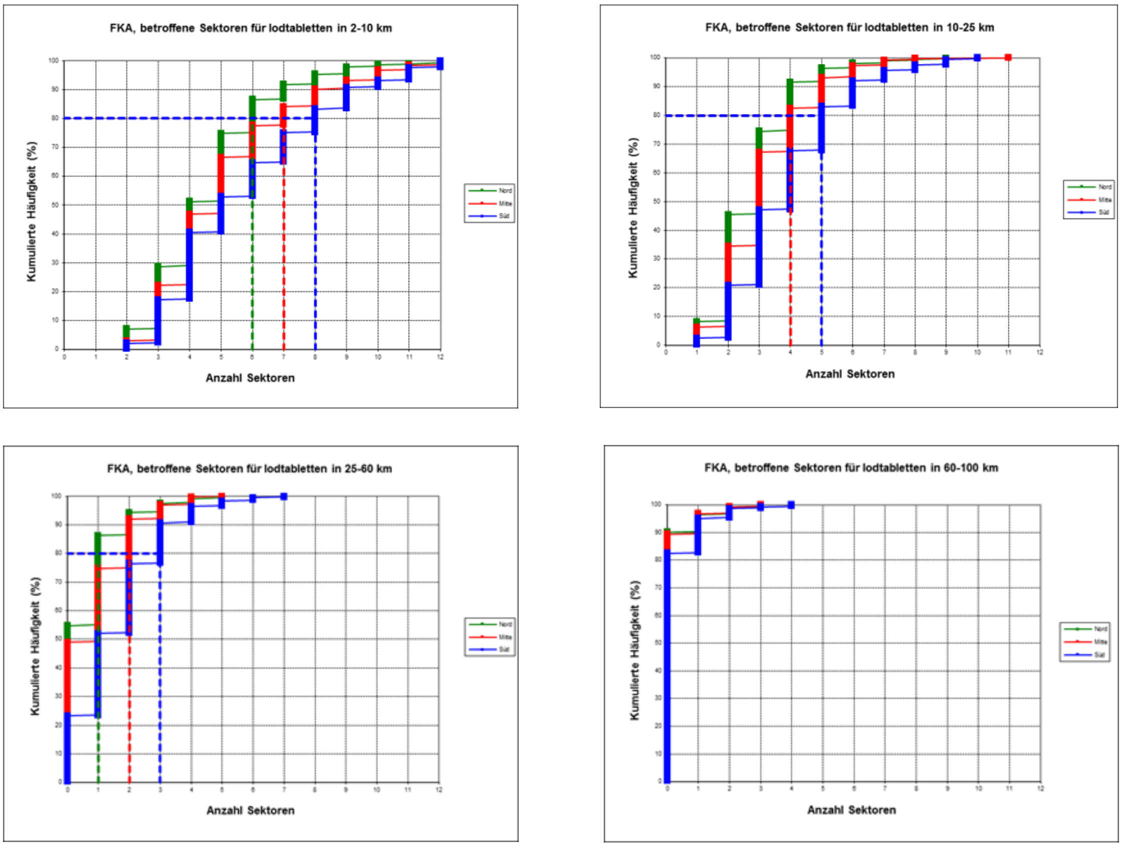


Fig. 8.4.3 a, b, c, d: Cumulative frequency distribution of the sectors affected by the intervention Stable iodine prophylaxis for individuals aged 18 to 45 and the source term FKA at the Northern, Central and Southern sites.

Table 8.4.3: Data on the cumulative frequency distribution of the number of sectors affected by the intervention Stable iodine prophylaxis for individuals aged 18 to 45, source term FKA, Northern, Central and Southern sites

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Effective dose	Individuals aged 18 to 45	100 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
Distance in km			Number of sectors in which the emergency reference level is exceeded		
			50th percentile	80th percentile	90th percentile
2 - 10			4-5	6-8	7-9
10 - 25			3-4	4-5	4-6
25 - 60			0-1	1-3	2-3
60 - 100			0	0	0-1

The figure and table relating to the cumulative frequency distribution of the sectors affected by the intervention Stable iodine prophylaxis for individuals aged 18 to 45 and the source term FKA show that a rather high number of sectors is impacted in the near range at all sites (80th percentile between 6 and 8 sectors). The affected area in the near range is thus a circle segment with an angle of 180° to 240° around the point of emission. The number of affected sectors decreases with increasing distance so that only 1 to 3 sectors are affected at a distance of 25 to 60 km (each at the 80th percentile). Please refer to the table above for the other percentile data.

The impact on sectors correlates with the meteorological dispersion situation.

Number of sectors affected by the intervention Stable iodine prophylaxis for children, teenagers under the age of 18 and pregnant women

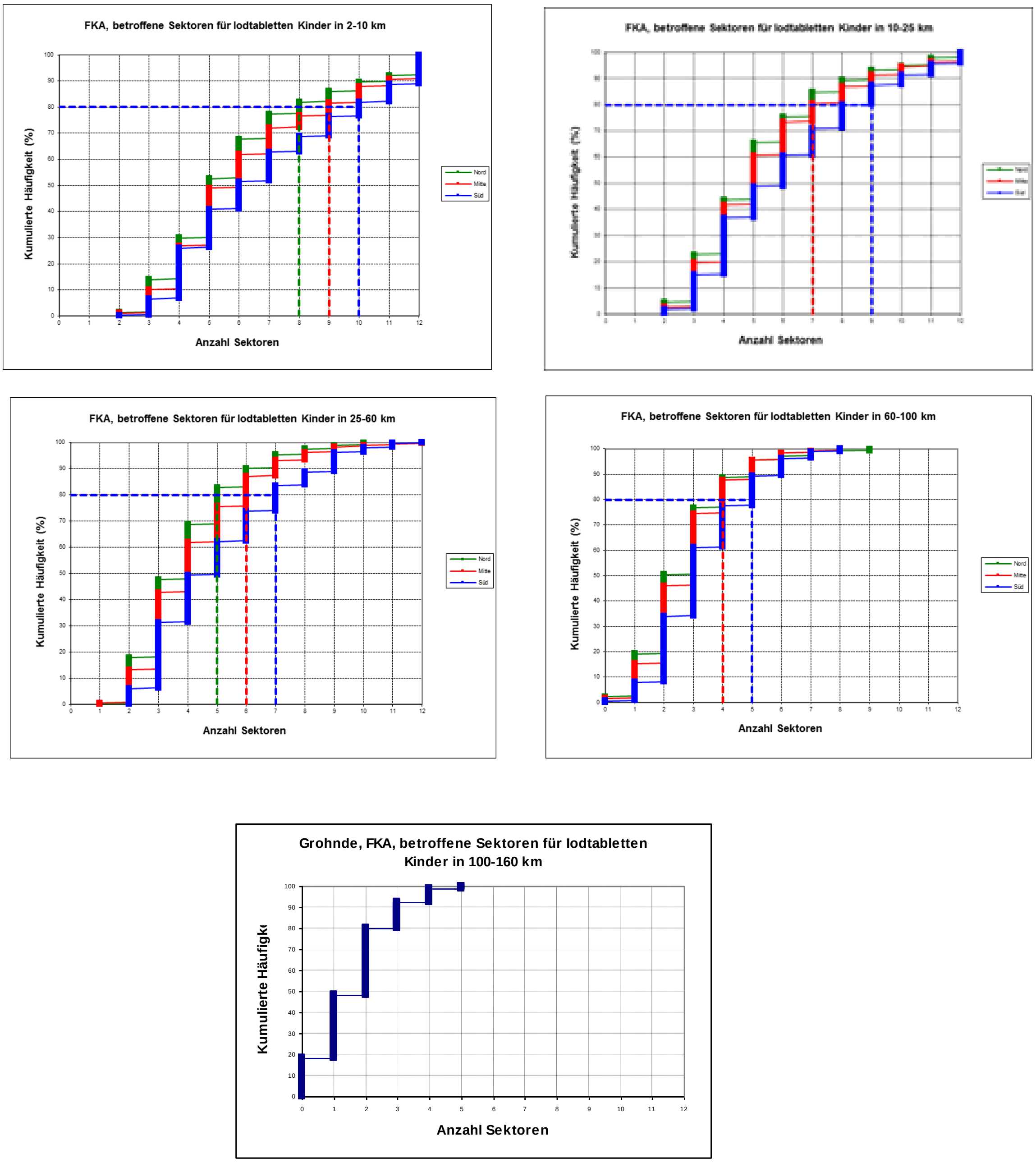


Fig. 8.4.4 a, b, c, d, e: Representation of the cumulative frequency distribution of the sectors affected by the intervention Stable iodine prophylaxis for children, teenagers under the age of 18 and pregnant women at the Northern, Central and Southern sites (Calculations for the distance range 100 – 160 km were only performed for Grohnde, Fig. 8.4.4 e.)

Table 8.4.4: Data on the cumulative frequency distribution of the sectors affected by the intervention Stable iodine prophylaxis for children, teenagers under the age of 18 and pregnant women at the Northern, Central and Southern sites

Type of intervention	Dose criterion	Group of individuals	Emergency reference level	Integration times and exposure paths	
Stable iodine prophylaxis	Effective dose	Children, teenagers under the age of 18 and pregnant women	50 mSv	Committed organ dose due to radioiodine inhaled within 7 days if the individual were to remain permanently outside	
			Number of sectors in which the emergency reference level is exceeded		
Distance range from the plant (km)			50th percentile	80th percentile	90th percentile
2 - 10			5-6	8-10	10-12
10 - 25			5-6	7-9	9-10
25 - 60			4-5	5-7	6-9
60 - 100			2-3	4-5	5-6
100 - 160			2 [1)]	2 [1)]	3 [1)]

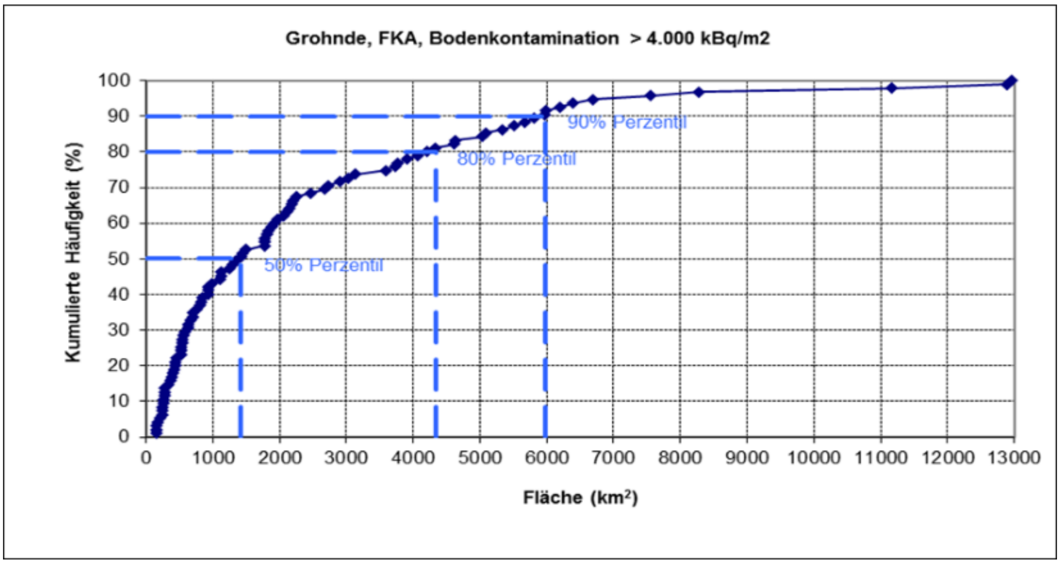
1) Calculation results for the distance range 100 - 160 km are only available for the Northern site.

The figure and table relating to the cumulative frequency distribution of the sectors affected by the intervention Stable iodine prophylaxis for children, teenagers under the age of 18 and pregnant women and the source term FKA show that a rather high number of sectors is impacted in the near range at all sites (80th percentile between 8 and 10 sectors). The affected area in the near range is thus roughly a circle segment with an angle of 240° to 300° around the point of emission. The number of affected sectors decreases with increasing distance so that only 4 to 5 sectors are affected at a distance of 60 to 100 km (each at the 80th percentile). Please refer to the table above for the other percentile data.

The impact on sectors correlates with the meteorological dispersion situation.

8.5. Size of areas with high soil contaminations

Areas with soil contaminations exceeding 4000 kBq/m², source term FKA



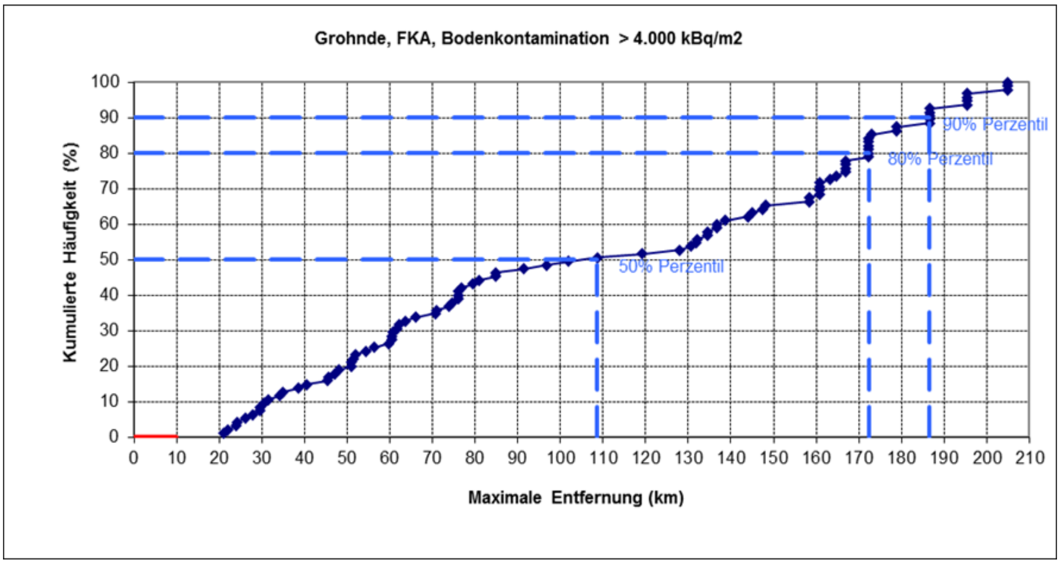


Fig. 8.5.1 a, b: Representation of the cumulative frequency distribution of the maximum distance and/or affected surface area where the soil concentration exceeds 4000 kBq/m² for the source term FKA at the Grohnde site

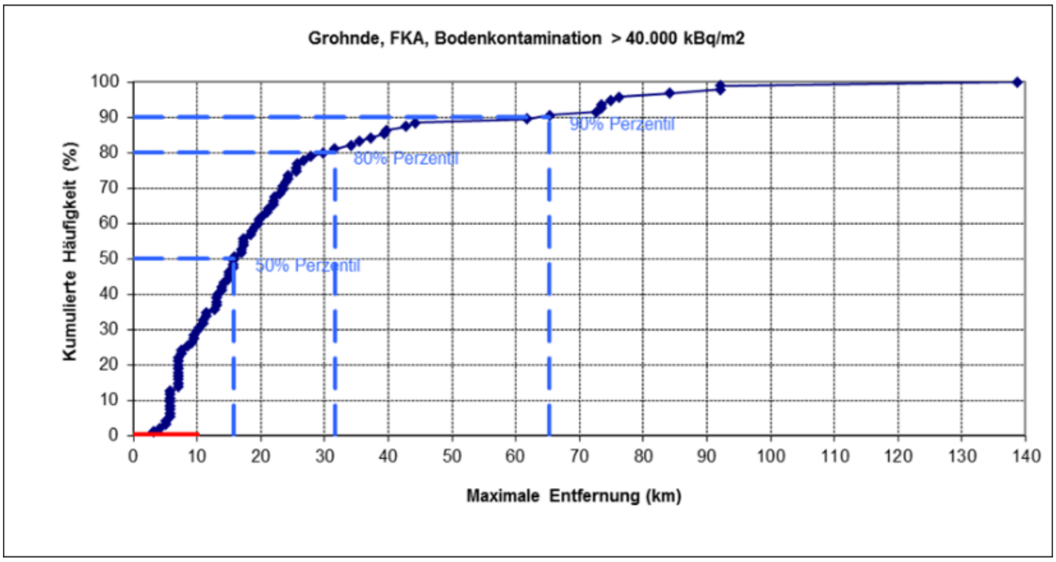
The figure above shows the cumulative frequency of the maximum distance (km) up to which an activity of 4000 kBq/m² is exceeded. A distance of up to 109 km is reached in 50% of the considered cases. Similarly, a distance of up to 172 km is reached in 80% of the considered cases and up to 187 km in 90% of the considered cases.

The cumulative frequency at which an activity of 4000 kBq/m² is exceeded amounts to an area of 1416 km² in 50% of the considered cases, an area of 4336 km² in 80% of the cases and an area of 5972 km² in 90% of the cases.

Table 8.5.1: Data on the cumulative frequency distribution of the maximum distance and/or affected surface area where the soil contamination exceeds 4000 kBq/m² for the source term FKA at the Grohnde site

Site	Maximum distance (km) at which an activity of 4000 kBq/m² is exceeded		
	50th percentile	80th percentile	90th percentile
Central site (Grohnde)	109	172	187
	Surface area (km^2) in which an activity of 4000 kBq/m² is exceeded		
	50th percentile	80th percentile	90th percentile
Central site (Grohnde)	1416	4336	5972

Areas with soil contaminations exceeding 40000 kBq/m², source term FKA



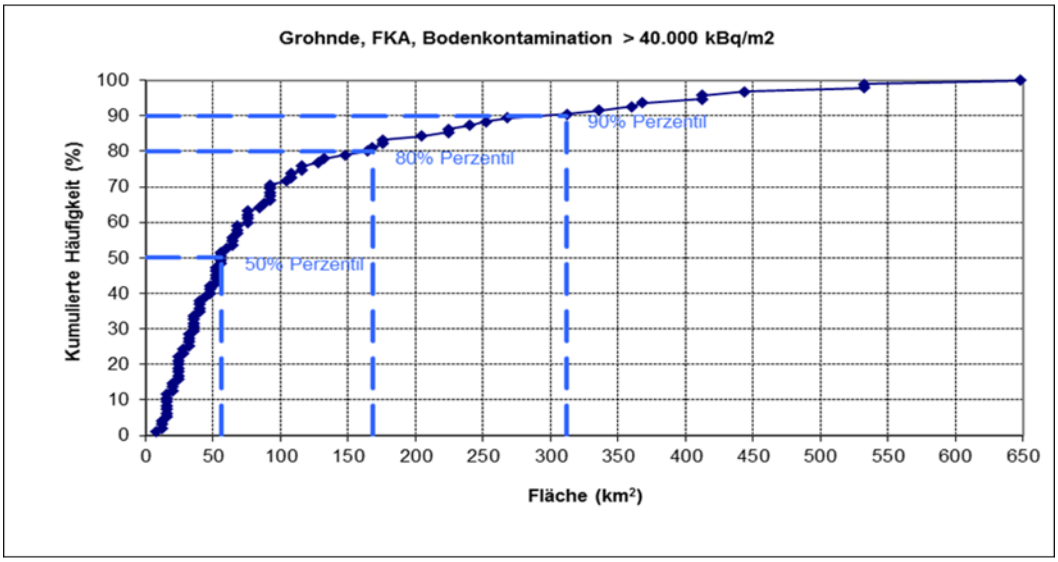


Fig. 8.5.2 a, b: Representation of the cumulative frequency distribution of the maximum distance and/or affected surface area where the soil contamination exceeds 40000 kBq/m² for the source term FKA at the Grohnde site

Table 8.5.2: Data on the cumulative frequency distribution of the maximum distance and/or affected surface area where the soil contamination exceeds 40000 kBq/m² for the source term FKA at the Grohnde site

Site	Maximum distance (km) at which an activity of 40000 kBq/m² is exceeded		
	50th percentile	80th percentile	90th percentile
Central site (Grohnde)	16	32	65
	Surface area (km^2) in which an activity of 40000 kBq/m² is exceeded		
	50th percentile	80th percentile	90th percentile
Central site (Grohnde)	56	168	312

The figure above shows the cumulative frequency of the maximum distance (km) at which an activity of 40000 kBq/m^2 is exceeded. A distance of up to 16 km is reached in 50% of the considered cases. Similarly, a distance of up to 32 km is reached in 80% of the considered cases and up to 65 km in 90% of the considered cases.

The cumulative frequency at which an activity of 40000 kBq/m^2 is exceeded amounts to an area of 56 km^2 in 50% of the considered cases, an area of 168 km^2 in 80% of the cases and an area of 312 km^2 in 90% of the cases.

8.6. Residual dose according to ICRP

In the framework of the present study BfS also analysed the question if the new ICRP concept of a reference value for the residual dose in the first year following the incident matches the existing German emergency reference levels. To this end, roughly 100 individual RODOS calculations were assessed, based on releases starting on every fourth day between 1 November 2011 and 31 October 2012 at the Grohnde site and for the source term FKA (i.e. a release over 50 hours). The dose reduction achieved through protective measures was taken into account for all areas where the German emergency reference levels were exceeded. When the protective measures were completed, a dose reduction due to normal living and leisure habits (percentage of indoor and outdoor activities) was taken into account. For each of the individual calculations the maximum residual effective dose for adults was determined that occurred in the entire computational domain. The median value of the maximum residual dose and the 10th and 90th percentiles for all calculations are shown in Table 8.6.1.

Table 8.6.1: Statistical analysis of the maximum residual dose for almost 100 individual calculations for the Grohnde site and the source term FKA

			Maximum residual dose (effective dose, adults, in **mSv**)		
Protective measures	Additionally: Relocation	Case	10%	Median value	90%
Evacuation, Sheltering, Stable iodine prophylaxis	No	1a	46	77	296
	After 30 d	1b	20	29	69
	After 7 d	1c	14	18	32

Protective measures were taken into account in all areas where the German emergency reference levels for the relevant measures were exceeded. It was assumed that the intervention Sheltering would be maintained for two days, that the effects of the intervention Stable iodine prophylaxis would last while the clouds pass and that the intervention Evacuation would mean that people do not return to their homes within the first year so that the residual dose at the evacuated places is zero. This also means that neither Sheltering nor Iodine thyroid prophylaxis nor Relocation had to be taken into account for the evacuated places since the residual dose was reduced to zero simply by the Evacuation. In other words, the residual dose assessed in Table 8.6.1 only occurs in non-evacuated areas where only the interventions Sheltering and Stable iodine prophylaxis are applied. The places with the maximum residual dose are situated at roughly 10 km from the NPP on average since the reference level for Evacuation is exceeded for shorter distances in most cases and the residual dose is zero due to the Evacuation.

The dose reduction achieved by protective measures and normal living and leisure habits was based on the following assumptions: reduction factor for external exposure and inhalation in the case of Evacuation = 0, in the case of Relocation = 0, in the case of Sheltering = 0.33 (ingestion was not taken into account). Additional reduction factor due to inhalation of iodine isotopes in the case of iodine thyroid prophylaxis = 0.1. Reduction factor for external exposure in the case of normal living and leisure habits = 0.55 (assumption: remaining outdoor 8 h per day, indoor 16 h, reduction factor indoor = 0.33).

It can be seen from Table 8.6.1 that the implementation of the three protective measures (Evacuation, Sheltering, Stable iodine prophylaxis in those places where the relevant emergency reference level is exceeded) leads to a median value of the residual dose that is below 100 mSv in all scenarios. In the event that the intervention Relocation is not additionally taken into account (case 1a) a significant portion of the scenarios (roughly 40 %; see Fig. 8.6 a) remains above 100 mSv (with a median value of 77 mSv). If a Relocation after 30 days is taken into account, the 90th percentile (69 mSv) remains significantly below 100 mSv in all scenarios (case 1b) and the residual dose is below 100 mSv in all scenarios except one (Fig. 8.6 b). However, the residual dose exceeds 50 mSv in one third of cases. If a Relocation after 7 days is taken into account, the 90th percentile (32 mSv) remains even significantly below 50 mSv in all scenarios (case 1c) and the residual dose is below 50 mSv in all scenarios (Fig. 8.6 c).

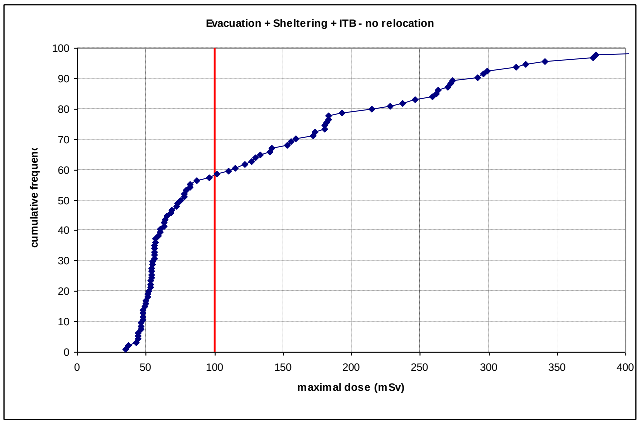


Fig. 8.6 a: Cumulative frequency of the maximum residual dose for case 1a (Evacuation + Sheltering + Iodine thyroid prophylaxis, no Relocation)

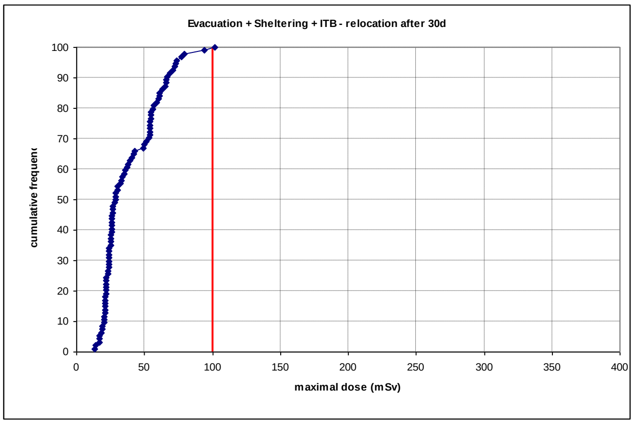


Fig. 8.6 b: Cumulative frequency of the maximum residual dose for case 1b (Evacuation + Sheltering + Iodine thyroid prophylaxis, Relocation after 30 days)

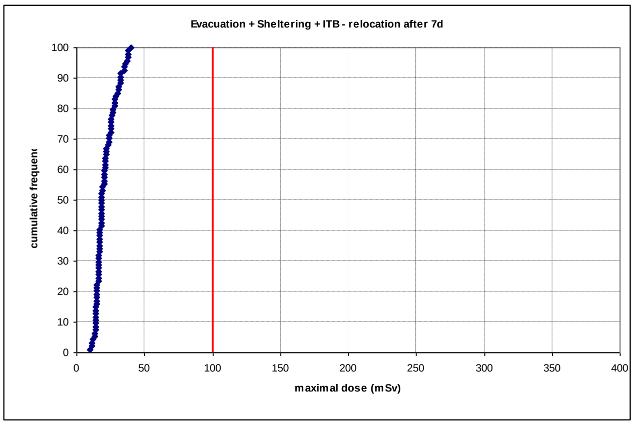


Fig. 8.6 c: Cumulative frequency of the maximum residual dose for case 1c (Evacuation + Sheltering + Iodine thyroid prophylaxis, Relocation after 7 days)

It was additionally investigated which dose can occur if an evacuation is impossible although the emergency reference levels are exceeded (e.g. due to the current weather conditions or if the time for advance warning is too short; cases 2a, b and c) or if both Evacuation and Stable iodine prophylaxis are impossible (cases 3a, b and c).

The red line shown in the diagrams represents the maximum value for the residual dose of 100 mSv within the first year, to be defined in the framework of emergency planning according to ICRP 103.

Table 8.6.2: Statistical analysis of the maximum residual dose for roughly 100 individual calculations for the cases 2 and 3, i.e. assuming that the interventions Evacuation (cases 2a, b, c) or Evacuation and Stable iodine prophylaxis (cases 3a, b, c) cannot be implemented although the emergency reference levels are exceeded.

			Maximum residual dose (effective dose, adults, mSv)		
Protective measures	Additionally: Relocation	Case	10%	Median value	90%
Sheltering, Iodine thyroid prophylaxis	No	2a	238	694	2036
	After 30 d	2b	88	271	925
	After 7 d	2c	54	171	568
Sheltering	No	3a	300	835	2723
	After 30 d	3b	151	412	1381
	After 7 d	3c	123	331	1090

If an Evacuation is impossible (cases 2) or both Evacuation and Stable iodine prophylaxis are impossible (cases 3) the median value of the residual dose exceeds 100 mSv in all cases (even significantly, for some parts). This shows that a residual dose of more than 100 mSv can occur in a number of weather conditions if no evacuation is implemented, in particular in the immediate vicinity and even if the population is relocated as early as 7 days after the event. Nearly all of the places where the residual dose is at its maximum (cases 2 and 3) are situated in the immediate vicinity of the NPP (distance of 1 to 3 km).

The results presented above lead to the following conclusions:

- A reference value of 100 mSv for the residual effective dose within the first year only matches the German emergency reference levels if Relocation is implemented – in addition to earlier protective measures.
- In the event of Relocation 30 days after the release has started, a level of 50 mSv for the residual effective dose within the first year is exceeded in almost one third of cases. However, the residual dose can remain below the level of 100 mSv in almost all scenarios even if the Relocation is only implemented after 30 days.
- A strategy comprising only the early protective measures – i.e. without Relocation – would lead to a residual dose above 100 mSv in a significant part (roughly 40%) of the scenarios considered.
- In the event that an Evacuation is impossible, the residual doses occurring in the immediate vicinity of the NPP can be very high so that even serious deterministic effects cannot be excluded. This demonstrates the key importance of appropriate planning that allows for an Evacuation in the immediate vicinity of the NPP in almost all circumstances within a very short delay.

9. SUMMARY OF THE RESULTS

9.1. Maximum dimensions of the affected areas

Tables 9.1 a and 9.1 b list the most important results of this study with respect to the maximum dimensions of the affected areas in which the indicated dose criteria are exceeded. Example: The dose criterion for the intervention Evacuation, i.e. an effective dose of 100 mSv, is exceeded in an area with a maximum distance of 6 to 31 km from the place of release in 80% of the considered weather scenarios (for release category FKA, see Table 9.1 a). The indicated maximum distances do not include those 10% of weather scenarios that would lead to a larger or smaller maximum distance since those cases are based on rare meteorological conditions. On average (median value), the area affected by an Evacuation extends to a maximum distance of between 9 km and 18 km from the place of release, depending on the NPP site. The indicated distances are not indicative of the shape, location or dimension of the affected areas; these types of analyses are represented in Tables 9.2 and 9.3 below.

Table 9.1 a: Summary of the results for the maximum dimensions of the affected areas in which the dose criteria are exceeded (for release category FKA)

Dose criterion	Type of intervention	Group of individuals	Range of maximum distance at which the dose criterion is exceeded [1)] (km)	Median value of the maximum distance at which the dose criterion is exceeded [2)] (km)
Threshold levels for the occurrence of serious deterministic effects:				
1000 mGy for the dose to the red bone marrow	-	Adults	0 - 1	0
(see above)	-	Infants	0 - 1	0
300 mGy for the brain dose to the foetus in 8th to 15th week	-	Foetus	0 - 3	0
100 mSv for the effective dose to the foetus in 2nd to 7th week	-	Foetus	3 - 11	3
High doses:				
Effective dose of 1000 mSv	-	Adults	0 - 5	0 - 1
~	-	Infants	0 - 10	1 - 3
Reference levels for emergency response measures:				
Effective dose of 100 mSv	Evacuation	Adults	6 – 31	9 – 18
~		Infants	9 – 47	14 – 24
Effective dose of 10 mSv	Sheltering	Adults	29 – 163	62 – 80
~	~	Infants	43 – 173	91 – 114
Thyroid dose of 250 mSv	Stable iodine prophylaxis	Individuals aged 18 to 45	15 – 84	24 – 34
Thyroid dose of 50 mSv	Stable iodine prophylaxis	Children, teenagers and pregnant women	20 – 195 [3)]	148 – 161
Effective dose of 30 mSv in one month	Temporary relocation	Adults	7 – 100	16 – 27
~	~	Infants	8 – 121	22 – 32
Effective dose of 100 mSv in one year	Permanent relocation	Adults	6 – 82	15 – 26
~	~	Infants	7 – 117	20 – 32

1) The lower value of the indicated range describes the maximum dimension of the affected area if 10% of all weather scenarios that lead to the smallest distances are taken into account.
The higher value of the indicated range describes the maximum dimension of the affected area if 90% of all weather scenarios that lead to the smallest distances are taken into account.
All three sites (Unterweser, Grohnde, Philippsburg) were taken into account in all calculations.
2) The indicated interval describes the minimum and maximum level of the median value for all three sites.

3) Distances of more than 160-225 km (depending on the direction of dispersion) were not investigated. A value of more than 160 km thus means that the relevant dose criterion can be exceeded at least up to the distances indicated and in some cases even beyond.

The key results of this study with respect to the maximum dimensions of the affected areas where dose criteria may be exceeded are given below (all results are given for the largest nuclear release scenario "FKA"):

- Threshold levels for deterministic effects and high doses (effective doses higher than 1000 mSv) can be reached or exceeded within a distance of about 3 km on average.
- The emergency reference level for the intervention Evacuation can be reached or exceeded within a distance of up to 9 to 18 km (adults) and/or up to 14 to 24 km (infants) on average (the indicated interval describes the minimum and maximum levels of the median value at all three NPP sites).
- The emergency reference level for the intervention Sheltering can be reached or exceeded within a distance of up to 62 to 80 km (adults) and/or up to 91 to 114 km (infants) on average.
- The emergency reference level for the intervention Stable iodine prophylaxis can be reached or exceeded within a distance of up to 24 to 34 km (adults) and/or up to 148 to 161 km (children, teenagers and pregnant women) on average.

Table 9.1 b: Summary of the results for the maximum dimensions of the affected areas in which the dose criteria are exceeded (for release category FKF)

Dose criterion	Type of intervention	Group of individuals	Range of maximum distance at which the dose criterion is exceeded [1] (km)	Median value of the maximum distance at which the dose criterion is exceeded [2] (km)
High doses:				
Effective dose of 1000 mSv	-	Adults	0 - 0	0
~	-	Infants	0 - 0	0
Reference levels for emergency response measures:				
Effective dose of 100 mSv	Evacuation	Adults	0 - 0	0
~		Infants	0 - 0	0
Effective dose of 10 mSv	Sheltering	Adults	0 - 8	3
~	~	Infants	1 - 16	7 - 8
Thyroid dose of 250 mSv	Stable iodine prophylaxis	Individuals aged 18 to 45	0 - 1	0
Thyroid dose of 50 mSv	Stable iodine prophylaxis	Children, teenagers and pregnant women	10 - 32	15 - 18
Effective dose of 30 mSv in one month	Temporary relocation	Adults	0 - 1	0
~	~	Infants	0 - 1	0
Effective dose of 100 mSv in one year	Permanent relocation	Adults	0 - 0	0
~	~	Infants	0 - 0	0

1) The lower value of the indicated range describes the maximum dimension of the affected area if 10% of all weather scenarios that lead to the smallest distances are taken into account.
The higher value of the indicated range describes the maximum dimension of the affected area if 90% of all weather scenarios that lead to the smallest distances are taken into account.
All three sites (Unterweser, Grohnde, Philippsburg) were taken into account in all calculations.

2) The indicated interval describes the minimum and maximum level of the median value for all three sites.

The calculations for release category FKF show (see Table 9.1 b) that the criterion of 1000 mSv (effective dose) and the emergency reference level of 100 mSv (effective dose) are not reached in any case. Distances of less than 1.4 km from the NPP were not included in the calculations.

9.2. Size of the affected areas and number of affected persons

Table 9.2 shows the most important results of this study with respect to the size of the affected areas in which the indicated dose criteria are exceeded. Example: The dose criterion for the intervention Evacuation, i.e. an effective dose of 100 mSv, is exceeded in an area sized between 16 and 168 km^2 in 80% of the considered weather scenarios. This analysis does not include those 10% of weather scenarios that would lead to larger or smaller areas since those cases are based on rare meteorological conditions. On average (median value), the area affected by an Evacuation has a size of between 28 km^2 and 72 km^2, depending on the NPP site.

Table 9.2: Summary of the results for the size of the affected areas in which the dose criteria are exceeded (for release category FKA)

Dose criterion	Type of intervention	Group of individuals	Size of affected areas in which the dose criterion is exceeded [1)] (km^2)	Median value of the size of the affected areas in which the dose criterion is exceeded [2)] (km^2)
Reference levels for emergency response measures:				
100 mSv Effective dose	Evacuation	Adults	16 - 168	28 - 72
10 mSv Effective dose	Sheltering	Adults	240 - 2920	604 - 1120
250 mSv Thyroid dose	Stable iodine prophylaxis	Individuals aged 18 to 45	92 - 956	144 - 336
50 mSv Thyroid dose	Stable iodine prophylaxis	Children, teenagers and pregnant women	1400 - 10444 [3)]	3410 - 5104

1) The lower value of the indicated range describes the maximum size of the affected area if 10% of all weather scenarios that lead to the smallest affected areas are taken into account.
   The higher value of the indicated range describes the maximum size of the affected area if 90% of all weather scenarios that lead to the smallest affected areas are taken into account.
   All three sites (Unterweser, Grohnde, Philippsburg) were taken into account in all calculations.
2) The indicated interval describes the minimum and maximum level of the median value for all three sites.
3) Distances of more than 160-225 km (depending on the direction of dispersion) were not investigated. The higher value of the indicated range is thus only a minimum limit, since the actually affected area might be larger than indicated here.

The key results of this study with respect to the size of the affected areas where dose criteria may be exceeded are as follows (all results are given for the largest nuclear release scenario “FKA”):

- The emergency reference level for the intervention Evacuation can be reached or exceeded in an area sized 28 to 72 km^2 (adults) on average.
- The emergency reference level for the intervention Sheltering can be reached or exceeded in an area sized roughly 600 to 1100 km^2 (adults) on average.
- The emergency reference level for the intervention Stable iodine prophylaxis can be reached or exceeded in an area sized 144 to 336 km^2 (adults) or roughly 3400 to 5100 km^2 (children, teenagers and pregnant women) on average.

The number of persons who would be affected by an Evacuation because the dose criterion of 100 mSv (effective dose) is exceeded amounts to between roughly 14000 and 50000 individuals for the Grohnde site and between roughly 45000 and 245000 individuals for the Philippsburg site in 80% of the considered weather scenarios. In this analysis 10% of those weather scenarios that would lead respectively to a larger or smaller number of persons were not taken into account.

9.3. Number of affected sectors

Table 9.3 summarizes the key results of this study with respect to the number of affected sectors where the indicated dose criteria are exceeded. (A sector includes an angle of 30 degrees, twelve sectors thus form a full circle around the NPP; a sector is considered as affected if the dose criterion is exceeded at any point within this sector.) Example: The dose criterion for the intervention Evacuation of 100 mSv (effective dose) is exceeded in 2 to 6 sectors (i.e. an angle of 60 to 180 degrees) at a distance of 2 to 10 km in 80% of the considered weather scenarios. This analysis does not include those 10% of weather scenarios that would lead to larger or smaller numbers of affected sectors since those cases are based on rare meteorological conditions. On average (median value), the area affected by an Evacuation includes 3 to 4 sectors (which corresponds to an angle of 90 to 120 degrees) at a distance of 2 to 10 km, depending on the NPP site.

Table 9.3: Summary of the results for the number of affected sectors[3)] in which the dose criteria are exceeded (for release category FKA)

Dose criterion	Type of intervention	Group of individuals	Distance from the NPP	Number of affected sectors in which the dose criterion is exceeded [1)]	Median value for the number of affected sectors in which the dose criterion is exceeded [2)]
	Reference levels for emergency response measures:				
Effective dose of 100 mSv	Evacuation	Adults	2 - 10 km	2 - 6	3 - 4
			10 - 25 km	0 - 3	0 - 1
			25 - 60 km	0 - 1	0
			60 - 100 km	0	0
Effective dose of 10 mSv	Sheltering	Adults	2 - 10 km	3 - 11	5 - 6
			10 - 25 km	2 - 8	4 - 5
			25 - 60 km	1 - 6	2 - 3
			60 - 100 km	0 - 3	0 - 1
250 mSv Thyroid dose	Stable iodine prophylaxis	Individuals aged 18 to 45	2 - 10 km	3 - 9	4 - 5
			10 - 25 km	2 - 6	3 - 4
			25 - 60 km	0 - 3	0 - 1
			60 - 100 km	0 - 1	0 - 0
50 mSv Thyroid dose	Stable iodine prophylaxis	Children, teenagers and pregnant women	2 - 10 km	3 - 12	5 - 6
			10 - 25 km	3 - 10	5 - 6
			25 - 60 km	2 - 9	4 - 5
			60 - 100 km	1 - 6	2 - 3
			100 - 160 km	0 - 3	2

1) The lower value of the indicated range describes the maximum size of the affected area if 10% of all weather scenarios that lead to the smallest affected areas are taken into account.
   The higher value of the indicated range describes the maximum size of the affected area if 90% of all weather scenarios that lead to the smallest affected areas are taken into account.
   All three sites (Unterweser, Grohnde, Philippsburg) were taken into account in all calculations.
2) The indicated interval describes the minimum and maximum level of the median value for all three sites.
3) A sector includes an angle of 30 degrees; a sector is considered as affected if the dose criterion is exceeded at any point within this sector.

The key results of this study with respect to the number of affected sectors in which dose criteria may be exceeded are as follows (all results are given for the largest nuclear release scenario “FKA”):

- The emergency reference level for the intervention Evacuation can be reached or exceeded on average in 3 to 4 sectors at a distance of 2 to 10 km and in 0 to 1 sector at a distance of 10 to 25 km.

- The emergency reference level for the intervention Sheltering can be reached or exceeded on average in 5 to 6 sectors at a distance of 2 to 10 km, in 4 to 5 sectors at a distance of 10 to 25 km, in 2 to 3 sectors at a distance of 25 to 60 km and in 0 to 1 sector at a distance of 60 to 100 km.

- The emergency reference level for the intervention Stable iodine prophylaxis for children, teenagers and pregnant women can be reached or exceeded on average in 5 to 6 sectors at a distance of 2 to 10 km, in 5 to 6 sectors at a distance of 10 to 25 km, in 4 to 5 sectors at a distance of 25 to 60 km, in 2 to 3 sectors at a distance of 60 to 100 km and in 2 sectors at a distance of 100 to 160 km.

10. LITERATURE

BMU 2001, Bekanntmachung der Dosiskoeffizienten zur Berechnung der Strahlenexposition. RS II 1-11413/28 vom 23.07.2001. BAnz no. 160a and b of 28 Aug 2001

BMU 2008, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Rahmenempfehlungen für den Katastrophenschutz in der Umgebung kerntechnischer Anlagen, GMBl. 2008 no. 62/63; p. 1278

BfS 2012, Die Katastrophe im Kernkraftwerk Fukushima nach dem Seebeben vom 11. März 2011 : Beschreibung und Bewertung von Ablauf und Ursachen, Bundesamt für Strahlenschutz (BfS), Fachbereich Sicherheit in der Kerntechnik. Report-Nr. BfS-SK-18/12, 7-Mär-2012. http://nbn-resolving.de/urn:nbn:de:0221-201203027611

Gering 2012, Gering F, Gerich B, Wirth E, Kirchner G. Analyse der Vorkehrungen für den anlagenexternen Notfallschutz für deutsche Kernkraftwerke basierend auf den Erfahrungen aus dem Unfall in Fukushima, Bundesamt für Strahlenschutz. Report-Nr. BfS-SW-11/12, 19. April 2012. http://nbn-resolving.de/urn:nbn:de:0221-201204128010

GRS 2013, Fukushima Dai-ichi 11. März 2011 - Unfallablauf, radiologische Folgen (2nd, revised edition), GRS-S-53, March 2013.

ICRP 2001, International Commission on Radiological Protection (IAEA). Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother, ICRP Publication 88, Ann. ICRP 31 (1-3), 2001

ICRP 2007. International Commission on Radiological Protection (ICRP). The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Annals of the ICRP Volume 37(2-4), 2007

ICRP 2009a. International Commission on Radiological Protection (ICRP). Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations, ICRP Publication 109, Annals of the ICRP Volume 39 (1), 2009.

ICRP 2009b. International Commission on Radiological Protection (ICRP). Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas After a Nuclear Accident or a Radiation Emergency, ICRP Publication 111, Annals of the ICRP Volume 39 (3), 2009.

ICRP 2012, Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119. Ann. ICRP 41(Suppl.).

Jacob 1990. Jacob, P., Rosenbaum, H., Petoussi, N., Zankl, M.: Calculation of Organ Doses from Environmental Gamma Rays Using Human Phantoms and Monte Carlo Methods. Part II: Radionuclides Distributed in the Air or Deposited on the Ground. München, Germany, Gesellschaft für Strahlen- und Umweltforschung (GSF), Report GSF-12/90 (1990).

Löffler et al. 2010, Löffler H, Mildenberger O, Sogalla M, Stahl T. Aktualisierung der Quelltermbibliothek des Entscheidungshilfesystems RODOS für Ereignisse im Leistungsbetrieb. Abschlussbericht zum Vorhaben S3609S60009, GRS-A-3580, Gesellschaft für Anlagen- und Reaktorsicherheit, October 2010.

Raskob und Gering 2010, Raskob W, Gering F. Key improvements in the simulation modelling for decision support systems developed in the EURANOS project, Radioprotection Vol. 45 (5), 149-159, 2010 DOI: 10.1051/radiopro/2010037

SSK 2008, Strahlenschutzkommission. Radiologische Grundlagen für Entscheidungen über Maßnahmen zum Schutz der Bevölkerung bei unfallbedingten Freisetzungen von Radionukliden, Revision of the publication from 1999 with the same title, published in GMBI no. 62/63 of 19 Dec 2008

SSK 2014a, Strahlenschutzkommission. Radiologische Grundlagen für Entscheidungen über Maßnahmen zum Schutz der Bevölkerung bei Ereignissen mit Freisetzungen von Radionukliden, Recommendation adopted at the 268th SSK session on 13/14 Feb 2014. http://www.ssk.de

SSK 2014b, Strahlenschutzkommission. Planungsgebiete für den Notfallschutz in der Umgebung von Kernkraftwerken, Recommendation adopted at the 268th SSK session on 13/14 Feb 2014. http://www.ssk.de

Bisher erschienene BfS-Schriften

BfS-SCHR-1/90
Warnecke, E.; Odoj, R.; Simon, R. (Editors)
Requirements for Waste Acceptance and Quality Control.
Proceedings of the 2nd International Seminar on Radioactive Waste Products.
28 May - 1 June 1990, Research Centre Jülich, Federal Republic of Germany.
Salzgitter 1990

BfS-SCHR-2/91
Sicherheitsreihe Nr. 6.
IAEO-Empfehlungen für die sichere Beförderung radioaktiver Stoffe. Ausgabe 1985.
(Diese Übersetzung enthält auch die von der IAEO im Nachtrag 1988 zu den Empfehlungen vorgenommenen Ergänzungen).
Salzgitter 1991

BfS-SCHR-3/91
Schüttmann, W.; Aurand, K.
Die Geschichte der Außenstelle Oberschlema des Kaiser-Wilhelm-Instituts für Biophysik Frankfurt am Main.
Salzgitter 1991

BfS-SCHR-4/91
Bornemann, O. (mit einem Beitrag von *R. Fischbeck*)
Zur Geologie des Salzstocks Gorleben nach den Bohrergebnissen.
Salzgitter 1991

BfS-SCHR-5/92
Herrmann, *A.G.*
Endlager für radioaktive Abfälle Morsleben (ERAM).
Lösungszuflüsse in den Grubenfeldern Marie und Bartensleben: Stoffbestand, Herkunft, Entstehung. Eine Dokumentation.
Zweiter Bericht. Abschlußbericht für den Zeitabschnitt 1. Januar bis 31. Dezember 1991. Clausthal-Zellerfeld, den 29. Februar 1992.
Salzgitter 1992

BfS-SCHR-6/92
Bestandsaufnahme IMIS-IT.
Seminar zum Projektstand IMIS am 3. Mai 1991.
Salzgitter 1992

BfS-SCHR-7/92
Empfehlungen der Reaktor-Sicherheitskommission (RSK) 1987 - 1991 (Band 7).
Zusammengestellt von der RSK-Geschäftsstelle.
Salzgitter 1992

BfS-SCHR-8/92
Radiologische Erfassung, Untersuchung und Bewertung bergbaulicher Altlasten.
Abschlußbericht zum ersten Teilprojekt.
Salzgitter 1992

BfS-SCHR-9/93
Grosche, B.; Burkart, W. (Editors)
Radiation epidemiology after the Chernobyl accident.
Proceedings of a workshop held at the Institute for Radiation Hygiene, Federal Office of Radiation Protection, Neuherberg, October 23-25, 1991

BfS-SCHR-10/93
von Borstel, L.E.
Lösungen in marinen Evaporiten.
Salzgitter 1993

BfS-SCHR-11/93
Herrmann, *A.G.*
Endlager für radioaktive Abfälle Morsleben (ERAM).
Lösungsvorkommen in den Grubenfeldern Marie und Bartensleben: Stoffbestand, Herkunft, Entstehung.
Eine Dokumentation.
Abschlußbericht für den Zeitabschnitt 1. Januar bis 31. Dezember 1992. Clausthal-Zellerfeld, den 29. Februar 1992.
Salzgitter 1993

BfS-SCHR-12/93
IMIS-Statusgespräch.
Seminar zum Projektstand IMIS am 1. Februar 1993.
Salzgitter 1993

BfS-SCHR-13/94
Przyborowski, S.; Röhnsch, W.
ICRP-Publikation 65
über den Schutz gegenüber Radon-222 in Wohnung und an Arbeitsplätzen und die Situation in der Bundesrepublik Deutschland.
Salzgitter, 1994

BfS-SCHR-14/95
Kammerer, L.; Peter, J.; Burkhardt, J.; Trugenberger-Schnabel, A.; Bergler, I.
Umweltradioaktivität in der Bundesrepublik Deutschland 1992 und 1993. Daten und Bewertung.
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz.
Salzgitter, Dezember 1995

BfS-SCHR-15/96
Solare terrestrische UV-Strahlung in Deutschland.
Meßergebnisse und strahlenhygienische Bewertung der Daten aus dem UV-Meßnetz des BFS/UBA für den Zeitraum Januar bis Dezember 1994.
Salzgitter, März 1996

BfS-SCHR-16/98
Kammerer, L.
Umweltradioaktivität in der Bundesrepublik Deutschland 1994 bis 1995. Daten und Bewertung.
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz.
Salzgitter, März 1998

BfS-SCHR-17/98
Radiologische Erfassung, Untersuchung und Bewertung bergbaulicher Altlasten.
Abschlußbericht zum zweiten Teilprojekt.
Salzgitter, März 1998

BfS-SCHR-18/98
Sonnek, C.
Die Euratom-Grundnormen für den Strahlenschutz 1996 und 1997.
Ausblick auf zukünftiges Strahlenschutzrecht in Deutschland.
Salzgitter, Juli 1998

Bisher erschienene BfS-Schriften

BfS-SCHR-19/99
Strahlenschutz und Sicherheit in der Medizin.
ICRP-Veröffentlichung 73.
Ein Bericht einer Arbeitsgruppe des Komitees 3 der Internationalen Strahlenschutzkommission.
Von der Kommission angenommen im März 1996.
Salzgitter, Mai 1999

BfS-SCHR-20/99
WORKSHOP
Strahlenüberwachung von Arbeitsplätzen mit erhöhten Konzentrationen von Radon und Radonzerfallsprodukten und Qualitätssicherung der Überwachungsmessungen.
22. bis 24. Juni 1998, Berlin.
Salzgitter, November 1999

BfS-SCHR-21/00
Kammerer, L.
Umweltradioaktivität in der Bundesrepublik Deutschland 1996 und 1997. Daten und Bewertung.
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz.
Salzgitter, Oktober 2000

BfS-SCHR-22/01
Ettenhuber, E.; Gehrcke, K.
Radiologische Erfassung, Untersuchung und Bewertung bergbaulicher Altlasten.
Abschlussbericht.
Salzgitter, März 2001

BfS-SCHR-23/01 (ist nicht als Druck erschienen, nur im Internet)
Steinmetz, M.
UV-Index in practical use
Proceedings of an International Workshop
Institute of radiation hygiene, Munich, Germany, December 4-7, 2000
Salzgitter, 2001

BfS-SCHR-24/02
Peter J.; Schneider G.; Bayer A.; Trugenberger-Schnabel A.
High Levels of Natural Radiation and Radon Areas:
Radiation Dose and Health Effects
Proceedings of the 5th International Conference on High Levels of Natural Radiation and Radon Areas held in Munich, Germany on September 4 to 7 2000
Neuherberg, März 2002

BfS-SCHR-25/02
Brix, J.; Matthes, R.; Schulz, O.; Weiss, W.
Forschungsprojekte zur Wirkung elektromagnetischer Felder des Mobilfunks.
Bundesamt für Strahlenschutz
21. und 22. Juni 2001
Salzgitter, Juni 2002

BfS-SCHR-26/02
Bruchertseifer, F.; Pohl, H.
Fachgespräch
Begrenzung der Strahlenexposition als Folge von Störfällen bei kerntechnischen Anlagen und Einrichtungen.
1. und 2. März 2001
Salzgitter, Juni 2002

BfS-SCHR-27/03
Trugenberger-Schnabel, A.; Peter J.;
Kanzliwius, R.; Bernhard, C.; Bergler, I.
Umweltradioaktivität in der Bundesrepublik Deutschland 1998 bis 2001
Daten und Bewertung
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz
Salzgitter, Januar 2003

BfS-SCHR-28/03
Walter, H.
2.Fachgespräch SODAR
19. u. 20. März 2003
Im Auftrag des Bundesministeriums für Umwelt,
Naturschutz und Reaktorsicherheit
Zusammenfassung der Vorträge
Salzgitter, Juni 2003

BfS-SCHR-29/03
Bergler, I.; Bernhard, C.; Gödde, R.; Schmitt-Hannig, A.
Strahlenschutzforschung
- Programmreport 2001 -
Bericht über das vom Bundesamt für Strahlenschutz fachlich und verwaltungsgemäß begleitete Ressortforschungsprogramm Strahlenschutz des Bundesumweltministeriums
Salzgitter, Juni 2003

BfS-SCHR-30/04
Lennartz, H.-A.; Mussel, Ch.; Thieme, M.
Beteiligung der Öffentlichkeit bei der Standortauswahl für die Endlagerung radioaktiver Abfälle
Abschlussbericht
Salzgitter, April 2004

BfS-SCHR-31/04
Weiß, D.; Bönigke, G.; Spoden, E.; Warnecke, E.
Übersicht zu stillgelegten kerntechnischen Anlagen in Deutschland und in Europa – Januar 2004
Salzgitter, September 2004

BfS-SCHR-32/04
Bergler, I.; Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2003
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrativ begleitete Ressortforschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2004

BfS-SCHR-33/05
Hartmann, M.; Beyer, D.; Dalheimer, A.; Hänisch, K.
Ergebnisse der In-vitro-Ringversuche: S-35 in Urin sowie Am-241 und Pu-Isotope in Urin
Workshop zu den In-vitro-Ringversuchen 2001 und 2002 der Leitstelle Inkorporationsüberwachung des BfS am 1. Juli 2003 im Bayerischen Landesamt für Umweltschutz, Kulmbach
Salzgitter, Januar 2005

BfS-SCHR-34/05 (nur als CD vorhanden)
Trugenberger-Schnabel, A.; Peter, J.; Kanzliwius, R.; Bernhard, C.; Bergler, I.
Umweltradioaktivität in der Bundesrepublik Deutschland
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz
Daten und Bewertung für 2002 und 2003
Salzgitter, Juni 2005

BfS-SCHR-35/05 (nur als CD vorhanden)
Bergler, I.; Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2004
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrativ begleitete Ressortforschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, August 2005

BfS-SCHR-36/05 (nur als CD vorhanden)
Steinmetz, M.
200 Jahre solare UV-Strahlung
Geschichte und Perspektiven
Wissenschaftliches Kolloquium
Salzgitter, Oktober 2005

BfS-SCHR-37/05
Facharbeitskreis Probabilistische Sicherheitsanalyse für Kernkraftwerke
Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
Stand: August 2005
Salzgitter, Oktober 2005

BfS-SCHR-38/05
Facharbeitskreis Probabilistische Sicherheitsanalyse für Kernkraftwerke
Daten zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
Stand: August 2005
Salzgitter, Oktober 2005

BfS-SCHR-39/06
Borrmann, F.; Brennecke, P.; Koch, W.; Kugel, K.; Rehs, B.; Steyer. S.; Warnecke. E.
Management of Decommissioning Waste in Germany
Contribution to the IAEA CRP on „Disposal Aspects of Low and Intermediate level Decommissioning Waste“! (T2.40.06)
Stand: August 2006
Salzgitter, Dezember 2006

BfS-SCHR-40/06
Bergler, I.; Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2005
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrative begleitete Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2006

BfS-SCHR-41/07
Schkade, U.-K.; Arnold, D. *); Döring, J.; Hartmann, M.; Wershofen, H.* *)
*) *Physikalisch-Technische Bundesanstalt*
Gammaspektrometrische Bestimmung der spezifischen Aktivitäten natürlicher Radionuklide in Umweltproben
7. Vergleichsanalyse „Boden 2006“
Leitstelle für Fragen der Radioaktivitätsüberwachung bei erhöhter natürlicher Radioaktivität
Berlin, Dezember 2006
Salzgitter, Januar 2007

BfS-SCHR-42/07
Dushe, C.; Ettenhuber, E.; Gehrcke, K.; Kümmel, M.; Schulz, H. *)
*) *IAF-Radioökologie GmbH Dresden*
Ein neues Verfahren zur Ermittlung der Radonexhalation großer Flächen
Salzgitter, Februar 2007

Bisher erschienene BfS-Schriften

BfS-SCHR-43/07
Richtlinie für die physikalische Strahlenschutzkontrolle zur Ermittlung der Körperdosis
Teil 2: Ermittlung der Körperdosis bei innerer Strahlenexposition; Inkorporationsüberwachung
(§§ 40, 41 und 42 Strahlenschutzverordnung)
Rundschreiben vom 12.01.2007 RS II 3 – 15530/1 (GMBl 2007 S. 623)
Salzgitter, September 2007

BfS-SCHR-44/07
Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2006
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrativ begleitete Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2007

BfS-SCHR-45/09
urn:nbn:de:0221-2009011200
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2007
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Januar 2009

BfS-SCHR-46/09
urn:nbn:de:0221-2009082120
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2008
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, November 2009

BfS-SCHR-47/09
urn:nbn:de:0221-2009082154
Die Empfehlungen der Internationalen Strahlenschutzkommission (ICRP) von 2007
ICRP-Veröffentlichung 103, verabschiedet im März 2007
Deutsche Ausgabe
Salzgitter, November 2009

BfS-SCHR-48/10
urn:nbn:de:0221-201009153217
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2009
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, November 2010

BfS-SCHR-49/11
urn:nbn:de:0221-201111236640
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2010
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, November 2011

BfS-SCHR-50/12
urn:nbn:de:0221-2012120510259
Beyermann, M.; Bünger, T.; Guttmann, A.; Schmidt, K.; Wershofen, H.; Winterfeldt, I.; Labahn, A.
Ringversuch zur Bestimmung von Radon-222, Radium-226, Radium-228, Uran-238, Uran-234 und der Gesamt-**α**-Aktivität in Trinkwasser – Ringversuch 4/2012
Salzgitter, Dezember 2012

BfS-SCHR-51/13
urn:nbn:de:0221-2013012210275
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2011
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2012

BfS-SCHR-52/13
urn:nbn:de:0221-2013110811124
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2012
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2013

BfS-SCHR-53/14
urn:nbn:de:0221-2014010911155
Schmitt-Hannig, A.; Peter, J.; Bernhard-Ströl, C.; Trugenberger-Schnabel, A.; Hachenberger, C, Löbke-Reinl, A.; Schulte-Büttner, B.
International Cooperation and Research
Report on International Cooperation and Research Activities at the Federal Office for Radiation Protection
Status 2013
Salzgitter, Januar 2014

BfS-SCHR-54/14
urn:nbn:de:0221-2014081211479
Schmitt-Hannig, A.; Gödde, R.; Löbke-Reinl, A.; Hachenberger, C.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2013
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, September 2014

BfS-SCHR-55/14
urn:nbn:de:0221-2015021712440
*Walter, H.; Gering, F.; Arnold, K.; Gerich, B.; Heinrich,G.; Welte,U. *)*
**) Strahlenschutzkommission*
Simulation potentieller Unfallszenarien für den Notfallschutz in der Umgebung von Kernkraftwerken mit RODOS
Salzgitter, Dezember 2014

BfS-SCHR-56/15
urn:nbn:de:0221-2015052612750
*Brendebach,B. *); Imielski P.*); Kühn, K.; Rehs, B.*
**) Gesellschaft für Anlagen- und Reaktorsicherheit*
Stilllegung kerntechnischer Anlagen in Europa
Stand: Dezember 2014
Salzgitter, Mai 2015

BfS-SCHR-57/15
urn:nbn:de:0221-2015082013351
Schmitt-Hannig, A.; Löbke-Reinl, A.; Peter, J.; Gödde, R.; Hachenberger, C.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2014
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, September 2015

BfS-SCHR-58/16
urn:nbn:de:0221-2016022414011
Arx, Cyrill von; Glaab, Hubert; Grimm, Christian; Martens, Reinhard; Päsler-Sauer, Jürgen; Scheuermann, Walter; Schnadt, Horst; Schumacher, Peter; Torchiani, Silke; Walter, Hartmut; Wilbois, Thomas
Vergleich aktuell eingesetzter Modelle zur Beschreibung der atmosphärischen Ausbreitung radioaktiver Stoffe
Abschlussbericht zum Arbeitspaket AP 5500 der Arbeitsgruppe „Erfahrungsfluss Fukushima“ des Ausschusses „Notfallschutz“ der Strahlenschutzkommission
Salzgitter, Februar 2016

BfS-SCHR-59/16
urn:nbn:de:0221-2016080114068
Schmitt-Hannig, A.; Löbke-Reinl, A.; Peter, J.; Gödde, R.; Hachenberger, C.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2015
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, August 2016

BfS-SCHR-60/16
urn:nbn:de:0221-2016091214084
*Walter, H.; Gering, F.; Arnold, K.; Gerich, B.; Heinrich,G.; Welte,U. *)*
**) Strahlenschutzkommission*
RODOS-based Simulation of Potential Accident Scenarios for Emergency Response Management in the Vicinity of Nuclear Power Plants
Salzgitter, September 2016

| Verantwortung für Mensch und Umwelt |

Kontakt:
Bundesamt für Strahlenschutz
Postfach 10 01 49
38201 Salzgitter
Telefon: + 49 (0)3018 333 0
Telefax: + 49 (0)3018 333 1885
Internet: www.bfs.de
E-Mail: ePost@bfs.de
Gedruckt auf Recyclingpapier aus 100 % Altpapier.

Bundesamt für Strahlenschutz