Strahlenschutzkommission

Geschäftsstelle der
Strahlenschutzkommission
Postfach 12 06 29
D-53048 Bonn

http://www.ssk.de

Planning areas for emergency response near nuclear power plants

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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Planungsgebiete für den Notfallschutz in der Umgebung von Kernkraftwerken

Empfehlung der Strahlenschutzkommission

Contents

I Recommendation

1 Introduction

On 11 March 2011 an earthquake measuring 9.0 on the Richter scale struck northern Japan, triggering a tsunami whose 15 m high waves devastated the coastal region. The earthquake and tsunami also caused a major nuclear accident at the Fukushima Daiichi Nuclear Power Station. The radiological impact demanded extensive measures for the protection of the affected population.

On the basis of what was learned from the accident in Japan, the German Commission on Radiological Protection reviewed the technical foundations of Germany's emergency preparedness and the accompanying regulations. The range of accidents included in the contingency planning was redefined to more closely reflect an accident's potential impact rather than its likelihood. This review has shown that the emergency preparedness planning areas near nuclear power plants must be revised.

2 Background

Pursuant to Article 70 of the Basic Law for the Federal Republic of Germany, hazard aversion is a duty of the federal states (Länder) which, to this end, have passed disaster control laws that form the basis for the general emergency response plans drawn up by the competent authorities. In addition to these, there must be special emergency response plans for areas near nuclear power plants as well as for other installations and facilities that have a high risk potential.

The “Basic Recommendations for Emergency Preparedness in the Vicinity of Nuclear Installations” (BMU 2008) aim to ensure that the dedicated emergency preparedness plans all across Germany are largely based on common principles. The “Basic Recommendations” include specifying planning areas. The “Radiological Bases for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides” (SSK 2014) provide the radiological basis for this dedicated planning.

This recommendation suggests changing Germany's emergency preparedness planning areas. Because the planning areas' nature and size are an important basis for the implementation of protective measures and the development of strategies, the recommendation was drafted in advance as the basis of the upcoming revision of the “Basic Recommendations for Emergency Preparedness”.

The recommendation should be seen as the basis for dedicated emergency preparedness plans for German nuclear power plants and those foreign facilities that require special planning measures within the scope of the “Basic Recommendations” given their proximity to the border.

3 Recommendations by the German Commission on Radiological Protection

Measures to protect the public must be prepared in the planning areas. These particular measures are part of a strategy to be implemented in case of an actual accident depending on the situation. The Commission on Radiological Protection recommends adopting the following planning areas:

- **Planning area "central zone"**

The central zone is a planning area in which certain public protection measures previously outlined (BMU 2008) such as “staying indoors”, “distribution and consumption of iodine tablets” as well as “evacuation” are to be readied. For nuclear power plants in operation, the central zone extends up to around 5 kilometres around the installation.

Local conditions, such as the structure of the terrain, settlement and administration are to be taken into account when determining the planning area.

Measures in the central zone are especially urgent because of the proximity to the nuclear installation. They are conducted regardless of the dispersal direction of radioactive substances.

The measures for the central zone must be planned in such a way that, if possible, they can be implemented before the release of radioactive substances in an accident.

It should be possible to completely evacuate the entire population from the central zone within around 6 hours of notifying the competent authorities.

The measures to prepare iodine blockade, i. e. the distribution of iodine tablets to all people for whom iodine blockade is envisaged, should be completable within the same time frame.

- **Planning area "middle zone"**

The middle zone surrounds the central zone, extending approximately 20 kilometres from operational nuclear power plants.

Local conditions, such as the structure of the terrain, settlement and administration are to be taken into account when determining the planning area.

For this area, as for the central zone, measures to avert acute dangers to lives and health of the public must be planned. These include in particular “staying indoors”, “distribution and consumption of iodine tablets” as well as “evacuation”. Middle zone measures can be implemented depending on the predicted or determined dispersal direction of the radioactive substances, if sufficient information is available to judge the radiological situation.

The evacuation must be planned in such a way that it is possible to completely evacuate the middle zone within 24 hours of notifying the competent authorities. The prerequisites for implementing iodine blockade, i. e. the distribution of iodine tablets to all people for whom iodine blockade is envisaged, should be set up within 12 hours.

The current division into sectors (12 sectors of 30 degrees with sector 1 to the north) can be retained.

- **Planning area "outer zone"**

The outer zone surrounds the middle zone. The outer limits of this planning area extend approximately 100 kilometres from operational nuclear power plants.

Local conditions, such as the structure of the terrain, settlement and administration are to be taken into account when determining the planning area.

In this planning area, measures are to be prepared to ascertain and monitor the radiological situation, so that it is possible to determine the necessity of further measures. In addition to monitoring programmes to ascertain the radiological situation, measures (staying indoors, distribution of iodine tablets to people envisaged for iodine blockade and warning the public about consuming recently harvested local produce) are to be readied. Outer zone measures are generally implemented depending on the predicted or monitored dispersal direction of the radioactive substances.

The current division into sectors (12 sectors of 30 degrees with sector 1 to the north) can be retained.

– **The entire territory of the Federal Republic of Germany**

The competent authorities should make concrete plans for the following measures for the entire territory of the Federal Republic of Germany:

- implementation of measures in accordance with the Precautionary Radiation Protection Act, especially the implementation of monitoring programmes to ascertain the radiological situation.
- providing iodine tablets to children and young people up to the age of 18 and to pregnant women to establish iodine blockade. Areas in the central and middle zones are subject to the applicable regulations concerning iodine blockade preparation.

The German Commission on Radiological Protection recommends including the changes to the planning areas in the special emergency preparedness plans for operational nuclear power plants.

The planning areas must be reviewed if in the future there are changes or expansions to the parameters relevant to determining planning areas (e. g. emergency reference levels, calculation methods for determining radiation exposure or other factors to be considered that arise from the harmonisation of Germany's planning with that of its neighbours).

4 Literature

BMU 2008 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Rahmenempfehlungen für den Katastrophenschutz in der Umgebung kerntechnischer Anlagen, GMBl (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Basic Recommendations for Emergency Preparedness in the Vicinity of Nuclear Installations) 2008 No 62/63; p. 1278

SSK 2014 Strahlenschutzkommission (SSK). Radiologische Grundlagen für Entscheidungen über Maßnahmen zum Schutz der Bevölkerung bei Ereignissen mit Freisetzungen von Radionukliden (Radiological Bases for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides), adopted at the 268th meeting of the German Commission on Radiological Protection on 13 and 14 February 2014.

II Scientific foundation

1 Introduction

On 11 March 2011 an earthquake measuring 9.0 on the Richter scale struck northern Japan. The epicentre was around 130 kilometres off the east coast of the northern part of the main island, Honshu. The earthquake triggered a tsunami whose 15 m high waves devastated the coastal region.

This natural catastrophe led to a very serious nuclear accident at the Daiichi Nuclear Power Station with its six boiling water reactors (BWR) and light water reactors which the Japanese government later categorised as a level 7 accident on the International Nuclear Event Scale (INES).

The accident affected blocks 1 to 4 at the plant, with blocks 1, 2 and 3 suffering a core meltdown due to the failure of the external power supply, internal emergency generators and cooling systems. The cooling water supply to the fuel pools was interrupted, which put the integrity of the fuel rods at risk. This was particularly hazardous in block 4 as the entire core was being temporarily stored there due to maintenance work.

The damage caused to blocks 1, 2 and 3 led to major discharges of radioactive substances into the surrounding area for a period of more than 7 days. The prevailing weather conditions during the main period of discharge meant that the radioactive substances were carried towards the sea. Nevertheless, a number of extensive measures were required to protect people affected by the accident.

Based on the experiences gleaned from the reactor accident in Japan and the revised "Radiological Bases for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides" (SSK 2014), the German Commission on Radiological Protection suggests an update to Germany's emergency response planning areas in its recommendation "Planning areas for emergency response near nuclear power plants".

2 Review of the legislation for nuclear emergency response in Germany

The measures taken and the experience and insights gained in Japan were followed with interest all over the world. In Germany, the Fukushima accident led to the competent authorities for nuclear emergency response at national and state (Länder) level immediately launching an investigation into their own provisions and precautionary measures.

In June 2011 the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) tasked the SSK with reviewing current legislation on nuclear emergency response in light of the Fukushima accident.

The review was to cover the following points:

- Do the requirements or criteria set out in the regulations still comply with the state of the art in science and technology in light of the Fukushima accident?
- Do any of the individual provisions need to be updated or supplemented?
- Do the Fukushima accident or a combination of natural disasters reveal any gaps in the regulations?

– Do any other new regulations or regulation drafts published by international organisations (EU, IAEA, WHO) need to be incorporated? If so, which ones?

The following documentation forms the technical basis for German nuclear emergency response and should therefore be reviewed separately:

– Radiological Bases for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides (SSK 2009)[1],
– Basic Recommendations for Emergency Preparedness in the Vicinity of Nuclear Installations (BMU 2008),
– Guide to informing the public in the event of nuclear emergencies (SSK 2008),
– Criteria for notifying emergency services incumbent upon nuclear power plant operators (RSK/SSK 2004)[2] and
– General guidelines for emergency planning by nuclear power plant operators (RSK/SSK 2010).

Emergency response regulations in Germany are reviewed and updated both at regular intervals and when required. At the time of the Fukushima accident, the regulations were commensurate with the state of the art in science and technology, and the latest ICRP recommendations (ICRP 2007) were in the process of being added to the “Radiological Bases”.

The SSK performed an extensive review of the insights gained from the Fukushima accident, discussed the lessons learned that were published worldwide, and performed an investigation as to whether these findings are of importance to emergency response measures in Germany. In addition, the SSK considered the process to update international regulations and legislation that was launched in the wake of the reactor accident and included the results of these changes in its investigation. The analysis into the experiences gained in Japan shows that the planning areas need to be reviewed.

The “planning areas” recommendation suggests changing Germany's emergency response planning areas. Because the planning areas' nature and size are an important basis for the implementation of protective measures and the development of strategies, the recommendation was drafted in advance as the basis of the revision of the “Basic Recommendations for Emergency Preparedness” (BMU 2008). A working group deployed by the SSK was supported by the Federal Office for Radiation Protection (BfS) and the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), and it also worked closely with the interstate “Fukushima” working group of the Standing Conference of the States’ Ministers and Senators of the Interior (IMK).

3 Initial situation

The planning areas for emergency response near nuclear power plants are set out in the “Basic Recommendations for Emergency Preparedness in the Vicinity of Nuclear Installations” (BMU 2008) which were last updated in 2008 to reflect the state of the art in science and technology. The planning areas are applied to German nuclear power plants and foreign facilities requiring special planning measures within the scope of the Basic Recommendations due to their proximity to the border.

[1] Revised version from 2014 (SSK 2014)
[2] Revised version from 2013 (RSK/SSK 2013)

Planning areas are areas near nuclear power plants where special planning measures are required. In the “Basic Recommendations” they are known as planning zones, which are then further broken down into a central zone, middle zone, outer zone and remote zone.

Table 1*: Planning zones as stipulated in the “Basic Recommendations for Emergency Preparedness in the Vicinity of Nuclear Installations” (BMU 2008)*

Central zone	The central zone is a planning area in which all emergency measures 2 are to be readied. Emergency measures 2 serve to avert acute danger to the lives and health of the public and include such measures as staying indoors, distribution and consumption of iodine tablets as well as evacuation. The central zone has a radius of approximately 2 kilometres. Measures in the central zone are especially urgent due to the zone's proximity to the nuclear installation. They are conducted irrespective of the dispersal direction of radioactive substances.
Middle zone	The middle zone is a ring-shaped planning zone where all emergency measures 2 are to be readied. The middle zone has an inner radius of approximately 2 kilometres and an outer radius of about 10 kilometres. Middle zone measures are generally implemented depending on the dispersal direction (divided into sectors) of the radioactive substances.
Outer zone	The outer zone is a ring-shaped planning zone where, in addition to monitoring programmes to ascertain the radiological situation, measures (distribution of iodine tablets to people up to the age of 45 and warning the public about consuming recently harvested local produce) are to be readied. The outer zone has an inner radius of approximately 10 kilometres and an outer radius of about 25 kilometres. Outer zone measures are generally implemented depending on the dispersal direction (divided into sectors) of the radioactive substances.
Remote zone	The remote zone is a ring-shaped planning zone where measures (distribution of iodine tablets to women and children and young people up to the age of 18 and warning the public about consuming recently harvested local produce) are to be readied. The remote zone has an inner radius of approximately 25 kilometres and an outer radius of about 100 kilometres. Additional rings can be specified within that range for the purpose of distributing iodine tablets. Remote zone measures are implemented depending on the dispersal direction (divided into sectors) of the radioactive substances.

Every zone apart from the central zone has to be divided into sectors.

The main objective of planning is to prevent or limit damage to public health due to the effects of a nuclear accident (BMU 2008).

4 Lessons learned from the Fukushima accident

The timings of events and the area contaminated by the Fukushima accident were used to investigate the potential impact of such an accident in Germany.

During the first few days after the accident, areas up to 20 kilometres away from the nuclear power plant were evacuated, while people within a radius of 30 kilometres of the plant were told to remain indoors. Contamination testing subsequently led to these residents also being evacuated.

The area in which protective measures (in particular evacuation) were implemented immediately after the accident occurred was much larger than the planning zones in place in Germany at that time.

These findings indicated a need to review the nature and size of the planning areas.

5 Radiological protection goals for emergency response planning

The radiological planning protection goals are stipulated in the "Radiological Bases for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides" (SSK 2014). The "Radiological Bases" are, in turn, based on radiobiological and radioepidemiological knowledge, particularly with regard to dose-risk and dose-response relationships for stochastic and deterministic effects. Pursuant to the "Radiological Bases", the common goal of emergency response measures is to reduce radiation exposure to humans by implementing measures to prevent major deterministic effects and limit individual doses to levels below the threshold doses for deterministic effects. According to (SSK 2014), the ICRP understands major deterministic effects as irreversible illnesses that are directly attributable to radiation exposure and highly detrimental to the quality of life.

Suitable measures should help to avoid deterministic effects and reduce and limit the risk of stochastic effects on individuals.

The avoidance of major deterministic effects and major risks due to stochastic effects forms the basis for emergency response planning near nuclear power plants.

Planning areas should be calculated and measured in such a way that it is possible to achieve the radiological protection goals for the range of accidents on which planning is based.

6 Bases for specifying planning areas

6.1 Range of accidents

The risk studies and accident analyses that have been in use in Germany since the 1970s also include accidents whose effects are classified as today's INES level 7. The range of INES 7 accidents adopted by German nuclear power plants has been revised over the last 40 years to maintain pace with the state of the art in science and technology. The latest analyses (Löffler et al. 2010) also include accidents where the radiological effects mirror those that occurred in Fukushima. This means that no new findings were gained from the Fukushima accident in terms of the extent of potential releases. The radiological impact of the Fukushima accident is therefore comparable with the results of analyses into potential major accidents at nuclear power plants in Germany.

In the past, the results of risk studies and accident analyses were also consulted to determine planning areas for emergency response plans and emergency preparedness in Germany. However, due to their low likelihood of occurrence, the consequences of incidents now classified as an INES level 7 were not used as a basis for determining requirements in terms of emergency preparedness plans required in addition to general emergency preparedness plans near nuclear power plants.

The SSK believes that the range of accidents included in emergency response planning should be redefined to more closely reflect an accident's potential impact rather than its likelihood.

The SSK therefore considers it necessary to expand the range of accidents included in the contingency planning and also add to emergency response planning and planning area considerations the INES level 7 accidents whose radiological effects mirror those of Fukushima.

The SSK therefore collaborated with the BMU offices responsible for nuclear safety and the GRS to agree on a reference accident to be used in the future as a basis for planning.

6.2 Concept and radiological criteria

The division of an area potentially affected by a hypothetical accident is based on fixed objectives and requirements in terms of effectively and efficiently implementing measures.

The concept used to size planning areas is based on the selection of a suitable reference accident and accompanying reference source term which are used to devise a dose-related approach involving a weighted assessment of the calculated dose distribution which, in turn, includes additional requirements and parameters such as ensuring that protective measures are accorded top priority.

Dispersion calculations were performed on the basis of the reference source term in order to size the planning areas. The aim of these calculations was to determine distances from the plant up to which protective measures would have to be carried out in the event of an accident. The planning areas were then drawn up on the basis of these calculations while also taking account of the determined requirements and parameters.

The emergency reference levels for the various different protective measures were used as criteria when drawing up areas in which measures to protect the general public would be required.

According to the “Radiological Bases”, emergency reference levels are dose values that people would or could receive in the event of certain exposure scenarios and also act as radiological trigger criteria for the respective protective measure. Emergency reference levels are planning values. Emergency reference levels refer to the effective dose for protective measures and the organ dose for the thyroid gland. The respective emergency reference levels are dose values that are well below the thresholds for deterministic effects.

The “Radiological Bases” stipulate the emergency reference levels for the protective measures set out below in table 2. The areas in which protective measures need to be carried out are determined on the basis of these emergency reference levels and various other influencing factors.

Table 2: Emergency reference levels for the measures "staying indoors", "consumption of iodine tablets" and "evacuation"

Measure	**Emergency reference levels**			
	Organ dose (thyroid gland)		**Effective dose**	**Integration times and exposure pathways**
Staying indoors			10 mSv	External exposure and committed effective dose due to inhaled radionuclides as a result of hypothetically remaining outdoors for a period of 7 days
Consumption of iodine tablets	50 mSv 250 mSv	Children and adolescents up to the age of 18 and pregnant women People aged 18 to 45		Committed equivalent dose due to inhaled radionuclides as a result of hypothetically remaining outdoors for a period of 7 days
Evacuation			100 mSv	External exposure and committed effective dose due to inhaled radionuclides as a result of hypothetically remaining outdoors for a period of 7 days

The above emergency reference levels allow three planning areas to be determined:

Firstly, an area situated in the immediate vicinity of the plant where the population should be evacuated due to the risk of exceeding the 100 mSv criterion. Secondly, an area surrounding the first one where people designated for iodine blockade should take iodine tablets due to the risk of the respective emergency reference level (thyroid dose) being exceeded. And thirdly, an area surrounding the second one where children and young people up to the age of 18 should take iodine tablets due to the risk of exceeding the thyroid dose of 50 mSv in the given circumstances.

The level of potential radiation exposure decreases the further away one is from the plant. People in the immediate vicinity of the plant would therefore be more highly impacted by the radiological effects of a hypothetical accident than people situated further away from the plant. The planning area for which evacuation is to be planned has to be subdivided in order to optimise human protection in terms of their potential level of impact as a result of a hypothetical accident.

Here it should be noted that in the event of a hypothetical INES level 7 accident, major deterministic effects and a high risk of stochastic effects could occur in the area immediately next to the plant's premises if protective measures are not carried out. This therefore makes it necessary to prepare protective measures for this area which can be assigned top priority and carried out and completed as quickly as possible, ideally before a release caused by an accident. There were two main aspects involved in determining the planning area with top priority: firstly, the avoidance of major deterministic effects, and secondly, ensuring optimised implementation of protective measures in a prioritised manner.

When determining the planning area with top priority, investigations were performed as to the distance from the plant up to which major deterministic effects are still likely to occur in people who spent 7 days outdoors in the wake of a hypothetical accident. The threshold dose of the respective deterministic effect was used as a criterion for the potential occurrence of such effects. (SSK 2014) provides a detailed description of the various different deterministic effects and their dose thresholds. The threshold doses described there are generally values which, in 99% of exposed people, do not lead to any effects.

In terms of major deterministic effects, (SSK 2014) indicates that brief exposure of red bone marrow to radiation could cause a major impediment to blood cell formation at a dose threshold of 1,000 mGy. When compared with the other major deterministic effects described in the "Radiological Bases", a brief exposure of haematopoietic red bone marrow with a threshold dose of 1,000 mGy constitutes the most restrictive combination for adults and children. According to (SSK 2014), the enhanced sensitivity to radiation during prenatal development requires separate threshold doses for highly radiation-sensitive development phases of tissue and organs. In terms of major deterministic effects and their assigned threshold doses, the most restrictive conditions involve a threshold dose of 100 mGy in the event of a brief full-body exposure during the weeks 2 to 7 of the foetal development phase and a threshold dose of 300 mGy for the brain during the highly radiation-sensitive development phase during weeks 8 to 15 of pregnancy.

The table below summarises the thresholds for the occurrence of major deterministic effects that were taken into account when determining the planning area with top priority. All of the thresholds were taken from (SSK 2014)

Table 3: Thresholds for the occurrence of major deterministic effects

Dose criterion	Group of people	Threshold	Integration times and exposure pathways
Dose to red bone marrow	Adults, small children	1,000 mGy	External exposure and dose commitment due to inhaled radionuclides as a result of hypothetically remaining outdoors for a period of 7 days
Effective dose / uterus dose*	Fetus Weeks 2 to 7	100 mSv	External exposure and dose commitment due to radionuclides inhaled by mothers as a result of hypothetically remaining outdoors for a period of 7 days
Brain dose	Fetus Weeks 8 to 15	300 mGy	External exposure and dose commitment due to radionuclides inhaled by mothers as a result of hypothetically remaining outdoors for a period of 7 days

* As organogenesis does not provide any calculation options for fetus organ doses, the effective dose to the fetus due to inhalation by the mother is used as the equivalent dose to the fetus while the dose to the mother's uterus is used to determine external exposure (ICRP 2001).

In addition to the thresholds for major deterministic effects, the SSK introduced another criterion with an effective dose of 1,000 mSv for determining the top-priority planning area. The groups of people, integration times and exposure pathways correspond with the parameters of the emergency reference levels set out in (SSK 2014). This criterion was thus used to determine an area where measures with an extremely high priority are to be carried out and in which protective measures are highly effective. Similar to thresholds for the occurrence of major deterministic effects, this criterion is merely a planning factor to be used as an aid in determining the area where protective measures have to be immediately performed within a 360-degree radius, irrespective of the prevailing weather conditions. This criterion serves to implement the planning requirement that ensures measures are carried out in a prioritised manner.

As set out in the (SSK 2014), in the event of a real emergency, the planning criteria set out above are irrelevant to the top-priority area and the decisions regarding protective measures for all planning areas are made on the basis of the emergency reference levels.

7 Other parameters and criteria

7.1 Ensure implementation priority

Planning areas and their accompanying measures need to be stipulated and planned in advance in order to be able to carry out measures, particularly urgently needed ones, without delay and to the extent necessary. Planning areas serve to ensure that protective measures are implemented in a prioritised manner, i. e. people who are most at risk of or impacted by radiological effects should be given protection first by means of sufficient measures.

The top priority here is to implement measures in areas where deterministic effects and high doses may occur, which is why a top-priority planning area in the immediate vicinity of the plant premises needs to be defined.

7.2 Ensure effectiveness of measures

Planning areas and their designated measures are to be planned such that protective measures can be used to the best-possible effect.

This means creating individual planning areas of a manageable size in terms of the measures that may have to be implemented there. If planning areas are very large, there is a risk of not being able to ensure sufficient priority is given to the radiological exposure. If very large areas for swift evacuation are chosen, the simultaneous evacuation of a large number of people could impede the evacuation of people in the immediate vicinity of the plant who are most at risk, in turn preventing radiological protection objectives from being achieved. According to (IAEA 2013), the outer limit of the inner planning area should not be more than 5 kilometres away from the plant.

(IAEA 2013) also stipulates that planning areas for which evacuations have to be planned in order to limit stochastic effects should have an outer limit of 15 kilometres to 30 kilometres away from the plant. Existing resources should be put to best-possible use and evacuation should take place in a number of stages based on the given and forecast situation as well as the prevailing weather conditions.

7.3 Consideration of site-specific conditions

Plant-specific and regional conditions such as population structure, infrastructure and regional problems should always be taken into consideration when defining the sizes and outer limits of planning areas. It is therefore not possible to stipulate planning area data that can be applied to all plants. The planning areas suggested by the SSK only apply to emergency response in Germany.

7.4 Planning comprehensibility, transparency and quality

The effectiveness of emergency response measures depends on the decisions to implement measures taken in the event of a real emergency. It also depends on the quality of measures planning and acceptance of the measures by the people who are or may be impacted by them.

Emergency response planning quality is defined by technical quality, completeness, clarity, transparency and topicality. Good planning quality ensures that everyone draws upon the plans put in place in the event of an emergency. This forms a sound basis for reaching radiation protection objectives.

The Japanese investigation commissions observed a number of planning deficits which were described in detail in several reports, including the one published by the Japanese parliament's investigation commission (NAIIC 2012). With the onset of the accident at the Fukushima Daiichi Nuclear Power Station, the following deviations from the plans took place in Japan in terms of organising and carrying out protective measures:

1) Due to the consequences of the natural disaster, planned measures could not be implemented and there was a lack of alternative plans,
2) The people responsible for and involved in the plans were not even familiar with them,
3) The plans had not been updated for a number of years and even proved to be incomplete.

Around 150,000 people had to be evacuated or resettled. This gave rise to confusion because outdated and incomplete plans had to be used which often lacked information on how to maintain the infrastructure and ensure care, e. g. of people in hospitals. The evacuation led to a number of deaths that could have been avoided if there had been a better quality of planning in place (NAIIC 2012).

The decisions taken were often unclear to people impacted by them, and they were not sufficiently informed about the given risks. For a long time after the accident, members of the public affected by these decisions were very concerned and unsure as to how they should deal with the situation, which in turn was highly detrimental to their quality of life.

The SSK therefore considers the quality and transparency of emergency planning to be essential. This applies in particular when determining planning areas that form an important basis for the implementation of protective measures and the development of strategies in order to protect the general public. This is why a transparent method had to be chosen to determine planning areas.

7.5 Standardisation within Europe and on a global scale

The Fukushima Daiichi accident again showed that an accident causing major damage to a nuclear power plant's reactor core can have consequences on an international scale. This is why the plans put into place by individual countries and, in particular, neighbouring countries, should not differ from one another to any large extent. This requirement should also be observed when determining planning areas.

To the extent applicable in this mandate, the SSK has taken account of international regulations, in particular those of the IAEA and the EU. In the "EPR-NPP Public Protective Actions: Actions to Protect the Public in an Emergency Due to Severe Conditions at a Light Water Reactor" (IAEA 2013) document published in 2013, the IAEA provided a number of recommendations regarding planning area structure and the determination of planning areas. The method used by the SSK adopts the IAEA's dose-related approach based on representative source terms, thus ensuring comparability. The planning area structure recommended by the SSK also largely reflects the IAEA's recommendations. The SSK's recommendation regarding planning areas is open to standardisation based on the IAEA's recommendations.

8 Method used to determine planning areas

An analytical method was used to determine the planning areas. To this end, RODOS (Real-time Online Decision Support System) (Raskob und Gering 2010; see also http://www.rodos.fzk.de) was used to select a reference source term for determining planning areas which was also used to determine areas where, under the given conditions, high doses and major deterministic effects may occur and emergency reference levels for protective measures may be exceeded (see Section 8.2). The areas determined using this method are proposed as planning areas. Any other important influencing factors in terms of emergency response will be taken into account when selecting the reference source term and determining the parameters for calculation and evaluation. The individual steps of the method are described below:

- Determination of parameters for the hypothetical release of radioactive substances,
- Selection of reference source terms including scenarios comparable with the Fukushima accident,
- Selection of representative nuclear power plants in Germany,
- Determination of parameters for the RODOS calculations,
- Stipulation of evaluation method used to determine planning areas for protective measures,

- Performance of RODOS calculations to determine areas where the 1,000 mSv criterion is reached, where major deterministic effects may occur, and where protective measures would be necessary based on the emergency reference levels set out in (SSK 2014).

8.1 Reference source term

One or more reference source terms are required as a basis for determining planning areas. Reference source terms are characterised by parameters that describe the release of radioactive substances via the air pathway. Consideration of the air pathway is sufficient for determining planning areas as the inclusion of releases with water does not have any impact on the results.

The selection of reference source terms should be based on the lessons learned from the Fukushima accident. However, where possible this selection should be linked to analyses and risk studies carried out for nuclear power plants in operation in Germany.

A reference source term is indicated by the quantity of released radioactive substances (release quantity), duration of release, and location of release. The duration of the pre-release phase, i. e. the time between identification and commencement of a major radionuclide release from a plant, is important in terms of emergency response.

The SSK defined the following requirements for the reference source term:

- The release quantity should include INES level 7 releases. It should be possible to view the scenarios used here as representative of the state of the art in science and technology for plants in Germany
- It should involve a source term to be expected in the event of accidents involving a core meltdown and failure of the protection measures in place
- The “Fukushima source term” should be covered by the release quantity
- The reference source term should be applicable as a posit for all nuclear power plants included in the scope of this recommendation
- Prolonged release scenarios should be included
- The location of release should be typical of releases in the event of failure or bypassing of containment.

A check was performed to see whether accident analyses that comply with the above requirements are available in Germany.

At the end of 2010, the GRS carried out a research project to ascertain representative events for pressurised and boiling water reactors whose source terms were added to the RODOS (Real-time Online Decision Support System) source term library (Löffler et al. 2010). Table 4 shows the scenarios devised for pressurised water reactors.

Table 4: Release categories in the source term library of the RODOS decision support system as set out in (Löffler et al. 2010)
(for comparison the Fukushima accident source term ascertained in (GRS 2013) is included)

Name	**Description**	**Release I-131** [Bq]	**Release Cs-131** [Bq]	**Start of major releases** in hours after reactor shutdown	**Calculated frequency** [10^{-7} per year]
FKA	Uncovered steam generator heat pipe leak	$3.1{\cdot}10^{17}$	$2.9{\cdot}10^{16}$	approx. 21	2.1
Fukushima	Cooling system failure in several reactors	$1{\cdot}10^{17}$ - $2{\cdot}10^{17}$	$1{\cdot}10^{16}$ - $2{\cdot}10^{16}$	approx. 13	-
FKI	Filtered pressure release via the ventilation stack	$2.8{\cdot}10^{15}$	$2.8{\cdot}10^{11}$	approx. 57	8.8
FKH	Filtered pressure release via the roof	$2.8{\cdot}10^{15}$	$2.8{\cdot}10^{11}$	approx. 57	2.6
FKF	Unfiltered pressure release via the roof	$2.3{\cdot}10^{16}$	$2.8{\cdot}10^{14}$	approx. 57	2.1
FKE	Suction pipe failure	$1.8{\cdot}10^{17}$	$9.4{\cdot}10^{14}$	approx. 33	1.4

The “FKA scenario” is considered suitable for determining planning areas for emergency preparedness and emergency response plans. The given parameters are met, despite it not being a scenario with a prolonged release. In order to determine whether an additional release scenario representing prolonged releases is required to stipulate planning areas, comparative calculations were performed using RODOS where the “FKA source term” was extended to a release period of 15 days for an additional release scenario. These calculations showed that the shorter release leads to larger planning areas, meaning that calculations involving the “FKA source term” with a release period of 50 hours was considered sufficient for determining planning areas.

The selected reference source term should not be considered as a source term specific to certain plants or certain types of plants; instead it should be applied to every plant of relevance to emergency response planning in Germany. This is both reasonable, justifiable and necessary in terms of precision of accident analyses as the bases and methods for sizing the planning areas should be the same at every plant in order to ensure that plans are standardised. Only the duration of the pre-release phase takes account of the fact that, in the event of a core meltdown, releases may occur earlier with certain reactor types than with the investigated pressurised water reactors. A pre-release phase of 6 hours was therefore assumed. According to the present FKA event sequence analysis, the main release requiring extensive emergency response measures would commence approximately 21 hours after reactor shutdown. However, a much shorter pre-release period was defined for other reactor types, including the type 72 boiling water reactors in operation in Germany. In the vast majority of potential events, a much longer period of time would be available to carry out immediate protective measures.

8.2 RODOS calculations

This source term was used as a basis for performing calculations with RODOS (Real-time Online Decision Support System), which the Federal Office for Radiation Protection (BfS) has been using operationally since 2003. Together with the Integrated Measurement and Information System (IMIS) and state-specific systems, RODOS forms the basis for decision-making in the event of nuclear incidents or accidents in Germany.

Three areas representing the various climatological conditions in Germany were defined in order to perform these calculations. The following areas were chosen:

– A flat orography, on average with high wind speeds

– A moderately structured orography in a valley, on average with moderate wind speeds, and

– A pronounced valley with a moderate orography, on average with low wind speeds and frequent inversions.

Nuclear power plants in such areas were then selected (Unterweser, Grohnde and Philippsburg) and calculations were performed using these locations.

To this end, the Remote Monitoring of Nuclear Power Plants (KFÜ) has meteorological measurements and statistical evaluations of this data stretching back many years. The BfS then evaluated this data as a monthly average for several years in order to show that the period for which calculations were performed can also be seen to be representative and not of limited value due to certain meteorological conditions.

The period from 1 October 2011 to 30 September 2012 was selected as the period to be used for the (annual) calculations. This ensures that every season and their specific meteorological characteristics are sufficiently accounted for. Investigation of the KFÜ’s meteorological data for each plant over a number of years also showed that the investigated period does not significantly differ from other years, meaning that it can be seen to be a typical year. In order to achieve a sound statistical basis for every day and every plant within the given period, a dispersion calculation based on the reference source term was started using RODOS. This produced a total of 1,095 calculations for 365 days and 3 plants. Individual calculations were initiated at precisely midnight on the respective day. By starting the calculation at this time, the results were conservative as night-time weather with its stable stratification leads to a reduction in the vertical exchange of contaminated air masses at the start of the emission where it is at its highest.

The data from the German Weather Service’s (DWD) COSMO-EM System (Consortium for Small-scale Modelling – European model) is available as a meteorological database for flow fields. The German Weather Service (DWD) sends this data to the BfS every day. Also available as an alternative is the meteorological data for the respective plant provided by the Remote Monitoring of Nuclear Power Plants (KFÜ). Here considerations needed to be made as to whether more accurate plant data with meteorological measurements at the point of emission would be of greater benefit than the DWD data which represent the entire simulation area. The DWD data was given preference as a dispersion of over 100 kilometres with relevant exposure based on the reference source term was to be expected when performing calculations for the simulation area.

When using RODOS, the user can choose between the ATSTEP and RIMPUFF dispersion models. ATSTEP is a model designed for rapid calculation results, which is why a simple calculation algorithm was used. As the calculation time only plays a minor part in these investigations, the RIMPUFF model was chosen as it provides more detailed modelling and a better reproduction of the meteorological processes. The only downside to the RIMPUFF model is that it takes longer to produce results, but this was of no importance to these investigations.

During each calculation for the respective area, doses were calculated as effective doses via the exposure pathways external radiation from the cloud and from contaminated soil and inhalation for all radionuclides. The organ dose for the thyroid gland due to radioactive iodine was also calculated at the same time. The doses were determined for an integration period of 7 days (external dose from contaminated soil) using the conservative assumption of people being permanently outdoors. A release lasting for a period of 50 hours was assumed. The results of these calculations were then compared with the emergency reference levels for the below measures to determine the respective areas of action:

– Staying indoors
– Evacuation
– Consumption of iodine tablets

Areas in which the calculated doses exceeded the 1,000 mSv effective dose (1,000 mSv criterion) were also determined.

All of the calculations were performed and evaluated for adults and small children (aged 1 to 2). Individual calculation evaluations were performed such that for each measure, the maximum distance from the point of emission was determined up to which a measure would have to be carried out upon application of the respective emergency reference level.

In order to determine the area where major deterministic effects could occur, additional calculations of the red bone marrow dose were performed for adults and small children (aged 1 to 2) along with the dose for the fetus. To this end, RODOS was used to carry out a dispersion calculation for the Grohnde nuclear power plant based on the reference source term. This calculation was performed every fourth day between 1 October 2011 and 30 September 2012. For each calculation the maximum distance from the point of emission up to which the calculated doses exceed 1,000 mGy (red bone marrow) in adults and small children was determined.

Calculations for the fetus have to take account of the various development stages of the fetus which lead to differing levels of sensitivity to radiation. This is why separate considerations of organogenesis (weeks 2 to 7; period of induction of anomalies due to ionising radiation) and early fetogenesis (weeks 8 to 15; main period of risk for mental retardation due to ionising radiation) are required. As organogenesis does not provide any calculation options for fetus organ doses, the effective dose is used as the equivalent dose (ICRP 2001). In the event of early fetogenesis, however, the organ dose to the brain can be determined (ICRP 2001). Radioactive iodine is the main contributor to the dose. Here it should be noted that the embryo/fetus does not store any iodine up to around the 10th week of pregnancy as the thyroid gland has not yet formed. The fetal thyroid gland is also not fully formed during weeks 8 to 15 of pregnancy, which is why a threshold dose of 100 mGy was adopted for weeks 2 to 7 of pregnancy and a threshold dose of 300 mGy for weeks 8 to 15 of pregnancy when evaluating calculations. For each calculation the maximum distance from the point of emission up to which the calculated doses exceed the above thresholds for the fetus was determined.

8.3 Evaluation methods

For each plant and emergency response measure, a statistical distribution of the measure's maximum distance can be plotted. The cumulative frequency is used to determine the distance up to which a certain measure should be planned and also provides the percentage of calculated weather situations in which the areas where the respective emergency reference level is exceeded are within the given distance. When choosing a percentile of cumulative frequency for determining planning radii, the SSK based its decision on the following aspects:

- In terms of frequency of occurrence and impact, the reference source term represents a highly unfavourable accident constellation that also covers major accidents
- When calculating radiation exposure, conservative assumptions and parameters were used as a basis, including in particular the assumption of spending 7 days outdoors without protection
- When determining radiation exposure, the normal behaviour and habits of people near the nuclear power plant were not taken into account, meaning that protective measures such as shielding were not included
- Radiation exposure levels were determined by performing calculations involving the meteorological dispersion characteristics and occasionally highly unfavourable weather conditions present at the nuclear power plants in Germany
- When sizing planning areas, it must be considered whether as large an area as possible should be covered, or whether areas likely to be most affected are accorded prioritised protection. Creating planning areas based on highly improbable scenarios of radiological consequence would reduce the number of protection options available to potentially highly affected areas near the plant, which is therefore not conducive to meeting the intended objectives.

Taking these aspects into account, the SSK stipulated the 80th percentile as the cumulative frequency for the maximum distance of a specific measure. In order to derive the planning radius for the top-priority area, the mean value of all three plants was calculated for adults and children. For the fetus, this process also included the results of the various stages of development that were determined for a plant. The mean values of all locations for adults were used as a basis for determining a planning area where the emergency reference levels for all designated protective measures may be exceeded. The determined maximum distances for administering iodine blockade to adults and children are relevant to planning areas situated further away from the plant.

9 Results of calculations

The calculations and evaluations carried out led to the following results:

- Major deterministic effects can be avoided with a high degree of certainty if an area around a nuclear plant with an approximate outer radius of 5 kilometres from the plant can be swiftly evacuated. This also applies to a fetus, which is far more sensitive in comparison to adults. Following exposure, the threshold doses of around 100 mGy for anomalies which can be triggered during weeks 3 to 7, and the threshold doses of around 300 mGy for mental retardation in weeks 8 to 15 (ICRP 2007) will no longer be reached beyond the 5-kilometre radius.
- The top-priority area determined using the 1,000 mSv criterion covers an area of up to around 5 kilometres away from the plant.
- Up to a distance of approximately 20 kilometres away from the plant, the emergency reference levels for “evacuation”, “consumption of iodine tablets” and “staying indoors” may well be exceeded.

- Up to a distance of approximately 100 kilometres from the plant, the emergency reference levels for “consumption of iodine tablets” and “staying indoors” may be reached. Measurement programmes should also be prepared for this area to ensure that the radiological situation can be quickly determined and any necessary measures implemented (e.g. further evacuation of areas more than 20 kilometres away from the plant).
- It may be necessary to administer iodine blockade to children, young people and pregnant women who are much further away from the plant (>100 kilometres) but within the dispersal direction. These calculations prove that dose levels may be exceeded at distances of up to 200 kilometres away from a plant. Distances of over 200 kilometres were not investigated as a radius of 200 kilometres around German plants and plants located near international borders would cover almost the whole of Germany. This is why sufficient preparations should be made throughout Germany.

10 Planning areas within the context of international developments

The SSK investigated whether the stipulation of new planning areas corresponds with the plans in place in other countries. There are no fixed plans at present in the assessed countries. The International Atomic Energy Agency (IAEA) is currently in the process of drafting guidelines on this topic. However, based on the current state of discussion within the IAEA and the EU at the time of preparing this recommendation, the SSK assumes that the planning areas determined for Germany will meet international requirements.

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