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Basic Radiological Principles for Decisions on Measures for the Protection of the Population against Incidents involving Releases of Radionuclides

Recommendation by the German Commission on Radiological Protection

Adopted at the 268th meeting of the German Commission on Radiological Protection on 13 and 14 February 2014

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Radiologische Grundlagen für Entscheidungen über Maßnahmen zum Schutz der Bevölkerung bei Ereignissen mit Freisetzungen von Radionukliden

Empfehlung der Strahlenschutzkommission

Introduction to the revised version

The previous version of the "Basic Radiological Principles for Decisions on Measures for the Protection of the Population against Incidents involving Releases of Radionuclides" from 2009 was an editorial revision of a document published under the same name in 1999. During this formal revision, the SSK initiated a detailed review of more recent scientific findings and developments on an international level to determine whether the document's content needs to be revised again. As a result of this proposal, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) commissioned the Federal Office for Radiation Protection (BfS) with performing this investigation and preparing a draft version. Following this preparatory work, in 2009 the BMU commissioned the SSK with performing further investigations and revisions based on the draft version submitted by the BfS. Said investigations and revisions were to include, in particular, the new basic radiation protection recommendations published in 2007 as ICRP 103 by the International Commission on Radiological Protection (ICRP), specific practical guidelines arising from ICRP 103, and any additional international developments in terms of radiological emergency response. This includes various other recommendations from the ICRP containing more detailed suggestions for practical implementation based on the basic ICRP 103 recommendations, the revision coordinated by the International Atomic Energy Agency (IAEA) published in 2011 as an interim version of the Basic Safety Standards for radiation protection and safety of radiation sources. The development of the Council Directive 2013/59/Euratom on radiation protection was also taken into account, although it had only been published in January 2014. The implementation of this directive within German radiation protection law over the coming four years may allow for further development or specification of these Basic Radiological Principles.

The reactor accident in Fukushima, Japan, also provided a reason to analyse current national and international crisis management processes and the associated radiological consequences in more detail. Both of these aspects were taken into account when investigating and revising the Basic Radiological Principles.

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Use of iodine tablets for iodine blockage of the thyroid gland in the event of a nuclear accident, Recommendation by the German Commission on Radiological Protection, February 2011

1 Introduction

1.1 Basis and intended purpose

German nuclear power plants have safety equipment and preplanned measures available to virtually exclude the occurrence of accidents with relevant radiological consequences on the plants' surroundings. Such events can only occur if the various graded safety measures in place fail and the additional measures taken to prevent major damage to the core and to mitigate radiological consequences have proven unsuccessful. For these situations emergency response plans to be implemented in the vicinity of a nuclear power plant need to be prepared.

If, in the event of a nuclear accident, a radionuclide release is imminent, in progress, or has already taken place, or in the case of releases due to other accidents or malicious acts, it may be necessary to introduce emergency response and precautionary radiation protection measures. Both types of measures are covered by the term emergency response and are designed to reduce the level of radiation exposure to humans with the aim of avoiding severe deterministic effects and minimising stochastic effects on the basis of commensurability

The pertinent laws put in place by the individual German states (Länder) form the basis for such emergency response measures. In the event of nuclear accidents, measures shall be planned and implemented based on the "Basic Recommendations for Emergency Preparedness in the Vicinity of Nuclear Installations" (BMU 2008). The Länder implement the Precautionary Radiation Protection Act within the scope of the federal executive administration unless state administrative authorities are already involved (e. g. in large-scale environmental radioactivity monitoring).

Irrespective of actual responsibilities, the established radiation protection findings and national, European and global experiences and recommendations for emergency response form the main basis for planning measures to protect the population against radiation exposure due to accidents or malicious acts in Germany. These "Basic Radiological Principles for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides", hereafter referred to as "Basic Radiological Principles", replace the version adopted in 2008 (SSK 2009a). The Basic Radiological Principles are aimed at the authorities that deal with emergency response measure planning.

The Basic Radiological Principles are based on radiobiological and radioepidemiological knowledge, particularly with regard to dose-risk and dose-response relationships for stochastic and deterministic effects, as well as on the comparison of radiation exposure due to a release with the level and fluctuation range of natural radiation exposure among the population totalled over their lifetime. In order to comply with the principle of commensurability, the gravity of intervening in people's lives as a result of imposing various measures is also taken into account. Reference levels for the residual dose due to a prevailing emergency are introduced and founded as an overriding radiological goal in line with recent concepts put forward by the International Commission on Radiological Protection (ICRP 2007). In general, the reference levels are based on the effective dose to a person following a radiological event (usually during the first year) under realistic circumstances, taking into account protective measures and typical behaviours. Intervention levels like the ones set out in the previous Basic Radiological Principles are used to swiftly implement specific protective measures in the early stages of an imminent release, a release in progress, or a release that has already taken place. When taking the commensurability between the health risks of a radiation exposure and the gravity of intervening in people's lives due to individual protective measures into consideration, quantitative dose levels are specified as intervention levels for each of the early measures, namely "sheltering", "iodine thyroid blocking" and "evacuation" (measure-specific intervention levels). The reference level of the residual dose in the first year is pivotal to decisions regarding subsequent protective measures involving temporary or prolonged relocation. In the event of an incident, other aspects are taken into account along with the defined Basic Radiological Principles in order to decide on measures to protect the population. Such aspects include influencing factors that only become apparent in the event of an incident such as characteristics of the affected area and feasibility of measures, or factors that are hard to quantify such as public reactions or sociopsychological aspects. The reference levels of the residual dose, intervention levels and incident-specific influencing factors set out in the Basic Radiological Principles form the basis for decisions on planning protection measures in a radiological emergency. The Basic Radiological Principles do not cover the specific design and content of the planning process, nor do they cover the accompanying optimisation process.

1.2 Link to international recommendations and regulations

In recent times, radiological emergency response developments and specifications have taken place on an international level and are largely based on the recommendations published in ICRP 103 (ICRP 2007) by the International Commission on Radiation Protection in 2007. These recommendations account for basic developments that have taken place in the field of radiation protection since the previous publication ICRP 60 (ICRP 1991) and include, in particular, the transition from a process-based protection approach based on practices and intervention to an approach based on the given exposure situation. This newly devised concept distinguishes between a planned exposure situation in a regulated area and emergency exposure situations as well as existing exposure situations. The latter two exposure situations are therefore closely related to the “Basic Radiological Principles” covered by this document. This link and key terms introduced and defined by the ICRP are described below.

The exposure situation concepts recently introduced with the publication of ICRP 103 that arise from a radiological emergency – be it during the phase known as an emergency exposure situation or a later phase deemed as being an existing exposure due to the original incident – are described in more detail in other publications, namely ICRP 109 (ICRP 2009a) and ICRP 111 (ICRP 2009b). These publications also investigated them in more detail with a view to real-life implementation. The transition from an emergency to an existing exposure situation based on a decision of the responsible authority may happen at any time during an emergency exposure situation, and may take place at different geographical locations at different times. Existing exposure situations may also be the result of earlier activities such as uranium mining, specific geological conditions or increased exposure conditions due to human activities, but these are not adressed within the current context.

The IAEA’s interim version of its International Basic Safety Standards (IAEA 2011) is based on the basic recommendations of ICRP 103 and the supplementary publications ICRP 109 and ICRP 111. The International Basic Safety Standards specify requirements for real-life implementation based on the ICRP recommendations. In addition to these general safety standards as guidance for every IAEA member state, the Council Directive 2013/59/EURATOM laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation (Euratom 2014) was published and applies to every EU member state. It also uses the same radiological emergency response terms and contains quite analogous requirements.

In order to illustrate and further discuss the link between the Basic Radiological Principles and current international radiological emergency response requirements, the need for preparedness and response to an emergency situation is described here based on ICRP 103, the interim version of the IAEA Basic Safety Standards (IAEA 2011) and Directive 2013/59/Euratom (Euratom 2014):

The competent authorities should make sure that protection strategies for emergency exposure situations are developed in advance as part of emergency preparedness, and that they are justified, optimised and, in the event of an incident, implemented in a timely manner. To this end, appropriate responses to an emergency exposure situation should be planned using postulated events and corresponding scenarios based on risk analyses with the aim of avoiding major deterministic effects and reducing the probability of stochastic effects resulting from public exposure. Key steps in developing a protection strategy include the three items listed below:

– A *reference level of the residual dose* is set which primarily refers to the effective dose and combines contributions from all relevant exposure pathways (inhalation, external radiation, ingestion). A maximum effective dose reference level of 100 mSv can be set for a period of up to one year after major radiological incidents. ICRP 103 suggests a typical band of 20 mSv to 100 mSv for the residual dose to be set for emergency planning in the first year after an incident. Here, the anticipated gravity of radiological consequences is to be taken into consideration when setting a reference level. In terms of the residual dose following public exposure, the number of exposed people and level of individual doses both below and above the reference level should be kept as low as reasonably achievable (ALARA principle) when planning the protection strategy to be developed and optimised.
– The results of the optimised protection strategy based on the reference level of the residual dose should be used to develop generic criteria for specific protective measures and other measures known as the *projected dose* or received dose. General criteria include, in particular, intervention levels for protective measures. If these criteria are expected to be met or exceeded, corresponding protective measures or individual or multiple measures should be implemented.
– Once the protection strategy has been optimised and a series of general criteria for protective measures and other measures have been developed, fixed trigger levels for initiating the various emergency measures of the plan − primarily during the urgent phase of an incident − should be derived in advance. These standard triggers should be expressed in the form of parameters and observable emergency action levels (EALs) or operational intervention levels (OILs). OILs may refer to dose rates, contamination levels on the ground and other surfaces, or activity concentrations in the environment or foodstuffs. Such levels should be made available in advance and can be adapted to changing conditions during a radiological emergency.

In general, each individual protective measure and not only the strategy as a whole should be justifiable, meaning that each protective measure should do more good than harm.

In order to highlight the link between these Basic Radiological Principles and the main requirements set out here regarding planning and implementation of emergency response measures, a number of terms were recently introduced or more clearly defined and are described below:

Protection strategies are to be planned in advance for emergency exposure situations on the basis of risk analyses involving postulated and analysed scenarios. A comprehensive protection strategy aims to optimise the protective measures to be implemented by considering all of the relevant exposure pathways and protection options during the decision-making process. This does not affect the overarching objective of radiological emergency response, i. e. avoiding severe deterministic effects and reducing the probability of stochastic effects.

This clarification includes the introduction or more accurate interpretation of key terms described below:

Residual dose: The residual or projected residual dose is the dose to which a person is expected to be exposed or to which a person is exposed after the implementation of protective measures. Apart from a few special cases where the equivalent dose is the key factor, the residual dose refers to the effective dose within the period of a year. In general, at the time of deciding on the measures to be taken, the residual dose within the considered period of time consists of an already received and a projected dose until the end of the given time period. Typical behaviours of the representative persons (see below) should also be taken into account for residual dose estimates. This applies in particular to the projected residual dose when making decisions regarding longer-term protective measures at a later stage of an incident where the radiological situation has been more accurately assessed by measurements. The reference levels for emergency and existing exposure situations refer to the residual dose as the sum of all exposure pathways, i. e. inhalation, external radiation and ingestion (food consumption). The reference time frame for determining the residual dose in the event of an emergency exposure situation is usually the first year after the incident, unless the period of exposure is limited to a shorter period of time. Once the prevailing radiological situation has been assessed, the residual dose reference level set in advance can be adapted for subsequent protective measures. If, within the first year, the authorities for certain regions recategorise an emergency exposure situation as an existing exposure situation, this will often lead to a lower reference level for the annual residual dose. The setting of the annual residual dose should be the subject of careful consideration which encompasses the current and projected radiological situations, protective measures already taken, and the needs and wishes of the affected population.

Projected dose: The projected dose is the dose to be expected if no protective measures are employed. It is an important factor in deciding on protective measures to be taken and is particularly important during the urgency phase where there is often a lack of reliable information about imminent radioactive releases or releases that have already occurred as well as a lack of information about the feared or prevailing radiological situation. When determining the projected dose, however, typical behaviours of representative persons from within the population may be taken into account. It is important that such assumptions are specified. The reference time period depends on the type of protective measures under consideration. When deciding on measures such as “sheltering” or “early evacuation”, the projected dose is limited to a few days, whereas the decision regarding “temporary or long-term relocation” covers prolonged periods of time.

Averted dose: The dose that could be prevented or averted by the implementation of protective measures, i. e. the difference between the projected dose if protective measures had not been taken and the (projected) residual dose.

Representative person: Calculated or suitably assessed doses in emergency exposure situations or existing exposure situations refer to protection of population groups. “Representative person” was introduced in ICRP 101 (ICRP 2005) and is the equivalent of, and replaces, “average member of the critical group” described in previous ICRP Recommendations. A representative person is an individual representing a population group with similar characteristics regarding exposure conditions, the received doses and the health risks resulting from these. In particular, this includes groups of people whose exposure conditions and characteristics in terms of their received doses and sensitivity to radiation are unfavourable but not extreme. In terms of radiation exposure, the groups of people covered by a representative person are characterised by their physiological characteristics and assumed behaviours. In order to cautiously but not excessively stipulate the characteristics for a representative person using quantified parameters such as dietary habits, ICRP 101 suggests using the 95th percentile. In the case of many influencing factors, this high percentile should refer to the total result of the dose determined for the respective representative person, not to each individual parameter. In emergency and existing exposure situations, in addition to adults and children, pregnant women also need to be considered a "representative person" with regard to the higher levels of sensitivity to radiation during prenatal embryo and fetus development.

Generic criteria for protective measures: Generic criteria for individual or multiple protective measures, particularly for the urgent phase of an emergency situation, should be developed as part of a protection strategy devised for emergency planning. They are based on the projected dose where no protective measures were taken, but may include typical behaviours among the affected population such as time spent indoors, etc. Generic criteria correspond to the intervention levels for certain protective measures described in further detail in these Basic Radiological Principles. Their dose levels as assigned in these Basic Radiological Principles are fully justified from a radiation protection perspective, and are also in line with the principle of commensurability by taking into account all of the circumstances surrounding a major radiological incident such as a nuclear power plant accident. If these protective measures criteria (intervention levels of the Basic Radiological Principles) are exceeded, corresponding protective measures or individual/multiple measures should be implemented.

The reference level of the residual dose set in advance prevails over such intervention levels or implemented intervention levels (see Section 4.3) used in an actual emergency exposure situation. Intervention levels should therefore be seen as key components of an optimised protection strategy to be developed within the scope of emergency planning.

Recategorisation to an existing situation: Protection strategies also need to be developed for the time after an emergency exposure situation is subsequently recategorised as an existing exposure situation by the authorities. Such strategies are often devised and implemented interactively and incrementally over a prolonged period. ICRP (ICRP 2007), IAEA (IAEA 2011) and the Council Directive 2013/59/Euratom (Euratom 2014) stipulate a band of 1 mSv to 20 mSv per year for the residual dose when defining a reference level for an existing exposure situation which has evolved from the possibly time and location dependent transition from an emergency exposure situation. In the course of time a value of around 1 mSv per year should be aimed at. Recategorising an emergency exposure situation as an existing exposure situation is to be seen as a sociopolitical process in which radiation protection is only one of several influencing factors. As concerns radiation protection considerations this refers in particular to a reduction in uncertainties regarding the radiological situation in the affected area as well as the associated radiation exposures and health risks.

1.3 Overview

When systematically mapping the decision-making basic principles and measures, an expedient distinction is made between three accident phases and a number of exposure pathways. This will be dealt with in Section 2 of these Basic Radiological Principles.

Section 3 "Health effects of radiation exposure" is split into two parts: dose terminology and effects of radiation. The first part describes the dose terminology used in the following sections, while the second part covers the effects of radiation relevant to setting reference levels and intervention levels.

Section 4 describes protective measures, i. e. the measures and the concept used to plan them. Here the focus is on major nuclear power plant accidents with widespread and radiologically severe consequences. The overarching reference level of the residual dose in the first year and the dose-related intervention levels for the individual measures are the main content of this section. The reference level and intervention levels for individual protective measures and countermeasures are being justified and described, and the need for implementing a measure from a radiological perspective if a dose reaches the intervention levels is also explained.

Section 5 covers the decision-making process in the event of an incident. Key influencing factors are described which are important when making decisions about initiating protective measures and countermeasures. The decision-making process is described as an iterative process for evaluating influencing factors along with the available methodical and mathematical aids.

Section 6 involves justification of residual dose reference levels and intervention levels in terms of implementing protective measures in case of radiological emergencies caused by other types of events. When compared to major nuclear power plant accidents, anticipated releases of radioactive substances are several orders of magnitude lower, meaning that a far smaller area is subject to any major radiological effects. This does not lead to any fundamental differences in terms of protective measures, but does of course involve gradual differences.

Sections 7 and 8 cover the topic of radiation protection of emergency personnel and certain professional groups.

2 Accident phases and exposure pathways

A nuclear accident can be broken down into phases in order to look at aspects such as the status of the release, the type and urgency of measures, the type and availability of resources, and the relevance of exposure pathways. This is why these Radiological Basic Principles distinguish between the *urgency phase* and the *post-accident phase*, which can in turn be broken down into several subphases. The aims of this classification are to fit the respective required measures into a schedule that is consistent with prior emergency planning and to clearly communicate the conditions that demand the implementation of said measures.

The *urgency phase* consists of a *pre-release phase* and, if applicable, a *release phase*.

The *pre-release phase* starts at the point in time where a nuclear plant operator realises that a major radionuclide release may occur, and ends with the onset of such a release or by bringing the incident under control. The pre-release phase may last for hours or days. The main tasks to be performed during the pre-release phase include initiation of crisis management, informing the public and taking action to protect the public. If deemed necessary and where possible during this phase, precautionary measures should be implemented in the first instance (e. g. “precautionary evacuation”). If “iodine thyroid blocking” may be required, this phase should be used to distribute or have people collect iodine tablets. The state of the plant is vital when it comes to making a decision with regard to source term projection. In spite of the large uncertainties in determining the source term from plant criteria and the uncertainty of predicting the meteorological conditions, dispersion and dose calculations support the decision-making process for precautionary measures.

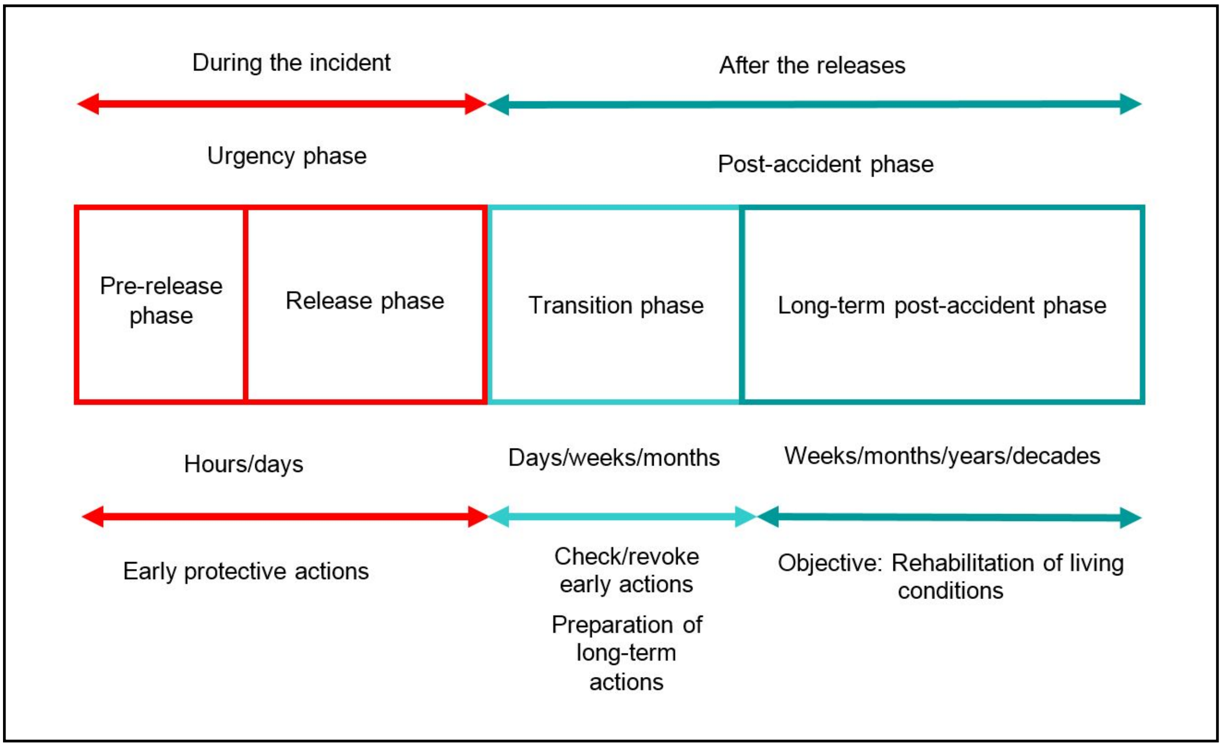

Figure 2.1: The phase model for a nuclear accident1

As part of the urgency phase, the *release phase* follows the pre-release phase and may last for hours, days or even a few weeks. If a "precautionary evacuation" was not or could not be carried out, measures to significantly reduce radiation exposure such as "sheltering" and "iodine thyroid blocking" are urgently required in the dispersion area of the radioactive cloud. Other precautionary measures to protect the public, especially "evacuation" in the immediate vicinity, should be primarily carried out in areas the radioactive cloud could reach within a short space of time. In order to reduce potential radiation exposure, an "evacuation" may also be of use when the radioactive cloud passes by. This measure will be dealt with in more detail later on. The release phase ends once dispersion and deposition have finished and the plant is under control such that no further major releases can be expected to occur. This phase is characterised by the transition from an initial projection of the radiological situation to ascertainment of the actual level of environmental contamination by evaluating the accumulating results of various measurements performed by stationary or mobile measuring facilities. Unpredictable or unforeseeable temporal changes to the release or atmospheric dispersion conditions may give rise to the need for changes or supplements to protective measures that have already been initiated. During this phase, special attention must be paid to the exposure pathways directly associated with the passing radioactive cloud and in order to protect emergency services – who are not generally occupationally exposed persons – from radiation.

The *post-accident phase* consists of the *transition phase* and *long-term post-accident phase*.

The *transition phase* covers the period where radiation from the cloud, direct inhalation of radioactive substances and deposition have ended or are at least of no further relevance. This may take several days, weeks or even months. Characteristically, contamination values for foodstuffs, drinking water, surfaces, soils, plants and bodies of water can be determined during the transition phase by performing a sufficient number of reliable measurements in order to gain a clear picture of the radiological situation. At the end of the transition phase, the required data, aids and time should be available in order to facilitate decisions on incident-based justification and optimisation of measures to protect the public during the long-term post-accident phase, and to justify and optimise radiation exposure to emergency and support personnel and certain groups of the population. When deciding on changes to measures agreed on during the previous phases, or on additional measures such as “relocation”, it should be noted that due to the delay only part of the total dose accrued without implementing the measures in question can be avoided (averted dose). Also, decisions need to be taken with regard to (gradually) revoking measures.

Depending on the level of contamination, the *long-term post-accident phase* may last for several years or even decades in certain areas. It is characterised by prolonged contamination of the areas and the risk of chronic human exposure at a low yet constant level. This phase, which can be categorised as an existing exposure situation within the sense of ICRP 103 and ICRP 111, gives rise to the question of how personal lives, society and the economy can be shaped and organised in affected areas. To this end, the affected population and businesses should be provided with practical information on implementing radiation protection (radiation protection culture). The still required optimisation of potential measures must be carried out with general public consensus that incorporates all relevant aspects, including those of no radiological importance. People who spent time or are still situated in more highly contaminated areas should be investigated to systematically determine the received effective dose and possibly thyroid dose due to external and internal exposure. The associated health risks should be conveyed in an easy-to-understand manner, and medical follow-up care should be organised for members of the general public in more highly contaminated areas in order to monitor the progress of their health.

During the post-accident phase, the transition phase and long-term post-accident phase may occur at different times and in different places from one another.

Both during the transition and the long-term post-accident phase, the authorities may recategorise a situation as an existing exposure situation.

Various pathways may lead to human exposure in the event of radioactive substances being released into the environment as a result of a nuclear accident. The main exposure pathways are as follows:

External radiation exposure caused by

- Radiation from the passing radioactive cloud
- Radiation due to contamination of the ground
- Radiation due to contamination of the skin and clothing
- Radiation due to contamination of objects and solid or liquid waste
- Direct radiation from the plant

Internal radiation exposure caused by

- Inhalation of airborne radioactive substances from the radioactive cloud
- Ingestion of contaminated foodstuffs. (Contamination of foodstuffs may come about for a number of reasons, e. g. direct contamination of leafy vegetables, root uptake by plants on contaminated ground, fodder crops containing radioactivity from contamination and root uptake, contaminated livestock and wild animals, and subsequent contamination of milk and meat. These mechanisms are described in the Catalogue of Countermeasures (SSK 2007).
- Inhalation of resuspended radionuclides previously deposited on the ground, objects and clothing

– Unintentional ingestion of contaminated earth (e. g. by children playing on contaminated ground) or oral ingestion of contamination from the skin or clothing
– Ingestion of contaminated drinking water

The observation period plays a key part when assessing the importance of exposure pathways. If no measures are taken, ingestion of contaminated foodstuffs may be the most important exposure pathway when observed over a prolonged period. Otherwise the main exposure pathways in the event of nuclear power plant accidents are inhalation of airborne radioactive substances following releases into the atmosphere and radiation from contaminated ground. Radiation due to ground contamination may have increased importance in the event of wet deposition.

With other radiological events, the same exposure pathways are theoretically possible, but the contributions of each exposure pathway may differ vastly from one another.

In certain cases, e. g. with the release of uranium hexafluoride, chemical toxicity due to hydrofluoric acid outweighs radiotoxicity.

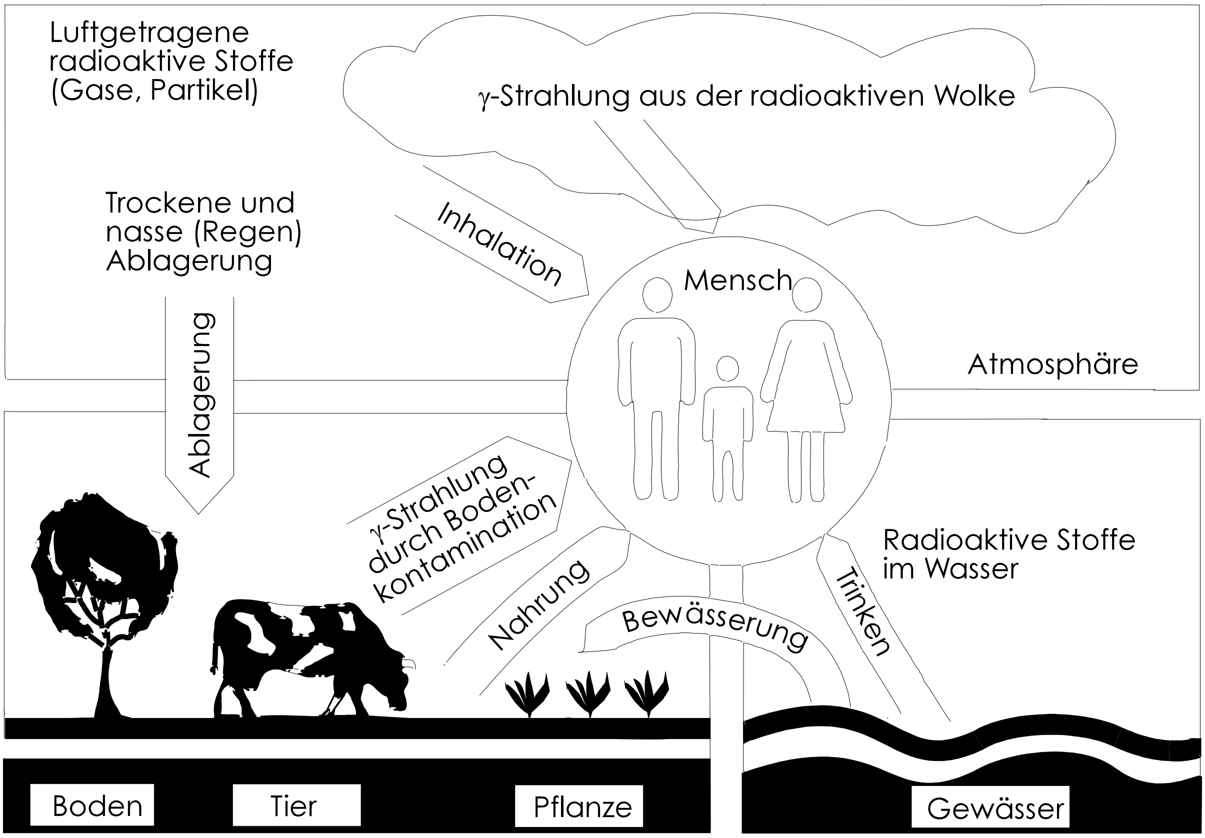

Figure 2.1: Schematic diagram of selected exposure pathways that can lead to external or internal human radiation exposure (from ISM-RLP 1986).

3 Health effects of radiation exposure

In medical radiation protection, radiation damage is split into two groups based on their fundamentally different origins. This distinction is essentially based on the clear presence or the absence of evidence for a dose threshold. Accordingly, so-called deterministic radiation effects for which a dose threshold arises and no visible biological effect is anticipated if this threshold is not reached fall into one group while so-called stochastic radiation effects for which no threshold is assumed for radiation protection purposes fall into the other group.

In order to simplify the use of these dose quantities below, the description of the various radiation effects shall be preceded by a summary of the dose quantities and units.

3.1 Dose terminology

Biological effects caused by radiation are attributable to the deposition of energy in a cell. The extent of this energy deposition is expressed in terms of the absorbed dose, i. e. the energy input into a volume element divided by the mass of said volume. The unit used to measure energy is the joule (J), while the unit used to measure mass is a kilogramme. Radiation protection generally focuses on the absorbed doses averaged for a biological tissue or organ. The unit used to measure the absorbed dose is the gray (Gy) where 1 Gy = 1 J/kg.

The biological impact depends both on the energy and type of radiation. Alpha particles and neutrons have a different biological impact to X-radiation, beta radiation or gamma radiation. In order to provide a unit for the stochastic radiation effects of all types of radiation, the absorbed dose is multiplied by a dimensionless weighting factor that is defined for each type of radiation and characterises its biological effectiveness in relation to that of photons. The mean absorbed dose in a tissue or organ multiplied by the radiation weighting factor is called the equivalent dose (in future this will probably be known as the organ dose equivalent ???). The frequently used term "dose equivalent" (in future this will probably be known as the measured dose equivalent) refers to a somewhat different concept where the absorbed dose is multiplied by a dimensionless quality factor determined by linear energy transfer (LET). The equivalent dose and dose equivalent are generally very similar from a numerical perspective, and are measured in sievert (Sv) where 1 Sv = 1 J/kg. The millisievert (mSv) is also frequently used in practice where 1 Sv = 1.000 mSv. The equivalent dose and dose equivalent should not be used within the context of deterministic effects as the conversion factors with which the absorbed dose is multiplied are far lower than those for stochastic effects. The biological impact of ionising radiation also differs between the various tissues and organs in the body. These differences should be taken into account in particular with regard to stochastic effects as the probability of radiation-induced cancer differs between the various tissues and organs in the body. Dimensionless tissue weighting factors were therefore introduced and are defined in ICRP 103 (ICRP 2007) in order to express the differing dose sensitivity. The sum of these weighted organ doses is known as the effective dose and is also expressed in sievert (Sv) and millisievert (mSv).

The effective dose is generally used in emergency response as the initiation of measures is foreseen for doses where only stochastic rather than deterministic effects may occur. Nevertheless, higher doses may potentially occur near an affected nuclear power.Under such conditions the effective dose model is inadequate as it applies to stochastic effects.

The time during which ionising radiation impacts biological tissue, i. e. whether a 1 Gy dose is reached in one hour or one year, is relevant to the biological impact, particularly in terms of deterministic effects. The quotient of the dose and its accompanying time interval is known as the dose rate and is often measured in Gy/h or Sv/h. In emergency response, the time interval to which a dose level refers is known as the dose integration time.

Ionising radiation affects the body in different ways. The skin provides almost no protection against gamma radiation, X-radiation and neutrons. Body tissues absorb these kinds of ionizing radiation to varying extents. Whole body exposure is the effect of ionising radiation on the whole body, while partial body exposure is the effect of ionising radiation on parts of the body.

If radionuclides are deposited on uncovered skin, this is known as skin contamination. Particularly in this case, beta rays such as from strontium-90 and iodine-131 decay with a relatively low penetration depth lead to the absorption of energy by the skin, thus largely creating a skin dose.

Alpha particles have such a low penetration depth that contamination does generally not lead to a relevant dose in the radiation-sensitive regeneration layer of the skin because the particles are not able to penetrate that deeply. This layer of the skin can only be reached by very high-energy Alpha rays.

There are various ways in which radioactive substances can be taken up by the body, and the resulting dose is known as the incorporation dose. The following distinctions are made:

- Airborne radioactive substances can be inhaled via the mouth and nose, and can lead to an inhalation dose.
- Radionuclides such as iodine-131 and caesium-137 can be consumed along with contaminated foodstuffs and are known as the ingestion dose.

If radioactive substances enter the body, they will be partially eliminated (breathing, urine, faeces) and, depending on the chemical composition, stored in organs for varying periods of time. The time that radioactive substances remain within the body is characterised by the biological half-life, which is the time after which half of the radionuclides have been eliminated from the body. This may differ vastly from the physical half-life of a radionuclide resulting from radioactive decay. Merging these two half-life periods results in the effective half-life. Once the radionuclides have entered the body, they will create a dose known as the dose commitment. Depending on whether the dose is an effective dose or equivalent dose, this is known as a committed effective dose or committed equivalent dose. Both types of dose commitment are determined for an integration period of 50 years for adults and 70 years for children.

3.2 Effects of radiation: Stochastic effects

Every biological impact due to ionising radiation occurs as a result of statistically distributed energy deposits in cells within the human body. This leads to ionisation in various cell molecules which can cause them to mutate. Major adverse consequences can result when the genetic information (DNA) is affected. These mutations may result in the following:

- Death or functional inactivation of the cell (either immediately or for a prolonged period), or
- molecular changes to the cell (especially a permanent DNA mutation).

Each cell is able to repair mutations, particularly those impacting the DNA, which is why most molecular mutations have no consequence. Molecular repair may, however, go wrong or not take place, meaning that the cell remains mutated, divides and then passes on this mutated genetic information. A chain of events that has not yet been fully clarified can cause a mutated cell to form a group of cells (clone) that then grow exponentially and may lead to the development of cancer or leukaemia. This phenomenon is also known as somatic effects.

If the molecular mutation occurs in a germ cell, the defect can be passed on to offspring. This phenomenon is also known as genetic effects.

Radiation protection assumes that there is no dose threshold for such effects due to molecular mutations. However, the likelihood of occurrence at low doses (up to tens of millisievert) is so low that current methods are not able to prove detrimental health effects. Any such detrimental effects will only become apparent following a latency period spanning a number of years or decades. An increase in radiation dose increases the probability of a potential disease, which is why the curve starts at zero with a linear rise in the lowest and mean doses.

In this form, the biological effects of radiation are known as stochastic effects.

It is not easy to quantify stochastic effects as the current state of knowledge does not allow us to determine whether cancer or leukaemia develops due to ionising radiation or for some other reason. Therefore, epidemiological investigations are performed among larger populations exposed to radiation (mainly survivors of the Hiroshima and Nagasaki atomic bombs). The aim of this is to determine the number of people suffering from cancer and leukaemia (incidence) as a result of exposure and to compare this number with the number of people suffering from cancer and leukaemia without having been subjected to radiation. The quotient of both numbers can then be put in relation to the dose of a previous radiation exposure. The risk of radiation as the probability of occurrence due to receiving a dose can be expressed in a mathematical-statistical manner. Changes to available data can lead to an alteration of the calculated risk. The ageing process of the investigated population will, for example, increase the number of illness cases. New findings in terms of estimating radiation dose will also affect the calculated radiation risk.

When it comes to stochastic effects, emergency response aims to keep the probability of additional cancer and leukaemia cases caused by public exposure to a minimum by taking appropriate measures. When doing so, care must be taken to avoid certain groups of the population from being unacceptably disadvantaged. When planning evacuations, the risk that comes with evacuating sick elderly people should, for example, be weighed up against the risk due to radiation exposure.

3.3 Effects of radiation: Deterministic effects

Deterministic effects require a higher energy deposition. There are threshold doses that vary depending on the tissue, organ and individual in question. The level of damage above the threshold dose depends on the actual dose, whereas the probability of occurrence is 100%.

The reason for threshold doses above which clinically manifest damage may occur is that a lot of cells have to be killed or functionally inactivated. Radiation doses below the respective threshold doses may cause individual cells to be killed or inactivated, but this does not generally involve enough cells to have an impact on the tissue, organ or organism as a whole.

With an absorbed dose of up to around 100 mGy, no human tissue or organ will display any clinically relevant functional limitations (ICRP 2007). To a large extent, this also applies to developing human embryos (exception: killing of cells at the single-cell stage due to the effect of densely ionising radiation).

If the absorbed dose exceeds 100 mGy, the following organs will display initial functional limitations:

- Male gonads (testes): A single dose of around 0.15 Gy leads to temporary sterility. Permanent sterility will only occur after exposures exceeding 3 Gy. This may be observed, for example, within the scope of acute radiation syndrome following whole body irradiation. Here, it should be noted that fractionated exposures are somewhat more effective than single exposures of the same total dose. (Dörr and Herrmann 2005)
- Female gonads (ovaries): Temporary disorders are to be expected from a dose of around 0.5 Gy, but doses of 1 to 2 Gy can lead to permanent cessation of ovulation among more than half of women. Doses of 5 Gy or more lead to complete sterility among all women.

Women over 40 exhibit more pronounced effects than women under 40. (Dörr and Herrmann 2005)

- Bone marrow reacts with a measurable disruption to blood cell formation from acute irradiation at doses of 0.5 Gy and above. This dysfunction may return to normal without leading to haematopoietic syndrome which is expected to occur following brief whole body exposures of 1 Gy or more.
- With a single dose of more than about 0.5 Gy, the lens of the eye exhibits a statistically significant increase in the occurrence of clouding after a latency period of several years or decades which can limit the person's eyesight. Clouding of the lens (a cataract) could be a stochastic effect (Ainsbury et al. 2009). In order to account for new findings, the ICRP (Kleinman 2012) recommended an annual occupational dose limit of 20 mSv. Further research is required to be able to account for gender-related and age-related risk.
- Animal testing and data from a few human investigations (Hiroshima and Nagasaki victims, radiation therapy patients) indicate a dose threshold of 100 mGy (ICRP 2003; ICRP 2007) for the induction of anomalies in developing human embryos.
- The threshold doses for other tissues and organs are above 1 Gy (ICRP 2005).

It should be noted that the threshold doses for deterministic effects described above are generally levels which, in 99% of exposed people, do not lead to any effects (ICRP 2007). Personal sensitivity to radiation, in particular, may cause deviations in individual cases, though.

The main aim of emergency response is to avoid severe deterministic effects by taking action to limit individual doses to levels below the threshold doses for these effects. The ICRP defines severe deterministic as irreversible injuries that are directly attributable to radiation exposure and highly detrimental to the quality of life, e. g. pulmonary disease or premature death.

Severe deterministic effects are often linked to acute radiation syndrome. Typical clinical syndromes can be categorised based on dose and exposed parts of the body (whole or partial body exposure). Examples of deterministic effects in the form of clinical symptoms are described below. Please refer to SSK volume 32 (SSK 2006a) for more information.

Acute radiation syndrome

Acute radiation syndrome occurs after brief whole body irradiation or after irradiating large parts of the body with doses of 1 Gy or more. There are four clinical manifestations that can be assigned to differing doses (Fliedner 1992, Fliedner et al. 2001, SSK 2006b). A reduction in the number of peripheral lymphocytes is initially observed, which is due to the rapid apoptosis of these cells. The extent of the reduction in the number of lymphocytes is a valuable indicator for estimating the exposure dose range.

The haematopoietic form is largely triggered by damage to the blood-forming bone marrow in a dose range of approximately 1 Gy to 10 Gy and starts with somewhat uncharacteristic early symptoms: nausea, vomiting and general physical weakness. A full blood count will exhibit characteristic changes resulting from the dose. The extent of the haematopoietic dysfunction and therapy used to treat it are the deciding factors as to whether or not the irradiated victim will survive.

The gastrointestinal form is indicated by additional damage to the intestinal mucosa which occurs due to exposure somewhere between 5 Gy and 10 Gy. Early symptoms (nausea, vomiting, general physical weakness, constant early erythema) are also uncharacteristic here, but they commence earlier and in a more pronounced manner. Both the mucosa of the small intestine and the haematopoietic process are severely damaged, which in turn leads to intestinal infections and constant diarrhoea. With such symptoms following a dose of up to about 20 Gy, intensive therapy may help the patient to survive.

The (muco)cutaneous form covers all pathological reactions of the skin and cutaneous mucosa to exposure with ionising radiation. Within the first 7 days of exposure, early skin lesions such as erythema, oedema, blisters and desquamation only occur after receiving very high doses (local >100 Gy), but may develop at a later time after having received far lower doses. A number of reaction phases can be distinguished: vascular reaction with erythematous and oedematic changes (early and main erythema). A phase involving dry flaking skin is followed by moist desquamation which ends in ulcerations or even severe necrosis. Higher doses lead to shorter latency periods. The formation of blisters may indicate acute necrosis in the event of extremely high doses.

The following radiation effects may be observed with the adnexa (skin appendages): drying of the skin, cessation of perspiration, loss of hair (dose >3 Gy, irreversible when approx. >10 Gy).

The cerebrovascular form also leads to damage to the central nervous system following a dose of more than 20 Gy. This is the most severe form of acute radiation syndrome where early symptoms such as nausea, vomiting and loss of appetite occur immediately without any latency period. If the dose increases, fatigue will also occur which, if enhanced, indicates a deterioration of the cerebrovascular syndrome. Diarrhoea also indicates central damage during this phase. Vascular dysfunctions give rise to headaches, hypotension and confusion. Sensomotoric dysfunctions manifest as ataxia and loss of consciousness. The acute occurrence of nausea can be observed during every phase of the cerebrovascular syndrome, although the severity of nausea declines the higher the dose. The emetic reflex is suppressed after receiving high doses (>10 Gy) and superimposed by general suppression of the central nervous system. Cardiovascular disorders result in myocardial damage and shock which will cause death within a matter of a few hours or days.

These are the main clinical symptoms, but other organs are also always affected, such as the salivary glands, the thyroid gland and, in particular, the lungs which can cause major complications due to them developing radiation-induced pneumonitis.

On top of that, radiation-induced multiple organ interactions and failures may occur (Fliedner et al. 2001). Depending on the dose, an interaction between irradiated organs may well occur, as may an interaction between irradiated and non-irradiated organs and organ systems. These interactions are the main influencers of the entire organism's reaction to radiation and may lead to radiation-induced multiple organ failure with high whole body doses that exceed about 4.5 Gy.

3.4 Impact of irradiation during prenatal development

This radiation effect also has to be observed because a fetus is highly sensitive to ionising radiation. Here, deterministic and stochastic effects are reviewed together. However, some of the following effects have only been observed during animal experiments:

- Death of unborn or newborn babies,
- physical deformities,
- growth disorders (this may in particular affect cerebral development and lead to functional disorders (e. g. cerebral dysfunctions)),
- fertility defects (sterility),
- malignant diseases (cancer or leukaemia) and

– heritable defects (only observed in animal experiments).

These effects depend on the prenatal development phase during which exposure occurs:

– During the preimplantation period, i. e. when the egg is fertilised but not implanted in the endometrium, the embryo is generally expected to die as a result of unrepaired radiation damage. This period lasts from the time of conception through to about the tenth day. The woman is not, however, aware of the fact that she is pregnant at that time.
– During the period in which the organs are formed, i. e. from the tenth day to the seventh week following conception, the fetus may die or exhibit severe deformities. A lot of women are also unaware that they are pregnant at that time.
– During the subsequent fetal period up to birth (approx. the 39th week), growth disorders may occur which particularly affect cerebral development in weeks 8 to 15 and, to a lesser extent, in weeks 16 to 25. This can lead to mental retardation following birth.

Thresholds exist for almost all of these effects below which the effect cannot be detected. However, the thresholds vary depending on the radiation effect and prenatal stage in which exposure takes place.

ICRP 90 (ICRP 2003) and ICRP 103 (ICRP 2007) stipulate 100 mGy as the minimum threshold for deterministic effects for the fetus. This value is primarily an estimate based on animal testing that involved brief whole body exposure. Threshold doses of 300 mGy (absorbed dose for the brain) are assumed for severe mental retardation in the 8th to 25th weeks of pregnancy (ICRP 2007).

Epidemiological investigations confirm the occurrence of postnatal malignant diseases (cancer or leukaemia) following irradiation of the fetus in the uterus. Today, it can be assumed that a fetus is more sensitive to radiation during prenatal development than adults. In terms of stochastic effects, a fetus dose of 10 mSv is reported to cause an increase of around 40% (SSK 2008b) in the likelihood of spontaneous leukaemia and cancer rates among babies and small children (0 to 4 years). The additional risk following in utero exposure is somewhat lower for older children and young people (Muirhead and Kneale 1989). The additional cancer risk following in utero exposure is 2 to 3 times higher than that for exposure of adults (Preston et al. 2008).

4 Measures to protect the population

4.1 Measures and their effectiveness

Emergency response and precautionary protective measures to protect the population are decided on by the respective command centres based on knowledge of the radiological incident, state of the plant, and following an assessment of the radiological situation and current situation in the affected areas. An overview of the most important early measures suited to avoiding or at least mitigating radiation exposure is shown in Table 4.1 together with the exposure pathways that can be affected by such measures.

“Sheltering” means that the public is told to stay indoors in protective rooms for the recommended period of time. The protective rooms to be chosen for staying indoors should be selected such that they reduce the inhalation of radionuclides and external radiation through shielding to the maximum possible extent. The level of shielding against external radiation can vary by several orders of magnitude (see Table 4.2) as it depends heavily on the type of building, the materials used in its construction, and surrounding buildings.

When employing “sheltering”, it is recommended to close all windows and doors and shut off any ventilation systems. This helps to reduce the exchange of indoor air with outside air and keep activity concentrations to a minimum while a radioactive cloud passes by. The remaining air exchange rate leads to a delayed increase in indoor concentrations and a certain averaging over temporally variable activity concentrations in the outside air. Deposition processes on indoor surfaces such as flooring lead to a decrease in indoor air concentrations.

For planning purposes, it can be assumed that “sheltering” provides a shielding factor of 3, both for exposure due to external doses and for inhalation of radioactive substances (Brenk, 1987, Thatcher, 2003).

“Sheltering” not only serves to protect against radiation exposure, it also makes it easier for the authorities to keep the public informed via radio, TV or the internet.

The term “evacuation” describes the swiftly organised relocation of the public—which may be supported by emergency and support personnel—from an endangered area and the transport to a safe location where accommodation, food and drink can be provided during the urgency phase (pre-release and release phase). The term “evacuation” does not stipulate whether or not the public is able to return home within a short space of time. If carried out in good time, this measure provides the most effective protection as it helps to avoid external and internal radiation exposure via the exposure pathways set out above in Table 4.1. If the place of residence is too highly contaminated, an evacuation may lead to the need for relocation.

“Relocation” is used to describe the transfer of the residents of an area to a different area during a post-accident phase. It only serves to prevent external irradiation from the ground and inhalation of resuspended radioactive substances. Resuspension of deposited radioactive substances is pronounced dependent upon time. Inhalation of airborne radioactive substances following resuspension only makes a minor contribution in terms of human exposure and declines over time for the scenarios under consideration. Generally, “relocation” is only initiated once extensive measurements are available. The implementation and duration of relocation may be of a temporary or long-term nature.

“Temporary relocation” is intended for a limited period of time, meaning that the people affected by this measure are permitted to return to their homes at a later stage. Decontamination measures in urban and rural areas may reduce the time period during which temporary relocation is enforced. The infrastructure and all manufacturing facilities and utilities within the affected area can continue to be used once the measure has been completed. This helps to reduce the level of social and economic impact when compared with long-term relocation.

Table 4.1: Measures and the exposure pathways they can influence

Measures	**Exposure pathways which can be affected by the measures**
Early measures	
Sheltering	External exposure and inhalation
Evacuation	External exposure and inhalation
Iodine thyroid blocking	Inhalation of radioactive iodine
Precautionary recommendation to avoid recently harvested foodstuffs and animal feed	Ingestion of contaminated foodstuffs
If “sheltering” and “precautionary evacuation” are recommended, the following measures are also recommended:	
Access restrictions	External exposure and inhalation
Personal decontamination	External exposure due to radionuclides deposited on the skin, in the hair and on clothing
Radiation measurements to determine the radiological situation and as part of medical screening processes	External and internal exposure
Later measures	
Intervention in the supply of foodstuffs and animal feed	Ingestion of contaminated foodstuffs[1]
Temporary and/or long-term relocation	External exposure due to deposited radionuclides and inhalation through resuspension
Decontamination of inhabited areas (roads, real estate, premises, objects, etc.)	External exposure due to deposited radionuclides and incorporation
Measures to reduce the presence of radionuclides in foodstuffs and animal feed	Ingestion of contaminated foodstuffs[1]

1 Foodstuffs also include drinking water.

Table 4.2: Shielding factors for external exposure in residential areas (Jacobi et al. 1989, Jacob 1998, Meckbach & Jacob 1988)

<table>
<tr><th rowspan="2">Location</th><th colspan="2">Shielding factors for external exposure in residential areas</th></tr>
<tr><th>From the radioactive cloud[b)]</th><th>Shortly after deposition</th></tr>
<tr><td>Outdoors</td><td></td><td></td></tr>
<tr><td>– Surroundings with trees</td><td>1.0 - 1.4</td><td>0.6[c)] - 2.0</td></tr>
<tr><td>– Urban surroundings with neighbouring buildings but no trees</td><td>1.2 - 3.3</td><td>3.3 - 10</td></tr>
<tr><td>Indoors [a)]</td><td></td><td></td></tr>
<tr><td>– Prefabricated houses</td><td rowspan="2">1.2 - 10</td><td>1.2 - 2.5</td></tr>
<tr><td>– Semi-detached and terraced houses</td><td>3.3 - 50</td></tr>
<tr><td>– Blocks of flats and houses</td><td>10 - 200</td><td>25 - 1,000</td></tr>
<tr><td>In cellars [a)]</td><td></td><td></td></tr>
<tr><td>– With windows above ground level</td><td rowspan="2">10 - 1,000</td><td>20 - 100</td></tr>
<tr><td>– Without windows, semi-detached house</td><td>330 - 5,000</td></tr>
<tr><td>– With light shafts and windows, in blocks of houses</td><td>500 - 10,000</td><td>1,000 - 20,000</td></tr>
</table>

a) Shielding factors are calculated excluding potential indoor contamination. If flooring, walls and ceilings in buildings exhibit around 1% of the level of outdoor contamination, the actual shielding factor is reduced to a maximum of 100, meaning that it is far lower for well-shielded rooms than the factor stated in the table.

b) Estimate based on homogenous atmospheric radioactivity distribution.

c) Shielding factors lower than one are the result of increased dry deposition on trees.

"Long-term relocation" over an undefined period of time is required if the dose rate in the affected area is high and only declines slowly due to contamination involving long-lived radionuclides. Consequently, the affected population has to be relocated to other areas and integrated into local societal and economic circles. This not only requires the building of new properties complete with their own infrastructure and the creating of new jobs but it also demands the handling of social problems due to affected people suffering at least a temporary loss of income as well as mental stress.

Timely "iodine thyroid blocking" helps to protect the thyroid gland against radioactive iodine entering the human body. This is important for population groups who inhale radioactive iodine when a radioactive cloud passes by. The absorption of radioactive iodine by consuming foodstuffs can be reduced and/or eliminated by supplying foodstuffs with no or low levels of contamination.

Interfering with the food supply of the public distinguishes between issuing the public with a precautionary warning about consuming recently harvested foodstuffs and fresh milk during the urgency phase of an incident on the one hand, and intervention in supplying foodstuffs and animal feed based on maximum permitted levels of contamination in the later phase after radionuclide deposition has taken place on the other hand. The precautionary warning is issued to the public at the latest with the onset of a dangerous release or unclarified radiological scenario when near to the place of emission. When further afield, a precautionary warning is issued to the public if there are significant radionuclide concentrations in the air or following deposition on the ground. The maximum permitted radioactivity levels in foodstuffs and animal feed in the event of a nuclear accident or other radiological emergency are stipulated in EC and Euratom directives (Euratom 1987, Euratom 1989a, Euratom 1989b, Euratom 1990, EC 2008) and described in detail in the Catalogue of Countermeasures (SSK 2007).

In the event of a nuclear accident, the most important way of achieving the maximum possible protective effect is to provide the public with accurate and comprehensive information.

4.2 Principles to be applied when planning and employing measures in the event of an incident

If a serious accident occurs at a nuclear power plant where a core meltdown and failure of containment barriers lead to a major release of the core's radionuclides, it may be necessary to impose extensive protective measures upon the population. Potential early protective measures include, in particular, "sheltering", "iodine thyroid blocking", "evacuation", issuing a "warning about consuming recently harvested foodstuffs and feedstuffs", and, after assessing the prevailing radiological situation and any other affected areas, the initiation of a "temporary or permanent relocation".

When deriving criteria under which conditions such protective measures should be employed, not only the health risks associated with radiation exposure should be taken into account, but also the gravity of intervention and its accompanying impairments on the affected persons. Limitation of the health risk associated with radiation exposure is based on the following two objectives:

- Avoidance of severe deterministic effects by taking action to limit individual doses to levels below the threshold doses for these effects.
- Suitable measures should help to reduce and limit the risk of stochastic effects to individuals.

The principle of avoiding severe deterministic effects and major risks of stochastic effects forms the basis for emergency response planning in the vicinity of nuclear power plants. Such importance is attached to severe deterministic effects that measures to avoid them are always necessary and must be employed.

With stochastic effects, the probability of an exposed person developing a malignant disease (cancer or leukaemia) depends on the dose level. As a result, when deciding on protective measure strategies, in each individual case considerations should be made to carefully weigh up the gravity of interfering with the lives of individuals against the dose level that would occur without taking any action. This corresponds with the principle of justification stipulated by the ICRP (ICRP 2007). The measure should do more good than harm. This principle of commensurability leads to measures that only infringe upon the lives of individuals (e. g. "sheltering" and intervention in trading in foodstuffs and animal feed) to a lesser extent being performed in the event of low doses as opposed to measures that have a major impact on people's lifestyles (e. g. "evacuation" and "relocation").

In line with this principle, these Basic Radiological Principles and previous versions thereof elaborate in more detail the bases for making decisions on deriving reference levels and intervention levels. To this end, the more recent basic radiation protection recommendations published by the ICRP in 2007 as ICRP 103 were taken into account. The distinction in exposure situations between planned, emergency and existing exposure situations forms a key conceptional framework of the ICRP recommendations. The principles of justification and optimisation apply to all of these exposure situations. Existing exposure situations include, in particular, conditions that may develop in the long term from an emergency exposure situation once the emitting source is under control but for which measures are still required to protect humans and the environment. Key elements of these current ICRP recommendations were adopted by the IAEA (IAEA 2011) and the Council Directive 2013/59/Euratom (Euratom 2014) that also applies to Germany. This has already been covered in the "Link to international recommendations and regulations" section which described the reference levels and intervention levels central to radiological emergency response and dealt with here in more detail.

4.3 Concept for setting reference levels and intervention levels

When setting an overarching reference level for the residual dose in the first year after a major nuclear power plant accident and intervention levels for taking action, the dose limits set out in the German Radiation Protection Ordinance (BMU 2001) cannot be applied because they were derived for an exposure situation that can be planned and controlled as per the principles of justification and optimisation. Apart from that, the German Radiation Protection Ordinance primarily governs activities that are continually carried out (e. g. operating nuclear power plants, radionuclide applications in medicine, research and development).

When setting and justifying reference levels and intervention levels, the following decision-making bases are taken into consideration:

- The dose-risk relationships for stochastic effects,
- the dose-response relationships for deterministic effects,
- the gravity of interfering with people's lives as a result of taking various measures,
- the principle of commensurability and
- the level and fluctuation range of natural radiation exposure.

The reference level of the residual dose refers to the effective dose people receive during the first year via all relevant exposure pathways − inhalation, external irradiation and ingestion – under realistic assumptions and conditions as a result of radionuclides released due to an accident. Intervention levels for individual measures refer, on the other hand, to a projected dose which could be reached or exceeded among the affected population given certain behaviours if a certain measure is not carried out. When deciding whether to implement "evacuation", for example, these Radiological Basic Principles apply the dose that would occur if a person were to permanently remain outdoors in the observed location without any shelter for a certain period of time (7 days in this case). When estimating this expected dose the exposure pathways controlled by the measure are taken into account. For an "evacuation", these are inhalation of released radionuclides and external radiation due to radionuclides in the passing radioactive cloud, and following dry or wet deposition on the ground and other surfaces.

When justifying and setting the overarching reference level for the residual (effective) dose in the first year after a major accident at a nuclear power plant, it should be noted that this is a temporally and spatially singular event and the additional radiation exposure it causes should be limited to tolerable and proportionate levels. This requires a weighing up of the gravity of interfering with the lives of the public, which also includes social and economic aspects, against the health risk associated with the additional radiation exposure caused by the accident. The level and fluctuation range of the natural radiation exposure to which everyone in Germany is exposed are an important aid during the consideration process. The average effective lifetime dose for a reference period of 70 years is around 150 mSv, and fluctuates between about 100 mSv and 400 mSv. By setting a residual dose reference level of 100 mSv in the first year one remains well within this lifetime dose fluctuation range of around 300 mSv attributable to natural causes. It should be noted that the principle of optimisation for emergency and existing exposure situations also exists below the accompanying residual dose reference levels. This value of 100 mSv in the first year equates to the maximum of the 20 mSv to 100 mSv band (cf. also Section 1.2) proposed by the ICRP (ICRP 2007) for the reference level of the residual (effective) dose. In doing this, the ICRP emphasizes that considerations are required when selecting and setting the residual dose reference level. Such considerations should include the severity of the radiological incident, any required emergency response measures, and the health risk resulting from exposure. The ICRP clearly states that in the event of major incidents such as nuclear power plant accidents, an effective dose of 100 mSv, which a person would receive in the first year after such an incident, can be seen as a tolerable and proportionate health risk. Radiation from natural sources to which a person is exposed during their lifetime is also considered to be a suitable benchmark. No link has been observed between natural radiation exposure and health effects in Germany, the exception here being a special case involving increased exposure of the lung from radon in buildings.

An effective dose reference level of 100 mSv for the residual dose in the first year refers to the entire population, including children, young people, and pregnant women. The probability of developing cancer or leukaemia over the course of a lifetime due to such a dose is still low (approx. 2% according to (ICRP 2007)) when compared to other causes under normal circumstances (cancer incidence rate of approx. 50% according to (RKI 2012)). This also applies when taking into consideration in utero and childhood radiation sensitivity which is two to three times higher than that for other population groups. Here, this reference level is to be seen as an upper initial value for planning and swiftly initiating protective measures to limit stochastic radiation effects. Of course, the principle of optimisation for protecting against radiation also applies to levels below the reference level of the residual dose.

This reference level of 100 mSv in the first year is used in these Radiological Basic Principles to plan early protective measures and, in the event of an incident, to employ protective measures during the early phases (urgency and transition phases) of a major accident at a nuclear power plant. Once the prevailing radiological situation has been ascertained in more detail, the reference level can be adjusted to the prevailing conditions, i. e. reduced accordingly with suitable protective measures to be employed during the subsequent later phase to reduce exposure levels due to an accident. With very serious radiological situations, this may also involve temporary or long-term relocation for certain areas. Once major releases due to an accident at a nuclear power plant have been completed and the spatial and projected temporal development of the radiological situation has been assessed, the transition to an existing exposure situation and, with it, the establishment of a new annual reference level within a range of 1 mSv to 20 mSv can take place, at least for certain areas, as set out in the ICRP recommendations (ICRP 2007). This reference level, which can only be set by taking essential circumstances into account, also plays a key part in deciding whether to revoke previously enforced access bans or relocation from highly contaminated areas. Further adjustments of this annual residual dose reference level should also be sought over time in the event of an existing exposure situation with the aim to reduce it to an annual level in the range of 1 mSv.

Following a major accident at a nuclear power plant, the reference level of 100 mSv for the residual effective dose in the first year is a derived radiological protection goal to specify the overarching objective of sufficiently limiting the probability of occurrence of stochastic effects by initiating protective measures. The ALARA principle also applies to exposures below this reference level. Specific protective measures are planned and carried out in order to achieve this protection goal by reducing residual doses to values where the reference level is largely not exceeded and where received doses, including those below the reference level, are kept as low as possible in the given circumstances. This includes, in particular, weighing up the level of anticipated individual doses with or without the protective measures in questions, and the gravity these intervention measures would have on the population. The reference level of the residual dose supersedes the intervention levels for the various protective measures discussed and justified below.

Intervention levels are dose levels that people would or could receive given certain exposure scenarios, and act as radiological trigger levels for the respective protective measure. Intervention levels are planning levels, while applied intervention levels are levels used in the event of an incident. Deviations from the intervention levels are only acceptable if, in the event of an incident, there are good reasons for doing so. One such good reason would be if the assignment of measures and areas defined in this way happen to conflict with major influencing factors.

Applied intervention levels above the intervention levels may be justified if implementation of a measure is associated with major disadvantages or if the averted dose is low.

Applied intervention levels below the intervention levels are not required purely for radiological reasons as the ALARA principle also applies to exposures below the intervention levels.

In any case, the public must be informed about the radiation risk by providing suitable benchmarks and comparison data.

Incidents with an international impact require coordination between the affected countries in order to avoid the application of differing intervention levels in the various different regions.

The collective dose is not suitable as a basis for making decisions regarding protective measures.

4.4 Intervention levels for employing protective measures

The intervention levels for protective measures described here refer to the effective dose or, in the case of the thyroid gland, the equivalent dose in order to limit stochastic effects. The sievert is used to express these levels. The respective intervention levels are dose levels that are well below the dose thresholds for deterministic effects. The intervention levels designated here for early measures refer to the following measures:

- Sheltering,
- iodine thyroid blocking and
- evacuation.

These intervention levels have in common that they all refer to an exposure resulting from released radioactive substances passing by due to atmospheric dispersion and, at the same time, exposure due to airborne and deposited radionuclides. These intervention levels should be compatible with the overarching reference level of the residual dose, i. e. compliance within the first year should not be questioned a priori. All of these intervention levels refer to an early period of 7 days after an accident has occurred. The decision as to whether and which protective measures are to be employed may therefore depending on the circumstances be taken during the pre-release phase, i. e. before a major release has taken place. In general, the dose determined for the decision-making process is based on information and data from the affected plant as well as projections regarding the source term and prevailing dispersion conditions, and possibly also initial measurements. At the same time the chosen reference period of 7 days, is compatible with the period of time relevant to severe deterministic effects which can be reliably avoided if an “evacuation” is carried out in good time.

The dose levels determined as a basis for deciding whether or not to carry out the measure in question are potential doses, i. e. not real doses, and may only occur under specified assumptions. Such assumptions include people permanently staying outdoors for the reference period of 7 days. Selecting a reference period of 7 days for projecting potential dose levels while assuming people permanently stay outdoors constitutes an extremely cautious assumption for deciding on protective measures. This assumption is justified by personal behaviours that give rise to very different protection levels, are hard to record and may also vary depending on the season (summer, winter). Another reason is the simplification of the dose projection. In contrast, the overarching reference level of the residual effective dose in the first year refers to a real or realistic projected dose that arises when taking the implemented protective measures and typical public behaviour into account. In general, the protective measures used on the basis of intervention levels and the reference level of the residual dose are considered parts of an overall strategy to protect the population in the event of radiological emergencies.

Other measures, i. e. temporary and long-term relocation, which are expected to occur once the prevailing radiological situation has been assessed and not initiated during the early phase of an accident at a nuclear power plant, and interventions that involve supplying the population with food and drink, are described below.

4.4.1 Sheltering

Staying indoors in protective rooms away from doors and windows or in cellars for short periods of time represents a minor intervention in the lives of the population when compared to “evacuation” and “relocation”. Relevant exposure pathways (see Table 4.1) involve external irradiation from the radioactive cloud, from radionuclides deposited on surfaces, and internal irradiation following inhalation. A period of 7 days is set as the dose integration period, for radionuclides incorporated during this period the dose commitment is applied. When setting this period of time, it is assumed that a measure such as “sheltering” cannot be sustained for a longer period of time. In this case, the majority of the population would probably leave the affected area without being instructed to do so.

This protective measure can be combined with “iodine thyroid blocking”. Should the radiological situation aggravate, it is also conceivable that the initial request concerning “sheltering” could develop into an “evacuation”.

> **Intervention level for “sheltering”:**
>
> **10 mSv as the total of the effective dose due to external exposure within a period of 7 days and the committed effective dose from radionuclides inhaled during the same period.**

In view of the extremely seldom occurrence of a major nuclear power plant accident, the instruction as regards temporarily “sheltering” does not represent a disproportionate intervention in the lives of the affected population. The intervention level of 10 mSv is a trigger level which, if reached or exceeded, should trigger “sheltering”. Given that this is a potential dose level pertaining to people staying outdoors for 7 days without protection, the actual effective dose threshold is in fact much lower.

4.4.2 Iodine thyroid blocking

The timely “iodine thyroid blocking” helps to protect the thyroid gland against radioactive iodine which entered into the body. Radioactive iodine can be incorporated by the human body via the respiratory system (inhalation) as well as by consuming contaminated foodstuffs (ingestion). Without performing any protective measures in the event of a nuclear power plant accident, the ingestion dose due to consuming local produce during the vegetation period may be much higher than the inhalation dose. When deciding on “iodine thyroid blocking”, it should be noted that in order to avoid or efficiently reduce radioactive iodine ingestion, the “warning the public about consuming local produce recently harvested from contaminated areas” and the “introduction and monitoring of maximum permitted levels for foodstuffs” should be planned in advance and put into effect.

The “iodine thyroid blocking” represents a minor intervention in the lives of the public. When setting the intervention level, however, potential side effects should be taken into consideration. After weighing up the pros and cons, an intervention level of 50 mSv thyroid dose was considered appropriate for children and young people under the age of 18 as well as pregnant women, and a level of 250 mSv for people aged 18 to 45 (SSK 2011). The annex provides further details regarding the tablet type and dosage.

People over the age of 45 are not advised to take iodine tablets as the risk of side effects is greater than the level of protection against potential effects. This age group is sufficiently protected by “sheltering”, the intervention in trading in foodstuffs and animal feed, and “evacuation”, all of which apply to every age group.

Intervention level for “iodine thyroid blocking”:

50 mSv thyroid dose (committed equivalent dose for children and young people under the age of 18 as well as pregnant women, and 250 mSv for people aged 18 to 45 for radioactive iodine inhaled within a period of 7 days.

4.4.3 Evacuation

An “evacuation” represents a major intervention in the lives of the public. As with the early measures “sheltering” and “iodine thyroid blocking”, the intervention level for this measure refers to the potential dose a person would receive if permanently staying outdoors for a period of 7 days. Relevant exposure pathways (see Table 4.1) involve external irradiation from the radioactive cloud, radionuclides deposited on surfaces, and internal irradiation following inhalation. This integration time also represents a conservative assessment of the contributions to the short-term dose, which is of relevance to deterministic effects.

Due to the gravity of interfering with people’s lives, an intervention level of 100 mSv is considered an appropriate effective dose. This puts it at a similar level to that of natural radiation exposure over a lifetime and makes it compatible with the overarching residual effective dose reference level of 100 mSv for the first year. This can be seen in the following example: If the intervention level of 10 mSv for “sheltering” is exceeded, the higher “evacuation” intervention level of 100 mSv may still not quite be reached, meaning that it will not be initiated. When employing “sheltering”, a reduction by a factor of 3 is specified in Section 4.4.1 as a conservative protection factor for planning purposes, both for external radiation resulting from a passing radioactive cloud and associated deposition of radionuclides, and for inhalation inside a building. By this cautiously selected protection factor, an exposure inside a building would be lower than permanently staying outdoors. In the specified example, the received effective dose of around 30 mSv is still far below the reference level of 100 mSv, meaning that additional subsequent measures could be carried out to prevent this level from being reached in the first year[1].

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[1] To this end, the Federal Office for Radiation Protection (BfS) has already conducted a number of consequence analyses for a very serious nuclear power plant accident rated as a level 7 accident on the International Nuclear Event Scale (INES). These analyses showed that in areas which were not evacuated because the intervention level of 100 mSv was not exceeded, the reference level for the residual effective dose in the 1st year can be complied with by taking other protective actions – “sheltering” and “iodine thyroid blocking” – into account. Relocation within a realistic period of time may be required for limited areas.

Intervention level for "evacuation":

100 mSv as the total of the effective dose due to external exposure within a period of 7 days and the committed effective dose due to radionuclides inhaled within the same period.

4.4.4 Combining early protective measures

In the event of a serious accident at a nuclear power plant, considerable uncertainties arise regarding the time at which major releases from the plant into the atmosphere start to occur, the projection for subsequent releases, and the level and composition of released radionuclides. All of these parameters largely depend on how effective the plant's own protection measures are and to what extent available accident management measures can reduce releases or influence their progress.

The criteria used for the time and areas in which the early emergency response measures

– sheltering
– iodine thyroid blocking and
– evacuation

are employed are the dose projections based on impending, already occurred and anticipated releases of radioactive substances from the plant where the accident occurred. These projected doses represent expected dose levels for the effective dose or thyroid dose via inhalation and external radiation with the same assumptions (permanently staying outdoors for 7 days) that are applied for the respective intervention levels. Due simply to the prognostic uncertainties in terms of quantity, nuclide composition and temporal distribution of released radioactive substances (source term) and the variability of atmospheric dispersion conditions and associated dry or wet (rain) depositions, the employed protective measures should be precautionary to a justified extent. This applies in particular to the immediate vicinity of the plant. Increasing distances from the plant require higher levels of technical and human resources in order to take action. This also increases the importance of commensurability between the level of potential radiation exposure and the negative impacts of the respective protective measure.

"Sheltering" can be relatively quickly implemented and then enforced for a limited period of time. Problems may well be encountered if this measure is to be taken for prolonged periods, e. g. more than 1 or 2 days.

"Iodine thyroid blocking" requires advance distribution or swift supply of the necessary tablets if an incident occurs. The public will be instructed to take iodine tablets if there is the threat of a release from the plant or if a release is already in progress. Increasing distances from the plant in the dispersal direction of the radioactive cloud provide some time until the cloud passes by. A high level of protection (over 90% dose reduction) will be achieved if iodine tablets are taken (up to 12 hours) before the radioactive cloud passes by. If the tablets are not taken until radioactive iodine has entered the body, the level of protection provided by the tablets diminishes quickly with the time delay of intake. Both measures should be combined, i. e. "sheltering" and timely distribution of iodine tablets along with instructions on taking them at the right time.

Depending on the anticipated or projected level and temporal development of releases from the plant, "sheltering" may be implemented among people in areas that are not in the direct vicinity of the affected plant but 5 or more kilometres away as they may still be heavily affected in the event of a release due to the present or projected atmospheric dispersion conditions. As already mentioned, this measure should be combined with a timely "iodine thyroid blocking".

“Sheltering” helps to reduce external exposure due to direct radiation from the radioactive cloud and to radionuclides deposited from the cloud, as well as from inhalation of respirable particles that manage to enter buildings (cf. Table 4.2). Timely “iodine thyroid blocking” helps to drastically reduce the thyroid dose caused by inhalation of radioactive iodine.

Depending on further developments at the nuclear power plant and foreseeable releases or releases that are already in progress, it may be necessary to employ an “evacuation” in areas where “sheltering” was initially implemented. This would be the case if the intervention level for an “evacuation” is exceeded due to release projections for the plant, the impact this may have on the areas in question and/or current or past releases. In this case, the level of protection accorded by “sheltering” is no longer sufficient, meaning that timely “evacuation” of the public from the endangered area to a prospectively safe or minimally affected area should be arranged and carried out.

Under these conditions it is not possible to avoid in all cases that during evacuation measures released radionuclides pass by in the air due to the prevailing dispersion conditions and are being deposited in dry or wet form. This means that evacuees may at times be exposed to a higher level of radiation than they would have been by “sheltering”. If iodine tablets were taken in accordance with the dose recommendations, the evacuees' thyroid glands will be protected against intake of iodine isotopes from any passing radioactive cloud during evacuation and the short space of time spent outdoors. Evacuation would help to prevent further exposure via external radiation and inhalation, but considerations should always be made on the basis of available information about expected conditions at the nuclear power plant that has suffered an accident as well as knowledge of the projected radiological situation in the area to be evacuated. Controlling the timing and organisational evacuation aspects can help to keep radiation exposure levels relatively low. Here, exposure due to prolonged “sheltering” with due consideration of the level of protection this measure provides is to be weighed against the temporarily higher level of exposure received during evacuation, primarily due to airborne activity in the event of a passing radioactive cloud. From a radiological perspective, the civil protection authorities take the averted dose to be the benchmark for alternative courses of action to be considered.

4.4.5 Temporary and long-term relocation

An informed decision regarding the “temporary relocation” and “long-term relocation” can only be taken once the radiological situation caused by the accident at the nuclear power plant has been ascertained. This is largely determined by the level and spatial distribution of contamination by dry or wet (rain) deposited radionuclides and their exposure-critical characteristics such as half-life, emitted (e. g. penetrating) radiation, radiation dose following incorporation (dose coefficient), behaviour in the biosphere, etc. Relevant radionuclides here include a range of iodine isotopes with a relatively short half-life consisting of days, as well as the two Cs isotopes Cs 134 ($T_{1/2}$ = 2.1 a) and Cs 137 ($T_{1/2}$ = 30 a). External radiation generated by gamma-emitting radionuclides that is effective for longer periods of time is essential to public exposure. In contrast to external exposure, the inhalation dose resulting from resuspension of deposited radionuclides is so low that it can be disregarded.

In areas evacuated at an earlier stage, this short-term measure may ultimately lead to “temporary or long-term relocation”. There are no set intervention levels for these measures. Once the prevailing radiological situation has been assessed, there is no real urgency to make an informed decision based on such longer duration measures as the accumulated external doses from gamma radiation over prolonged periods are most important to this decision. The ingestion pathway does not need to be taken into account as it can be assumed that there are sufficient uncontaminated or only slightly contaminated foodstuffs available.

In such cases, the reference level of the residual effective dose in the first year after an accident is a suitable benchmark. When making a decision about the measure in question, the projected effective dose via all exposure pathways within this period is ascertained and compared to the reference level. Residual dose assessments in the first year should be as realistic as possible and include the impact that implemented protective measures and typical public behaviours would have on the assessments.

The table below (Table 4.3) shows the intervention levels in terms of trigger levels for early measures. These intervention levels and the residual dose reference level of 100 mSv together represent compatible concepts and quantities:

Table 4.*1*: Intervention levels for "sheltering", "iodine thyroid blocking" and "evacuation"

Measure	Intervention levels		
	Organ dose (thyroid gland)	**Effective dose**	**Integration times and exposure pathways**
Sheltering		**10 mSv**	External exposure and committed effective dose due to inhaled radionuclides as a result of permanently staying outdoors for a period of **7 days**
Iodine thyroid blocking	**50 mSv** Children and young people up to the age of 18 and pregnant women **250 mSv** People aged 18 to 45		Committed equivalent dose due to inhaled radioactive iodine as a result of permanently staying outdoors for a period of **7 days**
Evacuation		**100 mSv**	External exposure and committed effective dose due to inhaled radionuclides as a result of permanently staying outdoors for a period of **7 days**

If, in the event of prolonged releases, radioactive clouds pass by for more than 7 days in certain areas, the dose received to date should be included when making a decision on measures based on a projected dose for the next 7 days. The received dose should be estimated using realistic assumptions.

4.4.6 Intervention in the supply of foodstuffs and animal feed

Intervention in public supply distinguishes between issuing the public with a (precautionary) warning about consuming recently harvested foodstuffs and fresh milk on the one hand, and intervention in supplying foodstuffs and animal feed based on maximum permitted levels of contamination on the other hand. The precautionary warning is issued to the public near to the place of emission at the latest with the onset of a dangerous release or unclarified radiological scenario. When further afield, a precautionary warning is issued to the public if there are significant radionuclide concentrations in the air. The maximum permitted radioactivity levels in foodstuffs and animal feed in the event of a nuclear accident or other radiological emergency are stipulated in EC and Euratom directives (Euratom 1987, Euratom 1989a, Euratom 1989b, Euratom 1990, EC 2008) and described in detail in the Catalogue of Countermeasures (SSK 2007).

4.5 Operational intervention levels

Operational intervention levels (OILs) are applied during a release or if a release has taken place. However, the doses to be ascertained in order to make decisions pertaining to measures, such as the effective dose in 7 days, can usually only be calculated and not directly measured. This is why the set intervention levels have to be attributed to measurable quantities which allow decisions to be made about taking action. Such levels are known as operational intervention levels (OILs).

Suitable measurands include:

- local dose rate
- (time-integrated) airborne activity concentration
- surface contamination on the ground, objects and skin and
- specific activity, e. g. in foodstuffs and drinking water, in surface waters, in animal feed and soils.

In order to be able to convert the measurement results for the above measurands into doses, additional assumptions generally have to be made, such as past and future developments and exposure time for the local dose rate. In general, determination of the operational intervention levels is based on the following requirements:

- A measurement procedure is specified to determine the derived quantity.
- Model assumptions provide a link between the derived quantity and dose that reflects the exposure conditions.
- In order to ensure compliance with the principle of limiting individual doses, the characteristics of highly sensitive groups of people within the sense of the already introduced representative person and the characteristics of dominating exposure pathways have to be included in the models.

As is the case with intervention levels, operational intervention levels are based on certain measures. The fact that the link between the measurand and dose may be specific to certain measures also plays a part in this.

Operational intervention levels can be specified for a number of contaminated environmental materials, exposure pathways and radionuclides. In general, this is limited to operational intervention levels that are important in terms of radiation exposure to large groups of the public and which can be sufficiently and easily measured. These levels therefore need to be provided in advance as a basis for making decisions. A comprehensive collection of operational interventional levels is available in the Catalogue of Countermeasures (SSK 2007).

5 Decision-making process in the event of an incident

In order to assess the necessity of protective measures and countermeasures, the intervention levels described in Section 4.4 are used. The isodose lines defined on the basis of the intervention levels are used to determine areas in which protective measures and countermeasures are required.

However, during the urgency phase (pre-release and release phases), it can be assumed that dose estimates contain a number of uncertainties due to a lack of knowledge and information. Nevertheless, the command centre is to discuss the question of ordering precautionary measures and the areas affected by said measures by taking account of information provided by the plant and qualified institutions.

Provided there is enough time to do so, statements from authority and institutional expert advisors should be heard and weighed up against one another in order to decide on implementing protective measures and countermeasures. The result of this process is to decide when and where emergency response and precautionary radiation protection measures should be initiated. If measures have already been carried out, a decision should then be taken as to whether additional measures are required or whether individual measures can be revoked.

In the early phase of a major imminent release, a major release in progress or a major release that has taken place, protective measures for the public will be of a precautionary nature. This decision involves all currently available knowledge about the course of events up to that time as well as additional projections regarding radioactive releases and their atmospheric dispersion and deposition in the surrounding area. Increasing levels of information about the developing or prevailing radiological situation will lead to implemented measures being continued, modified, extended or revoked. Decisions regarding post-accident phase measures in particular are closely related to the residual effective dose reference level during the first year after an accident has occurred. As already described in Section 4.3, once measurements have been performed, the residual effective dose reference level in the first year can be adapted, possibly in connection with an officially declared transition from an emergency exposure situation to an existing exposure situation. This transition may exhibit differences in terms of timing and area, particularly with larger, more heavily affected areas and associated variations of the prevailing contamination situation. The applicable residual dose reference level and intervention levels for early measures are the parameters used for deciding whether to revoke or modify protective measures agreed on in advance. When taking decisions during the post-accident phase, revoking measures, and in the event of an officially declared transition from an emergency exposure situation to an existing exposure situation, it is recommended to include the affected people and other stakeholders in such decisions.

5.1 Influencing factors

All relevant influencing factors are assessed and weighed up in order to identify a strategy involving measures which, by taking the given parameters into account, provides the best-possible level of public protection. The disadvantages of the envisaged measures also need to be accounted for. Expert advisors are particularly important here as their expertise allows them to provide qualitative and quantitative information regarding the relevant influencing factors. On the other hand, the importance of influencing factors depends on the time after the release as well as the location in question. Below is a list of the main influencing factors which does not take their order of priority into account:

- The potential dose to an individual:
  Avoidance of severe deterministic effects and reduction of the probability of stochastic effects
- The effectiveness and feasibility of measures:
  These include, in particular, feasibility aspects (availability of technical aids or administrative/human resources; the state of the infrastructure, traffic conditions, etc.),

specific infrastructural features (special facilities such as public utilities, airfields, retirement homes, hospitals, schools, prisons, etc.), the time at which measures are initiated as well as their timing and level of protection, the time until the radioactive cloud arrives, the level of averted doses and detrimental health effects and risks. In each case, infants, (small) children and young people should be united with a legal guardian and/or person they know and trust.

- Negative impact of measures:
  Radiation exposure to the emergency services, risk to the public (e. g. moving seriously ill people), health, economic and social consequences of carrying out measures
- Subjective influencing factors:
  Situation-related estimates and assessments by people involved in the decision-making process, such as acceptance by the public, equal treatment of the public, flexibility with regard to future decisions, sociopsychological aspects and political aspects
- Inclusion of uncertainties:
  Inaccuracies in estimating the meteorological or radiological situation (weather, source term, etc.)
- Planning requirements:
  Mapping of specific areas determined by isodose lines on the emergency response planning areas

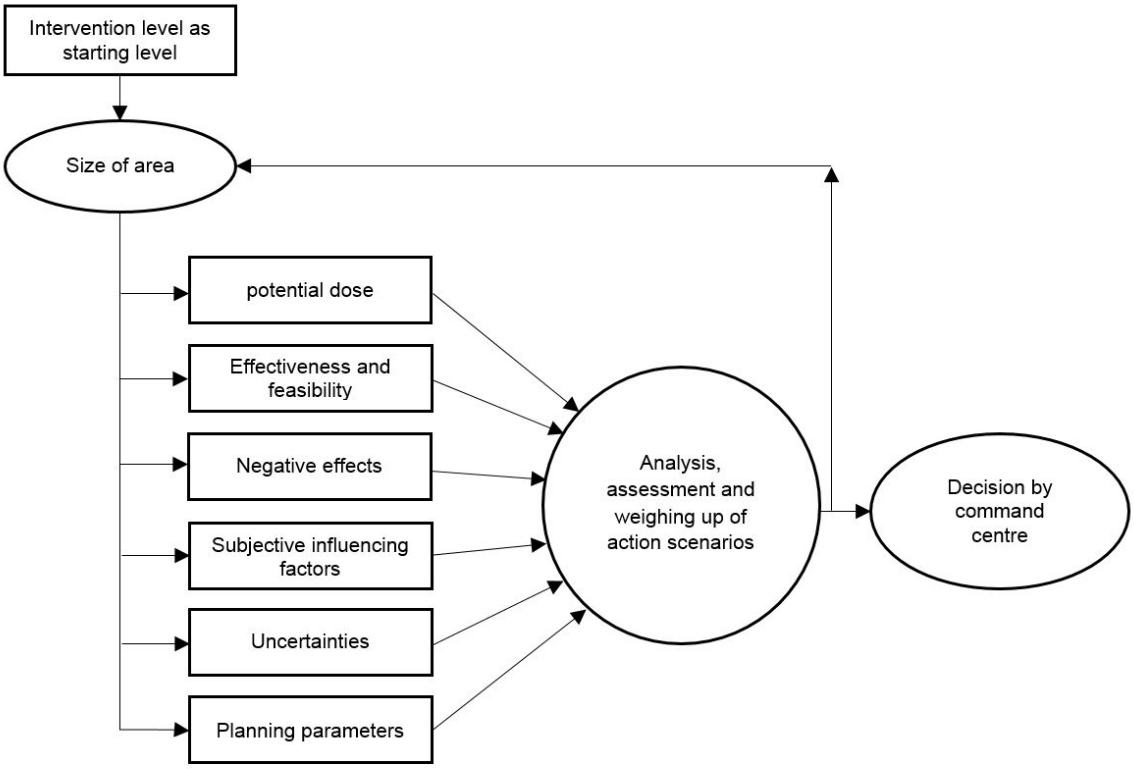

Figure 5.1: Influencing factors and decision-making as an iterative process

5.2 Decision-making process

In reality, it may be necessary to weigh up the various measure strategies against one another. Spatial and temporal variation of measures can, however, rapidly lead to a number of alternative measures. In such cases, the actual decision-making process involves taking these alternative measures and implementing, a largely iterative process to identify the best-suited timing and area in which measures should be carried out individually or in combination with one another (see Figure 5.1).

The appraisal and weighing-up process is at times intuitive and therefore sensitive in terms of availability of reliable information pertaining to individual influencing factors and relevance attached thereto by decision-makers. The extent to which influencing factors are taken into consideration depends on the amount of time available for the decision-making process on the one hand, and the level of specialist support available on the other hand. Objective influencing factors may therefore be taken into consideration by a lesser extent when deciding on emergency response measures if a decision has to be taken very quickly, if relevant specialist arguments are not presented, or if these aspects have not been covered during emergency exercises..

5.3 Methodical aids

From a scientific and technical perspective, a number of aids are available to support command centres in the described circumstances, including:

– PC-based or manual methods where tables, nomograms and algorithms can be used to estimate radiological parameters (Guidance for radiation protection supervisors in the commanding staff during nuclear emergencies (SSK 2002); Catalogue of Countermeasures (SSK 2007) primarily for taking precautionary radiation protection decisions).

– PC-based decision support systems help to create informed knowledge bases at various information processing levels which can then be used as a basis for making decisions. (KFÜ, RODOS, IMIS).

Decision support systems for emergency response measures (KFÜ, IMIS, RODOS, ELAN) cover the distance range for which emergency response measures may be required. These systems have, among other things, access to plant-specific emission and environmental data from a local monitoring network. Data from specific monitoring facilities or mobile task groups can also be processed. The circumstances may provide for a collaboration and/or coordination with the civil protection authorities of neighbouring countries.

Decision support systems for precautionary radiation protection measures (IMIS, RODOS, ELAN) cover an entire country right up to its borders. These systems automatically assess and evaluate all of the data from a national network of local dose rate measuring stations. In addition, in the event of radioactive contamination, prognostic calculations and other data regarding nuclide-specific contaminations of water, the ground and foodstuffs provided by specific measuring facilities or mobile task groups are fed into these systems.

6 Other radiological emergency situations following a major release of radioactive substances

Accidents at nuclear power plants involving major releases (level 6 or 7 on the IAEA's INES scale) have a special status in terms of the size of the areas in which emergency protective measures may be required. Other accidents involving nuclear fuel cycle plants operated in Germany, accidents involving radioactive substances or maliciously caused releases involving dispersion of radioactive substances with significant radiological relevance are expected to see release quantities several times lower. Accordingly, the areas in which people are at risk of higher exposure levels are much smaller. It is also possible to exclude high release quantities of radioactive iodine isotope which may occur in the event of an accident involving a core meltdown at a nuclear power plant. Other radionuclides may, however, dominate a release, e. g. if radioactive sources are added to a so-called improvised explosive device (IED), also referred to as Radiological Dispersal Device (RDD) or "dirty bomb".

The following measures should be considered as early emergency response for areas heavily affected by the releases described here:

- Sheltering,
- evacuation,
- warning against consuming foodstuffs freshly harvested and
- other conduct and behaviour advice.

Such incidents affecting much smaller areas than those from a major nuclear power plant accident may also involve significant radiation exposures, particularly from inhalation and external radiation of the general public and crisis management teams, meaning that severe deterministic effects and stochastic effects cannot be ruled out a priori. Here, effective doses in unfavourable exposure conditions without protective actions may reach levels of 100 mSv or more.

Contrary to expectations for major nuclear power plant accidents, some of these release scenarios do not have any early warning times to allow for notification of the civil protection authorities and a warning to be issued to the public. As a result, protective actions can only be taken following what is often a sudden release with a radioactive cloud passing by immediately afterwards. The basis for actions is to assess the prevailing radiological situation as soon as possible. The situation is largely determined by the level and spatial extent of resulting contamination in the surrounding area. This basis and other findings related to the release can then be used to clarify the question of potential exposure to people outdoors who were in the dispersal direction of the radioactive cloud at the time of the release. Under unfavourable circumstances, airborne radioactive particulates may result in significant radiation exposure from the inhalation of radioactive dust with respirable particle sizes and from external contamination of the skin and clothing due to dry or wet deposition. Exposed people should therefore be registered as soon as possible and subjected to contamination testing and a dose estimate.

In such case, the overarching radiological protection goal in terms of limiting the probability of stochastic effects (occurrence of cancer or leukaemia) is the reference level of the residual dose, the determination of which should include the impact of protective measures and typical public behaviours. In this case, too, the protective measures employed should do more good than harm and are thus subject to the principle of commensurability. This also does not change anything in terms of the argumentation regarding the setting of a residual dose reference level of 100 mSv within the first year after a rare incident by comparing it with the level of natural radiation exposure in Germany. It should again be pointed out that the ALARA principle still applies when carrying out protective measures and countermeasures to combat a prevailing radiological situation with the ALARA principle requiring optimisation of radiation protection below the residual dose reference level as well. Once the prevailing radiological situation has been assessed, it is to be expected that for releases being several orders of magnitude lower than that of a major accident at a nuclear power plant and due to the correspondingly smaller extension of more affected and contaminated areas a lower value for the reference level of the residual dose could be adopted as a benchmark for protective measures. This may also be linked to an officially declared transition from an emergency exposure situation to an existing exposure situation.

In such cases, the decision regarding “sheltering” and “evacuation” will also be taken based upon dose-related intervention levels as a projected dose to people in the affected area. Here, the 10 mSv effective dose for “sheltering” and the 100 mSv effective dose for “evacuation” set out in Table 4.3 continue to apply and refer to the potential dose a person could receive if they permanently remain outdoors for a period of 7 days.

The main aims of radiological emergency response measures are to swiftly avert hazards from already received exposure to individuals and anticipated exposures resulting from the prevailing contamination situation. A combination of available information related to released radioactive substances, measurements performed to assess the prevailing contamination situation, and other available diagnostic tools are used as a basis for making decisions on protective measures.

Preplanning is already in place for a number of measures that can be used to achieve these protection goals and they would be carried out depending on where the accident has taken place. Such plans include the following:

- Demarcation of areas where high levels of contamination are anticipated or proven by taking measurements, possibly also restricting access and recording and checking people for contamination when they leave such areas. The focus here is on people requiring medical care as a result of the incident who are found to have a high level of external contamination or are suspected of having been highly exposed.
- Provision of infrastructure and personnel needed to take measurements in order to assess the prevailing radiological situation and organise measures. These include characterisation of the level and nuclide composition of the contaminations, dose rate and local air activity concentration measurements, various decontamination measures, comprehensive specialist vehicle support for measuring work, decontamination, vehicles to transport people to other areas so they can receive further medical attention, etc.
- Care and treatment for people requiring medical first aid or surveillance and therapy if suspected of having or found to have increased levels of external and internal exposure. Set-up of emergency units offering contamination checks and medical advice to the public.

Section 7.2 provides more information about protecting emergency services staff who perform all of these radiological crisis management tasks.

7 Radiological protection for emergency and support personnel

Emergency services and support personnel within the scope of the Radiological Basic Principles are people deployed and therefore possibly exposed to radiation in the event of a nuclear accident or incidents involving a release of radioactive substances with the aim of managing the consequences of the radiological emergency.

These may include occupationally exposed persons (workers at plants licensed to handle radioactive substances and ionising radiation according to the StrlSchV) and non-occupationally exposed persons. Emergency services include, in particular, workers at a nuclear plant or other specialist and radiation protection-monitored workers as well as people deployed due to their general occupational qualification for certain tasks (e. g. measurements, transport, repairs, construction work) and safety and rescue staff (e. g. police, fire brigade, paramedics, doctors). The groups differ considerably in terms of their radiation protection expertise, meaning that some are more qualified than others to estimate their personal risk of exposure.

Emergency and support personnel differ from the general public in that their additional radiation exposure is the result of managing the consequences of a radiological emergency. Public exposure can be avoided or alleviated by measures taken by the emergency services, which is why the radiation protection principles for the general public have to differ from those that apply to emergency services.

7.1 Emergency services tasks

The tasks to be performed by emergency services depend on the present accident phase, i. e. the given situation. Justification for exposing emergency services to radiation is determined by the importance of their tasks, which can be divided up as follows:

- Life-saving measures,
- measures to prevent a risk to the public, e. g. prevent a dangerous release,
- measures to prevent a risk to individuals or to prevent major damage escalation,
- early measures to protect the public (workers to support evacuation, assessment and mitigation of the radiological situation, etc.),
- measurements to decide on life-saving and longer-term measures,
- deployments to protect the infrastructure and properties,
- deployments to operate an emergency unit and
- general tasks.

The rules and regulations currently in place in Germany shall be outlined before describing the resulting consequences. Section 59 of the Radiation Protection Ordinance (StrlSchV), “Radiation exposure with personal hazard and assistance” stipulates the following (BMU 2001):

(1) With measures for the fighting of dangers on behalf of persons, the aim shall be for an effective dose of more than 100 mSv to occur only once during any one calendar year and an effective dose of more than 250 mSv only once in a lifetime.

(2) The rescue measures may only be conducted by volunteers over the age of 18 who have first been instructed in the dangers of these measures.

The Federal and State Ministries of the Interior enacted the Fire Service Directive 500 “Fire Brigades in NBC Operations” (AFKzV 2012) for fire brigade deployments and the Police Guide (Polizei-Leitfaden) 450 “Hazards caused by chemical, radioactive and biological substances” (POL 2006) for police deployments. In addition to the stipulations from Section 59 of the Radiation Protection Ordinance (StrlSchV), the above directives and guides set dose constraints of 15 mSv per person and deployment (fire brigade), and 6 mSv per person and year (police) for deployments aimed at protecting properties. Section 59 of the Radiation Protection

Ordinance (StrlSchV) does not distinguish between occupationally and non-occupationally exposed emergency services workers.

These regulations and their dose limits are based on incidents such as accidents at radionuclide laboratories, transport accidents involving radioactive materials, etc. Such incidents do not justify an exceedance of the set dose limits for emergency services workers who are generally not occupationally exposed persons (the majority of fire-fighters and police officers). In the event of a nuclear accident, attempts should be made to comply with the dose limits set out in the above regulations. If these limits are exceeded in individual situations, however, they must be subsequently justified and recorded together with the relevant justification. It should also be noted that the intervention levels for the public do not represent a limit for radiation exposure to emergency services workers in the event of a nuclear accident.

7.1.1 Life-saving measures

The above regulations only provide for higher dose constraints below the deterministic effects threshold in individual situations where emergency workers are deployed to directly and indirectly save human lives. The exposure-related risk of late damage (stochastic effects) in this dose range does not exceed the general extent of health risks involved in accident and emergency deployments.

In volume 4 of its 2007 publication “Medical procedures in the event of nuclear power plant accidents” (SSK 2006b), the German Commission on Radiological Protection recommends that the organ dose equivalent of 1 Sv should not be exceeded during life-saving deployments. The Council Directive 2013/59/Euratom (Euratom 2014) allows the effective dose reference level of 100 mSv to be exceeded for emergency workers during life-saving deployments, but not exceeding 500 mSv. For this reason, as with other radiological emergencies, in the event of a nuclear accident, administrative measures (deployment plans, duty regulations, deployment guides, etc.) should ensure that dose constraints do not prevent emergency services from saving human lives.

Personal protective clothing and equipment commensurate to the given situation should be used during deployments. The level of radiation exposure must be monitored and recorded.

7.1.2 Measures to prevent a risk to the public and to prevent damage escalation due to releases at a nuclear plant

The tasks to be performed can be defined as follows:

- Urgent measures to restore control of an out-of-control radiation source and
- performance of measures to prevent or limit major radioactive releases into the surroundings.

Releases that may lead to acute (deterministic) effects among the population or the need to evacuate a large number of people are of particular relevance here, and may involve tasks such as switching operations, urgent repair work to restore cooling, and sealing and fire extinguishing work.

It can be assumed that these tasks are generally performed by staff from the affected nuclear plant who have received radiation protection training and know how to perform radiation protection measures (temporal limits for exposure, shielding, contamination and incorporation protection). This group of people also includes members of the plant’s internal fire brigade.

It cannot be excluded, however, that members of the public fire brigade, police and medical emergency services are called upon to assist in preventing a threat to the population and damage escalation. People from such groups, who may be deployed in such radiological emergencies, should therefore be provided with sufficient training. Emergency and support personnel that have not received any radiation protection training may only be instructed by other emergency services workers with the relevant skills, which is why personnel who have received radiation protection training should be called on to assist in dealing with radiological emergencies. Urgent measures to restore control over an out-of-control radiation source must only be performed by a trained expert and not delegated to an emergency services worker that has not received radiation protection training.

Measures to prevent a major release are generally justified. In this case, however, it must be ensured that the emergency services are not exposed to doses above the thresholds for acute effects (see Section 3).

As part of emergency response planning, the protection (respiratory protection, contamination protection, iodine tablets) required for such deployments must be available and present.

The level of radiation exposure must be monitored and recorded. Information on exposure and associated potential health effects should be provided to emergency and support personnel at the end of the deployment at the very latest.

7.1.3 Early measures to protect the public

Early measures to protect the public generally comprise re-routing of traffic or transportation of people, e. g. associated with an “evacuation”. The police, fire brigade, paramedics, support services and other additional aid workers (e. g. drivers) are responsible for performing such tasks which are generally justified. However, the 100 mSv effective dose should not be exceeded.

As part of emergency planning, particularly for a nuclear plant, the people expected to be involved in such an emergency are to receive basic training about the risks of ionising radiation, radiation protection practices (limiting exposure time, contamination protection, etc.) and will also learn how to use simple measuring devices (dosimeters, dose rate measuring devices, dose warning devices). The command centre is responsible for ensuring that emergency services are not subjected to any unjustified exposure.

Exposure levels among the emergency services must be monitored and recorded; simple methods are sufficient (e. g. using a dosimeter to measure the body dose of a single group member, using measured local dose rates and accompanying exposure times to provide estimates). Following deployment, the measured and/or estimated body doses and associated health risks should be pointed out and explained to those affected.

During the planning process, there may also be a need to provide the public and emergency services with psychosocial emergency care tailored to radiological emergencies.

7.1.4 Decisions regarding longer-term measures to protect the infrastructure and properties

Once the affected nuclear plant and/or radiological emergency is back under control, there is usually enough time available for the following tasks:

- Decontamination of the plant and surrounding area,
- repairs to the plant and buildings and
- waste management and storage.

In such situations, exposure to emergency services charged with such tasks can be managed. Such emergency services are classed as occupationally exposed persons as stipulated in the pertinent terms of the German Radiation Protection Ordinance (StrlSchV). However, they do not need to be classed as occupationally exposed persons if their annual dose can confidently be kept below the annual limit of 1 mSv that applies to the general public.

7.1.5 General tasks

In the event of a nuclear accident, measurements need to be taken both within the affected plant and in the local area in order to assess the radiological situation. This may lead to exposure among the people involved in such measurements.

The justification of such exposure depends on the purpose for which the results of such measurements are required. Exposure of individuals who take measurements required in preparation for life-saving measures may be higher than measurements taken to decide on longer-term remedial measures or to protect properties. After an accident at a nuclear power plant, exposure during deployments is largely determined by the dose rate of external exposure and the duration of exposure. The dose rate due to direct radiation and the received dose can be determined by simple measurements, e. g. handheld dose rate measuring devices and dosimeters. This makes it easy to reliably check and limit external doses to emergency services with a minimum of effort. Emergency services can also wear simple respirators (e. g. particle filtering half mask of type FFP2) to reduce potential internal exposure due to inhalation of airborne radionuclides. People will experience almost no impediment by wearing such respirators, and their incorporation due to inhalation will be more than ten times lower than when not wearing one. Once a radioactive cloud has passed by, the resuspension of contaminated surfaces continues to act as a source of airborne activity. The contribution that contaminated surfaces make to radiation exposure diminishes rapidly with time and remains low when compared to the dose from direct radiation.

When planning monitoring tasks, considerations should be made with regard to optimising potential exposure. These may include, for example, stationary measuring stations and, if required, probes with remote data transmission that can be deposited in various places, remote-controlled measuring vehicles, and aerometry (measurements performed by a plane or helicopter). Deployment strategies should be devised for situations where workers are required to take measurements in highly contaminated areas in order to help them assess the radiological situation with as little exposure as possible (deployment in measuring vehicles fitted with special air filters and other shielding equipment, providing dosimeters and dose warning devices so they can monitor the situation themselves, limiting the duration of the deployment, planning measurement deployments based on location, specification of return doses).

7.2 Deployment conditions for emergency and support personnel in order to manage other incidents involving radioactive releases

This section provides information about deployment conditions for people involved in other incidents associated with a major release not originating from a nuclear power plant accident. In the event of incidents leading to a release of radioactive substances into the atmosphere, crisis management workers are generally deployed only after the ground and other surfaces have been contaminated. An accident or malicious act (e. g. detonation of a dirty bomb) will lead to the rapid release of radioactive substances into the surrounding air. If particles with a moderate sink rate are released and remain airborne for prolonged periods, they will be atmospherically dispersed in the direction of the prevailing wind.

In the immediate vicinity of the release location, e. g. if a radioactive source is no longer shielded or fragments of the source have been scattered nearby, there may be high local dose rates from gamma radiation (and possibly beta radiation in exceptional cases) that require special methods and protective measures for emergency service workers. In such areas, only people who have received appropriate training and who are aware of radiation protection practices should be deployed.

In the dispersal direction of a released radioactive cloud, airborne radioactive particles lead to deposition that causes contamination levels on the ground and other surfaces that diminish with increasing distance and that can also lead to an exposure of persons. In the event of gamma-emitting radionuclides and beta rays with a high decay energy, external radiation dominates the exposure. Deposited radioactive particles with an aerodynamically respirable diameter (<10 µm) that have become airborne again through resuspension can contribute to internal exposure due to inhalation. Effective resuspension processes are the result of influences on contaminated surfaces such as the wind, moving people and vehicles. With alpha rays, there is no exposure due to direct radiation (the exception here being skin contamination and very high decay energy). In the somewhat unlikely event of a major release of alpha-emitting radionuclides, internal exposure following inhalation is dominant due to the high biological impact of alpha rays.

Under such conditions, both external radiation from deposited radionuclides and inhalation of resuspended activity are pivotal to exposure levels during deployments after contamination involving particle-borne radioactive substances has taken place. To this end, experiments involving resuspension processes (Koch et al. 2012, Koch et al. 2013) show that despite the prolonged impact of wind or repeated impact by moving people or vehicles, resuspension diminishes rapidly, even in the early phase after a contamination. This means that it generally makes less of a contribution to exposure. Workers deployed in more highly contaminated areas are recommended to wear a simple respirator (e. g. half mask of type FFP2) that represents almost no impediment as an additional protective measure.

Analyses of such incidents show that contamination levels of around 10^6 Bq/m² are somewhat high. In unfavourable cases, levels of 10^7 Bq/m² or–even more unlikely–10^8 Bq/m² may occur within several hundred metres of the dispersal direction. By way of example, a widespread contamination of 10^6 Bq/m² with a relatively hard gamma emitter Cs-137 at a reference height of 1 m above the ground would lead to a dose rate of 2 µSv/h, while an unlikely contamination of 10^8 Bq/m² would lead to a dose rate of 200 µSv/h. Emergency and support personnel deployed in such highly contaminated areas must be provided with dose rate measuring devices and dosimeters and/or be accompanied and supported by radiation protection specialists. If the dose rate is known, the level of the received effective dose from external radiation may be controlled such that it remains below 1 mSv or a few mSv during deployments without the need for further protective measures. Specialists should take the time to reassure emergency workers by providing them with information about radioactive substances and ionising radiation, alleviate any fears they may have, and support the efficient implementation of the various protective and supporting measures.

8 Radiation protection for specific professional groups

If an incident involving the release of radioactive substances led to a contamination of the surrounding area, many of the local residents (who returned to their homes) will be exposed to a low level of radiation that is higher than before the accident occurred. This increase in ambient radiation will not be evenly distributed; instead there will be localised peaks associated with certain operations.. This may be the case with the following activities:

– Sewage sludge processing,

– work involving industrial filter systems (local presence, replacing filters, cleaning filters, handling waste) and
– decontamination of surfaces and handling radioactive materials that are being produced in the process.

The General Administrative Provision on the Integrated Measuring and Information System for Monitoring Environmental Radiation (BMU 2006) may provide insights as to whether such activities could lead to increased exposures that possibly require special monitoring programmes and protective measures for on-site workers.

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List of abbreviations used

ALARA	As Low As Reasonably Achievable
EAL	Emergency Action Levels
ELAN	Elektronischen Lagedarstellung für den Notfallschutz.
EG	Europäische Gemeinschaft (bis 2009)
EU	Europäische Union
EURATOM	Europäische Atomgemeinschaft
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMIS	Integriertes Mess- und Informationssystem
INES	International Nuclear Event Scale
KFÜ	Kernreaktorfernüberwachung
ODL	Ortsdosisleistung
OIL	Operational Intervention Levels
RODOS/RESY	real-time on-line decision support / rechnergestütztes Entscheidungshilfe-System

Annex

Use of Iodine Tablets for Thyroid Blocking in the Event of a Nuclear Accident

Recommendation by the German Commission on Radiological Protection

Adopted at the 247th session of the German Commission on Radiological Protection, 24/25 February 2011

Contents

A 1 Recommendation and background

As part of its new information strategy concerning the use of iodine for thyroid blocking as an emergency response measure, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) requested the SSK to review the iodine information leaflets which were last published in 2004.

The review revealed a need for only minor changes to both the leaflet for doctors and pharmacists and the leaflet for the general public.

In the past Germany was regarded as an iodine deficiency area. However, thanks to factors such as the use of iodised table salt, the situation has improved significantly in recent decades, as increased iodine excretion and the lower incidence of thyroid autonomy show. The distribution of iodine deficiency is no longer a regional issue but is determined by nutrition habits. The frequency of thyroid disorders has shifted to higher age groups. The SSK recommends removing references to iodine deficiency from the iodine leaflets.

It was previously recommended that iodine tablets for the purpose of thyroid blocking should not be given to people over 45, since in their case the risk of side effects is higher than the risk of developing thyroid cancer at a later date. The SSK recommends retaining this age limit until further notice, since the thyroid status of older people has not yet changed as markedly as that of younger people.

The SSK continues to recommend that people who have been or are being treated for an overactive thyroid (hyperthyroidism) should consult the doctor who is treating them before taking iodine tablets.

The previous reference to the occasional occurrence of goitre in newborns can be removed, since it is not relevant to thyroid blocking with iodine.

As regards the frequency of tablet intake, the iodine information leaflets of 2004 stated that a one-off dose is normally sufficient. In exceptional cases the responsible authorities would recommend a second intake of tablets. The conditions under which a second intake of tablets should take place are described in more detail in the updated iodine information leaflets.

If the release of radioactive iodine persists (for several days or weeks) and thyroid blocking can no longer be assured by the one-off intake of inactive iodine, the absorption of radioactive iodine by the thyroid can be limited by taking additional inactive iodine. The inactive iodine is then present in the body in larger quantities than the radioactive iodine. If the intake of iodine tablets has already been recommended because of an acute risk of iodine release but the actual iodine release occurs very much later (days later), a further intake of iodine tablets could likewise be recommended.

Since the decrease of iodine in the thyroid depends on thyroid status and hence on the iodine supply and in addition varies widely between individuals, it is not possible to provide simple rules for a second administration of iodine. The authorities responsible for the decision to recommend the taking of iodine tablets should seek the advice of doctors with specialist knowledge in this area. The SSK recommends that the responsible authorities include the contact details of such doctors in their plans.

The SSK recommends that the authorities responsible for planning thyroid blocking provide doctors and pharmacists in potential distribution areas with the iodine information leaflets and information on thyroid blocking in advance – e. g. via the website www.jodblockade.de. Doctors can then discuss with their patients before an event occurs the action that they as individuals should take if thyroid blocking with iodine becomes necessary. The SSK continues to recommend that the subject of thyroid blocking should be addressed as part of doctors' medical training.

A 2 Information leaflet for doctors and pharmacists

Preliminary notes

The authorities responsible for civil protection maintain a stock of potassium iodide tablets (referred to in the following as iodine tablets) that can be distributed to the public when needed if they have not already been distributed to households under particular conditions. One tablet contains 65 mg potassium iodide (KI), which is equivalent to 50 mg iodide. This leaflet is intended to inform doctors about the key issues associated with thyroid blocking. A separate information leaflet is provided for the general public.

Why thyroid blocking?

The fission products produced by nuclear reactors include the various radioactive isotopes of iodine. Because iodine is biologically active – it is incorporated into the thyroid hormones – these isotopes are of special significance. At the temperatures found in nuclear reactors iodine occurs in a gaseous state; it must therefore be assumed that in the event of an accident in unfavourable circumstances radioactive iodine will be released into the air. Most of this radioactive iodine will be deposited on the ground and on vegetation. From there humans may ingest it with food, especially milk. In a nuclear accident iodine may also be inhaled from the air and resorbed into the lungs.

After absorption the radioactive iodine behaves in exactly the same way as stable iodine. The iodine enters the extravascular space; this leads to temporary accumulation of iodine in the salivary glands and the gastric mucosa and to long-term storage of iodine in the thyroid. The extent of this storage depends on the functional status of the thyroid and in particular – in euthyroid people – on the amount of iodine in the diet. The lower the amount of iodine in the diet, the higher the percentage of iodine that is stored in the thyroid.

The aim of thyroid blocking is to prevent radiation-induced thyroid carcinomas. Children are particularly at risk.

When is thyroid blocking indicated?

thyroid blocking should only be considered when it appears likely from an assessment of the situation that a significant release of radioactive iodine will actually occur. Especially in children under the age of four, incorporation of radioactive iodine can result in high doses to the thyroid. The protection of children and pregnant women should therefore be a priority of thyroid blocking.

A release of radioactive iodine in a quantity that justifies thyroid blocking for the population is normally detected promptly. There is therefore likely to be an early-warning period of hours or days during which the authorities can issue the necessary instructions, based on the information available to them and the assessment of the situation.

It is necessary to inform the population that it is pointless and may even be harmful for people to undertake thyroid blocking on their own initiative, i.e. without being instructed by the responsible authorities to do so. They would only be exposing themselves unnecessarily to the risk of side effects.

Is thyroid blocking permissible for pregnant and nursing women?

The recommended thyroid blocking should also be implemented during pregnancy, irrespective of the age of the pregnant woman.

The foetus absorbs iodine into the thyroid from about the twelfth week of pregnancy. From the sixth to the ninth month there is significant storage of iodine in the foetal thyroid. Thyroid blocking is therefore necessary for the older foetus; this is achieved via administration of iodine to the pregnant woman – there is no need for special adaptation of the dosage.

During lactation iodine is secreted in the mother's milk in quantities that vary from person to person. Since this does not ensure a sufficient thyroid blocking for the breastfed child, newborns and infants should also be given iodine tablets (see dosing schedule).

Women treated with high doses of iodine during pregnancy and lactation should be instructed to inform their midwife and paediatrician of this so that these health care professionals are alert to the possibility of thyroid dysfunction in the newborn.

How is thyroid blocking to radioactive iodine carried out?

Storage of radioactive iodine in the thyroid can be prevented by administering a relatively large amount of stable (non-radioactive) iodide in a high single dose (between 12.5 and 100 mg depending on age) before absorption of radioactive iodine takes place. Because of the thyroid's limited uptake capacity, this increased supply of stable iodine means that only a small percentage of the absorbed radioactive iodine is stored. The iodine that is not stored in the thyroid is excreted with a biological half-life of several hours. The biological half-life of iodine in the thyroid depends on the hormone turnover; it is usually between three and 60 days.

Since the thyroid's storage curve is initially very steep, thyroid blocking is most effective when the stable iodine is present in the organism shortly before absorption of the radioactive iodine takes place. However, a reduction in storage can still be achieved in the hours immediately following exposure to radioactive iodine (iodine administration after two hours – reduction of approx. 80%; iodine administration after eight hours – reduction of approx. 40%). By contrast, the administration of stable iodine more than 24 hours after the conclusion of absorption has no significant influence on storage and hence does not prevent radiation damage to the thyroid by the radioactive iodine. If high doses of stable iodine are taken significantly more than 24 hours after incorporation, this actually prolongs retention of the radioactive iodine. Iodine tablets should therefore not be taken after this 24-hour period.

What dosage of potassium iodide should be taken?

As well as the timing of administration, the quantity of stable iodine is also crucial if the storage of radioactive iodine is to be reduced. Since it is important for the blocking to be as complete as possible, a high plasma concentration of stable iodide is first required. In adults this is achieved by a 130 mg dose of potassium iodide. Provided that this is not taken on an empty stomach, this is generally unlikely to cause stomach upsets.

A reduction of the dose does not reduce possible side effects; an increase would not be harmful but achieves no noticeable additional reduction in radiation exposure.

The following dosing schedule is recommended:

These dosages apply only to the 65-mg potassium iodide tablets from the emergency stocks

Age group	One-day dose in mg iodide	One-day dose in mg potassium iodide	65-mg potassium iodide tablets
< 1 month	12.5	16.25	1/4
1-36 months	25	32.5	1/2
3-12 years	50	65	1
13-45 years	100	130	2
> 45 years	0	0	0

(For tablets with a different potassium iodide content please consult the dosage instructions supplied with them.)

Pregnant and nursing women should receive the same dose as individuals in the 13-45 age group.

Wherever possible, potassium iodide should not be taken on an empty stomach. The tablets can be swallowed or dissolved in liquid which is then drunk. Administration of the tablet to infants and children can be facilitated by dissolving it in a drink, such as water or tea. However, the solution does not keep and must be drunk immediately.

Iodine tablets should only be taken on the instructions of the responsible authorities. If necessary the authorities will specify in their instructions which groups of individuals should take the tablets.

A one-off intake of iodine tablets is normally sufficient. Depending on the radiological situation, the responsible authorities may under certain conditions (e. g. persistent release of iodine or intake of iodine tablets but delayed release) recommend a second intake of tablets.

In the case of pregnant and nursing women and newborns, other measures should be taken to ensure that a second intake of iodine tablets is not required.

What are the health risks of thyroid blocking?

Individuals with a known hypersensitivity to iodine (in very rare conditions such as genuine iodine allergy, dermatitis herpetiformis [Duhring's disease], iododerma tuberosum, hypocomplementemic vasculitis, myotonia congenita) should not take iodine tablets. Occasionally iodine tablets may also cause skin eruptions, sore throat, watery eyes, catarrh, swelling of the salivary glands or fever.

Very rarely there may be signs of hypersensitivity to iodine (genuine iodine allergy), e. g. iodine catarrh or iodine rash. The possibility of iodine intolerance should not be overrated. Iodine resorption can be inhibited by irrigating the stomach with starch solution (30 g to 1 litre, until the blue colour disappears) or 1 – 3% sodium thiosulphate solution. To accelerate excretion, administration of Glauber's salt and forced diuresis are recommended. If shock or fluid and electrolyte imbalances occur, they should be treated in the usual way.

In the event of pre-existing thyroid disorders, even if previously asymptomatic (and especially in the case of nodular goitres with functional autonomy), hyperthyroidism may be triggered within weeks or months of iodine intake.

By contrast, administration of iodine over a long period may lead to hypothyroidism, especially in newborns and infants.

Because there is a slight risk of radioactive iodine causing cancer in older people and a higher risk of pathologically significant functional autonomies with increasing age, thyroid blocking should not be administered to people over the age of 45.

Triggering hyperthyroidism:

A healthy thyroid gland has a number of regulatory mechanisms that enable it to tolerate an oversupply of iodine or a harmful increase in the production of thyroid hormones. The pathophysiology of clinically manifest hyperthyroidism as a result of an increased supply of iodine is not yet fully understood. It is, however, known that this transition to hyperthyroidism occurs mainly in areas where goitre is endemic and there is a high prevalence of functional autonomy.

If the iodine supply in Germany is increased, the possibility of hyperthyroidism being triggered must therefore be borne in mind.

Hyperthyroidism may occur as a result of:

1. autoimmune hyperthyroidism (Graves' diseases, Basedow's syndrome),
2. functional autonomy
   – unifocal/multifocal (autonomous adenoma),
   – disseminated.

All three thyroid disorders can also occur in latent form with no clinical signs of hyperthyroidism.

When is thyroid blocking contraindicated?

Contraindications occasionally referred to in the literature, although unsubstantiated, are coronary insufficiency and tuberculosis in its various forms. Both pregnancy/lactation and hypothyroidism/thyroiditis are also mentioned, but these are not contraindications.

Iodine should not be administered in cases of known iodine allergy. This must not be confused with an intolerance reaction or an allergy to x-ray contrast agents, which is usually not caused by the iodine in the agent.

In no circumstances should iodine be administered to patients with the very rare conditions of genuine iodine allergy, dermatitis herpetiformis (Duhring's disease), iododerma tuberosum, hypocomplementemic vasculitis or myotonia congenita.

Patients receiving treatment for hyperthyroidism should consult their doctor before taking iodine tablets. Once an emergency situation involving iodine administration has ended, doctors should monitor all hyperthyroid patients – whether in treatment or not – by carrying out hormone analysis at frequent intervals.

Options for thyroid blocking using other medication

A blocking to prevent the storage of radioactive iodine in the thyroid should be as complete as possible. Therefore the most suitable alternative to iodine is perchlorate, which competitively inhibits the uptake of iodine, e. g. sodium perchlorate as Irenat(R).

Since thyroid blocking is more effective with iodide than with perchlorate, the latter should only be used if high doses of iodine (100 mg iodide) are contraindicated.

The following dosage is recommended for adults:

Sodium perchlorate as Irenat(R)
- **initially 60 drops,**
  thereafter 15 drops every 6 hours for 7 days.

Attention must be paid to contraindications such as hypersensitivity reactions (agranulocytosis) and severe liver disease.

A 3 Information leaflet for the general public

A nuclear accident involving release of radioactive iodine

In unfavourable circumstances, accidents in nuclear facilities, especially in nuclear power plants, may result in the release of radioactive substances, including radioactive iodine. Radioactive iodine has the same chemical and biological properties as the iodine that occurs naturally in food and is therefore stored in the thyroid gland in the same way as normal, non-radioactive iodine. This concentrated storage in the thyroid distinguishes iodine from other substances. Taking iodine tablets as a countermeasure (thyroid blocking) can prevent the radioactive iodine being stored.

How does radioactive iodine enter the body?

Like other substances in the human environment, radioactive iodine can enter the body (incorporation) in three ways:

1. from the air via the respiratory system (inhalation),
2. with food and drink via the stomach and digestive system (ingestion) and
3. via the skin following contamination.

Absorption via the skin is usually so slight that it can be ignored. Absorption with water or food can be considerable – e. g. if milk is drunk from cows that have grazed on pasture contaminated with radioactive iodine. However, in the event of a radiation accident this type of absorption can be very easily prevented: such milk, or vegetables grown on land on which radioactive iodine may have been deposited, should be withdrawn from direct consumption.

The absorption of radioactive iodine through inhalation is only slightly reduced by remaining indoors. Taking iodine tablets reduces the effect of the radioactive iodine on the body by ensuring that it is excreted as quickly as possible.

How do iodine tablets work?

To function normally the thyroid gland needs small amounts of iodine, which are usually absorbed with food. This is why the use of iodised table salt or low-dose iodine tablets (0.1 – 0.2 mg) is recommended as a general means of preventing iodine deficiency disorders. However, these tablets are not suitable for a thyroid blocking.

Thyroid blocking requires tablets containing a significantly higher dose of iodine, since they prevent radioactive iodine being absorbed into the thyroid. The excess iodine is quickly excreted from the body.

Why is the preventive intake of iodine tablets necessary?

It must be emphasised that taking iodine tablets provides protection only against the absorption of radioactive iodine by the thyroid; it provides no protection against the effects of other radioactive substances. Protection is most effective when the iodine tablets are taken shortly before or virtually simultaneously with the inhalation of radioactive iodine. However, taking tablets a few hours after inhaling radioactive iodine still provides some protection. The intake of tablets more than 24 hours after the absorption of radioactive iodine no longer provides any protection; indeed, it is then more harmful than protective. Taking tablets too early is likewise ineffective.

Where and when can iodine tablets be obtained when needed?

The responsible authorities have adequate stocks of iodine tablets available for immediate distribution to the affected population in case of need, provided that they have not already been distributed to households under particular conditions. "In case of need" in this context means a situation in which – depending on developments following an accident – the intake of iodine tablets is to be recommended.

The distribution of iodine tablets is a precautionary measure and does not mean that the tablets should be taken immediately. If it should actually become necessary to take the tablets, the responsible authorities will expressly direct the affected population – e. g. via radio or loudspeaker announcements – to do so.

Only the authorities can decide whether the intake of iodine tablets is necessary, on the basis of the assessment of the accident situation. You should never take the tablets on your own initiative or because of your own fears.

Composition of the tablets used for thyroid blocking:

One tablet from Germany's emergency stocks contains 65 mg potassium iodide, which is equivalent to 50 mg iodide.

Tablets containing 130 mg potassium iodide, equivalent to 100 mg iodide, may also be available from pharmacies.

Effects and purpose of use:

When taken in the specified dose and at the recommended time, the iodine tablets saturate the thyroid with iodine and hence prevent it from storing radioactive iodine ("thyroid blocking "). Iodine tablets of this type are not suitable for iodine substitution. Any medical treatment with iodine should be continued.

Dosage

The following dosage applies only to 65-mg potassium iodide tablets (e. g. from the emergency stocks).

People aged between 13 and 45 should take a one-off dose of 2 tablets. Children between the ages of 3 and 12 should take a one-off dose of 1 tablet. Infants aged between 1 and 36 months should receive a one-off dose of ½ tablet. Babies less than 1 month old should be given a one-off dose of ¼ tablet.

(For tablets of different potassium iodide content please consult the dosage instructions supplied with them.)

Pregnant and nursing women should receive the same dose of iodine as people in the 13-45 age group. Adults over 45 should not take iodine tablets, since for them the risk of serious thyroid disorders (e. g. overactivity of the thyroid caused by iodine) as a result of taking the tablets is greater than the radiation risk from the inhalation of radioactive iodine.

Where possible the iodine tablets should not be taken on an empty stomach. The tablets can be swallowed, or they can be dissolved in liquid before taking. Giving the tablet to infants and children can be made easier by dissolving it in a drink, such as water or tea. However, the solution does not keep and must be drunk immediately.

Iodine tablets should only be taken on the instructions of the responsible authorities. If necessary the authorities will specify in their instructions which groups of individuals should take the tablets.

A one-off intake of iodine tablets is normally sufficient. A further intake of tablets should only be undertaken if this is recommended by the responsible authorities.

Iodine tablets in pregnancy:

The recommended thyroid blocking should also be carried out in pregnancy, irrespective of the age of the pregnant woman, since the intake of iodine protects both the mother and the unborn child. The pregnant woman should, however, inform her doctor that she has taken iodine: the doctor will then ensure that the routine monitoring of the newborn's thyroid function is conducted with particular thoroughness.

Intolerance and risks:

Iodine tablets should not be taken by persons who have:

– a known hypersensitivity to iodine (this is very rare and should not be confused with the commonly occurring allergy to x-ray contrast agents),
– dermatitis herpetiformis (Duhring's disease),
– hypocomplementemic vasculitis (allergic inflammation of the blood vessel walls).

Occasionally, taking iodine tablets may also cause allergic reactions such as skin rashes, oedema, sore throat, watery eyes, catarrh, swelling of the salivary glands, fever or other symptoms.

Persons who have ever been diagnosed with an overactive thyroid should consult their doctor before taking iodine tablets. In patients with an overactive thyroid or nodular changes in the thyroid, there is an increased risk that iodine tablets may cause their condition to deteriorate or trigger hyperthyroidism. Such persons should therefore consult a doctor soon after taking the tablet.

A doctor should also be consulted if symptoms that could indicate an overactive thyroid appear between one week and three months after taking the tablets. Such symptoms include agitation, palpitations, weight loss and diarrhoea.

People over the age of 45:

There are two reasons why thyroid blocking with iodine is **not** recommended for people over the age of 45:

1. Metabolic disorders of the thyroid become more common with increasing age. These disorders, known as functional autonomies, increase the risk of side effects from thyroid blocking with iodine.
2. The risk of a malignant thyroid tumour caused by exposure to radiation declines sharply with increasing age.

Side effects:

Irritation of the stomach lining can occur, especially if the iodine tablets are taken on an empty stomach. If symptoms persist a doctor should be consulted.

What do iodine tablets not protect against?

Iodine tablets provide no protection against radiation from outside the body, or against the effects of radioactive substances other than iodine that may be absorbed into the body.

Very important:

It is in your own interest to follow the instructions of the authorities, since they can assess the situation and issue directions for other appropriate protective measures.

Note:

Like all medicines, the tablets should be stored away from light and moisture and kept out of the reach of children.

Because of the possible side effects, iodine tablets should be taken only upon the specific instructions of the responsible authorities. People over 45 should not take the tablets. This age limit does not apply to pregnant women.